

FIDIC Asia Pacific Conference 2024 - Nepal

GOVERNANCE FOR CLIMATE SHOCKS



CONFERENCE BOOK

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**CLIMATE
SHOCKS**

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FIDIC Asia Pacific Conference-2024
Governance for Climate Shocks



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Forward

It is with immense pride and enthusiasm to present the full paper collection as conference book of the FIDIC Asia Pacific Conference 2024, themed “Governance for Climate Shocks.” This timely event, organized by the Society of Consulting Architectural & Engineering Firms (SCAEF)- Nepal from November 18–20, 2024, offers a unique platform for intellectual discourse and knowledge sharing. The increasing frequency and severity of climate shocks demand robust governance system. Governance is the Foundation for resilience to promote sustainable future. The technical sessions were designed around five sub-themes, reflecting the diverse and pressing challenges of climate governance in our region. These articles encapsulate the cutting-edge research, innovative practices, and insightful perspectives shared during the conference, making a valuable contribution to addressing climate-related challenges in Asia-Pacific and beyond.

I am grateful to the authors for their dedication and commitment to producing high-quality articles that align with the conference’s theme. The efforts in sharing research, case studies, and innovative practices have significantly enhanced the intellectual depth and diversity of this event.

On behalf of the Technical Committee, I extend my heartfelt gratitude to Er. Thakur Prasad Sharma, President of SCAEF, whose visionary leadership and unwavering commitment have been instrumental in bringing this conference to fruition. I also acknowledge the efforts of the 18th Executive Committee of SCAEF, whose dedication has ensured the seamless organization of this significant event. Special thanks to Er. Mandakini Karki, the Conference Director, for her exceptional effort in coordinating the event and to Er. Tarun Ranjan Dutta, Chair of the Publication Committee, for his outstanding support in compiling and curating this conference book.

It is my sincere hope that this compilation of full-length articles will serve as a resource and reference for policymakers, professionals, and researchers alike. May it inspire innovative solutions and adoptive stronger collaborations as we work together to build resilient governance systems capable of addressing the challenges of climate shocks.

Er. Hare Ram Shrestha, Ph.D.
Chair, Technical Committee
FIDIC Asia Pacific Conference 2024-Nepal



Table of Contents

Title	Page No.
Addressing the climate change Through the use of bamboo and laterite soil	7
Greening Linear Infrastructure: Ecosystem-based Adaptation (EbA) For Climate Resilient Infrastructure	15
Wewa-Ellangawa System (TCS) - Model for Climate-Resilient Water Management in Sri Lanka	25
Restoring a Sustainable Future for Urban Lakes: Engineering and Innovation in Yangtze River Catchment Protection	31
Addressing the Impacts of Climate Change in the Transport Sector in Asia	35
Enhancing the Resilience of Indonesian Triangle Region Coral Reefs to the Impacts of Future Climate Change through Conservation and Mitigation of Coastal Pollution	51
Fate of Melamchi Water Supply Project in the context of Changing Climate and Weakening Governance	61
Navigating Exceptional Events under FIDIC Contract Forms: Enhancing Project Governance in Sustainability-focused Construction Contracts	71
Plastic Waste Flow Analysis and Monitoring of Plastic Leakage Reduction Interventions in Three Select Ports in the Philippines	85
Flexible strategies for climate governance: from China's fiscal policy perspective	99
Integrating Hydropower Sustainability Standard (HSS) and FIDIC Conditions of Contracts to Enhance Climate Resilience and Sustainability in Hydropower Projects	107
Role of Instinctive and Anticipatory Resilience in Saving Lives and Infrastructures: Case Study of Seti and Melamchi Flooding	115

Enhancing Operational Resilience in Delivering Clean and Renewable Energy: Integrating Multidisciplinary Approaches to Mitigate Flood and Landslide Hazards in Geothermal Production Fields	133
Factors of Global Warming and Direct Mitigation Measures to Climate Shocks	141
Hydrogen-based Energy on the horizon of Carbon Neutrality	149
The Zhejiang Practice of China’s Leap in Renewable Energy	155
Planning of Flood Control in Unstable Rivers in Terai Plain of Nepal	161
Study on Strategies and Paths to Strength Meteorological Services to Ensure the Development of New Electric Power System	169
Innovation for sustainable deep foundation in Thailand	175





Addressing Climate Change Through the use of bamboo and laterite soil

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ABSTRACT

Building Construction has been one of the main sectors that has made an ironic contribution to the climate change. It is mostly because of the use of materials like cement and steel which have a large carbon print. Though Nepal's contribution is very little or nil at 0.22 per cent, one can see the use of the modern materials in the construction of the buildings. These are necessary for constructing multi storeyed buildings but for the construction of residential buildings in Nepal, alternative materials like bamboo and soil could be used which have been in practice since a long time. It has been found that bamboo reinforced soil competes with the brick masonry in cement mortar and thus can be used for the construction of the walls. For the construction of the floors also, bamboo grid structures have been found to take the incoming dead and live load quite effectively. In fact, such construction method has been employed in the erection of stages for public performance since a long time. Such a construction can be earthquake resistant in earthquake prone country like Nepal. Bamboo can also be used in conjunction with mud for temporary shelters also. This paper seeks to highlight on the use of bamboo and laterite soil for the construction of the temporary as well as permanent earthquake resistant residential buildings in Nepal. This may be useful not only in the post earthquake relief and reconstruction in the recently earthquake affected areas in Rukum as well as Jajarkot but also in case of such disasters in future. This construction method may need further research for its application for climate resilience.

1. INTRODUCTION

The climate change has been one of the serious threats to the whole world. Its impacts are many but the most descenibles are the increasing occurrence of disasters worldwide. Climate is a function of the temperature, humidity and rainfall among others. It has been seen in the unprecedented rise in temperature leading to hot spells in the world in general and Europe in particular. The other is the virtual downpouring of rainfall since last few years. Recently, Valencia a city in Italy, received within eight hours the rainfall which it would normally in a year. It suffered immensely with the demise of about 200 people.

In Nepal also, flood and landslide played a havoc with 232 people dying and several missing as well as injured in the district Lalitpur adjoining the capital city of Nepal,

Kathmandu. In the western part of Nepal, the Dodhara Chadani area, received 624 milimeter of rain which is about 40 per cent of the annual rain of around 1520 milimeters in average overnight.

It has now been clear that the climate change has been caused by anthropogenic activities giving rise to the emission of greenhouse gases. There are varous actors that have made ironic contribution to the climate change but the building activities is one of them ranking second next to transport sector in the overall standing.

Though Nepal's emission is very little or none at 0.23 per cent of the global emission, it is likely to go up in the future with the use of building materials having a high carbon print. It was however using climate resilient materials in the past right from the foundation to the ridge. The buildings constructed in this fashion are so appealing

particularly in the Kathmandu valley that it has earned the distinction of been a world heritage site. It has however been abandoned now and the tendency is to use modern materials which consume much energy during their manufacture.

Though the corporate buildings may need the use of energy consuming materials like steel and cement, the residential buildings which are many in number could be constructed using the traditional materials like bamboo and soil. Its laboratory test has indicated that its performance is at par with the modern brick work constructions. This paper seeks to highlight on the possibility of bamboo reinforced laterite soil in the construction of low-rise residential buildings.

2. CLIMATE CHANGE

Climate change was predicted long back in 1824 by the Spanish scientist Joseph Fourier. It was alright till 1850 at about 280 particles per million of Carbon Di Oxide (CO₂) but it started to increase from that year afterwards particularly due to industrial revolution underway in the west. There are other Green House Gases like CO₂ for example Methane, Nitrogen di oxide, Methane and the likes but we have control over CO₂. It is being generated exponentially with the increasing use of fossil fuels like coal and petroleum products. Now it has reached to a devastating level of 412 ppm which has caused adverse condition in the globe with one natural disaster after another.

The higher level of carbon di oxide concentration has led to global warming. Though the Conference of Parties (COP 22), held before two years in the United Arab Emirates had decided to restrict the global temperature to 1.5 degrees by 2030, but many fear that this target cannot be achieved. COP 23, is taking place in Ajerbaijan which will deliberate in how to tame the monstor called climate change.

2.1. Climate Change in Nepal

It is very well known that the world was not habitable due to one ice ages after another. But volcanoes erupted and with the evolution of CO₂, the earth began to warm up. People in the past new this fact and they performed fire sacrifices known as hom in order to facilitate adequate rain for agriculture. The third Chapter, in its 14th Verse mentions in Sanskrit that *ann ād bhavanti bhū t ā ni, parjanya ā d annasambhavah, yajñ ā d bhavati parjanyo yajn ā ha karmasamudbhava*. It means that all living

beings subist on food, and food is produced by rains; rains come from the performance of sacrifice, and sacrifice is produced by the performance of prescribed duties.

The holy men in Nepal still believe in it. Consequently, Siddhi Baba carried out Koti Hom (10 million sacrifices) which is an elaborate sacrificial Hindu ritual. He was however prevented by the local youths saying that it will aggravate the the climate change further. The Baba asked me about the concern shown by the youths and I said that they were right because the fire sacrifice would lead to the emission of carbon di oxide and thus contribute ironically to climate change. He asked me about the aforementioned verse of Geeta and I said that it was right in early times at the time of its writing around third century before Christ when the CO₂ concentration was lower than 210 ppm. The verse though right earlier on was wrong now with the passage of time. The Baba went on to perform the sacrifice. May it be a coincidence but later on, the area was struck by a storm on 31st March, 2019 killing 20 people in addition to rooting out trees and demolishing houses and industries.

It can thus be seen that there is some awareness about the climate change among the youths if not among the religious persons. But Nepal is continuing to use fire wood for domestic fuel and petroleum products for mechanical activities. Even then, its carbon emission is virtually nil at 0.23 per cent of the total global emission. But Nepal is suffering greatly by the Climate Change because of the location of Himalayas and the glaciers in its north. Recently, one of the glaciers erupted flooding Thame a village downstream which is the birthplace of legendary Tenzing Sherpa, one of the two with Edmund Hillary of New Zealand to scale the world's highest peak, the Mount Everest. The rise in temperature is higher in the north of Nepal which houses the snowy mountains and the glaciers.

The latest flood and landslide are also attributed to the climate change in addition to the encroachment of river banks in Kathmandu. Such events are likely to occur rather harshly in the future.

2.1.1. Aftermath of the Disasters

In the aftermath of such disasters, the rescue and relief are the first activities. But after that the construction of temporary shelters and then permanent houses have to be carried out. However, the Government has hopelessly failed to cater to these facilities. One can see in the last earthquake of Jajarkot. The vicitms were not provided

with adequate temporary shelter nor are there any sign of carrying out the construction of permanent houses in near future.

2.1.2. Construction of the Temporary Shelters

After the earthquake of 2015, several temporary shelters were constructed which varied in size as well as the shape. In Lalitpur, six shelters were assessed for their thermal performance by Ritu Thapa et al. It was found that in all the shelters, the temperature went below 11 degrees Celsius in the winter and above 35 in the summer as shown in the graph below both beyond the comfort limit. The heat transmission coefficient was 5.4 Watts per square meter per Kelvin and it was found that it had to be decreased to 1.4 through the application of thermal insulation materials. The recommendation was of 12 mm thick cellular polyethylene foam and 2mm thick tarpaulin. In the same research, there was a shelter using bamboo and mud for the wall and its coefficient was comparatively lesser at 4.4.

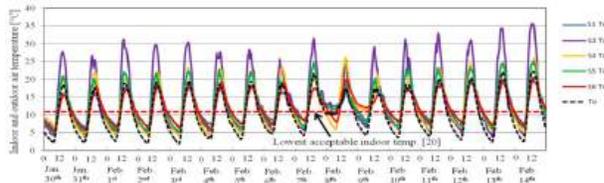


Figure 1: Source: Rita et al



Figure 2: One of the six shelters, Source Rita et al

2.1.3. Typical Temporary Shelter in Jajarkot

In Jajarkot, one can see some of the temporary shelter made using the Galvanized Iron Sheets. Needless to say, these shelters are very hot in the summer and cold in winter. There has been a narrative that the temporary shelters could be constructed using local materials such as timber, bamboo and mud. After all, the buildings that the

people were staying before the earthquake were using houses using such traditional materials.



Figure 3: GI shelter, Source: Author

2.1.4. Construction using local materials

It is because of this narrative that a pilot project for the temporary shelter was constructed in Rukum west district, in ward no 4 of Githakot Municipality. It uses



Fig 4: Temporary shelter as designed



Fig 5: Temporary shelter as constructed

bamboo and mud for the foundation and silpauline plastic sheet for the roffing. In addition to it, a 2-inch air gap has

been provided on the wall with the result that the temperature in the interior was recorded to be within the comfort limit compared to the Galvanized iron sheet.



Fig 6: Air gap between two bamboo lath partitions

A similar 2-inch air gap was provided in the roof also. This was achieved by plastering the outside and the inside of the roof as well as the bamboo wall with mud plaster.



Fig 7: Air gap between two bamboo lath roof partitions

2.1.5. Measurement of Temperature

The temperature was measured for 24 hours covering day and night of the bamboo and the Galvanized iron sheet temporary shelter. It was found that the temperature inside the bamboo shelter was very comfortable while the one inside the Galvanized iron one was lower in the winter and higher in the summer.

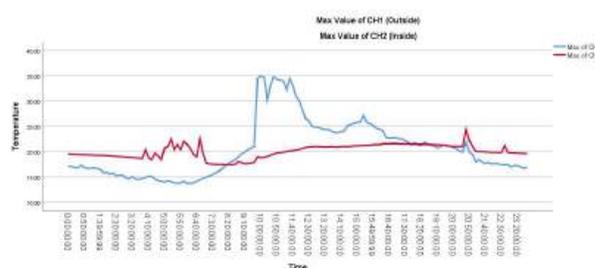


Fig 8: 24 Hour temperature

2.1.6. Retrofitting of the Galvanized Iron Shelter

A local Non-Government Organization, the Community Self Reliance Shelter in the earthquake affected Nulgadh, Jajarkot had helped construct the Galvanized iron sheet shelter wanted to retrofit it to make it comfortable in winter as well as the summer. The bamboo partition with the air gap was constructed in the wall as well as the ceiling. It was found that the temperature again in the retrofitted shelter was equally comfortable.



Fig 9: Retrofitting of the part of the Galvanized iron shelter

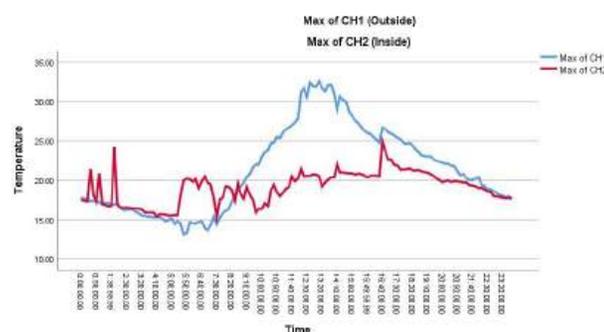


Fig 9: 24 Hour temperature

It can thus be seen that the bamboo and mud as well as plastic can be very handy for use in the temporary shelters. It is comfortable as well as cheap. It uses climate resilient local materials.

3.0. Bamboo Reinforced Laterite soil for Post Disasters permanent Building

It has been clear from the foregoing that bamboo and mud can be used for temporary shelter successfully. In fact, this type of construction has been used for permanent construction in the plain areas or the Terai of Nepal. It can thus be used for temporary construction without any hesitation.

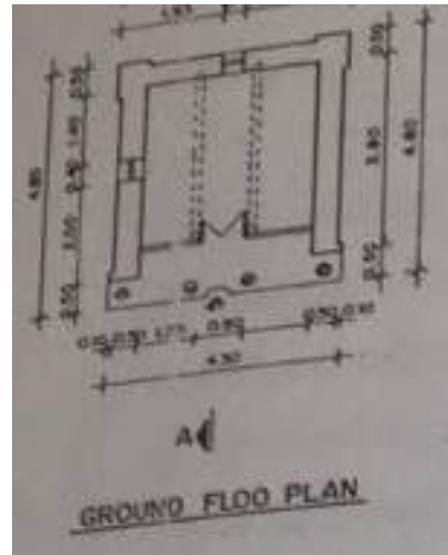


Fig 11: Plan of the House in Saptari district



Fig 10: A typical house using bamboo and mud in Terai

The reconstruction work of the post 2015 earthquake has been criticized heavily for making departure from the local architecture and thus erasing the age-old identity. Moreover, it uses foreign materials and it is costly. It has been opined in different fora that the reconstruction work should use local materials, follow traditional form and it should be cost effective.

Bamboo reinforced soil has been used in the Terai region since time immemorial. One can see such house being built in the Terai plans for example in Saptari district of Nepal. It is thus necessary to construct identifiable houses using local material which is within the financial reach of the local people.

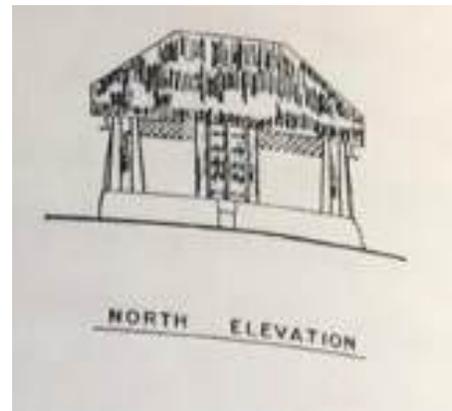


Fig 12: Sketch of the House in Saptari district

In this context, there is a need to make use of the existing settlement planning and architecture using local material such as the local laterite soil strengthened through the reinforcement of bamboo. It has been found that the compressive strength of the soil increases arithmetically with the use of bamboo.

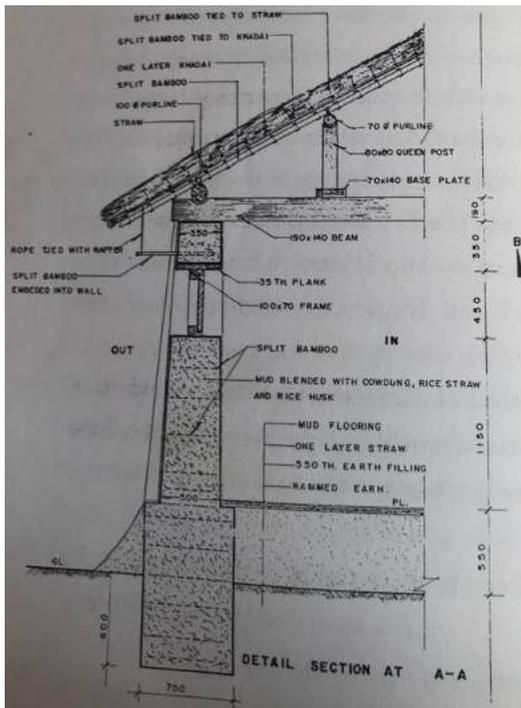


Fig 13: Wall Section of the mud bamboo house

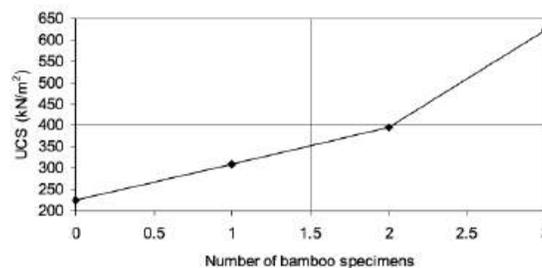


Figure 5. Variation of UCS with the number of bamboo specimens

Fig 15: Source: Mustafa, 1985

3.1.2. Study made by the Researchers

A study was made by the researchers using more bamboos. It was similar to the test carried out by Mustafa indicating its accuracy. It was found to attain a compressive strength of 3019 Kn/sq m. It is better than the compressive strength of the brick masonry in cement (1:4) in Nepal. The lower table shows the strength with varying bamboo addition.

3.1. Study of Bamboo Reinforced Laterite Soil

The soil has a rather low compressive but its compressive strength goes up with the introduction of the bamboo reinforcement. In a study carried out by Mustafa in Leonardo Journal of Sciences published by MIT Press it has been shown how its compressive strength at 221 KN/Sa m increases to 300, 400 and 661 KN/sq m with the insertion of 1, 2 and 3 numbers of a circular bamboo of 34 mm dia and 3 mm thickness in a soil sample of 78 mm x 38mm x 38 mm.

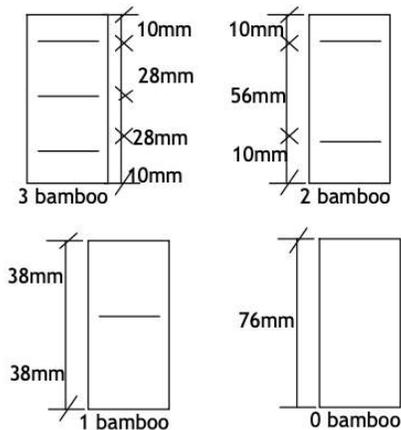


Figure 2. Soil specimens with 0, 1, 2 and 3 bamboo specimens

Fig 14: Source: Mustafa, 1985



Fig 16: Test using the compressive strength mould

Particulars	Mustafa	Our test
Only laterite	221	207
2.75%bamboo	300	286
5.5%bamboo	400	364
8.25%bamboo	661	529
11%bamboo		1144
13.75%bamboo		1770
15.5%bamboo		2217
17.25%bamboo		3019

Fig 17: Test using the compressive strength mould

The test of the wall pannel 400 x 400 x 120 was also carried out and it also gave a competitive stength of 2456 Kn/sq m.

Geo Lab and Infra Solution Pvt. Ltd. Lalitpur-17, Gwarko			
UNCONFINED COMPRESSION TEST			
Detailed soil Investigation of Building construction of Baram & Jajarkot.			
Description:	4 nos. of bamboo Panel, 40x40	width:	12.00 cm
	wall pannel-40x12x900 cm ³ , size		
	of bamboo-31.3x11.0x2.5 cm ³		
Length:	40 cm	Height:	40.00 cm
Volume:	19200.00 cc	Area:	480.00 cm ²
Load Dial Const:	0.0004 kN/Div	Strain Dial Const:	0.001 cm
Wet Weight:	51680 gm	Bulk Unit Wt.:	1.65 gm/cc
Dry Weight:	23765.0 gm	Dry Unit Wt.:	1.24 gm/cc
Date:		Prov. Ring No.:	1.8N 2518
Tested by:	Aayash Yadav	Checked by:	Sudhir Kumar Mishra
Certified by:			

Fig 18: Test done in.a local lab

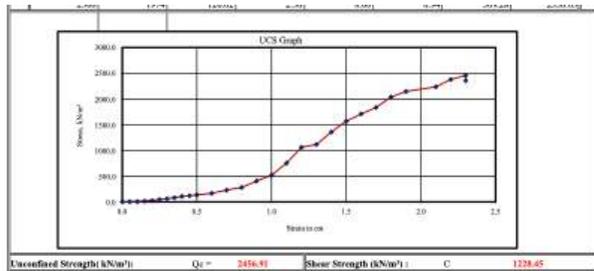


Fig 19: Test done in.a local lab

It can thus be seen that the bamboo reinforced laterite soil can be used for the construction of. the walls. Given that it is at par with the brickwork which is used in Nepal it fulfils the requirement of build back better.

3.2. Use of bamboo for floor construction

Bamboo has been used since a long time for the use of stage for public performance. It is not only subject to dead load but also for dynamic load which comes into being due to dancing and dramas performed on it. But it has not been used for permanent residence construction. Moreover, its tsting of load also has not been done.

It is in this context that a load testing was carried out for the bamboo floor using grid bamboo beams. It was found that it could withstand the load subjectced in the residences. In the residences, it is usually the dead load of about 240 and the live load of 200 Kg/square meter making it a total of 440 Kg. It has been found to bear four courses of bricks which is about 576.



Fig 19: Load Test

3.3. Bamboo as a building material

It can be seen from the above that bamboo can be used for temporary as well as permanent shelters especially now when the other building materials carry a very heavy carbon print. The one ton of steel and cement emit 2 and 1 Ton of Co₂ during their production but the same amount of bamboo absorbs 1 ton of Co₂. It is known as poor man's lumber in China, as brother in Vietnam and friend of people in India. It is also known as Green Gold because it is cheap than timber but it is equally robust.

It is one of the longest living plants and grows to a height of up to 30meters. Besides it is available worldwide in the form of 1500 species under 110 genra over. It covers 36 million hectares in area which is about 3.2 per cent of the global forest aea.

In Nepal, 53 species of bamboos are available over 12 genra. It is available all around the country with most of them available in eastern Nepal. It is used for life and death situations in Nepal. Life because it is used to make an outside pavillion in the time of marriage and death because the dead person is carried on a bamboo frame for cremation. It is also used for food as bamboo shoots. In the construction, it is used very widely in Nepal.

3.4. Laterite Soil

Laterite Soil is rich in alumunium and iron and is of red color. The use of red soil in Nepal can be seen everywhere as it is available in plenty. Rato Mato and Chiplo Bato or the red soil and slippery road is a common saying in Nepal.

In 1986, Land Resource Mapping Project carried out a study in which 14 types of soil were identified. The main soil types were Entisols, Inceptisols, Mollisols and Alfisols. The Rhodustalf which falls under the Alfisols resembles the laterite soil on account of the red color. Though the laterite soil has been used for this study because of done so by Mr. Mustafa, other soil types also could be studied for their possible use. Moreover, it is found extensively in Nepal.

From the internet(Google)

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4.0. CONCLUSIONS

At the present juncture when the world is threatened by the climate change which has been boosted by the use of energy consuming materials like steel and concrete, it is necessary to make use of non-energy consuming materials like bamboo and soil. Studies need to be made in the future in order to establish them and thus prevent the adverse impacts due to climate change.

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Greening Linear Infrastructure: Ecosystem-based Adaptation (EbA) For Climate Resilient Infrastructure

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ABSTRACT

Nepal, identified as one of the top ten countries vulnerable to climate change impacts, has an ambitious target for achieving middle-income country status by 2030, necessitating significant growth in physical infrastructure. With climate change as an underlying threat, investments and development priorities are at stake. Moreover, haphazard development without considering ecological integrity can further cause damage and destruction of the infrastructure. While non-linear infrastructure such as dams, industries, and built-up areas have concentrated impacts, large linear infrastructure such as highways, railways, irrigation canals, and transmission lines passing through the forests affect the habitats of the rare and endangered wildlife species and adversely impact the ecosystem services such as carbon sequestration, water recharge, and flow, soil conservation, etc. Currently, most infrastructure projects are developed in isolation without considering the nexus between ecosystem health, climate change, and infrastructure development. Thus, this paper attempts to analyze the role of the ecosystem in safeguarding infrastructure, identify key gaps and challenges, and find ways forward to adopting ecosystem-based adaptation for resilient and sustainable linear infrastructure development. The research is based on a review of existing policies, plans, and projects related to infrastructure and interviews with government experts and academicians. The respondents see the need for EbA to safeguard infrastructure and sustain ecosystem services. However, lack of policy updates including their proper implementation, research and demonstration, and cross-sectoral coordination are major hindrances. Key entry points towards climate resilient linear infrastructure are to build the capacity of policymakers, planners, engineers, and contractors on the application of safeguard measures; fill the knowledge gaps by initiating small-scale pilot sites, including EbA in the curriculum of civil engineers, documentation, and dissemination of best practices; revising/updating the existing policies and strengthening coordination across sectors and formulation and strict adherence of guideline that provides a clear framework of integrating EbA into planning, designing, and implementing linear infrastructure.

1. INTRODUCTION

The world is facing unprecedented impacts of climate change affecting all sectors, which are predicted to be more severe in the coming years. However, the impact would be more disproportionate, with small island developing states, the Arctic, South Asia, Central and South America, and much of sub-Saharan Africa already affected by different climate-induced hazards. Inequality,

conflict, poverty, and weak governance in developing country at the cost of ecosystem degradation through land-use change, unsustainable use of natural resources, pollution, and over-exploitation of species are weakening ecological resilience ultimately amplifying the vulnerability of these countries [1].

In South Asia, home to approximately a quarter of the global population, the frequency of climate-induced disasters, such as high floods and extreme temperatures,

and prolonged droughts has doubled since the 1990s [2]. The region has a population growth rate of 6.4% in 2024, making it the fastest growing, emerging market and developing economy. However, infrastructure, the backbone of development, remains susceptible to damage from natural disasters. Nepal, located in a seismically active Himalayan region of South Asia, is highly sensitive to climate-induced hazards because of its complex terrain and topography. Over the past two decades, Nepal has been among the top 10 countries severely affected by climatic disasters with 0.82 fatalities per 100,000 inhabitants and 0.39% losses per unit GDP [3]. A series of devastating climate-induced disasters have struck Nepal in recent months. In August 2024, the swollen Thame River, caused by glacial lake outbursts in the Everest region, destroyed 20 houses, Thame Elementary School, and a clinic in Ward 5 of Khumbu Pasang Lhamu Rural Municipality in Solukhumbu District, displacing 135 people [4]. In July 2024, a slope failure triggered by heavy rainfall swept away two passenger buses on the Narayanghat- Mugling road, leaving at least 60 people missing [5]. Most recently, in September, continuous heavy rainfall led to severe flooding and landslides, claiming 200 lives and causing US\$127 million in property damage [6]. These events reflect the increasing frequency of climate-related disasters in Nepal. By 2030, the number of people to be affected by river flooding and landslides in Nepal is projected to more than double, potentially tripling economic impacts [7]. A senior government official stated that **Nepal's recent climate disasters highlight the severe consequences of both climate change and human actions. While climate change plays a major role, the overexploitation of nature significantly contributes to the damage, underscoring the urgent need for ecosystem-based adaptation in infrastructure planning and design.** The vulnerability and risk assessment for Nepal projects a temperature increase of between 1.2°C and 4.2°C under a high emission scenario (RCP 8.5) by 2080 which is expected to have a severe impact on people, infrastructure, and the economy [8]. This warming trend is likely to lead to more frequent and intense climate-induced disasters in the coming years. Considering these projected changes, ecosystem-based adaptation strategies are becoming increasingly vital for mitigating risks and enhancing resilience to such disasters. These strategies offer sustainable solutions to cope with the growing challenges posed by climate change.

Global infrastructure demand is projected to increase

sharply by 2050, with estimates indicating the need for 25 million kilometers of new paved roads and 335,000 kilometers of rail. This 60% increase from 2010 levels will primarily affect developing regions, which are expected to account for 90% of the expansion [9]. While such development is critical for economic growth, infrastructure projects, particularly roads and railways, often cut through biodiverse areas, leading to habitat loss, ecosystem fragmentation, and lasting environmental damage [10]. With global vehicle numbers projected to hit 2 billion by 2030, sustainable infrastructure planning is increasingly essential to balance economic benefits with environmental impacts [11].

In Asia, where the infrastructure demand is particularly high, \$26 trillion is expected to be required from 2016 to 2030 to drive growth, alleviate poverty, and tackle climate change, with \$8.4 trillion allocated specifically to transportation infrastructure [12]. Against this regional backdrop, Nepal aims to transition to middle-income status by 2026, focusing on substantial investments in infrastructure. The country's development plan for 2022/23 to 2028/29 sets ambitious targets to nearly double the national highway network from 6,457 km to 12,857 km, expand expressways, feeder roads, and railway systems.

Additionally, Nepal's energy sector goals include raising electricity generation capacity from 2,437 MW to 11,969 MW by 2045/46, coupled with expanding transmission and distribution lines to meet rising demand. For agriculture, the strategy targets improved irrigation coverage to 1.12 million hectares, with groundwater irrigation reaching 633,000 hectares to enhance productivity and resilience to climate impacts.

Nepal's infrastructure expansion presents a distinct scenario of threats to country's unique biodiversity . Roads, canals, and transmission lines frequently pass through ecologically sensitive areas , including vital watersheds, protected areas, and wildlife corridors, affecting ecosystem services and natural habitats of globally significant wildlife species dispersed along different altitudinal gradients. Despite covering only 0.1% of the Earth's land area, Nepal is home to 3.2% of the world's flora and 1.1% of its fauna, including 4% of mammal species, 9% of bird species, and 3.7% of butterfly species [13]. Given this rich biodiversity, integrating conservation principles into infrastructure planning and designing is essential to ensure that development aligns with environmental sustainability and preserves Nepal's unique ecosystems. To adapt,



infrastructure planning and design must incorporate resilience strategies against climate impacts, leveraging modern construction practices and eco-friendly materials to enhance durability and mitigate environmental harm. Ecosystem-based climate adaptation can play a key role in this process, harmonizing both development and biodiversity conservation.

Climate change and biodiversity loss are interconnected crises that jeopardize human well-being by disrupting ecosystems and reducing nature's vital services, such as food security and climate resilience. Human activities, like greenhouse gas emissions and resource exploitation, are accelerating these issues, increasing poverty, displacement, and conflict. Despite current actions being insufficient, coordinated efforts are crucial to mitigate these effects. Solutions exist, including protecting ecosystems, which can efficiently capture and store carbon if warming is kept below 1.5°C through substantial emissions reductions [14].

Ecosystem-based adaptation (EbA) integrates natural ecosystems into infrastructure planning to provide climate resilience through nature-based solutions. By restoring ecosystems and incorporating green infrastructure—such as wildlife corridors, green bridges, and bioswales—EbA addresses challenges like habitat disruption, water runoff, and flooding, particularly in projects like roads and railways. Healthy ecosystems, with strong biodiversity and connectivity, are essential for maintaining ecosystem services, minimizing the impacts of climate change, and building resilient communities.

Traditional "grey" infrastructure, which does not consider ecosystem factors, is often inadequate to sustain the impacts of climate change. Infrastructure like road embankments, when designed without local hydrology in mind, can fail during heavy rainfall, leading to landslides and blockages. EbA addresses these issues by integrating green infrastructure, such as managing upstream ecosystems, implementing proper drainage, using native vegetation for bioengineering, and establishing conservation ponds and vegetation strips along roads and railways. These measures not only reduce risk but also provide co-benefits like carbon sequestration, improved water retention, and enhanced ecosystem services.

While Nepal has a long history of watershed and forest management practices, the integration of ecosystems into climate-resilient infrastructure planning is still in its early stages. This paper explores the potential for transforming traditional practices into green, sustainable, and resilient infrastructure development, promoting EbA as a critical

tool for building climate resilience.

2. METHODOLOGY

2.1. Data collection

2.1.1. Literature review

A preliminary literature review was conducted to understand the broader context of Greening Linear Infrastructure and Ecosystem-based Adaptation (EbA) for Climate Resilient Infrastructure. To assess the level of integration of EbA in infrastructure-related policies of the government of Nepal, national policies, acts, plans, and strategies were reviewed. Further, relevant documents of large linear infrastructure projects were also screened to assess if climate change was considered a primary risk and if measures to safeguard investment were in place.

2.1.2. Key Informant Interview (KII)

This paper heavily relies on the information provided by the key stakeholders related to linear infrastructure development and the conservation of natural resources. For the interview, a purposive sampling was carried out from government agencies (viz. Ministry of Physical Infrastructure and Transport and its departments, mainly the Department of Road and Department of Railways, Ministry of Forests and Environment), conservation and development projects, and academia. Altogether, 11 senior government officials, along with 1 professor from the academic sector and 1 technical expert in EbA were interviewed. The sample size was intentionally small to ensure that the respondents were senior officials with a high level of expertise and knowledge on the topic who held key decision-making roles and had specific expertise in the intersection of development, conservation, and infrastructure.

2.1.3. Case studies

We also studied how projects in other countries have used nature to reduce the risks of climate change.

2.2. Data analysis

The information collected was analyzed based on the six research questions designed to understand the status, key gaps, and challenges in governance, and recommendations to adopt ecosystem-based adaptation for resilient and sustainable linear infrastructure development. The information was assimilated to answer the following questions:

- a. How do ecosystems and their services contribute to safeguarding infrastructure and mitigating climate change risks?
- b. What are global or national provisions and best practices for incorporating EbA into the design and implementation of green and resilient infrastructure?
- c. How are government and development agencies integrating climate change and ecosystem protection into the planning, design, and implementation of infrastructure projects?
- d. What opportunities and challenges are there for applying global provisions and practices related to EbA for green and resilient infrastructure in Nepal?
- e. What could be key recommendations for integrating EbA into green and resilient infrastructure design and implementation at the national, provincial, and local levels?
- f. What is the connection between ecosystem health, climate change, and infrastructure development, and how do these elements influence each other?

To complement the qualitative data, a numerical Likert scale was used. While information from the interview provided a more nuanced understanding of specific viewpoints, practical insights, and examples shared by participants, by using the Likert scale, the study effectively quantified experts' perspectives, thus supporting a data-driven analysis of challenges and recommendations.

During interviews, participants were asked to provide a rating for the following four questions using the Likert scale from 1 to 5, with 1 as the low score to 5 being the highest:

- i. Role of the ecosystem in safeguarding infrastructure from climate risk.
- ii. Understanding global and national provisions and best practices on EbA.
- iii. Current practices of consideration of climate change and natural resource safeguards in infrastructure projects.
- iv. It is necessary to consider the nexus of ecosystem health, climate change, and infrastructure development.

Their ratings were then averaged across participants for each question, offering a collective view of the group's perspectives.

3. RESULTS AND DISCUSSION

3.1. Role of the ecosystem in safeguarding infrastructure and reducing climate risks

The majority (**62.5%**) of the respondents agreed that the role of ecosystems in safeguarding infrastructure and mitigating climate change risks is **"Very Important."** Another **25%** considered it **"Important,"** while **12.5%** rated it as **"Moderately Important."** This focused approach allowed for in-depth insights from those with a direct influence on policy and practice. The small percentage of respondents who considered the role of ecosystems as "Moderately Important" can be attributed to the novelty of the EbA approach, which is still emerging in Nepal's infrastructure planning and development. As this concept is relatively new and not yet widely implemented, it is less understood among some stakeholders, which may have contributed to a more reserved perspective on its importance.

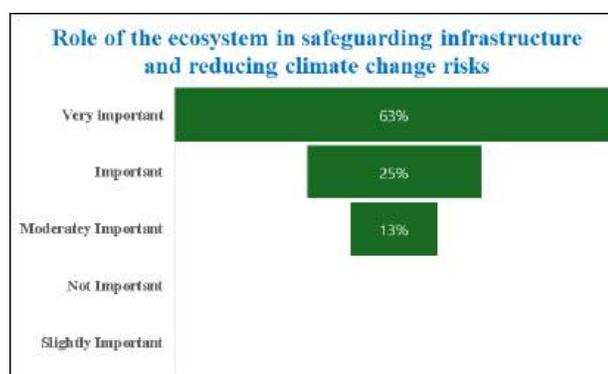


Figure 1: Graphical representation of understanding of the respondents on the importance of the ecosystem.

This clearly indicates that most government officials recognize the crucial role ecosystems play in safeguarding linear infrastructure and mitigating climate change risks in the long run and need to consider them while planning for any large infrastructure. Their responses highlight the understanding that ecosystems contribute significantly to the sustainability and resilience of infrastructure, ensuring that it is well-protected from environmental impacts and climate-related challenges over time. The representatives from the government were also asked to rate the nexus of Ecosystem health, climate change, and linear infrastructure development. The analysis of the interview responses on the importance of the nexus between ecosystem health, climate change, and linear infrastructure development revealed an overwhelming recognition of its significance. A striking **87.5%** of respondents rated the nexus as **"Very Important,"** while **12.5%** considered it **"Moderately Important."** Notably, no participant rated it as **"Not Important," "Slightly Important,"** or **"Important,"** emphasizing the

consensus among participants regarding the crucial role of ecosystem health and climate change in the development of linear infrastructure.

Most of the respondents agreed that the intersection of ecosystem health, climate change, and infrastructure development holds substantial importance. This strong alignment highlights the growing recognition of the need for integrating environmental considerations into infrastructure planning and development. The results indicate to a shared understanding that the health of ecosystems and the impacts of climate change must be central to discussions and decisions surrounding infrastructure development, ensuring both sustainability and resilience.

Studies progressively demonstrate that poorly designed linear infrastructure development contributes to ecosystem loss and fragmentation, heightened landslide risk, and loss of lives and assets. Further, conventional gray infrastructures are expensive and are proven vulnerable to climate-induced hazards. Thus, a combination of green and gray infrastructure is coming up as a promising approach that combines the conservation and/or restoration of ecosystems with the selective use of conventional engineering approaches to provide people with solutions that deliver climate change resilience and adaptation benefits [15].

After the 2004 Indian Ocean tsunami, which provided an example of how ecosystem services buffer the risk of disasters, the role of the ecosystem is being acknowledged globally. Recent global agreements, such as the Sustainable Development Goals, Sendai Framework [16], UNFCCC/Paris Agreement [17], Ramsar Convention, and CBD’s Decision XII/20 [18] acknowledge the vital role of ecosystems and natural infrastructure in achieving sustainable development and disaster risk reduction [19], [20].

EbA also supports hydropower resilience. For example, watershed management in Nepal’s Kali Gandaki Watershed significantly reduces erosion and sedimentation and boosts water quality and biodiversity [21]. Similarly, the Krishnabhir section of the Prithvi Highway (one of the most serious landslide prone sections) where bioengineering and civil engineering have been combined, the landslide has been ceased, addressing environmental risks and socio-economic loss [22].

3.2. Current practice on consideration of climate change and EbA in the project cycle.

The interview responses regarding the integration of climate change and EbA in the project cycle revealed

significant gaps at policy level. Most of the respondents (62.5%) rated the current practices as "Poor," and 25% as "Very Poor", with only 12.5% rating them as "Fair." Notably, none of the respondents rated the practices as "Good" or "Excellent," underscoring a shared recognition of substantial gaps in current practices throughout the project cycle. The major challenges identified include: i. absence of a mandatory requirement to integrate EbA measures from the planning phase of infrastructure projects. ii. limited knowledge and lack of site-specific provisions for implementing EbA measures, especially given Nepal's diverse topography and terrain, which makes applying frameworks from other countries difficult, and iii. insufficient implementation and monitoring of these measures. Further, there is no standardized approach to EbA practices that is tailored to Nepal's unique local context.

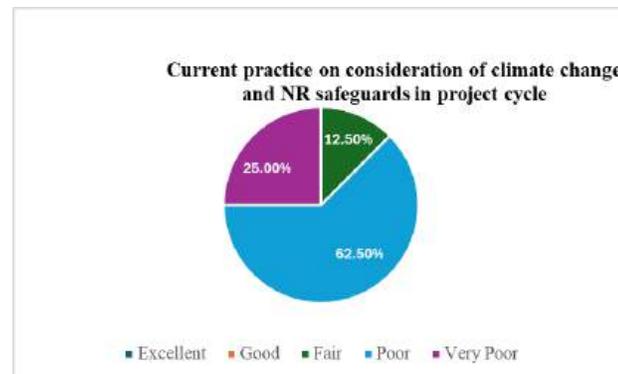


Figure 2: Pictorial representation of current practices on consideration of climate change and NR safeguards.

Most respondents pointed out that poor awareness among decision-makers and practitioners is a major factor in this gap. Many respondents also highlighted that the prevalence of small-scale projects, which typically lack the required budgets for environmental studies and safeguard measures, worsens the situation. Additionally, technical skill deficiencies were recognized, as stakeholders frequently lacked the knowledge necessary to properly integrate climate change adaptation and natural resource protections into project planning and implementation.

Environmentalists claim that Nepal, in the growing stages of infrastructure development, faces significant forest loss because of infrastructure projects. The 1,028 km East-West highway passes through 400 km of core areas and their buffer zones (Parsa, Chitwan, Bardia, and Banke National Parks) and wildlife corridors

(Barandabhar in Chitwan, Kamdi in Banke, Karnali, Basanta and Laljhadi in Kailali) . Irrigation canals such as Babai, Rani Jamara, and Sitka also pass through core areas and corridor forests, obstructing wildlife movement pathways. Transmission lines have also been stretched through protected areas, corridors, and critical watersheds and more are planned. While bridges are designed considering a 100-year flood return period as required by Nepal Bridge Standards 2010 regulated by the Department of Roads, Government of Nepal, there are no specific considerations for climate change and the needs for adaptation in policies, guidelines, and standards of linear infrastructure.

These findings highlight the critical need for a mandatory legal framework that ensures climate change considerations and the integration of EbA measures in infrastructure projects. Moreover, there is a pressing need for country-specific guidelines, stronger policy enforcement, enhanced capacity building, and increased awareness among decision-makers and leaders. Addressing these gaps is crucial to ensure that climate change adaptation and natural resource management are meaningfully incorporated into infrastructure projects, promoting more resilient and sustainable development.

The level of awareness of any global or national provisions and best practices for incorporating EbA into the design and implementation of green and resilient infrastructure, most respondents rated the awareness as **"Very Poor"** (50%), while **37.5%** rated it as **"Fair,"** and only **12.5%** rated it as **"Poor."** No respondents rated the awareness as "Good" or "Excellent."

These findings suggest a significant lack of awareness and understanding of EbA provisions and best practices. The high percentage of "Very Poor" ratings highlights a critical gap in knowledge and recognition of the potential benefits of EbA in enhancing the resilience of infrastructure. This underscores the need for focused efforts to raise awareness and improve understanding of EbA among stakeholders, policymakers, and practitioners to promote more sustainable and climate-resilient infrastructure development.

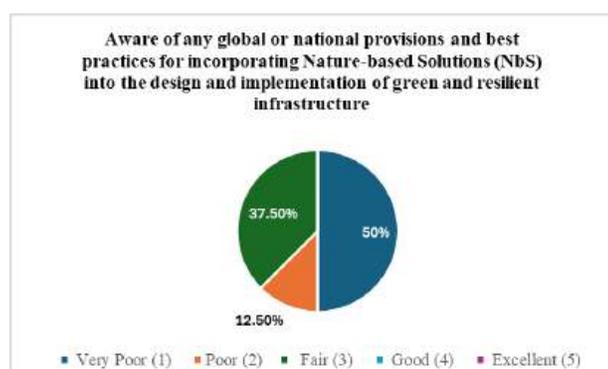


Figure 3: Pictorial representation of awareness of the respondents on global and national provisions for NbS.

3.3. Current practices, gaps, and challenges on the integration of EbA

The integration of EbA measures into infrastructure development in Nepal faces significant governance challenges that hinder effective implementation. **Policy and awareness gaps** were repeatedly highlighted as key barriers.

A significant challenge identified is the **technical capacity gap**, particularly within the academic sector, where EbA measures are not included in the engineering curricula. Currently, engineering education predominantly focuses on grey infrastructure, with many engineers perceiving massive, constructed infrastructure as resilient by default. This narrow view stems from a lack of technical knowledge on integrating ecosystem-based solutions, which leaves a critical gap in understanding the full spectrum of sustainable infrastructure options. Addressing this gap is essential for equipping professionals with the knowledge to integrate ecosystem-based adaptation into infrastructure planning.

Financial constraints were also highlighted as a major challenge. Funding is often insufficient for environmental studies, climate adaptation measures, and the incorporation of EbA into large-scale projects, which rarely have dedicated budgets for such initiatives. This financial gap hinders the progress of EbA integration, making it clear that significant investment is required to prioritize environmental and climate resilience in infrastructure development. One of the respondents emphasized that climate change represents an additional risk, and therefore, the government should allocate extra funds to address it. The respondent also pointed out that promoting a healthy ecology is not only important in building resilient infrastructure but equally beneficial to boosting the national economy.



Another crucial challenge highlighted by respondents is the **gap in standardization** for the undertaking of EbA measures in Nepal. International guidelines and frameworks for implementing Nature-based Solutions (NbS) or EbA do not always suit the specific needs of Nepal, primarily because of the country's **geographical diversity**. Nepal's varied terrain, from the high mountain region to the Terai plain, requires site-specific solutions tailored to local environmental and socio-economic conditions. The lack of standardized approaches that consider these unique challenges creates significant implementation barriers. This gap in a local adaptation of global frameworks underscores the urgent need for customized guidelines that reflect Nepal's topographical and ecological realities.

Additionally, **coordination and collaboration among like-minded stakeholders** have emerged as a critical challenge. The poor coordination among government bodies, the private sector, and civil society organizations results in fragmented approaches to EbA. Without effective collaboration, the integration of EbA into infrastructure projects becomes disjointed and inconsistent, further complicating efforts to ensure long-term sustainability.

Legal and institutional gaps also contribute to the failure of integration of EbA measures in infrastructure projects, as none of the existing policies, laws, and regulations clearly outline the need for this integration. Moreover, there is insufficient enforcement of regulations, leaving policies on paper but not in practice. This governance gap weakens the overall framework for implementing EbA measures and calls for stronger legal instruments and stricter enforcement mechanisms.

As highlighted by the senior official from the Ministry of Physical Infrastructure and Transportation, climate change consideration in infrastructure development is slowly gaining attention within the ministry and efforts have been started lately to integrate climate change as an important risk with measures to climate-proof the infrastructure. However, unless clear policies and guidelines are formulated and strictly regulated, there exists a question of sustainability and continuity.

Furthermore, inadequate resources- technical, financial, and human are key barriers to promoting climate-resilient infrastructure in Nepal. Conceptual clarity and knowledge gaps persist at every tier, from policymakers, planners, designers, and implementers to contractors involved in infrastructure development

projects. This knowledge gap persists because of a lack of demonstration, documentation, and research on the nexus of the ecosystem, climate change, and infrastructure and the benefits of EbA for climate-resilient infrastructure development.

EbA is often considered the responsibility of the Ministry of Forests and Environment and is mostly donor-driven [23]. Also, there are conflicting policies of sectoral ministries often creating a dis-balance in development and adaptation priorities hindering sectoral integration of EbA.

3.4. Way forward in the integration of climate change and EbA for green, sustainable, and climate-resilient infrastructure development

The way forward for successful integration of EbA for climate resilient infrastructure is drawn out from the recommendations from the key informants and learnings from the past projects.

Policy updates, policy enforcement, and institutional strengthening appear as the most urgent priority. Most respondents emphasized the need for updating existing policies that reflect the importance of EbA in the context of climate-resilient infrastructure in addressing the unique needs of Nepal. Policy enforcement and monitoring are imperative to ensure the integration of climate change and EbA in large infrastructure development. Most importantly, the government should develop a standard guideline for integrating EbA in the designing and construction of linear infrastructure projects, ensuring that they are context-specific and adaptable to local realities. As climate change and EbA integration in infrastructure development is an emerging concept, building capacity at all levels ranging from policymakers, investors, and engineers to contractors is imperative.

Respondents also called for **financial prioritization** of EbA measures, stressing the importance of ensuring adequate funding for environmental safeguards, climate adaptation, and the integration of EbA into small-scale infrastructure projects. The establishment of dedicated funding mechanisms, as well as seeking international financial support through global grants, were seen as critical for bridging the funding gap and ensuring the successful integration and implementation of EbA measures.

The need for improved coordination among stakeholders was consistently emphasized by all respondents. **Stronger coordination and collaboration among government agencies, the private sector,**

financial institutions and academia is essential for aligning efforts, sharing resources, and ensuring that EbA strategies are applied in a coordinated manner. The inter-ministerial coordination committee for climate change can play a significant role in ensuring coordination from the sectoral ministries.

Public awareness and education were key recommendations for building widespread support for EbA integration. Respondents stressed the importance of raising awareness among all stakeholders, from grassroots communities to government officials, about the benefits of EbA and the need for climate-resilient infrastructure was also stressed. Effective education campaigns, along with engaging the public through media and community outreach, will help foster a culture of environmental responsibility and create a broader base of support for EbA initiatives. Many participants suggested that training programs and educational initiatives must be expanded to equip current and future professionals with the necessary technical skills to integrate EbA measures effectively. The incorporation of EbA principles into academic curricula, from schools to universities, is seen as an essential step toward creating a skilled workforce capable of integrating EbA into infrastructure projects from the outset. Further, research and pilots are preliminary requirements to assess the effectiveness of EbA to safeguard infrastructures. The integration of course on natural resource safeguarding in infrastructure development in the academic curriculum at the Institute of Engineering (IoE) and Institute of Forestry (IoF) through the USAID-funded and WWF Nepal-implemented Asia's Linear Infrastructure safeguarding Nature (ALIGN) project marks a significant milestone in building technical capacity for Nepal's future workforce in this field. Finally, the **integration of precautionary principles into project planning** is essential in tackling the uncertainties that are brought about by climate change. Respondents suggested that the additional costs associated with climate adaptation should be explicitly included in project budgets. This approach would not only secure the investments made in infrastructure but also contribute to the long-term sustainability of projects by ensuring that they are resilient to the impacts of climate change. Investing in good ecology was repeatedly described as "good economics," emphasizing the importance of aligning environmental health with economic development goals.

With this realization, WWF an international non-government organization working in conservation sector has collaborated with the International Federation of

Consulting Engineers (FIDIC), the global representative body for national associations of consulting engineers to develop a Play for Nature-Positive Infrastructure Development that provides number of examples of projects that relied on nature-based solutions, as well as examples of projects that incorporated green and green-grey infrastructure solutions, to provide a simple guide for infrastructure practitioners to identify and select potential solutions for their projects, in order to drive the progress towards nature-positive infrastructure development. This playbook can be a basis for developing the guideline for integration of EbA or NbS into the linear infrastructure planning and designing [24].

Globally, successful EbA initiatives like mangrove restoration in Thailand and Vietnam have shown the benefits of protecting ecosystems from extreme weather while supporting sustainable livelihoods [25]. Such best practices should be used for improving the knowledge and contextualizing the EbA measure.

4. CONCLUSION

Climate change and poorly designed infrastructure in Nepal are two major factors for the loss of lives and the economy. The country's roads and other critical infrastructure are constantly affected by floods and landslides. As the temperature continues to increase and precipitation gets more erratic, these risks only intensify, putting all the investments at risk. This also weakens the ecosystems they are built within, creating a dangerous feedback loop. Eroding riversides and destabilized slopes further undermine the resilience of both the infrastructure and the environment, setting the stage for even greater disasters in the years to come.

Thus, it is imperative to resort to EbA to safeguard linear infrastructure from climate risk and for the overall protection of ecosystem services that harbor people and biodiversity. However, EbA is an emerging concept in the development sectors and there exist numerous gaps and challenges. A strategic framework that fills the policy and knowledge gaps is essential. Moreover, research and contextual pilots of EbA interventions should be prioritized as an entry point for evidence-based policy advocacy for the successful integration of EbA into linear infrastructure development.

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Wewa-Ellangawa System (TCS) - Model for Climate-Resilient Water Management in Sri Lanka

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ABSTRACT

The Wewa-Ellangawa System exemplifies an indigenous technology in Sri Lanka that addresses the pressing challenges posed by climate change, particularly prolonged droughts and floods in Sri Lanka. This intricate network of interconnected tanks, developed over a thousand years ago, captures and stores rainwater, effectively mitigating the risks associated with climate extremes. By promoting water recycling and efficient resource allocation, the system enhances water security for agriculture, livestock, and local communities. Key features of the Wewa-Ellangawa System include its ancient socio-ecological framework, naturalized design that harmonizes with the environment, and a distributed layout that optimizes resource use. The governance structure surrounding this system is concentric on community participation and shared responsibility, which ensures that local needs are met while safeguarding downstream users. Historically rooted in the dry zone of Sri Lanka, the tank cascade systems have thrived in a landscape characterized by limited rainfall and flat terrain. They have played a crucial role in sustaining ecosystems during dry seasons while fulfilling human water needs. The functionality of the Wewa-Ellangawa System illustrates how traditional practices can inform modern water management strategies. In light of contemporary climate challenges, this study highlights the governance mechanisms inherent in the Wewa-Ellangawa System as a model for enhancing climate resilience. By integrating traditional knowledge into current policies and practices, stakeholders can develop adaptive strategies that address both flood and drought risks effectively. This approach underscores the importance of participatory governance in fostering sustainable resource management in regions vulnerable to climate shocks.

I. INTRODUCTION

As climate change increasingly impacts global ecosystems, the need for resilient and sustainable practices has become a pressing concern. In Sri Lanka, significant challenges arising from climate change include prolonged droughts and floods.

The *Wewa-Ellangawa - tank cascade system (TCS)*, a prime example of indigenous technology, offers a remarkable solution to these issues and provides valuable insights for enhancing climate resilience strategies.

TCS is part of a traditional water management strategy in Sri Lanka, particularly prominent in the north central area

of the island. This system is an intricate network of interconnected tanks that collect and distribute water to enhance water security and make maximum use by promoting reuse of water. Developed over a thousand years ago, these tanks capture and store rainwater on surface and under the ground, effectively mitigating the risks associated with both droughts and floods. By channeling water between tanks, the system efficiently manages limited resources while also recharging groundwater tables. This approach supports agriculture, livestock, and local communities, demonstrating the sustainable use of water resources—an increasingly critical issue in the context of climate change.

Key Features of the System:

- Ancient socio-ecological system
- Highly efficient water management and recycling methodology
- Naturalized design that works in harmony With the environment.

II. TOPOGRAPHICAL AND CLIMATE CONDITIONS

The TCS date back to ancient times, specifically during Sri Lanka's first kingdom in written history, the Anuradhapura period (5th century BC to 11th century AD)[4]. This area belongs to the dry zone of the country, receiving rain water for only 3–4 months per year from northeast monsoon rains. However, the first and second kingdoms of Sri Lanka, located in this region, had been populated for over 2000 years, with the majority of their food requirements supplied through irrigation.

The terrain is relatively flat with sparse vegetation typical of dry monsoon forests, shrub lands, riverine forests, and open grasslands. A few rivers originating from the central hill country flow across this area but are insufficient to meet the demands of the local population. It is these TCS that have historically contributed to human water needs while allowing ecosystems to thrive during dry seasons.

III. FUNCTIONALITY OF WEWA-ELLANGAWA SYSTEM

A cascade system is defined as a “connected series of tanks organized within a ‘meso-catchment’ of the dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet” [2]

“Wewa” is the building block of the Wewa-Ellangawa System. Even though it looks like a tank which retains water, but it's functionality is more sophisticated than an ordinary tank. However, for easy usage of language the term “tank” is used for the “Wewa” in this article. Tanks, paddy fields, watersheds and canals are integrated and interwoven with the natural environment (naturalized) making up this irrigation water management system. [3]

Water originating from the catchment area initially flows into forest tanks, which serve as settlement tanks designed to trap silt, mud, and fallen leaves carried by surface runoff. These tanks not only provide water for wildlife, thereby keeping animals away from villages, but also recharge groundwater in forested areas, sustaining

ecosystems during dry seasons. The number of forest tanks within a particular Tank Cascade System (TCS) may vary depending on the size of the catchment area.

Subsequently, water flows into major village tanks intended for irrigation and domestic purposes. Supplementary tanks, known as Olagam Wewa or upper village tanks, may also be present within this system. The interplay between these tanks and the canals that transport water among them facilitates groundwater recharge, thus characterizing the TCS as a socio-ecological system.

Depending on the topography determined by geology and subsequent geomorphic changes in that topography, 4 types of TCS can be identified as linear, crescent shaped, dendritic and fan-like [6]. Figure 1 shows a typical layout of a TCS.

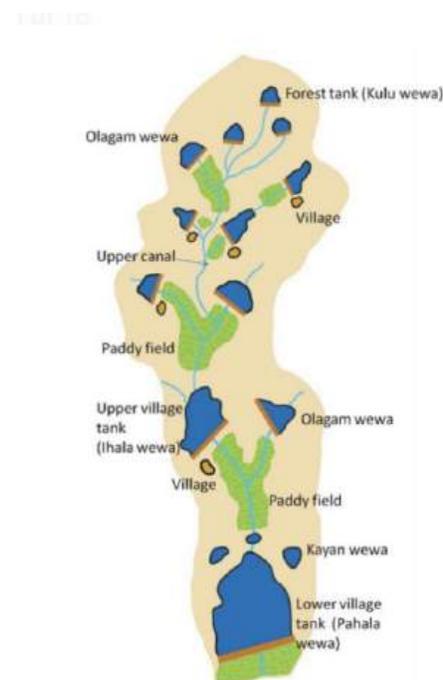


Figure 1: Typical Layout of a Wewa- ellangawa (Tank Cascade System)

IV. SUSTAINABLE ENGINEERING CONCEPTS ASSOCIATED WITH THE SYSTEM

1. Materials and Technology

Numerous sustainable concepts underpin the TCS. All materials utilized in constructing tanks or canals are derived from natural sources. The dams are primarily earth dams (Figure 2), with soil compacted using traditional methods involving elephants, cattle, and goats to achieve optimal compaction levels. This ancient

knowledge has informed modern engineering practices; for instance, the sheep foot roller exemplifies this continuity.

Remarkably, many ancient dams continue to function effectively with minimal maintenance. An example is the Kala Wewa dam, constructed around 460 CE, which remains operational today.

Larger tanks in Sri Lanka often feature rip-raps—rubble packs placed on the inner toe of tank bunds to prevent wave attrition during storms. For instance, the Kudawilachchiya tank, an abandoned tank in Sri Lanka showcases a rip-rap constructed from neatly cut stones measuring around 300mm x 400mm x 900mm over a length of 3 kilometers.



Figure 2: Rip Rap of the Kudawilachchiya tank, Sri Lanka

Another significant element is the Bisokotuwa, a chamber-like structure made from stone slabs or thick brick walls located within the dam and connected to the water outlet (Figure 3).

It is believed that this feature acts as a surge tank that mitigates water hammer effects caused by abrupt sluice closures (Figure 4).



Figure 3: A Bisokotuwa of an ancient tank

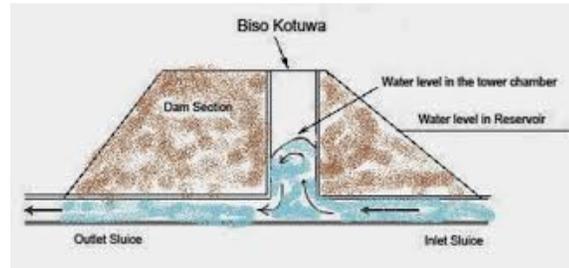


Figure 4: Cross section and function of Bisokotuwa[7]

2. Water Filtration and Treatment

The TCS employs various natural water treatment methods. Initially, debris from the catchment area settles in Kulu Wewa (forest tank). Before entering the major Wewa, water passes through two additional filtration systems: Goda Wala (water hole) and a grass filter (Perahana). These filters trap remaining debris and silt, allowing clean water to enter the tank.

Additionally, a water puddle known as Kattakaduwa forms between the dam and paddy fields where seepage occurs through the dam. This area serves as a bioremediation trap for salts and contaminants due to its dense vegetation. The plants and trees grown in that area can absorb heavy metals such as chromium and lead.

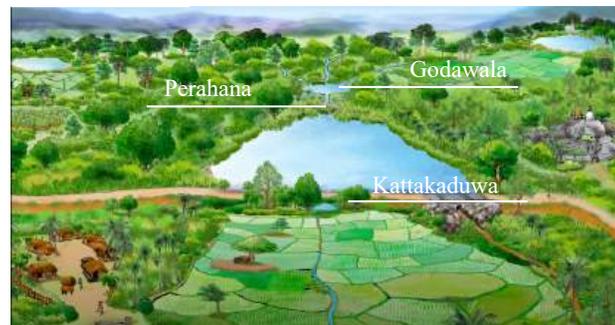


Figure 5: Water filtration & treatment methods associated with tanks [1]

The canals were constructed from earth with low gradients—such as the famous Yoda Ela canal with a maximum gradient of 20 cm per kilometer—minimizing bank erosion while recharging groundwater along their lengths. The *Kumbuk* tree (*Terminalia Arjuna*) is often planted along canal sides to purify water by absorbing contaminants.

3. Mitigation Methods for Evaporation of Water

To minimize evaporation from the water surface of the tank, a tree belts known as *Gas-Gommana* has been maintained along both sides of the tank. These belts act as windbreaks that reduce dry winds' contact with water surfaces, thereby decreasing evaporation rates. (Figure 6)

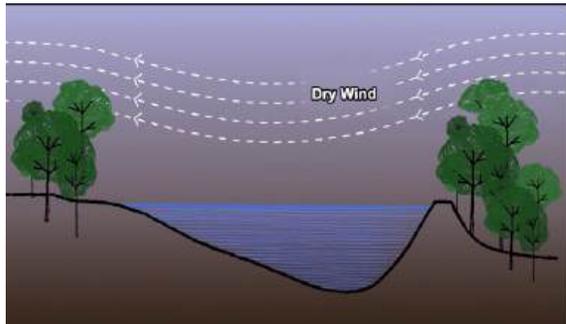


Figure 6: Effect of Gas-Gommana on water evaporation [1]

V. FLOOD CONTROL AND DROUGHT MITIGATION

The TCS plays a crucial role in flood control and drought mitigation.

The *Kalinguwa* (twin tank system) exemplifies an innovative engineering solution designed to address drought and flooding impacts in Sri Lanka. This system as shown in Figure 7, consists of a large tank divided into two sections: Tank B for irrigation and Tank A for overflow management during heavy rains.

As to Tennakoon M.U.A [6], a small earth bund runs upstream (C-D), perpendicular to the main bund of the tank complex. The uppermost shoreline (H1) indicates the maximum water level reached when the main spillway (I) releases a one-foot thick volume of water. Once spilling ceases, this maximum level recedes to a lower shoreline (H2). The gap between these shorelines is crucial for preventing bund breaches during periods of excessive water inflow. If water levels rise too high, an outer spillway at point G can be opened to release excess water. This design allows surplus water from Tank B to flow into Tank A, effectively reducing pressure on the main tank and preventing potential breaches. After the monsoon season ends, continuous irrigation from Tank B causes its water level to drop rapidly, moving from H1 to lower shorelines toward the tank bottom (*Mandakaluwa*). In contrast, Tank A retains more water due to its limited irrigable area downstream. Consequently, while Tank B faces a deficit, Tank A can hold surplus water. If additional irrigation is needed in Tank B, surplus water from Tank A can be transferred through a sluice gate at point F, replenishing Tank B and ensuring adequate water supply for downstream fields. Overall, this innovative tank design, featuring a diagonal bund and associated structures, effectively addresses two critical challenges: preventing bund breaches during heavy rains and mitigating drought impacts by managing water resources efficiently.

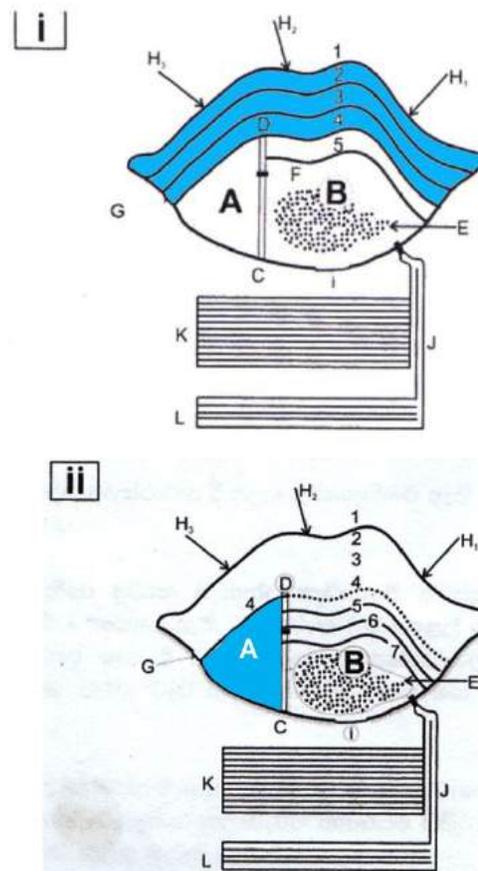


Figure 77: *Kalinguwa* (twin tank system) i) As a Flood Control Device, ii) As a Drought Mitigation Device [6]

Historically, tank bottoms or *Mandakaluwa* were designed to retain some water by positioning the lowest sluice slightly above ground level. (Figure 8)[6]

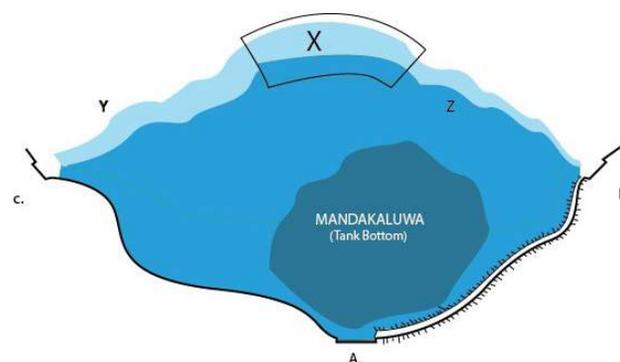


Figure 8: *Mandakaluwa*, the tank bottom [6]

This design ensured that residual water supported fish species capable of surviving in muddy conditions until subsequent rainy seasons. During droughts, this remaining water served as a vital drinking source for village livestock. However, decades of silt accumulation have diminished this capacity.



VI. GOVERNANCE OF THE SYSTEM

A critical aspect of indigenous technologies is their governance framework. Traditional governance systems supporting the TCS were founded on principles of community participation, shared responsibility, and equitable resource management. Communities historically collaborated with local leaders to construct and manage these tanks and canals.

In recent decades, governance has shifted significantly from farmers to government officials; resulting in diminished community engagement in maintenance efforts. Industrial agriculture and centralized irrigation projects have further eroded local involvement in tank management, leading to deterioration within cascade systems.

The socio-cultural context surrounding these tank systems is vital for their governance. Local communities have historically depended on these resources not only for irrigation but also for daily activities such as bathing and washing. However, growing concerns about water quality have led to decreased usage for drinking purposes, undermining community engagement.

VII. CONCLUSION

Legal frameworks governing water management often overlook local knowledge and practices essential for effective governance. It is imperative that effective governance integrates ecological considerations with socio-economic realities to enhance resilience within communities reliant on such systems. The study of the TCS underscores the necessity for policies that empower local communities while promoting sustainable management practices. Incorporating ancient systems into modern governance could significantly bolster climate resilience.

Strategies for Improved Governance

1. **Community Engagement:** Revitalizing community participation in decision-making processes can enhance stewardship of tank resources.

2. **Integrated Management Approaches:** Combining ecological assessments with socio-economic data can lead to more effective management strategies addressing both environmental sustainability and community needs.

3. **Legal Reforms:** Updating legal frameworks to reflect local practices can strengthen governance structures surrounding water management.

4. **Education and Awareness:** Raising awareness about these systems' importance can help shift perceptions

regarding water quality and promote more sustainable usage patterns.

By adopting these strategies, it is possible to foster greater climate resilience while ensuring sustainable management of vital water resources within communities reliant on traditional systems like TCS.

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Restoring a Sustainable Future for Urban Lakes : Engineering and Innovation in Yangtze River Catchment Protection

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ABSTRACT

Urban lakes are vital to the urban water cycle and ecosystems. However, rapid urbanization and increased human activities lead to critical challenges for ecological degradation in urban lakes globally. In 2016, China has launched a national strategy - The Yangtze River Catchment Protection, to advance the ecological and environmental protection and restoration of the Yangtze River basin, and with the vision to achieve sustainable economic and social development through a better eco-environment. Under such strategy, our team undertake water environment management project in over 100 cities throughout Yangtze River catchment and have completed ecological restoration in urban lake over 7000 km², result in great success at both local and catchment scale. We conclude five solutions as an integrated technical system to tackle the restoration and management of urban lakes, which is 'catchment planning as prerequisite, source control as core, system restoration as foundation, waterway connection as supplement, and smart management as guarantee'. Future management is recommended to focus on the establish the catchment-level coordination, while promote scientific research. Our engineering experience and technological innovation implies a feasible solution which support the management and restoration of urban lakes at the global scale.

1. INTRODUCTION

Lakes are vital to the water cycle and ecosystems. However, rapid urbanization and increased human activities dramatic change the land use which threatens the number, area and the composition of lake systems globally. Such a effect lead to decrease in flood resilience, deterioration of water quality, degradation of aquatic habitat and biodiversity^[1,2]. Gross changes above are further intensified in urban environment given the shallow water areas and smaller catchment scales of urban lakes, bringing enormous challenges to the social and economic development in world major cities.

The Yangtze River is the third-longest river in the world and is arguably the longest river in both China and Asia. It flows over 6397 km with an annual runoff of 9513 billion m³ [3]. It is also respected as the mother river of China and has contributed immensely toward the socio-economic development of China. To consolidate the continuous growth of the market economy and consumption, while further develop the ecological civilisation as a major imaginary of nation's future, China launched a national strategy in 2016, known as the Yangtze River Catchment Protection. This strategy aims to protect and restore the ecological system of the Yangtze

River catchment, while adapt economic development model towards a more sustainable and ecological way. It has been described as China's most prominent national catchment protection strategy since 1949, and is expected to be one of the most vital practices of China's ecological civilisation [4,5].

In response to Yangtze River Catchment Protection, our team undertake water environment management project in over 100 cities throughout Yangtze River catchment and have completed ecological restoration in urban lake over 7000 km², result in great success at both local and catchment scale. In this paper, the governance of Yangtze River conservation were first examined, including Yangtze River Catchment Protection, Yangtze River Economic Belt (YREB) and Yangtze River Protection Law. We then concluded five solutions as an integrated technical system to tackle the restoration and management of urban lakes. Recommendations in future management were also given to support the management and restoration of urban lakes in world major cities at the global scale.

2. GOVERNANCE IN YANGTZE RIVER CONSERVATION

2.1. Yangtze River Catchment Protection

On January 5 2016, at a symposium to improve the development of Yangtze River Economic Belt in Chongqing, Chinese President Xi Jinping, also general secretary of the Communist Party of China Central Committee and chairman of the Central Military Commission, made a speech to stressed that development must prioritize ecology for China's long-term benefits. Economic and social benefits can be obtained from our mountains and rivers. This symposium carried out the idea to 'step up conservation of the Yangtze River and stop its over development'. The strategy to protect the ecological environment in Yangtze River Catchment was then raised to national level^[6]. Since then, such symposiums were further held three times in Hubei, Jiangsu and Jiangxi province respectively, covering both the up- and downstream of the Yangtze River Catchment, with a vital aim to promote the conservation of the Yangtze River and consolidate its significance as national strategy^[7]. In the past 8 years, China has made remarkable progress towards sustainable development by taking effective measures to control pollution and emissions by strengthening environmental supervision, law enforcement, eliminating backward production, and controlling emissions from factories.



Figure 1. Area of the Yangtze River Catchment Protection

2.2. Yangtze River Economic Belt

The Yangtze River Catchment Protection is closely linked to the development strategy of the Yangtze River Economic Belt (YREB) which was also first proposed in 2016. The YREB not only plan the economic development along the Yangtze River Catchment, but emphasize its core in environmental oriented development, while priorities the ecological conservation and restoration of Yangtze River^[8]. The implementation of the Yangtze River Catchment Protection covers the entire YREB area which includes two municipalities and nine provinces, covering 21.27% of China's total land area and accounting for more than 40% of the entire population, and approximately 45% of national Gross Domestic Product^[9].

Since the promotion of such, China issued a series of government strategies, regulations and national laws to promote the conservation of natural environment and biodiversity in the YREB, including the Outline of the development plan for the Yangtze River Economic Belt in 2016, Ecological conservation plan of the Yangtze River Economic Belt in 2017, Opinions on comprehensively strengthening the judicial guarantee for the construction of ecological civilisation and green development in the Yangtze River Basin in 2017, Guidelines on establishing and improving the longterm mechanism of eco-compensation in the Yangtze River Economic Belt in 2018, Implementation opinions on supporting the green development of agriculture and rural areas in the Yangtze River Economic Belt in 2018, Opinions on strengthening the protection of aquatic organisms in the Yangtze River in 2018, Action plan for the protection and restoration of the Yangtze River in 2019, Announcement on the scope and time of the ban on fishing in key waters of the Yangtze River Basin in 2019, Yangtze River Protection Law, The action plan to support the establishment of a horizontal eco-compensation mechanism for the Yangtze River Basin in 2021. Among these, the most ambitious action

lies in China's 10-year ban on fishing in the Yangtze River from 2020 which is China's most radical and extensive biodiversity conservation plan since 1949^[10], and the Yangtze River Protection Law^[11] which is the first protection law for specific river basins.



Figure 2. Area of the Yangtze River Economic Belt

2.3. Yangtze River Protection Law

Yangtze River Protection Law is the first protection law for specific river basins in China. It passed at the 24th Standing Committee session of the 13th National People's Congress, will take effect on March 1, 2021. The law is formulated to strengthen the protection and restoration of the ecological environment in the Yangtze River Basin, promote the reasonable and efficient use of resources, guarantee ecological security, and achieve the harmonious coexistence of human and nature and the sustainable development of the Chinese nation.

3. URBAN LAKES RESTORATION IN YANGTZE RIVER CATCHMENT PROTECTION

Under the Yangtze River Catchment Protection, our team undertake water environment management project in over 100 cities throughout Yangtze River catchment and have completed ecological restoration in urban lake over 7000 km², result in great success at both local and catchment scale. We conclude five solutions as an integrated technical system to tackle the restoration and management of urban lakes.

3.1. Catchment Planning and Systematic Management

Urban lakes and its catchment is an integrated system. The restoration and management of its ecosystem should consider the integrity of all natural elements within its scale. It is vital to protect mountains, rivers, forests, farmlands, lakes and grasslands and address their degradation at the source in a coordinated way. Based on the comprehensive investigation of its current ecological status, management practice should be planned and designed at system level which integrates water security,

water resources, water environment, water ecology, water landscape, and water culture, to achieve the reduction of pollutant loads at its source, end of pipe control and the restoration of the water body in Urban lakes.

3.2. Source Control and System Restoration

To reduce the pollutant loads in urban lakes, it is vital to understand the process on how pollutant is transferred including its generation, transportation and way of discharge. Such understanding ultimately informs the implementation of systematic approach, i.e. source reduction, process control and end-of-pipe management.

Pollutants within urban lake systems generally sourced from industry wastewater, municipal sewage and urban stormwater runoff. Pollutant source control focus on the origin of urban water cycle, so that the quantity and the concentration of different pollutants can be reduced at its source. Control of industry wastewater requires a cleaner production line, while promotes law enforcement. Reduction of municipal sewage requires implementation of water conservation and waste classification. Decrease of urban stormwater runoff can be achieved via Sponge City (also known as Source Control Measures and Low Impact Development), which emphasize the detention and retention of stormwater at its source, thus preventing the transportation of pollutants, such as suspended solid and E.coli, at the impervious surfaces.

Process control concentrates on integrity and sustainable management of urban drainage systems. It has the major focus on improving both the wastewater pumping stations and treatment plants at various scales, and the construction of sewage pipe network. For newly developed area, where most of sewer are separate system, management could focus on the separation of waste and rainwater. For inner cities, where the combined systems dominates the wastewater system, measures, such as wastewater retention and interception of domestic wastewater, should be carried out to ensure the control of direct discharge.

End-of-pipe management focus on the receiving water bodies, such as urban lakes, which are the terminal in urban water cycle. Such an approach focus on further purification of external pollutant and the control of internal pollutant. Common measurement includes constructed wetlands, bioretention systems, river bankside rehabilitation, physical dredging, surface aeration and waterway landscaping.

3.3. River-Lake System Connection

River-

Lake System Connection project has the advantage to increase the flood resilience and environmental improvement. However, implementation of such requires careful plan

ning and design, to restore its pre-development states. This requires comprehensive research on its natural hydrological regime based on historical data and waterway relationships. Moreover, restored connection could provide additional retention capacity for urban flooding. For example, city of Wuhan could pre-empt multiple urban lakes, such as Donghu Lake, Shahu Lake, Tangxunhu Lake, so that these natural water bodies would have enough capacity to tackle the upcoming storm events.

3.4. Smart Management

Future management of urban lakes should focus on its capacity to tackle extreme condition (e.g. pollution and flooding) under climate change. This requires comprehensive monitoring of water environment and the intelligent platform to handle the complex environmental data, which may achieve automation in management and hazard warning. Problem found through monitoring could further optimise the management, which could offer insight in future integrated management at a larger scale.

4. CONCLUSION

In this paper, the governance relates to the Yangtze River Catchment Protection was examined, including Yangtze River Catchment Protection, Yangtze River Economic Belt and Yangtze River Protection Law. Based on the practice. Under such national strategy, we undertake various water environment management project. We summaries five solutions as an integrated technical system to tackle the restoration and management of urban lakes. Future management is recommended to focus on the establish the catchment-level coordination, while promote scientific research. Our engineering experience and technological innovation implies a feasible solution which support the management and restoration of urban lakes at the global scale.

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Addressing the Impacts of Climate Change in the Transport Sector in Asia

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ABSTRACT

The frequency and intensity of natural and climate events are increasing in Asia. As a result, Asia has witnessed severe impacts on transport infrastructure, services and human life. This paper assesses the impacts of climate change on the transport sector in Asia and explores various measures that can be employed to develop resilient transport infrastructure. It looks at both adaptation and mitigation measures to reduce the emissions from the transport sector in Asia. In response to the 28th Conference of Parties (COP28) call to shift away from the use of fossil fuels, many approaches and efforts are being implemented in the passenger and freight transport in Asia. The paper reviews various ongoing transport sectors' efforts to support implementation of the Paris Agreement. It will analyze emerging transport research and technologies such as electric vehicles, renewable fuels, measures to improve operational efficiencies and efforts to enhance overall sustainability and resiliency of transport system in Asian context. It analyzes the role of institutions and governance in planning, development and management of transport systems and services. It also compares trends vis-a-vis countries pledges made to the United Nations Framework Convention on Climate Change (UNFCCC) and reviews relevant transport sector strategies, policies and practices in Asia. It argues for a thorough review of the current development cooperation paradigm. Finally, the paper offers policy suggestions to enhance resiliency of infrastructure and accelerate the transition towards carbon neutrality in the transport sector that would include measures to enhance cross-sectoral policies and coordination.

1. INTRODUCTION

We are witnessing news of unprecedented rain, floods and extreme weather events in South Asia [1], rising levels of floods in India [2], super typhoon in Vietnam [3], flood and mudflow in Thailand [4], torrential rain and floods in Nepal [5], cyclone in Bangladesh [6] and their impacts on transport and infrastructure and on our lives. These are just a few of the many examples of these types of extreme weather events. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, Climate Change 2021: The Physical Science Basis clearly states we should not delay in implementing adaptation measures to the threats of climate change to human and planet [7].

Asia is one of the most affected continent and

countries like Bangladesh, China, Japan, India, Indonesia, Nepal, and the Philippines are vulnerable to climate and natural events such as floods, cyclones, and tsunamis. Sometimes, climate events combine with other natural and human-made disasters such as earthquakes. Coastal areas in Bangladesh, India, the Philippines, Vietnam for example, are extremely vulnerable to climate-related events and rising sea levels.

Human-induced activities are responsible for the increase in the frequency and intensity of climate events and global warming and the transport sector in Asia is responsible for 27% of CO₂ emissions and without more ambitious polices and actions the CO₂ emissions could increase by more than 50% by 2050 [39]. Despite efforts of countries and cities transport sector CO₂ emissions grew by 36% in Asia [38]. The IPCC reports states that

Asian countries need to implement transformative policies to meet climate mitigation goals in the transport sector [7]. The report also singles out cities as hotspots for global warming due to their lack of vegetation and the heat retaining properties of urban infrastructure [7].

Climate change poses a significant threat to global infrastructure, particularly in transport systems, where rising temperatures, extreme weather events, and sea-level rise are increasingly impacting the resilience of transport systems and coastal cities [7-10]. Transport and urban public transport systems, essential to sustainability and economic development, are particularly vulnerable to these climate-related disruptions. Efficient transport and public transport not only reduce greenhouse gas emissions by minimizing reliance on private vehicles but also supports equitable access to jobs, education, and services, contributing to overall urban resilience [10].

Transport systems play a vital role in promoting urban sustainability by reducing greenhouse gas emissions, alleviating traffic congestion, and providing equitable access to essential services such as employment, education, and healthcare [10]. However, these systems are increasingly at risk from climate change impacts, which can disrupt services, damage infrastructure, and reduce the reliability of transport networks. For instance, flooding can inundate railways and roads, while extreme heat can warp tracks and strain energy supplies, leading to widespread service interruptions [11-12].

Given these challenges, it is crucial to assess the impacts of climate change and resilience of transport systems in Asia, where rapid urbanization and economic growth are placing additional pressures on transport infrastructure [12].

This paper aims to assess the impacts of climate change on transport systems in Asia. It analyses the vulnerabilities of these systems and discusses potential adaptation strategies to enhance their resilience. By doing so, the paper seeks to contribute to the ongoing efforts to create more sustainable and resilient transport systems in the face of a changing climate. It looks at both adaptation and mitigation challenges to reduce the emissions from the transport sector in Asia. It analyzes the role of institutions and governance in planning, development and management of transport systems and services. It also suggests policy options for enhancing sustainability and

resilience of transport systems and infrastructure and accelerate the transition towards carbon neutrality in the transport sector that would include measures to enhance cross-sectoral policies and coordination.

2. TRANSPORT AND CLIMATE CHANGE

2.1 Transport, Sustainable Development Goals and Climate Change

Transport is directly or indirectly related to many Sustainable Development Goals (SDGs) such as 1, 2, 3, 7, 9, 11, 13, 16 and 17. The transport sector contributes to climate change as well as being affected by climate events. Therefore, transport sector strategies and policies are well reflected in Nationally Determined Contributions (NDCs) submitted by countries to UNFCCC process. There are established intergovernmental processes to review the progress of SDGs and the Paris Agreement at regional and global levels. COP is organized every year to accelerate the implementation of the Paris Agreement. High-Level Political Forum (HLPF) is organized in New York to review the achievements of SDGs and the Asia Pacific Forum on Sustainable Development (APFSD) review SDGs achievement at regional level.

The SDGs Progress Report for Asia-Pacific presents a gloomy picture of its achievement in the region. If the current trends continue it may take another 32 years beyond 2030 to achieve SDGs [41]. However, there has been some good progress in certain SDGs such as Goal 1: Poverty, Goal 7: Energy, Goal 9: Infrastructure, and Goal 11: Cities. But Goal 13: Climate is regressing. Therefore, transformative and accelerated actions are required to reverse the trend including efforts in the transport sector.

2.2 State of Transport Systems in Asia

Asian transport systems consist of networks of highways, railways, maritime and inland water routes and urban transport systems. All systems contribute to rising emissions through its operation as well as from construction. Among these modes water and maritime transport and railways have low emissions intensity while road has higher emission intensity as it accounts for about 75% of transport CO₂ emissions. Given that the Asia-Pacific is urbanized and more than 50% of the population are residing in Asian cities [50], the number of private vehicles is growing at a higher rate in Asia. In order to

make Asian transport system sustainable and resilient, urban public transport system has to be sustainable and resilient.

Figure 1 shows the share of public transport and active mobility in selected Asian cities. It shows a low share of passenger transport and a high share of active mobility. One of the challenges for the countries and cities has been to increase the share of public transport despite considerable investment in public transport systems. The high share of active mobility also indicates the need for good infrastructure for walking and cycling.

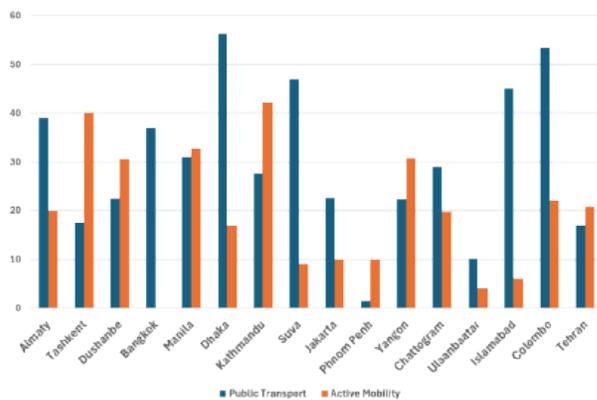


Figure 1. Mode share of public transport and active mobility, (Source [17])

2.3 Extreme Climate Events and its Impacts

During 2024 we have witnessed frequent extreme climate and weather events [1-6]. In early October 2024 we saw unprecedented floods in Kathmandu and Nepal, recent floods in Viet Nam, ongoing flood in Thailand, regular cyclone and storms in the Philippines. The frequency and intensity of these weather events is much higher than earlier events and have caused significant damage to human lives and transport infrastructure and disrupted transport operations for some days. Rapid urbanization and climate change are main drivers of recent floods and damages in Nepal [42].

There is climate event variability within Asia. Many Asian coastal cities will be affected by faster sea level increases. Extreme heat has increased, and cold has decreased in Asia. In East Asia, the frequency and intensity of precipitation will increase, and draught is expected to be more frequent. Meanwhile, rainfall will increase in the northern parts of Southeast Asia, monsoon

precipitation will increase in South Asia, and droughts are expected to be severe in Southwest Asia [7]. IPCC further predicts that Asia will experience rises in temperature, longer summer heat spells, more intense and more frequent precipitation, increased extreme rainfall, a higher number of extreme tropical cyclones, and rises in sea levels [7].

Climate change has intensified the occurrence of extreme weather events such as floods, heatwaves, storms, and rising sea levels, all of which pose serious threats to public transport systems across Asia. Flooding, for instance, can severely disrupt transport services by inundating roads, railways, and subways. In cities like Bangkok, where seasonal monsoons already lead to frequent flooding, rising sea levels and heavier rainfall due to climate change worsen the problem. Substantial parts of the city’s public transport infrastructure, especially road networks and railways, are often submerged during intense downpours, causing delays, damage to vehicles, and interruptions in services [14].

Heat waves also affect transport systems by increasing the wear and tear on infrastructure. High temperatures can cause rails to expand and warp, resulting in track failures, which disrupt train services. Similarly, intense heat can compromise road surfaces, leading to more frequent maintenance requirements. Urban heat islands, common in dense Asian cities like Manila, amplify the effects of heatwaves on public transport systems [5]. Storms and typhoons, which are also becoming more frequent, pose additional challenges, particularly for coastal cities. High winds and heavy rain from typhoons in cities such as Manila often led to road and rail closures, infrastructure damage, and stranded commuters.

2.4 Infrastructure Vulnerability

Several types of transport infrastructure—roads, railways, maritime routes, waterways and subways—vary in their vulnerability to climate change. Roads, being exposed to the elements, are particularly susceptible to flooding, extreme heat, and landslides. Railways face similar risks, particularly at bridges and tunnels, which are vulnerable to flooding and erosion. In coastal cities, subways are at risk from rising sea levels, which can cause flooding in underground stations and tunnels.

For instance, in Bangkok, the mass transit system is

highly vulnerable to flooding. The city’s road and subway infrastructure are often inundated during periods of heavy rainfall, disrupting services and damaging infrastructure [5]. Similarly, in cities like Jakarta, subsidence due to rising sea levels has given roads and railways in low-lying areas increasingly prone to frequent flooding, affecting the daily commute of millions of people [12].

Manila, another coastal city, faces similar challenges. Frequent typhoons and heavy rain cause regular flooding of roads and rail systems, leading to large-scale disruptions. The city has begun developing flood-resilient infrastructure, including elevated rail lines and improved drainage systems to mitigate these impacts. Nevertheless, the rapid pace of urbanization and inadequate infrastructure planning have made it difficult for Manila to fully protect its transport systems from the adverse effects of climate change [12].

Several cities in Asia have already experienced significant impacts on their public transport systems due to climate-related events. In Bangkok, seasonal monsoons and rising sea levels have caused repeated flooding of major road networks and sections of the metro system. The city has responded by investing in flood barriers and drainage systems to protect key transport infrastructure. However, these measures are increasingly inadequate in the face of more frequent and intense rainfall brought on by climate change [10].

How the transport sector responds to impacts of climate events. Let’s examine the case of Nepal. There are established mechanisms to respond to climate events emergencies (mainly floods, rains, landslides, and earthquakes). The home ministry leads coordination at the Federal level and District Disaster Response Teams under district administrator coordinate efforts at local level. Central relief funds are under the Prime Minister Office. As transport is crucial for relief operation, the Department of Roads mobilizes heavy equipment and labours to open the damaged roads for traffic. Usually, these relief operations face many coordination challenges as they involve various institutions and stakeholders.

Development of mass public transport systems, planning for infrastructure for non-motorized transport (walking and cycling), transition to electric mobility, integration of land use and public transport planning and micromobility, development of intermodal transfer points

and discouraging the use of private vehicles are some of the policy options to make transport sustainable and resilient [43].

2.5 Nationally Determined Contributions and Transport Strategies

Figure 2 shows transport mitigation policies and strategies reflected in the Nationally Determined Contributions (NDCs) of Asian cities. A review of NDCs of the Paris Agreement indicates that transition to electric mobility, use of alternate fuels and development of public transport are among the top three priority policies and strategies. Railway infrastructure development, green freight measures, fuel economy and energy efficiency measures are some of the mitigation policies related to freight transport of Asian countries [27].

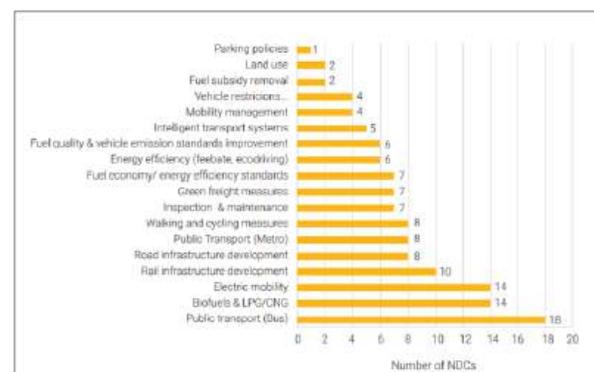


Figure 2. Transport sector mitigation policies in NDCs (Source [27])

Reviewing the commitments made in the NDCs, transport policy documents and trends of the transport emissions in Asian countries, there is lack of strong linkages and coherence among the commitments, transport policies, strategies and targets as well as the pace of implementation measures in the transport sector. Most of the policies, targets and measures are related to passenger and urban transport.

Even there is a lack of consistency of anticipated targets related to the GHG emission reduction, EV penetration in various transport related policy documents. For example, anticipated electric vehicle (EV) penetration rate is different in policy documents and NDCs in some countries. Current trends shows that targets such as Nepal 25by 2025 and Thailand 30by30 are difficult to achieve

[27]. There is some public EV buses operated by private and public sector and EV car fleets in Bangkok and Kathmandu. The aim of Thailand to be an EV production hub is work in progress as some FDI is arriving in this field. There is high interest for EV transition in Asia. However, the high upfront costs, charging facilities, renewable energy sources and policy consistency are seen as major obstacles for transition.

Electrification of transport systems is getting priority attention in Asia as a sustainable alternative to fossil-fuel-powered public transport. However, upfront investment, accessible charging network and transition to renewable energy are also equally important. To facilitate transition to electric mobility robust policy national framework for its development including cross-sectoral collaboration is important. EV adoption not only reduces greenhouse gas emissions but also contributes to long-term cost savings due to lower fuel and maintenance costs [18]. Asia countries could learn from experience of Norway and China on electrification.

EV transition in Norway can provide some policy insight where the government has provided incentives for acquisition and operation of electric vehicles. The example includes tax rebates, free tolls and parking and provision of a network of charging infrastructure [51]

As part of the Asia-Pacific Initiative on Electric Mobility, ESCAP has been providing policy support to developing countries on transition to electric mobility in public transport. ESCAP supported countries to develop comprehensive national electric mobility policy and organized many capacity building workshops for developing countries. A guidebook for EV policy development and a few case studies have also been developed to share experience among countries [44].

Many Asian countries have different carbon neutrality target year. For example, India 2070, China carbon neutrality before 2060, Laos, Thailand and Sri Lanka in 2050 and Bangladesh has not yet committed to carbon neutrality.

3. MITIGATION, IMPACTS AND ADAPTATION

Transport research literature related to mitigation is dominated by those addressing public transport. Even though freight transport is a stubborn sector to address

within the transport sector there is growing research interest in the freight and logistics sector. They can be categorized in the following four categories: (i) modelling and scenario analysis; (ii) improving operation efficiency; (iii) addressing policies; and (iv) a mode shift or shift to renewable energy sources.

3.1 Transport Emissions and Renewable Energy Transition

Figure 2 shows the growth of transport emissions during the last decade. The transport emissions in Asia grew by 36% despite various mitigation efforts and emissions from international shipping grew by 6%.

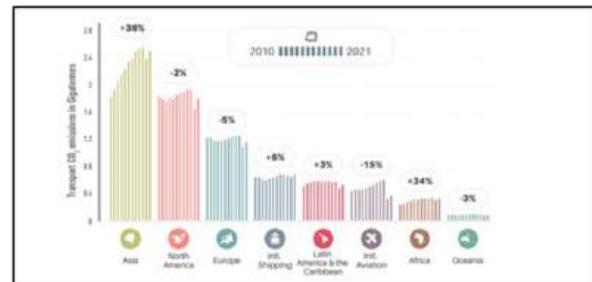


Figure 3. Growth of Transport Emissions (Source [32])

Figure 4 shows share of transport emissions by modes. The share of global CO2 emissions from freight is 42% and road transport accounts for more than three quarters of global transport CO2 emissions. Railways are responsible for small share of emission at just 1% even though we advocate a freight shift from road to rail. Once fully developed networks of freight railways their impact will be significant for emission reduction.

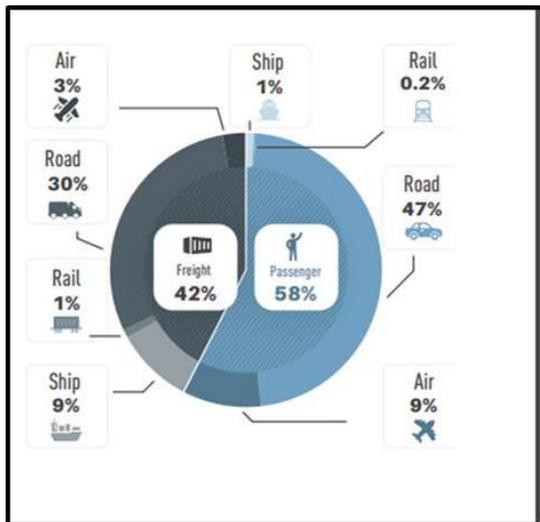


Figure 4. Share of Passenger and Freight Emissions (Source [32])

There is much discussion about green freight corridors. But there is no clarity on what they really mean and how the corridors are supposed to operate? Green shipping is one area that needs to be further explored. There are some initiatives to use ammonia in shipping lines led by private shippers, but ammonia and biofuel supply for use in freight is a concern. Need to develop a market driven and led approaches for commercial availability of these alternate fuels. Where feasible domestic ferry and water transport can be used for freight.

Air transport is another difficult area for mitigation. Use of sustainable aviation (SAF) are being tried. But the question is its production and supply along with biofuels for use in the aviation sector. For transition to electric mobility in freight, it lacks sufficient production and supply of heavy freight vehicles. How can we support the upfront investment in heavy-duty EVs? Innovative financing mechanisms and their accessibility are essential to support this transition. Hydrogen fuel is other option, Republic of Korea and Norway are leading in the efforts though it is costly.

The most effective method towards the decarbonizing of the freight sector has been seen to be electrification of the freight sector and complete shift from conventional combustion engines, however, such a complete shift may not be a viable option in all cases due to the high cost that is needed to construct the infrastructure. Changing the engine of the vehicle to a hybrid engine would also lower

the emission of carbon dioxide. Another option is to utilize a multimodal freight transport approach where the transport is less dependent on road vehicles (heavy and light heavy-duty vehicles) and the logistics is spread with railways that, in optimal cases are electrified, which again needs a well-connected railway system, the construction of which is one of high emissions. However, once constructed and utilized, it is seen to be effective in lowering emissions from freight transport sector and this has been seen in the case study of Poland and Switzerland. The shift to rail has been seen to be effective in reducing up to 60% of the emissions as compared to road transport. Without any shift in modes or shifts to electrification, proper maintenance of the freight transport vehicles along with avoiding the usage of aged vehicles is seen to decrease emissions significantly.

Although the solutions to decarbonizing the freight sector in theory is one that may look simply such the most effective one being a complete shift towards electrification, the implementation of the process is highly complex, and the capital required is not always viable for all nations. A multimodal freight transport approach seems to be the most appropriate for developing nations as distributing the logistics to rail and road, rather than exclusively road transport, is highly efficient and effective in reducing carbon dioxide emissions.

Figure 5 shows carbon grid factors of selected Asian countries. It shows that countries like Nepal and Bhutan have almost zero grid factors as the main source of energy is hydroelectricity. Other countries like Kyrgyzstan, Tajikistan and New Zealand have also low carbon grid factors thus indicating potential for transition to renewable energy use in transport such as EV. This transition would also allow for saving of foreign currency required for fossil fuel imports.

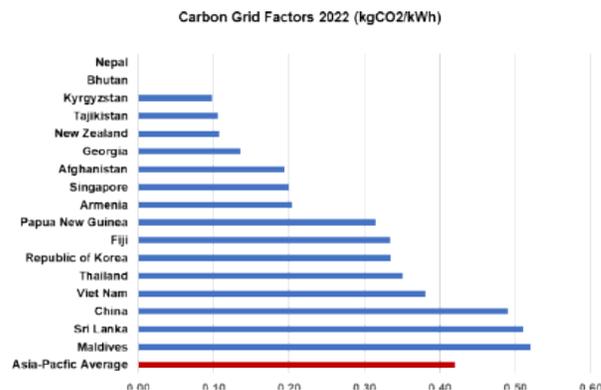


Figure 5. Carbon Grid Factors of Asian Countries (Source [32])

However, Asia region saw a slight increase in the use of renewable energy in the transport sector, reaching a mere 3% in 2021, up from 1.6% in 2015 [46]. The transport sector continues to lag behind other sectors in terms of energy diversification despite the availability and potential of alternatives such as hydroelectricity, solar, wind, renewable hydrogen, and biofuels. While Asian countries have shown a growing interest on transition to electric mobility.

The transition to green and renewable energy is equally important to move away from the use of fossil fuel in transport [48]. There are efforts to increase the share of renewable energy but their availability of sufficient quantity for transport operations is questionable. There are growing arguments on going back to nuclear energy by developing several micro plants with shorter construction time [46].

Arguing that there is too much focus on engineering resilience, the importance of transformability in addition to consideration of recovery and reliability of transport systems was stressed while considering comprehensive resilience in transport [38].

Efforts of Asian countries for reducing greenhouse gas emissions from the urban transport has been extensively reviewed and policy suggestions are offered to accelerate actions to move towards carbon neutrality in the transport sector in Asia [14]. Extensive review of climate change and transport has concluded that climate events affect transport and have implications for environment, economy, technology, health, and society [22].

Climate change study in US indicates that increases in very hot days and heatwaves, arctic temperatures, rising sea levels, intense precipitation events, and hurricane intensity would impact planning, design, construction, operation and maintenance of transport systems as well as provision of services [27]. Work on climate change impacts on transport in the US is further continuing [24]. Extreme weather events become disruptive and affect travel and mode choice decisions [27].

Modal shift of freight to rail from road is often cited as a feasible strategy. However, we have not seen a growth of freight being transported by rails in Asia. Is it due to its heavy construction cost? The share of freight emission from railway is mere 1% [39]. There are many initiatives underway, such as development of freight corridors in India and interest on development of high-speed rails in China, Thailand and Lao PDR. One of the major obstacles could be the huge investment required for railways and the long time required for their construction. The recent data from ATO shows a shift from road investment to urban transport and rails. Only a few European countries were able to increase the share of freight transported by railways [39] for example. Australia (+8%), Slovenia (+7%) and Italy (+5%), were able shift freight from road to rail transport.

There are country and region-specific studies covering adaptation planning incorporating technical and infrastructural measures such as in OECD [23] and in Canada [25].

Findings of an assessment of impacts of climate change on road transport in Asia and existing state of awareness are still relevant after 13 years and countries are in almost on similar state in terms of implementation of climate policies [13].

Developing counties in Africa and Asia are vulnerable to and less prepared for climate change and have high climate risk of transport infrastructure. Based on a study on high volume transport [30] list challenges for these countries in accessing and interpreting meteorological data, institutional arrangements in governance, accessing sufficient financial resources, climate change adaptation synergies with disaster risk reduction and transboundary partnerships.

3.2 Climate Change Impacts

Heat Waves, Rising Sea Level, Floods, Hurricane, Storms Cyclones, increase in arctic temp. There are project-based initiatives- many seem to be limited within the scope of projects. Like resilient ports, raising flood-level of bridges, raising embankments (example Bangladesh), strengthening river training (Example Nepal- sacrificial wall). Tsunami- road over dyke- which sustained. Main objective of resilience in transport context- should be to minimize disruption and damages. Examples including multimodal public transport routes/modes, - ensure network resilience. Transport critical for disaster relief – some network route planned for anticipated climate events- to withstand impacts- again issue of trade off.

Transport infrastructure and their operation will be affected by these climate events. Increases in temperature and precipitation, rises in sea levels, and storm surges will have significant impacts on planning, design, construction and maintenance, and operation of transport infrastructure. Transport systems are not only affected by these climate events, but also contribute to global warming through the emission of greenhouse gases (GHG) from transport operations. Following Table 1 lists some of key climate events, potential impacts and adaptation measures.

Table 1: Transport infrastructure, potential impacts and adaptation measures

Climate event	Potential impacts	Vulnerable infrastructure and adaptation measures
Temperature	Extended warm weather can cause pavement deterioration due to liquidation of bitumen, heating and thermal expansion of bridges and buckling of joints of steel structure Low temperature can affect road transport operations; operation and maintenance costs are likely to increase for additional snow and ice removal as well as additional costs of salts to be used for snow melting Rail track deformation and buckling	Pavement: use of stiff bitumen to withstand heat in summer, soft and workable bitumen with solvent in winter, control of soil moisture and maintenance planning Steel bridges: selection of material, provision of expansion joints, corrosion protection
Rainfall	Increased intensity of summer and winter precipitation would create floods of roads,	Bridges and culverts: flood estimation,

	railways and tunnels, affect drainage, road pavement, railways tracks, driving condition and visibility, affect bridges and culverts waterways and clearance, damage bridges and culverts foundation due to scouring Rainfall can trigger landslides and of drain, drain slope mudslides in mountainous roads and can create roadblocks	return period, design discharge, high flood level, clearance above high flood level, length of waterway, design load, wind load, foundation, river and bank protection, corrosion protection Drains: discharge estimation, size and shape Mountainous road: slope protection work, subsurface drains, catch drains Pavement: increase road surface camber for quick removal of surface water, frequency of maintenance, design of base and subbase, and material selection
Storms and storm surges	Rainfall and winds associated with storm/ cyclone can create flooding, inundation of embankments, and affect road transport. Disrupt traffic safety and emergency evacuation operations, affect traffic boards and information signs	Drains and cross drains: capacity enhancement, slope Road embankment: increase height Road signs: wind load, structural design, foundation, corrosion protection
Sea level rise	Rise in sea level will affect coastal roads, may be needed to realign or abandon roads in affected areas Damage to port infrastructure, disruption to shipping traffic, increase dredging requirements	Coastal road: protection wall, additional warning signs, realignment of road sections to higher areas, edge strengthening

Sources: Adapted from [13 and 35]

4. RESILIENCE AND ADAPTATION STRATEGIES

4.1 Resiliency Planning

Resiliency planning is fundamental for preparing public transport systems to withstand the growing impacts of climate change, such as increased flooding, heatwaves, and storms. Cities must invest in upgrading transport infrastructure to ensure they can cope with these extreme

events. For example, elevating roads and railways in flood-prone areas, installing drainage systems to prevent water accumulation, and using more durable materials in construction are key strategies [7]. Urban planning plays an equally important role. By integrating transport systems with land-use plans, cities can enhance accessibility while ensuring systems are built with future climate risks in mind. For instance, transit-oriented development (TOD) allows cities to reduce vehicle dependency and promote sustainable mobility, which is critical for both climate adaptation and mitigation [10].

4.2 Infrastructure Adaptation

Adapting infrastructure to withstand climate impacts is a vital component of building resilient public transport systems. Many public transport networks, such as metro lines, bus routes, and railway tracks, are vulnerable to extreme weather conditions like floods, heatwaves, and storms [7]. Infrastructure adaptation involves reinforcing bridges, building flood-resistant roads and railways, and using durable construction materials to ensure longevity under changing climate conditions [16]. For instance, Bangkok has begun retrofitting its public transport facilities to handle seasonal flooding, ensuring that key routes remain operational even during extreme weather events [21]. Moreover, cities like Kuala Lumpur are investing in climate-proof stations that are designed to be energy-efficient and resistant to rising temperatures.

4.3 Technology, Innovation and Sustainable Practices

The use of technology is a driving force in enabling public transport systems to adapt to climate impacts. Technological innovations such as predictive weather modeling, real-time data collection, and automated systems allow cities to respond proactively to climate events [9]. For example, deploying Internet of Things (IoT) devices can help cities monitor environmental conditions and adjust services accordingly rerouting buses or trains in response to floods or heatwaves can reduce delays and damage [20]. This transformation is a key element of making public transport systems more sustainable and resilient in the face of climate change.

The adoption of green and sustainable transport solutions is essential for mitigating climate impacts. Public transport systems must shift towards low-emission technologies such as electric buses, hydrogen-powered

vehicles, and energy-efficient trains to reduce their environmental footprint [18]. Initiatives like the introduction of electric buses in Bangkok, Kathmandu and Kuala Lumpur have set a precedent for how Asian cities can reduce greenhouse gas emissions while maintaining reliable public transport services [16]. Additionally, integrating non-motorized transport options such as cycling and walking infrastructure into urban transport plans enhances sustainability by reducing reliance on cars and minimizing pollution [8].

4.4 Community Engagement

In addition to direct adaptation pathways such as enhancing the robustness of infrastructure, indirect pathways such as preparedness and changing the behaviours of vulnerable communities can be useful in enhancing the resilience of transport systems [49].

One often overlooked aspect of resiliency is community engagement. Involving local communities in planning and decision-making ensures that public transport systems are designed with both climate adaptation and equity in mind [19]. Community input can highlight vulnerabilities specific to certain populations, such as low-income groups who may rely heavily on public transport but have limited resources to cope with service disruptions caused by climate events. By engaging communities through public consultations and participatory planning processes, cities can build more inclusive and resilient transport systems [10]. In particular, empowering marginalized communities ensures that transport solutions are tailored to meet diverse needs while addressing long-term sustainability challenges.

4.5 Financial Considerations

There is a need for systematic adaptation planning and quantify the trade-offs between adaptation costs and long-term benefits. Effective adaptation requires significant financial resources, and funding mechanisms are crucial to ensure that public transport systems can be climate resilient. Governments, international organizations, and private investors need to collaborate to create innovative financing solutions. Mechanisms such as green bonds, climate funds, and public-private partnerships (PPP) are widely used to support climate adaptation projects in transport [19]. For example, several Asian cities, including Thimphu, have accessed international climate

finance from the Green Climate Fund to support sustainable transport initiatives. Additionally, local governments are using revenue from congestion charges and carbon pricing to finance urban transport infrastructure upgrades [6]

4.6 Policy Measures

Governments play a central role in shaping public transport systems that can withstand are essential in building long-term resilience. For instance, cities can adopt climate action plans that focus specifically on transport, ensuring that future projects consider climate risks from the outset. Policies mandating the use of renewable energy for public transport fleets, such as electric buses or biofuel-powered vehicles, are critical in reducing greenhouse gas emissions [8]. Additionally, governments need to provide financial incentives for investments in green infrastructure, such as smart grids and electrification of transport systems, while also implementing stricter building codes to ensure that new infrastructure is resilient to future risks [16]. National and local coordination is essential to ensure that policies are effectively implemented across different levels of government.

The challenge for governments and institutions is to strengthen not only policy-making capacities but also their ability to deliver, enforce and implement resiliency and sustainability policies. This requires more effective coordination and information sharing mechanisms across sectors (urban, transport, energy, finance etc.), as well as more stable financing models to pay for infrastructure investments.

Following policy measures are proposed for policymakers, transport authorities, and stakeholders:

- Invest in resilient infrastructure by prioritizing upgrades that withstand extreme weather conditions through innovative financing mechanisms, green and climate bonds and public-private partnerships.
- Review design standards, practices and guidelines with consideration of climate change impacts, life-cycle cost and absorptive capacities of countries.
- Promote green transport solutions, such as electric buses and non-motorized transport, to reduce emissions.

- Plan and implement targeted capacity-building programs on climate change adaptation.
- Establish institutions and organization units responsible for climate impacts in the transport sector and enhance coordination among various stakeholders.
- Encourage regional collaboration to share knowledge, best practices, and resources for climate-resilient transport systems.

These policy suggestions are similar to the findings earlier study in 2011 [2] and are still valid that offered for development of sustainable and resilient transport in Asia:

5. CONCLUSIONS

This paper has highlighted key strategies for building resilience in the transport sector in Asia in response to climate change. By focusing on infrastructure adaptation, the integration of green and sustainable solutions, the creation of financial mechanisms, and the promotion of regional collaboration, cities and countries can significantly reduce their vulnerability to climate impacts. Asian cities and countries are at different stages of development, but all are making efforts to implement climate-resilient transport systems tailored to their specific needs.

In order to minimize the impacts of climate change on transport, a three-pronged approach would be necessary. Firstly, accelerating the transition towards net-zero emissions in the transport sector so as to reduce intensity and frequency of climate events. Secondly, enhancing the resiliency of transport systems and increasing adaptation measures. And finally, strengthening the governance of climate change.

5.1 Towards net-zero in the transport sector

Looking at the growing trends of carbon emissions from transport the transport sector, accelerated implementation of transport policy measures for targeted emission reduction are necessary. This is in line with messages coming out from many scientific, intergovernmental meetings and fora. However, more research and analysis are required for country and context specific policies to lead towards net zero emissions.

Effective mitigation policies in the transport sector for

on a low-carbon pathway can be placed into five categories: (a) improving the design, operations and planning of transport systems; (b) electrification; (c) use of low-carbon fuels; (d) encouraging shift to sustainable modes of transport and better management of demand; and (e) adoption of emerging technology and innovations for transport solutions. Such policies can take the form of economic and fiscal or regulations, or relate to infrastructure, innovation and awareness-raising. Ultimately, these policies need to change travel behaviour for passenger transport and logistics operations for freight transport and must improve vehicle, fuel and system efficiencies for passenger and freight transport activities.

Most of the current modelling and research point out the feasibility to decarbonize and reduce emissions from transport, but the pace of implementation is slow. It is high time to translate the research findings to policies and accelerate the implementation. Have we failed on our accountability? Is the current development paradigm working?

5.2. Enhancing resiliency of transport systems

Our responses to the climate change impacts are responsive and reactive to the situation. As degree of resiliency is directly related to costs, we need careful long-term planning of transport infrastructure and systems. There is also tendency to prefer high-end solutions where local nature based can be equally effective. The main objective of adaptation measures should be assessing risks and vulnerability and to minimize impacts and reduce scale of damage and loss.

There is tendency to focus more on engineering resiliency, adaptation planning, preparedness and strengthening communities can help to reduce impacts. Nature based solution, least cost measures and simple solutions are also being advocated. Planting trees, increasing vegetation covers, size of drainage and use of bioengineering measures can strengthen stability of slopes and reduce risk of landslides.

It is also observed that countries or cities tend to implement more project-based adaptation approaches rather than taking comprehensive adaptation measures.

There are plenty of opportunities to make transport infrastructure climate resilient. It is important to assess the

risks of climate events and need to start from planning, construction and operation. Consider the life cycle cost assessment as it is always a trade-off between the degree of resiliency of the system and cost.

There is enough knowledge around the resiliency of transport systems, and it got more prominence after COVID-19. Transport system started to explore other forms and measures to reduce demands such as use of technology for teleworking and shift to active modes of transport such as walking and cycling.

There is much focus on mitigation in the transport sector. We need to strengthen work and policies around adaptation. Need to utilize available data and information for resiliency planning and update design standards considering likely impacts.

After damage to infrastructure by Hurricane Katrina, USA outlawed and banned construction in vulnerable and risky and coastal areas in USA [27]. Construction practices in Norway also advocate minimum disruption of nature's green and vegetation cover to reduce risks. Now new regulation demands zero emission construction sites.

There are lot of resources and guidelines available for planning and development of resilient infrastructure [30-36]. The main challenge is to translate the knowledge or recommendations of guidelines or tools to practice. Policymakers and officials should bring these in practice to address specific context and impacts in field.

5.3 Governance of climate change and collaboration

Countries are giving priority to climate change issues and new ministries and institutions are being established to manage cross-sectoral coordination. Ministry of Environment, Forest and Climate Change, India, Ministry of Environment, Forests and Climate Change in Bangladesh, Ministry of Climate Change, Environment and Energy, Maldives, Department of Climate Change and the Environment, Thailand, and Malaysian Green Technology and Climate Change Corporation are some examples.

Climate change issue is usually coordinated by environment ministry and agency. There is a need to strength the role of transport ministry and agency in UNFCCC process. Governance of urban mobility in most

of Asian cities is fragmented with competing interest among city, state and federal authorities and limited coordination between land use and transport planning [15]. For example, in Kathmandu all three levels of government are involved in urban transport with overlapping functions and without a designated lead authority.

Funding adaptation measures and coordination have always been a challenge for developing countries. For example, in Nepal management of climate events and disaster is led by the Home Ministry and a committee manages central relief funds and coordinate sectoral efforts.

Various models to enhance coordination in planning and management of urban mobility are being used. Some cities have established institution to coordinate work on urban transport, the examples are Greater Jakarta Transport Authority, Dhaka Transport Coordination Authority and Metropolitan Transport Authorities in Inian cities.

There is a challenge for developing countries to access climate adaptation funds even though there are variety of green and climate funds aimed to support developing countries. But the process of application and time frame is different among different funding institutions. It is important to simplify the application process so as developing countries can access those funds. Some countries would need support for project formulation and application.

In this context, it may be a right time to review the current development cooperation paradigm. Development cooperation ideally should support countries plans and aspirations. We observe that many developed countries are yet to release the pledged funds. Have many capacity building projects led to improved design and management of projects?

Collaborative efforts across Asian countries can significantly enhance the resilience of transport systems by sharing knowledge, resources, and best practices. These collaborations enable cities and countries to learn from one another's experiences, adopt successful strategies, and address common challenges. Regional collaboration can also help cities and countries to access technical assistance and financial resources from development partners and developed nations. Regional

and subregional organizations such as ESCAP, Association of Southeast Asian Nations (ASEAN), BIMSTEC, ADPC are working to create frameworks for cooperation in climate-resilient transport planning and extending technical support to countries.

ESCAP, a regional arm of the United Nations in the region, has been advocating for right and evidence-based policies for sustainable, inclusive, accessible and resilient transport systems in the region. ESCAP focuses on development of regional transport networks as well as low-carbon urban public transport systems.

ESCAP regularly organizes expert group meetings and workshops on impacts of climate change on transport, low-carbon transport developments and publishes and disseminates research findings, policy briefs, background documents and knowledge products on mitigation and adaptation. Some of recent publications includes impacts of COVID-19 on mobility, Transport Review, Guidelines on Transition to Electric Mobility, Development of safe, sustainable, inclusive and resilient transport systems. ESCAP is also open for new partnerships and collaboration with academia and professional institutes.

5.4 Future research directions

Further research is needed to explore long-term cost-benefit analyses of climate-resilient transport systems, the impact of new technologies and construction practice on climate change adaptation, and the role of community engagement in enhancing the success of climate-resilient projects. Additionally, exploring disaster risk assessment, hazard mapping of vulnerable location and recovery strategies in the context of disruptions of transport operations, due to climate events would provide valuable insights for future resilient planning of transport infrastructure. It is also important to explore how the existing knowledge and guidance can be applied in practice in design, development and operation of transport systems.

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Enhancing the Resilience of Indonesian Triangle Region Coral Reefs to the Impacts of Future Climate Change Through Conservation and Mitigation of Coastal Pollution

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ABSTRACT

The Coral Triangle in Indonesia is a marine area with exceptionally high biodiversity and abundant marine resources. However, the sustainability of this region is threatened by accumulated environmental pressures, primarily from anthropogenic sources. These challenges are exacerbated by global climate change, which is causing shifts in marine conditions such as rising temperatures and ocean acidification (decreasing pH levels). This study, conducted in the Banda Marine Conservation Area, located in the heart of Indonesia's Coral Triangle, examines the contrasting effects of ocean acidification—simulated by hydrothermal vents from underwater volcanoes—against anthropogenic pressures from urban runoff pollutants. Water quality was analyzed in situ by measuring variables such as pH, salinity, total organic carbon, and nutrients (total inorganic phosphate and total inorganic nitrogen). Coral reef health was assessed using the line intercept transect method. The results showed that in areas where pH levels dropped to as low as 7.8, coral cover remained high, ranging from 70-80%, dominated by *Acropora* spp. In contrast, coral cover in waters near inhabited islands was significantly lower, ranging from 35-45%. The multivariate analysis indicated a strong correlation between increasing abiotic cover and algal growth with elevated nitrogen levels, commonly associated with runoff from urban areas. The implications of this research suggest that tropical coral reefs may withstand gradual pH reductions associated with future climate change, but this resilience must be supported by mitigating anthropogenic stressors. Optimal conservation efforts are essential to enhance the resilience of coral reefs against the changing chemical conditions of marine environments due to climate change.

1. INTRODUCTION

Coral reefs in the waters of the Indonesian Coral Triangle represent one of the regions with the highest biodiversity in the world. This area serves as an ecological

zone for feeding, breeding, and nursery grounds for more than 500 species, playing crucial roles both economically and ecologically [1-2]. Based on its economic and ecological functions, the total valuation of coral reef ecosystems within one conservation area in this region

reaches nearly USD 10 million per hectare per year [3]. Consequently, this area is of vital importance as a marine tropical ecosystem and significantly supports the local economy.

However, the sustainability of coral reef ecosystems in this region is declining due to anthropogenic pressures. Research indicates that, in general, Indonesia's coral reefs have experienced significant degradation, with approximately 70% of them now in fair to poor condition [4-5]. Human-induced factors such as sand mining, coral extraction, sedimentation, runoff from land, and unsustainable fishing practices have contributed to the deterioration of optimal environmental conditions necessary for coral reef life [6-8]. Additional pressures are expected to accumulate due to shifts in the physical and chemical characteristics of the waters because of climate change, including increased storm frequency, rising temperatures, and a decrease in pH levels due to elevated concentrations of dissolved CO₂ in seawater [9-10].

Thus, optimal conservation management is crucial to ensuring the sustainability of coral reef conditions. Ecological simulations that demonstrate the patterns of coral reefs under future climate change scenarios, in comparison with the impacts of direct anthropogenic pressures, can serve as baseline studies to highlight the importance of such conservation processes. However, research on coral reefs in tropical regions remains quite limited. Comprehensive studies have been conducted in subtropical waters, such as those in Hawaii, demonstrating the effects of temperature increases and acidification pressures on coral species growth [11]. In contrast, research in tropical waters in Indonesia generally focuses on patterns associated with peak annual sea surface temperature increases [12]. Meanwhile, data on the effects of ocean acidification on the characteristics of tropical Indonesian waters and its impacts on coral reefs remain scarce. Simulation analyses of natural ecosystems could be conducted in naturally acidified coral reef areas, such as shallow waters near hydrothermal vents. Studies in subtropical regions have shown that CO₂ from hydrothermal vents serves as a natural laboratory, providing simulations of coral reef shifts due to ocean acidification pressures [13-15]. Similar study can be conducted in Indonesia, given the geographical position of Indonesia, which lies along the global ring of fire, with several volcanoes have CO₂ vents beneath the sea, creating naturally acidified ecosystems, one of which is located near the volcanic island in the Banda-Neira marine conservation area.

The research aims to demonstrate the differences in coral cover patterns resulting from direct anthropogenic pressures in urban areas and acidification pressures, simulating environmental shifts due to future climate change within the Banda-Neira conservation area. Banda-Neira is a cluster of small islands situated in the middle of the Banda Sea, in eastern Indonesia, at the heart of the Coral Triangle. This cluster includes one volcanic island with hydrothermal vents and two inhabited islands. Comparing coral covers near hydrothermal vents with those around inhabited islands will provide insights into the potential impacts of acidification under future climate change and anthropogenic runoff on similar coral reef areas. This comparison may serve as a baseline study to enhance coral reef resilience within the Coral Triangle in facing future climate change.

2. METODOLOGY

2.1. Study Sites

Geographically, this archipelago is part of the Pacific Ring of Fire, making it a region with high geological activity, including the potential for earthquakes and volcanic eruptions [16]. The topography of this archipelago consists of small islands surrounded by deep seas, which contribute to high biodiversity, particularly in coral reef ecosystems [17]. The Banda-Neira Marine Conservation Area consists of four main islands: Neira Island, Banda, Pisang, and Gunung Api. The administrative and governmental center is located on Neira Island, mainly in the southern part. Meanwhile, Banda and Pisang Islands have only small urban areas.

Several hydrothermal vent fissures were detected decades ago, making the coral reef area in this region unique, with the endemic coral species *Acropora desalwii*, particularly after the volcanic eruption in 1988 [18]. 6 observation sites (a) were selected in the coral reef areas affected by acidification due to the presence of hydrothermal vents, as well as 6 sites (b) around the urban area of Neira and Banda Islands (Figure 1).

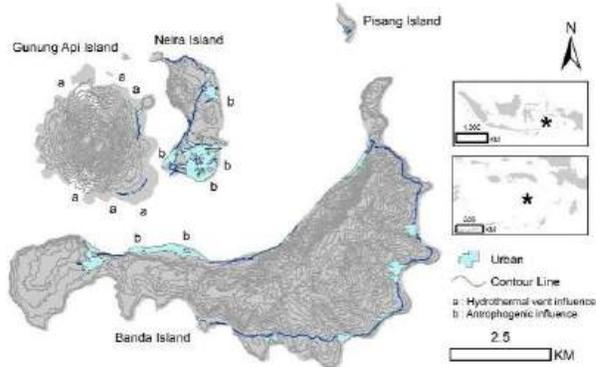


Figure 1. Study sites of coral reef which influenced by hydrothermal vents (a) and anthropogenic runoff (b) at Banda-Neira Conservation Park, Indonesia

2.2. Water Quality Analysis

Seawater samples were collected at 4-6 m, in the bottom layer of water column. pH, DO (dissolved oxygen), salinity, total organic carbon, total inorganic phosphate, and total inorganic nitrogen (sum of nitrate, nitrite, and ammonia) were analyzed on site using digital portable devices (Hach DR-890, Hach HQ40d with DO and pH probe, and Eutech Salt +6 Salt-meter). Three replicates of water samples were taken at each site and conducted twice a day at high and low tide.

2.3. Coral Cover Analysis

Coral cover at each site was analyzed at 4-6 m depth by employing three 30 m long line intercept transects that were parallel and 3 m apart. Underwater photographs were taken using a digital camera every meter on both sides of the transect line with a 0.5 x 0.5 m quadrant frame. Analysis of coral cover was undertaken employing CPCe 3.6 software [19]. Fifty random points were automatically placed on each photo and each point was then classified into one of five main groups, i.e. hard coral, other biota (Sponge, soft coral, and Ascidian), algae, and abiotic (dead coral, rock, and sand), to generally identify the impact of acidification and anthropogenic runoff on coral cover in observed sites.

2.4. Data Processing

All variables were transformed to meet the normal distribution data, prior to the multivariate statistical analyses. All environmental variables were logarithmic transformed and data from coral cover were square root transformed [20-21]. Shapiro-Wilk test checked all data normality. Principal component analysis was deployed to analyze the variance of coral cover and water variables

between ecosystem that influenced with hydrothermal vents and anthropogenic runoff. Moreover, Canonical Correlation Analysis (CCA) was used to find correlations between water variables and coral cover. All Statistical analyses were conducted with Past Statistical Software v3.08 [22].

3. RESULT AND DISCUSSION

3.1. Water Quality

The analysis of water quality reveals dynamic changes influenced by varying environmental pressures on coral reef areas in the waters of Gunung Api Island, Neira Island, and Banda Island (Figure 2). The pH levels in the waters around Gunung Api Island, which are closer to hydrothermal vents, have been detected to drop to 7.9, while in the waters around Banda and Neira Islands, the pH remains within the normal range of approximately 8.2. Additionally, distinct patterns of nutrients and organic pollutants were observed across the different monitoring areas. Total organic phosphate ions were detected at higher concentrations near hydrothermal vents, while total inorganic nitrogen and total organic carbon levels were higher in reef areas closer to urbanized islands. Two other variables, dissolved oxygen (DO) and salinity, were detected within the normal range for coral reef waters.

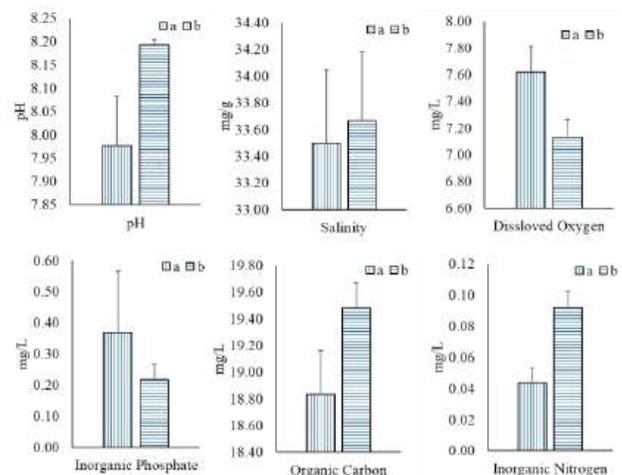


Figure 2. Water variables in the coral reef ecosystem which influenced by hydrothermal vents (a) and anthropogenic runoff (b) at Banda Neira Conservation Park, Indonesia

A multivariate discriminant analysis revealed variations between water parameters in the coral reef ecosystem of the Banda-Neira conservation area (Figure 3). Different trends were identified for variations between

coral reef waters affected by different factors. Vectors of Total Inorganic Nitrogen, Total Organic Carbon, and lower pH levels pointed towards water areas influenced by anthropogenic runoff. These three variables were detected as being associated with the principal component, distinguishing water parameter conditions across the observed locations. Meanwhile, the DO variable vector pointed towards areas affected by hydrothermal vents.

The detection of Total Inorganic Nitrogen and Total Organic Carbon as principal components in the multivariate analysis indicates the impact of urban runoff on the chemical dynamics of water in the coral reef ecosystem. The increase in these two variables is often associated with local anthropogenic inputs and can serve as an indicator of the influence of anthropogenic runoff in coastal waters [27-29]. Meanwhile, high levels of inorganic phosphate nutrients in the waters may have both anthropogenic and natural sources. Runoff from urban areas, sedimentation, and agriculture can introduce excess phosphate ions into coastal waters [30]. Furthermore, in volcanic areas, especially those recently erupted, volcanic ash, which contains high levels of nutrients, can also be a source of phosphate ions in the waters [31]. This is believed to be the cause of the high phosphate ion levels in the coral reef areas surrounding Gunung Api Island in the Banda-Neira marine conservation area. These results demonstrate the existence of two distinct environmental patterns in the Banda-Neira marine conservation area: waters around Gunung Api Island exhibit natural acidification characteristics, while the areas around Neira Island and northern Banda Island experience environmental pressures from anthropogenic sources.

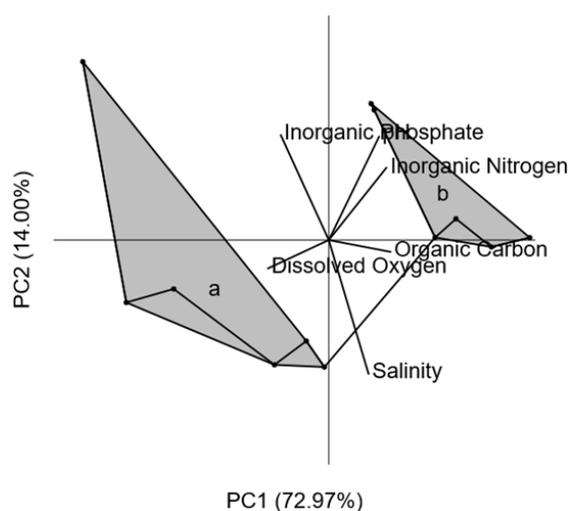


Figure 3. Dendrogram of principal components of water variables in the coral reef ecosystem which influenced by hydrothermal vents and anthropogenic runoff at Banda Neira Conservation Park, Indonesia

3.2. Coral Cover

The pattern of coral cover aligns with the environmental pressures in the waters (Figure 4). A shift in coral cover was observed between acidified areas and those experiencing anthropogenic pressures. Acidified waters had significantly higher coral cover ($P < 0.05$) compared to areas under anthropogenic stress. Conversely, areas impacted by anthropogenic pressures showed higher coverage of other biota, algae, and abiotic components.

Multivariate principal component analysis revealed a shift from natural conditions, despite moderate acidification to pH 7.9, towards areas affected by anthropogenic pressures (Figure 5). Hard coral cover emerged as the primary principal component distinguishing between observation sites, with vectors pointing towards waters influenced by acidification. On the other hand, abiotic and algae vectors pointed towards waters impacted by anthropogenic runoff. Further confirmation of the correlation between water variables and coral cover was obtained through canonical correspondence analysis (Figure 6). This analysis showed that hard coral cover corresponded with dissolved oxygen levels and inorganic phosphate concentrations, while higher inorganic nitrogen and organic carbon levels were associated with increased coverage of abiotic components and algae.

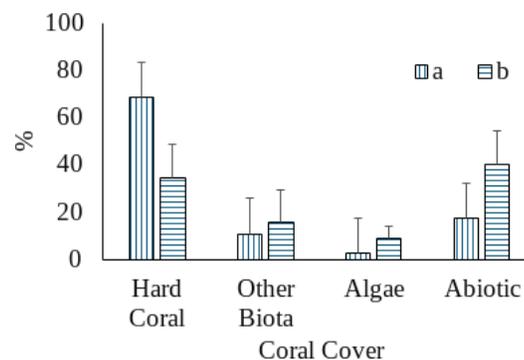


Figure 4. Coral cover in the reef ecosystem which influenced by hydrothermal vents (a) and anthropogenic runoff (b) at Banda Neira Conservation Park, Indonesia

Visual observations showed that the Acroporidae coral species dominated in the acidified waters around Gunung Api Island. This species is known to exhibit

higher resilience compared to other coral species under conditions of high phosphate nutrient levels and lower water pH. Biologically, this species can enhance its growth rate due to the symbiotic relationship that allows it to utilize high phosphate levels to boost photosynthesis without showing signs of stress from the environmental pressures [32]. Moreover, laboratory studies have found that Acroporidae can increase its productivity by up to 40% under moderate acidification in tropical temperatures [33-34]. This characteristic explains why hard corals continue to dominate in the acidified waters of Gunung Api Island. However, visually, this dominance also indicates a shift in coral community composition, with biodiversity declining as more resilient species dominate under acidified environmental conditions.

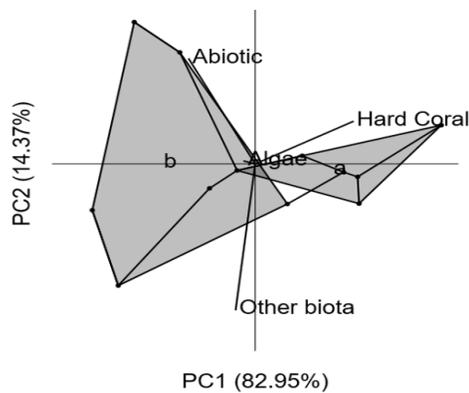


Figure 5. Dendrogram of principal components of coral cover in the reef ecosystem which influenced by hydrothermal vents and anthropogenic runoff at Banda Neira Conservation Park, Indonesia

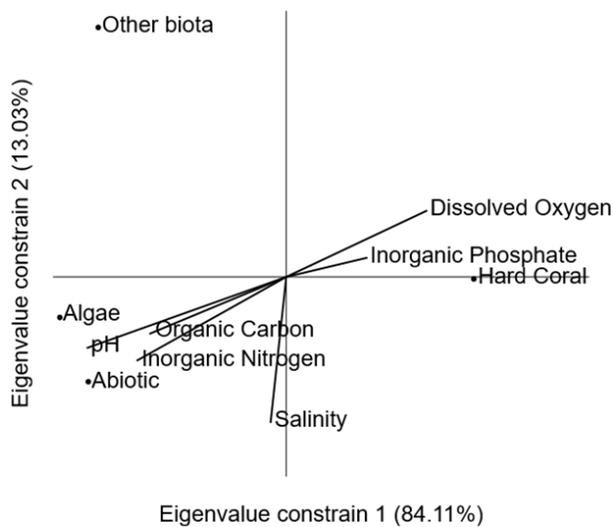


Figure 6. Dendrogram of canonical correspondence analysis

between water quality and coral cover in the reef ecosystem which influenced by hydrothermal vents and anthropogenic runoff at Banda Neira Conservation Park, Indonesia

Different data were detected in waters affected by anthropogenic runoff. Abiotic cover was significantly higher in the waters around Neira and Banda Islands. Increased competition with algae, which benefit from high nutrient levels, is one factor leading to the decline in coral cover in waters impacted by anthropogenic runoff [35-37]. Furthermore, the stress caused by high-nutrient conditions also weakens coral health, making them more vulnerable to coral diseases [38].

3.3. Implication for Conservation

This study shows that coral cover is not significantly affected by moderate ocean acidification. The impact of anthropogenic runoff is more substantial than the effects of acidification anticipated under future climate change scenarios. This finding contrasts with studies conducted in subtropical regions, which have detected disruptions to coral growth at pH levels below 8.0, leading to calcium dissolution at pH 7.4 [39-40]. The geographic characteristics of the Coral Triangle, located in tropical regions, explain this difference. Higher tropical water temperatures maintain the aragonite calcium carbonate saturation constant at 3.5 even at pH 7.95, with average water temperatures of 29°C [41]. This accounts for the relatively higher resilience of coral reefs in tropical regions to acidification and rising temperatures.

However, if future climate change pressures, such as rising temperatures and acidification, accumulate alongside anthropogenic runoff, the resulting impacts could be severe. The combination of rising temperatures and anthropogenic runoff has been shown to cause reproductive disruption, slower growth rates, increased disease vulnerability, and even coral bleaching and mortality [42-44]. Observations from hydrothermal vents in Papua New Guinea and Minahasa, North Sulawesi, Indonesia, have demonstrated that the accumulation of acidification and anthropogenic runoff leads to significant degradation of coral cover in tropical waters [45-46]. Thus, predictions of coral reef cover under future climate change scenarios may vary from current estimates, depending on multiple factors specific to the geographical location [47]. For coral reef areas in the Coral Triangle, such as in Indonesia, where tropical water temperatures are higher than in temperate regions, local anthropogenic pressures are likely to have a more significant impact than global

pressures from temperature increases and ocean acidification.

This implication should serve as a baseline for coral reef conservation efforts to prepare for future climate change. Efforts to mitigate climate change through carbon emission reductions and increasing carbon absorption areas have become central to conservation programs, as part of Indonesia's global participation through the Nationally Determined Contribution (NDC) commitment under the Paris Agreement [48]. Several national-level regulations have been enacted to support these climate change commitments [49].

However, mitigation efforts for anthropogenic runoff in conservation areas remain relatively weak and lack attention in public policy [50-51]. This has led to massive coastal and marine degradation in the Coral Triangle, as seen in the Halmahera Islands, located in the northern Coral Triangle. Land clearing and nickel mining development have caused environmental degradation, making it difficult for coral reef ecosystems to thrive in these small island areas [52-53]. A conservation approach that focuses primarily on carbon emission reduction and absorption will not be effective in ensuring the survival of coral reefs in the tropical Coral Triangle. Mitigating coastal pollution through the development of wastewater treatment systems is essential to improving the resilience of tropical coral reefs in the Coral Triangle conservation areas.

4. CONCLUSION

This study revealed that anthropogenic stressors, characterized by increased inorganic nitrogen and organic carbon levels, have a more significant impact on coral cover decline in Indonesia's Coral Triangle, particularly in the Banda-Neira conservation waters, compared to the effects of moderate acidification (pH 7.8-7.9) projected for the 2050-2100 period under future climate change. The geographic characteristics of this region, located in tropical waters with high aragonite calcium carbonate saturation levels even at pH below 8.0, allow some tropical coral species to withstand moderate acidification. However, the destructive power of anthropogenic runoff can lead to significant coral cover degradation. Therefore, the Coral Triangle requires localized conservation strategies, focusing on mitigating coastal pollution, to enhance resilience against future climate change pressures.

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Fate of Melamchi Water Supply Project in the context of Changing Climate and Weakening Governance

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ABSTRACT

The Melamchi Water Supply Project (MWSP) was conceived in 1968 as the most low-cost out-valley source which could keep the in-valley sources of water intact to be used for irrigation purpose in the fertile Kathmandu Valley. Since then, many things have changed- the climate, policy and practice of water and land use, political regime, and most importantly the valley population. Though with a sluggish pace, the first phase of the project with a 26 km diversion tunnel was about to see its completion, unfortunately, the 2021 devastating flood buried the entire head-works under up to 24 m of debris. Phenomenon such as Climate Change and Global Warming is being observed as both a global and a hyper-local issue these days. Black Carbon (Soot) is found to be culprit for melting of ice-caps of the Himalayas, on each side, the North and South, of which lives 1.5 billion population and that too is heavily industrializing at the same time. All of the three sources of the project, Melamchi, Yangri and Larke are the snow-fed rivers originating in the Langtang range. Cloud bursts and abrupt temperature rise within a day in the vulnerable moraine or glacial area with numerous cascading frozen lakes already turned fragile by repetitive earth tremors like in the case of southern flank of the Langtang mountain range, the upper catchment of Indravati river, could be many-fold disastrous than what happened in the 2021 Melamchi flood. Thus, the irony of the MWSP is that it has two-faced climate impacts- too much water during summer and too-less water available for supply during winter. Mitigation has to be wise, reliable and less-costlier which could be achieved only through adaptation, preparedness, making infrastructures more resilient to cope with climate shocks, establishing efficient disaster risk management mechanisms with adopting appropriate proven tools, resilient and robust city planning including enforcing population limit, and more importantly, establishing good water governance. This paper discusses how the phase-I of this multidisciplinary river-basin diversion project surpassed its excessively prolonged project cycle, lessons learned, and future challenges in the face of rising uncertainties- changing climate and weather patterns, political instability and weakening governance in the country, and the way ahead.

Keywords: adaptation, basin diversion, black carbon, climate change, diversion tunnel, population limit, resilience, soot, water governance.

I. INTRODUCTION

1.1 Project Area

The Melamchi Water Supply Project (MWSP) is an inter-basin diversion project with water abstraction at Indravati basin and diverted into Bagmati basin to distribute water in the Kathmandu valley (KV)- the national capital region.

1.1.1. The Indravati Basin

The MWSP is designed to divert water from 3 tributaries of Indravati river- Melamchi river in phase 1 and Yangri and Larke rivers in phase 2. The upper reach of Indravati itself is left untapped which also has almost the same flow as that of each of the aforementioned tributaries, all are snow-fed rivers emerging from the southern flank of the Langtang Himal.

1.1.2 The Bagmati Basin and the Kathmandu Valley

The Bagmati river basin extends from Sundarjial to the Karmaiya gorge in the Terai, after then flowing through the Terai plains ultimately discharged to the Ganga river. The KV is the upper alluvial fan of all of the Bagmati's tributaries. The KV as such encompasses the inner watershed area of three districts in the valley.

1.2. Population and Water Demand in the Valley

Unregulated haphazard urban leap-growth after each regime change in the country, especially those of 1980's and 90's led to development of an urban slum city. In average, the valley population thus is almost doubling each decade, with merely 0.2 million in 1950s to almost exceeding 5 million now. The Valley population growth is found to be around 6.5% [1]. On top of this, unplanned land use and poor services has degraded the urban

environment, increased urban poverty and exposed the growing urban population to multi-hazard risk [2]. The recent flood devastation evidenced the above statement. Interestingly, the valley population kept skyrocketing despite of acute water shortage, perhaps in the hope that the dream of the Melamchi water will be realized one day.

Haphazardly developing cities like in KV always remain thirsty, especially when large water bodies are not found in the vicinity. WHO's guideline is 150 litres per capita per day (lpcd) as a standard for basic needs of water while Nepal set it to 135 lpcd considering Melamchi water coming in the valley [3, 7]. Whatever the standards or design criteria say, water engineers in Nepal agree on 100 lpcd water sufficient for the KV having moderate climate. Based on this straight arithmetic, for every 1 million increase in population, a source augmentation of 10 million litres a day (MLD) is to be planned by the KV-Water Supply Management Board (KVWSMB).

1.3. Existing Water Supply in the Valley

Early residents of the valley used to rely on nearby cricks, shallow wells and ultimately stone spouts as improved systems, which were systematically connected to aquifers. Historical evidences of existence of public stone spouts are found since the 6th century [3].

The part of the pipeline network in the valley is now 130 years old and leading to excessive water loss, around 40% [5, 6]. Strange to note also that the valley residents' water consumption at present is merely 25 lpcd. The water deficit is obviously being met by mainly the groundwater, leading to a rapid drawdown in groundwater table by up to 3.5 m per annum. During the last 20 years, ground water table is reported to be declined 6 to 15m in in the valley affecting the yields of wells and stone spouts [3,5-7].

Studies reported around 233 stone taps in the valley but many being dry. The domestic water needs in the Valley are met from unsafe surface water, groundwater and stone taps. The 2020 annual report of the KV water provider company (KUKL) mentions water demand of 430 MLD, with supply of Min. 95 and Max. 196 MLD with 20 % leakage, indicating poor water security scenario in the valley. The KUKL has planned to supply 510 MLD within KV ring road by 2030. Before Melamchi, KUKL was supplying 150 MLD water in the wet season and 90 MLD in the dry season against the demand for 350 MLD. Apart from KUKL supply, around 50 MLD is being extracted mainly from groundwater.

Temperature hike along with climate change (CC) and abrupt population growth in the valley has exacerbated further its water security in the recent years. Even after Melamchi water was supplied, people in the valley are still deprived of piped water. This prompted to seek exploring other water sources outside the valley post 2021 Melamchi flood. In 2022, the Government started to study Sisneri impounding and pumping water project. [3,7].

1.4. Early Conception of the Melamchi Project

Notably, groundwater pumping technology at that time was not as advanced as it is now. Submersible pumps were not available at that time except for limited head VT pumps. Having been realized the capital's limited water sources as main impediment towards developing it into a modern city and under the pursuit of prosperity of the country and attaining self-reliant economy, King Mahendra, aside of many other sectors, also focused on the trade and tourism sector development. Already in 1968, He is said to have envisioned the Melamchi Diversion Project (MDP) to supply to the valley [8,9]. Unfortunately, his early demise set-back the plan until his heir King Birendra later took it in connection with the plan for reaching 'Asian Standards' during mid-1980s.

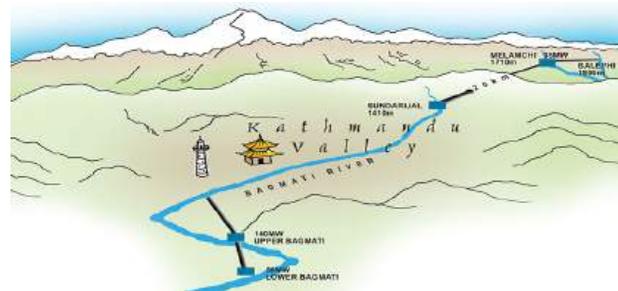


Fig. 1: Early Conceptual Plan of Melamchi WSP (MWSP)

As a follow up to those thinking, the Government of Nepal prepared KV physical development plan (1972), land-use plan (1976), physical development concept (1984) including Bagmati river basin water management strategy and investment programme (1994) to promote planned development of the KV. These plans and programmes also analysed water supply situation and focused on long-term supply needs.

1.5. Project Objectives and Rationale

The MWSP phase 1 is envisaged to improve the health and wellbeing of the then 1 million residents of the KV by addressing the pressing water stress, by providing



continuous and quality water while existing system supplied piped water for only 1-2 hours in 6-10 days. It is also expected to optimize the harvesting water resources in the valley. The Project also introduced institutional reforms with a view to ensuring sustainability of services. The Project also seeks to develop a comprehensive institutional framework for water resource management within the valley. It involves the transfer of water from the Melamchi Valley into Kathmandu Valley through a diversion scheme with a 26 km long tunnel. The Project comprises (i) infrastructure development; (ii) social and environmental support; (iii) institutional reforms; and (iv) project implementation support.

1.6. Institutional Arrangement for Melamchi Water

Melamchi Water Supply Development Board (MWSDB) was established in 1998 as asset owner of the valley water facilities under the WSMB Act 2006, along with other agencies such as Tariff Fixation Commission and KUKL as operator of the services. The water supply responsibility of the Nepal Water Supply Corporation in the Valley was transferred to the Board after its establishment as a self-governed and organised body. The Board has entrusted KUKL – a PPP venture agency – for water and sanitation services in the valley. The KUKL is facing challenges to supply water due to deficit in water source, resource base, ageing pipes, and high leakage. The KUKL with its project implementing directorate is engaged also in implementing bulk distribution systems and distribution network, ensure proportionate supply and control leakage. The MWSDB is mandated to continue to bring additional 340 MLD from Yangri and Larke rivers in its upcoming second phase including extension of Water Treatment Plant (WTP).

II. METHODOLOGY

This paper has been prepared by reviewing numbers of published and unpublished documents, and research outcomes. Similarly, it is also based on adopted project approaches and established practices as well as my experience of working in the project post-2021 flood disaster recovery phase. Official documents- especially project level documents, media publication and broadcast information, web surfing have been also resorted to.

III. OBJECTIVES OF THIS PAPER

The objectives of this paper are to inform and make aware the Nepali citizenry, planners and decision makers, on the

urgency of need to first understand the vulnerability of the water sources in face of changing climate and then prepare to build resiliency, devise adaptation plan as a proactive response to the vulnerability, implement mitigatory measures set in the adaptation plan thereby making the infrastructures resilient enough to withstand or cope with the foreseen climate risks.

IV. DISCUSSION

4.1. Project Delay- Causes and Consequences

Project Starts Amid Insurgency

The MWSP-I and the maoist insurgency onset parallelly. Many stakes appeared on surface to get their pie from the project, especially, under the lozung of ILO 169. Seemingly, it was hard to surpass all those hindrances for the then weakening state machinery. Today, nobody talks about the ILO 169, whether it was relevant and just issue. It remained grey issue though many schemes for local benefits including the water levy was agreed. The levy issue is still unclear and cause for project disturbances from time to time.

How Contracts are Handled in Nepal?

Every contract is treated in itself a law but this fact is grossly ignored in Nepal, both by practice as well as by law. Procurement laws and auditing regulations are found in contrary to standard contract provisions. No stakes other than the engineer, project director as representative of client and the contractor should enter in to the contractual arena. If contractors are weekly invited to brief the work progress in the floors and roofs of ministries, the contractors would, for sure, stop working. Rather they would simply start producing paper progresses. Such activities including too frequent VIP visits to construction sites, unnecessary pressure on premature inauguration of facilities under construction should be stopped in future.

Time and Cost Over-runs due to Project Delay

The overall country governance situation had apparent bearing on project delays and ultimately cost overruns. MWSP was delayed by 8 years with considerable cost over runs. Same is the case for majority of large projects in Nepal.

4.2. Present Status of the Project

Project Status

There is no clear answer to whether MWSP Phase I is completed or not. Actually before 2021 flood, the project completion was estimated to be above 95% with few

minor works remaining to accomplish in headworks and tunnel. Same was situation with two contracts on WTPs. Now it is known that all contract packages are closed or under closing process. Not to mention, litigations are inherent in large projects.

Testing and Commissioning and Supply

Testing, commissioning and seasonal supplies during last 2 post-flood years had to conduct in pressing situations. Due to excessively prolonged project delay, no body seem to have tolerance to coolly wait for a comprehensive system check. All these supplies till now and in many years to come has to be made through the alternate diversion system (ADS), intended for short diversion during lean flows.

Cause of the 2021 Melamchi Flood and Its Damages

An unprecedented temperature spike of above 5.5 °C reportedly occurred on mid-day of 14 June 2021, rain was not that significant those days. A catastrophic debris flood suddenly hit the Melamchi headworks the next day [10,11]. The flood of June 15 and subsequent flood of August 1 altogether swept away the project's intake weir at headworks as well as more than half stretch of the access road and all bridges along the river corridor. Luckily, since the tunnel gate at ADS was already shut the day before the first flood, the tunnel structures remained safe except for deposition of fine debris inside ADS and the first adit portal. All structures including adit portal and headworks were buried 15 to 24m below debris. The heavy-debris laden flood event is to be seen in the backdrop of the 2015 earthquake with epicenter in Gorkha and magnitude of Mw 7.8 followed by another big aftershock of Mw 7.3 three weeks later, with epicenter in Kodari area in the vicinity of the Indravati catchment. Those two mega tremors had already caused new rock fractures and ground fissures significantly from Gorkha to Dolakha districts. [12].

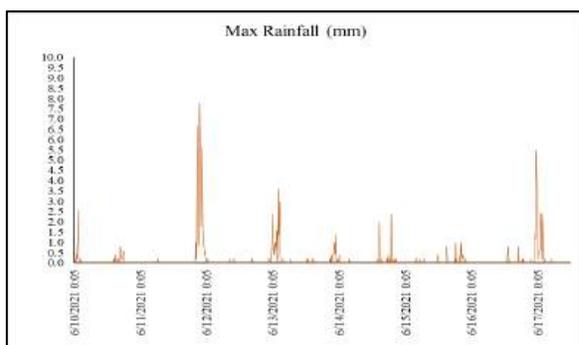


Fig. 2: Precipitation before and after the June 21 incidence

System Handover and Operation

Till recently, after headworks partial recovery the tunnel was being operated and maintained by the old contractor. It has now being prepared to operate through separate contractor after closure of the old contract. The 170 MLD WTPs were already handed over to the asset owner last year and being operated by KUKL.

4.3. Post-flood Initiatives

Immediately after the flood, the project team seemingly was in dilemma- whether to start works on recovering the buried structures or stay dormant till the river regime stabilizes. In the meanwhile, ADB had mobilised a post-disaster study team immediately after the flood. It delivered a report covering the incidence and its root-causes. In 2022-23 another TA team had also been fielded by ADB, which is envisaged to recommend conceptual level of headworks design. But, after taking a recy observation of the upper catchment area around Bhemthang, both of the TA team realized that u/s treatment is beyond the imagination [10,11].

4.4. Challenges Ahead of Melamchi Project

4.4.1. Weakening Governance in the Country

As in many under developed nations, prolonged political instability, peoples' trust on state and government, rampant corruption, impunity and ignorance of law, all in tandem has dragged Nepal since decades to impoverishment. Water and Sanitation services as many other essential services are not reaching to all in a just manner. No systematic practice of fee for service is in place. When governments in a poor state bear the burden of free WaSH services only for the shake of popularity, it means people will not get any services. Dependency on external funding for ever is not taking Nepal anywhere.

Laws are failing to hold state actors responsible and accountable. The scarce resources are being grossly misused in non-productive projects, duplicating and triplicating, which in turn compels people in dark and farthest corner of the country to wait infinitely to get their needy projects and services. Decisions are made usually in pressure of interest groups and that too remain unimplemented creating frustration and anger among the beneficiaries. With weak financial base the country is not in position to invest in R&D and promote innovation. In one hand, even O&M and system rehabilitation, if not extension, is being seen possible in lack of country's financial capacity, on the other hand, huge chunk of national purse is being wasted in non-priority and counter-



productive ventures. Even high-powered commissions, committees or establishments are helpless in front of interest groups. Great question is also posed on competency and integrity of the officials on the top echelon of power, their reputation badly damaged. Not to forget the irresponsiveness of the project insurers, not obeying the project insurance obligations. The headworks recovery works couldn't be carried in full fledge due to in-cooperation and lingering of the insurer to take its legal obligations even 2 years after the flood damage occurred. It is the mirror of anomaly in corporate accountability. National insurance regulator is seen flatly dormant.

4.4.2. Climate Change and the Changing Risk Landscape

Globally, the aggressively changing climate and growing exposure to disaster risk are pressingly threatening to achieving the SDGs as well as national development objectives of countries with low-income level and weak governance. In Nepal also CC is projected to increase incidences of CC induced disasters, resonated with fragility of topography, in turn will increase vulnerability to other natural hazards. Water supply is seen as one of most severely hit sector by CC-related risks. Speaking straightly, the fate of Melamchi water is ultimately connected with that of the world's highest water towers, the Himalayas. Langtang Himal where all 4 tributaries of Indravati emerge, is part of the Nepal Himalayas located on the North-East of the KV.

Soot: the Culprit Behind Melting Himalayan Glaciers

Snow being a highly reflective material, its reflectivity (albedo) is 0.8–0.9. That is to say 80–90% of the incident solar energy is reflected back to the atmosphere. Both, the reflecting as well as insulating properties of snow cover significantly reduce the heat exchange between the surface and the atmosphere. Black Carbon (BC) in soot is found as the major absorber of visible sunrays in the atmosphere. Anthropogenic sources of BC are mostly found concentrated in the tropics where solar irradiance is highest. As such, the southern slopes of the Himalayas are mostly prone to dense accumulation of soot due to excessive carbon emissions from the south Asian region with a population of above 1.7 billion. The soot can be transported over long distances, mixing with other aerosols on the way. This aerosol mix can form transcontinental plumes of atmospheric brown clouds (ABC), with elevations up to 5 km. BC is one of the main components of soot, smoke, and smog. It is what's left behind from the incomplete burning of organic materials like firewood or fossil fuels. Left suspended in the

atmosphere in the form of brown clouds, it is the second leading contributor to global warming, after CO₂. Settled on snow it increases the risk of catastrophic flooding due to rapid snow melt since it is 1500 time more heat absorbent than CO₂. It reduces the reflectivity and accelerates melting of snow cover. It has substantial effects on the regional climate through local pollution and the formation of ABC. It gets mixed into the atmosphere in the form of fine particles (PM_{2.5}) which can absorb about million times more solar energy than CO₂ does. When BC enters the air, it readily absorbs heat from sunlight, heat the atmosphere and can affect the region's climate. This may also affect cloud formation and precipitation.

Though global distribution of soot is difficult to measure, NASA researchers use satellite data and computer models to better understand how these short-lived particles influence Earth's climate. An article published in a scientific web journal says the Himalaya Mountain region is warming up 3 to 5 times faster than the global trends i.e. rise in about 0.5 °C per decade and many of its glaciers are rapidly retreating. It states that GHGs alone cannot explain this warming, however, and several new studies are pointing to an old form of pollution: i.e. soot. NASA Researchers have also estimated the amount of soot falling on a typical Himalayan glacier using data from an international atmospheric observatory in Nepal. Computer simulations suggested that the soot can cause a decrease of 1.6 to 4.1 % in the glacier's albedo and that the resulting heating can cause up to a 24 % increase in the annual snowmelt [13-17].

4.4.3. Then What is Happening with Snow-fed Himalayan Rivers?

To know the processes undergoing and planning for extension of the MWSP it is inevitable to seriously look back to the following geo-climatological factors of the catchment area. Since 1972 many studies have been carried out for KV water supply sources including Melamchi river, findings of which can be applied to entire Indravati catchment, on the basis of similarity in nature.

Catchment

About 11% of the Melamchi catchment falls above snow line (elevation > 5000m). Some evidences of landslides have been seen in aerial photos [20].

Climate

Spring snow melt boosts flows in rivers with catchment including the elevations 3000-5000m, but the effect is

limited by the relatively low winter precipitation. Low flow generally occurs slightly earlier, generally in March [20, 21]. In a shorter term, the early snow-melt due to CC impacts may increase the dry flow but in longer term, it may lead to depletion of the water tower as snow cover is retreating continually.

Precipitation

During June to September, this climate is influenced by S-E monsoon. In winter, continental wind patterns are generally from the N-W and the precipitation diminishes. Winter precipitation hardly exceeds 15% of the country's total. The annual precipitation varies from >4500mm in the higher elevations to 2500mm in the lower elevations. The mean annual precipitation near the intake area is 3536mm (1988-98) [20, 21].

Temperature

With the range of altitude of the project area, temperatures can be described as sub-tropical to temperate. The vertical temperature gradient being about 5 °C per 1000m. Mean annual temperature decreases from 21 °C to 11 °C along the ridges [20, 21].

Hydrology

Monthly runoffs

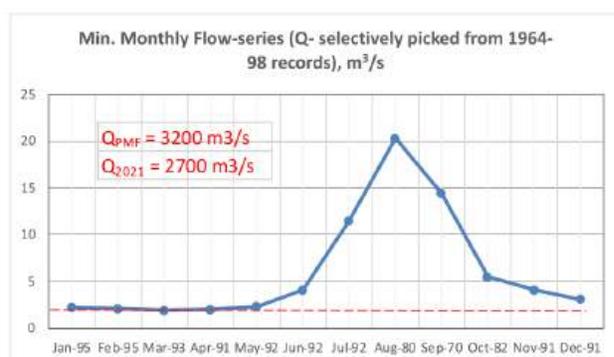


Fig. 3: Melamchi Min. Monthly Flows (selectively picked)

Due to data gap, hydrological estimates have been based on correlation of Melamchi flows with Balephi river flows having flow record of 1964-1991. Mean monthly flow in the minimum month (March) was estimated 2.2 m³/s [20]. Hydrological data from Nakote Station 627.5 with a 10 years long daily discharge series for the period 1991-2000 shows dry season flow of 2.9 m³/s (January-April) stable over the years. For Yangri and Larke rivers, Melamchi data have been used on the basis that all these 3 basin characteristics are similar being in close proximity and similar geo-ecological settings [21].

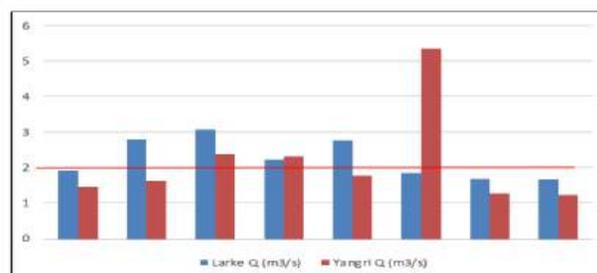


Fig. 4: Summer and Winter Discharge measured at Yangri and Larke (1991-99)

Riparian/Environmental Flow

Legal provision is 10% of dry-flow but the design considers 40%.

Floods

The NORPLAN design report derived the probable maximum flood (PMF) of Melamchi river and compared with max. recorded floods in Nepal and worldwide. The adopted PMF estimates were found greater than the recorded max floods in Nepal and closer to the max recorded floods worldwide.

Table 1: Derived Probable Max. Flood in Melamchi River

Return Period (Year)	Estimated Max Flood (m ³ /s)
2	140
10	220
100	310
PMF	3200 > 2700 (2021 flood)

Sediment Flow

Apart from water flow, boulders, mud and other debris have been recorded in Nepal and are a matter for concern. The two basic types of debris torrents are those caused by GLOF and those due to overflow of lakes forming behind landslides (LDOF). SMEC report saw less possibility of GLOF and overlooked the presence of past landslides and damming in the u/s catchment while the NORPLAN report had foreseen these and a model study (flood simulation) was carried out in lab-scale estimated a debris flood of 600 m³/s [20].

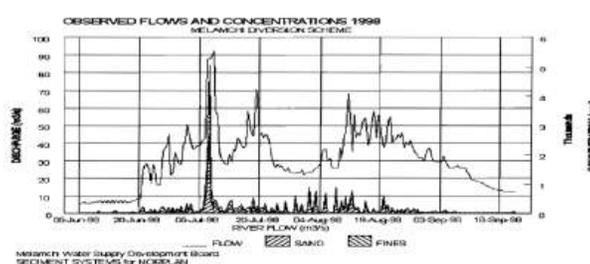


Fig. 5: Observed flows and Sediment concentrations in Melamchi Headwork site

Seismicity

The Himalayan arc has experienced 4 major quakes of >8 Mw in the last 100 years. The 2015 MWSP design suggests that underground structures need not be designed for seismic loads, since they are less subject to earthquake damages compared to overground structures [20-21].

4.5. Quest for Alternative Sources

By frustration after 2021 flood damage, study of another bulk source at Sisneri with impounding dam and pumping is being carried out. The Sisneri scheme will have its own drawbacks. About 80m dam, 380m x140 MLD pumping with 18 km pumping mains to be laid along fragile and narrow Bagmati gorge, already congested by Fast Track road and proposed Railway route, requiring colossal protection and support works. Roughly estimating, it may come around 45-50 billion rupees in present costs.

V. CONCLUSION

Demand for water and sanitation facilities bears direct proportion to population size. The bowl-shaped Kathmandu valley with unplanned urbanization has limited population capacity to accommodate. Looking from this stand-point, the current planning approach of the valley in general and the water sector in particular, is flatly going on adhoc basis. The 5 M+ population bomb can explode any time if large water systems at some time in future would go dysfunctional for a prolonged time. A serious course correction is urgent.

Internal capacity of asset owner and operator of such infrastructure system serving such size of population, should be well equipped in all aspect with adequate resource base. With smart management a population of 5 million can be well served 24x7 with 510 MLD Melamchi water altogether, with source augmentation to compensate CC impacts. Or, ultimately, it will have to initiate for enforcing legal population capping in KV.

With the current available knowledge on CC impacts as discussed here we can foresee our snow-covered Himalayas to turn into bare rocky-mountains and extreme hydrological developments by the end of this century. Preparedness, building coping capacity and transforming developmental philosophy only can maintain status quo.

5.1. Preparation of Priority Project Banks

As the valley population grows or the existing system either dysfunctions due to any reason including source

drying up or system irreparably damaged, there should be ready plan for picking projects in the project bank for implementation. The projects should be well studied and analysed for comparative merits and demerits in the face of changing climate. Few priority projects for source augmentation, listed here based on conceptual projections, worth pondering.

5.1.1. Phase 1: Improvement of Melamchi Phase 1

Full recovery of the buried headworks and rehabilitation of all damaged components including adit tunnels including Full-fledged installation of automatic control system, Rehabilitation of ADS and Left bank slope stability works. Even after Yangri-Larke extension, the conveyance capacity of the Melamchi tunnel can be increased from 6 m³/s to about 8 m³/s by improving tunnel geometry and wall characteristics to draw additional water from other sources- Phases 3 to 5.

5.1.2. Phase 2: Yangri and Larke River Diversion

Includes headworks at Yangri and Larke rivers with desanders (not in original design), 9+2 km tunnelling with vehicular transport permissibility and docking with Melamchi tunnel.

5.1.3. Phase 3: Indravati River Diversion (not in plan)

Should include headworks without desanders but with a low-dam ponding, 1.5 km diversion tunnel discharging in to Larke river. In time horizon of 10-15 years from now, if possible, the tunnel shall be trafficable.

5.1.4. Phase 4: Langtang River Diversion (not in plan)

Should include headworks without desanders but with a low-dam ponding, 8 km diversion tunnel discharging in to Yangri river. In time horizon of 10-15 years from now, if possible, the tunnel shall be trafficable. Possibility of high rock bursts, squeezing, high temperatures and water pressures needing in special method of construction.

5.1.5. Phase 5: Balephi Diversion (not in plan)

Should include headworks without desanders but with a low-dam, 8 km diversion tunnel discharging in to Indrawati river. In time horizon of 20-25 years from now, if possible, the tunnel shall be trafficable. Same difficulties as in phase 4.

5.1.6. Phase 6: Upper Taadi Diversion (not in plan)

Includes headworks with desanders and a low-dam ponding, 9 km tunnel docked to the Melamchi tunnel. In time horizon of 30-35 years from now, if possible, the tunnel shall be trafficable. Same difficulties as in phase 4.

5.2. Additional Recommendation on Phased Source Augmentation

After the 2021 flood disaster, the MDP has been turned into a seasonal system, until a reliable permanent solution is devised. It looks like rather than starting MWSP Phase II (Yangri & Larke diversion), emphasis is being given to alternative source at Kulekhani river (Sisneri impounding with pumping), as a result of frustration from Melamchi catastrophe. Since a heavy long-term investment already incurred in Melamchi, where except for its buried headworks with front part partially damaged, all

components are believed to be intact and the next phase of tapping Yangri and Larke could be completed with almost half the cost of that of the Sisneri. The Alternate project study is definitely appreciable but comparing all parameters including water quantity and quality, the pristine Himalayan waters at cheaper investment will by far out-weight any other alternatives seen so far, since all d/s infrastructures of Melamchi I will be common to all 5 phases (2 to 6) of proposed extensions mentioned above.



Fig. 6: Prioritised Extension Phases of Melamchi Water Supply System

5.3. Adoption of Risk-informed Development

The Himalayan region often experiences extreme weather events and geophysical shocks and is considered among the most vulnerable region globally to multi-hazard impacts. It is impossible to control natural disasters but with adaptation, resilience building and mitigation actions, same can be reduced and impacts softened. This

entails necessity to ensure resiliency of infrastructures and also to enhance planned investments in DRR and CCA. Different tools and approaches have been developed and in use worldwide towards achieving climate proof, disaster resilient and sustainable infrastructures and services yet affordable and economical in long run:

- Building Resilience and implement CCA actions. The local and indigenous knowledge, skills and wisdom could be useful in devising proper adaptation

measures. But the ironical question arises, do Nepalis still possess such indigenous knowledge and skills that our ancestors had? Also, governance acts as enabling factor, since a multitude of actors have to be involved in coordinated way.



Source: Asian Development Bank.

Fig. 7: Holistic Approach to Resilience

- GoN entities- MWSDB and DHM to be serious to ensure that even without an externally funded project, hydrological data gathering is continued along with establishment of remote sensing and early warning systems.
- Mainstreaming for Disaster and Climate Risk-informed Development [18].



Fig. 8: Framework for Mainstreaming Principles [UNDP]

- Nepal should embark on IRBM approach for critical river basins, including the Melamchi. ADB’s plan to provide TA on interventions at a regional level (eg the HKH-CRM Project) based on the outcome of the study on Mapping Hazards in Melamchi Catchment. Guidelines that will be developed during this study can be believed to serve as good platform for developing new projects in the region.

5.4. Adoption of New Criteria and Approach for Maximum Flood Estimation

The Melamchi headworks designed in 2000s for a 10,000-year return period flood of 600 m³/s, obtained using a model study conducted, was many times higher than the max-flood given by using conventional method of flood estimation practiced then. Conventional method of high flood determination is based on probability and risk estimate but the impact of sediment load and debris flows is neglected which could be critical for steep and dynamic rivers in younger Himalayan geology. With the same amount of water discharge the flow depth and total discharge could be manifold due to presence of debris load in the flow. But the 2021 events floods exceeded by almost 4.5-fold (2700 m³/s) the design flood. This exceedance of the design flood highlighted the need for incorporation of CC impacts in estimation of probable maximum outburst floods (PMOF) by including various processes in geo-morphology, hydrology, etc., that culminate in to multi-hazards. This need to be mainstreamed in national policy and standard guidelines. The concept of PMOF involves estimations of GLOF, LDOF, cloudburst floods, and PMF for the catchment and the selection of the peak flood discharge based on a rational combination and comparison of the various floods. Amazingly, the adoption of the PMOF approach to the Melamchi catchment suggested a maximum flood of 3200 m³/s. Noteworthy that, given the diverse possible scenarios of multi-hazard combinations in the catchment, the PMOF estimate thus derived can be highly full of uncertainty.

In this connection, it worth looking back at Red-flag Report given by a due-diligence consultant mobilized on the verge of testing of the Melamchi tunnel:

- Possible flooding of structures: Revise design flood and river training to include 1992 event flood; usually 1000-year flood instead of 100-year because $Q_{design} = Q_{100} = 158 \text{ m}^3/\text{s}$ but $Q_{1992} = 288 \text{ m}^3/\text{s}$
- Possible lateral loading by water; 50 cm freeboard is in-sufficient, 120 cm is required.
- Settling basin walls’ stability: 0.15 g seismic coefficient used instead of 0.5 g.
- L- bank weir slope instability may cause dam up the river u/s of the cofferdam. [19]

5.5. Lobbying for Climate Solutions

Consequences of BC (soot) on snowmelt is a global environmental justice issue, as the risks primarily affect people who live in poverty. Countries like Nepal

negligibly contributing to GHGs, are suffering badly. UNFCCC's call for the global community to implement its plan of reducing global warming by an estimated 0.2 °C by 2050 to abate the CC impacts. BC and CO₂ are often emitted during the same combustion processes, so vulnerable countries should actively lobby for the efforts to reduce CO₂ emissions which automatically have the effect of reducing BC as well.

5.6. Optimum Utilization of Existing Facilities

It looks like the MWSDB has abandoned recovering and rehabilitating the buried headworks in frustration with the insuring company's act of non-accountability to take binding responsibility. Rumours were also spread on abandonment of buried headworks and going for a new, at some 500m upstream site, with additional cost of 5 billion Rupees. Given the still inappropriate river section there with the same overhanging risk of debris flow in future, shifting of headwork abandoning the existing one can be a blunder. Rather with some investment, it would be wise to build back the partially (front head of the intake and weir) damaged headwork.

Authorities are to be aware of the purpose and make of the ADS. Since last 3 years, even during high river bed-load periods, there seems a hurry to supply water, which is possible only through the ADS at present. The steep slope of >7% and normal shotcreted tunnel walls, intended only for occasional diversions without heavy bed loads, will be exposed to risk of abrasion and spalling of wall surface thereby jeopardizing the ADS. With additional restrengthening it can prolong its service life.

5.7. Water Governance Improvement

Water governance, though cannot be seen in separation from the overall country governance, a well-designed and economically self-propelled service delivery system could be expected to function aloof from the ongoing political game. Before starting next phase of MWSP, make sure to:

1. Reorganise MWSDB with metro-mayor as board chair,
2. Tariff commission to be revitalized, sustainable tariff base developed and implemented,
3. Attract private investment/operators in service delivery,
4. Stop groundwater abstraction, keep it as emergency reservoir for the future.

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Navigating Exceptional Events under FIDIC Contract Forms: Enhancing Project Governance in Sustainability-focused Construction Contracts

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ABSTRACT

FIDIC contract forms have gained significant popularity in international construction and engineering projects. To that extent, this Paper seeks to examine how considerable FIDIC provisions on exceptional events or force majeure clause as it was in the previous version are effective in the current settings more specifically in sustainability projects. This paper evaluates how the FIDIC 1999 and 2017 Rainbow suits of Red, Yellow, and Silver Books contract forms respond to the brought-about difficulty or advancement of exceptional events on sustainability-focused construction contracts and how inherent FIDIC forms are useful in enhancing project governance. Sustainability initiatives in construction projects relate to reducing environmental loads, improving resource utilization, and improving people's health and welfare needs. It is also noted that such projects frequently apply new technologies and practices, making them more vulnerable to outstanding events. Based on the studies, sustainability projects and conventional infrastructure projects differ on the environment, technological advancement, stakeholder and regulatory framework concerns. The Paper then points out that both Contract Data and Particular Conditions should be used appropriately to prevent misunderstandings and to manage the contractual consequences of such circumstances within the Contract. In addition, the paper identifies recommended improvements in governance actions, such as sophisticated risk management systems; combined sustainability and resilience strategies; and efficient communication and cooperation tools throughout the contract life cycle. It also stresses the importance of creating or providing on-going capacity building and training to empower the project teams to gain the knowledge and requirements for critical events necessary to continue the sustainment of standard of sustainable requirements under FIDIC Contract. The paper concludes by arguing the need to formulate good provisions on resilience and sustainability within construction contracts, in order to achieve successful delivery of Projects even under adverse circumstances.

1. INTRODUCTION

In the rapidly evolving landscape of global infrastructure and construction projects, the role of standard contract forms has become an indispensable tool for managing risks

and responsibilities and setting up contractual frameworks. Among the most widely recognized and respected contract forms are those issued by the International Federation of Consulting Engineers (FIDIC). Renowned for its structured approach to risk allocation, FIDIC contracts are frequently

employed in a diverse range of international construction and engineering projects. These contracts provide a structured legal foundation for executing projects that are often large scale, complex, and subject to numerous uncertainties.

One of the major risks faced in these projects involves unforeseen circumstances, referred to as "force majeure" in previous editions of FIDIC Books and as "exceptional events" in the latest editions.

The projects driven by the global push toward minimizing environmental impact and optimizing resource efficiency for sustainability are often more vulnerable to exceptional events because of their reliance on emerging technologies, innovative practices and stringent, yet evolving, regulatory frameworks.

Sustainability projects, which prioritize environmental stewardship, social responsibility, and resource efficiency, face unique risks when exceptional and/or force majeure events occur. Disruptions, such as extreme weather events, supply chain interruptions for sustainable materials, or sudden regulatory shifts regarding environmental compliance, can severely impact project delivery.

2. FORCE MAJEURE AS PRINCIPLE OF LAW

The term *force majeure* is not a defined legal term and confusingly it bears different meanings in different legal systems.^[1] Merriam-Webster's Law Dictionary attempts for literal meaning of force majeure as "*superior or irresistible force*" or "*an event or effect that cannot be reasonably anticipated or controlled*"^[2]

Black's Law Dictionary defines a force majeure clause as:

"a contractual provision allocating the risk if performance becomes impossible or impracticable, esp. as a result of an event or effect that the parties could not have anticipated or controlled"^[3]

It is a doctrine that allows for the excusal of liability for non-performance because of unforeseen events that are beyond control and render fulfilling an obligation impossible, qualifying them as "force majeure events." Force majeure events are generally understood to be occurrences, whether natural or man-made, that are unforeseeable and unavoidable.

More than the definition, *Force Majeure* is a contractual mechanism used to address situations where it becomes

impossible to fulfill a contract or impractical due to unavoidable and unforeseen events beyond the parties' control. The purpose of a Force Majeure clause is to excuse parties from nonperformance that results solely from such unexpected events rather than from their own negligence or wrongdoing.

2.1 Governing Legal Principles For Force Majeure Clause

2.1.1 Impossibility of Performance

a. Economic

Long-term contractual arrangements are generally more vulnerable to future risks, including economic change and instability. Significant shifts in economic conditions at the time a contract is formed can sometimes lead to the complete failure of the parties to meet their obligations. These dramatic economic changes can result in various negative consequences, such as a major disruption in the contract's initial economic equilibrium, such as price volatility or currency instability that makes fulfilling the contract costly and unprofitable for one party, or a major shift in the financial status of the parties involved, such as a debtor declaring bankruptcy. a significant change in the financial conditions of the parties involved, such as a debtor declaring bankruptcy.

• Economic Strain

Over the duration of a contract, various factors, such as rising costs or currency depreciation, can impact its economics. In situations of economic force majeure or hardship,^[4] these factors can result in a significant rise in performance costs for one party. Generally, parties are expected to adhere to their contractual terms, even in the face of economic hardship, as such fluctuations are foreseeable risks that should have been managed during contract negotiations. Courts tend to reject claims of force majeure from professional merchants because they are assumed to have the knowledge to allocate risks appropriately, often through clauses addressing price fluctuations or hardships.^[5]

The relatively low success rate of economic hardship claims among international tribunals reflects this strict approach. In some instances, courts have determined that economic changes are predictable risks that the parties should have accounted for. For example, Amid the oil price crises of the 1970s, affected parties frequently sought to

invoke force majeure but were unsuccessful, as courts found that the market deterioration was foreseeable.¹⁶¹

In other cases, even when changes were deemed unforeseeable, courts ruled that the changes were not significant enough to justify claims of an unreasonable burden. The ICC Tribunal, for instance, a rise of 13.16% in costs was considered within the normal range and did not render the contract impossible to execute.¹⁷¹

- **Financial Limitations of Parties**

In exceptional circumstances, a court may permit a force majeure claim if a subsequent economic change makes the contract performance excessively burdensome or ruinous for one party. However, it is insufficient for the claim to rely solely on the seller's financial ruin, as subjective situations do not impact contractual obligations.¹⁸¹

In *Christy v. Pilkington*, the difference between objective impossibility—where something cannot be done—and subjective impossibility—where someone cannot do it—asserting that financial inability does not discharge contractual obligations.¹⁹¹

This strict perspective has been mirrored in international arbitration. For instance, in *Alsing Trading Co. and Swedish Match Co. v. Greece*, the tribunal noted that a subsequent unforeseeable change could support a hardship claim if it rendered performance ruinous for the debtor or unjustly enriched the creditor.¹⁰¹

However, successful claims of hardship have been relatively rare, as evidenced in the Alsing case, where the tribunal denied such a claim.

This firm position aligns with international contract practices, where bankruptcy and the inability to pay are clearly excluded from force majeure events.

- **States and Macroeconomic Crises**

Just as individuals can declare bankruptcy, states may also face significant and unexpected changes in economic conditions that hinder their ability to fulfill contractual obligations on time.¹¹¹ However, in the absence of international bankruptcy laws, such situations should be handled using alternative legal doctrines, including force majeure. *The Himpurna v. Republic of Indonesia* case illustrates how macroeconomic crises can affect state contracts, emphasizing that parties involved in international contracts cannot plead ignorance of potential macroeconomic risks, even if those risks are severe.¹²¹

Historically, tribunals have rejected force majeure defenses from states facing economic crises that led them to default on loan agreements.¹³¹ In cases like the Russian

Indemnity¹⁴¹ and Brazilian Loans,¹⁵¹ states attempted to invoke force majeure due to financial difficulties but were unsuccessful. For instance, Brazil argued that it could not pay interest to bonds because of the unavailability of specific gold coins. However, the Permanent Court of International Arbitration rejected this claim, stating that the obligation could be viewed as a promise to pay in gold value, which was still obtainable.¹⁶¹

Similarly, in the Russian Indemnity case, the tribunal determined that a payment of six million francs did not jeopardize the state's existence or vital interests. This strict view is echoed in recent ICSID arbitration cases, such as *CMS Gas Transmission Company v. Argentina*, where Argentina cited force majeure in response to emergency measures during a severe economic crisis. However, the tribunal found that the events leading to these measures were foreseeable, thereby rejecting the claim of force majeure.¹⁷¹

Overall, international tribunals are generally reluctant to accept economic hardship as a valid force majeure claim. Whether presented by public or private parties, such claims are often dismissed as economic instability is regarded as a normal risk in commercial transactions that should be addressed through appropriate contract provisions.

- b. Legal Effects of Force Majeure Excuse**

A non-performance that is excused due to force majeure does not grant the obligee the right to seek damages¹⁸¹ or demand specific performance.¹⁹¹ However, this excused non-performance fails to prevent the obligee from pursuing other remedies typically available in non-performance cases. These remedies include the right to terminate the contract for essential non-performance, withhold performance, reduce the price, and request interest on any owed amounts.

The contract and any associated non-performance continue to exist, even when non-performance is excused.²⁰¹ This exemption does not automatically release the obligee from their obligation to perform (or counter-performance). The obligation for counter-performance is eliminated only if the contract is terminated; nonetheless, the obligee can withhold their counter-performance as long as the non-performance and the contract remain in effect. Generally, termination as a remedy requires a (fundamental) non-performance and is available solely to the obligee, not the obligor. However, if a total and permanent impediment occurs, the contract is automatically terminated. The obligee

has the option to terminate the contract if they seek a permanent release from their counterperformance obligations or wish to recover what they have already paid or provided under the contract.

The force majeure exemption applies only to the extent to which the impediment affects performance; in the case of a temporary impediment, the exemption persists for the length of the impediment or its effects. During this time, the obligor's performance obligation is suspended and the excused non-performance does not result in a damage claim. If the impediment partially affects performance, it excuses non-performance only for that portion. If the obligee has no valid interest in the unaffected part of the performance, they may terminate the contract because of fundamental nonperformance.

It is generally accepted that remedies that are not mutually exclusive can be accumulated.^[21] In instances of excused non-performance, compatible remedies include: the obligee may initially withhold their performance and subsequently terminate the contract for fundamental breach, or the obligee may terminate the contract after a temporary impediment if they did not receive performance.^[22] Conversely, a party that terminates the contract cannot later claim specific performance or remedies that assume the contract remains in force, such as price reduction or requests for repairs or substitute goods, after the impediment has ended.^[23]

2.1.2 Frustration of Contract

Frustration of a contract takes place when, due to significant and unforeseen changes in circumstances that are not caused by either party, the contract is rendered impossible to perform or the performance no longer aligns with what was originally agreed upon. This termination happens automatically, unlike in cases where a contract is terminated due to one party's repudiation, where the choice of the innocent party is key.^[24]

When a contract is ended due to frustration, the entire contract becomes terminated.^[25] The contract is considered to have been valid until the frustrating event took place, which means that any rights and obligations that arose were recognized.

Under common law, a contractor who has completed work on a frustrated contract is entitled to payment for their work, even if the owner cannot derive any benefit from it.^[26] However, if the contract is classified as an entire contract

and the contractor's work is unfinished, they cannot claim any payment following the frustration.^[27] Unlike contract termination due to repudiation, frustration does not result in a right to damages.^[28]

The principle of unjust enrichment is often applied under civil law. This means that, if a contract is frustrated, the contractor may be entitled to compensation for the work completed to prevent the owner from being unjustly enriched at the contractor's expense. The specific provisions can vary by jurisdiction, but generally, the contractor can claim for the value of the work done or materials provided up to the point of frustration.^[29]

2.2 Standards Adopted in Various Jurisdictions

a. Doctrine of Frustration under English Law

The Law Reform (Frustrated Contracts) Act 1943 (UK) applies when a contract becomes impossible to perform or is otherwise frustrated, leading to the parties being discharged from their obligations.^[30] In cases of frustration, the legislation generally aims to return the parties to their initial positions as if frustration had not occurred, taking into account any detrimental changes in their circumstances due to the performance of the contract. The goal is to prevent either party from being unjustly enriched at the other's expense.^[31] However, it does not seek to position the parties as if the contract had been fully executed.^[32] Under the 1943 Act, any payments made before the contract were frustrated could be recovered from the payee. If the payee incurred costs before frustration, the court may grant the payee to retain all or part of the amounts paid, as long as the retained amount does not exceed the payee's expenditures. Therefore, if a partly performed building contract is frustrated, the owner can typically recover all payments made to the contractor up to that point, but the court may permit the contractor to keep a portion of the amount equal to their expenditures deemed just.^[33]

In cases where a party receives a non-monetary benefit from a frustrated contract, the party who provided that benefit is entitled to recover an amount that the court deems fair, up to the value of the benefit obtained.^[34] The court will consider various factors, including any expenses incurred by the benefiting party before the contract was discharged, such as payments made under the contract or recoverable amounts due to the frustration.^[35] Additionally, the court will assess how the circumstances that led to the frustration affected the benefit received.^[36] It is crucial to identify the

benefits, if any, that the other party receives. In some instances, a frustrating event may completely negate any conferred benefits. For example, if an owner hires a builder and a fire destroys the work in progress midway through the project, no benefit would be conferred on the owner, meaning they would not owe any payment for the work performed by the contractor.¹³⁷¹

The contract price, or the rates outlined in a contract, can act as a cap on the amount a contractor can claim for work performed under a frustrated contract.¹³⁸¹ For example, if a financially constrained owner hires a contractor and the contract is frustrated after some work has been completed, it may be reasonable to limit the contractor's recovery to the contract price or a proportional amount, instead of demanding payment beyond what the owner can afford.¹³⁹¹

b. The Doctrine of Frustration under the French Law

In France, the Civil Code states that if a contract is terminated because of frustration, each party must return what they have received under the contract. If restitution in kind is not possible, a monetary equivalent must be provided.¹⁴⁰¹

Changes in circumstances alone do not automatically frustrate a contract, and the doctrine of frustration should not be invoked casually.¹⁴¹¹ It is meant to be used in very specific situations.¹⁴²¹ Courts lack the authority to free a party from their contractual obligations solely because performance has become difficult due to unforeseen events.¹⁴³¹ For instance, in *Tsakiroglou and Co Ltd v. Noble Thorl GmbH*,¹⁴⁴¹ the court ruled that regardless the closure of the Suez Canal, the contract remained valid, requiring performance via a more expensive alternative route since rising freight costs alone do not justify non-performance.

c. The Doctrine of Frustration under the Indian Contract Act

The doctrine of frustration is codified in India under Section 56 of the Contract Act, establishing a clear rule for when contracts are frustrated without relying on varying theories.¹⁴⁵¹ This section provides relief based on subsequent impossibility, specifically when an unforeseen event disrupts the fundamental purpose of a contract.¹⁴⁶¹

Section 56 declares agreements that become impossible or unlawful as void. A notable case illustrating this is

*Satyabrata Ghose v. Mugneeram Bangur and Co.*¹⁴⁷¹, where the Supreme Court found that the requisitioning of land for military purposes did not substantially prevent contract performance, so the contract remained valid under Section 56.

Section 56 applies when a contract does not include provisions regarding the outcomes of unforeseen events. If such provisions exist, parties are bound by them and cannot invoke Section 56.¹⁴⁸¹ The Supreme Court clarified in 2016 that if parties foresee potential intervening circumstances and explicitly agree that the contract remains effective despite these events, frustration cannot be claimed when those events occur.¹⁴⁹¹ A force majeure clause can address uncertainties related to uncontrollable events, and if an alternative method of performance is specified in the contract, parties must use it instead of invoking force majeure.¹⁵⁰¹ Furthermore, if a party agrees to perform an act that is not inherently impossible, they cannot use the defenses of act of God or illegality to excuse non-performance.¹⁵¹¹

Section 56 is comprehensive in addressing contract frustration. The Law Commission of India recognizes that this section departs significantly from English Common Law, making it unnecessary to apply those theories to Indian cases. The Supreme Court has stated that Section 56 comprehensively governs frustration in India, rejecting the notion that it is not exhaustive, as previously suggested in *Purshotam Das Shankar Das v. Municipal Committee Batala*.¹⁵²¹ Additionally, reliance on foreign judgments to interpret Indian law has been considered unhelpful, although such judgments may provide persuasive insights into how similar cases are handled in England.

d. Contractual Terms

The legal principles regarding contract frustration, whether under common law or statutory law, can be altered, modified, or replaced through an agreement between parties. This can be beneficial, as determining whether a contract has been frustrated due to a subsequent event is often challenging, due to the broad definition of frustration in the law.¹⁵³¹ Additionally, such clauses typically outline the consequences of frustration, which may align with common law or statutory outcomes, or they might differ, allowing the contract to remain in effect while adjusting the parties' rights and obligations.

3. FIDIC 1999 CONTRACTS: FORCE MAJEURE

Sub-Clause 19.1 of the FIDIC 1999 Red^[54], Yellow^[55] and Silver^[56] Books, define the term 'Force Majeure' as an exceptional event or circumstance that is beyond a Party's control and could not have been reasonably anticipated before entering the Contract. Moreover, the event must not be something the Party could have reasonably avoided or mitigated, nor should it be 'substantially' caused by the other party.

Following this definition is a non-exhaustive list of event categories that may qualify as Force Majeure, as long as the event is considered 'exceptional' and meets the criteria mentioned earlier. Because the available relief differs based on the event type, it is essential to specify each category.

- **Category (i)** covers war and other hostility.
- **Category (ii)** includes rebellion, terrorism, and civil war;
- **Category (iii)** pertains to riots and strikes but only those involving individuals other than the contractor's personnel and subcontractors.
- **Category (iv)** involves munitions of war, explosive materials, and radioactive contamination, as long as they are not due to the contractor's own use of such materials.
- **Category (v)** encompasses natural catastrophes, such as earthquakes, hurricanes, typhoons, and volcanic eruptions.

Relief is provided only when the Contractor is 'prevented' from meeting its obligations due to an event that satisfies all the Force Majeure criteria mentioned above. To be eligible for this relief, prevention must be either physical or legal rather than simply stemming from economic unprofitability. In other words, a party cannot claim to be "prevented" from performing the contract solely because the cost of performance has risen beyond what was initially expected.^[57] In *Fairclough Dodd & Jones Ltd v J.H. Vantol Ltd*^[58], the court determined that the term "prevented" indicated that relief would only be granted if shipment remained impossible until the end of the contract period.

The Contractor is entitled to an extension of time for delays resulting from being 'prevented' from fulfilling the contract due to any type of Force Majeure event. However, it can only recover costs (not profits) associated with

specific categories of Force Majeure: for all category (i) events, and for categories (ii), (iii), and (iv), if they occur in the country where the site is situated. The costs related to natural disasters (category (v)) cannot be recovered by the contractor.

The Contractor can recover costs and receive an extension of time for remedial work due to Force Majeure events, with compensation applicable under clause 17. For category (iii) events, this entitlement is valid only if it occurs in the country in which the site is located. Either party can terminate the Contract if Force Majeure lasts more than 84 days for a single event or over 140 days in total, which significantly hinders completion. In such cases, the contractor can recover specified costs, whereas any unpaid advance payment becomes immediately due to the employer (Clause 14.2).

Although relief is provided for Force Majeure, Clause 19.7 allows the parties to be excused from further performance of the contract if an uncontrollable event occurs (including, but not limited to, Force Majeure) that either makes it 'impossible or unlawful' to meet their contractual obligations or gives them the right to be released from performance under the governing law of the contract, such as common law frustration under English law. In the first scenario, since 'prevention' in English law encompasses impossibility and includes unlawful prevention, it could be argued that both Clauses may apply to the same event. However, the phrases 'impossible or unlawful' in Clause 19.7 indicate a higher threshold for being released from performance than the 'prevention' standard used for Force Majeure relief.

4. FIDIC 2017 CONTRACTS: EXCEPTIONAL EVENTS

The term "force majeure" has its origins in French law and has been widely used in legal systems globally, but it often led to inconsistent interpretations across different jurisdictions. In some legal contexts, as discussed in the preceding sections, the definition and application of force majeure varies, creating uncertainty about what specific events would qualify and how they should be managed. To address these issues, and probably to bring jurisdiction-neutrality for Civil and Common Law jurisdictions, instead of "Force Majeure," Clause 18 of the new FIDIC 2017



Books termed these events or circumstances as "Exceptional Events."

By replacing it with "exceptional event," FIDIC aimed to remove the ambiguities associated with force majeure and provide a more precise and universally applicable definition. The term "exceptional event" offers clearer and broader guidance on the types of events that fall within its scope, ensuring that both parties have a better understanding of the circumstances under which contractual obligations can be suspended or modified.

4.1 Definition and Condition-Precedence of Exceptional Events

Sub-clause 18.1 defines what qualifies as an "Exceptional Event." An "Exceptional Event" is characterized by several criteria: it must be beyond a Party's control, cannot have been reasonably anticipated or prevented before entering into the Contract, cannot be reasonably avoided or managed once it has occurred, and is not primarily caused by the other Party's actions. Examples of Exceptional Events include, but are not limited to, war, hostilities, invasions, or acts of foreign enemies; rebellion, terrorism, revolutions, or civil war; riots or disturbances caused by individuals other than the Contractor's personnel; strikes or lockouts not limited to the Contractor's personnel;¹⁵⁹ encounters with war munitions, explosive materials, or radiation contamination not due to the Contractor's actions; and natural disasters such as earthquakes, tsunamis, or hurricanes. In summary, the sub-clause outlines the criteria and examples for what constitutes an Exceptional Event, emphasizing that these events must meet specific conditions to qualify.

4.2 Notice Requirement

Sub-clause 18.2 specifies that if a Party cannot fulfill its contractual obligations due to "Exceptional Events," the affected Party must notify the other Party within 14 days and identify which obligations are hindered. The affected Party will remain excused from these obligations for as long as the Exceptional Event continues to obstruct their performance. However, neither Party's obligation to make payments owed under the Contract will be excused due to an Exceptional Event.

4.3 Duty to Minimise Delay

Sub-clause 18.4 mandates that each Party must make every effort to minimize delays in fulfilling their obligations caused by the Exceptional Event and to issue further notices if the impact of the event persists. If the affected Party does not send any notice, the other Party is required to inform them, indicating that it believes the affected Party's performance is no longer obstructed by the Exceptional Event, along with the reasons for this conclusion.¹⁶⁰

4.4 Consequences of an Exceptional Event

This sub-clause stipulates that if the Contractor is the affected Party and incurs delays and costs due to an Exceptional Event, for which they have given notice as required in sub-clause 18.2, they will be entitled to an Extension of Time (EOT) and/or reimbursement for those costs. The EOT or payment will be governed by the provisions in sub-clause 20.2, titled "Claims for Payment and/or EOT."

4.5 Optional Termination and Release from Performance under the Law

If nearly all the Works are halted for a continuous period of 84 days due to an Exceptional Event, for which Notice has been given under Sub-Clause 18.2, or if there are multiple interruptions totaling over 140 days from the same event, either Party may issue a Notice to terminate the Contract under sub-clause 18.5.

Sub-clause 18.6 specifies that if an event occurs beyond the Parties' control (including, but not limited to, an Exceptional Event) that either makes it impossible or unlawful for one or both Parties to fulfill their contractual obligations, or permits their release from further performance under the governing law, then the Parties will be released from their obligations.¹⁶¹

5. TESTING OF FIDIC CONTRACTS IN TIMES OF CRISIS

5.1 Impact of The Gulf Crisis on Construction Contract

In June 2017, Bahrain, Saudi Arabia, and the UAE severed diplomatic ties with Qatar, leading to a broader boycott that included Comoros, Egypt, the Maldives, Mauritania, the Tobruk government of Libya, and Yemen.¹⁶² A directive from the UAE's Federal Authority for Land and Maritime Transport on June 11 confirmed that all land, air, and sea routes to Qatar were closed, prohibiting nationals from boycotting countries from traveling there.¹⁶³ These restrictions significantly impact Qatar's construction industry, hindering the import of essential materials like cement, steel, and aggregates, which were previously transported via the Saudi-Qatar land border or by sea. Contractors now face the challenge of sourcing materials through alternative routes, disrupting their supply chains. Additionally, the mobility of skilled workers, including the 2.4 million foreign residents in Qatar involved in various sectors, is restricted, resulting in delays and increased costs.

Following the diplomatic break with Qatar, uncertainty surrounds the future of investments and business relationships in a region previously seen as stable. This disruption, whether anticipated or not, has reignited discussions on the legal defenses available to protect investors, particularly in construction projects involving standard contract forms.

5.2 Impact of The Russia- Ukraine War on Construction Contract

In Ukraine, the use of FIDIC contracts for large infrastructure projects has increased, covering significant public works such as the Beskyd rail tunnel, a metro line in Dnipro, and the M-05 Kyiv-Odesa road. FIDIC contracts are also common in private renewable energy projects, with the 1999 Red and Yellow Books and the 2006 Pink Book being the most used editions.

Since the Russian invasion in February 2022, many construction projects have been suspended due to safety concerns, labor shortages, rising energy prices, and supply chain issues. In these circumstances, parties have a recourse to invoke force majeure provisions defined in FIDIC contracts, which include events beyond a party's control, not reasonably foreseeable at the contract's inception, unavoidable, and not caused by the other party. War is specifically included as a force majeure event, allowing parties to claim its effects.

Following Russia's invasion of Ukraine, the Chamber of Commerce declared a force majeure situation, acknowledging the military aggression as "extraordinary, unavoidable, and objective circumstances."¹⁶⁴ This declaration has been used to certify force majeure claims in construction contracts.

Key consequences of serving a notice include excusal from obligations, extension of time, and/or reimbursement of Costs in form of restitution or compensation depending upon the law of the Contract. In addition, either party may terminate the contract if the event prevents significant progress for specified periods (84 continuous days or 140 total days). Both employers and contractors may also consider terminating the contract, particularly as military actions have persisted for over 84 days. However, it must be carefully assessed.

It is crucial to provide proper notices in the specified format and timeframe, while also adhering to local regulatory requirements to ensure the applicability of the force majeure clause. However, specific terms and circumstances of the contract, the Particular Conditions of the contract should be reviewed for specific entitlements on rights and obligations of the parties.

5.3 Impact of Covid - 19 on Construction Contracts

The COVID-19 pandemic and the ongoing war have posed significant challenges for the global construction industry, leading to major disruptions, delays, and increased costs due to material shortages, supply chain issues, and fluctuating market conditions. In light of these challenges, it is crucial for the parties involved to understand the contractual provisions and mechanisms for seeking relief under FIDIC contract forms.

5.3.1 Impact of COVID-19 on Goods Availability

The unavailability of goods due to the COVID-19 pandemic poses a significant risk event that can disrupt construction projects, leading to delays and increased costs, regardless of alternative sources. This issue is covered in Sub-Clause 18.4¹⁶⁵ (Exceptional Events) and Sub-Clause 8.5¹⁶⁶ (Delay Damages) of the FIDIC Red and Yellow Books, allowing the Contractor to seek an extension of time (EOT) and compensation for inflation-related cost increases.¹⁶⁷ To qualify for relief, the Contractor must demonstrate that the goods' unavailability was due to a prevention event defined in Sub-Clause 18.2¹⁶⁸ and follow



the claims process in Sub-Clause 20.2, which necessitates timely notice, mitigation efforts, and supporting evidence. Compliance with the requirements in Sub-Clauses 18.2 (prevention and notice), 18.3 (mitigation and notices), and 20.2 (claim procedure) is crucial for eligibility for relief.^{169]}

5.3.2 Impossibility to Continue Due to COVID-19

The inability to proceed with a project due to COVID-19 may lead to a release from performance obligations. This situation is addressed in Sub-Clause 18.6 (Release from Performance) and Sub-Clause 18.5 (Costs) of the FIDIC contract, where the Contractor may be entitled to compensation if continuing the project becomes impossible or unlawful, and if the parties cannot agree on a contract amendment.^{170]} To qualify for this entitlement, the Contractor must notify that it has become impossible or unlawful to continue the project and that no agreement has been reached on amending the contract. Compliance with the requirements in Sub-Clause 18.6 and adherence to the cost claim procedures in Sub-Clause 18.5 are essential for the Contractor to seek relief.

5.4 But for Test for Quantum Assessment

Under English law, it is likely that the "but for" test will be applied to *force majeure* or exceptional event clauses that simply exempt parties from liability for non-performance. This means that a party would need to demonstrate that, if not for the *force majeure* event, they would have been able to fulfill their contractual obligations. Parties alleging *force majeure* will no doubt be called upon to show that they would have been able to perform had the *force majeure* event not occurred.

6. SUSTAINABILITY AND CYBER CONSIDERATIONS IN FIDIC CONTRACTS

Sustainability provisions are designed to reduce the environmental impact of large-scale construction projects, both during the construction phase and after project completion. These provisions aim to ensure that projects are developed in an environmentally responsible manner, minimizing harm to natural resources, ecosystems, and communities.

While sustainability clauses are increasingly being incorporated into standard form contracts, their presence has

historically been somewhat limited in both scope and practical effectiveness. These provisions often focus on basic environmental protection measures but may not always extend to broader sustainability goals such as energy efficiency, waste reduction, or long-term ecological benefits. However, there are notable examples of how sustainability is addressed in widely used construction contracts. In the FIDIC Red, Yellow, and Silver Books, contractors are required to adopt measures that protect the environment during the course of the works. These provisions include complying with any environmental impact assessments (EIA), ensuring that emissions remain within the limits set out in the project specifications, and adhering to legal regulations on environmental standards. For example, Clause 4.18 of these contracts specifically mandates that contractors take appropriate steps to control pollution, manage waste responsibly, and prevent any emissions from exceeding those prescribed by law or stated in the project's technical documentation.

Although these clauses provide a baseline for environmental protection, they tend to focus on compliance rather than proactive sustainability measures. The evolving nature of sustainability in construction now requires contracts to go beyond regulatory adherence, addressing a wider array of environmental concerns such as carbon footprint reduction, resource conservation, and long-term environmental stewardship. This trend highlights the need for more comprehensive sustainability provisions that can better align with global sustainability goals, such as those outlined in the United Nations' Sustainable Development Goals (SDGs) or in international frameworks for green infrastructure development.

As construction projects become increasingly complex and subject to higher sustainability standards, it is expected that future iterations of standard contracts, including FIDIC's, will incorporate more robust and forward-thinking sustainability requirements. These may include mandatory use of renewable energy, stringent waste reduction targets, enhanced biodiversity protection, and more extensive monitoring and reporting obligations to ensure environmental sustainability throughout the entire project lifecycle.

In today's digitally driven construction landscape, cybersecurity has become an essential aspect of project management. As construction projects increasingly rely on advanced technologies, data management systems, and digital communication tools, they become vulnerable to

cyber threats, such as data breaches, hacking, and malware attacks. Recognizing this, FIDIC has taken steps in its 2017 editions to address cyber considerations, although these are not as explicitly detailed as other risks like environmental and safety provisions. Nevertheless, cyber risks are indirectly covered through broader risk management, compliance, and communication provisions.

7. INCLUSION OF NEW EXCEPTIONAL EVENTS

Christopher R. Seppala has suggested that it would be helpful – in the interests of clarity – to expand the list of exceptional events under Clause 18 to include additional illustrative events (even though they may already implicitly be included, as they appear to be comparable to those listed)¹⁷¹ such as:

- (a) not only the ‘war, hostilities, invasion act of foreign enemies’ but ‘the serious threat of’ should be inserted and additional events like, ‘blockade, cyber attack, military embargo, extensive military mobilization and economic sanction’ be added;
- (b) in the case of sub-paragraph 18.1(b), ‘sabotage’ and ‘piracy’ be added;
- (c) a new sub-paragraph dealing with such things as ‘plague’, ‘epidemic’ and ‘pandemic’ should be added;
- (d) a new sub-paragraph dealing with such things as ‘explosion’, ‘fire’ and ‘prolonged breakdown of telecommunication or information system’ not attributable to the Contractor should be added; and
- (e) to the list of natural catastrophes in sub-paragraph 18.1(f), ‘blizzard’, ‘tidal wave’ and ‘tornado’ might usefully be added.

Without a doubt, providing such clarifications and an expanded list of potential events would be highly useful in situations where these additional events occur. However, the key issue remains unresolved: does this updated list represent an exhaustive catalogue of all possible "exceptional events," beyond which no other event can qualify? If the answer to this question is "no," then the parties would still be required to turn to the relevant governing law to determine how to handle unforeseen events not covered by the list.

Furthermore, the term "exceptional event" inherently implies occurrences that go beyond what the contract drafter could reasonably foresee or anticipate. By its very nature, an exceptional event is something rare or unpredictable, making it difficult to capture every possible scenario within

the confines of the contract. Therefore, while a more detailed list offers some degree of guidance, it cannot fully eliminate the need for parties to navigate complex legal interpretations when unprecedented events arise that were not explicitly addressed in the contract. This underscores the importance of allowing flexibility and acknowledging that exceptional events may still fall outside the scope of even the most comprehensive contract provisions.

8. DEFENCES IN FIDIC CONTRACTS AGAINST UNSTATED EVENTS LIKE SUSTAINABILITY AND CYBER SECURITY THREATS

It is noted that neither Clause 19 of 1999 edition nor Clause 18 of 2017 FIDIC Books clarify what financial remedy the Contractor would receive for an exceptional event that meets the criteria in the first paragraph of Clause 19.1 but does not fall within any of the specified categories. The circumstances related to sustainability requirements as one of the project objective and also as an important metric to measure contractor’s performance during execution also do find a place under this list. Incidentally, despite increasing use and reliance on electronic communication, database management, the exceptional events related to cyber security do not find place in the list of force majeure or exceptional events.

Be that as it may, the moot question is can FIDIC contract address such circumstances and events, even if they are not specifically mentioned or do they require to be more prescriptive? One viewpoint may be enlarge the gamut of events under Clause 19/18 to include as separate such events which are being experience across the world. Even if it is done, there may still be some event, which may surprise the commercial business not only by its occurrence but also in anticipating its effect the way COVID-19 did in 2020.

NG Bunni has even been very critical on the introduction of ‘force majeure’ clause in 1999 book – “if the truth be told, such a move in the context of "force majeure" is neither necessary nor desirable”.¹⁷²

While the 1999 editions did not explicitly contemplate cyber risks, the 2017 editions broaden the scope of potential risks that could disrupt project execution. Cybersecurity threats can now be considered as "exceptional events" (formerly known as "force majeure") under certain conditions, especially if a cyberattack significantly affects the contractor’s ability to perform the works.



For instance, if a project's digital infrastructure is compromised, leading to delays or financial losses, the provisions under Clause 18 (Exceptional Events) allow the contractor to suspend performance or seek relief from liability if the cyber event meets the criteria of an exceptional event—unforeseeable, unavoidable, and beyond the parties' control. This includes risks such as large-scale cyberattacks or data breaches that may affect project management systems or critical digital communications.

FIDIC contracts, particularly in the 2017 editions, emphasize the contractor's obligation to comply with all applicable laws and regulations, which now includes adherence to cybersecurity standards and data protection laws (e.g., GDPR in Europe or other national data privacy laws). For instance, the requirement to follow "all applicable laws" under Clause 1.13 (Compliance with Laws) indirectly extends to cyber considerations, making it mandatory for contractors and employers to ensure that their project's IT infrastructure, data management systems, and digital platforms are in compliance with current cybersecurity and data protection legislation.

This means that both parties need to implement proper safeguards, such as encryption, secure communication channels, and data backup protocols, to protect sensitive project information and mitigate potential cyber risks.

It could be argued that the implementation of sustainability and climate change initiatives is likely to be more effectively managed and demonstrable when structured approaches are in place, rather than leaving the parties to handle them independently in bespoke form.

The 'Option X.29'¹⁷³ clause developed by the Institution of Civil Engineers to complement suite of NEC standard contracts on climate risk and sustainability, does offer a possibility of using a performance table to measure maturity of compliance, or as a financial incentive to contractors to fulfil particular metrics¹⁷⁴.

Although, these beginnings are yet to be tasted in details, but having such contractual mechanism to address substantive law issues may lead to more problems than solving it.

In the ICC Awards referring to the UNIDROIT Principles of International Commercial Contracts in Case 8873, the Tribunal finds that the relevant rules contained in the FIDIC and ENAA forms of contract are not "ripe" for consideration as autonomous principles of law¹⁷⁵. Although the FIDIC Contract forms have experience and rigorous use of over 25 years since then, the provisions

contained in these standard contracts cannot override the mandatory principles of local laws.

It is opined that the risks arising out of such events be dealt with the substantive law of the contract rather than creating new untested obligations in the standard forms.

9. CAN AN INSURANCE CLAUSE COVER THE RISK OF EXCEPTIONAL CIRCUMSTANCES?

9.1 Insurance Clause under FIDIC 1999 Books

The Contractor is responsible for indemnifying and protecting the Employer, the Employer's Personnel, and their agents from any claims, damages, losses, and expenses (including legal fees) arising from bodily injury, sickness, disease, or death linked to the design, execution, and completion of the Works, as well as defect rectification, unless these issues stem from negligence, willful acts, or breaches of contract by the Employer or their agents. Additionally, the Contractor must cover damage to or loss of property, excluding the Works, if such damage arises from the design, execution, and completion of the Works and is due to negligence, willful acts, or breaches of contract by the Contractor or their personnel.¹⁷⁶

If the Contractor is responsible for the care of the Works, Goods, or Contractor's Documents and any loss or damage occurs that is not covered by Sub-Clause 17.3 (Employer's Risks), the Contractor must manage and rectify the loss or damage at their own risk and expense to ensure compliance with contractual requirements.

Insurance is the primary method for transferring risks to cover losses and damages resulting from the aforementioned risks. Various types of insurance are available, including Contractor's All Risk Insurance (CAR), Third Party Liability Insurance (TPL), and Worker's Compensation Insurance, to address these risks.

9.2 Insurance Clause under FIDIC 2017 Books

Clause 17.2(d) of 2017 addresses natural forces that are unforeseen and against which a competent contractor could not have taken reasonable preventative measures. Clause 19.2(d) discusses insurance coverage for work and contractor's equipment. It states that, unless specified otherwise, the insurance must also cover damage to parts of the work caused by the Employer's use of other parts, as well as losses from certain risks outlined in Clause 17.5

(Indemnities by Employer), provided those risks can be insured at commercially reasonable terms.

In short, under these Books, the insurance provides a limited recourse for events falling under force majeure or exceptional event that too subject to applicable local laws.

10. CONCLUSION

FIDIC's change from "force majeure" to "exceptional event" in the 2017 Books was designed to clarify and modernize the handling of unforeseen events, ensuring greater alignment with jurisdiction-neutral global legal and commercial practices. This shift enhances the applicability of FIDIC contracts to contemporary construction projects, providing a clearer framework for risk allocation and dispute resolution in an increasingly complex and uncertain world.

The COVID-19 pandemic and ongoing war have created unimaginable challenges for the construction industry, specially in understanding its impact on the time and cost related claims giving a fillip to reconsider the force majeure or exceptional event clauses in the standard FIDIC forms in a way to include more and more such events. However any such effort to include more events should be looked into with due care as it may not necessarily add to the clarity.

The local laws related to impossibility of performance, hardship and frustration of contract may be sufficient to provide an understanding on the liabilities and entitlements for the damages should an unknown exceptional event occurs. The FIDIC Guide and the FIDIC Guidance Memoranda serve as an essential resource, outlining risk events, contractual provisions, conditions, and entitlements as a guidance. By thoroughly evaluating the situation, adhering to contract provisions, and clearly establishing causation, stakeholders can effectively manage the complexities of this unprecedented scenario and pursue appropriate relief under the FIDIC contracts.

Although FIDIC contracts do not explicitly address sustainability or cybersecurity related risks in the same detailed manner as physical risks, they do provide several avenues for implementing and evaluating their impact in to construction contract. Through provisions related to exceptional events, compliance with laws, secure contract communications, and shared risk-responsibilities, FIDIC contract forms offer an excellent framework for managing even such risks in today's increasingly complex construction environment.

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Plastic Waste Flow Analysis and Monitoring of Plastic Leakage Reduction Interventions in Three Select Ports in the Philippines

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ARTICLE INFO	ABSTRACT
Received (c/o FIDIC ASPAC 2024) Received in revised form (c/o FIDIC ASPAC 2024) Accepted (c/o FIDIC ASPAC 2024)	<p><i>Plastic pollution and climate change are interconnected critical environmental issues which manifest globally, especially in marine ecosystems. Ports, which serve as intersections between local communities and the ocean, become pathways for plastic leakage. In effect, coastal ecosystems which are often vulnerable to climate change impacts, are also affected by the accumulation and degradation of the leaked plastics. As part of the “Clean Ports, Clean Oceans: Improving Port Waste Management”, this study focuses on providing baseline data on plastics and determining scientifically based interventions to reduce plastic waste leakage in ports and then assessing the implemented interventions to reduce plastic leakage by 50% in three key Philippine ports – Port of Batangas, Port of Cagayan de Oro, and Manila North Harbor. The baselining phase included analysis and characterization of wastes from the three select ports, along with a series of interviews with relevant stakeholders, truck tailgating activities, and site visits to recovery facilities. Waste Flow Diagram (WFD) tool was used to measure and visualize the flow of waste from generation to disposal. The monitoring phase included devising a monitoring tool to gauge the reduction of Single-Use Plastics (SUP) and assessing the impact of the implemented interventions by identifying key factors influencing its effectiveness. The baseline results show a total of 2,050,373 kg of wastes in all three ports are generated annually in which 29% of these are attributed to plastics. About 23% of the generated plastic wastes are calculated as unmanaged wastes which mostly leak to waterbodies, while few are retained in land. The monitoring findings demonstrate the effectiveness of implemented measures in mitigating plastic pollution, achieving a 50% reduction in plastic leakage compared to baseline figures. The enforcement of the SUP ban and the introduction of Material Recovery Facilities and programs for collecting recyclable waste were pivotal in reducing plastic leakage.</i></p>
Keywords <i>plastic pollution, waste characterization, interventions monitoring.</i>	

1. INTRODUCTION

Plastic pollution and climate change are two of the most pressing environmental challenges faced globally [1,

2, 3, 4, 5, 6], with particularly severe impacts on marine ecosystems [7, 8, 9]. These issues are interconnected in several ways, exacerbating each other's effects and creating a compounding environmental crisis [10, 11, 12,

13, 14].

Plastics contribute to greenhouse gas emissions at every stage of their lifecycle, from production to disposal [15, 16]. The production of plastics relies heavily on fossil fuels, particularly natural gas and crude oil [17]. The extraction and refining processes release significant amounts of carbon dioxide (CO₂) and methane (CH₄), potent greenhouse gases that contribute to global warming [18]. Manufacturing processes also emit various greenhouse gases, further adding to the carbon footprint of plastics [11].

Once in the environment, particularly when exposed to sunlight, plastics can release methane and ethylene as they degrade, becoming a direct source of greenhouse gases [19, 20]. The degradation of plastic can also release microplastics [21] which have been found to interfere with the ability of the ocean to absorb CO₂ [22], which in turn can disrupt the biological pump [23, 24]. The disruption of this process could reduce the ocean's capacity for carbon sequestration [22, 25], further exacerbating climate change.

Conversely, climate change can affect the distribution and breakdown of plastics in the environment. Rising temperatures can accelerate the degradation of plastics [26], increasing the release of greenhouse gases. Extreme weather events, such as storms and floods, can transport large amounts of plastic waste into the ocean [27, 28]. Ocean acidification which is another consequence of increased CO₂ levels [29, 30], can alter the breakdown of plastics [31, 32], potentially increasing the release of toxic substances [33] that further harm marine life and ecosystems.

Ports, serving as critical nodes between local communities and the ocean, are significant pathways for plastic leakage into coastal and marine environments [34]. Ports are bustling hubs of commercial activity, handling vast quantities of goods, including plastics daily. The complex logistics and operations involved in loading and unloading ships, along with the transportation of passengers and storage of goods, create numerous opportunities for plastics to enter the marine environment. Inefficient waste management practices, improper handling, and accidental spillage contribute to the problem, with plastics often ending up in nearby water bodies.

Moreover, ports are frequently located in coastal areas that are already environmentally sensitive and prone to the impacts of climate change [35]. The influx of plastic waste into these areas can compound existing ecological stresses, such as habitat destruction, water pollution, and biodiversity loss. As plastics accumulate in coastal zones, they can degrade into microplastics [36], which are more challenging to manage and remove, posing long-term risks to marine life and human health.

In the Philippines, where the economy is heavily reliant on maritime trade, the role of ports in plastic pollution is significant. The country has several major ports, including the Port of Batangas, Port of Cagayan de Oro (CDO), and Manila North Harbor, which are vital to its economic infrastructure. These ports handle large volumes of goods, and consequently, generate significant amounts of waste, including plastics. Reducing plastic pollution in these large ports is essential for the Philippines as is an archipelagic nation with rich marine biodiversity, and plastic pollution poses a significant threat to its ecosystems. Marine life, flora and fauna, are directly impacted by plastic waste.

This study, part of the "Clean Ports, Clean Oceans: Improving Port Waste Management" initiative, aims to tackle the marine plastic problem by focusing on the role of ports in plastic leakage, determining the amount and composition of port- and vessel-generated plastic wastes, developing strategies to mitigate its impact on coastal and marine environments, reduce plastic leakage to open environment by 50%, and monitoring the impact of the programs to plastic leakage reduction targets.

2. STUDY AREA

The study was conducted in three national ports owned by the Philippine Ports Authority (PPA) – Port of Batangas, Manila North Harbor, and Port of Cagayan de Oro. Port of Batangas is located along the coastal area of Batangas Bay, a Class SC semi-closed body of marine water [37] with a surface area of 220 km². The port mainly serves container-carrying vessels, bulk cargoes, and passenger vessels. The port covers 150 ha and within its area are container terminals, three passenger terminals, and administrative buildings.

The Manila North Harbor in Manila City is the biggest

and primary port in the Philippines for domestic cargos. It is located along the periphery of Manila Bay, a Class SB marine water that has an area of around 2,000 km² [39]. The port offers cargo handling services, berth management, ancillary services needed by port users such as bunkering, watering, weighbridge operations, parking, and passenger terminal management [40].

The Port of Cagayan de Oro in Cagayan de Oro City, Misamis Oriental is one of the busiest government ports in Northern Mindanao in terms of cargo throughput. It is located along the periphery of Macajalar Bay, a Class SB/SC marine water with an area of around 1,250 km² and bordered by two cities and 12 municipalities. The 364-ha Cagayan de Oro Port Zone has around 25 has of land area and 340 has of sea area. It is an advanced port complex housing the biggest Passenger Terminal Building (PTB) among PPA-owned seaports. With a floor area of 5,597 m², it can accommodate approximately 3,000 passengers during peak passenger-season which is triple its original capacity [41]

The baselining and monitoring activities of this study were conducted in each of the three ports.

3. MATERIALS AND METHODS

3.1. Assessment Processes and Tools Used

Local and international guidelines and tools were utilized to assess the baseline plastic waste management in the three ports. The Philippine Waste Analysis and Characterization Study (WACS) guidelines developed by the Industrial Technology Development Institute (ITDI) of the Department of Science and Technology (DOST) and published by the National Solid Waste Management Commission (NSWMC) provided data on the amount and composition of plastic waste from both the port- and vessel-generated wastes at the end-of-pipe.

Waste Flow Diagram (WFD) tool which is a rapid and observation-based assessment tool for mapping waste flows and identifying potential leakage of plastics was used to measure and visualize how the wastes flow from generation to disposal, depicting the complete picture of the current solid management of the study areas in terms of the quantity and quality of waste as well as the leakage of waste of plastics into the open environment [42].

3.2. Conduct of End-of-Pipe Waste Analysis and

Characterization Studies

Waste from port facilities and docking vessels through their respective shore reception facilities (SRF) was collected for the conduct of three-day WACS across the three ports from September to October 2021. The trucks with incoming wastes from the port facilities and SRFs were weighed using weigh pads. After weighing, the trucks tip the wastes near the sorting area where around 500 kg were taken from every truck sample. The sample wastes were divided using coning and quartering method. Approximately 125 kg were selected and sorted from each waste truck. The remaining 375 kg were retained for analysis of bulk density. A container of known volume and weight was filled with the waste up to the brim and weighed. This process was repeated until all the 375 kg of waste were weighed. Bulk density is computed by dividing the weight of the waste by the volume of the container. The average bulk density of port- and vessel-generated wastes was calculated using Equation 1.

$$\text{Average Bulk Density} \left(\frac{\text{kg}}{\text{m}^3} \right) = \frac{\sum (\text{Gross Weight}_{\text{Waste+Container}} - \text{Weight}_{\text{Container}})}{\sum \text{Volume}_{\text{Container}} \times \text{Number of Sampling Days}}$$

Equation 1. Bulk Density Formula

The 125 kg samples were sorted to the standard waste categories. After sorting, each waste category was weighed and recorded for analysis. The samples are then disposed of in the landfill after each sorting activity.

3.3. Conduct of Field Activities using Waste Flow Diagram Tool

Site inspections, interviews, and tailgating of collection trucks were conducted in between the sorting activities during the baselining phase. Visual assessment was also conducted to determine the leakage factor at each point of the waste management in the three ports especially during the collection, transportation, and disposal. Recovery and disposal facilities involving the solid waste management system of port and vessel generated waste were visited. A series of interviews with relevant stakeholders including representatives from port management, SRF service provider, landfill operator, training institute, shipping association, port facilities, port janitorial service and shipping operators was also conducted using phone communication, video conferencing apps, and in person

3.4. Monitoring of Interventions

The monitoring phase of the study involved assessment of the effectiveness of the interventions aimed at reducing plastic leakage. Two monitoring activities were undertaken, the first activity conducted on May 2023 which focused on capturing the initial interventions, including the distribution of communication materials, organizing collection events, conducting clean-up initiatives, providing segregation bins, implementing the ban on the use of single-use plastics (SUP), and other pertinent activities. The second monitoring activity conducted on August 2023 served to reassess the status of the SUP ban, gather supplementary data regarding recovery efforts, and ascertain the potential impacts stemming from the development of infrastructure, such as Material Recovery Facilities, and the provision of collection vehicles and other essential materials for the ports and their surrounding communities.

The monitoring activities included segregation and plastic ban inspection, which tackled the factors that affect the implementation of the SUP ban, such as the alignment between the port and the city, availability of information, education, and communication (IEC) materials within port facilities, awareness on the SUP ban and the actual participation of key port stakeholders, such as port employees, passengers, and businesses, the effort of the port management to ensure compliance of port employees, passengers, and businesses to the SUP ban policies being implemented, and the extent to which available plastic alternatives are utilized within the port. To achieve the objectives of the monitoring activity, interviews with stakeholders including the port utility workers, concerned government agencies and units, and currently existing consolidators and aggregator facilities, were conducted. Constructed port MRFs, developed community MRFs, and other existing MRFs at nearby communities were also visited to evaluate their operations and infrastructure in relation to improving the recycling activities and increasing the waste diversion out of the landfills.

Aside from the interventions implemented at the three select ports aimed at reducing plastic leakage into the ocean, community-led and vessel-focused initiatives were identified. This documentation is conducted to capture the various measures undertaken beyond the port premises, showcasing the collaborative efforts and effective strategies employed by both the local communities and the

maritime stakeholders.



Figure 1. Monitoring Methodology Flowchart

A visual assessment was conducted during the monitoring activity to update and validate some of the leakage factors at different functional elements of the waste management system, specifically during the collection, recovery, and transportation of wastes that are affected by the interventions. Potential leakage sites of plastic wastes were also observed during the site visit.

A set of compliance criteria with a corresponding scoring system was developed in this study to provide a standardized method to estimate the compliance level of a port with the single-use plastic ban and to calculate the potential plastic reduction due to the ban that is reflected in the waste flow diagrams. Each criterion is assessed based on the level of compliance from snapshot observations during the monitoring activities for each port. In cases where no trace of banned SUP was observed during the inspection, it was considered that these items no longer exist within the port and were treated as eliminated in the system. The compliance criteria were prepared to maintain consistency and objectivity due to limitations in the availability of data. It should be noted that the developed compliance criteria are solely intended for the assessment of port compliance to the SUP ban, as there are currently no available methods that can be adopted.

3.4.1. Port-City Policy Alignment

Port-city policy alignment measures the level of synchronization between the port and the city policies regarding the ban on the use of single-use plastics. To assess this influencer, the number of similar banned items in both the port and city regulations is considered, where a higher number of matching banned items signifies a stronger alignment between the two entities. This



alignment is important as it promotes consistency and cooperation in implementing the ban, reducing confusion among stakeholders, and ensuring a unified approach in addressing the issue of plastic pollution.

3.4.2. Information, Education, and Communication Efforts

The availability of IEC materials within port facilities plays a crucial role in raising awareness and educating stakeholders about the ban on the use of SUPs and proper waste segregation. IEC efforts include, but are not limited to, dissemination information, and conducting training and awareness and education programs for the port stakeholders. The port’s commitment to raising awareness among its stakeholders is vital for achieving compliance. An example of IEC efforts influencer evaluated with high compliance is the observation of IEC materials across port facilities and conduct of public service announcements

3.4.3. Stakeholder Participation

The awareness on the SUP ban and the actual participation of key port stakeholders, such as port employees, passengers, and businesses, were gauged to determine the extent of their involvement in complying with the ban. The key stakeholders were engaged through interviews and observations to ascertain their familiarity with the SUP ban and their participation in refraining from the use of banned SUP items and other related initiatives for proper waste management. The areas observed were determined based on the areas where interventions were implemented, which are available at the time of visit.

3.4.4. Compliance Monitoring

The compliance monitoring influencer quantifies the effort of the port management to ensure compliance of port employees, passengers, and businesses to the SUP ban policies being implemented. This influencer considers the frequency of monitoring activities and the enforcement of incentives and penalties, if available. Regular monitoring ensures adherence to the ban and enables timely intervention to address any lapses. By implementing effective monitoring mechanisms and providing appropriate rewards and penalties, port authorities can reinforce compliance, incentivize stakeholders, and discourage non-compliant behavior.

3.4.5. Use of Alternatives

The use of alternatives examines the extent to which available plastic alternatives are utilized within the port.

The adoption of available alternatives can encourage port stakeholders, especially the business establishments operating inside the port, to shift away from the use of single-use plastics. This criterion is evaluated through observations made during waste bin inspections, interviews, and site visits. It considers the number of banned plastic items replaced by observed suitable alternatives.

4. RESULTS AND DISCUSSION

4.1. Waste Analysis and Characterization Study Results

The port-generated wastes were collected from the passenger terminal, container terminals, and port offices. Vessel-generated waste data was collected from the waste on-board vessel information form from the shore reception facility operators in each port. Based on the WACS results, 19.72% of the wastes generated in Port of Batangas are composed of plastics, and with a waste generation rate (WGR) of 603.14 kg/day, the port offices, passenger terminals and container terminals produce 118.94 kilograms of plastics daily. The vessels generate 873.33 kg/day of solid waste in which 32.98% are plastics. The Port of Cagayan de Oro generates less plastics compared to the Port of Batangas having a total of 92.87 kg of plastics daily from both port- and vessel-generated wastes. The Manila North Harbor only had port-generated wastes during the conduct of the baselining phase, with a daily waste generation of 155.25 kg in which 21.16% of the wastes were plastics as shown in Table 1.

Table 1. Waste Generation Rates of the Three Select Ports

Study Area	Port-Generated Waste (kg/day)	Plastic Waste Generated (kg/day)	Vessel-Generated Waste (kg/day)	Plastic Waste Generated (kg/day)
Port of Batangas	603.14	118.94	873.33	288.02
Port of Cagayan de Oro	794.29	60.13	192.00	32.74
Manila North Harbor	155.25	32.85	-*	-*

*No vessel-generated waste sample available during COVID-19 pandemic

4.1.1. Port-Generated Waste Composition

The port-generated waste in the Port of Batangas is composed of biodegradable wastes at 51.88%, recyclable wastes at 13.7%, residual wastes at 23.88%, and special

wastes at 10.54%. Focusing on plastic wastes, 6.51% of the plastic are residuals for recycling composed of plastic bags, clear sachets, laminated sachets, sacks, tarpaulins, and drinking straws as shown in Figure 2, recyclable plastics at 6.82% composed predominantly of polyethylene terephthalate (PET) bottles, polypropylene (PP) containers, and polystyrene (PS) with few high and low density polyethylene (HDPE and LDPE), and polyvinyl chloride (PVC) plastics. 5.14% of the wastes are plastic residuals for disposal composed of heavily soiled plastics, and diapers and napkins, while special plastic wastes at 1.25% are mostly facemasks with some consumer electronics and pesticide containers.

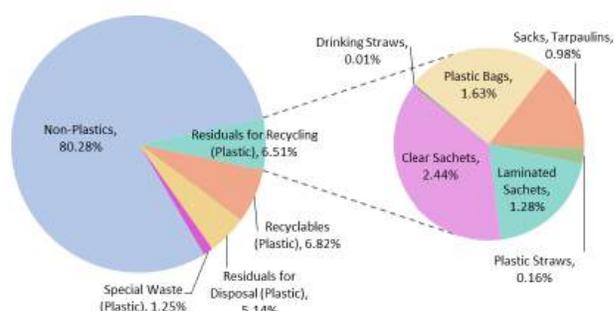


Figure 2. Port-Generated Residual Plastic Wastes with Potential for Recycling in Port of Batangas

In Port of CDO, 92.43% of the port-generated wastes are non-plastics, with only 7.57% of wastes composed of plastics as shown in Figure 3. Residual plastics with potential for recycling are mainly composed of clear sachets (1.88%), plastic bags (1.02%), nylons and plastic straws (0.46%), and laminated sachets (0.41%) with a few sacks and tarpaulins.

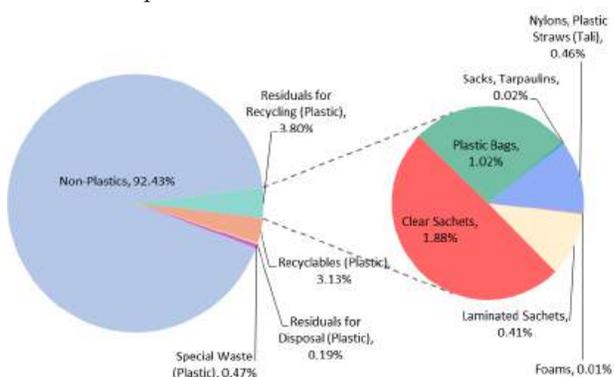


Figure 3. Port-Generated Residual Plastic Wastes with Potential for Recycling in Port of Cagayan de Oro

Manila North Harbor has the largest port-generated plastic waste percentage among the three select ports at

21.16%. Most of these plastics are residual plastics for recycling such as clear sachets (6.04%), laminated sachets (1.42%), plastic bags (0.55%), sacks and tarpaulins (0.50%), plastic straws (0.43%), and plastic foams as shown in Figure 4.

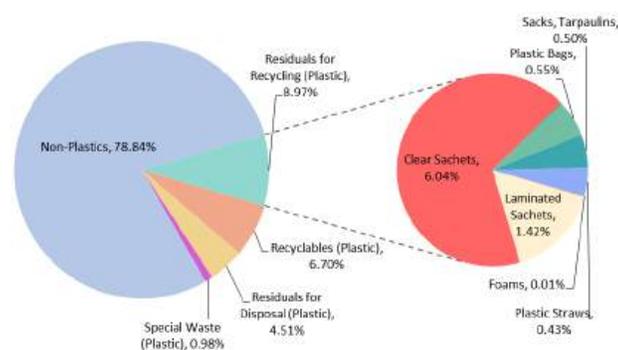


Figure 4. Port-Generated Residual Plastic Wastes with Potential for Recycling in Manila North Harbor

4.1.2. Vessel-Generated Waste Composition

Vessels wastes in Port of Batangas which are collected from the SRFs are composed of 67.02% non-plastic wastes and 32.98% plastics. Most of these plastics are residuals with potential for recycling (12.70%), and recyclable plastics (12.21%). Residual plastics with potential for recycling in Port of Batangas vessel wastes are mostly clear sachets (7.77%), plastics bags (2.81%), and laminated sachets (1.97%) with traces of plastic foams as illustrated in Figure 5.

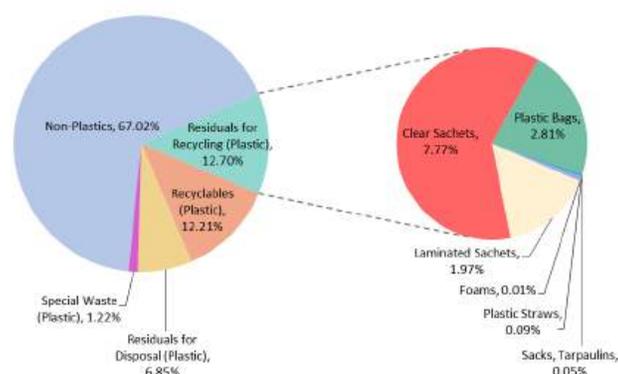


Figure 5. Vessel-Generated Residual Plastic Wastes with Potential for Recycling in Port of Batangas

Most of the plastic vessel-generated wastes in Port of CDO are comprised of residuals with potential for recycling (8.55%), and recyclables (6.99%). Top residual plastics for recycling in CDO are composed of clear sachets (4.07%), plastic straws (1.92%), and plastic bags

(1.22%) shown in Figure 6.

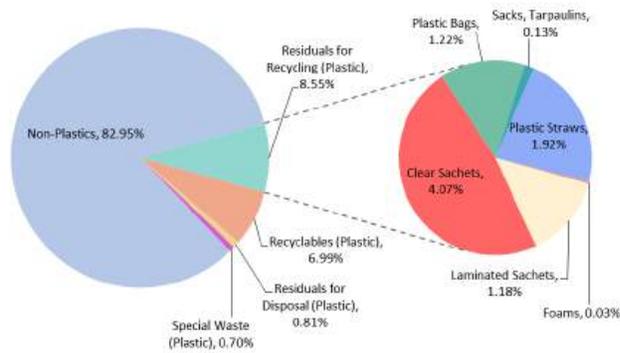


Figure 6. Vessel-Generated Residual Plastic Wastes with Potential for Recycling in Port of Cagayan de Oro

4.2. Plastic Leakage

Based on the visual observations on the waste management system existing within the three select ports, leakage factors were assigned per influencer in accordance with the WFD tool criteria as shown in Table 2.

Table 2. Determined Plastic Leakage Factors in Three Ports

Leakage Source	Leakage Influencer	Port of Batangas	Port of Cagayan de Oro	Manila North Harbor
Leakage from Collection Services	Collection Containers	Medium	Low	Medium
	Loading Method	High	Medium	Medium
	Primary Transportation	Low	Low	Medium
	Multiple Handling/Waste Transfer	Low	Low	Medium
Leakage from Informal Value-Chain Collection	Recyclables Extraction Method	Low	Low	Low
	Transportation Method	Low	Low	Low
Leakage from Formal Sorting	% of Formally Collected Plastics	0%	75%	0%
	Disposal of Rejects	-	Low	-
Leakage during Transportation to Disposal	Capacity vs Load	Low	Low	Low
	Waste Containment	Low	Low	Low
	Vehicle Cover	Medium	Low	Very High
Leakage from Disposal Facilities	Environmental Hazards	Medium	Low	Medium
	Exposure to Weather	Low	Medium	Medium
	Waste Handling	High	Low	Medium
	Coverage	Low	Medium	Medium

Leakage Source	Leakage Influencer	Port of Batangas	Port of Cagayan de Oro	Manila North Harbor
	Burning	Very High	High	Very High
	Fencing	Medium	High	Medium
Leakage from Storm Drains Entering Waterways	Frequency of Rainfall/Storm	Medium	Medium	Medium
	Drain Clean-up	Very Low	Medium	High

Based on the findings, collection services within the three ports, focusing on the loading method, show high leakage potential, especially at the Port of Batangas, while Manila North Harbor and Port of CDO has medium leakage risk. With regards to formal sorting, the Port of CDO stands out with 75% of plastics being formally collected by recovery facilities. In contrast, Port of Batangas and Manila North Harbor have no formal plastic waste recovery system in place. Vehicle cover, which is under transportation to disposal leakage category, presents a very high risk of leakage at the Manila North Harbor, suggesting that improper covering of vehicles during waste transportation is leading to significant plastic leakage. For the disposal facilities, burning is a major concern across all the three study areas, with both Batangas and Manila North Harbor showing “Very High” risks. This indicates that improper waste disposal methods, such as open burning, are contributing significantly to plastic leakage and pollution. Waste Handling and Environmental Hazards also present moderate risks across the ports, especially in Batangas and Manila North Harbor. Drain clean-up effort varies significantly, with Manila North Harbor being the most proactive, while Batangas is at a very low level.

4.3. Waste Flow Diagram

Considering the results of the WACS conducted and the identified leakage factors within the three ports, waste flow diagrams (WFDs) were generated per site, illustrating the flow of waste within each stage of waste management. In Port of Batangas, about 539,160 kg of waste is projected to be generated every year as shown in Figure 7. 59% of this waste is generated from vessels while the remaining 41% are from port facilities. About 148,604 kg or 28% of the annual generated waste are attributed to plastics. 98% of these generated plastic wastes are collected by service providers while the remaining 2% or 2,972 kg of plastic waste are calculated as leakage from the collection. There is also an estimated

1.5 kg of plastic waste that is being leaked during transportation. About 130,927.5 kg or 88% of the plastic waste are disposed to landfill. The remaining 11.8% are unmanaged plastic waste or the combined leakages from the collection, transportation, and disposal. 6.4% or 9,639 kg of plastic waste are leaked to water while 5.2% or 7,701 kg retained to land and 0.2% or 336.5 kg are leaked to drains every year. Higher leakage rates in the disposal area were due to the presence of a water body near the landfill site which makes it prone to flooding.

In Port of CDO WFD, as illustrated in Figure 8, about 360,293 kg of wastes is projected to be generated every year. 81% of these wastes are generated from port facilities while the remaining 19% are from vessels. About 33,927 kg or 10% of the annual generated wastes are attributed to plastics. All the plastic waste generated is collected by service providers, but 1% or 374 kg is leaked during the collection. About 4% of the plastic waste is being recovered in the MRFs. These plastic wastes are PET and hard plastics such as PP and HDPE only as these are the only recyclables that can be sold to junkshops. There is also an estimated 12 kg of plastic waste that is being leaked from the MRFs. About 31,544 kg or 93% of the plastic waste are disposed to landfill. The remaining 3% are unmanaged plastic waste or the combined leakages from the collection and disposal. 1% or 361 kg of the plastic waste are leaked to water while 1.9% or 642 kg retained to land and 0.1% or 60 kg are leaked to drains every year

Manila North Harbor study area included the Isla Puting Bato (IPB) and Barangay 29 which are communities residing within the port area. About 1,150,920 kg of waste is projected to be generated every year. 95% of these wastes are generated from IPB and Barangay 29, while the remaining 5% are from Port Operations. About 408,961 kg or 36% of the annual generated wastes are attributed to plastics. 81% of these generated plastic wastes are collected by service providers while 3% or 11,467 kg are recyclable plastics brought to junkshops and 16% or 65,235 kg are uncollected. There is also an estimated 104 kg leaked from informal value-chain collection and 3 kg of plastic waste that are being leaked during transportation. About 278,979 kg or 64% of the plastic waste is disposed to landfill. The unmanaged plastic waste or the combined leakages from the informal value chain collection, collection services, transportation, and disposal make up 29% of the plastic wastes. 18.2% or

74,311 kg of plastic waste are leaked to water while 10% or 42,413 kg retained to land and 0.4% or 1,791 kg are leaked to drains every year.

4.4. Monitoring Results

The monitoring results following the implementation of targeted solutions, developed in response to the baseline assessment study, were categorized according to the specific points of intervention within the waste stream. These interventions were grouped into three primary categories: first, the reduction of single-use plastics (SUP) usage; second, the enhancement of recycling activities at port facilities; and third, the collection of unmanaged waste.

4.4.1. Reduction in Usage of Single-Use Plastics

Implementation of the ban and restriction on the unnecessary use of single-use plastics is one of the key interventions identified during the baselining phase of the project to reduce the plastic leakage in the three ports. The compliance rates of the three ports based on the assigned influencers for SUP ban is summarized in Table 3.

Table 3. Evaluated SUP Ban Compliance of the Three Ports

Compliance Influencer	Port of Batangas	Port of CDO	Manila North Harbor
Port-City Policy Alignment	High (20%)	Low (5%)	Low (5%)
IEC Efforts	High (20%)	High (20%)	High (20%)
Stakeholder Participation	High (20%)	High (20%)	Medium (10%)
Compliance Monitoring	High (20%)	High (20%)	High (20%)
Use of Alternatives	High (20%)	High (20%)	High (20%)
TOTAL	100%	85%	75%

While the Port of Batangas demonstrates full compliance at 100%, the Ports of Cagayan de Oro (CDO) and Manila North Harbor show lower compliance at 85% and 75%, respectively. Several factors contribute to these differences, with Port-City Policy Alignment standing out as a key area where compliance is significantly lower in CDO and Manila North Harbor compared to Batangas (20%). Consistent high scores across all ports (20%) suggest that IEC campaigns have been effective in raising awareness about the SUP ban. These efforts have likely contributed to the positive response from stakeholders and the public. Batangas and CDO show high stakeholder

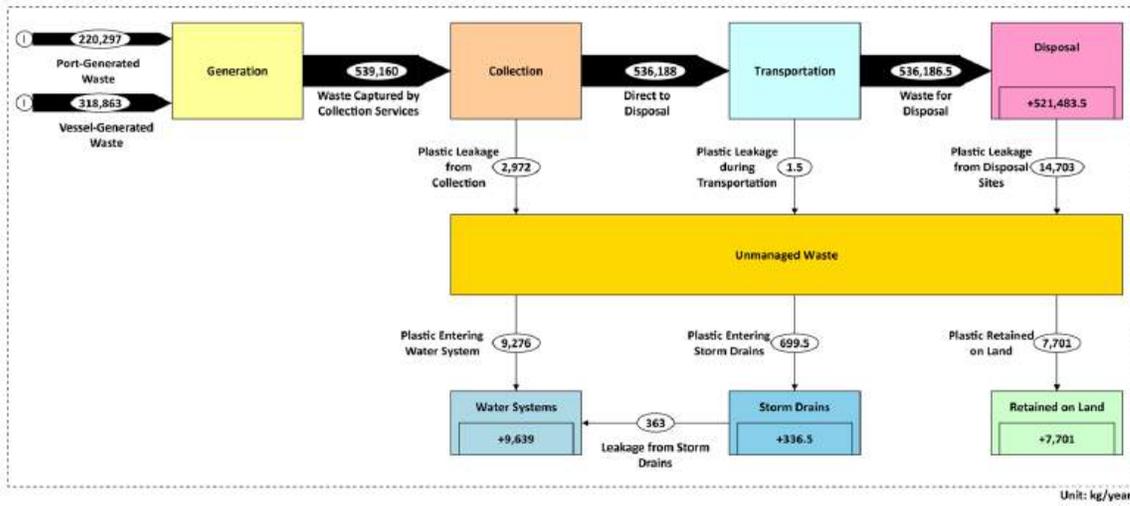


Figure 7. 2021 Solid Waste Flow Diagram for Port of Batangas

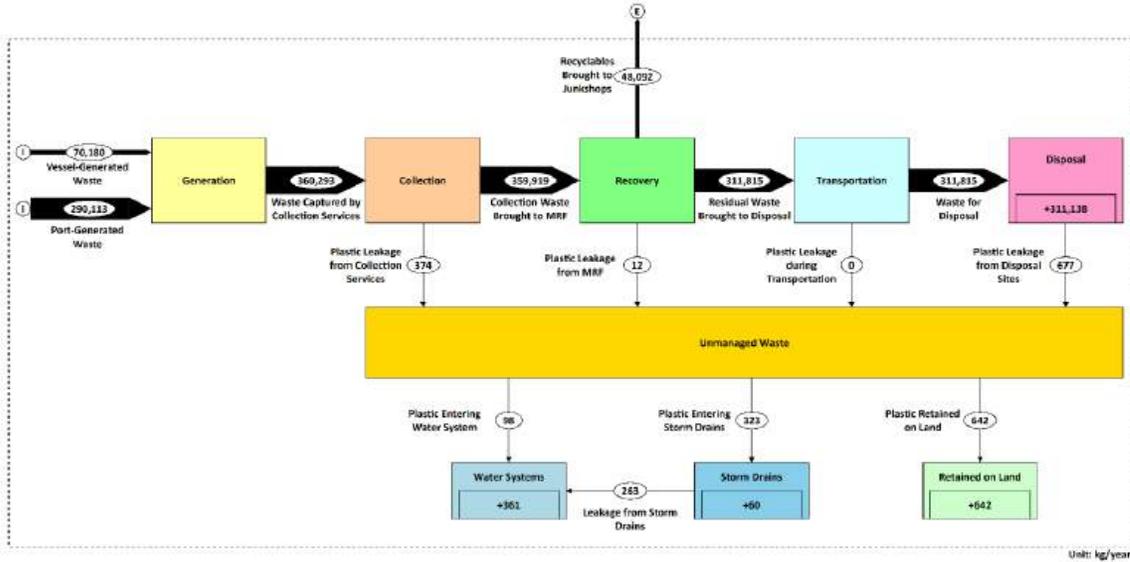


Figure 8. 2021 Solid Waste Flow Diagram for the Port of Cagayan de Oro

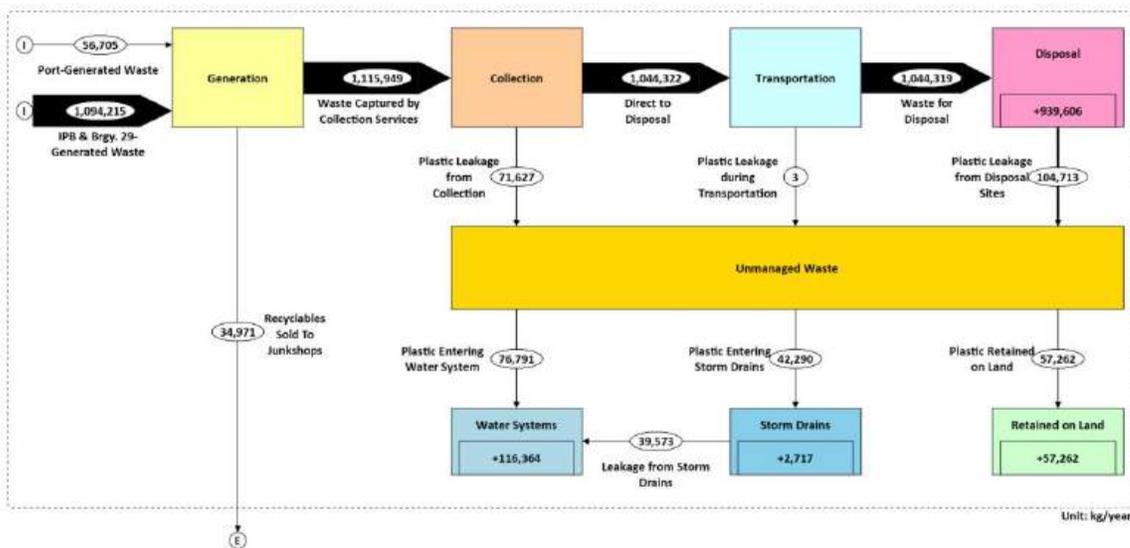


Figure 9. 2021 Solid Waste Flow Diagram for Manila North Harbor

participation (20%), whereas Manila North Harbor records only medium participation (10%). This suggests that further engagement with key stakeholders, such as businesses, local communities, and port employees, may be needed in Manila to improve compliance. All ports demonstrate high levels of compliance monitoring (20%). This indicates that enforcement mechanisms are functioning well across the board, ensuring that any violations of the SUP ban are identified and addressed. The use of sustainable alternatives to SUPs is consistent across all ports (20%), signaling that viable alternatives are available and accepted by port stakeholders.

4.4.2. Improvement of Recycling Activities in the Port

The second category interventions for the three ports aim to improve recycling activities by diverting 30% of the recyclable plastics from the baseline scenario through the conduct of collection events, exploration of possible secondary markets for recyclables, provision of support for the construction of a port MRF, and empowering utility workers within the ports. These strategies and initiatives were designed to develop the recovery of plastic waste and increase the waste diversion from the landfill. The interventions in each port with their corresponding calculated diverted plastic wastes reduced from the activities are summarized in Table 4.

Table 4. Recycling Interventions and Plastic Diversion in the Three Ports

Port	Intervention	Plastic Diverted (kg)	%Plastic Diversion vs Generation
Port of Batangas	The Plaf Collection Events	4,754	17%
	Port Manager Office Collection	2,196	11%
Port of CDO	BEST Collection Events	2,335	17%
	Export to Zayas MRF	4,186	35%
Manila North Harbor	The Plaf Collection Events	2,232	26%
	Port Manager Office Collection	964	12%

4.4.3. Collection of Unmanaged Wastes

The third type of intervention implemented in the three ports is the collection of unmanaged waste to reduce the plastic leakage into the storm drains by at least 10% from the baseline data through community efforts such as the conduct of clean-up activities, organization of collection events, and construction of community MRF.

Table 5 summarizes the unmanaged waste interventions in each port with the calculated plastics collected for recovery.

Table 5. Unmanaged Waste Interventions and Collection in the Three Ports and Nearby Communities

Port	Intervention	Unmanaged Plastics Collected (kg)
Port of Batangas	Coastal Clean-up	23
	Basura 2 Barya Program	1,126
	Calicanto MRF Pilot Operations	27
Port of CDO	Bitag-an Waste Trap Collection	4,800
Manila North Harbor	Plastic Bank/Eco-Patrols Collection	75,000

4.4.4. Overall Plastic Leakage Reduction

The interventions implemented have successfully reduced the baseline plastic leakage by 50% across all three studied ports, with the Port of Batangas achieving a 52% reduction, the Port of Cagayan de Oro fulfilling a 58% reduction, and Manila North Harbor demonstrating a 50% reduction as shown in Figure 10. The plastic leakage reduction values were based on the combined effects of the SUP ban, recycling activities, and unmanaged waste collections in the three ports.

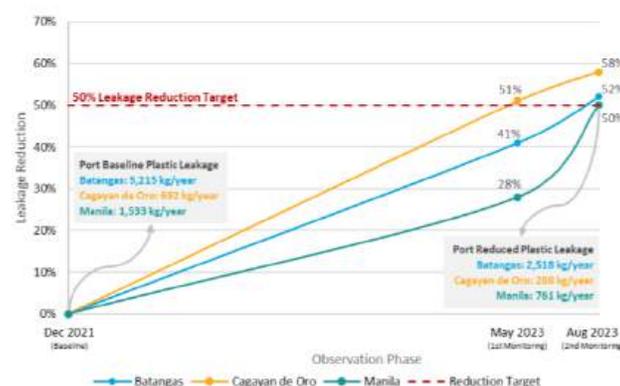


Figure 10. Plastic Leakage Reduction (%) of the Three Select Ports

5. CONCLUSION

Plastic pollution and climate change are interconnected environmental challenges, with reducing plastic leakage into marine environments serving as a key strategy for mitigating climate impacts. This study aimed to establish baseline data on plastic waste and develop scientifically based interventions to reduce plastic leakage at selected ports. Subsequently, the effectiveness



of these interventions was assessed against predetermined plastic leakage reduction targets. The baseline study revealed that significant volumes of plastic waste are generated at the three ports, with much of it leaking into the open environment due to deficiencies in the waste management system. Using the WACS manual and the WFD tool, the quantity of plastic waste leakage at each stage of the solid waste management process was identified. Targeted interventions were then implemented to achieve the project's goal of a 50% reduction in plastic leakage. The effectiveness of these solutions was scientifically measured through observation and rapid assessment, with specific attention to the impact of SUP bans, waste recovery activities, and unmanaged waste collection. The monitoring results indicated that the interventions successfully reduced plastic leakage by 50% at the three selected ports.

This study highlights the intersection between waste management and environmental sustainability. By providing baseline data and implementing scientifically based interventions, the research contributes to a more comprehensive understanding of how targeted actions can reduce plastic leakage in critical areas. The successful reduction of 50% of plastic leakage through specific interventions demonstrates the potential for scaling such initiatives, presenting a model that can be applied to other ports and maritime facilities globally. Furthermore, the study's insights into the effects of SUP bans and waste recovery activities provide valuable data for policymakers and environmental advocates working to curb plastic pollution on a larger scale.

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Flexible strategies for climate governance: from China's fiscal policy perspective

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ABSTRACT

Climate- Change has become the most crucial cross national problem of the twenty-first century, jeopardizing people's health and economic progress. Being the largest developing country in the world, China is heinously sensitive to the shocks of climate change making the quest for the Beautiful China and the Chinese road to modernization particularly challenging. All the same, China has goals, in 2020, on maximum carbon emissions which is expected to be around 2030 and carbon neutrality by mid-century, 2060 that show engagement in climate change. But, managing climate shocks is a systematic approach. It needs to be a comprehensive concept which implies the usage of innovative approaches and activity of policy management. It calls for the development of anticipatory and adaptive approaches; as well as the drawing up of background policy. For this purpose, the present study first presents a systematic review and discussion on the status of China's fiscal policy coordination with climate change, and then makes policy improvement suggestions. These suggestions aim at guiding specific resources and elements towards positive climate action so as to foster the transformative shift of the Chinese economy and society towards deep decarbonization.

1. INTRODUCTION

Climate change has emerged as the paramount challenge of the twenty-first century, posing a significant threat to human well-being and economic development. This multifaceted crisis manifests through a variety of environmental, social, and economic impacts that are increasingly difficult to ignore. For instance, rising global temperatures have led to more frequent and severe heatwaves, which not only cause direct health problems such as heatstroke and dehydration but also exacerbate chronic conditions like cardiovascular and respiratory diseases. The 2019 European heatwave, which resulted in thousands of deaths, is a stark reminder of the lethal potential of extreme heat events (The Intergovernmental Panel on Climate Change (IPCC) 2022). In addition to these direct impacts, climate change is also altering weather patterns, leading to more intense and

unpredictable storms, floods, and droughts. The devastating floods in Pakistan in 2022, which affected over 33 million people and caused billions of dollars in damage, illustrate the catastrophic potential of climate-induced extreme weather events (Cho 2019). These disasters not only result in immediate loss of life and property but also have long-term economic repercussions, disrupting agriculture, industry, and livelihoods. Economically, the costs of climate change are staggering. The increased frequency and severity of natural disasters lead to substantial economic losses, straining public finances and diverting resources from other critical areas such as healthcare and education. The World Bank estimates that climate change could push an additional 100 million people into poverty by 2030, highlighting the disproportionate impact on vulnerable populations and developing countries.

As the world's largest developing country, China is particularly vulnerable to the adverse impacts of climate

change, rendering its quest for the Beautiful China initiative and the Chinese path to modernization particularly challenging. This vulnerability stems from several factors, including China's vast and diverse geography, its large population, and its rapid economic development, which has historically relied heavily on fossil fuels. Rising sea levels and increased storm surges threaten cities like Shanghai and Guangzhou, which are critical to China's economy (United Nations Development Programme 2013). These cities face the dual challenge of protecting their populations and infrastructure from flooding while continuing to drive economic growth. The World Bank estimates that without significant adaptation measures, climate change could lead to GDP losses of between 0.5% and 2.3% by 2030 (World Bank 2022).

In response, China has set ambitious goals in 2020 for reaching peak carbon emissions by approximately 2030 and achieving carbon neutrality by 2060, demonstrating a proactive stance in addressing climate change. However, addressing climate shocks is a systematic project. It requires a holistic approach that incorporates forward-thinking strategies and the coordinated efforts of policy management. It necessitates the formulation of proactive and flexible strategies and the preparation of supporting policy. To this end, our study undertakes a comprehensive review and analysis of the current status of China's fiscal and tax policy tools in the context of climate change, and finally provides recommendations for policy refinement.

2. CHINA'S CURRENT SUPPORTING POLICY FOR CLIMATE GOVERNANCE

China has introduced several policies on climate governance, ranging from climate action planning to methodological guidelines for carbon and greenhouse gas accounting, all of which have played a positive role in climate governance. Among them, fiscal policies are important components of climate governance, and they support climate governance technologies and programs by providing financial support, reducing operating costs, and increasing social capital investment.

2.1. Fiscal Revenue

Finance is the foundation and important pillar of China's national governance, and since General Secretary Xi Jinping of the 18th CPC National Congress made ecological civilization construction an important part of the "five-in-one" overall layout and the "four

comprehensive" strategic layout of socialism with Chinese characteristics, finance should play an important role in the modernization of national governance and new development, including green development. Since General Secretary Xi Jinping made the modernization of national governance and new development, including green development, an important part of finance, fiscal expenditure has also played an indispensable role in supporting the construction of ecological civilization. According to the different nature of policy tools, fiscal policy tools to support green development can be divided into fiscal revenues and fiscal expenditures. Among them, the main source of fiscal revenue is tax policy; according to the economic nature of expenditure, fiscal expenditure can be categorized into three major categories: purchasing expenditure, transfer expenditure and government investment, and government investment mainly includes government direct investment and investment funds. The following will introduce the various types of fiscal policies by type.

2.2. Fiscal Expenditure

Fiscal expenditure is the general expenditure of the government to meet public needs. Since the 18th CPC National Congress, the national financial investment in ecological environmental protection, energy saving and emission reduction and other core issues of green development has been increasing, and in terms of absolute scale, the cumulative expenditure scale of the national energy saving and environmental protection financial expenditures in 2012-2021 reached 5107 billion yuan, with an average annual growth rate of 8.11%. In 2021, the central government strengthened the coordination of resources, optimized the expenditure, the central financial government strengthened the integration of resources, optimized the expenditure structure, and arranged about 350 billion yuan of funds related to supporting green and low-carbon development. According to the economic nature of expenditures, fiscal expenditures can be divided into three categories: purchasing expenditures, transfer expenditures and government investments, with purchasing expenditures mainly for government green procurement, transfer expenditures mainly for green financial subsidies, and government investments mainly including government direct investments and investment funds.

2.2.1. Government Green Procurement

Government green procurement is a typical policy tool for government purchasing expenditures in support of green development. Government green procurement



refers to the comprehensive consideration of the environmental protection effect of government procurement, adopting a series of policy measures, such as preferential procurement and prohibited procurement, to directly drive the production, investment and sales activities of enterprises in favor of environmental protection goals.

China's government procurement policies have been introduced since 2004, the scope of green procurement has been gradually expanded, and the policy measures and implementation mechanisms have been continuously improved. 2020 to the present, China has issued the Notice on the Issuance of "Standards for Government Procurement Requirements for Commodity Packaging (for Trial Implementation)" "Standards for Government Procurement Requirements for Courier Packaging (for Trial Implementation)" "Standards for Government Procurement Requirements for Green Data Centers (for Trial Implementation)" "Standards for Government Procurement Requirements for Green Buildings and Green Building Materials". Green Building and Green Building Materials Government Procurement Demand Standards", several government green procurement of the scope and demand for standards made a detailed description, but also released to participate in the implementation of government procurement of energy-saving products, environmental labeling products certified organizations directory. Among them, the focus is on publicizing and promoting the leading role of government procurement in promoting green production and green consumption, with the goal of promoting recyclable building materials, high-strength and high-durability building materials, green parts and components, green decoration materials, water-saving and energy-saving building materials and other green building material products in government procurement projects, actively applying assembly, intelligent and other new types of building industrialization construction methods, and encouraging the completion of two-star and above green building.

In recent years, the Ministry of Finance has continued to improve the government's green procurement policy, and has promoted the active procurement and use of green and low-carbon products by state organs, institutions and organizations.

First, it has increased the mandatory procurement and prioritized the procurement of energy-saving and environmentally friendly products. Improve the implementation mechanism of government procurement of energy-saving and environmentally friendly products, products belonging to the scope of the list of energy-

saving and environmentally friendly government procurement items, as long as they have passed the national certification, they can enjoy the preferential procurement policies. In 2020, the procurement scale of energy-saving and environmentally friendly products accounted for the proportion of the scale of government procurement of the same type of products to reach more than 85%, which effectively promoted the development of the relevant industries, and played a positive leading role in the green consumption of the society. According to statistics, from 2016 to 2020, the government procurement of green office furniture reduced a total of 149,000 tons of volatile organic compounds and 2,191.48 tons of formaldehyde; the procurement of desktop computers and portable computers reduced a total of 1,719,000 tons of carbon dioxide, which is equivalent to the annual carbon sink of 191,000 hectares of forests; and the procurement of photocopy paper reduced a total of 3,924.87 tons of chemical oxygen demand.

The second is to promote the application of green buildings and green building materials. It has pushed forward the use of green building materials in hospitals, schools and other public buildings on a pilot basis in Shaoxing and six other cities, utilizing assembly, intelligence and other new construction methods, with the number of projects included in the pilot amounting to 102.5 billion yuan.

Thirdly, the government has built a standardized system for green procurement requirements. In conjunction with the Ministry of Ecology and Environment and the State Post Bureau, we have formulated standards for courier packaging requirements, stipulating indicators for heavy metal content in packaging materials in terms of greening, minimization and recycling, and guiding suppliers to use recycled, organic and renewable packaging products. Research and development of green data centers, printing and copying consumables and other government procurement demand standards.

Fourth, support for green procurement of key products. Promote the application of new energy vehicles, requiring the procurement of new energy vehicles in principle for aircraft communications and relatively fixed-route law enforcement duties, commuting and other vehicles, and guiding Hainan Province to pilot the mandatory procurement of domestically produced clean energy vehicles. In the central budget units of furniture, printing, automobile maintenance and other fixed-point procurement programs, explicitly require the use of low volatile raw and auxiliary materials to reduce air pollution. As a next step, the Ministry of Finance will accelerate the

establishment of a sound system of government procurement requirements standards for green and low-carbon products, categorize and formulate government procurement requirements standards for green buildings and green building materials; vigorously promote the application of assembly-type buildings and green building materials, and promote the improvement of building quality; strengthen the main responsibility of the purchaser, and make clear the requirements for green and low-carbon in government procurement documents, and increase the procurement of green and low-carbon products.

2.2.2. Green financial subsidies

Green subsidies refer to financial subsidies, including grants, soft loans, and tax subsidies, that are provided to encourage pollution reduction, or for measures necessary to reduce pollution. Green subsidies incentivize payments for economic agents to adopt certain environmentally friendly measures, such as payments for the installation of pollution control equipment. Some green subsidy policies are shown in Table 1.

Table 1. Green Subsidy Policies at the Central Level

Name of Subsidized Project - Basis of Subsidy	Subsidy recipients	Mode of subsidization	Subsidy timeframe
Agricultural Resources and Ecological Protection Funds - Cai Nong [2017] No. 42	Eligible farmers, new agricultural entities and project undertakers	Funding is provided by the provincial government through a detailed implementation plan and subsidies.	2011-present
Renewable Energy Tariff Subsidy - Renewable Energy Law of the People's Republic of China	Grid enterprises	Electricity subsidy according to renewable energy feed-in energy	2012-present
Subsidies for a new round of returning farmland to forest and grassland - Cai Nong [2018] No. 66	Farmers who return cultivated lands and grasslands	Measured and arranged according to tasks and subsidy standards, provided to provincial governments	2014-present

Funding for Energy Conservation and Emission Reduction - Cai Jian [2015] No. 161	Demonstration, promotion, transformation and upgrading of energy-saving and emission reduction mechanism innovation, infrastructure construction, key industries and key industries	Financial support	2015-present
Funds for Prevention and Control of Water Pollution - Cai Jian [2015] No. 226	Water pollution prevention and control, water source protection and restoration, etc.	Award in lieu of subsidy	July 2015-present
Preferential tax on the purchase of low-emission vehicles - Cai Shui [2015] No. 104, Cai Shui [2016] No. 136	Purchase of passenger cars with engines not exceeding 1.6 liters	(1) The tax rate after vehicle purchase tax reduction is 5%; (2) Vehicle purchase tax rate of 7.5% after reduction; 10% restored on January 2018	(1) October 1, 2015 - December 31, 2016 (2) January 1, 2017 - December 31, 2018
Preferential VAT on Solar Power Generation - Cai Shui [2016] No. 81	Electricity generated by solar energy	Refunded at the time of collection in accordance with 50% of VAT	January 1, 2016 - December 31, 2018
Funding for Air Pollution Prevention and Control - Cai Shui [2016] No. 600, Cai Shui [2018] No. 578	Northern winter clean heating pilot, key areas, HFC destruction enterprises	Financial support	August 2016 - Present

2.2.3. Specialized Funds

Since the 18th CPC National Congress, the central government has supported ecological environmental protection through a series of financial special funds,



including pilot projects for ecological protection and restoration of mountains, waters, forests, fields, lakes, and grasses, blue bay remediation actions (marine restoration), pilot projects for clean heating in the north, and pilot projects for model cities for the treatment of black-smelling water bodies.

2.2.4. Government Investment

Government investment refers to constructive expenditures by the treasury for capital projects that will eventually result in various types of fixed assets. The government's investment projects mainly refer to basic industries, public facilities, and emerging high-tech leading industries that have a large external effect, a high degree of industrial relevance, and a demonstrative and inducing effect, among which support for green development is an important area of policy investment, and the government investment in green development is dominated by investment funds.

(1) National Green Development Fund

Attracting social capital participation by cooperating to set up a government investment fund to jointly promote green development is an important new type of government investment in recent years. In August 2016, the 27th meeting of the Central Leading Group for Comprehensively Deepening Reform considered and passed the Guiding Opinions on Building a Green Financial System, and seven ministries and commissions, such as the People's Bank of China, the Ministry of Finance and others, jointly issued the Guiding Opinions, which for the first time proposed that the central government integrate existing energy conservation and environmental protection and other special funds to establish a national green development fund, and encouraged conditional local governments and social capital to jointly launch a regional green development fund. In September 2019, the State Council approved and agreed to the Establishment Program of the National Green Development Fund. In July 2020, the National Green Development Fund Company Limited was officially registered and established in Shanghai. As the first state-level investment fund in China's ecological and environmental fields, the National Green Development Fund was jointly initiated and established by the Ministry of Finance, the Ministry of Ecology and Environment and the Shanghai Municipal People's Government. The total size of the fund is 88.5 billion yuan, of which 10 billion yuan will be contributed by the central government, including 11 provinces and municipalities along the Yangtze River Economic Belt, some financial institutions and related industry enterprises. The fund focuses on

environmental protection and pollution prevention and control, ecological restoration and greening of land space, conservation and utilization of energy resources, green transportation, clean energy and other green development areas.

(2) National Low Carbon Transformation Fund

The Opinions of the Central Committee of the Communist Party of China and the State Council on the Complete and Accurate Implementation of the New Development Idea and Doing a Good Job in Carbon Peak and Carbon Neutral Work clearly put forward the need to study the establishment of a national low-carbon transition fund, and to support the green transformation of traditional industries and resource-rich regions. Give full play to the guiding role of existing government investment funds, including the National Green Development Fund. Social capital is encouraged to set up green low-carbon industrial investment funds in a market-oriented manner.

3. KEY ISSUES AND BOTTLENECKS

3.1. Insufficient Fiscal Investment

Firstly, the total fiscal expenditure on promoting energy conservation and emission reduction is relatively small. From 2016 to 2019, the national fiscal expenditure on energy conservation and environmental protection was 2.4 trillion yuan, accounting for 2.82% of fiscal expenditure and 0.69% of GDP, which is far from sufficient to leverage the guiding role of fiscal policy. Secondly, the current fiscal support for the development of the clean energy industry and energy conservation and emission reduction primarily relies on special funds. However, the lack of a scientific budget preparation process and effective supervision leads to low efficiency in the use of fiscal funds and unsustainable sources of fiscal funding.

3.2. Inadequate Fiscal Investment Methods

Firstly, there is a lack of strong legal constraints on government green procurement. Currently, government green procurement mainly follows the basic guidance in the "Government Procurement Law," which states that "government procurement should help achieve national economic and social policy goals, including environmental protection goals." This is supplemented by provisions in laws such as the "Energy Conservation Law," "Cleaner Production Promotion Law," and "Environmental Protection Law." However, there is still no systematic and specialized legal document specifically for government green procurement, leading to a lack of constraints in actual operations and significant loopholes

that hinder the true implementation of government green procurement.

Secondly, the management system for government green procurement is not yet fully developed. China currently lacks dedicated departments and personnel for green procurement, and the standards for green procurement are relatively low, reducing procurement efficiency. In contrast, the United States employs the EPP (Environmentally Preferable Purchasing) principle, tools, databases, and success stories, which require a high level of environmental expertise from procurement personnel. In China, the requirements are much lower, only requiring compliance with environmental label standards and inclusion in the environmental protection list.

Thirdly, the information on green procurement is underdeveloped, and supervision is inadequate. Due to the absence of a green procurement performance evaluation system, the procurement process lacks effective supervision, and the benefits of fiscal expenditure fall far short of expectations.

3.3. Insufficient Synergy Between Fiscal Policy and Other Public Policies

The existing green fiscal and tax policies and their supporting policy systems are not yet fully developed, the policy tools are not sufficiently diverse, and the support is not strong enough. There should be more emphasis on the systematic nature of fiscal policies and the synergy and linkage between various policies. Firstly, the connection and support effect of fiscal policies on green financial policies are insufficient. Although China's green financial market is leading globally in scale, there is still a significant investment gap for green transformation. Fiscal policies should create more green financing channels for enterprises that need to transition from high carbon, high pollution, and high energy consumption, increase market demand for green finance, and assist in financial risk analysis and the construction of financial tool systems. This would help overcome the credit constraints of green low-carbon construction projects and build a complete green financial incentive system.

Secondly, fiscal subsidies, tax incentives, and other policies have not formed a closed-loop governance system with industrial policies. Fiscal support usually focuses on promoting technological innovation in new energy and energy conservation and environmental protection industries, but the coordination and promotion of supporting industries are insufficient. This leads to resource misallocation and lagging development of supporting industries, which in turn affects the development of target industries. For example, although

the wind power industry is currently a key focus of renewable energy industry policy support, its pricing mechanism is still unclear, and the corresponding infrastructure is not well-developed. This reduces the attractiveness of the wind power market to investors, leading to slow market demand growth and affecting the healthy development of the entire industry.

4. RECOMMENDATIONS FOR POLICY REFINEMENT

Adopt diversified fiscal investment methods. Promote the comprehensive application of government green procurement systems, ecological compensation systems, and public-private partnerships. Fully rely on national special funds to increase fiscal investment in smart green low-carbon energy, scientifically plan and utilize special funds to support green and clean development, establish crowdfunding platforms and green investment funds, and encourage infrastructure construction in the green low-carbon energy sector. Additionally, crowdfunding activities targeting the green low-carbon sector can be conducted, and crowdfunding platforms can be established to support the formation of green investment funds, attracting public and private capital to invest in green low-carbon projects.

Adjust the direction of fiscal policy support, targeting key areas of green low-carbon development. Firstly, expand the coverage and reach of fiscal policies. The government should strengthen fiscal support for key areas of green low-carbon development, such as energy conservation and emission reduction, and address prominent ecological and environmental issues. Increase fiscal funds' focus on resource development and efficient utilization, pollution prevention, and control, supporting key areas such as clean energy, energy conservation, environmental protection, and carbon reduction technologies, and enhance funding support for low-carbon technology research and development. Secondly, coordinate efforts and identify key areas to promote the research and application of green low-carbon technologies, enhancing the innovation capacity of core green low-carbon technologies. Focus on key areas such as front-end emission reduction technologies, carbon sequestration, carbon sinks, carbon reduction, and allocation. By coordinating various stages and key areas, especially infrastructure construction related to climate change and emerging energy industries, projects adopting public-private partnership models and third-party environmental pollution management should be given priority support to address complex risks such as climate



change.

Promote fiscal system reform to adapt to green low-carbon transformation and development. In terms of fiscal system reform, green principles can be incorporated into decision-making goals, gradually adding green development elements to transfer payments, the division of responsibilities and expenditures, and budget supervision and management mechanisms. Firstly, promote the reform of the division of environmental functions among horizontal government departments, deepening the reform of the division of responsibilities and expenditures related to resources and environmental protection. Appropriately elevate fiscal responsibilities for the use and protection of natural resources, environmental monitoring and quality assessment, and support for low-carbon technology research and development to provincial and higher levels, implementing environmental responsibilities and expenditures at the provincial level and above. Accelerate the introduction of more schemes for the division of responsibilities and expenditures in the fields of ecological environment and pollution prevention, detailing the responsibilities and capacity-building issues in ecological environment management and pollution prevention. Secondly, improve the regular direct fiscal funding mechanism in the ecological environment field, establishing a budget supervision and performance evaluation system for ecological transfer payments and green special funds. Thirdly, accelerate the formation of a scientific and effective budget preparation and supervision process. Focus on budget supervision for clean energy development, energy conservation, and emission reduction, enhancing the efficiency of fiscal funds supporting low-carbon development. Gradually incorporate green low-carbon principles into the budget management system, covering the entire process of fiscal budgeting at all levels.

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Integrating Hydropower Sustainability Standard (HSS) and FIDIC Conditions of Contracts to Enhance Climate Resilience and Sustainability in Hydropower Projects

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ABSTRACT

Climate change has become a major threat to the global energy system. The IPCC's reports forecast a future with intensified climate fluctuations e.g. flood, drought and extreme precipitation patterns. Hydropower, crucial for clean energy production, plays a vital role in reducing greenhouse gas emissions and adapting to climate change impacts. Hydropower, which is a key component of the renewable energy portfolio, is intertwined with climate change - being capable of aiding in fighting climate change while being affected by climate change. The changing precipitation patterns and hydrological cycles pose challenges to hydropower plant operations. The Hydropower Sustainability Standard (HSS) assesses sustainability criteria, including climate change mitigation and resilience, for all types of hydropower projects. Conversely, the FIDIC standard contracts, widely used in the construction industry, address risks but lack specific provisions for climate change-related challenges. Integrating HSS criteria into FIDIC contracts can enhance climate resilience and sustainability in hydropower projects by promoting adaptive infrastructure design and stakeholder engagement. By combining the strengths of both frameworks, developers can ensure that hydropower projects remain viable in the face of climate variability and extreme weather events, contributing to global climate resilience and the transition to a sustainable energy future.

INTRODUCTION

Global warming caused by human-induced reasons has caused significant changes in climate. The impact of climate change is evident from the increased frequency and intensity of extreme events such as floods, hurricanes, and wildfires. The Intergovernmental Panel on Climate Change (IPCC)'s report predicts future climate with more extreme changes in climate. It is predicted to have more intense and extreme in precipitation and variation in pattern in

rainfall.

Hydropower, a crucial component of the global energy portfolio, is intertwined with climate change - being capable of aiding in fighting climate change while being affected by climate change. Its capacity to produce clean and reliable energy in significant quantity positions it as an essential resource in transition away from fossil fuels. So far, only a fraction of global energy is supplied from the hydropower. In order to reduce Green House Gas (GHG) emission and keep the emission within the desired threshold,

hydropower plays very crucial role (IEA, 2021). In addition to reducing GHG emission, the capacity of handling flood and drought makes the hydropower a key player in climate change adaptation and mitigation measures. On the other hand, the changes in precipitation patterns, including extreme precipitation, prolonged drought, and altered

sustainable development goals.

The International Federation of Consulting Engineers (FIDIC) provides a set of standard contracts widely used in the engineering and construction industries (FIDIC, 2017). FIDIC contracts are known for their clear allocation of risks and responsibilities between parties, promoting fair and balanced contractual relationships. In the construction of the hydropower project, the FIDIC is the standard contract documents employed for the construction works. The FIDIC documents have provisions for natural disasters and force majeure conditions that address the natural disasters and climate change induced disasters. However, there is a growing recognition that FIDIC contracts need to evolve to address the specific risks associated with climate change (Bosher et al., 2013).

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hydrological cycles will adversely impact water availability and operational reliability of hydropower plants (Zarfl et al., 2015). As these climate-induced phenomena become more pronounced, the resilience of hydropower infrastructure to withstand and adapt to such changes is increasingly critical.

Several studies have examined the potential for integrating climate resilience into FIDIC contracts. For instance, Smith (2018) discusses the limitations of current FIDIC contracts in managing climate risks and suggests incorporating specific clauses for climate risk assessments and adaptive infrastructure design. Similarly, Babovic and Chan (2020) propose the inclusion of climate resilience provisions in FIDIC contracts to ensure that infrastructure projects can withstand extreme weather events and other climate-related impacts.

Hydropower Sustainability Standard (HSS) is a globally recognized framework for the assessment of sustainability of the hydropower projects (IHA, 2020). This is applicable to any and all types of hydropower project (e.g. storage, Peaking run-of-river, Run-of-River and Pumped storage) at all stages of development (e.g. preparation, implementation and operation). It evaluates hydropower projects based on 12 criteria covering Environmental Social and Governmental (ESG) as well as technical aspects. One of its criteria is Climate Change Mitigation and Resilience. The framework provides guidelines to manage environmental and social impacts, engage stakeholders effectively, and ensure that hydropower projects contribute positively to

This paper aims to review the state of art on provisions related for climate change impacts on FIDIC documents and HSS and find the similarities and gaps among them and find a way out for integrate these two to combat the impact of climate change. The primary objective of this paper is to bridge the gap between HSS and FIDIC by proposing practical integration strategies that leverage the strengths of both frameworks. By providing a structured framework for integrating HSS and FIDIC, this paper aims to



contribute to the development of hydropower projects that are better equipped to meet the challenges of a changing climate.

LITERATURE REVIEW

The IPCC's Sixth Assessment Report (AR6) report confirms that we are approximately 1.1 °C warmer than the pre-industrial era which is unprecedented in at least 2000 years. Further, it details that climate change-driven changes such as rising temperatures, melting glaciers and more frequent extreme weather events are widespread, rapid and intensifying.

The global review by Asphota Wasti and her team analyzed the impact of climate change on hydropower projects worldwide. It considered glacier retreat, droughts, and increased water demand. The report covers key international watersheds, including the Nile, Columbia, and Indus rivers. For instance, the Tarbela Dam on the Indus River generates a significant portion of Pakistan's electricity, but climate change is affecting its energy generation capabilities (Wasti et al 2022).

The UNFCCC highlights the dual relationship of hydropower with climate change: it contributes to emissions reduction but is also vulnerable to changing rainfall patterns that affect river flow (How Hydropower Can Help Climate Action | UNFCCC).

The Hydropower Sustainability Standard is a global certification scheme designed to outline sustainability expectations for hydropower projects worldwide. Its purpose is to ensure that hydropower development contributes positively to local communities and the environment. The Standard covers twelve critical environmental, social, and governance (ESG) topics, including biodiversity, indigenous people, cultural heritage and

more(<https://www.hydropower.org/sustainability-standard>).

It is the only global certification scheme for operators to accredit their hydropower projects as Certified Sustainable. Supported by industry, governments, and NGOs, certification indicates that a project meets minimum sustainability expectations across a comprehensive range of topics. The Standard aligns with green finance initiatives, making it easier for projects to access green financing ([Hydropower Sustainability Standard: International Hydropower Association](https://www.hydropower.org/sustainability-standard)).

1.1.1. Integrating HSS and FIDIC

The integration of HSS and FIDIC represents a promising approach to enhancing the resilience and sustainability of hydropower projects. This integration can address the gaps in current FIDIC contracts by leveraging the comprehensive guidelines provided by HSS for climate risk management and sustainable practices (Lindegard et al., 2014).

Case studies have demonstrated the benefits of integrating HSS criteria into FIDIC contracts. For example, the Bajo de Mina Hydropower Project in Panama successfully incorporated HSS guidelines to enhance its climate resilience, including adaptive management strategies and sediment management practices (Haasnoot et al., 2018). Another notable example is the Nam Theun 2 Hydropower Project in Laos, which implemented HSS standards to improve flood management and stakeholder engagement, resulting in increased community resilience (Diana et al., 2020).

1.1.2. Financial Implications and Insurance Considerations

The financial implications of climate change for hydropower projects are significant, particularly regarding insurance premiums

and risk management costs. Increased risks of natural disasters due to climate change can lead to higher insurance premiums, which must be accounted for in project planning and contractual agreements (Mills, 2009).

Research indicates that integrating HSS-driven mitigation measures within FIDIC contracts can reduce these financial risks. For instance, implementing adaptive infrastructure design and enhanced water management practices can lower the likelihood of catastrophic failures and associated costs (International Finance Corporation, 2015). Moreover, stakeholder engagement and inclusive decision-making processes, as emphasized by HSS, can foster community resilience and support long-term project viability (Brown et al., 2018).

1.1.3. Enhancing Stakeholder Confidence and Governance

Effective stakeholder engagement is a critical component of sustainable hydropower development. The HSS framework emphasizes the importance of involving local communities and other stakeholders in project planning and implementation (Scudder, 2005). This inclusive approach helps build stakeholder confidence and ensures that local knowledge and concerns are addressed.

Governance structures that align with HSS standards can enhance project compliance and continuous improvement. For example, transparent reporting and inclusive decision-making

processes can ensure that stakeholders are kept informed about project progress and climate risk management efforts (International Hydropower Association, 2018).

1.1.4. Training and Capacity Building

Training and capacity-building initiatives are

essential for the successful implementation of integrated HSS and FIDIC approaches. Developing expertise in climate risk management and sustainable project implementation can enhance the capabilities of project managers, engineers, and other stakeholders (UNESCO, 2019). Certification programs and professional development opportunities can further support the adoption of best practices in hydropower sustainability and resilience (Hydropower Sustainability Assessment Council, 2020).

2. METHODOLOGY

Comprehensive review of available literature on impact of climate change on infrastructure, water resources and hydropower, Hydropower Sustainability Standard (HSS) and How to Guides and FIDIC Conditions of Contracts are carried out. Comparative study of the various FIDIC's provisions and Hydropower Sustainability Standard (HSS) related to climate change and mitigation measures are carried out. Find out the possible way of integrating HSS and FIDIC's provisions to combat the climate change and make the hydropower project climate resilient.

DISCUSSION

The hydropower projects have a relatively very low carbon footprint per unit of energy generation. A study carried out by Ubierna et al., 2022 quantified hydropower global median lifecycle greenhouse emission at 23 gCO₂e/kWh which also aligned with the IPCC estimates. Thus, hydropower projects play a critical role in the global energy transition, providing renewable electricity and helping to stabilize the grid reliant on intermittent renewable sources like wind and solar. In the context of climate change, it has become necessary to make hydropower projects sustainable and climate resilient.



The Hydropower Sustainability Standard (HSS) and the FIDIC Conditions of Contract are two distinct but complementary frameworks that aim to enhance the sustainability and climate resilience of hydropower projects. The HSS developed and managed by the International Hydropower Association (IHA), provides a comprehensive set of guidelines and criteria to assess the environmental, social and economic impacts of hydropower projects throughout their lifecycle. The HSS ensures that the hydropower projects not only generate renewable energy but also do so in a way that minimizes ecological disruption, promotes social welfare, and supports long-term climate resilience. The framework ensures that hydropower developers adhere to best practices in environmental protection and social responsibility with an added focus on long-term project sustainability in the face of climate change.

In contrast, the FIDIC Conditions of Contract, published by the International Federation of Consulting Engineers (FIDIC), offers a standardized contractual framework to govern the relationship and responsibilities among various stakeholders involved in project development. These conditions provide standardized contractual provisions that allocate risks, define responsibilities and outline mechanisms for project execution, such as dispute resolution mechanisms and performance monitoring. FIDIC Conditions of Contracts are renowned for their flexibility and global applicability, allowing project stakeholders to efficiently manage time, cost and quality issues while also addressing legal obligations. While FIDIC books include provisions related to environmental compliance it focusses remains on ensuring successful project delivery from a technical and contractual standpoint rather than explicitly promoting sustainability.

Despite their differences, there are several similarities between the two frameworks.

Both the HSS and FIDIC Conditions of Contract aim to promote sustainable and climate-resilient practices in the hydropower sector. One key similarity is the emphasis on risk identification, assessment and mitigation. Both frameworks recognize the importance of proactively managing risk, such as those related to financial, technical, environmental, and social factors, to ensure the long-term viability of hydropower projects. While the HSS focuses on ESG risks, such as environmental degradation and social unrest, FIDIC books address contractual risks like delays, cost overruns, and technical failures. Together, these frameworks offer a more holistic risk management approach that covers both sustainability and technical performance, ensuring that all potential risks are addressed.

Another similarity lies in their governance and accountability mechanisms. Both HSS and FIDIC books promote strong governance structures and transparent decision-making processes. The HSS ensures that the hydropower projects adhere to clear ESG benchmarks, while FIDIC books formalize these governance structures within the contractual framework, making responsibilities and accountabilities legally binding. The combination of these frameworks thus reinforces accountability, both in terms of sustainability outcomes and contractual performance.

However, it is important to recognize the fundamental differences between the HSS and FIDIC Conditions of Contract, as these differences highlight the unique value each framework brings to the table. The most notable difference is their scope and focus. The HSS is explicitly concerned with sustainability outcomes, particularly environmental protection and social responsibility. It provides a detailed framework for assessing and improving a

hydropower project's sustainability performance, addressing climate resilience, biodiversity conservation, and community well-being. FIDIC, on the other hand, is primarily focused on the legal and technical execution of the project, ensuring that construction is completed on time, within budget, and to the specified quality standards. This distinction means that while FIDIC ensures the technical success of the project, it does not inherently guarantee that sustainability objectives will be met unless they are specifically included in the contract.

This difference in focus extends to how each framework handles environmental issues. HSS offers comprehensive guidelines on environmental management, requiring developers to take proactive steps to conserve biodiversity, manage water resources sustainably, and reduce greenhouse gas emissions. FIDIC contracts, while allowing for environmental provisions, do not prescribe specific sustainability goals or standards. Instead, FIDIC relies on the project's specifications to incorporate environmental requirements, which can lead to variability in how environmental protection is prioritized across different projects. This makes the integration of HSS into FIDIC contracts essential for ensuring that environmental sustainability is not only considered but also enforced contractually.

Despite these differences, the integration of HSS and FIDIC can create a synergistic effect that enhances the climate resilience and sustainability of hydropower projects. By embedding the sustainability benchmarks of the HSS into the contractual provisions of FIDIC, project developers can ensure that environmental and social performance metrics become legally binding obligations. This means that developers and contractors are not only accountable for delivering the infrastructure but also for meeting specific sustainability goals, such as reducing carbon

emissions or protecting endangered species. FIDIC's flexibility in contract design allows for the inclusion of HSS guidelines, ensuring that sustainability becomes a core part of the project's contractual framework.

Moreover, the combined use of HSS and FIDIC enhances the climate resilience of hydropower projects by addressing both the technical and sustainability aspects of climate risks. The HSS requires developers to assess the potential impacts of climate change on hydropower infrastructure, such as increased flood risks or reduced water availability due to shifting

precipitation patterns. These climate risk assessments can then be incorporated into FIDIC contracts, which can include provisions for adaptive design measures, climate-resilient construction methods, and performance-based penalties or incentives for meeting climate resilience targets. By embedding climate adaptation strategies into the contractual framework, developers can ensure that hydropower projects remain viable in the face of climate variability and extreme weather events.

The broader significance of integrating the Hydropower Sustainability Standard and FIDIC Conditions of Contract extends beyond individual project success. Together, these frameworks contribute to the global effort to combat climate change by ensuring that hydropower projects, which are a key component of the renewable energy transition, are developed in a way that minimizes environmental harm and maximizes climate resilience. Hydropower projects, when designed and managed sustainably, provide a renewable source of energy that can reduce dependence on fossil fuels and lower greenhouse gas emissions. However, poorly planned hydropower projects can lead to significant environmental and social damage, undermining their potential benefits.



By integrating the HSS and FIDIC, developers can avoid these pitfalls, ensuring that hydropower projects are both technically successful and environmentally sustainable. This integration supports the creation of infrastructure that not only provides clean energy but also helps communities adapt to the impacts of climate change, such as increased flooding, droughts, and changing weather patterns. In the bigger picture, this integrated approach contributes to global climate resilience, helping mitigate the effects of climate shocks and supporting the transition to a more sustainable energy future.

CONCLUSION

The hydropower projects are crucial for combating the adverse effects of climate change as it has a very low GHG emission footprint and it has a unique capacity to reduce the impact of flooding and prolonged drought. The HSS and FIDIC Conditions of Contract, while distinct in their focus, provide complementary frameworks for ensuring the sustainability and climate resilience of hydropower projects. The HSS offers a comprehensive sustainability assessment tool, while FIDIC provides a robust contractual framework for managing the technical and financial aspects of project delivery. By integrating these two frameworks, developers can ensure that sustainability considerations are embedded throughout the project lifecycle, from planning and design to construction and operation. Further, the integration of these two frameworks assures that the hydropower projects are both legally and environmentally sound, contributing to the global fight against climate change while providing a reliable source of renewable energy. The integration of HSS and FIDIC thus represents a powerful strategy for enhancing the long-term success of

hydropower projects in a world increasingly affected by climate change.

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Role of Instinctive and Anticipatory Resilience in Saving Lives and Infrastructures: Case Study of Seti and Melamchi Flooding

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ABSTRACT

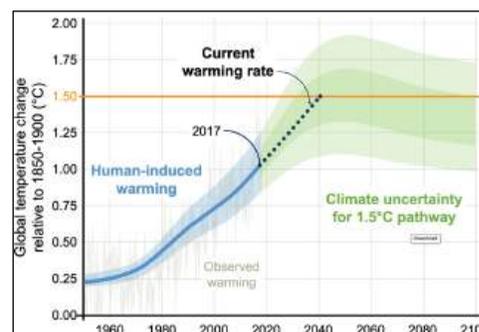
Climate change is at work in the Hindukush Himalayan Region, which includes Nepal. Mountain regions are warming at a faster rate than at lower altitudes. Climate scientists anticipate that the Himalayan average temperature would go up to 1.8 °C, even if the world sticks to the Paris Agreement limit of 1.5 °C. They argue that the 1.8 °C temperature can cause one-third of the Himalayan glacier mass to disappear by 2100. The loss of glacial mass means increases in size and number of glacial lakes and associated risks of glacial lake outburst floods. Damage to infrastructures, hydropower, and human habitat downstream. Nepal has experienced at least 25 glacial lake outburst floods in the past. This paper uses two case studies to show how instinctive and anticipatory resilience can save lives and minimize infrastructure damage from glacial lake outburst floods in Nepal. The Seti River flooding illuminates the role of instinctive resilience and the Melamchi anticipatory resilience. This paper concludes that the application of both instinctive and anticipatory resilience at the individual level and institutional levels can significantly reduce the risks associated with climate uncertainty in the Himalayan Republic.

INTRODUCTION

Since preindustrial times, the earth has already warmed by about 1 °C (Ramanathan, 2019). Emissions caused by fossil fuel and coal-run automobiles and industries are the leading causes of global warming. That concentration has since increased steadily, shooting past 300 ppm by 1950, 369 ppm by 2000, and 400 ppm by 2016. Carbon dioxide concentration was about 410 ppm in 2018. This ppm means humans have increased the overall concentration of carbon dioxide by nearly 50% since the preindustrial era. We have already emitted 2.2 trillion tons of carbon dioxide into the air. The emission is going to reach three trillion by 2030. In 2021, 65% of electricity produced by burning fossil fuels worldwide, including 38% from coal and 23% from natural gas. Coal emits about twice as much CO₂ per unit of electricity generated as natural gas, so burning coal to generate electricity is particularly concerning.

The Paris Agreement agreed to keep a global temperature rise this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C. However, according to the World Meteorological Organization (MARCH 19, 2024), the global mean near-surface temperature in 2023 was 1.45 °C. Intergovernmental Panel on Climate Change indicates that crossing the 1.5 °C threshold risks unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves, and rainfall. With unchecked emissions, more than 1.5 billion people would be exposed to extreme heat waves, storms, floods, fires, droughts, and various diseases (Ramanathan, 2019).

Figure 1 Global Temperature is on the Rise



Source: IPCC, 2018

Not only floods, fires, and droughts but also the Himalayas are warming at a faster rate. Climate scientists anticipate that the average temperature of the HKHR will go up to 1.8 °C, even if the world sticks to the Paris Agreement limit of 1.5 °C. They argue that the 1.8 °C temperature can cause one-third of the Himalayan glacier mass to disappear by 2100 (International Centre for Integrated Mountain Development, 2024). The glacier meltdown would form numerous glacial lakes that may trigger glacier lake outburst flooding (GLOF) in the region.

Figure 2 Glacial Lake Formation at HKHR



Source: Alton C Byers

Nepal has already experienced at least 24 GLOF events in the past. Those events were catastrophic to the people and property downstream (International Centre for Integrated Mountain Development, 2011). Recent incidents in Nepal's neighborhood are eye-opening. The South Lhonak glacial lake outburst in

Sikkim on October 4, 2023, swept away a 1200 MW hydroelectric plant, bridges, and highways. The total damage was over 2 billion US dollars (Awale, 2023). In 2021, an avalanche caused a flood in Chamoli district, Uttarakhand, damaging two hydropower projects and resulting in more than 200 dead or missing persons (Caceres, Jaramillo, Matthews, Samaras, & Nijssen, 2021). The 2013 flood in Uttarakhand damaged at least 10 hydropower projects and killed 6000 people (A. Gupta, 2022). Researchers suggest that climate change could reduce usable hydropower capacity in 60-75% of hydropower plants worldwide by 2040-2069 (Caceres et al., 2021). The increasing risks of GLOF on people, settlements, and hydropower plants warrant strong resilience: The ability to cope with and adapt to sudden and unexpected flooding disasters in Nepal.

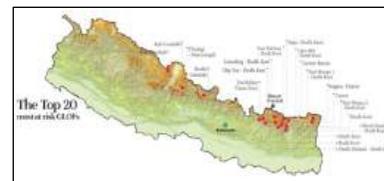
This paper presents the role of instinctive and anticipatory resilience in minimizing GLOF damages to people, settlements, and riverine development projects, using two case studies from Seti and Melamchi River flooding. First, it introduces the context of Nepal's climate change vulnerability in the mountains, including the impacts of GLOF on the settlements and properties. Second, it defines various concepts of resilience, including the instinctive and the anticipatory ones. Third, it elaborates on Seti River flooding from Kaski and Melamchi Flooding from Sindhupalchok District. Fourth, it makes a reflection on those case studies by elaborating on their instinctive and anticipatory resilience strengths and weaknesses. Fifth, it makes a brief conclusion followed by recommendations. The paper uses all secondary sources, including journal articles, reports, and newspaper coverage to make the argument.

1. NEPALESE CONTEXT

Nepal, a Himalayan republic is part of the Hindu Kush Himalayan Region (HKHR). About 80% of Nepal's land mass is

situated in the HKHR. The region is a significant source of freshwater for the habitats, living downstream (Vaidya et al., 2014). However, in recent years, the mountain areas of the HKHR have been warming. The Himalayan ice is melting, and creating a condition for the glacial lake outburst floods (GLOFs). The GLOF is a catastrophic discharge of water from the glacial lakes due to failure or breach of ice or moraine dam, formed at the end of these lakes (Ghimire, 2005). Nepal, Bhutan, and China have already experienced at least 35 GLOFs in the past (Miya, 2022). The trend is on the rise. Nepal, India, and Tibet regions altogether have 3,624 glacial lakes (Miya, 2022). The 47 of them are at high risk of outbursts. 21 of the 47 glacial lakes are in Nepal. So far Nepal has experienced 25 GLOF incidents: 14 originated from Nepal and 11 from Tibet (Miya, 2022).

Figure 3 GLOF Prone Locations in Nepal



Source: Nepali Times, 2021

It is estimated that the Imja outburst might harm 96,767 people and Chho Rolpa 141,000 (Miya, 2022). The 2021 flood caused 2 billion Nepalese rupees in losses in MWSP, 10 billion in hydropower projects, and over 2 billion in roads and bridges (Shrestha, 2021). According to the Home Ministry of Nepal, every year 330 people die and damage worth 17.24 million US dollars due to climate change-related disasters in Nepal (Miya, 2022). Most Nepalese hydropower projects are along glacial-fed river basins like the Arun, Bhote Kosi, and Marsyangdi (Awale, 2023). The majority of them did not consider the GLOF, climate change, and geological vulnerabilities while designing and building those structures.

Figure 4 List of Some of the GLOF Incidents in Nepal

	Date	Bursting lakes	Major River Basin	Sub River Basin
1	3 Sept. 1977	Nare	Dudh Koshi	Imja Khola
2	25 July 1980	Nagma Pokhari	Tamor Basin	Yangma Khola
3	27 Aug. 1982	Jinco	Pum Qu (Arun)	Yairu Zangbo Tibet
4	12 July 1991	Chubung	Tama Koshi	Rolwaling Khola
5	3 Sept. 1998	Tam Pokhari	Dudh Koshi	Inkhu Khola
6	05 May 2012	Seti River upper catchment glacier rock collapse	Seti River	Seti River

Source: Dwivedi, Kamal 2021

Recently, the government has taken some actions to reduce GLOF risks in Nepal. It has reduced the water levels of 4 of the 47 risky lakes: Chho Rolpa and Imja in Nepal and two in Tibet (Miya, 2022). The United Nation's Green Climate Fund and UNDP have put 35 million US dollars into reducing glacial lake water levels (Miya, 2022). This project will target four risky lakes: two in Solokhumbu (Lumdi Chho and Haangu), one in Sankhuwa Sabha (lower Barun), and one in Gandaki (Thulagi: Dona). By 2030, they have plans to reduce the water level and install early warning. They are installing early warning all along the river up to Chatara in Koshi, and Devghat in Gandaki (Miya, 2022). The project expects that half a million people will directly benefit from the project. These are good physical adaptation moves, but more efforts are necessary to enhance the overall resilience at the individual and institutional levels.

RESILIENCE: INSTINCTIVE AND ANTICIPATORY

Resilience is the ability to cope with, adapt to or transform if necessary (new normal) in a disaster (Davoudi et al., 2012). It is not only about avoiding human harm and irreparable damage in a disaster (Johnson & Blackburn, 2014) but also the ability to cope with, recover

from, thrive, and transform into a new normal if necessary. Davoudi et al. (2012) classify three types of resilience in their paper. They are engineering, ecological, and evolutionary resilience. Engineering resilience is the ability of a system to return to equilibrium or bounce back after a disturbance such as a disaster. Ecological resilience is not only to bounce back but also to persist and remain within critical thresholds (Davoudi et al., 2012). Evolutionary resilience is not only to return to normality but also the ability of the systems to change, adapt, and crucially transform in response to stresses and strains (Davoudi et al., 2012). It also means the ability to self-organize, learn, and adapt to the new normal (Intergovernmental Panel on Climate Change, 2012) (Johnson & Blackburn, 2014).

Evolutionary resilience could be viewed at three levels. Those levels are individual, institutional, and regulatory. Individual resilience is the adaptive capacity of citizens to cope with, recover from, change, and transform from disasters (Gupta et al., 2010). It is also the extent of citizen's access to essential services and infrastructure that protect them and enable them to cope with and recover from disasters (Johnson & Blackburn, 2014)

Institutional resilience is the ability to plan and manage the consequences of climate by organizations or agencies (Haque et al., 2014). Much resilience comes from responsive governance as a political process (Johnson & Blackburn, 2014). Local institutional resilience is also a function of a bottom-up planning approach, technical training, and financial resources to local governments (Chau, Holland, & Cassells, 2014). Local government’s collaborative approach to elicit cooperation among individual citizens and institutions during disasters can make a difference (Jabeen, Johnson, & Allen, 2010). It is about the ability to capitalize on cross-disciplinary collaborations (water management, spatial planning, and disaster management), including citizen-willingness (Restemeyer, Woltjer, & van den Brink, 2015).

Finally, regulatory resilience is the ability to develop and enforce land use and other regulations to avoid the development of settlements in vulnerable locations, and guide development in less vulnerable places (Gleeson, 2007; Matthews, 2011). It is also about creating regulations for hinterland and land use adjustment to minimize disaster damages (Bedsworth & Hanak, 2010; Restemeyer, Woltjer, & van den Brink, 2015). However, two other resilience lenses are extremely relevant in the face of rising climate uncertainties. They are instinctive and anticipatory resilience.

Instinctive resilience: Instinctive resilience is the ability to apply judgment to an unfolding incident and take appropriate action (Lorenz, 1965). The action can either instantly pop up in the head or is drawn from previous similar incidents (Lorenz, 1965). One example of instinctive resilience could be cited from far western Nepal. On January 7, 2022, a pregnant woman from a remote area of Rukum faced a baby delivery complication. The doctors had to take the baby through surgery at the Rukum

District Hospital. However, as the doctors were in the middle of the surgery, the electricity went off. Immediately the doctors used their mobile lights to continue their task and were able to take out the baby safely (Gautam, 2011). Some folks instantly jumped into the flooded Nakhu River on September 28, 2024, and saved lives is also an example of instinctive resilience.

Figure 5 Mobile Phone Light Used for Surgery



Source: Hari Gautam, Kantipur

Anticipatory resilience: Anticipatory resilience is the ability of people to anticipate potential disasters and take extra precautionary measures (Bolin & Stanford, 1998). It spots negative impacts of planning decisions or project planning, unforeseen by many, or offers insights for taking appropriate measures to minimize disaster harm and destruction (Bolin & Stanford, 1998). Anticipatory resilience looks into exposure: the inventory of elements in an area in which hazard events may occur, evaluates vulnerability—predisposition, susceptibilities, and fragilities, to anticipate risks (Intergovernmental Panel on Climate Change, 2012).

Figure 6 Eagle Vision Risk Anticipation



Source: Judi Dressler, 2020

However, anticipatory resilience takes its back seat if project managers, planners, and politicians are emotionally attached (biased) to a project: seek out only the information that supports their point of view and discount the opposing ones (Confirming-evidence-trap). Stay blind to what is in front and look for evidence that conforms to their beliefs. Highlight only the positive and hid the negative side of the project (Framing trap).

CASE STUDY: SETI RIVER and MELAMCHI FLOODING
Seti River Flooding

On May 5, 2012, a Russian pilot Alexander Maximov of Avia Club Nepal was at the Pokhara Airport ready for his mountain flight. It was a bright and sunny Saturday Morning. Alexander took off with a tourist on a sight-seeing flight with his two-seater blue Aeroprakt plane (Dixit, 2014). As he gained 10,000 feet above the Seti, he started taking videos of the area below. Suddenly, Maximov noticed something unusual.

Figure 7 Pilot Alexander Maximov

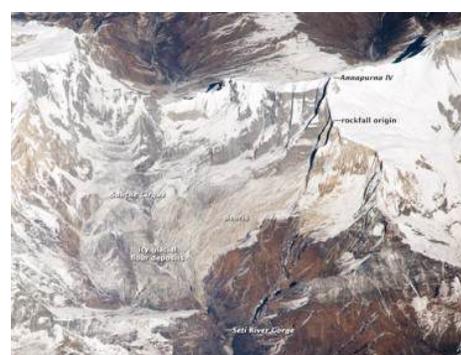


Source: Santosh Pokharel

He saw a billowing brown cloud below Annapurna created by the rock-ice avalanche. Moments later, he saw white Seti River turbid and brown. A wall of water carrying mud, boulders, and tree trunks was surging down the Seti gorge. The pilot turned his plane around and raced the flood,

radioing ahead a warning to Pokhara airport. The debris mixed Seti River flash flood swept settlements downstream and damaged Kharapani village in Sardikhola Village Development Committee (VDC) and Sadal village in Machhapuchre VDC (ReliefWeb, 2012). The flooded river destroyed dozens of homes and killed 72 people. The flood water level had reached 30 meters high in some places. The government had declared 25,000 Nepalese rupees for the homeless, and 125,000 rupees for the deceased person's family (ReliefWeb, 2012).

Figure 8 Slipping Down Annapurna Glacier



Source: NASA Earth Observatory image

Seti-river had slowed to a trickle several hours before the flood finally hit the area (South Asia Network on Dams, 2014). The glacier debris dammed the river before it finally burst to inundate the downstream. Maximov flew back the next day and took amazing photographs of the devastation on the ice shelf below the 7,525m-high Annapurna IV in the headwaters of the Seti. Scientists analyzing those images have concluded that a rock face very near the summit of

Annapurna IV broke off, taking down a part of the ice cornice of the ridge as well (Dixit, 2012).

Figure 9 GLOF's Damage on Seti River



Source: Dr. Kargel

Melamchi River Flooding

Search for drinking water for Kathmandu Valley had been at work since the 1970s. Finally, in 1992, SMEC consultants identified three water sources for a long-term water supply in Kathmandu Valley. Those sources were the Melamchi, Yangri, and Larke rivers. These rivers are snow-fed

rivers originating from the Langtang National Park glacier. The government of Nepal endorsed this idea and created the Melamchi Water Supply Project (MWSP) in 1995 as phase one. The project was created to meet at least 30 years of water demand in the three major cities of Kathmandu Valley. In particular, its first phase target was to divert 170,000 cubic meters of water per day from the Melamchi River to the water treatment plant in Sundarijal, Kathmandu, through a 26.5-kilometer (km) water diversion tunnel to serve 180,000 households in the Kathmandu Valley.

Figure 10 Melamchi-Sundarijal Tunnel



Source: Mukesh Pokharel

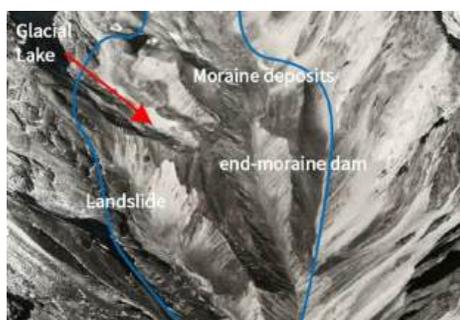
Prime Minister Krishna Prasad Bhattarai, in 1999, told its citizens that he had initiated a Melamchi water supply project to serve them soon. He further said that the water is sufficient not only to drink but also to clean the streets of the valley towns. This initiative was a big hope and excitement to the residents of Kathmandu Valley, who were tired of waking up early in search of water for years. The project went ahead but through several upheavals, including the hiring and firing of consultants, contractors, and construction delays.

The project period saw 19 Prime Ministers, 24 Water Ministers, 29 Secretaries and 11 project chiefs. Twenty-six years later, on February 22, 2021, the project completed the tunnel. It spent 464 million US dollars or 31 billion Nepalese rupees for the work. On March 28, 2021, the water finally reached the taps of 100,000 households on March 28, 2021. This breakthrough spurred a series of inaugurations by Ministers, Prime Ministers, and Presidents: Some at the project site, a few of them at the Sundarijal Water Treatment Plant, and others at several taps and water spouts in Kathmandu Valley. None of the politicians and government heads were willing to miss this credit-taking opportunity.

However, in the first week of June 2021, something unusual happened. Weeklong heavy rain disturbed the geological and glacial ecology of the Melmachi's upper

catchment. The rain triggered huge Melamchi river flooding on June 15 that brought about 20 meters of boulders and debris and buried the MWSP's headworks structure built to divert water to Kathmandu (Asian Development Bank, 2023). First, the heavy rain triggered landslides. Second, the Pemdang Khola tributary's glacial terrain melted faster generating more sediments downstream to the Melamchi river. It further caused massive landslides near Melamchigaon and Bhremathang. Third, the landslides dammed the Melamchi River which led to a flood outburst that buried MWSP headwork.

Figure 11 Glacial-lake Moraine, Melamchi



Source: ICIMOD, 2021

The incident stalled water supply to Kathmandu Valley. The flood crippled 26 years old dream of a smooth supply of water in Kathmandu Valley. It almost put the 31 billion Nepalese rupees investment under-water. In addition, the flood incurred 2 billion Nepalese Rupees to the MWSP (Shrestha, 2021). The most depressing outcome was that the MWSP could no longer deliver year- round water supply. In rainy season, the supply gets closed. According to the government authorities, the MWSP would require 3 billion additional funding to relocate the damaged water- intake from the buried area (Aryal & Thami, 2023). Even after the relocation, no one could rule out the possibility of similar flooding damage in the future. Nobody knows how many similar future floods would hit the project and what costs it has to bear. The MWSP had an EIA report in 2000 which

was revised in 2001. The report highlighted the MWSP's impacts on physical, biological, and socio-economic environments (Melamchi Water Supply Project, 2022). However, it stayed silent on the impacts of geological vulnerability and GLOF on the MWSP.

Figure 12 Melamchi River Flood June 15, 2021



Source: Nepali Sansar

On that disastrous evening, Melamchi Municipality Ward 11 chairman Rudra Prasad Dulal was busy mobilizing the community for road and drainage building around the market situated along the Melamchi River (Himalkhabar, 2021). Rudra had received a message in the daytime that heavy rain was ongoing in the north. However, there was no reporting regarding the flooding possibility. So, he focused his time on the market infrastructure building. It was evening time and many had returned to their home after the daylong farm activities. However, after a while, suddenly, the ward chairman received a phone call that said a flash flood was heading in the area and to be safe. As soon as he received this message, he reported to the police and army security forces of the area. He called all the residents by one whose numbers were with me. Also, he reached out to as many

houses as possible and told them that a big flood was coming, not to stay near the river, leave their home, and go to safer land. As people were leaving their homes, the flood reached the area and inundated the entire market.

Six months later in December 2021, the Asian Development Bank (ADB) sent a 16-member team to the Bhremathang area to investigate the causes of the Melamchi Flooding and its impact on the MWSP (Pandit, 2021). The ADB was the major funding agency of MWSP. The team was composed of geologists, glaciologists, support staff, and porters. Bhremathang was 3,600 meters above the sea level. The ADB contracted an Abadhya consultant to manage and take the team to the disaster site. The consultant sent Sonam Lama as a key route guide for the team. Lama was a mountaineering guide with 16 years of experience. He was from Helambu having a good grasp of the study area.

Figure 13 ADB Study Team



Source: Anil Tiwari, Kantipur

On December 23, 2021, Sonam helicoptered the team and made them land safely early in the Morning at Bhremathang. The area was a flat terrain made up of lime and glacier material. They set up four tents near the flat land. The tents were set up to allow people to cook eat, and sleep. By Dec 28, 2021, five days later, they had finished 90% of their work. However, the weather started to change by the evening. The atmosphere started to become foggy. By midnight, the snow piled up in the tent (Pandit, 2021).

The morning, the team wanted to shift

their tent away from the slopy area to the central flatland to protect tents from snow burial. However, a strong afternoon snowstorm buried their tent and all the eating material. They called a helicopter, but it could not come due to poor visibility. Day and night, they stayed near a cave adjoining their head together. The next morning, on December 30, the weather slightly improved. Luckily the helicopter was able to come and land in the area, and finally, they were rescued.

REFLECTION

The case studies revealed two important insights: one related to instinctive and the other anticipatory resilience. First, regarding instinctive resilience, two examples were worth noting. One from the pilot in the Seti River flooding and the other from the Ward chairman in Melamchi. Pilot Alexander applied his instinct when he saw clouds due to glacier rock falling in Annapurna. He sensed the situation, saw huge debris mixed flood going down along the Seti River to harm people, and promptly sent a message to Pokhara Airport tower that the GLOF was building up upstream, and urged the tower to alert all the people and security forces. His instinct could not save all the people but saved many lives.

From pilot Alexander, we learned that all pilots flying above Nepal's sky, if they see something disastrous can say something to the tower and save lives. Many pilots flying in the sky might notice similar unfolding disasters but the urge to inform the tower might never strike their psyche. It is not their primary duty. However, some apply their instinctive resilience, inform the tower and save lives. The pilot's case unfolds the role of pilots in climate change and disaster risk reduction in society through their ability to observe disaster and warn the ground for possible risk reduction. The work of municipal ward chairman Rudra Dulal from Melamchi Municipality is another example of instinctive resilience. His

instinct to make phone calls to many Melamchi Bazar residents and inform security forces and some house-to-house alerting played an important role in saving lives and property.

Regarding anticipatory resilience, two examples from the cases stand out. One, the people and authorities' inability to notice and anticipate the sudden drying of the Seti River, as a sign of GLOF possibility. The other is the MWSP's inability to research and anticipate the GLOF possibility at the MWSP. The MWSP project planners, politicians, and experts were so confident, excited, and engrossed in designing and constructing a 26 KM tunnel from Melamchi River to Sundarijal, that they hardly paid attention to see the upstream glacial and geological vulnerability; and failed to notice the grave threats of GLOFs on the project. The project's EIA report in 2000 and the revised one in 2001 stayed neutral on the geological and glacier lake outburst and flooding vulnerability. Since the GLOF risks were kept in the dark in the EIA report, the project planners took no measures for such disaster risks.

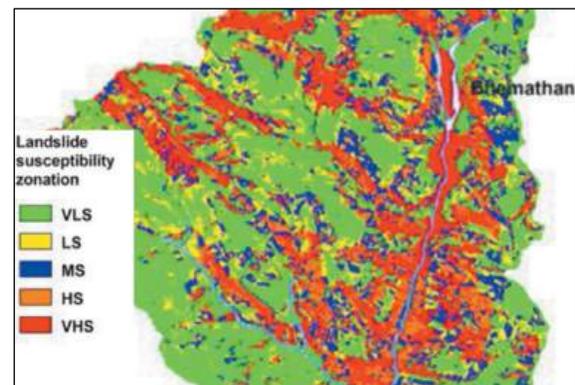
They carried out the MWSP construction for 26 years, completed the tunnel, and brought water to the valley. However, a few months later, the flooding completely blocked the headwork and stalled the project. Only after the aftermath of the flood disaster, the ADB was able to identify huge vulnerability in the MWSP surroundings (Figures 15 and 16). The 2023 ADB study found many glacial lakes in the Melamchi River's upper catchment area, and it discovered that the entire Melamchi River corridor was highly prone to landslides (Asian Development Bank, 2023).

Figure 14 Glacial Lakes in Melamchi Upper catchment



Source: ADB, 2023

Figure 15 MWSP in landslide Prone Melamchi River Corridor



Source: ADB, 2023

This raises the question of how none of the MWSP planners noticed the geological vulnerability of the reason. Why did no one question the GLOF or landslide-associated flash flood damage possibility in the area? Why the EIA carried out in 2000 and 2001 fail to caution against or warn of this risk? The incomplete EIA report led the project to go to square zero after 26 years of hard work and the expense of 31 billion Nepalese rupees. Not only the MWSP project but also the Asian Development Bank (ADB) that supplies climate resilience expertise to projects lacked anticipatory resilience while sending the Melamchi flooding study team in December to Bhremathang. Without looking into the weather forecast, they selected the study dates. The weather forecast as we have seen is pretty accurate in predicting the snow storm in the advanced nations.

Figure 16 State of Resilience Revealed by Seti and Melamchi Flooding

Resilience type	Individual level	Institutional level
Instinctive Resilience	<p>Strength: Seti River—Pilot Alexander contacted Pokhara Airport to inform unfolding flooding in Seti River</p> <p>Strength: MSWP—The Municipality ward chairman's action to inform local people to evacuate and go to safe place</p>	<p>Weakness: Seti River—The inability of the authority to instinctively and effectively respond and save lives once the unfolding disaster message was received</p>
Anticipatory Resilience	<p>Weakness: Seti River: People's inability to notice and anticipate the sudden drying of Seti River, as a sign of GLOF possibility.</p> <p>Weakness: MWSP: The project planners, managers, experts, and employee's inability to notice, sense and anticipate risks. Their inability to stand up and speak the truth about anticipated risks</p>	<p>Weakness: Seti River—The authorities' inability to notice and anticipate the sudden drying of Seti River, as a sign of GLOF possibility</p> <p>Weakness: MWSP's inability to research and anticipate the GLOF possibility at the MWSP</p> <p>Weakness: MWSP—the inability of the MWSP's EIA report to identify and highlight the geological and glacier lake outburst and flooding vulnerability</p> <p>Weakness: ADB—Inability to sense the sensitivity of the season and weather while deploying Melamchi flooding study team</p>

To sum up, the work of the pilot and the ward chairman hints well at the importance of instinctive resilience during unfolding disasters. The lessons from the flood destruction at MWSP and the

ADB's resilience study team management significantly elevate the importance of anticipatory resilience in dealing with development projects and disasters.

CONCLUSION

The two case studies suggest that instinctive and anticipatory resilience play crucial roles in saving lives and minimizing damages to properties, settlements, infrastructures, and hydropower projects from climate change-related disasters, GLOFs. Instinctive resilience is proactive action during an unfolding disaster. Its contribution is huge when time is too short to save lives and properties. Anticipatory resilience is best at the project planning stage. It can avert post-project disasters by sensing, anticipating, and addressing adverse impacts on the project at the project planning stage. It enables early action before it is too late. Instinctive and anticipatory resilience is about setting habits or initiating a new culture to deal with uncertainty and disaster risks. Embracing resilience both at the individual and institutional level is essential for coping with and adapting to disasters, including GLOFs.

RECOMMENDATIONS

Instinctive Resilience

Individual level: The individual citizen, the people living and working along the riverside should be watchful: if they see some flooding unfolding upstream, they should inform as many people as possible downstream, make phone calls, tell the people to leave the settlement, and go to higher grounds. In particular, local residents living near the snow-fed

rivers should be cautious and watchful if the water in the river suddenly dries up. It may be an indication of upstream river blockage due to landslides and a possible building up of river flood outburst. People living near those rivers should consider relocating their settlements to safer uplands. It is critically important to educate, inculcate, and internalize instinctive resilience to all, including those living and working near disaster-prone rivers and locations. School and college curricula must offer resilience training such as swimming, rescuing, and other drills.

The case from Seti River, Pokhara unfolds the role of pilots in climate change and disaster risk reduction in society through their ability to observe disasters and warn the ground for possible risk reduction. The Civil Aviation Authority of Nepal (CAAN) can play an important role by encouraging pilots to be disaster watchdogs and whistle-blower without compromising their air safety responsibilities. They can act as early-warner from the sky globally. Some of the key individuals whose instinctive resilience can save many lives and prevent property damage are ordinary citizens, mountain and riverside residents, road, bridge, dam, and hydropower project managers and employees.

Institutional level: The local municipal ward chairman and all representatives, including mayors, apply their instinct immediately to inform and evacuate people from the potential GLOF threat zone at the time of unfolding disaster. Use bulk text message, alarms, loudspeakers, radio to warn. Immediately mobilize municipal firefighters rescue team, and boatman on the ground. Mobilize Tol Bikash Samiti members for rescue and relief. The federal government deploys all necessary resources including helicopters, army, and police for search and rescue. The concerned federal



agencies are the National Disaster Risk Reduction Authority (NDRRA), the Home Ministry, the Ministry of Defense, and the Department of Meteorology.

Anticipatory Resilience

Individual level: The MWSP has taught us that at the project planning stage, the planners, project managers, and decision-makers should come out of the narrow (tunnel vision) project approach and embrace eagle vision to see what is going around the projects and anticipate what are the external threats to the project. For that matter, they should pay serious attention to the issues related to climate change risks, including local geology and glacial vulnerability. Next, project planners and managers should not stay blind to the project risks and look for evidence that highlights benefits. To counter such biases, project planners and designers must invite and receive wider criticism from all stakeholders, including local people. They must listen to project employee's observations and local people's experiences. The project experts involved in road, bridge, dam, hydropower, and land use control are critical in spotting risks and daring to tell the truth to avert possible future disasters in the face of looming climate change, heavy rain, flooding, and GLOF.

Institutional level: It is imperative that the projects like MWSP in Nepal take into account all the internal and external project risks, including climate-related disasters, at the project planning stage. Make sure that the project receives broader views and town hall meetings. It invites public criticism and listens to the critical take of the experts in order to better anticipate both internal and external

risks. In Nepal, most town hall meetings and comment-seeking are just a formality. The authorities mostly hear but don't listen. In the end, they do what they want. It should change. The EIA report should not be a document to justify what the project is doing. It should not hide crucial project risk factors such as GLOF and landslides, as we saw in MWSP. The autonomous committee of diverse experts and environmentalists should approve the EIA report in order to avoid false project praise.

Figure 17 What We do to Enhance Instinctive and Anticipatory Resilience in Society?

Resilience type	Individual	Institutional
Instinctive Resilience	<ul style="list-style-type: none"> Local residents living near the snow fed rivers should be cautious and watchful if the water in the river suddenly dries up. It may be an indication of upstream river blockage. They should consider relocating their settlements to higher grounds. Educate and internalize instinctive resilience to every individual to make them alert and responsive to any uncertainties and disasters. Training to be proactive in alerting, helping and rescue, and swimming ability Encourage airplane pilots to be disaster-watchdog and whistleblower to any unfolding disasters including GLOF. Civil Aviation of Nepal can encourage pilots to be sensitive to this social responsibility. Key stakeholders: All residents; people living nearby snow fed and flood prone rivers, fisherman, boatman, shepherds, employees and owners of hydropower projects, dam, bridge and road in-charge 	<ul style="list-style-type: none"> The local ward chairman and all representatives, including mayor apply their instinct immediately to inform and evacuate people from the potential GLOF threat zone. Use bulk text message, alarms, loudspeakers, radio to warn. Prompt mobilization of municipal firefighters and rescue team, boatman on the ground. Mobilize Tol Bikash Samiti. The federal government apply its instinct to deploy all rescue and relief resources Key stakeholders: Mayor, Ward Chairman, Members of Tol Bikash Samiti, NDRRA, Ministry of Home, Ministry of Defense
Anticipatory Resilience	<ul style="list-style-type: none"> The project planners embrace eagle vision approach to spot and anticipate external threats, including climate related disasters right at the planning stage The project planners and designers should not ignore geological and glacial vulnerability, in the face of rising climate change They should not fall prey to project biasness and they should dare to tell the truth to avert possible future disasters in the face of looming climate change, heavy rain, flooding, and GLOF. Key stakeholders: Project planners, designers, experts, decision makers, employees, employers, and engineers, land use planners, geologists 	<ul style="list-style-type: none"> Institutions need to invite wider criticism to spot and anticipate external risks at the planning stage, and avert post-project disasters. An autonomous committee of diverse experts and environmentalists approve the EIA report to maintain its integrity. It is important that the agencies such as ADB and World Bank show resilience in their climate resilience tasks. Key stakeholders: Dam, hydropower, and infrastructure development agencies, government regulatory bodies, land use and zoning agencies, and EIA professionals

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Enhancing Operational Resilience in Delivering Clean and Renewable Energy: Integrating Multidisciplinary Approaches to Mitigate Flood and Landslide Hazards in Geothermal Production Fields

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ABSTRACT

Climate change is increasingly affecting the Philippines, bringing extreme weather events in recent years. With the country being frequently affected by natural hazards, it is imperative that proactive hazard mitigation strategies be employed to ensure the stability and efficiency of power plants for an uninterrupted supply of energy despite adverse weather conditions. In the highlands, critical infrastructures like geothermal power facilities have experienced significant damage, leading to power outages as operations were affected by major flooding and debris flows that swept away multiple steam pipelines. This prompted comprehensive hydrologic and hydraulic studies across geothermal production fields, aiming to determine flood scenarios, assess risks to infrastructures, and identify effective risk reduction measures to mitigate hazards such as flash floods, and debris flow. This study employs a multidisciplinary approach, integrating hydrologic- hydraulic modeling techniques and landslide inventories to identify vulnerable areas. Remote sensing also revealed that at least sixty-five landslides have occurred within the watershed. Some could be reactivated and may contribute significantly to the sedimentation and clogging of the structures. Risk assessments were conducted to prioritize mitigation measures based on their potential impact, enabling decision-makers to allocate resources efficiently and address the most critical risks promptly. The findings underscore the importance of collaborative governance in climate adaptation and risk mitigation. By combining expertise from various disciplines and engaging stakeholders, robust strategies can be developed to ensure sustained clean energy delivery amidst increasing climate shocks.

1. INTRODUCTION

1.1. The Philippines' Exposure to Climate Shocks

The Philippines is an archipelago located west of the Pacific Ocean, where numerous tropical storms and typhoons are generated annually. These typhoons take landfall in the Philippines bringing heavy rains which cause various hydro-meteorological hazards such as flooding, rain-induced landslides, and debris flows causing damage to properties, disrupting operations of various industries, and tragic loss of lives.

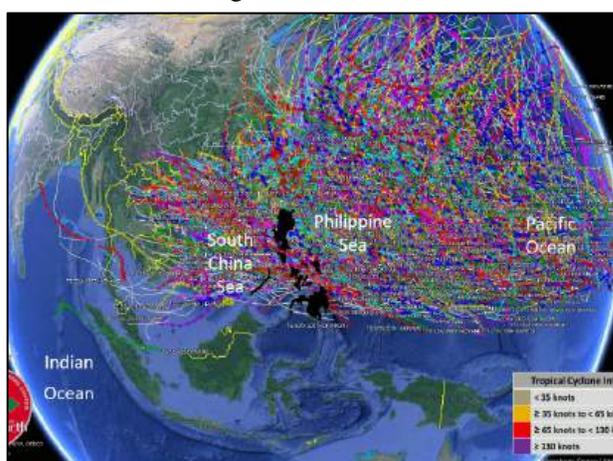


Figure 1. Pacific Tropical Cyclone Tracks from 2007 to 2022.

A study revealed (Eckstein, 2020) that the country is among the top 10 most affected by climate-related extremes between 1999 and 2018. The immense impacts of climate change were observed in changes of annual rainfall patterns and distribution, unpredictable onset of droughts, and sea level rise, among others, which resulted to losses in GDP (NICCDIES, 2018). This was supported

Rank	Country	Risk
1.	Philippines	46.91
2.	Indonesia	41.13
3.	India	40.96
4.	Colombia	37.81
5.	Mexico	35.93
6.	Myanmar	35.85
7.	Mozambique	34.44
8.	Russian Federation	28.12
9.	Bangladesh	27.73
10.	Pakistan	27.02

Figure 2. Excerpt from the World Risk Report 2024

by the World Risk Reports in 2023 and 2024 identifying the Philippines as the top country with the highest risk index in the world in the last two years. Given its vulnerability to climate-related disasters, the Philippines, like many other nations, faces a growing imperative to reduce its carbon footprint and enhance resilience to climate shocks.

1.2. The global shift towards renewable energy to contribute to climate resilience

The urgent need to reduce carbon emissions and mitigate climate change drives global efforts to shift towards renewable energy. Countries are increasingly investing in solar, wind, geothermal, and hydropower technologies, aiming to transition away from fossil fuels. International agreements, such as the Paris Agreement, have set ambitious targets for reducing greenhouse gas emissions, encouraging the development of cleaner energy sources. Technological advancements and decreasing costs have made renewable energy more accessible, supporting widespread adoption in both developed and developing nations. These efforts are critical for achieving net-zero emissions and limiting global temperature rise to below 1.5°C.

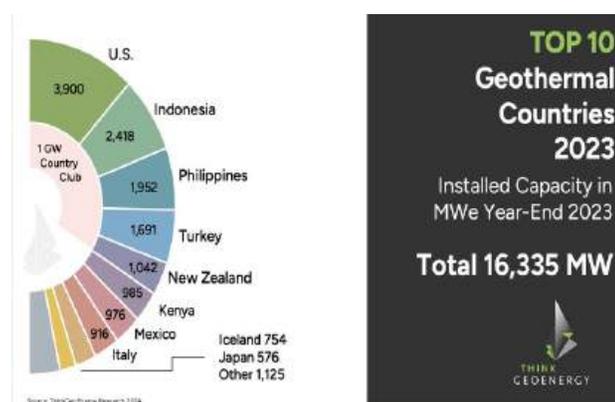


Figure 3. Top 10 Geothermal countries with the most installed capacity in MWe towards the end of 2023.

Image Source: Thinkgeoenergy.com

In 2023, the Philippines is listed as the third largest producer of geothermal energy globally, with 1,952 MW capacity. This is largely attributed to its unique geological position along the Pacific Ring of Fire. This tectonically active region is characterized by high volcanic activity, providing the country with abundant geothermal resources. The heat generated from underground volcanic processes makes geothermal energy a reliable and

sustainable source of power in the Philippines. With several large geothermal fields, such as those in Leyte, Mt. Apo, Sorsogon, and Negros, the country has been able to harness this energy to reduce its dependence on fossil fuels.

1.3. Objectives

This paper presents multidisciplinary approaches that incorporate hydrologic, hydraulic, geological, and geotechnical studies to reduce the impacts of floods and landslides on geothermal facilities. These technical approaches are vital in creating infrastructure that can withstand climate-related disruptions, ensuring that energy production remains stable even under adverse conditions.

2. CHALLENGES IN GEOTHERMAL PRODUCTION DUE TO CLIMATE SHOCKS

The Philippines' geothermal energy facilities are uniquely vulnerable due to their location in hazard-prone areas, primarily because of the country's geological setting along the Pacific Ring of Fire. Geothermal production fields are often situated in mountainous terrains, where the topography increases the risk of landslides, especially during the rainy season and in the event of prolonged or extreme weather conditions, such as typhoons. These slopes can become unstable when subjected to heavy rainfall, leading to debris flows and landslides that can damage infrastructure, disrupt operations, and pose significant safety risks to personnel.

Additionally, many geothermal facilities are placed on relatively flat grounds which could be affected by nearby watersheds and make them exposed to flooding and other hydrological hazards. Continuous or intense rainfall can cause rivers and streams to overflow, threatening geothermal infrastructure like pipelines, access roads, and drilling pads. Flooding not only damages physical assets but also causes operational delays, as access to these areas becomes restricted and safety concerns escalate. In some cases, debris from landslides can block natural drainage paths, compounding flood risks by diverting water flow into critical operational zones.

The combined effects of these hazards—landslides and floods—can severely impact the reliability and safety of geothermal energy production.

2.1. Impact of Extreme Weather Events to Energy Infrastructures in the Philippines

In December 2017, heavy rains from Typhoon Kai-Tak (locally known as Typhoon Urduja) caused significant flooding and debris flow at the geothermal power plant facilities. The downpour began on December 15 and peaked on December 16, with rain gauges on-site recording a maximum hourly rainfall of 70.5 mm. This extreme weather event resulted in approximately 6 billion Philippine pesos in losses, including damage to assets and a suspension of operations.



Figure 4. Impact of Typhoon Kai-Tak in a geothermal production field in the province of Leyte, Visayas Islands.

On February 10, 2024, a huge landslide affected an access road to a geothermal drilling pad at Maco, Davao de Oro in Mindanao Island Philippines. The slope failure occurred following three weeks of continuous rainfall in the area. The landslide debris extended more than 50 meters into the lake, and formed as a fan-like deposit, which is similar to the old landslides in the region that were identified

through remote sensing. The debris include dislodged rock blocks, disintegrated tuffaceous rocks, residual soils, and uprooted trees. The landslide event significantly disrupted the exploration and development schedule of the geothermal project, underscoring the impacts of extreme weather events on energy delivery.

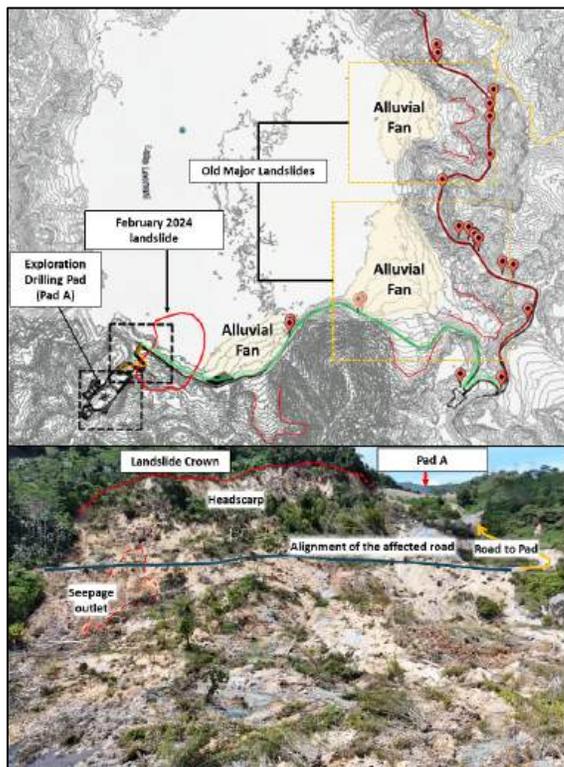


Figure 6. (Top) Detailed topographic data shows the presence of landslide scars at the eastern and southern side of the inner caldera rim where the access roads are located. (Bottom) An aerial shot of a landslide occurred last February 2024.

3. MULTIDISCIPLINARY APPROACH TO MITIGATE FLOOD AND LANDSLIDE HAZARDS

3.1. Hydrologic and Hydraulic Studies: Mitigating Floods and Debris Flow

Flooding is a natural consequence of the hydrologic cycle. It results from a combination of excessive precipitation and saturated or impervious ground conditions, wherein the surface runoff exceeds infiltration (National Oceanic and Atmospheric Administration, n.d.). Hydrologic analysis involves the study of these processes to define the

movement and distribution of water in the environment. In synergy with this, hydraulic analysis is performed to determine the behavior of water within water systems such as rivers and channels.

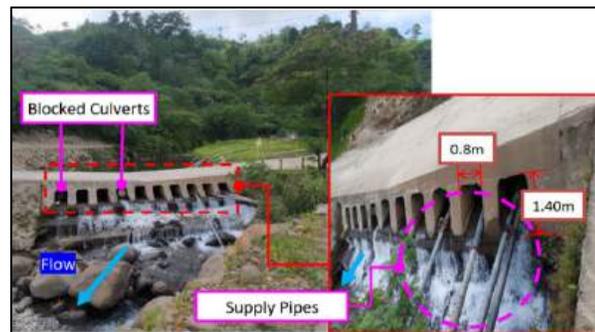


Figure 5. Conditions of hydraulic structures observed and noted during field inspections.

The process begins with the collection of data. Secondary data such as meteorological records, topographic maps, digital elevation models (DEM), existing flood hazard maps from government agencies, and land use maps, are compiled to establish baseline conditions. These datasets are complemented by site visits, which provide field-based observations for validation and refinement of the gathered data.

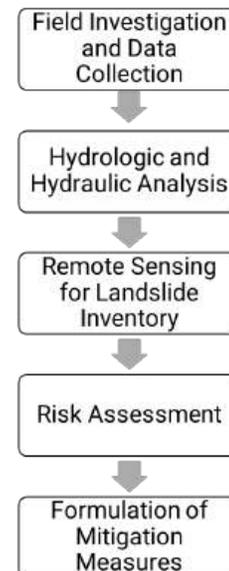


Figure 7. Simplified process flow of the assessment.

The gathered data is then used for the hydrologic model. This entails the delineation and characterization of watersheds, the application of historical rainfall, and the identification of key waterways and outfalls to simulate

surface runoff and obtain peak discharges at key points in the form of flow hydrographs. Moreover, synthetic hietographs are generated to represent water rainfall distribution over time, depicting varying weather conditions (25-, 50-, and 100-year return periods).

Hydraulic models are generated using HEC-RAS (Hydraulic Engineering River Analysis System), a program developed by the US Army Corps of Engineers, to simulate two-dimensional unsteady flow and sediment transport on the study area. Additionally, dam break analysis is performed using the HEC-RAS software to predict the impact of landslide-induced damming within the waterways. The hydraulic models entail the generation of a two-dimensional geometry which covers the areas of concern within the project site and considers the topographic data, inflow hydrographs, and synthetic hietographs as the main input data. Other important considerations in the model include the properties of the hydraulic structures (culverts and spillways) and bed gradation or subsurface particle size distribution for the sediment transport analysis. From the analysis results, drainage structures within the project site are assessed for adequacy by determining whether the existing dimensions cater to the simulated peak flow conditions. Additionally, the culverts and spillways within the project area are assessed under varying debris flow scenarios, namely half-blocked and fully blocked culverts to quantify the worsening effects of the blocked scenarios.

Moreover, it was assessed whether the locations of geothermal pipelines are susceptible to debris flow and scouring through the evaluation of the flow velocity, flood depths, and scour depths. These specific checks are performed based on the history of flood and debris flow-induced damage to the site facilities.

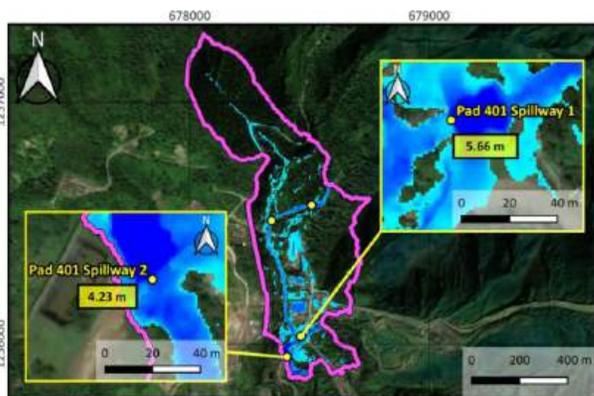


Figure 9. Maximum inundation model for a spillway adjacent to a geothermal pad,

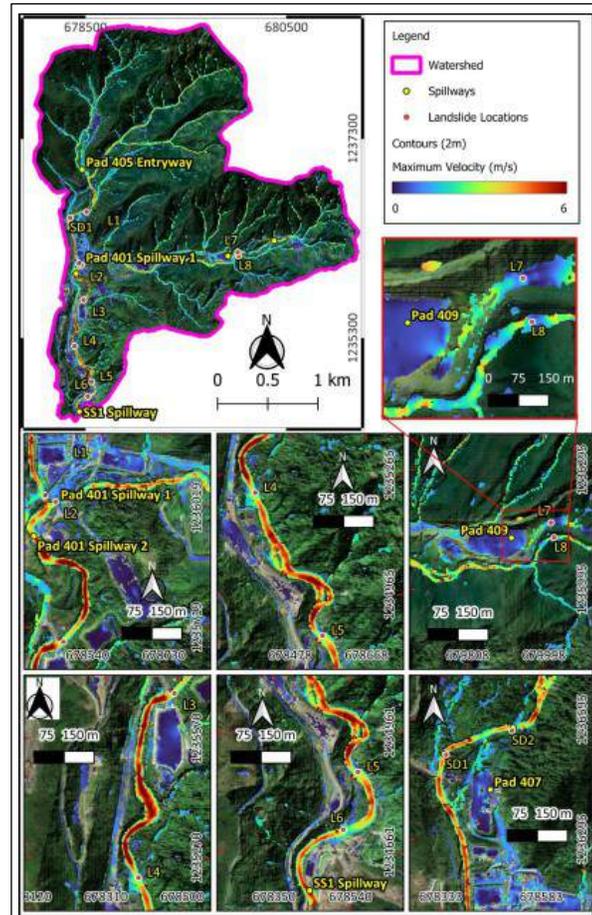


Figure 8. Sample generated inundation map showing the maximum flood velocity model

3.2. Landslide Hazard Assessment

Commonly, geothermal sites are prone to landslides due to the inherently weak rock and soil properties. In volcanic areas, heterogenous and fractured rock masses are prone to this type of degradation when hydrothermal fluids seep through the cracks and cause chemical reactions to the surface in contact. This is very evident on the rust-colored boulders and soil observed in the area.

Previously observed landslides on-site revealed volcanic rocks of various properties including bedded friable tuff, and hydrothermally altered rocks, overlain by either thick loose colluvium or residual soils. The slope materials were mostly oxidized, which is common in active geothermal fields. When rocks are oxidized, they become less resistant to weather and may cause degradation to the overall strength of the slope which may result to instabilities (Pereira ML, 2024).

An assessment is usually undertaken to determine if a site or facility is exposed to landslide hazards, and the

results also provide a basis for determining the site's susceptibility to debris flow.

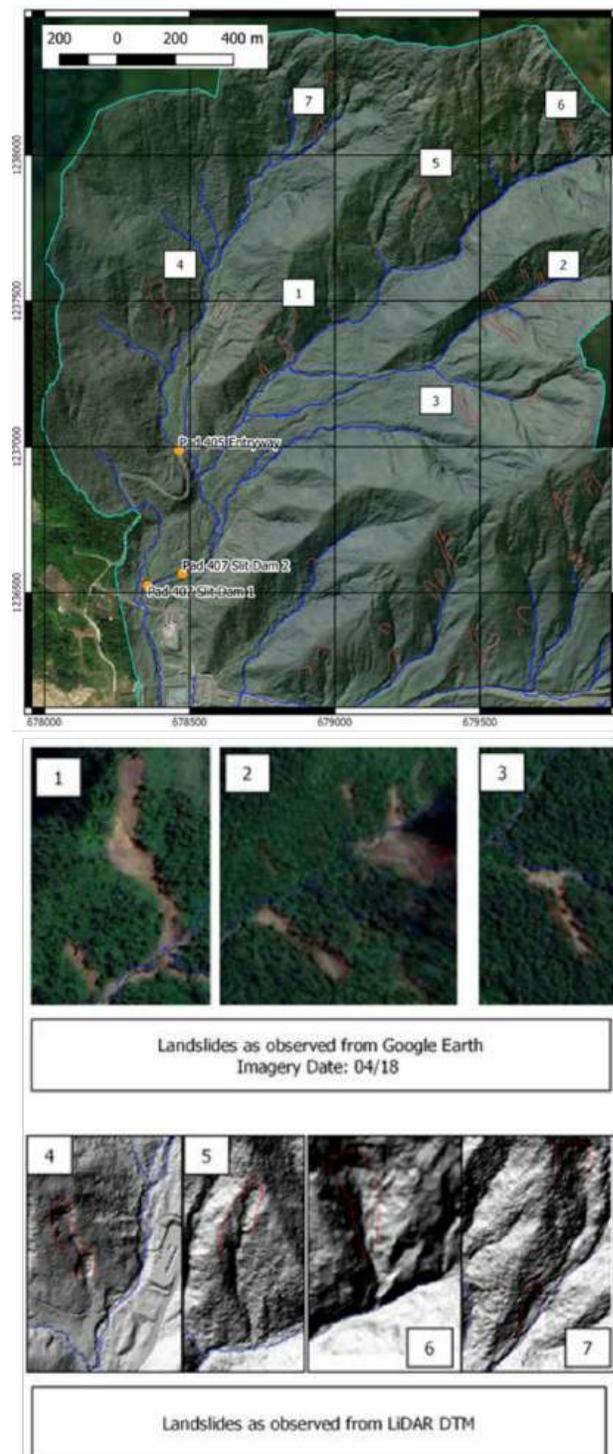


Figure 10. Remote sensing of landslides in a catchment area within a geothermal field in Leyte, Philippines.

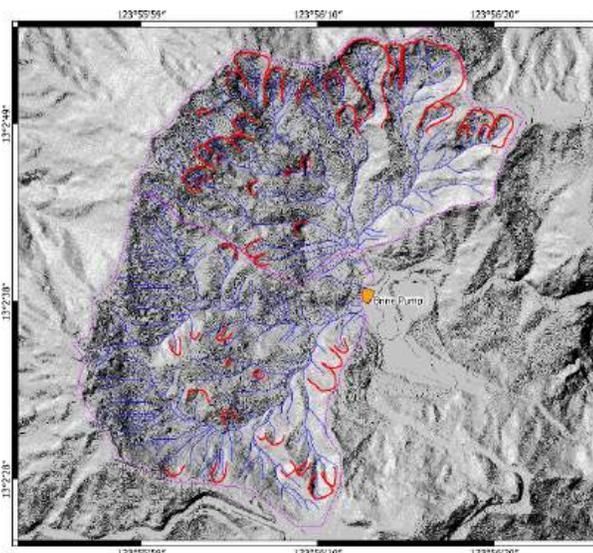


Figure 11. Mapped landslide scars within two catchment areas that drain towards a brine pump facility.

Landslide scars are delineated through morphological interpretations of LiDAR topographic maps. The preliminary interpretation was then compared with imagery and field observations for their relative aging. Barren landslide scars or those without vegetative cover are classified as active. Scars with thin vegetative covers composed of grass, shrubs, bushes, and fast-growing trees are classified as recent landslides. These usually have a light green color on images and in the field. Highly vegetated scars are classified as old landslides. It should be noted that reactivation of old landslides is always a possibility especially if their toes are cut by earthmoving.

3.3. Geotechnical Studies and Engineering Solutions

The slope stability analysis utilizes the Limit Equilibrium Method (LEM), wherein the mass is divided into small slices along an assumed or known failure surface. The surface and subsurface soil properties are determined using the available borehole data and site reconnaissance observations. The analysis considers varying levels of porewater pressure buildup (saturation) for both static and pseudo-static loading conditions. The representative sections are then modeled using a computer software (Rocscience SLIDE) to determine the factors of safety (FoS).

If the obtained FoS is inadequate, suitable remediation schemes which can be a combination of different types of

slope stability measures and drainage systems are designed to address the critical slope failures and mitigate against possible geohazards such as landslides, debris flow, and earthquakes. Some of the commonly used slope stability measures are retaining walls, soil nails, mechanically stabilized earth (MSE), gabions, geotextiles, and sheet piles. Drainage systems such as interceptor canals, cascading chutes, and subsurface drainage are designed to reduce porewater pressure build-up.

Erosion control and rockfall prevention measures such as geomats, coconets, and steel grids are also recommended as additional slope protection. Slope monitoring such as the installation of the Geohazard Early Detection Instrument (GEDI) system are also implemented as early warning systems for landslides. During the design process, several factors such as cost of construction, availability of materials on site, and deployment of equipment must be considered to optimize the slope remediation scheme.

4. MONITORING, EARLY WARNING, AND MITIGATION SYSTEMS

The Geohazard Early Detection Instruments (GEDI) are crucial tools used to monitor ground movement and progression, especially in areas prone to natural hazards like landslides and subsidence. In geothermal production fields, which are often located in high-risk, mountainous regions, these instruments play a vital role in ensuring operational safety and resilience. They enable monitoring of ground stability, providing information to safety officers and site personnel that could aid in decision-making especially in the suspension and resumption of work activities during rainy seasons. This allows early warnings that help mitigate the risk of catastrophic failures due to landslides, or slope instabilities.

GEDIs are equipped with sensors to detect ground inclination/movement and moisture content which provide indications of incipient slope movement. Rain gauges are also installed to record the landslide-triggering amount of rainfall on a certain location on-site.

Continuous monitoring of rainfall intensity and accumulation helps correlate precipitation data with ground movements. High-intensity, prolonged rain events often lead to increased soil moisture and instability, making these tools essential for understanding when conditions are ripe for slope failure.

5. GOVERNANCE AND POLICY FRAMEWORK FOR CLIMATE RESILIENCE

In 2019, GeoRiskPH was launched with a vision “to be the Philippines’ central source of information for accurate and efficient hazards and risk assessment to help the government increase the nation’s resilience to natural hazards” (PHIVOLCS, 2023). The GeoRisk Philippines Integrated Platform (GRIP) allows stakeholders to access various GeoRiskPH products and services including the HazardHunterPH which is widely used to identify various geohazards in specific locations within the entire country on a regional scale. It also provides crucial information such as distance to the nearest active faults and volcanoes, earthquake events, and even landslides and liquefaction-prone areas.

The multidisciplinary approach discussed in this paper promotes integrated risk management that is well-aligned with the efforts of Philippine government agencies to enhance for risk reduction and climate resilience through data-driven governance. It utilizes the secondary data publicly provided by the government for literature review on a regional scale, and employs site-specific solutions based on ground observations at an engineering scale. For geothermal energy fields in hazard-prone areas, collaboration between geologists, engineers, hydrologists, and stakeholders is crucial for reducing risk.

6. OPERATIONAL RESILIENCE: LESSONS LEARNED AND APPLIED PRACTICES

The experience of floods and landslides has significantly shaped the operational resilience of geothermal energy production in the Philippines. These events have served as critical learning opportunities, prompting a more proactive approach to risk assessment and mitigation. The importance of conducting geohazard assessments across all sites is recognized. This practice was initiated as a direct response to the perceived impact of a natural hazard or damage sustained at the exposed facilities, where the understanding of site-specific vulnerabilities became paramount. Such assessments involve evaluating geological conditions, hydrological factors, and historical data to ascertain potential risks.

The initial geohazard assessments serve as a scoping mechanism that helps prioritize sites needing more in-depth analysis. When significant hazards are detected, these assessments trigger further hydrological or

geotechnical studies to develop targeted mitigation measures. For example, if a geohazard assessment identifies a high risk of landslides due to unstable soil conditions, the next step would involve detailed soil analysis and the design of slope stabilization measures. This approach allows for a more efficient allocation of resources and ensures that interventions are based on specific, localized data.

Lessons learned from previous incidents have led to the formulation of more effective mitigation strategies. Following the identification of risks through geohazard assessments, structural changes such as improved drainage systems, vegetation management for slope stabilization, and the construction of retaining walls can be implemented.

7. CONCLUSION

The proactive measures implemented by energy business units in the wake of floods and landslides exemplify how organizations can enhance their operational resilience through systematic risk assessments and targeted mitigation strategies. By embedding these practices into their operational frameworks, they not only safeguard their facilities but also ensure the uninterrupted delivery of renewable energy, contributing to broader national goals of climate resilience and sustainable development.

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Factors of Global Warming and Direct Mitigation Measures to Climate Shocks

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ABSTRACT

The greenhouse gases like carbon dioxide, methane, nitrous oxide, and other artificial fluorinated gases that increase warmth trapped within a globe's atmosphere are responsible for increasing of global temperatures. In the same regard, land use and cover change, including deforestation, urbanization, and expansion of agricultural land affects climate system by disturbing energy flow and enhancing CO₂ emissions. Emissions of methane and black carbon are especially emphasized for their global warming capacity and their negative impacts on human health and environmental conditions at the regional level, respectively. The mitigation measure plan entails phasing out of fossil fuels and increased use of renewable energy like solar, wind, and geothermal energy and improvement in energy efficiency in transport, industry and buildings. Renewal energy, reforestation and afforestation procedures are underlined as vital approaches of establishing carbon pools that remove CO₂ from the atmosphere. Environmental protection technologies include saving soil, water and energy through accuracy farming, and organic farming all of which address the issue of emissions while on the other hand, Curbing methane emission from landfills by improving waste management and technological practice like recycling and composting. Recycling is promoted with proper segregation of materials and a circular economy is recommended. The necessity of prompt and consistent actions implemented and performed on personal, neighborhood, industrial, and governmental levels is stressed to respond to the global warming environmental issues. Through such combined mitigation and adaptation measures, risks and impacts of climate change shocks may be prevented and discouraged for future generations and social sustainability. The duty to respond lies with everyone in the community therefore indicating call for concerted actions to protect ecosystems and strengthen climate resilience.

INTRODUCTION:

Global warming, driven primarily by human activities, presents a significant challenge to our planet's ecosystems and human societies. It is crucial to comprehend the factors contributing to global warming and implement effective mitigation measures to address climate shocks directly.

The consequences of climate change are far-reaching and affect every corner of the globe. Rising temperatures result in melting ice caps, leading to sea-level rise and threatening coastal communities. Extreme weather

events, such as droughts and heat waves, become more frequent and severe, causing widespread devastation.

Global warming is a pressing environmental challenge characterized by the gradual increase in Earth's average surface temperature due to rising concentrations of greenhouse gases (GHGs) in the atmosphere. This paper explores the primary factors contributing to global warming, including anthropogenic activities and natural processes, while proposing direct mitigation measures to alleviate the impacts of climate shocks. The analysis underscores the importance of

immediate action to curb emissions, enhance resilience, and promote sustainable practices.

PURPOSE:

It becomes evident that our actions have far-reaching consequences. Therefore, the urgency to address these environmental challenges cannot be overstated. Climate change, biodiversity loss, and resource depletion require immediate attention and concerted efforts from individuals, communities, governments, and businesses.

The phenomenon of global warming has far-reaching implications for ecosystems, human health, and global economies. The Intergovernmental Panel on Climate Change (IPCC) has highlighted that human activities, particularly fossil fuel combustion, deforestation, and industrial processes, are the primary drivers of climate change. Understanding the factors contributing to global warming is essential for developing effective mitigation strategies. This paper aims to delineate these factors and present direct measures that can be implemented to mitigate the effects of climate shocks.

1. GREENHOUSE GASES

Climate change is primarily driven by the greenhouse effect. Certain gases in the Earth's atmosphere function similarly to the glass of a greenhouse, capturing the sun's heat and preventing it from escaping back into space, which results in global warming. As these greenhouse gases accumulate, they trap heat, leading to rising global temperatures and shifts in climate. Currently, the planet is experiencing unprecedented warming rates. Over time, these increased temperatures are altering weather patterns and disrupting the natural equilibrium.

Carbon dioxide (CO₂), a byproduct of burning fossil fuels, is the main greenhouse gas linked to global warming. Other significant contributors include methane, nitrous oxide, and various industrial gases. Collectively known as greenhouse gases (GHGs), these substances in the atmosphere capture heat. During the day, sunlight warms the Earth's surface, and at night, this heat is released back into the atmosphere. However, greenhouse gases retain some of this heat, maintaining the Earth's average temperature at around 14°C (57°F).

The greenhouse effect functions like the glass walls of a greenhouse; without it, temperatures could plummet

to -18°C (-0.4°F), which would be uninhabitable for most life forms. Human activities are significantly altering this natural process, leading to a dramatic rise in greenhouse gas emissions. Since the Industrial Revolution, the volume of these gases released has surged, correlating with an increase in global temperatures over the last 30 years, making them the highest on record.

1.1 Main Greenhouse Gases

1. **Carbon Dioxide (CO₂):** Naturally produced through volcanic eruptions, respiration, and decomposition, CO₂ levels have surged by 50% since the Industrial Revolution due to human activities like fossil fuel combustion and deforestation. This makes it the primary driver of climate change.
2. **Methane:** This gas is generated through natural decomposition, but human practices, such as cattle farming and landfill operations, have significantly increased methane emissions.
3. **Nitrous Oxide:** Produced from extensive use of fertilizers, fossil fuel combustion, and other industrial processes, nitrous oxide also contributes to greenhouse gas emissions.
4. **Water Vapor:** Although the most abundant greenhouse gas, water vapor levels rise with temperature and only remain in the atmosphere for a short time compared to CO₂.

While the gases mentioned above occur naturally, their elevated concentrations are largely due to human activities. In contrast, industrial fluorinated gases—hydro fluorocarbons (HFCs), per fluorocarbons (PFCs), and sulfur hexafluoride (SF₆)—are entirely human-made and do not exist in nature. Though found in small amounts, they are highly effective at trapping heat, with SF₆ having a global warming potential 23,000 times greater than CO₂.

1.2 Reducing Greenhouse Gases

To mitigate greenhouse gas emissions, a transition away from fossil fuels like coal, oil, and gas toward renewable energy sources, such as solar and wind power, is essential. Everyone can contribute to protecting the planet through everyday actions like recycling and reusing materials, as well as making significant lifestyle changes, such as adopting electric vehicles.



2. Land Use Changes

Climate interacts with changes in land cover (the physical attributes of the land, such as vegetation or urban surfaces) and land use (human activities and management of land, like farming or development). For instance, a forest may have tree cover but could also include areas where trees have been cut down, now featuring grassland. Land cover and land use are interconnected: alterations in land use can modify land cover, and specific land covers support certain uses. Understanding the variations in land cover, use, condition, and management over time and space is complex. While remote sensing can estimate land cover, determining land use often requires local data, such as field surveys. Challenges arise from factors like terminology consistency, time scales, data sources, and methodologies. Different methods of classification may yield varying insights at different scales, making it crucial to select appropriate data sources and clearly define measurement parameters.

Changes in land cover can result from both human actions and climate influences. For example, expanding settlements can lead to the permanent loss of natural areas, affecting local weather patterns, temperature, and precipitation. Over larger regions, these changes can impact Earth's climate by altering circulation patterns, changing surface reflectivity, and affecting atmospheric CO₂ levels. Conversely, climate change can also lead to changes in land cover, such as forest loss due to climate-related disturbances, the encroachment of woody plants into grasslands, and the degradation of coastal wetlands from rising sea levels.

Land use shifts are similarly driven by human and climatic factors. Economic considerations often guide land-use decisions, which are increasingly influenced by global market trends. Additionally, policies at various governmental levels can drive changes in land use, such as programs that remove farming from erosion-prone areas, regulations addressing sea level rise, or incentives for expanding energy crops. Technological advancements have also played a role, enabling irrigation and influencing the conversion of agricultural lands based on crop productivity trends. For instance, recent growth in oil and gas extraction illustrates how policy, economic factors, and technology can collectively alter land use and cover.

Land use also adapts to climate and weather

variations. For example, droughts may lead to arable land being left fallow or converted to open water during heavy rainfall. Rising temperatures can adversely affect agricultural yields, while climate change may also extend growing seasons in northern regions. Forest management is particularly vulnerable to weather changes; for instance, droughts in California have resulted in significant tree die-offs, affecting timber production. Insect outbreaks in western North America have been linked to climatic changes, which could create feedback loops in the climate system. Additionally, rising sea levels may necessitate adjustments in coastal land use, with increased flooding frequency affecting areas previously unaffected.

Decisions regarding land use, cover, and management are crucial for society's capacity to adapt to and mitigate climate change. Enhancing land-based carbon storage can help lower atmospheric greenhouse gas levels. This can be achieved by expanding forested areas, stabilizing soil and forest carbon storage, preventing the release of stored carbon from disturbances, and increasing carbon retention in wood products. However, uncertainties remain about future decisions and the overall impacts of changes in land use and cover.

2.1 Land-Cover Changes Influence Weather and Climate

Changes in land cover significantly affect weather and climate at local and global scales by modifying the flow of energy, water, and greenhouse gases between the land and the atmosphere. For instance, reforestation can lead to localized cooling, while urban areas are likely to experience intensified warming due to the urban heat island effect.

The relationship between land-use and land-cover change (LULCC) and climate is intricate. The specific impacts depend on various factors, including the nature of the land changes, the scale of analysis (local, regional, or global), the size of the affected area, the climate aspects being evaluated (such as temperature or precipitation), and the geographic location of the changes.

Recent research indicates that forests generally have cooler temperatures compared to herbaceous croplands in many temperate regions. Reforestation in these areas can promote cooling, with the effect diminishing as latitude increases. The extent and location of reforestation will influence the degree of cooling. Changes in biogeophysical factors (like albedo, surface

roughness, and transpiration) typically result in localized climate effects, while biogeochemical changes (such as carbon sequestration) have broader, more global implications. Thus, reforestation serves as an effective strategy for climate mitigation and adaptation.

Wildfires in forests, grasslands, and agricultural lands influence climate in two main ways: first, by releasing carbon and other greenhouse gases into the atmosphere, and second, by increasing aerosol concentrations that can temporarily enhance atmospheric reflectivity, thereby reducing solar energy reaching the Earth's surface. Climate also significantly influences fire regimes—patterns of fire occurrence characterized by size, severity, and frequency. Most indicators of fire regimes in the United States are on the rise. However, the overall impact of altered fire regimes on climate remains uncertain, as the warming from carbon emissions might be counterbalanced by increased atmospheric reflectivity and carbon storage from re-growth.

Urban areas possess several characteristics that affect climate, including construction materials that retain heat more than vegetation, impervious surfaces that limit cooling through evapotranspiration, and building designs that trap heat. These factors contribute to the urban heat island (UHI) effect, making cities warmer than their rural surroundings. While urbanization has a minor influence on global temperatures, its effects are more pronounced in regions with significant urban development. The severity of the UHI effect tends to be more intense in the eastern United States compared to the west. Additionally, urbanization may potentially enhance precipitation downwind, although evidence for this is inconclusive. Climate change could also interact with future urbanization, increasing the frequency and intensity of flood events.

Water management for agriculture also influences climate. From 2002 to 2007, irrigated land in the United States expanded by about 1.3 million acres, particularly in the Great Plains. In 2012, approximately 88.5 million acre-feet of water were applied to about 55 million acres of irrigated farmland. Globally, the volume of water evaporated from irrigated agriculture is roughly equal to the water loss from deforestation. Studies have shown that irrigation can lower surface air temperatures nearby due to evaporation and increase precipitation downwind by adding moisture to the atmosphere. However, these localized cooling effects are tempered by limitations on water availability for irrigation.

3. The Impact of Methane on Climate Change

Methane is a potent greenhouse gas (GHG) that significantly contributes to global warming. When released into the atmosphere, it undergoes oxidation, converting into water vapor and carbon dioxide. This means methane not only directly contributes to global warming but also indirectly increases carbon dioxide emissions.

Methane emissions are particularly concerning because they have a much greater warming effect than carbon dioxide, acting about 28 times more powerfully over a century and approximately 80 times more over 20 years. The oil and gas industry is a major source of anthropogenic methane emissions, which have risen alarmingly in recent centuries.

3.1 Understanding Methane

As the primary component of natural gas, methane (CH₄) acts like a thermal blanket, trapping heat and slowing the release of energy from the Earth's surface. While the greenhouse effect is a natural process that keeps our planet warm enough to support life, the significant rise in greenhouse gas emissions, particularly methane, has intensified this effect, leading to rapid climate change.

3.2 Methane vs. Carbon Dioxide

Although methane is the second most abundant greenhouse gas after carbon dioxide (CO₂), it is relatively short-lived in the atmosphere. Despite this, its efficiency at trapping heat means it plays a far more significant role in global warming. During its oxidation, methane reacts with hydroxyl radicals (OH), which clean the atmosphere of various pollutants. This reaction reduces the availability of hydroxyl radicals, potentially allowing other harmful pollutants to persist longer in the atmosphere.

Additionally, methane contributes to ozone formation, negatively affecting air quality and leading to health issues in humans and animals, as well as reduced agricultural yields. Reducing methane emissions can mitigate these effects and significantly slow global warming.

3.3 Global Warming Potentials



Global warming potentials (GWP) measure the relative impact of different greenhouse gases compared to carbon dioxide. Since CO₂ serves as the reference gas, it has a GWP of 1. Gases with higher GWPs contribute more to warming than CO₂. For example, a gas with a GWP of 50 would cause the same warming as 50 tons of CO₂ for every ton emitted.

Fossil fuel production is a major contributor to methane emissions, prompting global commitments to reduce these emissions as part of climate initiatives. The International Energy Agency (IEA) supports efforts like the International Methane Emission Observatory (IMEO) to enhance data collection on methane emissions and track reduction efforts, particularly in the energy sector.

3.4 Detecting Methane Emissions

Technological advancements now allow for effective detection of methane emissions throughout oil and natural gas operations. For instance, Gas Mapping LiDAR technology can identify over 90% of methane emissions in typical production areas, making it possible to pinpoint and address leaks efficiently.

3.5 Conclusion

Addressing methane emissions is crucial for combating climate change. With current technology, industries can significantly reduce these emissions, making a substantial impact on global warming.

4. Black carbon, often referred to as soot, is a significant contributor to atmospheric warming. It absorbs incoming solar radiation and converts it to heat, similar to how asphalt surfaces create urban heat islands. Additionally, black carbon affects cloud formation and influences regional weather and rainfall patterns.

As a component of fine particulate air pollution (PM_{2.5}), black carbon is produced through the incomplete combustion of wood and fossil fuels, a process that also generates carbon dioxide (CO₂), carbon monoxide, and volatile organic compounds. Its effectiveness in absorbing light means that black carbon can intensify warming in areas where it is prevalent, disrupting local weather patterns and ecological cycles.

Although black carbon persists in the atmosphere for only a few days to weeks, its impacts are profound. It

affects climate, snow and ice melt, agriculture, and human health. Emissions of black carbon primarily result from the burning of fossil fuels, wood, and biomass. This combustion process also releases a mix of gases and particulate matter commonly known as soot.

Emission sources vary significantly across regions. In

Asia and Africa, residential solid fuels account for 60-80% of black carbon emissions, while in Europe and North America, diesel engines are responsible for about 70% of emissions.

Solid fuels and kerosene, commonly used for cooking, lighting, and heating homes, are responsible for nearly half of global anthropogenic black carbon emissions. These fuels also release methane and various other air pollutants.

The primary sectors contributing to black carbon emissions include:

- **Household Energy**
- **Transport**
- **Industrial Production**
- **Agricultural Burning**
- **Waste Burning**
- **Fossil Fuels**

4.1 Trends in Black Carbon Emissions

Fortunately, black carbon emissions are on the decline due to advancements in brick manufacturing practices, reduced open burning in agriculture, improved fuel and vehicle standards, cleaner household energy solutions, and increased access to finance and technology. A global commitment to clean air initiatives is expected to drive further reductions as efficiency improves and the electrification of vehicles continues. While progress is being made, there remains significant potential to accelerate emission reductions.

4.2 Impacts of Black Carbon

The effects of black carbon can sometimes be obscured by co-emitted compounds, some of which may cool the climate. The ratio of warming to cooling pollutants varies by source, making those with a high warming impact key targets for mitigation efforts that could yield both climate and health benefits in the short term.

When black carbon settles on snow and ice, it accelerates

melting by reducing surface albedo, or the ability to reflect sunlight. This phenomenon has contributed an estimated 0.04°C of warming since 1750, with the Arctic and glaciated regions like the Himalayas particularly vulnerable.

4.3 Health Impacts

As a component of fine particulate matter (PM2.5), black carbon poses significant health risks, being the leading environmental cause of premature deaths. These minute particles, which are much smaller than a grain of table salt, can penetrate deep into the lungs and enter the bloodstream, carrying toxic compounds. Approximately 4 million deaths annually are linked to long-term exposure to PM2.5.

Health issues associated with PM2.5 include premature death in individuals with heart and lung conditions, strokes, heart attacks, and chronic respiratory diseases such as bronchitis and asthma. Vulnerable populations, including infants and children, are also affected; PM2.5 exposure contributes to premature deaths from acute respiratory infections and has been found in the lungs and brains of unborn babies, potentially affecting early development.

4.4 Agricultural and Ecosystem Effects

Black carbon impacts ecosystems by settling on plant leaves, raising surface temperatures, and altering sunlight and rainfall patterns. Changes in precipitation can disrupt essential monsoon cycles, affecting agriculture in regions like Asia and Africa. In combination with tropospheric ozone, black carbon contributes to global staple crop losses exceeding 50 million tonnes each year, indicating that areas with high emissions could benefit greatly from reduction efforts.

5. Direct Mitigation Measures to Climate Shocks

5.1. Transitioning to Renewable Energy

Shifting from fossil fuels to renewable energy sources is fundamental to reducing greenhouse gas emissions. Governments and industries should invest in solar, wind, and geothermal energy to provide sustainable alternatives.

5.2. Enhancing Energy Efficiency

Improving energy efficiency in buildings, transportation, and industrial processes can significantly reduce energy consumption and associated emissions. Implementing energy-efficient technologies and practices is crucial for long-term sustainability.

5.3. Reforestation and Afforestation

Restoring forests and creating new forested areas can act as carbon sinks, absorbing CO₂ from the atmosphere. Policies promoting sustainable forestry and land management practices can aid in this endeavor.

5.4. Sustainable Agriculture

Adopting sustainable agricultural practices can mitigate emissions from the agricultural sector. Techniques such as precision farming, agroforestry, and organic farming can reduce the carbon footprint while maintaining productivity.

5.5. Waste Management Improvements

Improving waste management practices, such as recycling and composting, can reduce methane emissions from landfills. Implementing circular economy principles can also minimize waste generation and resource consumption.

5.6. Climate-Resilient Infrastructure

Building infrastructure that is resilient to climate shocks—such as flooding, heat waves, and hurricanes—can reduce vulnerability and ensure that communities are better prepared for extreme weather events. This includes investing in resilient urban planning, flood defenses, and disaster preparedness systems.

Solutions

Black Carbon Reduction: The Climate and Clean Air Coalition (CCAC) advocates for measures that could reduce global black carbon emissions by up to 80% by 2030, many of which could be implemented at net cost savings. These actions would provide significant co-benefits for public health and environmental quality.



Household Energy: Many of the world's poorest populations rely on primitive fuels. Simple technologies can greatly reduce indoor air pollution, black carbon emissions, and deforestation.

Transport: The transport sector contributes about 20% of black carbon emissions. Using existing technology and higher-quality fuels can significantly lower these emissions.

Agriculture: Open burning practices in agriculture generate substantial black carbon but can be replaced with no-burn waste management techniques.

Waste Management: Open burning of waste is preventable. Implementing integrated waste management systems can significantly improve local air quality and reduce emissions.

Fossil Fuels: Emissions from the fossil fuel sector can be reduced at low costs through targeted interventions.

Industrial Production: Brick manufacturing is a major source of black carbon, but redesigning kilns can drastically cut emissions.

Individual Actions: Every citizen can help protect the Environment and reduce Global Warming. Taking the green pledge on www.greenpledges.com can also contribute in helping to achieve this objective.

By prioritizing these strategies, we can achieve rapid climate and health benefits, particularly given black carbon's short atmospheric lifetime and potent warming effects.

Conclusion:

Addressing global warming requires a multifaceted approach that involves understanding the underlying factors contributing to the problem and implementing direct mitigation measures. By transitioning to renewable energy, enhancing energy efficiency, promoting sustainable land use, and investing in resilient infrastructure, society can mitigate the impacts of climate shocks. Immediate and sustained action including relevant policies and governance actions are essential to safeguard future generations and preserve the planet's ecosystems.

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Hydrogen-based Energy on the horizon of Carbon Neutrality

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ABSTRACT

Under the dual challenges of global climate change and sustainable development, hydrogen and its derivatives have become one of keys to global energy transition, thanks to their cleanness and high efficiency. Synthesis of green chemicals is one of the largest applications of hydrogen, green ammonia and green methanol synthesized with green hydrogen shows great potential to facilitate carbon emission reduction in sectors of industry, transportation, electricity and construction, especially in hard-to-abate sectors such as maritime industry. By studying the technical characteristics and application scenarios of hydrogen-based energy in China, this paper analyzes the market space and development potential of hydrogen-based energy, suggests cooperations in Asia Pacific region, and puts forward that hydrogen-based energy should act a significant role in global energy transition and respond to climate change.

1. HYDROGEN-BASED ENERGIES ACT AS MAJOR PILLAR IN RESPONSE TO CLIMATE CHANGE

The signing of the Paris Agreement in 2015 marked a new stage in global climate governance. In response to climate change, the international community has put forward Nationally Determined Contributions (NDCs) targets and a series of commitments on emission reduction. Clean energy transition is one of major pillar in achieving the targets and commitments, and hydrogen, along with its derivatives, acts an important part of the energy transition.

The European Union's "Green Deal" is proposed to achieve carbon neutrality by 2050, with hydrogen seen as a key energy source to support the target. The European Union has developed the EU Hydrogen Strategy [1], including deploying 6 GW of renewable hydrogen electrolyzers with 1 million tonnes of renewable hydrogen production by 2024, and deploying additional 40 GW of renewable hydrogen electrolyzers with 10 million tonnes of renewable hydrogen production by 2030, respectively, to ensure Europe's leadership in the global hydrogen market. Germany updated its national hydrogen strategy [2] in 2023 to increase hydrogen demand from 90-110 TWh to 95-130 TWh by 2030, which included other

derivatives such as ammonia, methanol and synthetic fuels in addition to hydrogen.

United States announced ambitious clean energy plan after returning to the Paris Agreement. The Department of Energy released the U.S. National Clean Hydrogen Strategy and Roadmap in 2023 [3], restating the goal to reduce the cost of clean hydrogen to 1 USD per 1 kg in 1 decade and increase clean hydrogen production to 10, 20 and 30 million tonnes per year in 2030, 2040 and 2050, respectively.

Japan proposed a "hydrogen society" scheme to reduce the cost of hydrogen to parity with fossil fuels by 2030, and promoted hydrogen vehicles and fuel cells nationwide.

China is committed to peak CO₂ emissions before 2030 and achieve carbon neutrality before 2060. Energy transition and hydrogen industry development are considered as important actions to achieve this ambitious "dual carbon" goal [4-5]. As one of the few countries in the world with the ability to deploy the entire hydrogen industry value chain, China is actively promoting the application of hydrogen-based energies in industry, transportation, electricity and construction sectors, contributing to the energy transition and climate change response.

The hydrogen-based energy discussed in this paper mainly are hydrogen, ammonia, and methanol.

2. TECHNOLOGIES FOR HYDROGEN-BASED ENERGY ARE UNDER CONTINUOUS DEVELOPMENT

2.1. Production

Hydrogen produced from water electrolysis is often the primary step in obtaining other hydrogen-based energies. Efficient hydrogen production from green electricity is the cornerstone of future hydrogen-based energies production. Alkaline electrolysis of water (AEW) is the most matured method for hydrogen production. Using a 30% mass concentration KOH solution or a 26% mass concentration NaOH solution as the electrolyte and no precious metals required, the most significant advantages of AEW are low cost and scalability. The nominal capacity and efficiency of alkaline electrolyzers made in China have reached 2500 Nm³/h and 4.0 kWh/Nm³, respectively, which is comparable to that is made by leading manufacturers. Proton exchange membrane (PEM) electrolysis of water for hydrogen production is under rapid development, characterized by high current density, high hydrogen purity, and fast response speed. However, due to the use of precious metal materials, the cost is relatively high comparing to AEW.

With technology advances, application scenes continue to expand. Liu et al [6] and Dongfang Electric Corporation jointly designed and developed a wind-powered floating seawater electrolysis system scaled 1.2 Nm³/h hydrogen production. Stable electrolysis operation was achieved for over 240 hours with an electrolytic energy consumption of 5 kWh/Nm³ H₂ and a high purity (>99.9%) of hydrogen under fluctuating ocean conditions (0~0.9 m wave height, 0~15 m/s wind speed), which is close to that during onshore water electrolysis.

After green hydrogen is obtained, green ammonia can be synthesized by Haber-Bosch process together with nitrogen separated from air using green electricity. Green methanol can be produced through various pathways, mainly divided into e-methanol and bio-methanol, based on carbon and hydrogen feedstocks. Bio-methanol can be further divided into two categories: bio-methanol made with synthesis gas from biomass gasification, and bio-methanol made with bio-methane from biomass fermentation.

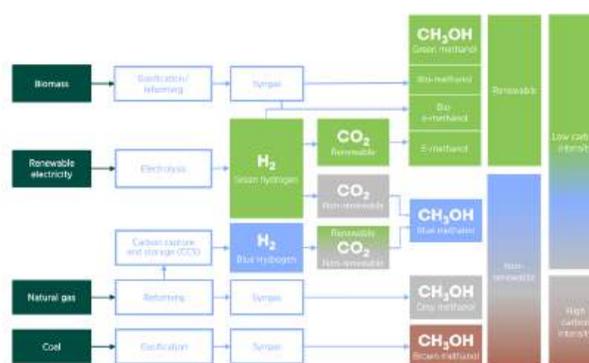


Figure 1. Principal methanol production routes [7]

GENA Solutions Oy's renewable methanol update [8] indicated that, as of August 2024, there are a total of 104 e-methanol projects with total production capacity of 16.8 million tonnes per year, 70 bio-methanol projects with total production capacity of 11.2 million tonnes per year, and in addition to above renewable methanol projects, there are 13 low-carbon methanol projects with total production capacity of 8.1 million tonnes per year worldwide planned or under construction. According to the Orange Group's China green methanol project tracker, by June 2024, there were over 100 green methanol projects announced with planned production capacity exceeding 50 million tonnes per year. Half of the projects are e-methanol projects with roughly two-thirds of the planned capacity, while the other half projects are bio-methanol projects with one-thirds of planned capacity.

2.2. Storage and Transportation

For storage and transportation, hydrogen can not only be stored in high-pressure gaseous and low-temperature liquid form, but also be made into ammonia, methanol, other liquid organic hydrogen carriers (LOHC), and even be stored in solid materials through physical adsorption and chemical bonding. China's high-pressure gaseous hydrogen storage industry is upgrading from 35 MPa to 70 MPa. A ton-level demonstration hydrogen storage and transportation vehicles was launched in 2023, using magnesium (Mg) based solid-state material as hydrogen storage medium.

Pipelines can be used for hydrogen transportation, either pure hydrogen or hydrogen mixed with natural gas. Most existing hydrogen pipelines in China are operated under pressure under 4 MPa. A demonstration project with designed pressure of 6.3 MPa is under construction, which is expected to carry 500,000 tonnes hydrogen per year. For hydrogen-natural gas mixed pipelines, the first

high-pressure demonstration project between Baotou and Linhe has started construction. This 258 km, 6.3 MPa project is designed to transport 1.2 billion Nm³ gas with up to 10% hydrogen.

Ammonia can be liquified and stored under 10 MPa at 25°C. Methanol is liquid under ambient pressure and temperature. Massive storage and transportation of ammonia and methanol can be achieved with existing experiences, standards, technologies and infrastructures of chemical industry.

3. HYDROGEN-BASED ENERGIES CONTRIBUTE TO DECARBONIZATION IN MULTIPLE SECTORS

Green hydrogen-based energy will contribute to decarbonization in industry, transportation, electricity, and construction sectors. We estimated that China's demand for green hydrogen-based energies (green hydrogen equivalence) will reach around 23 million tonnes in 2030, and increase to 69 million, 91 million, and 120 million tons as of year 2040, 2050, and 2060, respectively.

Industry sector is the largest and most fast-growing area of hydrogen-based energies in China. Hydrogen is an important industrial raw material and has been widely used in industrial fields such as chemical engineering, petrochemicals, and metallurgy. China's "dual carbon" strategy, policies of energy consumption and intensity control, and carbon emission and intensity control, among others, will further drive green hydrogen-based energy's applications in these sectors. In 2023, China's first million-ton hydrogen-based vertical furnace project started operation at Baosteel Zhanjiang Iron & Steel. The project uses hydrogen instead of coke as reducing agent, reducing carbon emissions by approximately 60% compared to traditional blast furnaces.

The transportation sector is a hard-to-abate sector in 4. carbon emission. One of the key ways is to replace fossil fuels with clean energy. Green hydrogen-based energies as transportation fuels, can be used in various scenarios such as biodiesel for road transportation, sustainable aviation fuel (SAF) for aviation, biodiesel/green methanol/green ammonia for maritime shipping industry. The high energy density makes green hydrogen-based energies promising alternatives to achieve a low transition cost way for transportation decarbonization. Most of announced and planned green methanol projects in China are targeting maritime shipping industry. Used cooking oil is being collected and made into biodiesel in Shanghai,

but also has great potential to produce other hydrogen-based energies with higher values, such as SAF.

Hydrogen-based energies can be applied in multiple aspects of the electricity system. On the source side, gas-fired power plants could adopt a proportion of hydrogen as fuel together with natural gas, and similarly ammonia for coal-fired power plants. In December 2021, Jingmen green power plant of State Power Investment Corporation retrofitted gas turbine to adopt designed 30% mixture of hydrogen and 15% mixture of hydrogen in operation. Yantai Longyuan power plant of CHN Energy completed a 40 MW pilot platform with 35% ammonia. Tongling power plant of Wenergy completed a demonstration study of ammonia ratio between 10% to 35% for a 300 MW power generation system. On the network side, leveraging existing infrastructure of petroleum and chemical engineering industries, the cross regional long-distance transportation of hydrogen-based energies can serve as an effective supplement to the ultra-high voltage power transmission network. At the load side, electrolysis of water for hydrogen production can serve as a flexible demand side response system. On the storage side, hydrogen-based energy can be used as a long-term energy storage and feed electricity back to the grid through fuel cells.

The energy demand in the construction field mainly includes building heating and cooking. Hydrogen would be used as supplementary for natural gas when mixed in the gas distribution system for cooking and powering heating system. Shenzhen Gas launched a comprehensive technology experimental platform for hydrogen mixed in urban gas system, achieved the successful usage of 5% to 20% hydrogen mixed distribution in gas networks. The platform has been operating continuously for nearly 200 days and provides hydrogen for over 4000 people.

4. THE ECONOMICS OF HYDROGEN-BASED ENERGY DIRECTLY DETERMINES ITS APPLICATION PROCESS IN VARIOUS FIELDS

The green attribute of hydrogen-based energies is the source of premium comparing to traditional fossil fuels. The economics of hydrogen-based energies mainly come from the cost of green electricity. The cost reduction of green electricity is thus the main driving force for the cost reduction of green hydrogen-based energies. In near future, wind power and solar photovoltaics (combined with energy storage if needed or required) can be considered as major green electricity sources for hydrogen,

ammonia, and methanol production. Estimation of costs of major hydrogen-based energies are as shown in table 1.

Table 1. Cost Estimation of major hydrogen-based energies

Green Hydrogen-based Energies			H ₂	NH ₃	CH ₃ OH
Mass Energy Density	(MJ/kg)		120	18.6	19.9
Cost of Product	(RMB Yuan/ton)	2024	14000-21000	3000-4200	4000-8000
		2030E	12000-16000	2500-3500	3300-4200
		2035E	10000-16000	2200-3300	3000-4200
Cost of Energy	(RMB Yuan/MJ)	2024	0.12-0.18	0.21-0.42	0.21-0.42
		2030E	0.1-0.13	0.17-0.22	0.17-0.22
		2035E	0.09-0.13	0.15-0.21	0.15-0.21

In China, hydrogen has been proven commercially feasible without subsidies in specific areas and scenes. One example is hydrogen fuel cell heavy-duty trucks used for mining industry in Shanxi province. This was achieved due to abundant chemical by-product hydrogen (gray or blue hydrogen) resources, low hydrogen prices (<30 RMB Yuan/kg), and fixed track routes that facilitates hydrogen refueling station siting. Yet green hydrogen applications are still in early stage, due to economics.

Li et. al [9] studied the cost of electricity when green ammonia is introduced. The results shows that the price per kWh will increase by 0.213 RMB Yuan when 25% green ammonia is added to coal-fired power plants. At current stage, ammonia mixed power generation technology is under technology validation, and its economics improvements should be closely monitored and carefully examined.

Green methanol has become under the spotlight recently in the region. Compared to traditional marine fuels, green methanol is about 2.5 times more expensive per equivalent calorific value, making it uneconomical. According to our calculations, based on the current carbon price of 70 euros/ton, the price of green methanol would be reduced below 4000 RMB Yuan/ton before compatible with traditional maritime fuel. Even if the carbon price rises to 180 euros/ton, the price of green methanol is estimated to be under 6000 RMB Yuan/ton to keep its economic compatibility.

5. SUGGESTION S TO ASIA-PACIFIC REGION

FROM CHINA'S LESSONS LEARNED IN HYDROGEN-BASED ENERGY DEVELOPMENT

The biomass and green electricity resources in the Asia Pacific region will be the resource endowment for the development of green hydrogen-based energy in the region. In the short term, biomass coupled with green hydrogen from green electricity will be the relatively low-cost way to obtain green hydrogen-based energies. The abundant biomass resources in the Asia Pacific region, especially in Southeast Asian countries, can support regional economy development as well as energy transition. IRENA's research [10] shows, approximately 75% of primary energy in Southeast Asian countries came from fossil fuels in 2018, but by 2050, biomass energy has the potential to contribute to 40% of primary energy source, making itself largest part in the energy mix. At the same time, the rapid urbanization process in the region indicates significant increase of waste cooking oil, which would become an excellent raw material for green hydrogen-based fuels production. In the medium to long term, wind and solar resources will be the dominating factor for hydrogen-based energy production. Yet it is necessary to consider in advance the planning of production capacity and the upgrading of infrastructures, such as ports/storage/refueling.

Technology innovation, equipment manufacturing, system integration and continuous improvement of production operations will be the key factors for hydrogen-based energy industry development in the Asia Pacific region. There are still technical challenges in large-scale conversion and utilization of biomass energy, such as the development and optimization of large-scale continuous biomass gasification equipment, research and development of high-efficiency and durable catalysts based on different raw material in specific areas. The improvement in performance and durability of wind and solar power plants and large-scale green hydrogen production systems, such as alkaline water electrolyzers and PEM electrolyzers, should only be driven by continuous investment in technology improvement, system optimization, and equipment manufacturing. The new technologies, equipment, and systems should be carefully reviewed through a bankability study performed by reputable third-party institutions, before present to the market, to increase the product and project credibility and transparency, and the chance to receive financial support.

Countries in the Asia Pacific region should strengthen cooperation in the field of green hydrogen-based energies.



On the one hand, international standards and certifications are still in consolidation, which indicates confusions and high compliance costs, for project owner, investors and buyers. This confusion can also expose project to the risk that the green attribute premium not be recognized and realized. This could be a major bottleneck for the Asia Pacific countries when promoting hydrogen-based energies products in international market. Countries can put joint effort to develop regional standards and promote mutual recognition with regional and international standards. On the other hand, countries in the region can work together under the "the Belt and Road Initiative" cooperation framework to jointly establish green shipping corridors in the region. These green shipping corridors could enhance regional green hydrogen-based energy demand, accelerate collaborative technology innovation and demonstration project construction, as well as industry development.

6. CONCLUSION

This paper introduces the application scenes and cases of hydrogen-based energy, especially the major green hydrogen-based energies, in China. With technology developments and production capacity accumulations, the cost of green hydrogen-based energies is expected to continue to decline, and its applications in industry, transportation, electricity, and construction sectors will gradually expand. Asia Pacific countries can work together to strengthen the cooperation of green hydrogen-based energies in the region of resource coordination, technology innovation, standard development, and green shipping corridor establishment. Green hydrogen-based energies development in Asia Pacific region can contribute more to regional and global energy transition and response to climate change.

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The Zhejiang Practice of China's Leap in Renewable Energy

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ABSTRACT

Zhejiang province has achieved the commitment made at COP26 of achieving net zero carbon emissions by intensifying wind and solar capacity to 39.41 million kilowatts by December 2023. This progress highlights a complex approach which includes pre-research and policy development, technology adoption, resources procurement, innovation, and user enhancement. As a result of emphasizing policy frameworks, Zhejiang has established clear renewable energy targets and formulated legislation to support the development of renewable energy projects while constructing a comprehensive project library. In terms of technology, the province has created models like 'Photovoltaic+' for the purpose of shared value and implement integrated projects containing the Haining Jianshan source-grid-load-storage system, which includes the offshore wind and solar energy. Resource security has been secured with the safe lands, seaways and green financial guarantee, laying an organizational material base for sustainable renewable extension. Innovation lies at the core of the Zhejiang Model, as envisaged by the Baimahu Lab focused on the renewable energy sources and the green technology exchange center, which promotes commercialization of the new technologies, including the advanced photovoltaic products. The province has also optimized consumption through standardized incentives of both export-oriented industries and high energy-intensive sectors purchasing and hence promoting renewable electricity. Taken together, all these measures have not only increased the use of renewable energy in Zhejiang, but also fostered best practices and lessons for other areas. This success underlines a paradigm that coordinated policies, innovation in technology, and optimum use of resources can effectively address issues relating to sustainable energy policies making Zhejiang as a role model for enhancing the shift from the supply of fossil energy to that of renewable energy across the world.

1. RATIONALE FOR ACCELERATE THE DEVELOPMENT OF RENEWABLE ENERGY

Zhejiang Province's renewable energy development is currently at a critical juncture, marked by rapid expansion, technological breakthroughs, and opportunities for reform-driven empowerment. Thus, the acceleration of renewable energy development is of paramount importance.

1.1. Promoting green energy transition

The Chinese government is actively and steadily advancing its carbon peaking and neutrality goals by expediting the planning and construction of a new energy system. Transitioning from high-carbon to low-carbon energy and shifting from fossil fuels to clean energy sources is crucial [1]. China aims for non-fossil energy to account for 25% of the total energy consumption, with wind and solar power capacity projected to reach 1.2 billion kilowatts by 2030. In alignment, Zhejiang plans to increase its non-fossil energy consumption ratio to 24% by 2025 and 30% by 2030. Achieving these targets requires the swift expansion of wind, solar, hydro, and energy storage systems to create a power grid dominated by renewable energy.

1.2. Enhancing energy supply security

Zhejiang Province has limited fossil fuel resources and largely relies heavily on external imports, resulting in ongoing pressure on energy security and supply. Currently, Zhejiang is entering a new phase characterized by a tight energy supply-demand balance, with a significant and persistent electricity supply gap, heightening the need for stable energy provision. However, the province boasts abundant renewable energy resources with substantial development potential, including approximately 80 GW of photovoltaic capacity, 40 GW of offshore wind power, and 40 GW of pumped storage. Furthermore, new forms of energy storage are rapidly advancing [2]. As illustrated in Fig 1, by the end of 2023, the installed capacity of wind and solar power reached 39.41 GW, more than doubling from 2020 (17.03 GW). Additionally, the share of renewable energy in the province's energy mix has increased from 16.3% in 2014 to 42.9% in 2023. Renewable energy is thus evolving from a supplementary power source to becoming the second-largest primary power source in Zhejiang, playing a crucial role in ensuring energy supply. In light of these developments, it is essential to maximize the potential of renewable energy to bolster energy security, enhance its supportive capacity, and further strengthen the resilience of the energy supply system.

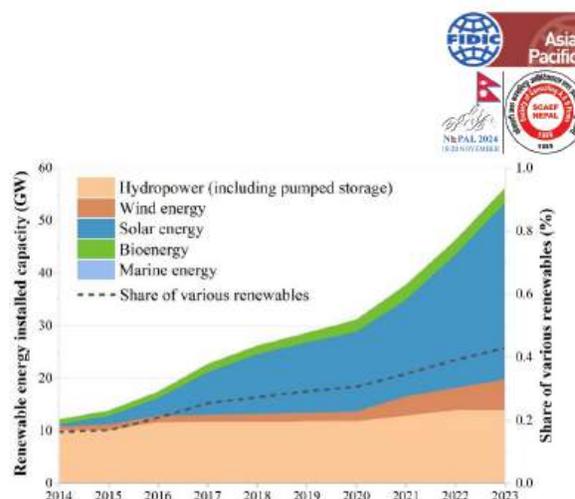


Fig. 1 Renewable energy installed capacity in Zhejiang Province from 2014 to 2023

1.3. Promoting stable energy supply

Fueled by subsidies and various policy incentives, China's renewable energy sector, particularly photovoltaic and wind power, has entered an era of grid parity during the 14th Five-Year Plan period, with the levelized cost of renewable energy now lower than that of newly constructed coal-fired power plants in most regions [3]. In Zhejiang Province, photovoltaic and onshore wind power have achieved grid parity and possess a price advantage over the currently high-priced fossil fuels. In 2022, the province's average electricity generation cost reached 0.538 yuan/kWh, reflecting a 24% year-on-year increase. In contrast, the on-grid photovoltaic electricity price was set at 0.4153 yuan/kWh, matching the benchmark coal-fired power price, making it over 20% lower than the provincial average electricity generation cost. This cost advantage has encouraged many enterprises to develop and utilize renewable energy, actively purchase green electricity or green certificates, and lower their overall energy expenses [4]. Although offshore wind power has yet to achieve grid parity, ongoing technological advancements and the gradual realization of the energy transition will continue to drive down the cost of renewable energy and flexible, adjustable resources, making them an increasingly affordable power source that benefits both enterprises and the public [5].

1.4. Driving green industry development

Renewable energy intersects with infrastructure and industrial development, inherently integrating digitalization and intelligent technologies, showcasing strong traction, high growth potential, and a broad impact. As global energy and technological revolutions evolves, the renewable energy sector is set to create and establish extensive industrial chains [6]. Furthermore, the international landscape is experiencing increased competition around carbon-themed trade rules and investment frameworks, while domestically, there is a shift from energy consumption control to carbon control. Under China's 14th Five-Year Plan, renewable energy consumption is no longer part of energy consumption control assessments, and the carbon content of industries and products has become a critical determinant of regional



industrial, and product competitiveness. Zhejiang Province has a clear first-mover advantage in the renewable energy industry, with a complete photovoltaic industry chain ranking second in production capacity nationwide, and the offshore wind power sector advancing into large-scale development, currently ranking fifth in the country. The province also leads in sectors like power batteries and molten salt energy storage. However, compared to Zhejiang's abundant renewable energy resources, there is still room for accelerated industrial growth. Moreover, as a major export-oriented economy, Zhejiang faces stringent control assessments on energy consumption. It is urgent for the province to enhance its competitiveness regarding carbon content. Therefore, it is essential to fully leverage the role of renewable energy as a driving force for industrial development, expand the integration of digitalization, green practices, and low-carbon development models, reduce the carbon footprint of industrial growth, establish a new growth engine for economic development, and ultimately enhance overall competitiveness.

2. GOALS FOR ACCELERATING RENEWABLE ENERGY DEVELOPMENT

In light of the evolving context, accelerating the development of renewable energy in Zhejiang Province necessitates a systematic approach. This includes a leapfrog expansion in the total installed capacity of renewable energy, promoting high-quality development within the innovation and industrial chains, enhancing the utilization and integration of renewable energy, and achieving large-scale, high-proportion, market-driven, and high-quality growth. The specific goals are as follows:

By 2027, Zhejiang aims to establish a diversified renewable energy landscape, primarily based on wind, solar, hydro, and biomass power generation, supplemented by the integrated utilization of ocean and geothermal energy, with rapid development in energy storage and hydrogen energy. The province seeks to add 30 GW of new renewable energy capacity, targeting a total installed capacity of 76 GW, accounting for more than 45% of the province's total installed capacity. Additionally, the goal is to generate an additional 40 GW of renewable energy annually, aiming for a total annual generation of 110 GW, which would represent more than 15% of the province's total electricity generation. The renewable energy industry is expected to reach an output value of 300 billion yuan.

Developing offshore wind power bases. The province will expedite the large-scale development of nearshore wind power and designate deep-sea wind power as a key growth driver and the primary domain for future renewable energy development. By 2027, Zhejiang aims to achieve an installed offshore wind power capacity of 10 GW, with the wind power industry projected to reach an output value

of 120 billion yuan.

Expanding "photovoltaic+" multi-scenario applications. Zhejiang will pursue a balanced development strategy for both centralized and distributed photovoltaic systems, advancing offshore and onshore applications concurrently. The goal is to actively create diverse, integrated "photovoltaic+" application scenarios to explore new opportunities for photovoltaic development. By 2027, the province aims to reach a photovoltaic installed capacity of 42 GW, with the photovoltaic industry projected to achieve an output value of 350 billion yuan.

3. STRATEGIES FOR LARGE-SCALE DEVELOPMENT AND UTILIZATION OF RENEWABLE ENERGY

3.1. Strengthening renewable energy development planning and guidance

Firstly, enhancing the leading role of renewable energy development planning. Zhejiang should position itself as a pioneer in establishing a new energy system by developing a renewable energy-centered power system. This includes advancing specialized planning for offshore wind power, pumped hydro storage, photovoltaic power, and hydrogen refueling stations, ensuring their formulation, adjustment, and implementation. Secondly, formulating annual renewable energy project plans. Establish a comprehensive planning and implementation mechanism, develop annual progress plans for renewable energy, and clearly define the scale and timeline for project execution. Thirdly, ensuring coordination between source and grid planning. Strengthen the coordination between renewable energy planning and supporting grid infrastructure to ensure that generation and grid projects are integrated, approved, and operational simultaneously.

3.2. Accelerating renewable energy project implementation

Firstly, approving and initiating a series of projects. Approve and launch key initiatives, including the Wuxijiang and Qingyuan pumped hydro storage projects, several offshore wind power projects, centralized photovoltaic power stations, and advanced energy storage projects. Secondly, accelerating the construction of various projects. Expedite the development of projects such as the Taizhou No. 1 offshore wind farm, the Sanmen tidal flat photovoltaic project, and 14 pumped hydro storage projects currently under construction in Ninghai, Jinyun, and other areas. Thirdly, ensuring the timely commissioning of a set of projects. Implement a reverse scheduling approach to ensure a batch of projects is commissioned each year before the peak summer period. Fourthly, planning and researching a batch of projects. Conduct comprehensive surveys of wind and solar resources, actively research deep-sea wind power development, and explore "photovoltaic+" application

scenarios to establish a robust reserve of potential projects.

3.3. Expanding the renewable energy equipment manufacturing

In the photovoltaic sector, focus on expanding the application of photovoltaic technologies by innovating "photovoltaic + building" [7], "photovoltaic + transportation" [8], and "photovoltaic + agriculture" scenarios [9]). Prioritize the R&D and industrialization of next-generation photovoltaic products, such as flexible thin-film and perovskite technologies, and enhance the manufacturing capabilities of critical components like inverters and controllers. In the offshore wind power sector, drive the development of offshore wind power by establishing an internationally competitive offshore wind power hub that integrates equipment research, production, assembly, product certification, and operation & maintenance. Accelerate the formation of a large-scale industrial cluster with an output value exceeding 100 billion yuan.

3.4. Cultivating new business models and development patterns

Firstly, promoting the integrated "source-grid-load-storage" model. Actively promote the "renewable energy + energy storage" model, vigorously advance the "Wind-Solar-Storage 10 GW Action," and establish several "Wind-Solar-Hydro-Storage Integration" demonstration bases. Secondly, exploring cross-sectoral renewable energy development models. Develop integrated development models that combine offshore wind power, ocean energy, energy storage, hydrogen production, marine ranching, and onshore industrial bases. Explore the creation of a deep-sea offshore wind power hub that integrates research, production, certification, and maintenance of wind power equipment, and initiate the "Hydrogen Energy+" demonstration projects, planning for the construction of offshore hydrogen islands. Thirdly, strengthening regional energy cooperation models. Adhere to a strategy that prioritizes Zhejiang's needs while considering the broader Yangtze River Delta region. Establish a shared mechanism for pumped storage power station construction and operation to enhance the resilience and flexibility of the East China power grid. Fourthly, creating renewable energy models for common prosperity. Utilize renewable energy projects such as pumped hydro storage, photovoltaic power generation, and biomass energy to support the shared prosperity of 26 mountainous counties. Encourage the integration of renewable energy projects with eco-tourism and urban-rural infrastructure development to achieve synergistic growth.

3.5. Improving renewable energy development and utilization policies

Firstly, strengthening land and marine space support. Ensure adequate consideration for renewable energy land and marine space requirements in spatial planning by reserving space for renewable energy development through flexible planning methods. Secondly, utilize a range of green finance products and tools, such as green loans, insurance, bonds, and industry funds, to provide substantial support for renewable energy projects [10]. Thirdly, facilitating renewable energy consumption. Promote the national Green Electricity Certificate (GEC) system and ensure its issuance for renewable energy electricity within the province. Use the GEC as the sole proof for calculating renewable energy consumption and ensure that it is not included in the overall energy consumption and intensity control targets. Expand GEC application scenarios and encourage high-energy-consuming enterprises and export-oriented companies to purchase green certificates.

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Planning of Flood Control In Unstable Rivers in Terai Plain of Nepal

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ABSTRACT

In Nepal, there is a variety of landforms, mountainous areas are represented by the steep Himalayas, the low-altitudes areas form the Terai Plain, and the capital of Nepal, Kathmandu locates in hilly areas. Terai Plain is a vast low-altitudes area that accounts for 17% of Nepal's land area. Nepal has increased disaster risks due to weather extremes including floods that are related to the effects of climate change. Progress of capital accumulation is expected in the Eastern part of the Plain; Biratnagar metropolitan and Itahari sub-metropolitan city of Morang and Sunsari District in Koshi Province. At the same time, subject area function as a logistic hub as they locate near the Indian border. In such circumstance, it is important to consider future flood risk in the basins of Budhi-Keshaliya / Singhia / Lohandra rivers that flows through the areas, and to promote investment in disaster risk reduction of the rivers. Major issue on hydrological aspect of the basins is that these rivers are currently natural rivers without dikes, and that river channels are unstable by sedimentation and erosion. Land use along the river banks due to rapid development of the areas, limited government budget allocation and complicated administrative system for flood control are also constraints on social and economic aspects. In this paper, countermeasures, as appropriate technology under such unique environment, have been proposed including both structural / non-structural methods.

1. INTRODUCTION

Terai Plain is a vast low-altitudes area that accounts for 17% of Nepal's land and is at high flood risk due to the confluence of large and small rivers originating in the Himalayas, causing economic damage. In addition, Nepal is at greater risk of disasters such including floods due climate change.[1] Under these circumstances, the cities of Biratnagar (Morang District) and Itahari (Sunsari District) in Koshi Province, which are the most economically active cities in the Terai Plain, currently have an industrial structure centered on agriculture, but because they locates near the Indian border and are distribution centers, capital accumulation is expected to progress along with the expansion of industrial and urban areas in the future. However, the Keshaliya, Singhia, and Lohandra river basins that flow through the region are frequently flooded, but there is no detail survey in the past flood history and flood characteristics are unclear. In addition, after the government system was reformed into federal structures, budgets and organizational capacity are not enough that adequate countermeasures

have not been taken. Furthermore, there are concerns that land acquisition for river projects is difficult due to ongoing urbanization.

Therefore, considering natural conditions including climate change and sediment dynamics, as well as the social impacts of river improvement, flood hazard risk maps and flood control plans for flood risk reduction should be developed for the above three basins, both in terms of structural and non-structural measures.

JICA Technical Cooperation (Hereafter referred to "the Project") is now implemented to build a sustainable and resilient society with advance investment for disaster risk reduction to prevent disasters in future. This paper discusses flood control planning for sustainable development in Nepal, where the budget is limited and the administrative structure for flood control is insufficient.

2. OVERVIEW AND CHARACTERISTICS OF THE TARGET RIVERS

2.1. Topography and Rivers Overview

The three target rivers are small and medium-sized

ivers that originate in the Siwalik Mountains and flow into India. (Table 1) The rivers cross the east-west highway that connects the regions and the irrigation canals of the Sunsari-Moran Irrigation Project. They pass-through settlements and urban areas scattered along their courses. Sediment production is active in the upper reaches of the rivers, which yields a risk of landslides and flash floods during the rainy season. In the middle and lower reaches, flood inundation occurs due to insufficient flow capacity. Localized riverbank erosion also occurs. The land use ratio of the entire river basin is dominated by agricultural land and forests. (Figure 1)

extraction of large grain size materials upstream and sand and gravel even in the middle reaches of the river has resulted in the riverbed materials in the lower reach plains being mainly fine sand and silty, which is a cause of riverbank erosion.

Table 1. Overview of target river basin

River	Basin Area (km ²)	Channel Extension (km)	River Width (m)	Longitudinal Gradient
Keshaliya	309	63.2	90-150	1/800
Singhia	98	20.7	50-100	1/1050
Lohandra	357	62	150-200	1/960

2.2. River Characteristic to be noted for Flood Control

The characteristics of rivers that should be taken into account for flood control are as follows

2.2.1. Rivers are under natural condition where the river structures are less implemented

Basic river management is carried out by the provincial government (Keshaliya and Singhia rivers) or by the federal government (Lohandra river), with partial dikes and gabion construction in flood affected areas on the basis of local people's requests. However, most of the rivers are under the natural condition. In addition, international assistance from JICA (Lohandra River) [2], ADB (Keshaliya River) [3], and other international agencies has been carried out to study flood control plans for the target rivers, focusing a design flood discharge and proposal of river structures such as dikes based on the target flood water level, but the plans have not been implemented due to the financial constraints.

2.2.2. Sediment deposition is active

Sediment deposition is active in Siwalik, and sediment deposition from the mountainous area is estimated at 2.7 mm/year in the Lohandra River.[2] On the other hand, in recent years, riverbed material extraction has been active throughout the basin as a construction material for development in urban areas. (Figure 2). Although the local government monitors the amount of sediment extraction annually when conducting environmental impact assessments, the riverbed has been declining. The

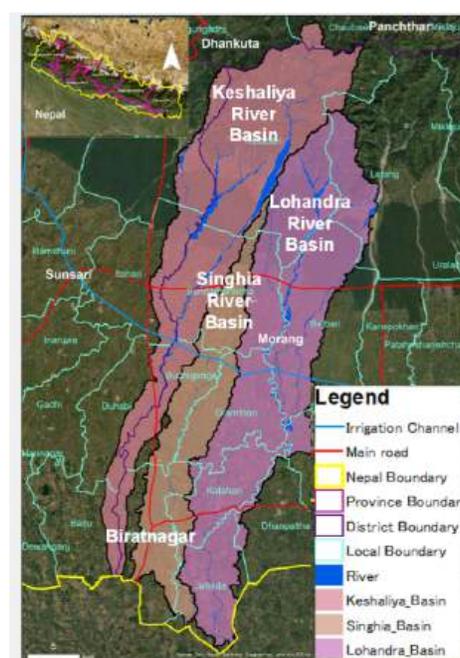


Figure 1. Target River Basin Map



Figure 2. Riverbed excavation in Keshaliya River

2.2.3. River management sections are ambiguous.

In conventional river management, the boundary between the flood flow channel and the flood protection area where houses and farmlands are located in the flood plain should be defined by dikes or a reference river width to define the management section. On the other hand, in the river targeted in the Project, housing and farmland have developed along the rivers, and the distinction between public and private land is unclear, making land acquisition and compensation during river maintenance a challenge. In Nepal, the river administration has a three-tiered structure (central, provincial, and municipal), and the management entity differs depending on the size of the

river basin, even if the river flows through the same municipality. Even within the same river, there are sections where the dike management section switches in the middle of the river. In this case, from the perspective of management for maintenance, there is a risk of delay in rehabilitation due to the management section in the event of damage to the dikes or revetment. In addition, if the organization in charge does not have a budget for regular maintenance, there is a risk that the structure will be left as it is even after it has deteriorated over time, creating vulnerable areas from the perspective of the continuity of river structures. (Figure 3)



Figure 3. Different river structures implemented in one section

2.3. River Flooding Characteristics

The characteristics of river flood damage caused by the target rivers are summarized below.

2.3.1. Risk of flooding at narrow sections

In plain areas where many rivers flow, many bridges have been constructed, and flood inundation is likely to occur in sections where the river width is reduced at bridge sections. Where dikes have been constructed around the bridges, the risk of flooding increases because the design water level has been raised due to restrictions on the bridge length or surrounding residences. Where the design water level is set higher than the local ground level within the dikes, identical phenomenon take places.

As a result of the development of settlements over lower ground elevations within the floodplain, the river width near the village along the flood plain, where it should be protected, is narrower, making continuous channel widening and dike construction difficult, increasing the risk of flood inundation (Figure 4).



Figure 4. Example of flood control measures in the Keshaliya River

2.3.2. Land runoff due to riverbank erosion

In plain areas, riverbeds and banks are prone to erosion during floods due to the small size of the riverbed material. Although dikes and revetments have been partially constructed, erosion is likely to occur in sections where such structures have not yet been constructed due to unclear land boundaries and financial constraints, and only emergency flood control measures are being taken.

In the downstream areas where farmland and residential areas have developed, gabion groins / revetments have been constructed to protect riverbank erosion. Since they are constructed in front of the existing riverbank, the width of the river is reduced, increasing the risk of flooding. (Figure 5)

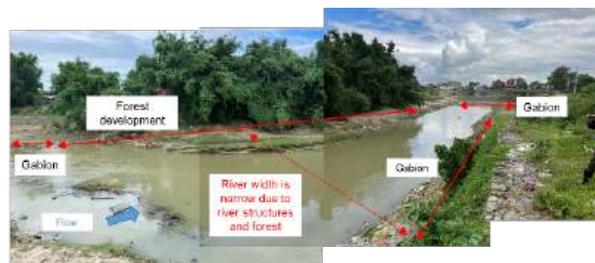


Figure 5. Example of flood control measures in the Singhia River

2.3.3. Increased inland water risk

The risk of inland water damage is also increasing due to the difficulty of draining into the river channels caused by the lack of city drainages. There are also many tributaries which remain natural condition. In the surrounding farmlands, damage from inland flooding due to poor drainage occurs every year.[4] Drainage water that cannot flow into the rivers flows down the drainage channels along dikes, causing inland water inundation depending on the rainfall conditions in the catchment area. [3]

3. ISSUES AND POLICIES FOR FLOOD CONTROL PLANNING IN NEPAL

The following describes the challenges facing Nepal's flood control sector and the policies to address them.

3.1. Appropriate identification of flood risks in the target river basins

In Nepal, the law refers to the establishment of river boundaries, but the boundary between private and public lands is not clearly identified, as land acquisition has not been much practiced in river projects. Since the assets are dispersed, cost-effectiveness are assessed small in case a large project is implemented over the entire river basin. Flood risks need to be properly evaluated and priority

areas to be protected should be identified.

3.2. Proposed flood control measures according to Nepal's socio-economic situation

In Nepal, the amount of budget allocated for public works in the flood control sector is insufficient, and emergency rehabilitation based on the requests of residents and the scale of damage is the mainstream. Regarding the past international cooperation on flood control projects, the study items have been limited to benefit assessment. When they come to implementation stage, they have not progressed due to organizational capacity and financial background. The Project will propose plans that will lead to sustainable measures for flood control by utilizing plans / designs / construction methods that are reasonable for the size of Nepal's budget.

3.3. Proposed implementation system of flood control projects

In Nepal, the capacity of the Department of Water Resources and Irrigation, which plans and implements flood control measures, is not sufficient for the number of rivers, about 6,000, that must be managed. In Nepal, many river-related activities are not centralized; flood control planning, implementation operation & maintenance by the Department of Water Resource, and irrigation, rainfall & water level monitoring by the Department of Meteorological and Hydrology.

For river management, whole activities should be integrated and coordinated between each other. It is effective and necessary for the one who know the situation under both normal and disaster conditions to carry out everything from observation to planning, and facility construction to maintenance. However, under the current situation where authority over rivers is divided, it is not realistic to establish a new river administrator to concentrate the authority into this position, as it would involve reorganization of concerned ministries and agencies throughout the country.[5] A feasible structure under the current organizational and legal framework are proposed. Organizational capacity building is also carried out in the Project.

4. INPUTS TO FLOOD CONTROL PLANNING

In line with the aforementioned policy, the following is proposed solutions for developing a feasible flood control plan and improving its implementation system in Nepal.

4.1. Policy 1: Appropriate identification of flood

risks in the target river basin

4.1.1. Flood risk hazard mapping

To understand the characteristics of past floods and to identify the vulnerable areas, flood risk/hazard maps are prepared. In Nepal, there are no records of past damage, and rehabilitation is inefficient, focusing only on damaged areas. Understanding the risk of damages in advance will help to control settlements and development plans, thereby preventing future increases in damage risk. Flood hazard maps are prepared to develop flood control plans that take into account land use and its anticipated damages in the vicinity of rivers.

4.1.2. Appropriate setting of river boundaries

River boundaries are to be established in coordination with relevant agencies to ensure appropriate implementation of flood countermeasures. In establishing river boundaries, river boundaries should be set after identifying the risk of damages based on the prepared flood hazard maps. Since it is possible that the river may not be able to carry all of the flood discharge with its current flow capacity, the surrounding land, as well as the future development plans, should be taken into consideration. River channel conditions, existing river structures and sediment dynamics should be also considered.

4.2. Policy 2: Proposed flood control measures according to Nepal's socio-economic conditions

4.2.1. Installation of non-continuous dikes

In the case of a continuous dikes, which is one of the flood control measures, there is a risk of significant damage if the dike is breached by the flood larger than the one designed. In addition, if sediment accumulates in the river channel due to the continuous dike, it is necessary to consider the cost of maintenance, such as dredging. Therefore, in Nepal, a continuous dike is not necessarily the optimal solution. It is assumed that a non-continuous dike will be applied only in the necessary areas to be protected such as the concentrated asset. An alternative of the non-continuous dike is Kasumi Dike, which is known as a Japanese traditional river structure. The typical layout plan and functions of the Kasumi Dike is shown in Figure 6. The functions of the Kasumi Dike are summarized below;

- 1) To return flood waters from upstream to the river channel and to exclude internal waters in the rapid

flow section (riverbed gradient of 1/500~1/600 or more)

- 2) To provide retarding effects in the gentle flow section (gradient is less than 1/1000).

The openings of the dikes serve as drainage outlets, and the excavation of the channels through the outlets facilitates the drainage into the river.

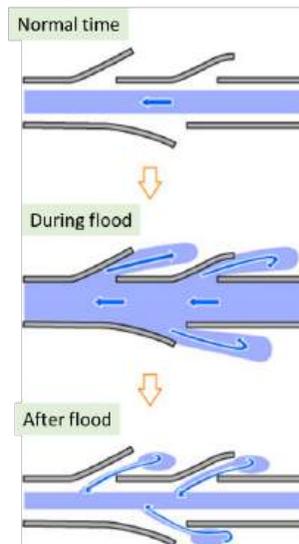


Figure 6. Typical layout plan and function of a non-continuous dike or Kasumi Dike [6]

The dikes facing the river prevent flood inundation, and if the dike fails, the overlapping dike behind it minimize flood inundation. [7] It also has an additional function as a groin. [8] The flood retarding function reduces flood damage downstream with a temporary storage effect. In areas where floodwaters are stored, buildings and roads may be raised over the assumed water level during the flood period.

4.2.2. Application of surrounding dikes and utilization of river basin retarding functions

Another alternative of non-continuous dike is the surrounding dike. A surrounding dike is limited to a certain section to protect important facilities such as settlements and infrastructures, and continuous dikes are not planned. Single-sided dikes will also be considered. The lands that are currently allowed to be inundated during flooding will continue to be used for their flood control functions. In the Mawa-Latouwa River improvement project by ADB, a surrounding dike are planned. An example of its layout is shown in Figure 7.

In planning the surrounding dikes for the ADB project, priority targets to be protected were surveyed in the field, and the effectiveness of the surrounding dikes was confirmed by inundation calculations. [3]

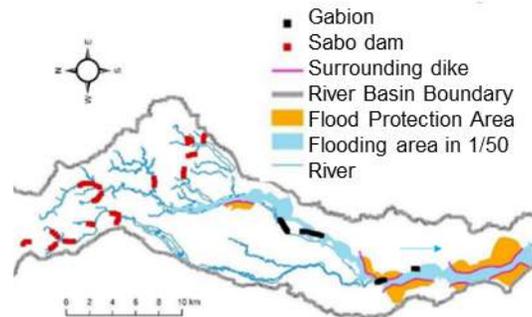


Figure 7. Surrounding dike planned for ADB Mawa-Latouwa River rehabilitation [3]

4.2.3. Selecting sustainable construction methods in Nepal

In Nepal, gabions, steel wire cages filled with boulders, are used for various infrastructures such as riverbank revetments and road slope retaining walls. Gabions are installed around the location where riverbed or riverbank is eroded. After this erosion, gabions deform without collapsing and maintain their functions. The materials for gabions, steel wire and boulders, can be procured locally at a price that can be met with local funds. Since only two types of materials are used and no advanced technology is required for the construction, it is excellent in terms of workability and maintenance management. In the Shindhuli Road, for example, a total of 306,000 m³ of retaining walls were constructed using gabions. Gabions are regarded as a sustainable technology in Nepal and its practicality is high.[8]

4.2.4. Sediment management plan

The sediment dynamics of the entire river basin should be monitored and plans be developed to manage the sediment within the river basin. Although there is a system in Nepal that controls sediment mining, there is a need to stabilize sediment delivery throughout the river basin through regular surveying, monitoring, and mandatory reporting from private miners.

4.3. Policy 3: Proposed administrative structure for flood control project implementation

4.3.1. Proposed structure for flood control master plan preparation and implementation

In order to integrate the countermeasures as proposed above, a master plan should be prepared. The Department of Water Resources and Irrigation (DWRI), under the Ministry of Energy, Water Resources and Irrigation (MoEWRI), is primarily in charge of flood control, and will take the initiative in coordinating with relevant agencies and encourage them to implement flood control

measures based on the master plan that is being developed in the Project. The Department of Meteorology and Hydrology, which is in charge of hydrology and meteorology, is also under MoEWRI, making it easy to coordinate with DWRI. They are cooperating with each other in providing data and assistance.

On the other hand, in the local rivers (Keshaliya and Singhia rivers), where the river management sections are different, cooperation between the central government and the regional government is not very active. As the budget and organizational scale of the regional government are smaller than those of the central government, large-scale flood control measures are not feasible for the regional government that is responsible for the local rivers. In the Project, river administrators from both central and regional governments meet regularly to discuss issues and the countermeasures, and will continue to use such opportunities on a regular basis to increase opportunities for personnel communication and data collaboration. In the future, the Project will also consider a system that specifies river management sections and allows for the sharing of roles and collaboration at each government level, with reference to Japan's river laws and systems.

4.3.2. Human resource development through public-private partnerships

In the Project, a master plan for flood control measures is being prepared jointly by the Nepal government officers, together with consultants from Japan and Nepal. Traditionally, the consultant conducts the necessary studies and the client side scrutinizes the results. In this technical cooperation, engineers from the client side are also actively participating in the various study tasks to improve their capabilities. By working together in the actual planning process, the client will be able to view river management as their own affair, with the aim of improving their ability.

In addition, the Project invites relevant officials to Japan. Training opportunities to learn about the history and knowledge of flood control in Japan are set up, views with Japanese administrative officials are exchanged and current flood control effects are observed to deepen understanding of the effects of flood control measures over the medium to long term. The history of flood control in Japan is long and has evolved in various ways before the current flood control plans and projects are developed. These findings can be deeply understood by learning the historical background and the effects of flood control measures.[5]

5. CONCLUSION

The study clarified issues related to flood damage in natural rivers in the Terai Plain of Nepal, based on data collected in the field and proposed flood control measures from the three perspectives of 1) identification of flood risks, 2) application of locally feasible countermeasures, and 3) enhancement of the project implementation system. The main conclusions are described below.

i. Capacity development for human resources and organization

Considering the three-tier structure of Nepal's organizational structure, joint study on flood control is proposed. The Project will begin with collaboration in data collection, and human resource exchange, to seek building relationships actively. Since the flood control plan for the Terai Plain requires long-term measures for both sediment and flood control, international cooperation from Japan, which has accumulated knowledge in the both fields, will be utilized and human resource development will be implemented.

ii. Definition of specific river management section

The water flowing in a river is continuous, whereas the management sections are discontinuous, which means that measures are implemented in parts, and the risk of flood damage will be the higher. It is important to define river management sections based on flood hazard maps in order for managers to take responsibility for each management section. The continuity of the rivers should be considered.

iii. Applicable construction method based on the situation

- Surrounding dikes and Kasumi dikes are assumed to protect the areas at high risk of flooding. They are planned based on field surveys and numerical calculations for the six ADB-funded rivers. Although the Kasumi dike is a traditional river structure in Japan since before the Meiji era (1868-1912), its function and effectiveness have been reaffirmed through recent studies, and it is considered to be of sufficient modern significance. On the other hand, with regard to the flood control effect of Kasumi dikes and retarding basins, it is necessary to take care to minimize the impact of flood waters due to storage on the human/industrial activities in the surrounding area.

- Gabions, which has been used locally, does not require complicated technology, the construction



cost is relatively low, and maintenance can be handled by local technology. However, it is important to consider the continuity with other structures and the river boundary. It also needs to be planned and constructed so that it does not obstruct the flow of floodwaters.

- iv. Development of the roadmap for flood control and phased implementation following flood control master plan

Rather than taking a reactive approach to flood control, the master plan will set clear future targets, and will be used as a road map for flood control measures. In Nepal, there are limitations on organizational capacity and budgets, and it is difficult to implement all the measures at once, therefore, flood risk in the entire basin will be reduced through phased development while monitoring the flow balance in the basin and the state of urban development.

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Study on Strategies and Paths to Strength Meteorological Services to Ensure the Development of New Electric Power System

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ABSTRACT

China is a global leader in green energy, and pushed lots of efforts for low-carbon reforms, including the construction of the national new electric power system to reduce greenhouse gas emission by increasing the proportion of clean energy in power generation. It is necessary to strength the meteorological services to ensure the development of new electric power system because climate factors have great impacts on the stable and safe operation of the power grid. The study adopted methods of literature analysis and expert consultation. The result of the research showed that the construction of the national new electric power system puts forward new requirements for meteorological service, such as optimizing the overall service layout, improving the forecast accuracy, and expanding service scenarios, though China Meteorological Administration have carried out full-chain energy meteorological services in wind power, solar power, hydropower, nuclear power etc. Then the specific proposals were put forward such as to improve service capabilities, to optimize the service layout, and to strengthen talent cultivation, according to the requirements of the construction of the national new electric power system.

1. INTRODUCTION

China is an active promoter of green and clean energy, and pushed lots of efforts for low-carbon reforms. Clean energy is dominant in the new power system, and the construction of the new electric power system is an important measure to ensure the realization of carbon peaking and carbon neutrality goals on schedule.

The uncertainty of weather conditions makes the supply of renewable energy fluctuates randomly (Li et al., 2015; Yu et al., 2022), because the new electric power system is highly dependent on climate related resources such as wind, light, water etc. Thus, China Meteorological Administration (hereafter CMA) delivers the whole chain meteorological services in the construction of new electric power system, including general investigation and

evaluation of climatic resources, station planning and site selection, power generation prediction, and disaster prevention. And it is necessary to strengthen the service capability of CMA to ensure the construction of the national new electric power system, because there is still a gap between the meteorological service and the demand of construction and operation of the national new electric power system.

2. CURRENT SITUATION OF ENERGY SERVICE BY CMA

CMA attaches great importance to promoting the development of new energy meteorological services, and launched the meteorological service demonstration plan for wind and solar power generation. And organized

matching meeting of energy meteorological service between energy enterprises and CMA. CMA has a good business structure in providing services for the construction of new electric power system. In this study, wind, light, water and nuclear power relevant energy meteorological services conducted by business units at all levels of CMA were investigated (Figure 2).

Focus of Service	
	Wind power General investigation and evaluation of wind and solar power resources, weather forecast, climate resources trend prediction, power forecast, energy consumption prediction, power facility meteorological disaster risk warning
	Hydropower Climate analysis and ecological impact assessment, construction, operation and maintenance of hydropower project
	Nuclear power Site selection service, and service for nuclear power safety operation such as meteorological disaster monitoring and early warning (for typhoon, extratropical cyclone and tornado)
	Power grid Meteorological disaster monitoring and early warning for strong convection, lightning, flood, wire ice and wind dancing, and meteorological disaster risk assessment service
	Consumption Forecast of power generation and demand, prediction of extreme weather and climate events to ensure the energy supply

Figure.2 Energy service structure of CMA

3. THE NEW REQUIREMENTS OF METEOROLOGICAL SERVICES FOR THE CONSTRUCTION OF THE NEW ELECTRIC POWER SYSTEM

Meteorological service is of vital importance to the construction of the national new electric power system of China, because which is dominated by renewable energy. And climate factors such as wind, light and water are the energy sources of renewable energy, so which is easily affected by climate factors. Meanwhile, the change of climate factors such as temperature will affect the demand of electricity in the whole society (Tian and Wang, 2017; Wang, et al., 2018; Wang et al.,2021). Weather process (strong wind, heavy rain, etc.), as well as meteorological disasters (typhoon, drought, etc.) will cause drastic fluctuations of energy generation, leading to the decline of power supply reliability, and affect cross-regional power supply of by damaging power facilities (Wang, et al.,2018; Panteli and Mancarella, 2015).

The future development direction of the new electric power system includes the construction of energy base, power grid, and regulatory resources (Shu, et al., 2021; Gao, et al., 2023; Zhou, et al., 2023). And the construction of new electric power system has put forward new requirements for meteorological services (Figure 1).

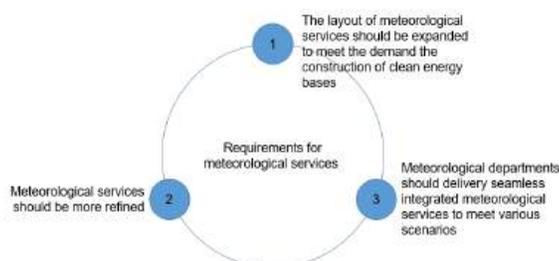


Figure.1 New requirement for meteorological services of new electric power system

4. MAIN WORKS NEED TO BE CARRIED OUT TO ENSURE THE CONSTRUCTION OF NEW POWER SYSTEM

Contrasted the general service demands of the construction of new electric power system, the main works that the meteorological department needs to carry out are as follows.

(1) **To improve the energy meteorological service system and layout according to the construction of clean energy bases.** At present, the energy meteorological service business mainly carries out services for single stations, and it has not yet developed overall service layout for major clean energy bases.

(2) **To improve the basic capacity of energy meteorological services to fully meet the service needs of the construction of the new electric power system.** In terms of power generation facilities services, due to data confidentiality of the power enterprise, it is difficult for meteorological departments to obtain disaster data of power generation facilities, resulting in a lack of understanding of relevant needs and disaster impact characteristics. The national and cross-regional meteorological disaster evaluation, forecast and early warning standards and related services of transmission lines have not been established. Meteorological services for micro-grid and power trading have not been carried out yet. And for data services, due to the lack of data platform and meteorological data sharing policy restrictions, meteorological data open sharing cannot meet the demand of energy enterprises.

(3) **To improve the refinement level of energy meteorological services.** It is necessary to further enhance the spatial and temporal resolution, time of forecast advance, and accuracy of professional energy meteorological forecast products, to meet the needs of smart grid construction. The forecast accuracy of wind and solar energy resources needs to be further improved, especially the prediction ability of turning weather (dust,

strong convection, etc.). Artificial intelligence technology adoption is insufficient for meteorological department and which application of is still in the initial exploration stage.

5. POLICY RECOMMENDATIONS FOR STRENGTHENING METEOROLOGICAL SERVICE TO THE CONSTRUCTION OF NEW ELECTRIC POWER SYSTEM

5.1 The layout of energy meteorological service should be optimized around the construction of major clean energy bases

(1) **To strengthen the overall planning of energy meteorological services.** Suggestions of different agencies of CMA were listed below (Table 1).

Table 1 Suggestions of different agencies of CMA

Items	Proposals
CMA	<ul style="list-style-type: none"> ● to optimize and adjust the business layout of national, regional center and provincial levels around major clean energy bases ● to carry out the construction of new energy weather stations at the national and regional center levels and coordinate the resources of various business units ● to strengthen the capacity of new energy power forecasting by developing new energy models based on the numerical model of CMA—MESO ● to strengthen the application of artificial intelligence algorithms
Regional meteorological center	<ul style="list-style-type: none"> ● to establish sub-center of energy meteorological observatory according to the demands of major clean energy bases
Meteorological bureau at provincial level and below	<ul style="list-style-type: none"> ● to delivery cross-regional energy supply service ● to carry out big data construction ● to carry out optimization and correction of local new energy meteorological service products ● to dock the actual needs of local new energy enterprises

	<ul style="list-style-type: none"> ● to conduct research and development of technology methods
Meteorological service alliance	<ul style="list-style-type: none"> ● to promote close cooperation between national, regional center, provincial meteorological departments and social enterprises

(2) **To promote demonstration projects in key provinces.** It is suggested that according to the requirements of the construction of the new electric power system, CMA should select relevant provinces of clean energy base to carry out service demonstration. CMA should issue corresponding planning for the demonstration provinces. It is suggested that CMA should promote the construction of a new energy system service business system integrated by the country and the province, and effectively improve the service ability of provincial meteorological departments for new power systems.

(3) **To optimize the network layout of regional energy meteorological service observation stations around clean energy bases.** It is suggested that CMA should jointly plan the observation layout with social enterprises, optimize the network framework of new energy observation stations around the major clean energy bases and key areas with dense energy transmission channels. In addition, according to the development needs of offshore large-scale wind power etc., CMA needs to increase the resolution of observation station network, such as high-altitude wind and radiation, and strengthen the collection of real-time power generation data of new energy enterprises. At the same time, CMA needs to and promote the unified planning, design and coordinated management of professional meteorological observation networks of new energy and other observation networks. And CMA needs to strengthen the construction of database.

5.2 The whole chain service scenarios should be further expanded

(1) **In terms of resource development and infrastructure construction,** CMA needs to refine meteorological services such as offshore wind power development, and power plant construction etc. To delivery wind and solar resource census, and integrate the results of census into land and resources planning.

(2) **In terms of power system operation,** CMA needs to strengthen the development of professional numerical models for energy meteorological services to improve the accuracy of weather forecasting and climate prediction.

CMA needs to develop targeted meteorological services such as cross-regional transmission and dispatch, thermal power generation measurement, energy storage system regulation, and reservoir regulation and storage, and carry out relevant research on wind-solar complementary, decentralized wind power, and distributed photovoltaic.

(3) In terms of power transmission, CMA needs to develop high-impact weather forecasting and warning services related to power and gas transmission line such as lightning strikes, wind, ice, and heavy rain.

(4) In terms of disaster prevention and reduction, CMA needs to carry out meteorological services for the safety operation of power grids to enhance the resistance of power equipment to extreme weather, such as defense against the impact of typhoons on nuclear power, and severe weather warning for coal mines.

(5) In terms of new energy consumption, CMA needs to develop service capacities for electricity demand forecasting, and electricity trading etc.

5.3 Scientific and technological innovation, talent training, and cooperation mechanisms should be further strengthened

(1) To strengthen the open sharing of data. The reanalysis, live and forecast data of CMA were more precise compared to most foreign data for China, in particular for reanalysis data. It is suggested to leverage the big data advantages of CMA, build a data service platform, trade the reanalysis, live and forecast data of meteorological departments to new energy enterprises, and integrate data products into the enterprise dispatching system, and thus to attract energy enterprises to make deepen cooperation in the field of new energy meteorological services.

(2) To strengthen scientific and technological innovation. CMA needs to set up joint funds with energy-related government departments and enterprises, cultivate joint key laboratories, focus on the research and development of observation equipment and early warning technologies, and conduct technical research on image recognition, wind field inversion, power forecast and energy storage forecast, and independently formulate a number of important national and industry standards. CMA should cooperate with universities, research institutes, and social enterprises to strengthen the training of composite talents in energy meteorology, and build a team of high-level scientific and technological talents in energy meteorological services.

(3) To promote cooperation with energy enterprises. CMA should strengthen the cooperation mechanism, support the backbone enterprises of new energy meteorological services, and build an innovative

ecosystem for small, medium and micro enterprises conducting energy meteorological services led by the CMA. CMA should build energy meteorological service system covering China and countries along the Belt and Road, with policy, technology system, standard, and user system. And CMA should strengthen its guidance on the development of the energy meteorological service market.

6. CONCLUSION

This study systematically analyzed the current situation of energy meteorological service of CMA and the demand of meteorological service for the construction of new energy system, and relevant policy recommendations are put forward for meteorological departments to enhance service for the construction of the national new electric power system from the aspects of optimizing the service layout and improving the service guarantee capacity.

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Innovation for sustainable deep foundation in Thailand

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ABSTRACT

Population growth and advancement in infrastructure development in major Thai cities, often concretizing in highly populated population densities, has influential the velocity of deep foundation construction. However, this growth came with several environmental implications in respect to carbon output and sustainability especially in asset construction. Amidst the contemporary challenges viz. carbon footprint assessment, design considerations, and construction methodologies of deep foundation systems in Thailand, this paper aims to present a systems view of sustainable solutions. A change in the conventional design philosophy is recommended to make more effective use of material, create efficient structures and to minimize embodied carbon in construction. A large database of pile load-settlement curve is adopted to efficiently calculate pile capacities. This method resulted in significantly reduction in carbon emission caused by bored pile construction. Furthermore, this research demonstrates the possibility of reusing construction waste, especially bentonite which is regularly used in deep foundation techniques. The ability to reuse bentonite waste and give it another life would minimize its effects on the environment whilst providing solutions to fight for circularity within construction industries. In conclusion, the paper contributes to the development of a new and more viable conception for deep foundation in Thailand where the construction industry demands fresh innovative environmentally friendly concept to suite its ever fast growing nature.

1. INTRODUCTION

Thailand's rapid urbanization, particularly in major cities like Bangkok, has led to an ever-growing demand for high-rise buildings to accommodate its increasing population density [4]. As available land becomes scarce, deep foundation solutions are essential for the construction of these structures. However, the urban environment presents numerous challenges, including strict regulations on construction-induced vibrations, the depletion of natural resources, and the growing concern over carbon emissions and construction waste.

Traditional foundation design and construction methods often rely heavily on resource-intensive materials and processes, contributing significantly to environmental degradation. The extraction and use of natural resources, such as cement and steel, as well as high-energy construction techniques, result in considerable carbon footprints. Furthermore, densely populated urban areas impose strict restrictions on construction vibrations, as excessive vibrations can damage nearby structures and disrupt local communities. Sustainable construction practices are now a necessity, not only to meet regulatory requirements but also to align with

global trends towards reducing environmental impact. In response to these challenges, the construction industry in Thailand must innovate to develop greener foundation systems [2]. This includes redesigning conventional techniques to minimize resource consumption, incorporating renewable materials, and finding ways to recycle or upcycle construction waste, such as bentonite—a common byproduct of deep excavation.

This paper explores innovative solutions for sustainable deep foundation design and construction in Thailand, focusing on reducing carbon emissions, managing construction waste, and adhering to stringent vibration regulations. By examining these factors, the study aims to provide a roadmap for sustainable urban development that can meet the demands of modern construction while reducing environmental impacts.

2. CURRENT ISSUE IN DEEP FOUNDATION CONSTRUCTION

Bangkok faces significant challenges in deep foundation and deep excavation projects due to its unique geotechnical conditions and rapid urbanization. Figures 1a and 1b show an overview of construction of deep foundation and deep excavation sites, respectively. In these sites, soft compressible clay layers, coupled with high groundwater levels, complicate the design and construction of deep foundations and excavations. These conditions lead to settlement issues, soil instability, and the potential for damage to adjacent structures, especially in densely populated urban areas.



Figure 1. Typical construction sites of: (a) Large deep foundation construction; (b) Deep basement construction

3. INNOVATION FOR SUSTAINABLE AND RESILIENT DEEP FOUNDATION

Innovation for sustainable and resilient deep foundation systems is crucial in addressing the pressing challenges posed by urbanization and environmental sustainability. By integrating advanced materials, optimizing design techniques, and implementing innovative construction methods, the industry can enhance load-bearing capacities while minimizing resource consumption and carbon emissions. Emphasizing the use of eco-friendly alternatives, such as hydraulic cement and recycled materials, further contributes to creating foundations that are not only structurally sound but also environmentally responsible, setting a new standard for infrastructure development. The following topics present the method for constructing deep foundations and retaining walls considering sustainability and resilience concepts.

3.1. Monitoring of carbon footprint emissions

Monitoring carbon footprint emissions in deep foundation and deep excavation projects is essential for promoting sustainable construction practices. Using an Excel-based program provided by the DFI (Deep Foundations Institute) and EFFC (European Federation of Foundation Contractors) guidelines, contractors can effectively track and calculate the carbon emissions generated during various stages of construction. An example of carbon calculation is shown in Figure 2. This tool allows users to input data such as material quantities (e.g., concrete, steel), equipment usage, and energy consumption, which are then translated into carbon emission figures. The program follows a systematic approach based on lifecycle assessment (LCA) principles, providing detailed insights into the environmental impact of each construction activity. By continuously recording emissions data, project managers can identify opportunities to reduce the carbon footprint, such as optimizing material usage, selecting low-carbon alternatives, or improving energy efficiency. This monitoring process not only helps comply with environmental regulations but also supports decision-making for sustainable deep foundation and excavation design, aligning projects with global carbon reduction

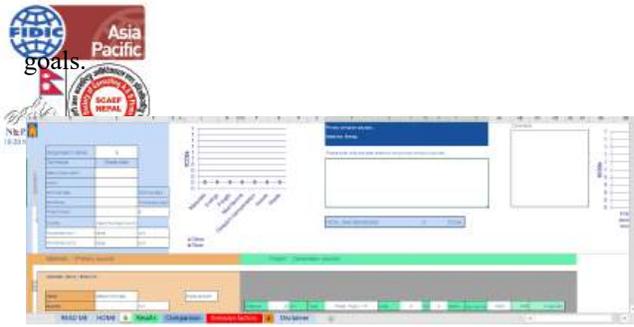


Figure 2. An example of carbon calculations in deep foundation construction

3.2. Adopting new concept of deep foundation design

Adopting a new concept in bored pile design involves reconsidering the traditional factor of safety, transitioning from a conservative value of 2.5 to a more optimized factor of 2.0. This shift is supported by the implementation of static load tests and the utilization of a comprehensive database from previous projects. By conducting static load tests, engineers can obtain reliable data on the actual load-bearing capacity of bored piles, enabling a more accurate assessment of structural performance. Coupled with historical data, this evidence allows for a more confident reduction in the factor of safety, ensuring that the piles can safely support the anticipated loads while minimizing material usage and construction costs. This approach not only enhances the efficiency of bored pile design but also promotes sustainability by reducing excess material and the associated carbon footprint. By leveraging empirical evidence and advanced testing methodologies, the construction industry can adopt a more rational and efficient design philosophy that aligns with modern engineering practices and environmental goals.

3.3. Efficiency in design for green construction

Enhancing load-bearing capacity while minimizing material usage stands as a paramount goal in optimizing deep foundation design. As discussed in the previous topic of reducing factor of safety, a database of pile load-settlement is required to gain confidence in design. Figure 3 compares two different approaches to designing the deep foundation system. The conventional method employs a larger number of piles with shallower pile tips while the innovative method uses a smaller number of piles with deeper pile tips.

By strategically engineering deeper piles, engineers can harness the higher unit skin friction of deeper soil layers, thereby distributing loads more efficiently and reducing the overall quantity of materials required. Moreover, the footprint of the pile cap is also smaller for

the deep pile approach. This focus on optimizing load-bearing capacity with minimal material usage not only ensures structural integrity but also aligns with sustainable construction practices, promoting resource efficiency and minimizing environmental impact.

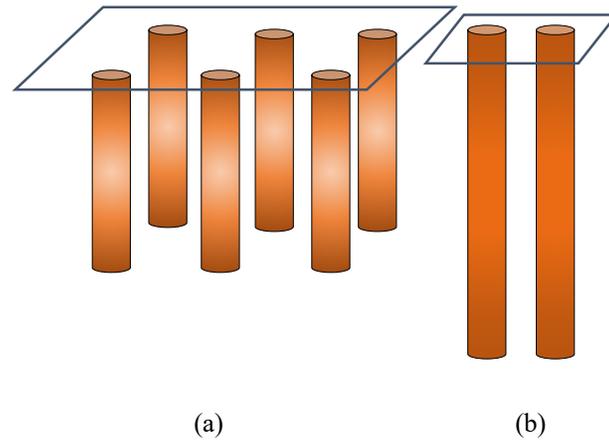
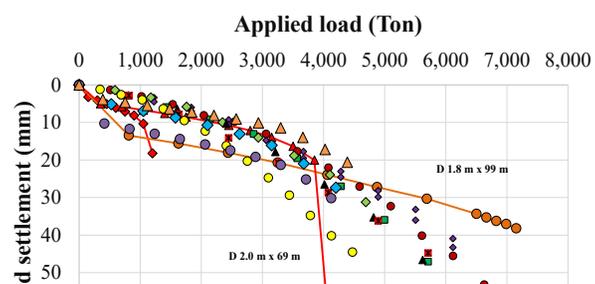


Figure 3. Comparison of two approaches of foundation design; (a) Larger number of piles with shallower pile tip; (b) Smaller number of piles with deeper pile tip

Figure 4 (based on data from [1]) demonstrates the increased load-bearing capacity per unit of pile material. For piles with depths of 99 m and 69 m, the load capacities are 12.7 T/m³ and 7.0 T/m³, respectively. The load-bearing capacity of the deeper pile is 50% greater than that of the shallower one. This improvement translates to a material saving of approximately 40% to 60%.

Another key factor contributing to the higher load-bearing capacity of piles is the advancement in technology, quality control, and design expertise. As shown in Figure 5, there has been a noticeable improvement in the friction factor (Beta) for sand layers in Bangkok. Prior to 2001, bentonite was commonly used in bored pile construction, but the filter cake it formed led to a decrease in skin friction. By switching to polymer-based drilling slurry, implementing systematic quality control, and constructing deeper piles, the friction factor has significantly improved.



Public Company Limited, Elkem Company Limited, and Mahidol University. The forced bleeding behavior, a key factor for fresh concrete, is illustrated in Figure 6a, showing no significant difference between Portland and hydraulic cements. While the compressive strength of concrete using hydraulic cement is lower than that of Portland cement, all samples tested showed strengths exceeding 500 ksc at 28 days—well above the typical range of 280–320 ksc required for deep foundations (Figure 6b). These results were based on fly ash content not exceeding 20%. Therefore, hydraulic cement can be fully substituted for Portland cement in deep foundation construction

Figure 4. Record of static pile load test results of pile with different diameters and depths [3]

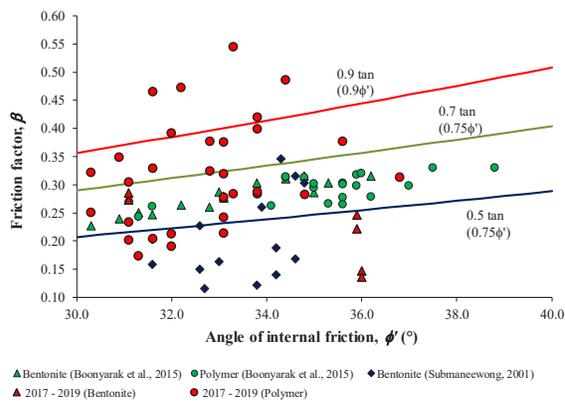


Figure 5. Development of friction factor of Bangkok sand [6]

3.4. Carbon emission reduction in concrete n

The shift from Portland cement to hydraulic cement marks a significant advancement in reducing the environmental impact of construction practices. Unlike Portland cement, which requires high energy consumption during production, hydraulic cement offers an eco-friendlier alternative. Hydraulic cements, such as those based on calcium aluminate or calcium sulfoaluminate binders, have lower embodied carbon due to their production processes involving lower kiln temperatures and reduced limestone content. This transition not only helps to reduce carbon emissions but also promotes greater sustainability in construction projects. By using hydraulic cement in deep foundation work, the construction industry can lessen its environmental footprint while maintaining structural strength and meeting performance standards, paving the way for more sustainable infrastructure development.

However, the performance of hydraulic cement in deep foundations is still not fully understood. Figure 6 presents test results from a joint research project involving Seafco Public Company Limited, Siam City Cement

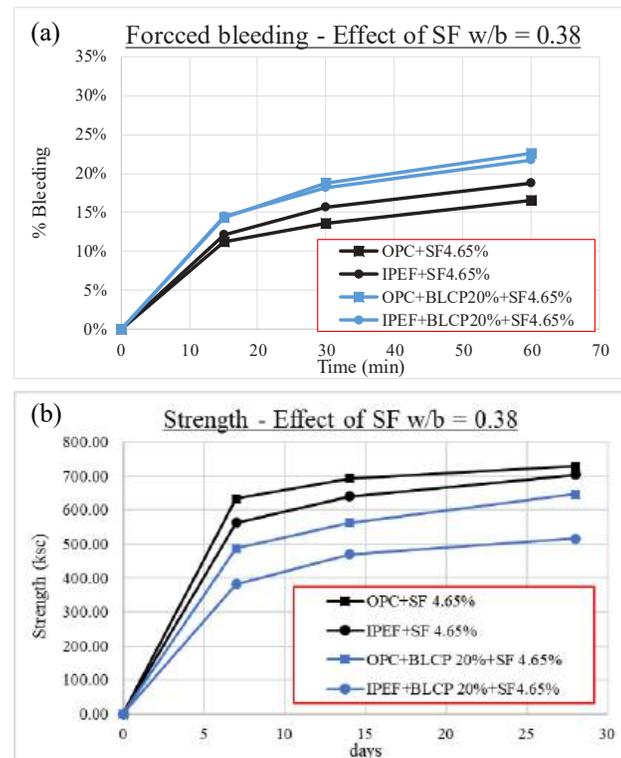


Figure 6 Test results of hydraulic cement concrete; (a) Force bleeding behavior; (b) Compressive strength

The carbon emission of hydraulic cement is 4.5% smaller than that of Portland cement or equivalent to 50 kg of carbon emission reduction per 1000 kg of cement powder. Figure 7 shows the amount of concrete consumption by SEAFCO. The replacement of hydraulic cement started in 2020. By using about 350 kg per cubic meter of concrete, SEAFCO can reduce about 5,400 tons of carbon emissions each year.

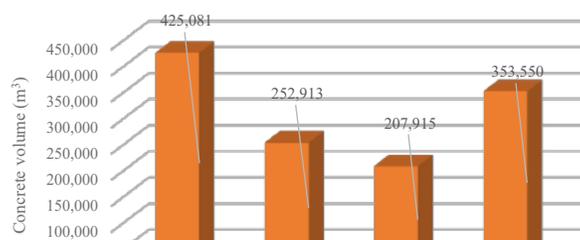


Figure 7 Records of the amount of concrete consumption by Seafco

3.5 Management of waste material

Bentonite slurry is commonly used as a drilling fluid for bored piles and diaphragm walls, as shown in Figure 8a. Composed of volcanic clay, bentonite typically becomes waste after use. Its disposal poses challenges due to its high pH, low permeability, and unsuitability for public drainage systems. Therefore, finding a solution for managing waste bentonite is crucial.

By separating the slurry into its solid and liquid components (as shown in Figure 8b) and applying appropriate treatment and processing, the solid portion can be converted into durable ceramic materials (Figure 8c) or clay liners (Figure 8d). Upcycling bentonite slurry into ceramic or clay liners offers an innovative and sustainable approach within the construction industry.

These repurposed materials can serve as effective barriers or liners, ideal for preventing seepage or contamination in projects involving sandy soils or underground structures. This upcycling process not only reduces waste but also creates valuable functional materials, promoting a circular economy in construction and lowering the environmental impact of excavation activities.



Figure 8 Upcycling of bentonite slurry waste; (a) Bentonite slurry; (b) Solidified bentonite; (c) Ceramic from bentonite sludge; (d) Clay liner from bentonite sludge



Figure 9 presents the void ratio (e) and the calculated coefficient of permeability (k) derived from oedometer test results. A general trend is observed where a decrease in the void ratio leads to a reduction in the permeability. At equivalent e -values, bentonite sludge exhibited a higher k value compared to bentonite powder, suggesting that the structure of the anionic polymer-modified bentonite reduces its effectiveness as a barrier. The minimum permeability requirement for compacted clay liners is a k value of 1×10^{-9} m/s [5]. When compacted at optimum water content following the standard Proctor energy procedure, the bentonite sludge produced k values

slightly below this threshold, indicating its potential suitability for use as a compacted clay liner material.

The study concludes that bentonite sludge, when compacted at optimal water content using the standard Proctor method, can achieve a k value of approximately 0.3×10^{-9} m/s. This makes it a viable option for use as a clay liner, particularly for water storage applications in irrigation systems in regions like Northeastern Thailand, where water storage and supply are limited.

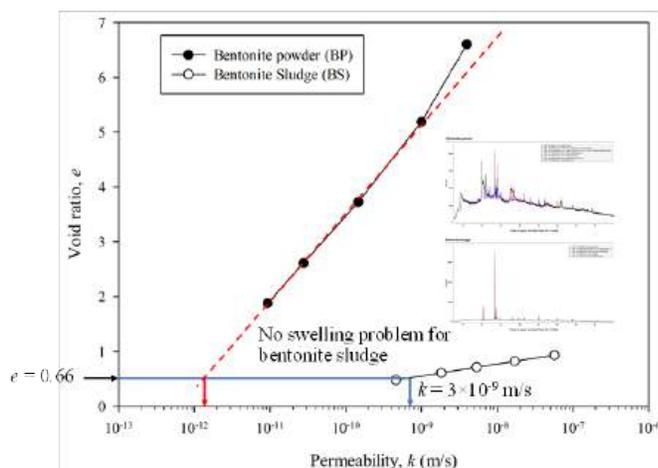


Figure 9 Engineering properties of solidified bentonite sludge

4. SUMMARY AND CONCLUSIONS

The development of sustainable and resilient deep foundation systems in Thailand has become a critical necessity due to the challenges posed by urbanization, environmental concerns, and resource management. Based on the data presented, several key conclusions can be drawn:

- The adoption of a new design concept coupled with rigorous carbon footprint emission monitoring enables the construction industry to enhance structural efficiency while significantly reducing environmental impact, paving the way for more sustainable and resilient infrastructure development.
- Enhancing design efficiency through innovative techniques to boost load-bearing capacity while reducing material consumption is central to sustainable construction. This can be achieved by increasing pile depth to reach soil layers with higher unit skin friction, resulting in material savings of approximately 40% to 60%.
- Shifting from carbon-intensive Portland cement to more environmentally friendly hydraulic cement represents a major step towards lowering the construction industry's carbon footprint, aligning

with global sustainability efforts. Hydraulic cement reduces carbon emissions by 4.5% compared to Portland cement, with no significant performance difference between the two.

- Waste bentonite slurry should be treated by separating the solid and liquid components. Upcycling waste bentonite into valuable products like ceramic or clay liners reduces environmental impact and supports a circular economy within the construction industry.

By incorporating these strategies, Thailand can establish sustainable and resilient deep foundation systems that foster environmentally conscious, efficient, and community-focused infrastructure development, setting a global example for responsible construction practices.

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