2023 - 2024

HELP Global Report on Water and Disasters

HELP Water & Disasters

GRIPS

Ministry of Land, Infrastructure, Transport and Tourism

University of Nairobi

UN environment United Nations Environment Programme

Global Water Partnership

Myanmar Water Academy

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Dear Readers,

I am pleased to share with you the HELP Global Report on Water and Disasters 2023-2024, the 6th volume of the annual series that compiles experiences, lessons learned and good practices in dealing with major disasters on Earth in recent months.

The former parts of this volume contain detailed reports on major disasters that occurred between mid-2023 and mid-2024. With climate change making unwanted progress every day, business as usual is not an option in many sectors. The water sector is no exception. Increasing variability and uncertainty due to climate change are challenging water management and water-related disaster risk reduction. Not only the means, but also the basic concepts of water management need to be transformed to meet the challenges of climate and other global changes. To this end, countries and stakeholders need to learn from past experiences and lessons, so that they can be translated into new experiments and proposals to create shortcuts for transformation. The articles in this report will provide in-depth insights into the causes, chronology and lessons of the disasters, thereby facilitating fundamental improvements in water-related disaster risk reduction at the field level.

The latter parts of this volume contains the Principles on Gray and Green Infrastructure and case studies on the Principles launched at the Bandung Spirit Water Summit in May 2024. While sharing lessons at the field level is a necessity, promoting dialogue at the highest level is a must to transform 'policy-as-usual' at the global and country levels. In this context, HELP organised the Bandung Spirit Water Summit as part of the 10th World Water Forum in Bali, Indonesia in May 2024. The Bandung Spirit Water Summit, an agora of more than twenty current and former heads of state and government, created a new political dynamic. The Summit's direct dialogue between leaders, stakeholders and audiences, a first attempt to shorten the path between politics and water, opened corridors to bring water into transformative decision-making in the world. The Bandung Spirit Water Summit focused on three key areas of water urgency: climate change and water resilience, sanitation and water for all, and water for peace. The outcomes of the Summit, titled "Bandung Summit Call for Actions" with background paper and "Bandung Water Action Agenda", include concise and bold proposals and supporting concrete actions to transform business as usual of, for and by all in the world.

HELP's tangible contribution to transforming water and disaster policies and practices through this Summit was the launch of the Principles on Grey and Green Infrastructure. Today, green infrastructure has re-emerged as another tool for water management. However, green infrastructure cannot replace grey infrastructure, at least not completely, and vice versa. The lesson is to combine the two appropriately. They differ in function, applicable scale, hydro-meteorological effectiveness, social and environmental impacts, and socio-economic costs and benefits. There are many cases where a grey or green structure added to an existing green or grey infrastructure dramatically increases its water benefits to people. Our challenge is to find the best "grey"-"green" combinations for the specific situations of our countries, cities and catchments. The principles and case studies in this volume provide practical guidance that you can use as a decision-maker, coordinator, practitioner or other stakeholder when dealing with green, grey and combined infrastructure for water management. It will help you to make informed choices about the best options to consider.

I sincerely hope that this edition will help readers to be better prepared for disasters that may occur at any time in your country, province, or community.

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1 Overview of Water-related Disasters and Addressing Challenges of Disaster Risk Reduction in 2023

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Water-related disasters in 2023 resulted in death toll of 23,330(of which 22,449 by flood and storm and 247 by drought), affected people of over 71.7 million (of which 49.7 million by flood and storm, and 21.8 million by drought), and economic loss of 144.3 billion US Dollars (of which 121.2 billion USD by flood and storm and 22.1 billion USD by drought) worldwide. Share of water-related disasters are 27.0 % for deaths, 77.0% for number of affected people, and 71.1 % for economic loss. The share of water-related disasters decreased not by reduced loss but sharp increase of loss by the earthquake by a single earthquake disaster in Türkiye. The death toll in 2023 was 1.79 times of that in 2022 (12,569) whereas the number of affected people and economic loss were 0.40 and 0.69 of those in 2022, respectively. increased by 79%. Water and disasters were squarely addressed in the UN 2023 Water Conference and the Bandung Spirit Water Summit to meet those recurrent challenges of water-related disasters.

1.1 Human loss and number of affected people by water-related disasters in 2020

The year 2023 was characterized by recurrent water-related disasters including one of massive scale in Libya. In 2023, 23,330 people lost their lives by 337 water-related disasters (e.g., floods, tsunamis, slides and debris flow, storms, and droughts) out of total yearly death of 86,473, meaning that 27.0% of deaths were caused by water-related disasters. The death toll is 1.79 times higher than 12,569 in 2022 and 3.35 times than 6,500 in 2021.The largest death by single water-related disaster in 2023 was 12,352 by Hurricane Daniel in Libya.

According to EM-DAT (International Disaster Database) of Centre for Research on the Epidemiology of Disasters (CRED), 71.7 million people were affected by water-related disasters out of 93.1 million of people affected by all disasters, meaning 77.0 % of disaster-affected people were caused by water-related disasters. Deaths by water-related disasters is 133%% of that of the average in the recent 20 years (17,495 in 2003-2022). Death Toll by Disaster Type (2023 vs. average 2003-2022) are shown in Figure 1.1. Top 10 severest disaster events by number of affected people in 2022 are shown in Table 1.2. The increasing trend of number of affected people by water-related disasters continue due to, inter alias, climate change, population growth, and urbanization. In the recent twenty years (2002-2021), number of people affected by water-related disasters is 3.75 billion and accounts for 94% of total (3.98 billion). Heavy rain and flooding In Pakistan immersed around 40% of the national territory, resulting in deaths of over 1,700 people. The year 2022 was also marked by series of droughts, resulting in death toll of 2,601 and affected people numbering 206.9 million.

Table 1.1 Death Toll by Disaster Type (2021 vs. average 2002-2021)

Event	2023	Average (2002-2022)	Rate (2023/average of 2002-2022)
Drought	247	1,157	0.21
Flood	7,763	5,518	1.41
Mass movement (wet)	654	803	0.81
Storm	14,666	10,017	1.46
Subtotal by wate-related disasters	23,330	17,495	1.33
Earthquake	62,451	35,124	1.79
Extreme temperature	406	11,470	0.04
Mass movement (dry)	0	35	0.00
Volcanic activity	23	80	0.29
Wildfire	264	86	3.07
Subtotal by the other disasters	63,144	46,795	1.35
Grand Total	86,473	64,148	1.35

Source: UNDRR using EM-DAT (International Disaster Database)

Table 1.2 Top 10 severest disaster events by number of deaths in 2023

(Bold letter by water-related disasters)

Country	Name of event	Death toll
Türkiye	Earthquake	50,783
Libya	**Storm Daniel**	**12,352**
Syria	Earthquake	5,900
Congo, DR	**Flood**	**2,970**
Morocco	Earthquake	2,946
Afghanistan	Earthquake	2,445
India	**Flood**	**1,529**
Malawi	**Storm Freddy**	**1,209**
Nigeria	**Flood**	**275**
Yemen	**Flood**	**248**
Share of water-related disasters	**6 events**	**18,583/80,657=23%**

Source: 2022 EMDAT Report

Table 1.3 Top 10 severest disaster events by number of affected people in 2023

(Bold letter by water-related disasters)

Country	Name of event	Death toll
Indonesia	**Flood**	**18.8 million**
India	**Flood**	**10.2 million**
Türkiye	Earthquake	9.2 million
Syria	Earthquake	8.8 million
Guatemala	**Flood**	**4.4 million**
India	**Storm Michaung**	**4.4 million**
Tanzania	**Flood**	**2.9 million**
Somalia	**Flood**	**2.5 million**
Malawi	**Storm Freddy**	**2.3 million**
Philippines	**Flood**	**2.1 million**
Share of water-related disasters	**7 events**	**46.6 million/64.6 million=72.1%**

Source: 2022 EMDAT Report

1.2 Economic loss by water-related-disasters

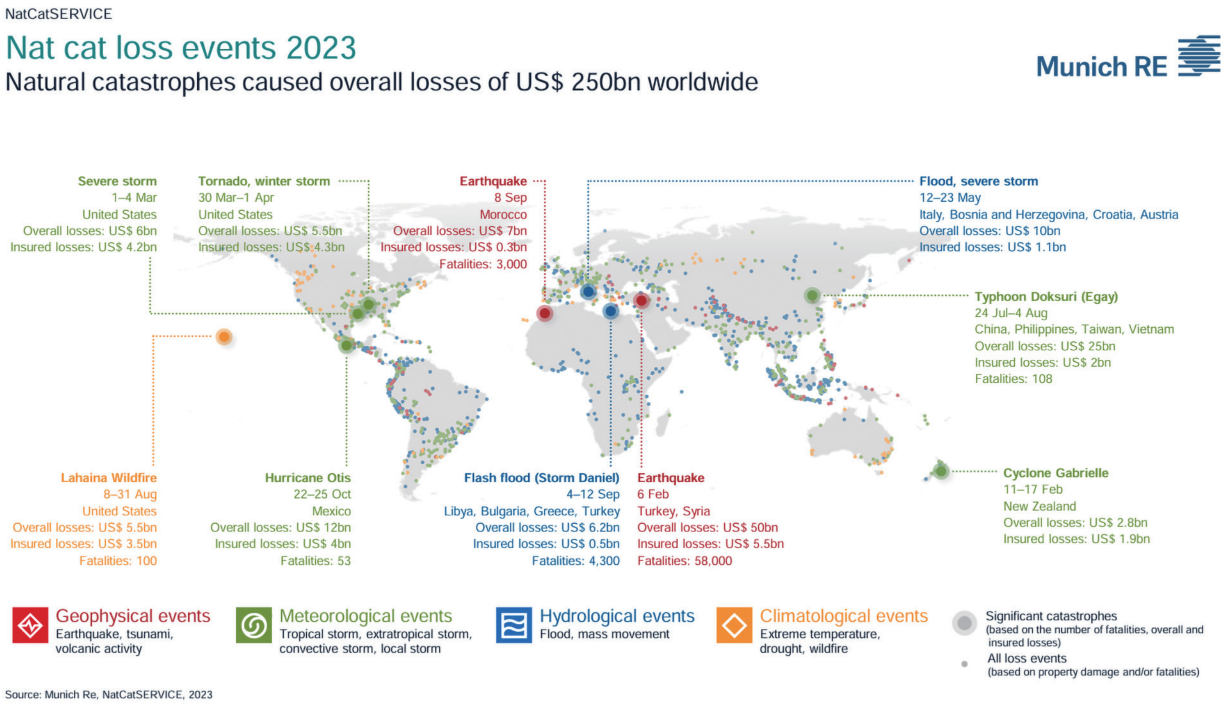
The overall economic loss by water-related disasters in 2023 was US$ 144.3 billion, or 71.1 % of total loss of US$ 202.7 billion by all disasters. Storms, floods, and droughts hit and caused severe damage in various parts of the world. Economic loss by drought was 22.1 billion USD, 2.3 times of the average of recent 20 years whereas those by floods and storm kept the largest share at 121.2 billion USD. The annual loss of 144.3 billion USD was nearly same as the average of US$ 146.6 billion in the recent twenty years of 2003-2022. 7 out of ten top economic loss disasters were water-related.

Table 1.4 Top 10 severest disaster events by economic loss in 2023
(Bold letter by water-related disasters)

Country	Name of event	Economic loss
Türkiye	Earthquake	34 billion
China	**Typhoon Doksuri**	**25 billion**
USA	**Drought**	**14.5 billion**
Mexico	**Storm Otis**	**12.0 billion**
Italy	**Flood**	**9.8 billion**
Syria	Earthquake	8.9 billion
Morocco	Earthquake	7.0 billion
Lybia	**Storm Daniel**	**6.2 billion**
USA	**Storm**	**6.0 billion**
USA	Wildfire	5.5 billion
Share of water-related disasters	**6 events**	**73.5 billion/128.9 billion=57.0%**

Source: 2022 EMDAT Report

Fig. 1.2 Map of natural catastrophe loss events 2022



Source: Munich Re. Natcast 2024

09/10/2022: file:///C:/Users/hirok/Downloads/MunichRe-NatCat-2023-world-map.pdf

1.3 Major water-related disasters in 2023

Disasters continued to occur in all continents of the world (Fig. 1.2). Major water-related disaster events include Tropical Storm Daniel in Syria, Cyclone Freddy in Malawi, Floods in Indonesia, Floods in India, Typhoon Doksuli in China, Hurricane Otis in Mexico, and Drought in the West Coast of USA. Storm Daniel in Libya, et al, resulted in 5-digit human loss including that by burst of a dam.

2. International process to address water-related disasters.

2023-2024 period was marked by discussion trends of the international community to squarely address issues of water-related disasters reflecting recurrent disaster events in many parts of the world. Water-related disaster risk reduction was taken up as one of main themes in the 3rd Interactive Dialogue (ID3) of the UN 2023 Water Conference in March, 2023, the first UN conference dedicated to water issues since 1977. There were a number of recommendations and commitments made in ID3 as shown in Fig. 1.3.

Fig. 1.3 Key Messages of the 3rd Interactive Dialogue of the UN 2023 Water Conference

The UN 2023 Water Conference

The 3rd Interactive Dialogue: Water for Climate, Resilience and Environment: Source to Sea, Biodiversity, Climate, Resilience and DRR

KEY MESSAGES

I. Changing Climate: Water scarcity, droughts and the melting cryosphere

1- Human-induced climate change has a multidimensional negative effect on the human right to water and water-dependent sectors. It negatively affects both water supply, in terms of availability, quantity, and quality, as well as water demand for different uses. Food security, human health, urban and rural settlements, the energy sector, industrial development, economic development, and ecosystems are also increasingly vulnerable to the impacts of climate change.

2- Growing extreme water-related hazards and threats, such as droughts, floods, and the melting cryosphere, have drastic impacts on people, socio-economic development, and ecosystem functions and related ecosystem services.

3- A key challenge to build climate-resilient water management is the internal fragmentation and external isolation of the current water management systems. Water systems are fragmented along the hydrological cycle and the geopolitical landscape. In addition, water is an ecoservice managed in isolation from its surrounding and interacting ecosystems.

4- COP27 achieved a breakthrough agreement to provide “loss and damage” funding for vulnerable countries hit hard by climate disasters. Creating a specific fund for loss and damage marked an important point of progress. However, the risks of inadequate knowledge, lack of robust and appropriate scientific information, and insufficient needs assessment not only constitute key bottlenecks to climate action and resilience, but also lead to maladaptation. Accurate data and valuation on water-related climate-induced loss and damage, as well as adaptation actions and strategies are critically needed.

5- Water-related climate action suffers from a double finance challenge. On the one hand, there are escalating financing needs to build new resilient infrastructure and to maintain and enhance the resilience of existing infrastructure. On the other hand, available financial resources are not always directed to their optimal use as a result of the undervaluation of water-related ecosystems and their related ecoservices. Means of implementation, particularly concessional finance, are key enablers to implement effective water-related climate action.

6- Water, food, energy, and ecosystems form a nexus at the heart of sustainable development, and pressure on all four is increasing rapidly. Thus, there is a need to strengthen transnational political systems and logistical support to maximize available resources, including water, in a sustainable way to effectively adapt to climate change. We need to turn the current energy and food crisis into opportunities to transform – nationally and globally – the energy mix, food production, and consumption patterns by addressing water scarcity.

II. Resilience to water disasters: Decreasing risks and conserving biodiversity

7- Climate change will adversely affect the risk of water-related disasters. The impact is more severe on vulnerable areas, such as the Least Developed Countries or Small Island Developing States, and on persons most at risk, such as women, children, the elderly, people with disabilities, and indigenous peoples.

8- Various frameworks and initiatives for Disaster Risk Reduction (DRR) have been put forward, but lack of reliable data, inadequate risk management, and lack of understanding on the part of decision-makers hinder efforts to strengthen preparedness and build resilience to the water-related disasters.

9- Water-related DRR requires close cooperation among multi-stakeholders, including decision-makers and vulnerable people, as well as scientists and engineers. Substantial data and understandable information through technological innovation can connect science and decision-making. It also requires early warning mechanisms, anticipatory action approaches, and resilient infrastructure to enhance preparedness.

10- 80% of climate change impact is felt through water. Focus on effective measures that contribute to both mitigation and adaptation of climate change. Water wise green and grey infrastructure, supported by advanced IT on water, can help meet this objective. Embed the concept and system of resilience throughout the whole lives and livelihoods of people and society.

11- Invest in water wise green and grey infrastructure that creates a foundation for tomorrow's growth and the well-being of next generations, while at the same time sustaining trust in the future of countries for financial markets. Generate billions in benefit by investing millions through drastically enhancing the capacity of existing infrastructure through digital transformation. Encourage all financial institutions, including International Financial Institutions, to step up their efforts to support green and blue transitions and to align financial flows. In order to combat climate change, all countries and stakeholders should be united to achieve breakthroughs in urgent water challenges such as the degrading cryosphere, or deteriorating water quality and aquatic ecosystems. Establish symbolic days and years, such as the International Day for Glacier Conservation and World Lake Day, to unite global will and commitments for actions to meet urgent water challenges.

12- Water is not only part of the problem; it is also part of the solution. Terrestrial and freshwater ecosystems provide invaluable services for climate action. Water is fundamental to all systems' transition required for climate-resilient development. Transformative water actions can be a catalyst for climate resilience.

13- An integrated view of water resources, the biosphere, and environmental flows can help to devise the sustainable water, food, and economic systems needed to develop resilient socio-ecological systems. Decoupling water consumption from economic activity is indispensable and a prerequisite to achieve water sustainability and climate resilience.

14- National mechanisms for cross-sectoral coordination and mutually agreed, mutually beneficial, no-harm-based policies for cooperative water-related adaptation can be a solution to building resilience.

15- Taking into account the close links between resilience, biodiversity, and the status of water-related ecosystems, holistic conservation approaches are required to implement coherent policies, linking biodiversity conservation and climate-resilient water management.

III. Working for the future: Early warning from source to sea

16- Enhance awareness, integrated preparedness, and timely information-sharing by both governments and citizens to detect and prevent future disasters, including pandemics, and all sorts of disturbances. Share lessons and good practices that have been amassed in the last few years as assets for the future we want.

17- In order to build resilience, it is essential to mainstream integrated policy frameworks that combine integrated water resources management (IWRM) with other holistic water-related approaches that link the interconnected ecosystems of the hydrological cycle with the associated socioeconomic processes. Such holistic approaches include source to sea, inclusive transboundary governance, integrated coastal zone management, and disaster risk management.

18- Water can and should play a critical role to build a post-COVID-19 society that is more resilient and adaptive to both sudden and slow onset disturbances. Decisions by leaders should be both evidence-based and timely. Here, science and technology play a critical role. Position science and technology as “a game changer” towards a fully resilient post-COVID society through three actions: 1) Promote water cycle consilience by accelerating the Open Science policy, particularly focusing on observation, modelling, and data integration; 2) Foster "facilitators," that is, catalytic individuals who can lead the way toward resolving problems by providing professional advice on-site using a broad range of scientific and indigenous knowledge; and 3) Work together across disciplines and sectors, and among different levels, while taking an end-to-end approach.

19- Water, DRR, and climate change issues should be firmly connected to discussions and actions. Dedicated discussion processes should be established by regularizing the Special Thematic Sessions on Water and Disasters, the 6th session of which took place back-to back with this Conference. Also, a special discussion to connect water and DRR under the context of climate change should be held during the Mid-term Review of Sendai Framework for Action. IV. Commitment, Actions, and Coalitions to meet water challenges towards full-achievement of water-related goals and targets

20- Adopting an “Inter-COP” process to connect, integrate, and fully implement water- related decisions made at the global assemblies, conventions, and frameworks dedicated to climate, resilience, and the environment, building on COP27 in particular which brought water discussions to the centre of the climate discourse.

21- Identification, mapping, and alignment of existing water- and climate-related initiatives, such as the UN Secretary-General’s call to action on Early Warning for All by 2027, the “Action on Water Adaptation and Resilience (AWARe)” initiative, the UN action program on water scarcity, (other initiatives can be added here), in order to facilitate finance allocation and cost-effective implementation.

22- A Global Water Information System is a prerequisite for improved water management, climate resilience, early warning, and risk-informed decision-making for climate action and disaster risk reduction, and thus should be among the top priorities of water-related climate action.

23- Without prejudice to vital human needs for water, a Contextualised Environmental Economic Accounting Systems should be considered as a means to reveal the potential of investment directed to water-related climate and environmental resilience-building, and to support countries suffering from water-related climate-induced loss and damage by providing an accurate assessment of them.

24- To secure successful and swift implementation of transformative commitments in the water action agenda, we encourage the office of the PGA to work with Member States to propose a UN Water platform to discuss policy and prepare joint programming to be discussed in preparation of the SDG Summit.

[Action Workflow]
All the contributions referred in the Key Messages can get closer to being truly "action-oriented" if they are implemented through the critical steps, with support from appropriate contributions, starting from challenges to solutions. An Action Workflow was proposed in Interactive Dialogue 3, and the discussion in line with this Action Workflow.

Following the outcome of the UN 2023 Water Conference, Indonesian Government, the host of the 10th World Water Forum (WWF10), and HELP organized the Bandung Spirit Water Summit in May, 2024. The Bandung Spirit Water Summit, an agora by over twenty incumbent and former Heads of State and Government, created, with your proactive participation, new political dynamism in WWF10. The direct dialogue between Heads of States, stakeholders, and audience in the Summit, a first attempt to shortcut the path between politics and water, opened corridors to carry water into transformative decision making in the world. The Bandung Spirit Water Summit focused on three key areas of water urgency, namely climate change and water resilience, sanitation and water for all, and water for peace. The outcomes of the Summit titled “Bandung Summit Call for Actions” as shown in the Fig 1.4 with background paper as well as “Bandung Action Agenda” included succinct and bold proposals and supporting concrete actions to transform business as usual of, for, and by all in the world.

The Spirit of Bandung: A Call to Actions

The Leaders, organizers, and stakeholders who participated in the Bandung Spirit Water Summit call leaders of the world at all levels to take the following actions based on the Bandung Spirit:

Rationale

Water, the connective element of the planet, and humanity itself, is in peril. Current crisis on peace, food, energy, health, natural hazards, environment, immigration, human rights, and social harmony and integrity cannot be countered without attention to water. As global leaders, we are committed to working for the protection and preservation of people and planet through bold actions by, of, and for water.

Our proposed actions are based on the Bandung Spirit. Drawn from the Bandung Principles of the Asian-African Conference that was held in Bandung, Indonesia in 1955, the Spirit of Bandung is symbolized in a phrase “live and let live”. It is a spirit of tolerance, mutual respect, sustainable growth, valuing diversity, and belief in the power of youth and next generations, which are essential in the face of current global challenges.

Call to Actions

In the lead-up to and during Summit, we the leaders conducted direct dialogue with stakeholders and citizens based on the Bandung spirit as our common ground for discussion. Through the dialogue, all were mindful that the human rights to water and sanitation must be fulfilled at all times, that international humanitarian law must be respected in international and non-international armed conflicts, and that states must integrate gender into their laws, policies and practices. This must be reflected in all water actions.

In the Summit, we dealt with the most imminent water challenges of (1) water and peace, (2) climate change and disaster risk reduction, and (3) sanitation and water for all, while addressing overarching subjects of (4) global water governance, and (5) the actions of, by, and for the youth. Resultantly, we come up with the following priority areas of actions as well as tangible actions. We call upon all leaders to join in the following actions:

1. **Water and Peace**
   - **Ban Weaponizing Water formally in the international community**
   - **Organize Summits by Heads of State and Government on transboundary water cooperation at all regions**
   - **Establish, where necessary, and strengthen legal and regulatory instruments on water cooperation mechanisms at global, regional, and national levels.**

2. **Establish where necessary, and strengthen legal and regulatory instruments on water cooperation mechanisms at global, regional, and national levels.limate Change and DRR**
   - **Decide water as a core piece of adaptation negotiation in UNFCCC, and adopt "globally halving human and economic loss by disasters" as a post-Sendai target**
   - **Embed a mechanism in every country to support Leaders' science-evidenced decision making for water and DRR**
   - **Establish a global Center of Excellence on Water and Climate Resilience, a Center for Water and DRR Policy, Global Water Information System, and World Lake Day**

3. **Sanitation and Water for All**
   - **Accelerate progress towards universal access to water and sanitation through Leaders' explicit top prioritization of financing, governance, and transparency in the sector with focus on the marginalized and excluded.**
   - **Led by governments, all stakeholders to identify joint actions and mobilize the necessary annual 114 US billion dollars for full-achievement of water-related SDGs. Countries, IFIs, and donors to discuss ways to mobilize annual 114 billion dollars in their summits and financial meetings.**

4. **Finance and Governance**
   - **Globally triple financial flow into all water sectors**
   - **Promote the Nine Game Changers proposed in the UN 2023 Conference and support the UN 2030 Strategy globally and in countries**
   - **Urge UN Secretary-General to appoint Special Envoy for Water. Support the envoy once appointment is made.**

5. **Youth**
   - **Use the power of the youth in elevating the human right to water to the highest priority and taking immediate action to combat weaponization of water in the international community**
   - **Empowering youth as long-term stakeholders.**
   - **Utilize existing youth networks to innovate lasting solutions for water challenges with transparency and accountability at the forefront.**
   - **Integrate youth in water governance processes, particularly at transboundary watersheds to ensure global connectivity transcending borders and ideologies".**

2 Water Related Disasters in Kenya: Examples of Dam Burst and Landslide

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ABSTRACT

Kenya experiences water-related disasters such as floods, drought and landslides that cost 2% to 5% of the Gross Domestic Product annually. The disasters are associated with the bimodal rainfall regimes: one from October to December (OND) generally referred to as “short rains” and the other is March to May (MAM) known as the “long rains”. Climate change induced irregularities in amount and frequency of extreme rainfall events are likely to increase and the impact manifests in the form of El Nino in Kenya. The frequency, intensity, and duration of extreme weather events like heavy rainfall and droughts are projected to rise. This has resulted in prolonged dry periods between heavy rainfalls, which could strain water resources management practices and constrain agricultural production.

The present paper examines two case examples of water related disasters, namely, dam burst and landslides, both associated with extreme rainfall and flooding, especially in the highland areas. These frequency of these two disasters have become common, partly contributed by deforestation and soil erosion thus reducing water retention capacity and increasing flash floods. The cost of floods to Kenya’s economy is estimated at 5.5% of GDP every seven years and droughts at an estimated cost of 8.0% of GDP loss every five years. The economic cost of floods and droughts is estimated to create a long-term fiscal liability equivalent to about 2.0 % to 2.4% of GDP each year, or approximately US$500 million per year. The number of landslides is reported to be increasing as forested lands are converted to agriculture and pasture, resulting in looser soils and fewer trees to slow the flow of water down slopes. However the cost of landslides have not been quantified.

The two water-related disasters occurred in Nakuru County within the Rift Valley region of Kenya. The highlands, lowlands, and coastal areas frequently experience floods, especially during the "long rains" (MAM) and "short rains" (OND). Rainfall data for Nakuru City shows that for the month of April the highest rainfall (109 mm) and an average of 9 rainy days are recorded. November follows with 100 mm of rainfall and 11 rainy days. On the other hand, the driest months are January and February with only 21 mm of rainfall and 2-3 rainy days. The temperature shows a slight cooling from March through August, with the wettest periods corresponding to the long rains in April and May and the short rains in November. Climate change predictions indicate that extreme rainfall events have become more intense and frequent, leading to more devastating floods. Similarly, the distinction between the long rains and the short rains is becoming blurred. The unpredictability of rainfall can lead to both droughts and floods, disrupting the planting and harvesting schedules, which harm crops and reduce yields thus exacerbating poverty. Floods are aggravated by human activities such as interfering with

wetlands, deforesting watersheds, and human settlements or farming along floodplains.

The collapse of the Solai Dam in Kenya is a tragic incident that highlights several critical issues related to dam construction, safety regulations, and disaster preparedness. The dam, an earth-filled structure primarily built for agricultural purposes, failed in May 2018, leading to significant human loss and suffering. The local inhabitants had complained that the quality of construction was compromised[1]. The Solai dam busted killing 47 people, 41 were injured and hospitalized, and 223 households lost their homes and a total of 5,000people were displaced. Public amenities were also heavily damaged. The unfortunate event resulted in the closure of most of the surrounding schools since they were converted in to holding camps for the 223 displaced households. There were also damages to farms, beacons to plots and power connections; loss of monies (in cash), food stuff, assets, personal valuables, certificates, official documents among others. People also suffered and continue to face indescribable and irreparable social, emotional, psychological and mental harm and anguish.

The Mai Mahiu disaster, triggered by a landslide, is another significant water-related catastrophe with severe consequences. This disaster, which took place on April 29, 2024, was largely caused by heavy rainfall, leading to soil saturation, landslides, and eventually the formation of a temporary dam embanked by the railroad. The landslide started by reduction of mechanical strength of deep weathered soils. The strength was decreased further by infiltration of water and strength further weakened under the dynamic action such the passage of a train. The rainwater percolates between the spores thus saturating the soil. Boulder and rocks embedded in the soil begin to slip free and tumble downhill. Eventually the soaked soil breaks free and flow down slope. The infiltration depth at the slope top crest, is deeper than that of the slope surface after continuous heavy rainfall. The water-filled gulley around a railway carrying everything with it on its path: mud, rocks and uprooted trees. The water also destroyed part of the Nairobi-Nakuru highway. The Mai Mahiu disaster illustrates the dangers posed by landslides, particularly in areas with poor drainage systems and saturated soils. It underscores the need for improved land management, soil stabilization, and early warning systems in areas prone to landslides and flooding, especially during periods of heavy rainfall. The disaster also calls for urgent attention to the safety of infrastructure, such as railways and roads, in hilly areas where landslides are a known risk.

One of the challenges in water-related disasters in Kenya is the weak law enforcement in dam construction. The Water Resources Authority (WRA) and the National Environment Management Authority are unable to ensure that dam licensing, operations and maintenance and the environmental regulations are followed, leading to potential risks. The case of Solai dam, inspected by WRA and classified as low-risk, reflects issues in classification and regulatory follow-ups. The way forward calls for strengthening enforcement of laws and environmental regulations and need for clear delineation of responsibilities between the national and county governments. For flood mitigation, Nature-Based Solutions such as increasing vegetation cover, promoting afforestation, and developing soil conservation techniques will reduce the risk of flooding, landslides and soil

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[1] *Water monitoring report for Patel Coffee Estate Ltd dated 23rd July 2018, Ref. No. F/9/1/5*

erosion.

Kenya lacks comprehensive flood preparedness and response plans. While early warnings exist, they are often limited to advisories without well-planned evacuation routines or contingency measures. The government needs to provide leadership in creating a detailed national and county disaster preparedness and response plans, including evacuation routes, pre-identified relocation sites, and stockpiling of essential resources. Engaging and capacity building of the local communities in simulations and drills are essential for effective disaster management. Funding for flood mitigation and disaster preparedness is not prioritized neither by the County nor the national governments, leading to reactionary responses rather than proactive planning. The humanitarian organisations and the civil society organisations are generally flexible and fill the gap by the public sector. However this also leads to limited accountability and duplication of effort. River basin planning in Kenya has been practiced for over 35 years. The authorities, should be added additional mandate for catchment management to mitigate floods and implement efficient water use. However the organisations have not received sufficient resource allocations for long-term flood mitigation strategies, including rainwater harvesting, installation of check dams, and desilting of water bodies. Kenya will require to strengthen real-time monitoring systems and establish reliable feedback mechanisms to ensure timely and effective maintenance of dams and water infrastructure.

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1. BACKGROUND

1.1 Geography

Kenya is located along the eastern coastal zone of Africa, characterized by diverse geography and climate. The country covers a total land area of 582,646 kilometers square (km2). Its topography includes coastal lowlands, central highlands, and vast semi-arid and arid areas. The coast is typically hot and humid, the Lake Victoria region is generally hot, but with more rainfall, supporting fisheries and agriculture. The region plays a key role in food security with crops like maize and sorghum. The northern and northeastern areas are extremely hot and arid. Livestock farming is the primary activity in these regions, though droughts and erratic rainfall patterns often disrupt livelihoods. The central highlands are cooler, more temperate climates due to higher elevations, supporting rainfed agriculture. The country's central highlands, western region near Lake Victoria, and parts of the coastal belt are densely populated because of their agricultural potential, driven by more reliable rainfall patterns. Conversely, the northern and northeastern areas are arid constituting nearly 85% of Kenya’s land and mainly inhabited by nomadic pastoralists due to harsh climate conditions.

Figure 1: Location of Kenya in Africa

Kenya’s vulnerability to disasters is not just linked to geographic conditions but also to social dynamics, particularly in areas classified as fragile arid and semi-arid ecosystems. The central and western highlands, situated at 1,500 to 3,000 meters above sea level, are agriculturally rich and relatively cool. These highlands are home to both commercial and smallholder farms, growing crops like tea, coffee, wheat, maize, and flowers, and supporting livestock production. The Great Rift Valley runs through this region, dividing it into eastern and western highlands, and forming a distinctive trench that is 48 to 64 km wide and 600 to 900 meters deep.

Tourism, centered on wildlife protected areas and conservancies, is another significant land use, covering around 8.2% of Kenya's land area, further highlighting the interaction between natural resources and livelihoods.

1.2 Rainfall Regime in Kenya

Kenya, while considered a lower middle-income country, has the largest economy in East Africa. It has a population of 52.6 million people (2019) and an annual population growth rate at 2.3%. Approximately 27% of Kenya’s population currently lives in urban areas. This is projected to increase to 33% and 46% of the population by 2030 and 2050, respectively. The Gross Domestic Product (GDP) in 2018 was US$95.5 billion and the economic annual growth rate 5.4% (2019).

Kenya experiences bimodal rainfall regimes: one from October to December (OND) generally referred to as short rains and the other is March to May (MAM) known as the long rains. The rainy season that appears to be devastating is between April and June during which the Intertropical Convergence Zone (ITCZ) moist winds coming off the Indian Ocean swing around and drop heavy rain on eastern Africa. The rainfall regime is also influenced by relief. The rainfall regime is also influenced by sea surface temperatures for which when it's warmer off the coast of Australia than temperatures off Kenyan coast then dry weather conditions prevail in Kenya. When sea surface temperatures off Kenyan coast are warmer than those off Western Australia, wet weather conditions are experienced. The larger the difference in temperatures between the eastern and western tropical Indian Ocean, the more severe the climatic effects will be. This dipole cycles between these extremes occurring over three to five year periods, ordinarily with a 1°C difference in sea surface temperature. Between these extremes, temperatures will be fairly uniform across the tropical Indian Ocean.

Climate change induced irregularities in amount and frequency of extreme precipitation events are likely to increase and the impact on rainfall manifests in the form of El Nino in Kenya. El Niño Southern Oscillation (ENSO) is a naturally occurring climate pattern typically associated with increased heat worldwide, leading to drought in some parts of the world and heavy rains and floods in the Horn of Africa. These processes are exacerbated by climate change for which projections point to increased rainfall variability. Rainfall is expected to remain highly variable, with increasing uncertainty in seasonality. By mid-century, average rainfall is predicted to increase, particularly during the "short rains" (October-December). However, arid regions experience declining rainfall, intensifying drought conditions. As already noted, the frequency, intensity, and duration of extreme weather events like heavy rainfall and droughts are projected to rise. This will result in prolonged dry periods between heavy rainfalls, which could strain water resources and agriculture.

Under High Emission Scenario (RCP8.5), Kenya's annual average precipitation is expected to increase slightly by the end of the century, but the variability will continue, with more intense rain in some regions and drier conditions in others. The implications for Kenya is the increasing exposure to water-related disasters, driven by climate change and unsustainable land use practices, has accelerated water-based disasters Figure 6 shows the disaster prone areas.

The two water related disasters occurred in Nakuru County within the Rift Valley region of Kenya. The month of April has the highest rainfall (109 mm) and an average of 9 rainy days. November follows with 100 mm of rainfall and 11 rainy days. On the other hand, the driest months are January and February with only 21 mm of rainfall and 2-3 rainy days. The temperature shows a slight cooling from March through August, with the wettest periods corresponding to the long rains in April and May and the short rains in November. The rainy days increase during the rainy seasons (April-May and October-November) and decrease during the dry months (January-February). This climate pattern is typical for many regions with distinct wet and dry seasons, where rainfall is concentrated in a few months, while temperatures remain relatively mild throughout the year.

Table 1: Monthly Weather Averages for Nakuru 1991 – 2021

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Avg. Temperature °C	18.4	19.3	19.4	18.2	17.4	16.7	16	16.1	16.9	17.4	17	17.4
Min. Temperature °C	12.6	12.5	12.9	13	12.6	11.8	11.2	11.1	11.1	12	12.6	12.7
Max. Temperature °C	24.4	26.1	26	23.8	22.8	22	21.1	21.3	22.6	22.9	21.9	22.6
Precipitation mm	21	21	53	109	74	53	61	78	53	94	100	45
Rainy days (d)	3	2	5	9	7	7	9	9	6	9	11	6

Mean annual rainfall varies considerably across the country (Figure 2), with less than 250 mm falling in the arid zones of north, to over 2,000 mm per year in the west annually. Highland areas, where the majority of agriculture takes place, receives approximately 1,200 mm of rainfall each year.

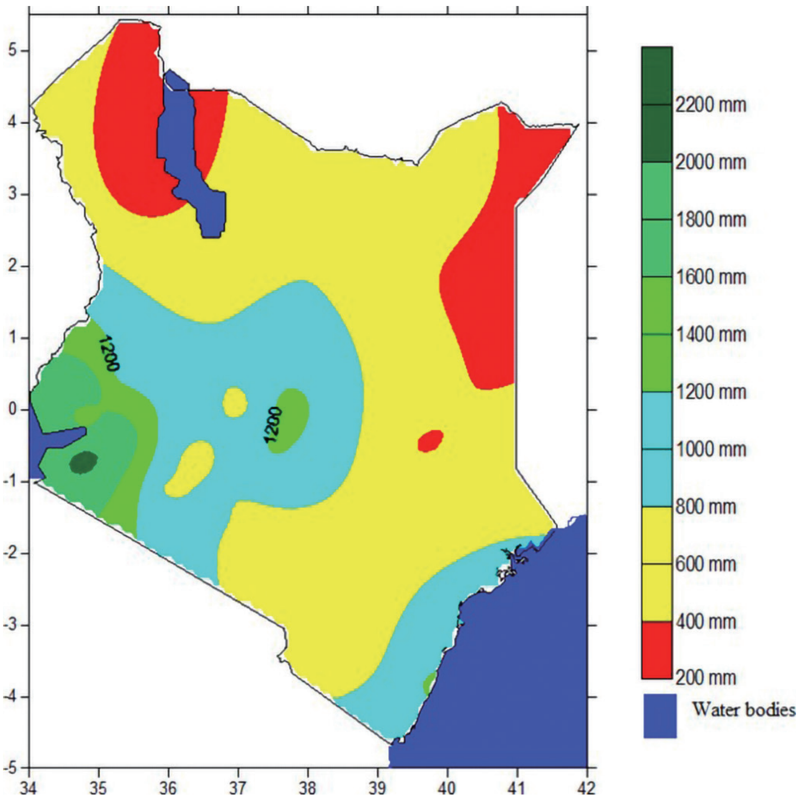


Figure 2: Spatial distribution of average annual rainfall over Kenya.

Source: Segero, et al, 2018.

The rainfall patterns around the periods of disasters provide some information for comparison. Extremely heavy rainfall were recorded in Pokot South and Sigor Sub counties located in West Pokot County (Kenya) on 23 and 24 November 2019. During this period a landslide occurred that killed over 50 people as homes were swept away in villages of Parua, Nyarkulian and Muino. Similarly, the forecast for March-April-May 2024 "Long-Rains" season was based on the prevailing and expected evolution of Sea Surface Temperature Anomalies (SSTAs) over the Pacific, Indian, and Atlantic Oceans as well as the synoptic, mesoscale, and local factors that affect the climate of Kenya. Earlier the Kenya Meteorological Department noted that the January 2024 sea-surface temperature was by far the highest on record for January and this continued to March and reported on 7th March 2024. These are the weather conditions that led to the Mai Mahiu disaster. The Climate Centre announced also that the latest El Niño is one of the five strongest ever recorded.

In tracing the developing weather conditions before the Mai Mahiu disaster, it was observed that OND season of 2023 had a high inter-annual variability, with most stations having greater than 50% of the coefficient of variation compared to MAM season, which had only 4 stations with over 50% coefficient of variation. The annual rainfall in Nakuru City is 1012 mm per annum. These phenomena provides weather forecasters with fairly accurate associations to the reported disasters. The Kenya Meteorological Department's (KMD) warnings in May 2023 that Kenya would experience enhanced rainfall due to El Nino and it would continue into 2024. The MAM period is the major rainfall season (long rains) over most parts of Kenya and specifically in Nakuru County. The KMD outlook for MAM in 2024 was that above-average rainfall is expected over the Lake Victoria Basin, Highlands West of the Rift Valley, Central, Northern and Southern Rift Valley, Highlands East of the Rift Valley (including Mai Mahiu and Nairobi County), Northeastern, Southeastern Lowlands, and Northwestern regions. In any case the southern Rift Valley expected above average rainfall.

In contrast, the country recorded seasonal rainfall performance percentages for OND ranging from 135.37% to 140.51% of their long-term means (Figure 4). The highest seasonal rainfall amounts greater than 300mm for April were normally received in most parts of the country. Figures 3, 4, and 5 illustrate the areas where rainfall climatology during the March to May (MAM) 2024 rainfall season. Before the Mai Mahiu disasters, there was strong anticipation in Kenya that the peak of the rains were expected in April. There was compelling evidence that Kiambu, Nakuru and Narok counties, areas of which disaster occurred, were expected to receive enhanced rainfall throughout the season. Mai Mahiu monthly precipitations above 150mm are mostly wet and below 30mm mostly dry. Kenya experienced above-average rainfall during its March-April-May (MAM) long rains season that resulted in flooding and landslide from late March, throughout April 2024 and into early May (Kenya Meteorological Department (KMD) on 8 April).

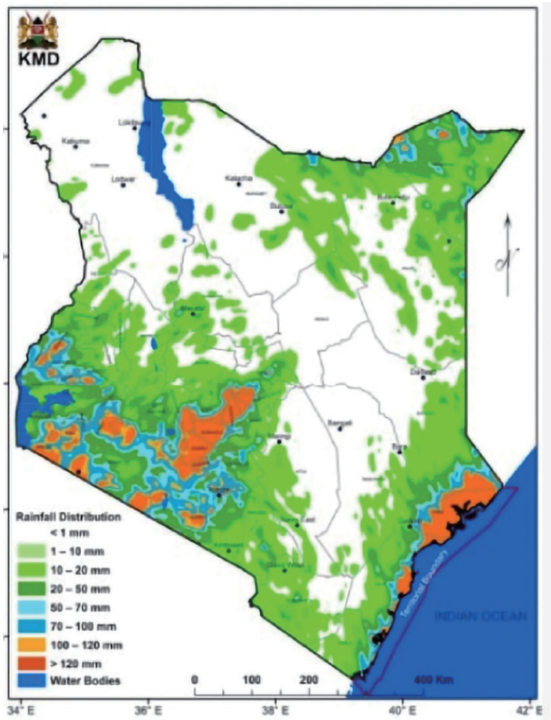
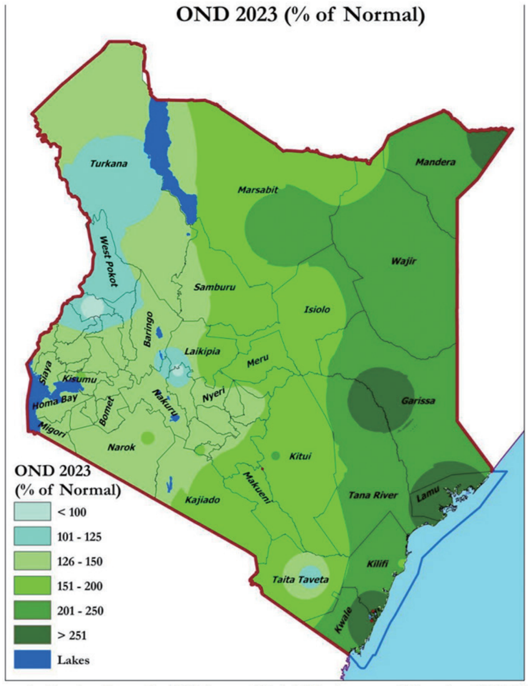


Figure 3: Review of OND 2023 "Short-Rains" Seasonal Performance



igure 3a: October-December 2023 Seasonal Rainfall Performance (%) against OND LTM

Figure 4: Rainfall forecast 19th -22nd April 2024

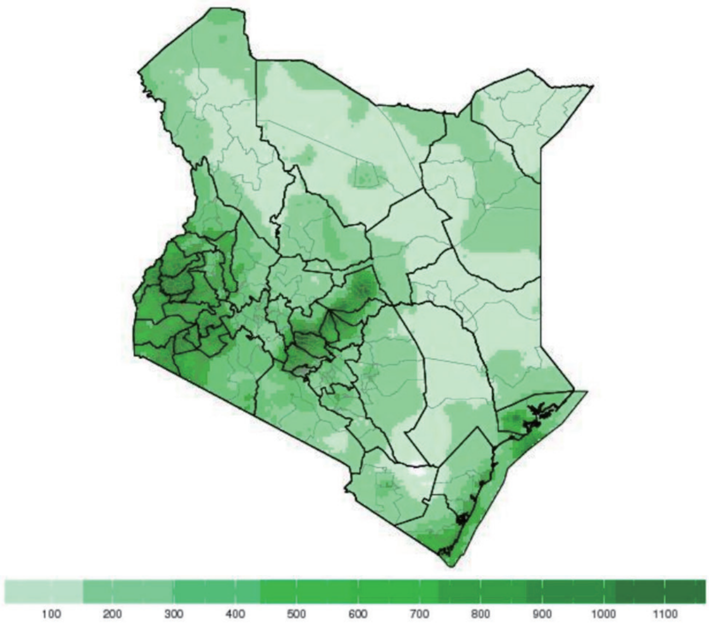


Figure 1a: Rainfall climatology during the March to May rainfall season

Figure 5: Rainfall Outlook for MAM 2024 "Long-Rains" Season

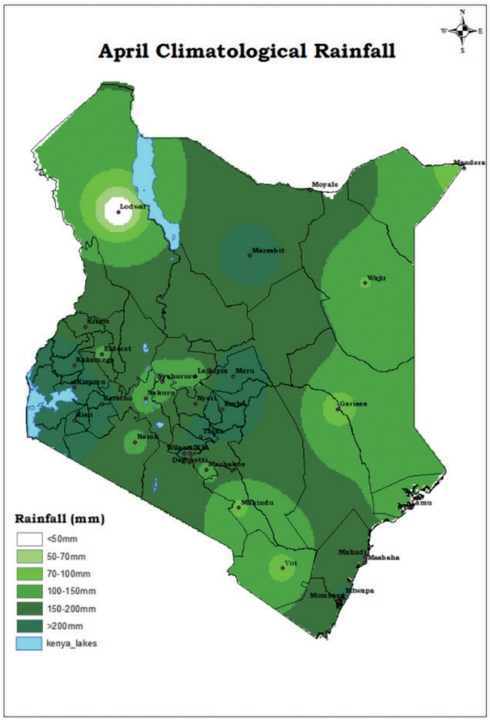


Figure 6: April Climatological rainfall

1.3 Kenya's Water-Related Disasters

Kenya's diverse topography and climate create a complex environment for water-related disasters, which are exacerbated by climate change and human activities. The country is prone to various water-related challenges, including floods, droughts, and coastal erosion, affecting its natural resource base and threatening biodiversity, livelihoods, and food security.

The key water-related disasters include floods, drought and coastal erosion. The highlands, plains, and coastal areas frequently experience floods, especially during the "long rains" (March-May) and "short rains" (October-December). Climate change predictions indicate that extreme rainfall events will become more intense and frequent, leading to more devastating floods. Similarly, the distinction between the long rains and the short rains is becoming blurred. The unpredictability of rainfall can lead to both droughts and floods, disrupting the planting and harvesting schedules, which harm crops and reduce yields. This is likely to strain urban infrastructure, damage crops, displace populations living in fragile environments, and increase health risks such as waterborne diseases.

The arid and semi-arid regions of Kenya, particularly in the northern and eastern parts, are highly susceptible to droughts. Decreasing rainfall in these regions, coupled with increasing temperatures, is expected to worsen drought conditions, resulting in reduced water availability for agriculture, livestock, and human consumption. This will further aggravate food insecurity and conflicts over scarce water resources.

Along Kenya's coast, rising sea levels and coastal erosion pose significant risks to coastal communities and ecosystems. Mangroves and coral reefs, which serve as natural barriers, are threatened, leading to increased vulnerability to storm surges, habitat loss, and reduced fish stocks, impacting both biodiversity and local livelihoods.

Landslides and other mass wasting processes, although associated to extreme rainfall and flooding, especially in highlands are increasingly common and contributed by deforestation and soil erosion thus reducing water retention capacity. This exacerbates both flooding and drought cycles, further stressing the natural resource base and undermining efforts to ensure sustainable land management.

Table 2: Areas prone to water related disasters

Hazard	**Areas most affected(hotspots)**
Riverain Floods	Budalangi, Nyando, Homa Bay areas (all within Lake Victoria Basin) and Tana River County, in the Lower Tana River Basin.
Flash floods	Mainly urban areas like Nairobi, and Mombasa due to poor drainage and uncontrolled urban settlements Arid semi area areas
Landslides and mudflow	Central Kenya, and around Mount Kenya region mainly Muranga and parts of Kiambu and Nyeri

1.4 Kenyan Flood map

Severe flooding in Kenya has been observed to be triggered by severe thunderstorms, tropical cyclones, as well as heavy rainfall over consecutive days. The El Nino Southern Oscillation, Madden Julian oscillations and other phenomena have been observed to exacerbate the flood situation in the country. Other non-climatic factors play a role in determining the impacts that flooding will have on a region. Figure 7 shows the areas of flooding in Kenya.

Most flooding in the country occurs during the March to May (MAM) long rainfall season and particularly during the month of April which is the peak of the rainfall season. The most devastating floods are flash mainly in urban centres and arid lands, river-rain or lakeshore areas and coastal inundation from intense rainfall associated with seasonal weather patterns. Floods are aggravated by human activities such as interfering with wetlands, deforesting watersheds, and human settlements or farming along floodplains. In Figure 9 below, residents gather on the safe grounds with their belongings after their homes were flooded as the River Nzoia burst its banks and due to heavy rainfall and the backflow from Lake Victoria in Budalangi, Kenya. On the other hand, flash floods occur in urban centres and arid and semiarid areas after a period of prolonged drought that renders the ground very compact followed by rainfall falling on this now hard surface having much lower-than-normal infiltration capacity. In urban areas increased paved surfaces and clogged drainage systems thus reducing infiltration and increasing downstream flow of rainwater.

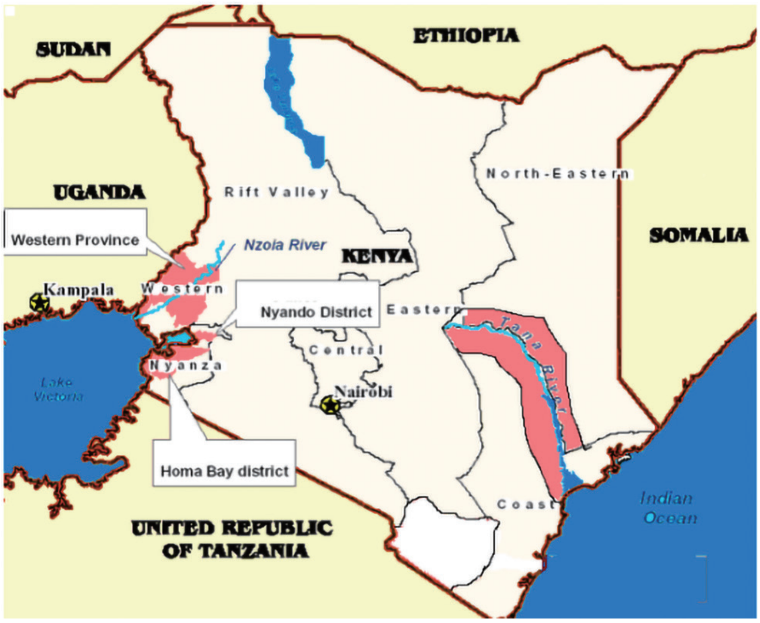


Figure 7: Kenya's flood prone areas

Source: Relief Web

Figure 8: Example of flooding as River Nzoia burst its banks and due to heavy rainfall and the backflow from Lake Victoria in Budalangi, Kenya.

Source: REUTERS/Thomas Mukoya)

Table 3: Seasonal rainfall variability and floods phenomenon 2012-2016

Year	Rainfall magnitude	Reported Fatalities/ Damage	Remarks
April 2012	274.3mm against a monthly average of 120.2mm. This was 228% of the rainfall normally received.	Deaths reported at Hell's Gate National Park	Floods and landslides in Central Kenya
April 2013,	Narok recorded over 100% more April rainfall than its normal amounts for April.	10 people dead in Narok County, about 50 people had lost their lives and about 4,000 families had been evacuated	Coastal strip, western region and parts of central Kenya, where the heavy rains and floods leading to loss of lives and destruction of property, including damage to infrastructure that rendered most roads impassable.
October to December (OND) 2013		12 people died between December 14th and 15th in Kajiado County	OND rainfall season covered Makueni, Laikipia and Narok.
March to May (MAM) 2014		Flooding in Narok county, fatalities. In April, Kisumu and Nairobi both reported losses of lives and damaged property	

Year	Rainfall magnitude	Reported Fatalities/ Damage	Remarks
April 2015,	Bursting of dams	Southwestern Kenya, specifically in Bondo, Siaya County; Kajiado 6 people dead. 40 dead in Mandera May 2015 a building collapsed in Nairobi	
October, November, December - OND) 2015		Flooding in parts of Kenya including Talek in Narok, where three people dead. Migori, Horr, Laisamis and Chalbi desert in Marsabit County	at least 112 people had died and over 100,000 people were displaced
10th March 2016		Turkwel and Kawalase Rivers. At least three people died	Large numbers of livestock were also reported to have been swept away
April 2016,	rainfall (>50mm/24hrs)	Buildings collapsed trapping and killing people, traffic was brought to a standstill	
May 2017 as well as parts of received very heavy rainfall (>50mm/24hrs)	Garissa, Coastal counties of Mombasa, Kilifi, Kwale. south-eastern lowlands of Taita Taveta County	Nyeri landslide	
October to November 2017,	Turkana, Marsabit, Tharaka Nithi and Meru, with reports of loss of human life, displacement of families and damaged bridges and roads.		

Year	Rainfall magnitude	Reported Fatalities/ Damage	Remarks
MAM 2018	Deaths were reported in Kisumu Turkana and Taita Taveta counties and people were forced to evacuate their homes.		
OND 2019	November 2019, consecutive days of heavy rain (>20mm/24hrs) in western Kenya triggered massive landslides and flash floods in West Pokot County.		

Source: Kenya Meteorological Department Extreme Weather Events in Kenya between 2011 and 2020.

2. Solai Dam Collapse

2.1 Location of Solai Dam

The Solai dam(specifically referred to as (Milmet or Patel after the name of the owner of the farm) was one of five earthen embankment dams constructed on the private property in Solai area, Subukia sub County of Nakuru County on LR. No. 19242/1. The sites GPS coordinates are Lat: 0O 6’27.211” Long: 36o 7’48.162”E. The farm is 1,400-hectare of commercial horticultural farm and business, Solai Roses. The other dams were known as Main House, Moi, DO, and Tinderess. The Solai dam had a capacity of 200,000 m3, The Solai dam had a capacity of 80 million liters of which 72 million poured out during the burst. The dams collectively had a capacity of 600 million m3. The specific dates of construction for the dams are not known, but according to the general manager of the farm, the dams were constructed between 15 and 20 years old at the time of the burst on 9th May 2018.

According to the 2009 census, the area had a population of approximately 12,800 people but the number had risen over the years (KNBS).

Figure 9: location of Solai dam.

Amount of change by Land Use and Land Cover Change (LULC) between 2018 and 2022 is very minimal. There a under crops, trees and rangeland had increased however.

2.3 Water use

The company deals in dairy farming, coffee, tea, macadamia and flower farming for export. It has a sanctuary that hosts a variety of wild animals including zebras, impalas, waterbucks, giraffes, ostriches among others. Solai area has seen the building of reservoirs to meet the demand from coffee and flower farms which take advantage of the rich volcanic soils in the Rift Valley. The main water supply in the farm is from dams, boreholes and rain water harvesting. There are 4 boreholes and 7 dams that serve the area. The residents relied on boreholes for water supply after the respondent tapped Watkins stream flowing from Ndondori forest.

In the consequent 2018 audit report[2], there was mention, albeit very casually, of 7 earthen dams and 4 boreholes in his farm and is supplemented by rainwater harvesting for irrigation on flower farms, coffee, tea and macadamia plantations, the sanctuary and other general purposes such as cleaning, cooking and drinking.

[2] *conducted and submitted to NEMA on 22nd June 2018,*

2.4 Construction and design of the Solai earth dams

Of the seven dams, three of them were significant because they were points of conflict with the local communities. Tindress dam had blocked river Kabaazi which flows into Lake Baringo, Ottoman dam had blocked a stream that would flow down into the Nyakinyua settlement scheme and Solai dam had blocked a stream that would flow through Endao settlement farm. The local inhabitants had complained of these interventions.

Quality of construction itself may have been questionable[3]. The construction and design of the Solai earth dams was shrouded in controversy, especially following the tragic Solai Dam disaster in 2018. The seven Solai dams, including the ill-fated Solai Dam, were constructed primarily for agricultural purposes are typically earth-filled, meaning they are made by compacting layers of earth to form a barrier. The geological features representing dam stability may only be speculated about since there are no design plans available. The underlying rocks are volcano-sedimentary succession of the Neogene-Quaternary age characterized by basalts, trachytes, pyroclastic rocks, and tephra with intercalated lacustrine and fluvial deposits crops out (Conti, et al, 2020). The soils are developed from colluvial materials derived from sedimentary rocks in the Rift valley. The area being part of the Great Rift Valley has occasioned fractures that sometimes have been exposed during heavy runoffs.

Before construction, it is a requirement that an EIA is conducted in which the dam site geology, design, and construction materials are assessed against adverse social, environmental and economic impacts are assed and mitigated. The EIA includes no option for selecting rain and river water harvesting sites. The Water Resources Authority (WRA) and other regulatory bodies oversee the construction and maintenance of dams to ensure safety and compliance with environmental standards. This incident highlighted the need for stringent safety measures and regular inspections raising questions for increased scrutiny and calls for better regulatory frameworks to prevent such tragedies in the future.

In February this year, panic struck residents of Solai as the newly constructed dam locally known as Nyaru Dam, in Solai Subukia Sub County developed a huge fault. It is suspected the dam lies on the volcanic line running from the nearby Menengai crater. The fault lines were running below the Nyaru water pan, and some of the neighboring homesteads due to deep cracks and soil slides, resulting in the loss of all the water in the dam and cracks in some houses. During heavy rains and flush floods, the fissures, due to unconsolidated deposits accompanied by slumping and flushing of material deep down, produce holes and funnel shaped depressions, which cannot hold heavy weights.

2.5 Incidences leading to dam failure

The burst was occasioned by structural deficiencies of the dams which caused the dams to burst under the

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[3] *Water monitoring report for Patel Coffee Estate Ltd dated 23rd July 2018, Ref. No. F/9/1/5*

pressure of excess water from three rivers that were blocked by the Patels and directed to the ill-fated dam.

Prior to the Patel dam disaster, official statistics said heavy rains had already caused 132 deaths across the country since March. Many dams had been reported to overflow and considered dangerous[4]. More than 220,000 people have also had their homes destroyed. The downpours came after a severe drought in the region, which left millions in need of food aid and the soil unable to absorb heavy rain.

Excessive rains began falling in the month of March 2018 following a year of severe drought. This caused had devastating impacts especially across Kenya, Ethiopia, Uganda, and Somalia, These floods resulted in widespread displacement, loss of livelihoods, and destruction of infrastructure. Locally, the heavy rainfall in Dundori forest in Nakuru County, caused massive soil erosion with high pressure water loaded with dead stumps logs and big boulders damaged the walls of the Solai (Milnet) dam. Nearly 170 people in Kenya were killed in the floods which preceded and led to the breaking of the dam. The general manager of the farm stated that the rain had been particularly intense during the two days preceding the dam's failure, and that resulting flood waters, carrying boulders and roots, had damaged the wall of the dam. The dam collapsed on May 9, 2018 killing more than 40 people. Residents of affected villages: Endao, Energy, Nyakinyua, Milmet and Arutani in Solai division believe that the bursting was brought about by excess water from three rivers that were blocked by the Patels and directed to the ill-fated dam.

The Solai dam burst in the evening of 9 May 2018, just as many area families were beginning their evening meals. Residents reported hearing a loud bang immediately followed by the rushing of "a sea of water". Out came 70 million litres of water were unleashed, creating a wall of water about 1.5 m. high and 500 m wide. The tragedy was not an accident but thought to be a case of "human error". Communities living in the surrounding villages had complained severally to the farm owners and the local leaders; through parents' meetings and chiefs' barazas, about visible cracks on the ill-fated dam but no meaningful actions had been taken by the company and state authorities. Similarly, the community indicated that they had also made complaints to the area Member of Parliament about blocked rivers by the farm owners but there was still no action taken, even after one other dam overfilled and leaked due to cracks in 2012.

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[4] *Another dam by Finlays in Naivasha had its water overflowing into the Sher Karuturi flower farm, and in the process, causing minor damages to the company and its residents. Incidentally, and over the same period, Masinga dam was full.*

Figure 10: Breached section of Solai Dam

Source: New African. August 2, 2018

Figure 11: Water damage through a settlement

Source: Ministry of Interior and Coordination of National Government Multi-Agency Report (9th to 19th may 2018)

Figure 12: Deep gully erosion caused by water from the Solai Killer Dam

The construction of dams during the colonial and post-colonial period was done haphazardly at best. Most of the dams, including those in Solai, were built without community participation and little consideration was given to the needs of the surrounding communities who rely on agriculture as a means of livelihood. “Little attention was given to social and environmental protocols when building the dams and systemic and structural weaknesses that led to the collapse of the dam and its eventual tragedy. The defects and poor workmanship that characterised the Solai dam and noted that the malpractices were not unique to Solai dam only.

Box 1:Damned Dams: Exposing Corporate and State impunity in the Solai Tragedy

We found that 47 people lost their lives in this tragedy while 41 were injured and hospitalized. Further 223 households lost their homes and a total of 5,000people were displaced. Public amenities like the Solai Nyakinyua Primary and a Private Medical Dispensary were also heavily damaged. The unfortunate event resulted in the closure of most of the surrounding schools since they were converted in to holding camps for the 223 displaced households. Such schools included; Jamhuri Primary School, Solai Nyakinyua Primary, Akuisi and Ruiru Secondary Schools. There were also damages to farms in Nyakinyua, beacons to plots and power connections; loss of monies (in cash), food stuff, assets, personal valuables, certificates, official documents among others. People also suffered and continue to face indescribable and irreparable social, emotional, psychological and mental harm and anguish.

The possible reasons of the collapse of the Solai dam include unusual high volumes of water caused by inflow or high rainfall which releases hydrostatic force that can collapse the walls of a dam. But based on the hilly landscape, due to soil moisture saturation, the hillside may have become unstable and experience a landslide. The soil displaces the water and it topples over a section of the embankment making it to collapse. The third reason would be that the outdated design and lack of maintenance caused weakness and consequent collapse. The changes in land use practices, for instance conversion of forest lands to farm lands and settlements have reduced infiltration capacity and increased runoff.

The other dams in Patel’s farm (Figure 15) showed weakness and were emptied to avoid any disaster.

Figure 13: An aerial view of Solai dam

Source: Nation Media, May 10th, 2018.

Figure 14: Water curved fissure from Patel dam burst

Figure 15: Tinderess dam being emptied for fear of breach

Source: Nation Media, May 10th, 2018.

2.6 The Flood Damage

The flood disaster had catastrophic impacts on both the physical landscape and the affected communities. The tragic event left a deep mark on the area, causing loss of life, widespread displacement, and extensive damage to infrastructure. The flood carved a chasm through a hill, washed away power poles, destroyed buildings (including a school), and submerged the villages of Nyakinyua and Energy. Homes over a radius of nearly 2 km were submerged. About 48 were confirmed dead, of whom more than 20 were children. More than 2,000 people were left homeless. There will be need for backfilling activities on the deep galleys created after the floods, restoring lost soil fertility or top soil and clearing of debris and huge rock boulders strewn over the farming area. The people also suffered psychological trauma associated with living in the place where the tragedy happened.

The Kenya government promised support to the displaced families reorganize their lives again, support processing of 1300 title deeds swept away by the floods and in rebuilding schools, roads, and other infrastructure destroyed by the disaster.

2.7 Rescue and recovery operation

The rescue team was a joint effort involving the Kenya Defense Forces, Kenya Red Cross Society, the National Youth Service, and various local and regional police forces. During the first day of the disaster response, forty people were rescued and taken to hospitals operated by the Kenya Red Cross and other local relief organizations. On May 14, the official government response team announced that the 38 individuals who had been reported missing of May 10 were all accounted for.

A temporary shelter was established for survivors in the Solai Boy's High School. The displaced there were provided with three months of living provisions and access to psychological counseling. On Saturday, May 19, 10 days after the disaster, the temporary shelter was closed so that school could resume the following Monday. 200 families were still at the shelter without any housing solutions at the time of the closure. Other forms of support included the European Union's Humanitarian Aid office (ECHO) on May 13 announced their support to assist in the disaster relief efforts.

Box 2: Rescue Team

Kenya Red Cross (KRC), National Disaster Unit (NDU) in collaboration with the local administration, security organs (National Police Service and Kenya Defense Forces), county officials, political leaders (area MP, MCA and Governor) and citizenry. The search and rescue was initially commenced by locals supported by the area MP and the MCA and later by the police and the National Youth Service (NYS). Subsequently, the search was taken over by the Kenya Defense Forces (KDF) as from Thursday 10th May 2018. KDF continued with the search until 15th of May 2018 when it scaled down.

2.8 Disaster response and management

The shocking audit report presented before the Parliamentary Special Committee revealed that of Kenya's 4,140 dams and water pans appraised countrywide, only 843 were regulated and inspected by the government. It became apparent that no one could vouch for the safety standards of the remaining 3,257 dams. For Solai dam victims, the people were acquitted because of lack of commitment by the owners to rectify the situation from occurring because the rainfall had not stopped.

On 9th May 2018, Solai dam located in Nakuru County, broke its banks, leaving in its wake; the gruesome deaths of about 50 people; horrifying injuries emotional, mental, and as well as physical; great destruction of property and displacement of people (Mburu, 2018; KHRC, 2014). Civil-military coordination in resource mobilization has a statistically had positive significant impact on disaster response operations effectiveness in Kenya. According to National Disaster Management Unit director (2021), the official multi-agency response team comprised approximately 350 personnel drawn across all leadership ranks from Kenya Red Cross, Kenya Defence Forces, Kenya Police Service, National Disaster Management Unit, National Youth Service, and County Government of Nakuru. There was, however, suggestions that civil-military organizations must improve their command and control, understanding, knowledge, and relations to improve coordination in resource mobilization. The study further recommended strict adherence and implementation of the existing policies, legal and institutional frameworks on disaster management. There was poor coordination in resource mobilization. The little resources that were mobilized were not utilized specifically to benefit the victims of the Solai Dam. There were looting funds, supplies, and other resources meant for Solai Dam victims. Neighboring communities who were never victims were wrongfully added to the victim list. There was poor coordination as there was duplication of work which further depleted the resources that were mobilized without meeting all the objectives.

The government offered support for re-construction of the infrastructure, and normalization of the community's life. The owner of the dam also offered support to the affected households since most of them were farm workers in the farm. Different charitable organisations including faith-based organization came handy to offer support. Nine people were charged manslaughter in Naivasha court with causing the deaths of 48 people following the collapse of a Solai dam but were later on acquitted. Controlling and preventing future landslides requires combination of engineering solutions such as slope stabilization, water drainage control and river and stream management, environmental management, and land-use planning practices, vegetation and reforestation and soil improvement techniques, and early warning systems and community awareness and education.

3. Mai Mahiu Flash Floods Damage by Landslide in March-April 2024

3.1 Mai Mahiu: Location, Topography and Geology

Mai Mahiu is a town located at 0.98078°S 36.58742°E in Kenya's Nakuru County. Its name means "hot water" in native Kikuyu while in Maasai, it might derive from "me'imayu," meaning impassable. The town historically developed as a key train station and is now home to an inland container depot along the Nairobi–Malaba Standard Gauge Railway, inaugurated in 2019. Situated at an elevation of 1,757 meters above mean sea level, Mai Mahiu is rapidly growing, having recently been marked for an industrial park that has attracted 80 investors to a 50-acre Special Economic Zone in nearby Naivasha.

3.2 Mai Mahiu Flash Floods Damage

Mai Mahiu flash floods damage is attributed to cumulative landslides that barricaded water. A landslide or landslip is a geological phenomenon which includes a wide range of ground movement, such as rock falls, deep failure of slopes and shallow debris flows, which occur in steep environments. Although the action of gravity is the primary driving force for a landslide to occur, there are other contributing factors affecting the original slope stability. Typically, pre-conditional factors build up specific sub surface conditions that make the area/ slope prone to failure, whereas the actual landslide often requires a trigger before failing. Landslides occur mostly during the rainy season and are associated with floods, areas with steep slopes and annual rainfall of over 1,200 mm including Central, parts of the Coast, Western, Nyanza and the North Rift Valley. In general, all varieties of slope movement, under the influence of gravity. The main causes of landslides include geological weak material such as volcanic slopes, jointed or fissured or unconsolidated sediments or mass or structured discontinuity, fluvial erosion of foot toe, subterranean erosion (piping or solution holes), intense rainfall causing building up of pore pressure, sand extraction or quarrying, earthquake shaking and volcanic eruption. Impacts of landslides include disruption of infrastructure and settlements, displacement of people, loss of top soil, and destruction of livelihoods. The number of landslides is reported to be increasing as forested lands are converted to agriculture, resulting in looser soils and fewer trees to slow the flow of water down slopes.

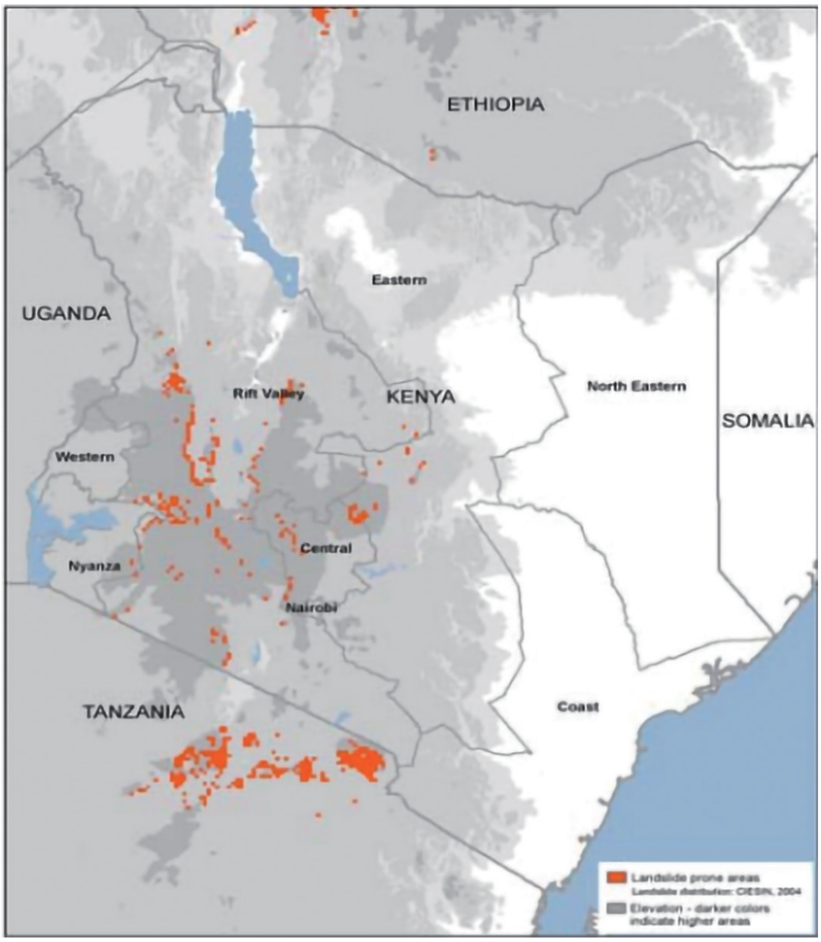

Figure 16: Kenya Landslide Map

Source: Relief Web

Landslides have been a recurring natural disaster in Kenya, particularly in the highland areas (Figure 17)and heavy rainfall and land use change. Table 4 shows a list of notable landslides in Kenya since 2000. It may be noted that the landslides occur mainly in the months of March, April and May during the long rains and in November during the short rains.

Table 4: Frequency of landslides in Kenya since 2000

Date	Location	County	Damage
August 2023	Nandi Landslide	Nandi County	Continuous rains caused a landslide that displaced several families and destroyed farms and homes. Mudflows caused by sustained heavy rainfall buried homes and farms in mud, displacing many families. Emergency services were deployed to assist affected communities.
August 2023	Njabini	Nyandarua County	Intense rainfall resulted in a mudflow that destroyed farmlands and properties. Although no deaths were reported, many homes were covered in mud, and residents were displaced

Date	Location	County	Damage
April 2022	Meru Landslide	Tigania, Meru County	Heavy rains triggered a landslide that buried farms and displaced several families. There were no reported fatalities, but significant property damage occurred.
April 2022	Mathioya	Murang’a County	Mudflows were triggered by torrential rains, destroying homes and sweeping away crops. Several families were displaced, though no fatalities were recorded
November 2021	Taita Taveta Landslide	Mghambonyi, Taita Taveta County	Landslides and mudflows caused by persistent rains buried homes and roads, displacing several families and killing a few people
November 2020)	Nyamira Landslide	Nyamira County	Landslides triggered by heavy rains led to the destruction of homes and farmlands. A few people were reported dead
May 2020	Kericho Landslide	Kipkelion, Kericho County	Heavy rains caused landslides that killed at least five people and displaced hundreds
April 2020	West Pokot Landslide	Chesegon, West Pokot County	Torrential rains caused a landslide that resulted in at least 12 deaths and displacement of families. The incident also damaged roads and bridges
April 2020	Taita Taveta Landslide	Taita Taveta County	triggered by heavy rains buried homes, killing several people
April 2020	Kipchumwa, Embobut	Elgeyo Marakwet County	Continuous heavy rains caused a landslide and mudflows that resulted in the deaths of several people, with houses and farmlands destroyed. Flash floods compounded the disaster
May 2020	Kipkelion	Kericho County	Continuous heavy rainfall caused a devastating mudflow that destroyed homes and farmland. Five people lost their lives, and hundreds were displaced
November 2019	West Pokot Landslide	West Pokot County	One of the deadliest landslides and mudflows in Kenya’s history, triggered by extreme rainfall. Over 50 people were killed as homes were swept away in villages like Parua, Nyarkulian, and Muino. The landslide also caused extensive infrastructural damage
2017	Murang’a Landslide	Kangema, Murang'a County	Several people died after heavy rains caused a landslide in the mountainous region, burying homes

Date	Location	County	Damage
2009	Nyeri Landslide	Mukurweini, Nyeri County	Triggered by heavy rainfall, the landslide caused widespread destruction in the region. Crops, homes, and roads were damaged
2008	Budalang'i Landslide	Budalang'i, Busia County	Floods and landslides due to torrential rains. No fatalities were recorded, but displaced thousands and caused severe damage to property and infrastructure. Mudflows occurred in the region. No fatalities but extensive displacement of families, and farmland was buried under mud
2006	Ngong Hills	Kajiado County	Intense rains caused a mudflow that swept away several homes, damaging properties and infrastructure in the Ngong Hills area
April 2003	Elgeyo Marakwet Landslide	Murkutwo, Kaben, Elgeyo Marakwet County	Multiple landslides caused by heavy rains. Several homes and farmlands were buried, and around 15 people died.[Br]Heavy rains triggered mudflows in addition to landslides. Homes and farms were destroyed, and several fatalities were recorded.

3.3 Progression of Landslide and flooding

Landslides occur mostly during the rainy season and are associated with floods. The situation is worsened by human activities such as clearing natural vegetation, quarrying, mining and construction. Landslides cause loss of life, destruction of crops, human settlements and other infrastructure. Landslides in Kenya are common in areas of steep slopes and annual rainfall of over 1,200 mm,

The mechanical strength of deep weathered soils decreases rapidly when soaked in water and that its strength would be further lowered under any dynamic action. The rainwater percolates between the spores thus saturating the soil. Boulder and rocks embedded in the soil begin to slip free and tumble downhill. Eventually the soaked soil can break free and flow down slope. The infiltration depth at the slope top, crest, is deeper than that of the slope surface after continuous heavy rainfall. With the rapid increase in the residual deformation and pore water pressure of the soil mass, the weathered soil properties change substantially, leading to liquefaction when the pore water pressure and residual deformation reach a certain threshold. The trigger for mass movement is associated with tremours or earthquakes. Under the action of the subsequent ground motion, the liquefied mass of the front edge of the slope top rushes out along the sliding bed and slides down the slope surface in the form of a mudflow or landslide.

Figure17: Location of the West Pokot landslide

Figure 19: Initial minor slides before the onset of the West Pokot landslide

Source: Council of Governors

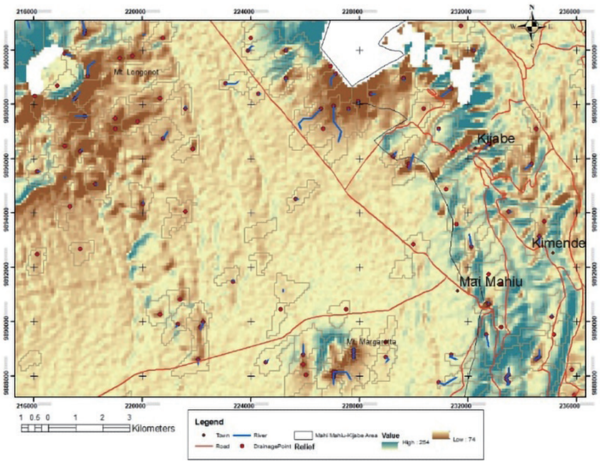

Figure 18. Relief Map of Mahi Mahiu-Kijabe Area

Source: Created using the DEM (NASA terrain database), Kenya Highlands Roads and Kenya Administrative Boundary2019 Databases

Using the ESRI 10m LULC Annual Report based on Sentinel-2 Satellite Imageries the Land Use and Land Cover by area (km2) for the period 2017-2023 has not changed drastically. Built up areas and crops have expanded and rangelands has declined compared to any other land uses.

3.4 Progression of damage

The association of floods and landslides are progressive phenomena that takes a long time to reach the turning point. The rainy season from OND 2023 and El Niño conditions brought heavy storms, causing flooding in various regions resulting in widespread flooding. According to OCHA, nearly 6,000 households (around 36,000 people) were displaced, and 17 people lost their lives by November 5, 2023. The death toll from persistent rain and flooding rose to at least 120 people by end of November 2023.Over a thousand livestock and 221 acres of agricultural farmland were also affected. Cumulatively, nearly 10,230 households (about 61,380 people) were impacted during this period, all requiring urgent humanitarian support. More than half a million people were displaced due to flooding and heavy rains. Waterborne diseases like cholera and diarrhea were reported in flood-affected areas.

The Kenya Meteorological Department, the national weather agency, gave more than five heavy rainfall advisories between 1 March and 15 May 2024. MAM season in 2024 started when the effect of OND rainy season was still there. Rainfall greater than 50mm in 24 hours is in most cases used as a proxy for flood early warning and preparedness. Between March and June 2024, heavy rains continued and floods caused further devastation since most of the soil were already soaked. OCHA reported an estimated 315 people were killed, 188 injured, and 38 remained missing. Over 293,200 people (58,641 families) were displaced, and nearly 306,520 (61,304 families) were affected. Despite the challenges, humanitarian partners worked tirelessly to assess needs and provide assistance to affected communities.

Figure 20: Site of the 29 April 2024 landslide disaster at Mai Mahiu in Kenya.

Figure 21: Scar of the 27 April 2024 landslide at Mai Mahiu in Kenya

Figure 22: Site of the landslides that caused the 29 April 2024 at Mai Mahiu debris flow in Kenya. Image copyright Planet Labs, acquired on 7 April 2024,

Figure 23: Path of the 29 April 2024 landslide

Figure 24: Site of the channelised debris flow at Mai Mahiu disaster in Kenya.

Image copyright Planet Labs, acquired on 12 May 2024

3.5 Circumstances leading to dam burst at Mai Mahiu

The impact of landslides includes, destruction of infrastructure, communication and settlements, damming of river and streams, consequently causing floods, loss of top soil, water quality disruptions, and fatalities. On 29 April 2024, a blockage in a culvert beneath a railway embankment led to a catastrophic failure and inundation in Kenya, killing at least 50 people. The event was initially described as a 'dam failure'. The flood occurred following heavy rains in the previous month of March had killed over 110 people countrywide. The flood carried away the railway embankment and poured downstream at a very high speed and velocity. One survivor said he was awakened by his home shaking and screams; he managed to escape with his family before the flood arrived. The debris included stones, trees, and mud accumulated from past rain. The area lies in a region of the Great Rift Valley susceptible to flash floods. The concentration of landslides in the source area of this event suggests that the rainfall must have been extremely intense locally. Mai Mahiu is a stream at an elevation of 1,757 m. By the end of May, the impact of the floods continued to worsen as more information became available. Nationally, there were at least 245 fatalities, 78,683 households affected, and 45,778 households displaced including the Mai Mahiu incidence.

The incident occurred near Nakuru County, Kenya. The raging water, as confirmed by the Water Resources Authority (WRA), came from a water-filled gulley around a railway line in Kiambu County sweeping away everything carrying with it, mud, rocks and uprooted trees on its path. The water also destroyed part of the Nairobi-Nakuru highway. The Mai Mahiu tragedy occurred on 29th April 2024 whereby a tunnel situated on the hilly area of old Kijabe Road in Kiambu County accumulated water due to blockage along the Meter Gauge Railway and the increased water burst the soaked walls, sweeping households along River Tongi from Kamuchira village through Mai Mahiu. At least 42 people died.

Figure 25: People try to clear the area after a dam burst at Mai Mahiu, Kenya
AP, Monday, April 29, 2024.

Figure 26: People gather around a bus after a dam burst in Mai Mahiu, Nakuru County, Kenya, Monday, April 29, 2024.

(AP Photo/Patrick Ngugi)

Figure 27: Blocked roads around Naivasha and Narok.

Figure 28: Following a landslide at Mai Mahiu

Source: Associated Press, April 29, 2024

Figure 29: Destruction of homes, and farms along the flood path

Figure 30: Destruction of homes

Figure 31: People gather on the main road after a dam burst at Mai Mahiu, Kenya, April 29, 2024.

Figure 32: Massive debris and uprooted trees during the disaster

Figure 33: View of damaged houses after heavy flash floods in Mai Mahiu, Kenya.

Photo credit: Reuters

Figure 34: Search and Rescue team members in Mai Mahiu

Figure 35: Destroyed road crossing at Mai Mahiu

The landslide impounded dam burst was not the only thing happening at this time. In other news, the Kenya Red Cross said it had retrieved two bodies after a boat carrying "a large number of people" capsized at the weekend in flooded Tana River County in eastern Kenya, adding that 23 others had been rescued. On By Saturday, officials said 76 people had lost their lives since March. Flash floods submerged roads and neighborhoods, leading to the displacement of more than 130,000 people across 24,000 households, many of them in the capital Nairobi, according to government figures released Saturday. The ongoing rains caused flooding that killed nearly 100 people and postponed the opening of schools. Overturned vehicles, destroyed homes, uprooted trees, scattered boulders, and distraught faces painted a grim picture of destruction and loss.

3.6. Emergency and rescue operations

The National Disaster Management Authority’s role is to coordinate disaster risk management through the National Disaster Operation Centre (NDOC), the National Police Service, the Department of Defense, the National Youth Service (NYS), local Fire Brigades, St John’s Ambulance Service, Kenya Red Cross Society, Occupational Health and Safety Services, Kenya Wildlife Services and the National Environment Management Agency (NEMA). Emergency Responses are organized by a Multi-Agency Team, composed of various Ministries, Departments and Agencies, the County Government and other non-state actors including public volunteers. The work of these agencies have been found to be uncoordinated, appropriate equipment missing (Figure…), and lack common operational code of ethics. Additionally, the Rescue Centres, generally decided at the point of disaster, are ill-prepared in terms of basic services such as water and sanitation, emergency medical services, etc. Schools have been used to host displaced families.

The official response was the establishment of Mai Mahiu Disaster Recovery Center (DRC) to assess the ongoing multi-agency efforts following recent flash floods that led to the loss of lives, displacement of people and destruction of infrastructure. This was given leadership from the highest level from the Kenya Defense Forces (KDF), General Officer Commanding Border Security Command, who is also the National Floods Coordination Centre Commander, alongside the Governor of Nakuru County. The deployment is in line with the secondary role of the KDF of assisting and cooperating with other government agencies, especially during emergencies and disasters to safeguard the lives. The DRC’s terms of reference is to continue with search and recovery efforts for victims of the tragedy.

Fighure 36: Kenya National Highway Authority monitors debris and heavy traffic on roads in the affected area.

4. Lessons learnt in Disaster Preparedness, Response and Recovery

The magnitude, frequency, and impacts of drought and floods, which are the most common in the country, have increasingly become severe. An estimated 3 to 4 million Kenyans are affected annually by water-based disasters that disrupt livelihoods and draw back gains achieved in human development. A good example of this is that, while the cost of floods is estimated at 5.5% of GDP every seven years, droughts cost an estimated 8.0% of GDP loss every five years. The economic cost of floods and droughts is estimated to create a long-term fiscal liability equivalent to about 2.0 % to 2.4% of GDP each year, or approximately US$500 million per year. The number of landslides is reported to be increasing as forested lands are converted to agriculture, resulting in looser soils and fewer trees to slow the flow of water down slopes.

The National Disaster Risk Management Policy of 2017 aims at reducing natural and human-induced disaster risk and associated losses through the establishment of an integrated multi-hazard DRM approach based on a participatory, impartial, transparent and useful DRM framework creating a collaborative partnership. On the other hand, the National Disaster Management Policy (2018) aims to build a safe, resilient and sustainable society. It establishes a legal and institutional framework for management of disasters, ensures coordinated, participatory and consultative institutional and stakeholders partnerships, and promotes accountability, monitoring and learning. It focuses on preventing or reducing the risk of disasters, mitigating their severity, improved preparedness, rapid and effective response to disasters and post-disaster recovery. The policy is aligned to United Nations International Strategy for Disaster Reduction (UNISDR), particularly the Hyogo Framework for Action (HFA) for Disaster Risk Reduction (DRR) and the Sendai Framework for disaster risk reduction 2015-2030 on the importance of governance in disaster management. The National Disaster Risk Management Authority and County Disaster Risk Management Committees, established by Act of Parliament, are charged with coordination and operationalization disaster risk management activities.

According to the Kenyan laws, the Water Resources Authority (WRA) is in charge of water allocation, licenses and supervises construction of dams. But once a dam is constructed, WRA monitors its operation to ensure it adheres to the set regulations and standards. The dam owner is responsible for the operation and maintenance of the private dam. Enforcement of the law during construction is generally weak and environmental regulations are not followed. Noting that both the national and county governments have shared responsibility especially regarding environmental audits, the Solai dam was audited in the 2014, 2015, 2016 and 2017 audit reports[5] and of the dams[6]. The WRA carried inspection on 7th November 2014 and permitted structure which is a weir of 2.5m high[7]. According to the fourth schedule of the Water Act, 2016, the dam is classified as having low risk[8].

There are no comprehensive measures regarding preparedness, relief and rehabilitation, mitigation and prevention for floods. The recent floods have highlighted several gaps in the country's approach to managing water disasters. There are generally advisories rather than a well-planned routine to be followed in case disaster occurs. Anticipatory warnings generally includes advice against driving or walking through flooded areas or crossing flooded rivers to prevent loss of lives. The early warning information through various channels, including radio, newspapers, TV, and social media, ensuring inclusivity for all demographics are generally opined.

5. Challenges in Kenya's Flood and Water Management

One of the challenges in water-related disasters is the weak law enforcement in dam construction, The Water Resources Authority (WRA) oversees water allocation and dam licensing but enforcement during dam construction is weak because of lack of capacity. Additionally, the National Environmental Management Authority is unable to ensure that the environmental regulations are followed, leading to potential risks. It has also been demonstrated that the shared responsibility of operation of dams and environmental audits between the national and county governments is unclear in their roles, causing inefficiency. The case of Solai dam, inspected by WRA and classified as low-risk, reflects issues in classification and regulatory follow-ups. The way forwards calls for strengthening enforcement of laws and environmental regulations during dam construction and future operations, especially private dams and pans. Regular inspections, audits, and stricter penalties for non-compliance should be prioritized. Clear delineation of responsibilities between the national and county governments is needed, particularly in disaster planning and water resource management. For flood mitigation, Nature-Based Solutions such as increasing vegetation cover, promoting afforestation, and developing soil conservation techniques will reduce the risk of flooding, landslides and soil erosion.

For the Solai Dam, NEMA and Water Resources Authority should conduct an audit of the other existing six dams in the farm to assess their viability and ability to withstand extreme environmental conditions and that the

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[5] *No mention of dams[6] under chapter 1(See Annex 1, Paragraph 1), See Annex 2, See Annex 3.*
[6] *No mention of dams[6] under chapter 1(See Annex 1, Paragraph 1), See Annex 2, See Annex 3.*
[7] *Report was prepared in Annex 7.*
[8] *Low risk classification in Annex 8)*

dam owners undertakes proper environmental restoration of the area affected by the flood water in accordance with the precautionary and the polluter pays principles.

Kenya lacks comprehensive flood preparedness and response plans. While early warnings exist, they are often limited to advisories without well-planned evacuation routines or contingency measures. There is no systematic planning for preparedness, relief, and rehabilitation in the event of floods. Long-term disaster planning is weak and poorly resourced. Mapping of high-risk flood areas is often absent, and pre-positioning of essential supplies is rarely implemented. Desilting of dams, unclogging drainage systems, and reinforcing water and sanitation infrastructure before the rainy season is inconsistent. Poor wastewater and solid waste management increase the risk of epidemics following floods. The government needs to provide leadership in creating a detailed national and county disaster preparedness and response plans, including evacuation routes, pre-identified relocation sites, and stockpiling of essential resources. Engaging and capacity building of the local communities in simulations and drills are essential for effective disaster management.

Funding for flood mitigation and disaster preparedness is not prioritized neither by the County nor the national governments, leading to reactionary responses rather than proactive planning. The humanitarian organisations and the civil society organisations are generally flexible and fill the gap by the public sector. However this also leads to limited accountability and duplication of effort. Accompanied by limited monitoring and feedback mechanisms, public resources have been spent public complaints regarding impropriety are common, highlighting a lack of reliable feedback mechanisms. Relocation sites for communities in flood-prone areas are often not pre-identified, leading to chaotic evacuations when floods occur. Evacuation drills and simulations are rare. Early warning systems through diverse communication channels should be expanded to ensure inclusivity and anticipatory guidance that is actionable, such as specific instructions for evacuation and road closures adds value to effectiveness of disaster response.

River basin planning in Kenya has been practiced for over 35 years. The Tana and Athi Rivers Development Authority, Lake Victoria Drainage Basin, The Ewaso Ngiro Development Authority have been used for integrated planning units. These authorities, should be added additional mandate for catchment management to mitigate floods and implement efficient water use. However the organisations have not received sufficient resource allocations for long-term flood mitigation strategies, including rainwater harvesting, installation of check dams, and desilting of water bodies. Kenya will require to strengthen real-time monitoring systems and establish reliable feedback mechanisms to ensure timely and effective maintenance of dams and water infrastructure.

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3 Earthquake Countermeasures for Water Supply and Sewage Systems Based on the 2024 Noto Peninsula Earthquake

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1. Introduction

We extend our deepest sympathies to all those affected by the 2024 Noto Peninsula Earthquake. We also would like to express our respect and appreciation to all the individuals who are tirelessly working to rebuild the affected areas.

The recent earthquake has caused extensive damage, particularly to water supply and sewerage facilities, and the water supply to around 140,000 houses were disrupted. In response to this significant damage, in March 2024, the Ministry of Land, Infrastructure, Transport and Tourism, in collaboration with the Ministry of Health, Labour and Welfare, which was in charge of waterworks projects at the time, established a "Study Committee on Countermeasures in Water Supply and Sewerage Systems against Earthquake" (Chaired by Prof. Satoshi Takizawa, School of Engineering, the University of Tokyo) to investigate future earthquake countermeasures and how water supply and sewerage systems should respond to disasters as one system.

This report provides an overview of the recent disaster response efforts and outlines the findings of the Water and Sewerage Earthquake Preparedness Study Committee.

2. Overview of Damage to Water Supply and Sewerage Facilities

(1) Overview of the 2024 Noto Peninsula Earthquake

On 1 January 2024, an earthquake with a magnitude of 7.6 and a depth of 16 km occurred. An intensity of 7 was observed in Wajima City and Shiga Town, Ishikawa Prefecture, and an intensity of 6+ to 1 was observed from Hokkaido to Kyushu region. The Japan Meteorological Agency (JMA) has designated the series of seismic activity that has occurred in the Noto region of Ishikawa Prefecture since December 2020 as the "2024 Noto Peninsula Earthquake".

The earthquake also caused significant crustal deformation, including a 4 m uplift in the western part of the Noto Peninsula.

Comparing the seismographs in each region of the National Research Institute for Earth Science and Disaster Resilience: a nation-wide strong-motion seismograph network (K-NET) with the standard acceleration response spectra given in the Guidelines and Commentary on Seismic Countermeasures for Sewerage Facilities 2014 Edition (Japan Sewage Works Association), it is assumed that the seismic motion of this earthquake was equivalent to Level 2 earthquake motion in the Noto Peninsula region. The seismic motion of this earthquake is assumed to have been equivalent to level 2 seismic motion in the Noto Peninsula area. In some areas, such as those where intensity 7 was recorded, the seismic motion exceeded the level 2 seismic motion in some periodic zones.

(2) Overview of damage to water supply and sewerage facilities

The earthquake caused extensive damage to water and sewage facilities. Up to 140,000 houses had their water supplies cut off in six prefectures: Niigata, Toyama, Ishikawa, Fukui, Nagano, and Gifu. The damage was particularly severe in six cities and towns in the Noto region of Ishikawa Prefecture: Nanao City, Wajima City, Suzu City, Shiga City, Anamizu City, and Noto Town. The damage rate to pipes in these areas exceeded that of any major earthquake in recent years.

The strong earthquake, equivalent to a level 2 earthquake, caused damage to essential facilities such as water treatment plants, distribution reservoirs, and pipelines directly connected to sewage treatment plants due to their lack of earthquake resistance (Figure 1). This resulted in widespread water cuts and water stagnation in sewage pipes. The restoration process took a long time due to limited transportation, common in the peninsula area, and restricted working hours caused by bad weather conditions. Water mains were finally restored at the end of May, except in areas where buildings had collapsed in Wajima City and Suzu City, which took long time.

Figure 1. Damage to Vital Facilities in Water and Sewerage Systems
(left: water supply pipe; right: pressure pipe directly connected to the treatment plant)

(3) Effects of earthquake-proofing

Despite the extensive damage to many facilities, no damage that would significantly affect their functioning was observed in water treatment plants and sewage treatment plants that had been made earthquake-proof. There was a noticeable difference in functional security within the same facility, depending on whether the ponds were earthquake-proofed, reaffirming the effectiveness and necessity of earthquake-proofing facilities for disaster prevention in advance (Figure 2).

Figure 2. Damage with and without earthquake-proofing
(left: water treatment plant; right: utility holes floating up)

3. Disaster Response and Challenges

The Noto Peninsula is a mountainous peninsula surrounded on three sides by the sea, which is a geographical limitation, and the situation made it more difficult than in previous disasters to survey damage to water supply and sewerage facilities and carry out support activities for restoration due to large-scale landslides and road disruptions. Under these circumstances, the dedicated support activities of a total of approximately 74,600 people (water supply: approximately 49,500 people, sewage: approximately 35,900 people (as of 31 May)), including water supply and sewerage related officials from local governments, companies and related organizations nationwide, resulted in the restoration of water mains as of 31 May, except in areas where had collapsed buildings in Wajima City and Suzu City. Sewerage main flow functions were also secured as of 25 April, except in areas where buildings had collapsed in Suzu City.

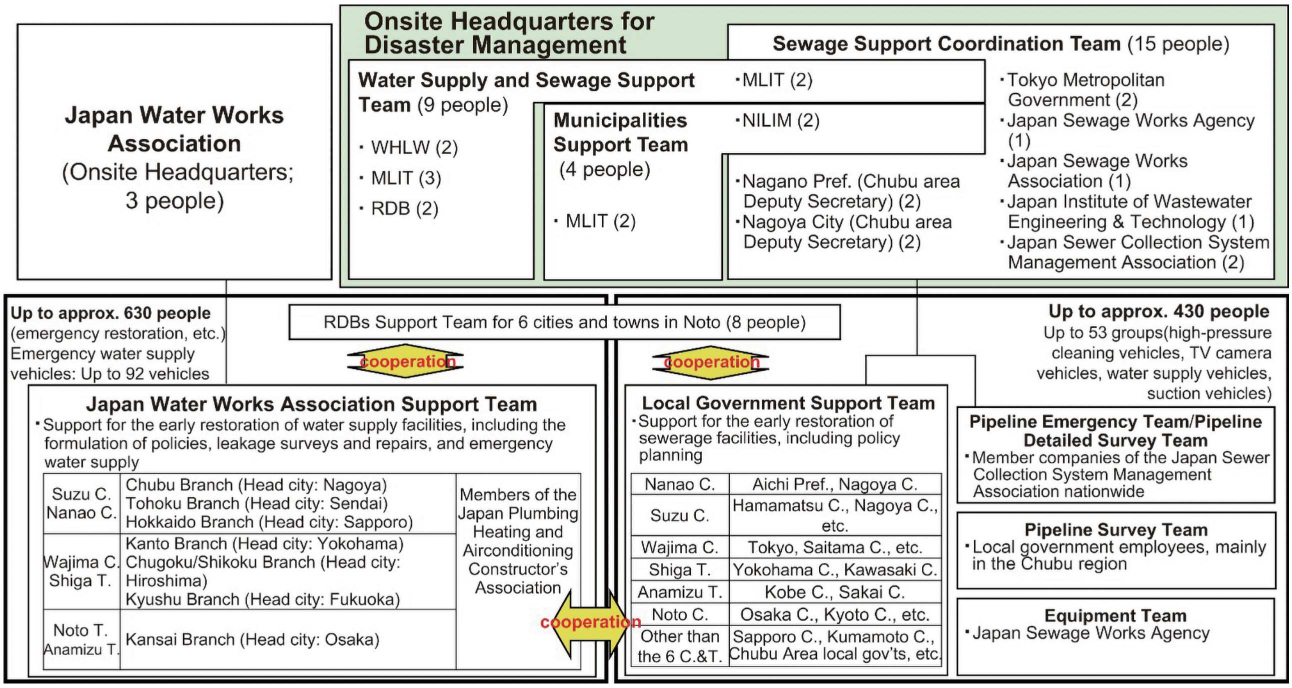
In a series of disaster responses, various new approaches and trial-and-error efforts were made, such as restoration support of water supply and sewerage systems as one system, disaster response prioritizing the securing of functions, and water supply activities in cooperation with relevant organizations, ahead of the transfer of water supply maintenance and management administration from the Ministry of Health, Labour and Welfare to the Ministry of Land, Infrastructure, Transport and Tourism in April 2024.

(1) Support system for the restoration of water supply and sewage systems as a single entity

The Ministry of Health, Labour and Welfare (at the time) and the Ministry of Land, Infrastructure, Transport and Tourism dispatched officials to the onsite headquarters for disaster management set up in Ishikawa Prefecture to carry out overall coordination in collaboration with the two ministries. In addition, officials from the Water Supply Development and Management Administration Transfer Preparation Office of the Regional Development Bureau were dispatched to the disaster-affected area to provide support to the affected municipalities in cooperation with the Japan Water Works Association (Figure 3). They coordinated, such as eliminating road obstacles and assessing the needs for water supply vehicles, in cooperation with the Japan Water Works Association and the supporting municipalities.

This enabled the restoration of water supply and sewage systems as one system prioritizing the maintenance of functionality, and based on the information collected, it also had the effect of promoting the early elimination of obstacles of affected roads that the emergency restoration work had disrupted, and the early restoration of power to areas that had lost power, as well as the smooth utilization of the equipment (such as sprinkler trucks with has water supply functions and standby support vehicles) held by the Regional Development Bureau, and so had an effect on the early restoration of services.

On the other hand, in mutual assistance, immediately after the disaster, there were situations where municipalities that could aid were on standby, waiting for the affected municipalities to contact them with requests for assistance, etc. Therefore, it is necessary for the national government to make overall coordination to implement push-type support. In addition, with inconvenient transport access, a large part of the operating time had to be spent travelling, leading to reduced work efficiency. In order to improve the efficiency of support activities by securing accommodation and work bases in the neighbors of the disaster area, it is effective to convert water and sewage treatment plants into disaster prevention bases.



Notes: Numbers in brackets indicate the number of people.
Abbreviations: WHLW: Ministry of Health, Labour and Welfare;
MLIT: Ministry of Land, Infrastructure, Transport and Tourism;
RDB: Regional Development Bureau; and
NILIM: National Institute for Land and Infrastructure Management.
C.: City; and T.: Town.

Figure 3. Restoration Support System that Integrated Water Supply and Sewage Systems

(2) Emergency restoration with priority on resolving water breaks.

Even if the water supply is restored, it will only be possible to use water freely if the sewage system is restored. For this reason, an attempt was made to restore the sewerage system in conjunction with the restoration of the water supply in order to resolve the water cut-off as soon as possible (Figure 4). In the past disaster responses, detailed (secondary) surveys were carried out sequentially from the point where a schematic (primary) survey was completed, with disaster recovery work (disaster assessment) in mind. This time, however, we decided to prioritize emergency recovery work, such as confirming the priority areas for water supply restoration and grasping the restoration process, and installing temporary piping as necessary to ensure that there would be no delay in the start of water supply, over the secondary survey (Figure 5).

In addition, in order to ensure sufficient construction capacity in the affected areas to ensure the early functioning of sewerage facilities, there were also cases of new initiatives where supporting local authorities and specialist contractors' expertise in the maintenance and construction of sewerage systems were sent to the site as a team to provide support.

In the case of water supply, some areas used temporary piping (rolling piping) for the pipes in the sections where damage was concentrated (Figure 6), and they could restore water supply early without waiting for the results of a leakage survey.

These efforts effectively ensured the early functioning of water supply and sewerage systems in evacuation centers and other locations.

On the other hand, in some cases, there was insufficient awareness of the need to prioritize ensuring functionality over detailed surveys in sewerage support activities, and insufficient personnel, including civil engineering contractors, involved in emergency restoration and other activities.

Therefore, it is necessary to establish a support system that prioritizes the restoration of functionality in advance, to determine which facilities should be restored as a matter of the highest priority and how to respond, and to provide appropriate advice from the national government.

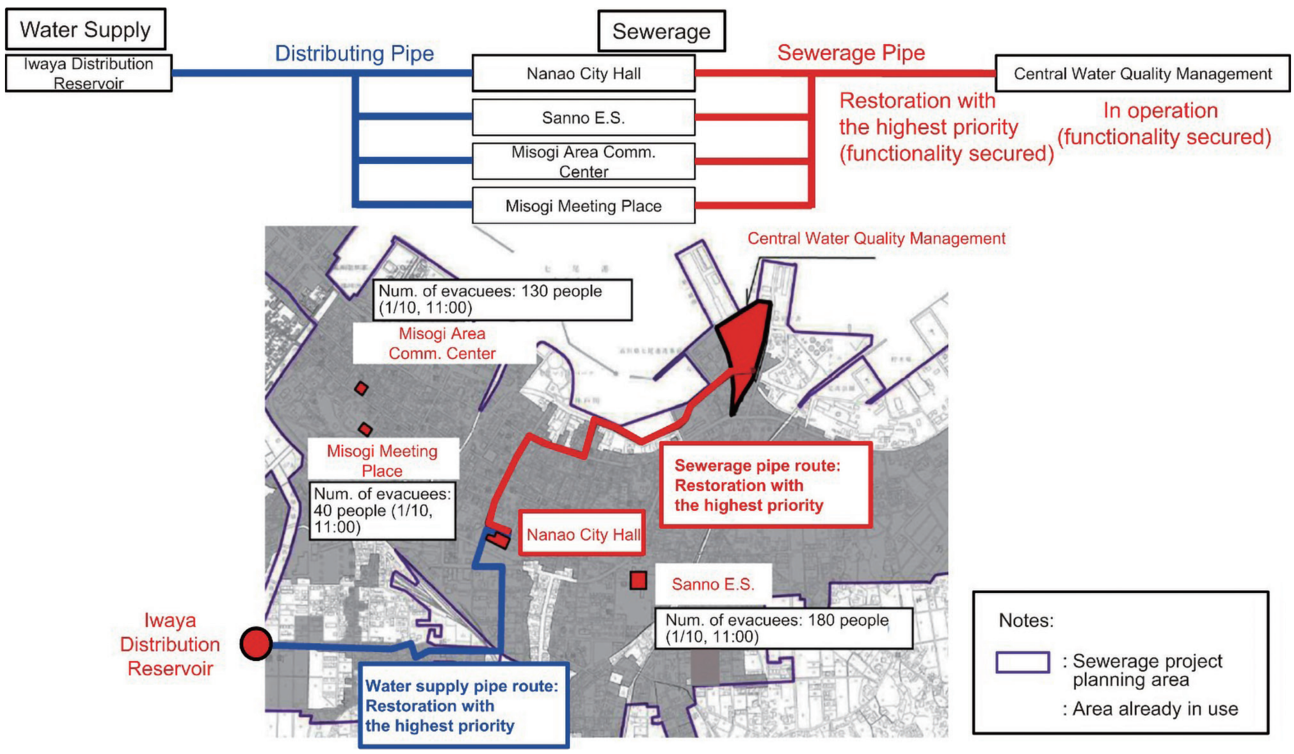


Figure 4. Efforts to Achieve Early Recovery by Integrating Water Supply and Sewage Systems

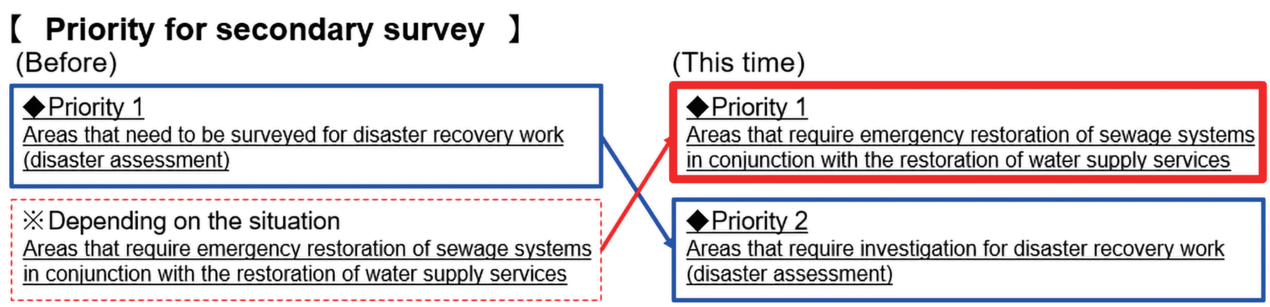


Figure 5. Accelerate Emergency Restoration with Priority on Ensuring Functionality

Figure 6. Temporary Piping (example of using rolling piping)

(3) Multi-agency water supply support

As water supply facilities were damaged in large numbers and over a wide area, and water supply was cut off on a large scale, many organizations from across the country provided water supply support from the outset, including water utilities under the framework of the Japan Water Works Association, the Self-Defence Forces, the Water Resources Agency and regional development bureaus.

In order to coordinate the dispatch of water supply support from a large number of organizations over a wide area, information on the water supply needs of municipalities, disaster relief medical teams (DMAT) and others was gathered mainly by Ishikawa Prefecture, and this information was listed by the water supply support team in the onsite headquarters for disaster management of the Ishikawa prefectural government and shared daily with the relevant organizations to provide efficient water supply support. This information was then compiled into a list and shared with relevant agencies on a daily basis, while efficiently providing water supply support (Figure 7). In addition, as the water supply was cut off for a prolonged period, not only drinking water but also water for daily use such as bathing, toilets and laundry became necessary, and the water supply support team coordinated with the relevant organizations and carried out water supply activities according to the needs of each affected area.

As the water treatment plant was damaged in the earthquake and was unable to supply drinking water to water trucks, portable water purification facilities and equipment owned by private companies were installed and utilized at the water treatment plant site as alternative facilities to supplement the capacity of the damaged water treatment plant, while installed and utilized portable water purification facilities and equipment owned by the Japan Water Agency and private companies as water sources in the neighboring rivers of the affected area

(Figure 8). Furthermore, the water supply support team collated this information and shared it with the relevant organizations, enabling them to carry out efficient water supply activities.

Through these efforts, water supply activities were coordinated based on the outlook for water supply restoration, and water supply needs and support were smoothly matched to ensure prompt water supply support. At the same time, leakage tests were conducted quickly using water supplied by portable water purification facilities and equipment, even though it was difficult to conduct leakage tests on pipelines due to damage to upstream backbone facilities. The leakage tests could be carried out quickly using water supplied by portable water purification facilities and equipment.

In view of the recent response, in addition to water supply vehicles, it is also effective for water utilities to have portable water purification facilities and equipment that were used in the recent earthquake so that they can be used quickly and efficiently in the event of a disaster, and to have disaster wells, earthquake-resistant water storage tanks, temporary water tanks, etc. in place to ensure immediate water supply if water supply facilities are damaged which are also effective.

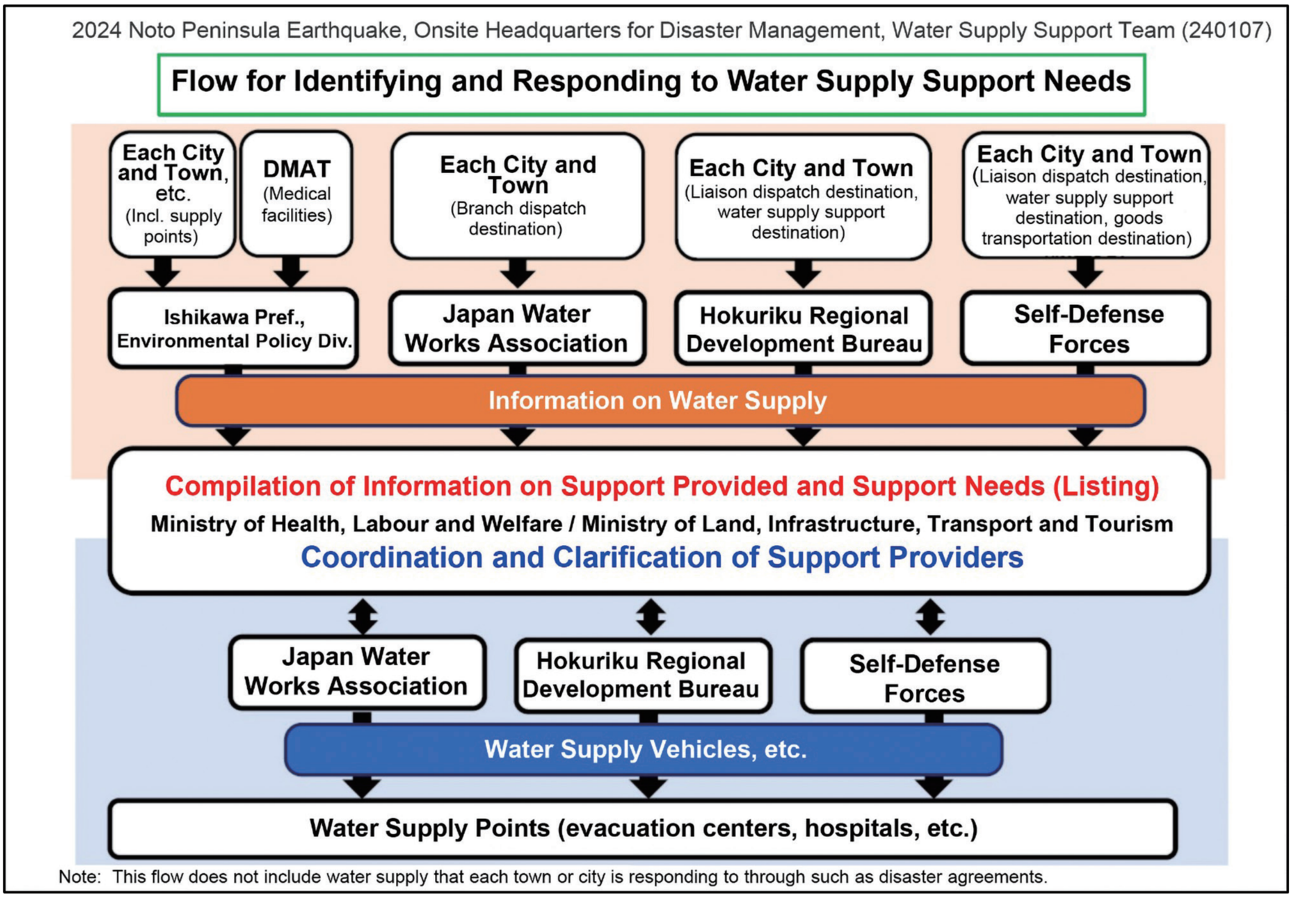


Figure 7. Flowchart of Identification and Response to Water Supply Support Needs

Figure 8. Examples of Portable Water Purification Facilities and Equipment Installation

(4) Lessons learned from the disaster response

We believe that the coordination of the water and sewerage systems as one system, along with prioritizing emergency restoration to resolve water cut-offs, had a positive impact on early restoration. However, in order to effectively utilize the lessons learned from this disaster response in the future, it is necessary to establish a system and response methods in advance. In a questionnaire survey of the municipalities that provided support, issues such as a shortage of earthwork teams for emergency restoration, inadequate accommodation and work bases, and challenges with working in bad weather due to the inability to use pipeline register data electronically were raised. Table 1 provides a summary of the disaster response and challenges faced during the 2024 Noto Peninsula Earthquake.

Table 1. Response to the 2024 Noto Peninsula Earthquake and Its Effects and Challenges

Items addressed	Response to the 2024 Noto Peninsula Earthquake	Effectiveness and Challenges
Support system for the integrated water supply and sewage systems	• Establishment of a support system for water and sewage services. • Establishment of a support team for affected cities and towns (regular visits to affected cities and towns).	◯ The support system for water and supply sewage systems as one system was effective in early recovery. However, there were cases where municipalities that could provide support were waiting for requests for assistance right after the disaster, so prefectures need to dispatch a request quickly and for the national government to provide overall coordination through push-type support.
	• Dispatch of TEC-FORCE for water supply and sewerage systems (e.g., implementation of elimination of road obstacles based on the information that they are impeding the restoration of water supplies).	◯ The dispatch of TEC-FORCE to collect information and coordinate the elimination of road obstacles in relation to water supply and sewage systems was effective in speeding up the recovery process.
	• Use of standby support vehicles as part of the support system (reduction in travel time).	◯ Using standby support vehicles owned by the Regional Development Bureau as part of the support system effectively reduced travel time. Water treatment plants and sewage treatment plants should be turned into disaster prevention bases, and efforts should be made to secure accommodation and work bases.
Securing the early functionality of water supply and sewage systems	• Process coordination for water supply and sewage systems. • Emergency restoration was carried out with a policy that prioritized the securing of functionality.	◯ The prioritization of process coordination and emergency restoration for water supply and sewage systems positively affected early restoration. On the other hand, because the original workflow was designed to allow for the speedy completion of detailed surveys, there were cases where the prioritization of functionality did not allow for thorough communication.
		◯ If the coordination of the areas that need to be restored as part of the water supply and sewage systems could be done in advance, then a smooth and speedy restoration would be possible, so it is necessary to determine the areas that need to be restored as a top priority.
		◯ It is imperative to train and secure personnel with technical skills, decision-making abilities, and coordination skills. This will enable them to make immediate decisions in the initial response and recovery stages of a disaster. Particularly, it is important to train personnel by removing the barriers between water and sewage in order to promote the integrated water supply and sewage systems initiative.

Items addressed	Response to the 2024 Noto Peninsula Earthquake	Effectiveness and Challenges
	• Local governments and contractors dispatched as a set.	○ When trying to implement emergency restoration, there were cases where there was a shortage of civil engineering contractors or a mismatch between the local government providing support and the contractors, so building a support system in advance is necessary.
	• Utilization of temporary piping.	○ The use of temporary piping and other measures was effective for rapid emergency restoration. Still, there were also cases where such measures were delayed, so the government must provide appropriate advice and clarify in advance the cases that disaster restoration projects will cover.
		○ There is a need for technological development to enable early damage assessment and early restoration of facilities.
Several organizations collaborated to provide support for water supply	• Information gathering and overall coordination of water supply needs and related support activities • Individual support provided in response to needs	○ Emergency water supply support using the sprinkler trucks owned by the Regional Development Bureau was effective because of their large capacity. However, as they do not have a pump function, it is necessary to make adjustments so that the right equipment is used for the right purpose.
	• Utilization of portable water purification facilities and equipment.	○ It was challenging to test for leaks in the water pipes because of damage to the upstream main facilities. However, it was possible to make use of the water supplied by the portable water purification facilities and equipment. It is also effective to have portable water purification facilities and equipment. It is effective to have portable water purification facilities and equipment, disaster prevention wells, water supply vehicles, temporary water tanks, etc. ready to go, so that water supply support can be carried out quickly and efficiently.
Coordination of sewage treatment	• Disaster recovery for community wastewater and septic tanks	○ Since there was extensive damage to community wastewater and septic tanks, establishing a support system for early recovery is necessary.
	• In addition to setting up temporary toilets in evacuation centers, human waste from these facilities is collected using vacuum trucks.	○ As there was not enough provision of comfortable and hygienic toilets in evacuation centers, etc., it is necessary to promote the introduction of utility hole toilets.

Items addressed	Response to the 2024 Noto Peninsula Earthquake	Effectiveness and Challenges
	• In light of the damage to human waste treatment facilities, it is necessary to receive human waste at sewage treatment plants	◯ Due to damage to human waste treatment facilities, it became necessary to make on-site adjustments to receive human waste at sewage treatment plants. It is important to determine the method of receiving human waste in advance in order to make smooth adjustments.
Disaster response using DX technology	• Use of electronic information such as ledgers and location information	◯ Using paper forms during the survey was time-consuming and made management difficult, especially in bad weather. On the other hand, electronic ledgers proved to be effective in some cases.
Communicating information to residents	• Visualization of information on the restoration of water supply and emergency restoration of sewage systems • Setting up a night-time consultation service for overflowing sewage	◯ Since it took time to make the information public, and there were cases where incorrect information was communicated, such as a ban on using the sewage system even though it was usable, it is necessary to provide accurate information, such as by standardizing terminology, ensuring appropriate expressions, and building a system for visualization.
Accelerate response to in-house piping	• Provide a list of in-house piping companies • Implementation of temporary water supply taps	◯ Since it was challenging to secure contractors and the repair of in-house piping was prolonged, it was also challenging to grasp the actual situation, so it was necessary to build a system in advance for early grasp of the disaster situation and rapid restoration of water supply and drainage facilities as a whole.

4. Final Report of the Study Committee on Countermeasures in Water Supply and Sewerage Systems against Earthquake

As mentioned earlier, in order to verify the disaster response of the water supply and sewerage systems as one system, as well as to discuss the future of earthquake countermeasures in light of earthquake damage, the Ministry of Health, Labour and Welfare (at the time) and the Ministry of Land, Infrastructure, Transport and Tourism established the Study Committee on Countermeasures in Water Supply and Sewerage Systems against Earthquake, which was consist of experts, local public bodies, and related organizations. The committee discussed three points: (1) the direction of water supply and sewage systems development for the recovery of disaster-affected cities and towns (advice for the region), (2) the way forward for earthquake countermeasures in light of damage to water supply and sewage facilities, and (3) the way forward for disaster response involving water supply and sewage systems as one system. After reviewing the situation of facility damage and recent initiatives, the committee discussed the construction of a disaster-resistant and sustainable water supply and sewage system.

At the first committee meeting, held on March 12, opinions were expressed regarding the necessary measures to be taken in the future for each item under discussion, and it was confirmed that facilities that had been retrofitted to withstand earthquakes were generally able to maintain their functions despite the extensive damage caused by the disaster, confirmed that it would be appropriate to apply the current earthquake resistance guidelines to the restoration work in order to achieve a full recovery in the disaster areas as soon as possible, and immediately issued an administrative notice to the disaster-affected areas on March 22.

At the second committee meeting, held on May 10, the committee made an interim report and compiled a list of points to consider when developing water supply and sewage facilities in the disaster-affected municipalities as part of the recovery process. The administrative notice to the disaster-affected areas was dispatched on March 22.

Based on the discussions at the third committee meeting, held on August 27, the final report was published on September 30. The following is an overview of the final report.

(1) Direction of water supply and sewage system development for the recovery of disaster-affected cities and towns

- Development appropriate for a disaster-resistant and sustainable future, including the use of decentralized systems, while taking into account various perspectives such as reconstruction town planning and the wishes of local community residents
- Construction of a system that balances the securing of alternatives and redundancy with improving the efficiency of projects
- Proactively introducing new technologies that can flexibly respond to changes in population demographics, etc.
- Promotion of DX, such as digitization of ledgers and remote monitoring of facilities
- Further strengthening of project execution systems and disaster response capabilities through wide-area cooperation and public-private partnerships, etc.

(2) Future earthquake countermeasures based on the damage to water supply and sewage facilities

- Making facilities that are the “vital points” of the water supply and sewage systems earthquake-resistant
- Integrally making water supply and sewage pipelines for essential facilities such as evacuation centers earthquake-resistant
- Locating facilities away from areas where there is a risk of ground deformation such as landslides
- Securing redundancy and diversity through the use of portable water purification facilities and equipment, sewage treatment facilities and equipment, etc.
- Measures to prevent utility holes from floating up and measures for joints
- Securing and training personnel, developing, and implementing new technologies, etc.

(3) How to respond to disasters with water supply and sewage system as one system

- The national government should coordinate the overall water supply and sewage systems and establish a system to provide recovery support in a push-type manner.
- Securing support bases by turning treatment plants and other facilities into disaster prevention bases
- Establishing an early recovery flow for integrated water supply and sewage systems that prioritizes ensuring functionality
- Technological development of inspection and survey techniques and recovery methods
- Efficient disaster response using DX
- Early identification of damage and response status for in-house piping and sewage overflow, etc., and establishment of rapid recovery methods and systems, etc.

5. Conclusion

The 2024 Noto Peninsula Earthquake has reminded us of the importance and public necessity of having access to water. We are committed to collaborating on the implementation of the recommendations outlined in the final report of the Study Committee on Countermeasures in Water Supply and Sewerage Systems against Earthquake, with the aim of building a disaster-resistant and sustainable water supply and sewerage system.

4 Floods in the Northeastern Region of Libya

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1. Summary

In early September 2023, Storm Daniel, named by the Hellenic National Meteorological Service, formed and traveled from Greece to Libya (Figure 1), exhibiting the characteristics of a Mediterranean hurricane, or "Medicane." The storm also displayed features typical of both tropical cyclones and mid-latitude storms.

The storm reached its peak in northeastern Libya, impacting approximately 1.5 million people—about 22% of the country's population. On September 10, Libya's National Meteorological Centre reported wind speeds of 70-80 km/h. In addition, torrential rainfall ranging from 150 to 240 mm triggered flash floods in multiple cities. The storm initially struck Benghazi before progressing eastward towards the Green Mountain region.

Significant damage occurred across the region, including to road networks and telecommunications, particularly in cities like Derna, Al Bayda, and Al Mkheley. Derna was one of the worst-affected areas, where heavy rainfall overwhelmed two dams in the city's wadi. The dams collapsed under the immense pressure, releasing millions of cubic meters of water. This unleashed floods and destructive mudslides, sweeping away buildings and the people inside them. The catastrophe resulted in 5,923 deaths, with approximately 250,000 people affected and 45,000 displaced. Economic losses from the disaster were estimated at around US$1.7 billion, which is approximately 3.6% of Libya's GDP for 2022.

It is clear that multiple factors contributed to the humanitarian disaster caused by Storm Daniel in Libya. While climate change played a role in intensifying the storm, human factors, including poor infrastructure and preparedness, significantly worsened the disaster, leading to the widespread loss of life, property, and essential infrastructure.

2. Introduction

The Mediterranean region is vulnerable to numerous natural hazards, including earthquakes, volcanic eruptions, floods, fires, and droughts. In recent years, these challenges have been compounded by the impacts of global climate change. According to global climate scenarios, the Mediterranean has been identified as one of the regions most sensitive to climate change (UNEP/MAP, 2020).

The southern Mediterranean, in particular, is a climate change hotspot, warming 20% faster than the global average (IPCC, 2023). Floods, especially flash floods, are among the most common and dangerous natural disasters. Year after year, floods are becoming more frequent and destructive, causing severe damage to infrastructure and loss of life. These events have historically posed a threat to human societies, particularly in agricultural communities, which have faced the loss of crops, livestock, and homes due to torrential flooding (Sellami E., Rhianne H., 2024).

Between 80% and 90% of all documented natural disasters in recent years have been linked to floods, droughts, tropical cyclones, heat waves, and severe storms. Floods are the most frequent type of natural disaster, and their intensity is expected to increase as climate change drives more frequent and intense heavy rainfall.

Flash floods in arid regions are particularly hazardous due to their sudden onset and rapid intensity, often resulting in loss of life, property damage, and disruption to local ecosystems (Khorchani, N., 2023). Libya is one of the most exposed countries to natural hazards, particularly floods (IFRC, 2023) (Figure 1). Rising temperatures, the increasing severity of extreme weather events, declining rainfall, and rising sea levels present significant risks to coastal population centers, where approximately 70% of the country's population resides (IFRC, 2023).

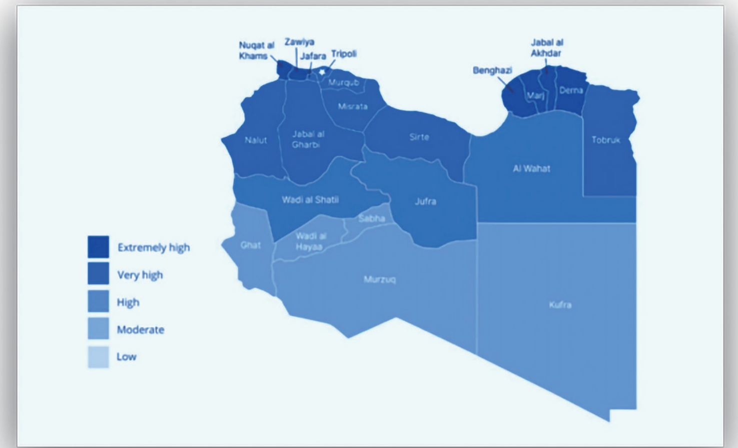

Figure 1: Map of flood risk in Libya (source: CLACL-UNICEF)

3. History of flooding in Libya

The Mediterranean region is experiencing an increase in storm activity, which is now affecting densely populated coastal urban areas that historically have not been prone to catastrophic flooding.

Flooding in Libya is rare due to its arid desert climate, which is characterized by minimal annual rainfall. However, there have been instances of flooding, particularly in coastal areas and dry wadi beds (Oduoye M. et al., 2024).

Some major floods that have occurred in Libya include:

- In 1967, massive floods struck the city of Benghazi, leading to the deaths of more than 100 people [4]. Similarly, in 1988, heavy rainfall caused flooding in eastern Libya, damaging infrastructure and displacing thousands of residents.
- In September 2004, severe flooding in the Kufra oasis, located in southeastern Libya, was triggered by increased rainfall, leading to disastrous consequences. A similar event occurred in 2009, displacing a significant number of people and causing extensive damage to infrastructure and residential buildings.
- In the capital city, Tripoli, and surrounding areas, heavy rains in October 2018 led to widespread flooding. A similar event was recorded in May and June of the same year.
- In July 2019, the Ghat district experienced severe floods due to heavy rains from July 3-7, affecting more than 20,000 people and displacing around 2,500 individuals. Tragically, four people, including three children, lost their lives, and about 30 others were injured.
- In June 2019, floods devastated southern Libya, damaging roads, farmland, and essential infrastructure, which suffered irreparable damage.
- On November 6, 2020, torrential rains and extreme flooding hit Al-Bayda, Libya, displacing thousands of people. Floodwaters made commuting impossible, left thousands without electricity, and caused significant damage to properties.

Notably, Derna has experienced a series of floods originating from the Wadi Derna. Over the past century, the wadi has been struck by five violent and destructive floods (Figure 2), with the most recent being Storm Daniel in 2023.

Figure 2: Images of past floods in Derna city (Source: Facebook, Libya weather)

Derna's history of flooding includes a devastating event in 1941, during World War II, where some accounts describe floodwaters sweeping away German tanks, troop carriers, and military equipment near the Wadi al-Naqa stream at the city's western entrance.

In early October 1959, the country faced severe weather disturbances, leading to heavy rainfall that caused the Wadi Derna to flood. The flooding displaced massive amounts of land, and a large pile of rocks blocked the wadi, causing water to overflow and sweep through the city, destroying many homes. Rainfall measured 300 mm in just 48 hours at the Derna meteorological station. This flood is considered one of the most severe in Derna's history during the last century.

Due to the city's vulnerability to frequent flooding, studies conducted in the 1960s recommended the construction of dams to protect Derna and provide agricultural irrigation and water supply. As a result, two embankment dams were built along the wadi during the 1970s (Figure 3). The construction spanned four years, from 1973 to 1977.

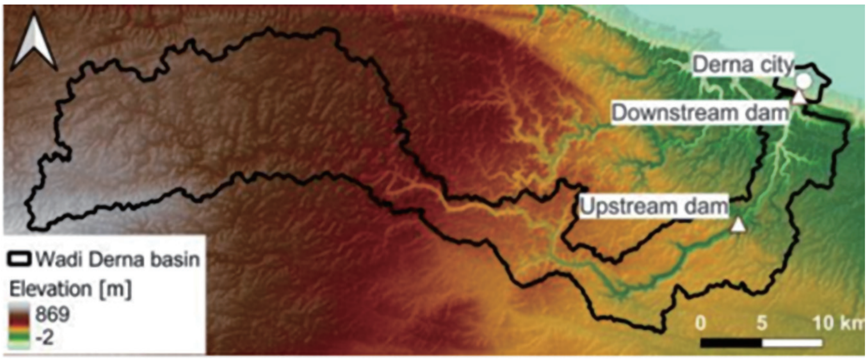

Figure 3: Location of Derna city dams (source: google.com)

The upper dam, named Al-Bilad Dam, had a storage capacity of 1.5 million cubic meters of water, while the lower dam, known as Abu Mansour Dam, had a significantly larger capacity of 22.5 million cubic meters. The Abu Mansour Dam is located approximately 13 kilometers south of the Al-Bilad Dam (Figure 1). Both dams were constructed with a core of compacted clay, encased in a layer of stone. The construction of these dams successfully resolved the city's long-standing flooding problems (Ashoor, 2022).

4. Floods of 2023

In early September 2023, a series of extreme rainstorms caused devastating flooding in parts of Greece, Bulgaria, and Turkey before crossing the Mediterranean Sea and making landfall in northern Libya (Figure 4). Storm Daniel persisted for eight days, spending six days over the Mediterranean before reaching Libya's northeast coast. After causing significant destruction, the storm finally dissipated over Egypt (Hewson T. et al., 2024).

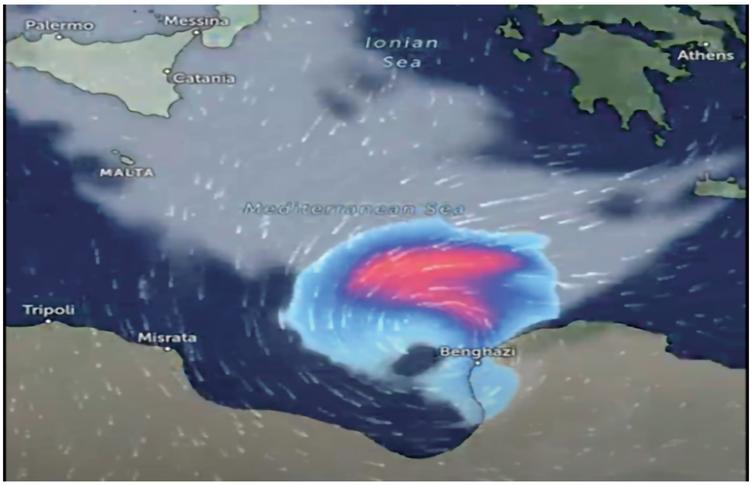

Figure 4: Mediterranean Storm Daniel unleashed its fury upon Libya (Source: bne IntelliNews)

These events were related to the development of a surface cyclone on the night of September 4. Storm Daniel initially formed over the Ionian Sea in Greece and intensified as it moved southward across the eastern Mediterranean. The storm's strength was amplified by the unusually warm waters, a result of the extreme summer heat in southern Europe that year (Hewson T. et al., 2024).

In the following days, the storm slowly drifted across the Mediterranean before taking an east-southeastward path toward northern Libya, where it evolved into a "medicane" (Mediterranean hurricane) (Figure 5).

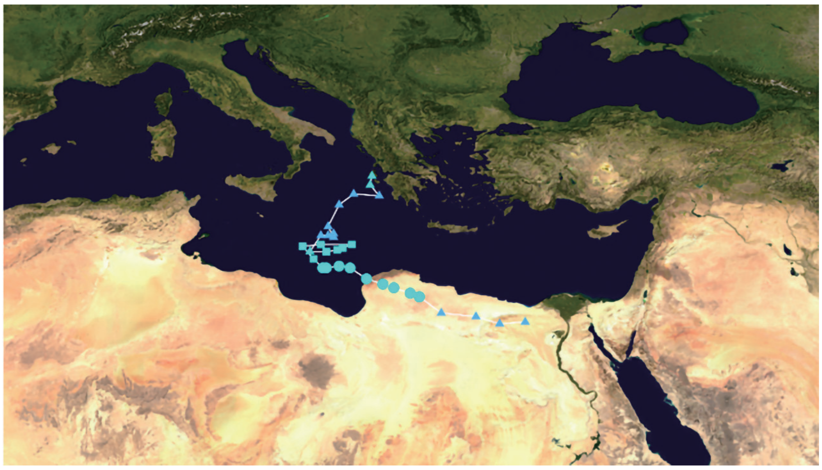

Figure 5: T rack of map of Storm Daniel in Mediterranean Sea (Source: Media Viewer)

Landfall occurred near Benghazi early on September 9, in the city of Toukra, before the storm moved eastward toward cities in the Green Mountain region, including Shahat, Marj, Al-Bayda, Susa, and Derna. Soon after, winds increased, and heavy rain began to fall. By the afternoon, it was evident that the rain was far beyond normal levels (Rogerson M. et al., 2023).

Remarkably, the storm intensified further over land, bringing intense rainfall and high winds of up to 120 kilometers per hour. In the Green Mountain region, 25 hours of continuous rain resulted in precipitation levels reaching 240 mm, with Al-Bayda recording up to 414 mm. Al-Bayda, a coastal city, received 80% of its annual rainfall before midnight, according to local weather station data (Mike Rogerson M., et al., 2023).

The precipitation observed during the storm was nearly equivalent to the annual average rainfall for this region, which is typically around 270 mm (Normand J.C.L., Heggy E., 2024). On the night of September 10–11, rainwater flowed into the Wadi Derna catchment area, leading to catastrophic flooding in the city of Derna. While Derna was notably affected, other coastal cities also suffered significant damage, with 28% of the houses in Susah destroyed.

In addition, cities like Al-Bayda, Al-Marj, Shahat, Taknis, Battah, Tolmeita, Bersis, Tokra, and Al-Abyar also experienced severe damage. The storm destroyed or severely damaged 18,838 houses across the coastal region, which includes Benghazi, Jabal Al Akhdar, Al-Marj, and Derna (Figure 6). The floods caused the deaths of 4,352 people, left over 8,000 missing, and displaced 43,400 individuals (see Table 1).

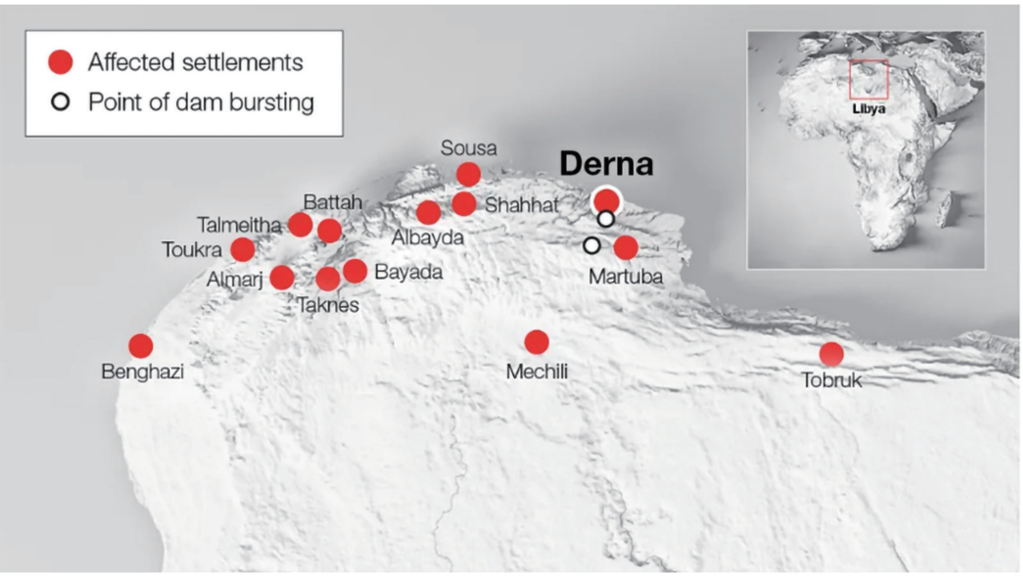

Figure 6: Areas Affected by storm Daniel in northeast Libya (Source: redcross.org.uk)

Table 1: Number of displacement individuals in affected areas in Northeast Libya

The city	Number of displacement individuals
Benghazi	2,195
Almarj	1,500
Takness	1,095
Albayyada	785
Wardeah	200
Albayda	3,000
Soussa	350
Labraq	600
Almkheley	1000
Total	10,950

It is estimated that approximately 250,000 people will require humanitarian assistance, making Storm Daniel the deadliest storm in Africa since 1900 (Henson B., Masters J., 2023).

The storm caused significant damage to infrastructure, including the destruction of road networks and the disruption of telecommunications in several cities, such as Derna, Al-Bayda, and Al-Mkheley (Figure 7) (IMO, 2023).

Figure 7: General view of flood water covering area in Almkheley town (Source: Libya Al-Hadath / Teuters)

5. The Derna Catastrophe

5.1 General information on Derna

Derna, a coastal city in northeastern Libya (Figure 8), is located in the Jabal al-Akhdar mountain range (Green Mountains). It serves as the administrative center of the Derna district and is home to approximately 120,000 residents. The city covers an area of 31,511 square kilometers.

Figure 8: Map showing the location of Derna in Libya.

The topography of Derna is divided into six main regions due to its mountainous landscape, with variations in elevation and numerous valleys. The higher areas consist of four regions adjacent to the Green Mountain, while the lower areas, known as the Balad region, are divided into eastern and western banks by the Wadi Derna. This division has guided much of the city's new urban expansion towards the sea (Agfir.N., Sassi.E., 2024).

A series of bridges crosses the Wadi, linking the port area to the western part of the city. Wadi Derna, a semi-arid valley, extends 75 km from the Jebel Akhdar Mountains to Derna's port. It receives water from approximately seven large tributaries and drains a basin covering 575 square kilometers, with an average width of about 8 km.

Figure 9: Map of Wadi Derna basin (source: Environmental Earth Sciences)

The stream in Wadi Derna is typically dry, except during periods of heavy rainfall. The topographic and climatic conditions that define semi-arid basins are characterized by diverse land cover, including trees, cultivated crops, bare soils, rangelands, and built areas. Within the Derna Basin, these features vary widely across the landscape. Additionally, there are several urban centers located within the surface area of the basin (Ashor, 2020).

5.2 Derna Floods

On September 10, the city of Derna experienced catastrophic and unprecedented flooding. By the night of September 11, heavy rains and strong winds hit areas south of the city, where the dams were located. The rainfall exceeded the annual average of 200 mm in just 10 to 24 hours—roughly double the usual amount, overwhelming the dams' capacity (UNOSAT, 2023).

Initially, the Bou Mansour Dam breached around 3 a.m. on September 11. The floodwaters then traveled 12 kilometers downstream to the Bilad Dam, which also collapsed. As a result, floodwaters surged to a height of three meters, submerging entire neighborhoods. Experts estimated that 30 million cubic meters of water rushed down from the Derna Mountains, sweeping away people, vehicles, and debris into the sea (Figures 10, 11 & 12).

Figure 10: Flood Intensity in the City of Derna (source Washington Post)

Figure 11: The combination of satellite photos was taken before and after the flooding in Derna (source: Plant labs PBC)

Figure 12: Devasting in Derna (Source: Agence France Press)

The ensuing heavy floods caused widespread damage to infrastructure, homes, and livelihoods. Entire neighborhoods were submerged, and a substantial portion of the city's buildings and urban infrastructure was destroyed. Roads connecting the eastern and western sides of Derna were damaged, and telecommunications networks and bridges were disrupted. The flood left behind 8.8 million tons of debris (IMO, 2023).

For example, 10% of the houses were destroyed, and 18.5% were damaged (Normand J.C.L., Heggy E., 2024) (Figure 13).

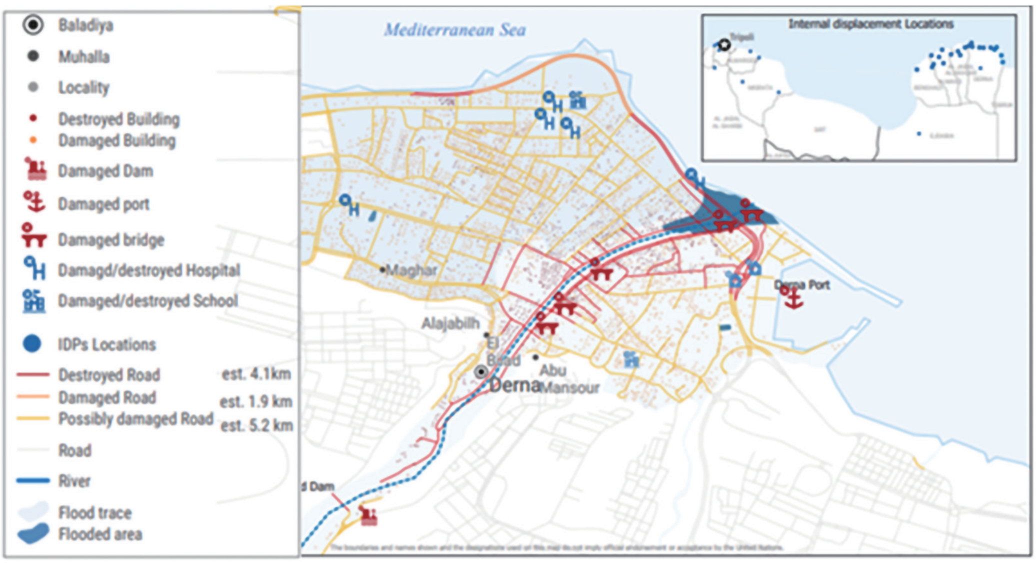

Figure 13: Building Exposed to Rushing Floodwater (source: Libyan Flash Appeal Extension-romena-Libya-Fac

A report issued by the United Nations Office for the Coordination of Humanitarian Affairs on March 20, 2024, estimated that the death toll from the flooding had reached 5,923 people. Additionally, approximately 250,000 people were affected, and 45,000 were displaced.

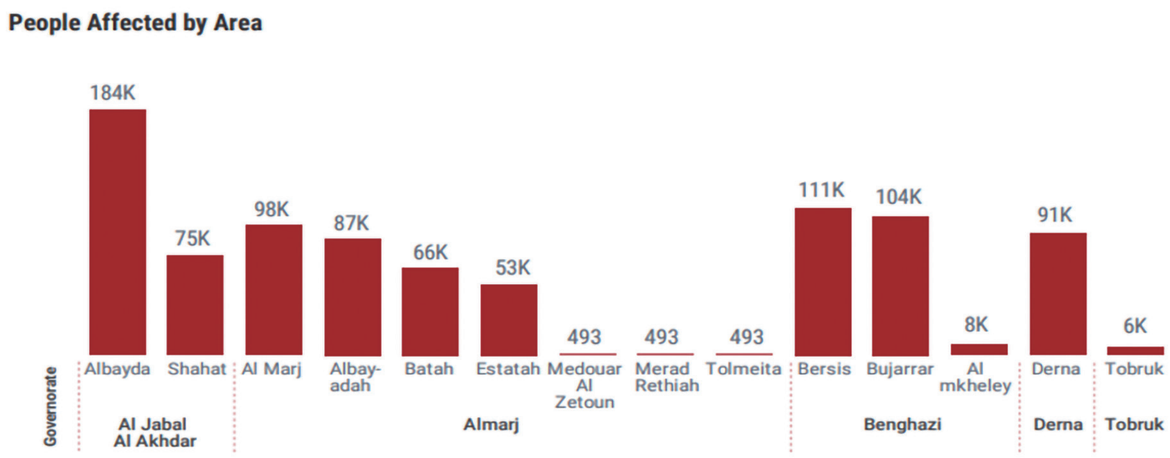

Figure 14: People affected by area (source: OCHA)

6. Impact of northeast flood

The flood impacted a coastal zone stretching 210 kilometers long and 50 kilometers wide, between Benghazi and Derna, along Libya's 1,970-kilometer coastline. The municipalities of Al Bayda, Benghazi, Derna, Shahaat, and Soussa were the hardest hit, collectively accounting for 85% of the damages and losses (World Bank, 2023).

The long-term consequences for Libya are severe, with significant economic costs. The World Bank estimates that flood repairs will cost US$1.8 billion, including damage to crops across 16,209 hectares and the loss of 74,363 livestock, which is 3.2% of the region's strategic reserve. The total estimated damages and losses from the storm are US$1.65 billion, or approximately 3.6% of Libya's 2022 GDP (World Bank, 2023).

Table 2: Show the cost damage and losses by sectors)

Sector	Damage	loss
Housing	US$ 361.8 million	US$ 65.8 million
Education	US$ 30.1 million	US$ 28.7 million
Health	US$ 28.3 million	US$ 68.6 million
Cultural Heritage	US$ 108.7 million	US$ 64.5 million
Agriculture	US$ 22.7 million	US$ 53.4 million
Transport	US$ 140	US$ 21 million
Energy	US$ 34	US$ 40.8 million
Telecommunication	US$ 0.45	US$ 0.02 million
Water and Sanitation and Water Resources	US$ 136.5	US$ 20.5 million
Municipal Service	US$ 11.7	US$ 20.5 million
Governance public Institutions	US$ 1.2	US$ 0.35 million
Environment	US$ 157	US$ 257.5 million

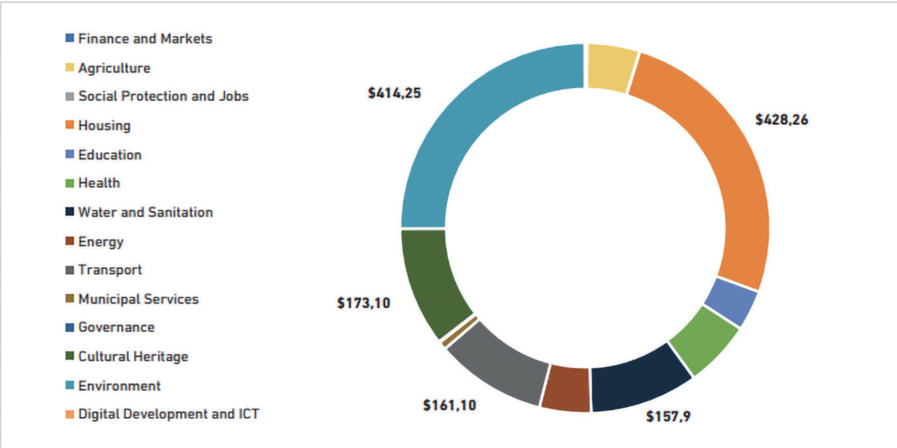

Figure 15: Total Damages and Losses by Sector ($USM) (Source: World Bank Group)

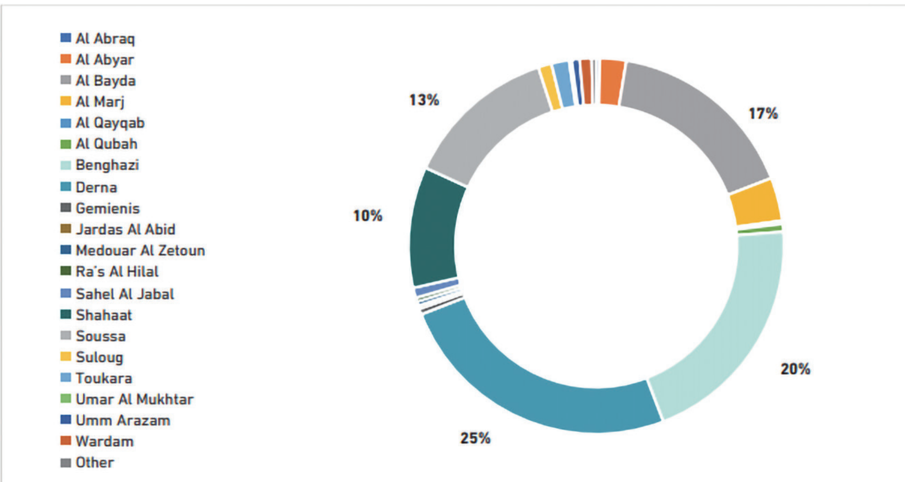

Figure 16: Total Damages and Losses by Municipality ($USM) (Source: World Bank Group)

7. Factors effecting the storm Daniel

It is evident that multiple factors contributed to transforming Storm Daniel into a humanitarian disaster in Libya. It wasn't solely climate change, but a combination of climate and human factors. While climate change intensified the storm, human elements had a greater impact.

In Derna, the devastating effects of the 2023 flood were not only due to rainfall but also political and security divisions, as well as the fragility of Libyan government institutions, which significantly worsened the flood-related destruction.

Libya is already experiencing increasingly severe climate impacts. Rising temperatures will extend heatwaves and intensify dust storms, while precipitation will become less frequent but heavier. As the Mediterranean warms, rising sea levels will threaten low-lying coastal areas.

Environmental degradation in Libya has also played a key role in worsening floods. Deforestation and urbanization have reduced the land's ability to absorb rainfall, increasing surface runoff. Poor land management, including inadequate soil conservation, has worsened soil erosion and sediment buildup in waterways.

A rapid analysis by the World Weather Attribution group compared today's climate, after about 1.2°C of warming, with the past. Their findings indicate that human-caused climate change made heavy rainfall in northeastern Libya up to 50 times more likely than it would have been in a world without climate change.

Since 2014, Libya has faced political and institutional divisions. Two governments—one in Tripoli and one in Benghazi—have split the country, dividing key economic institutions. This prolonged division has weakened governance, eroded the rule of law, and exacerbated the suffering of Libyan citizens. Libyan authorities on both sides of the conflict have done little to address climate resilience. Furthermore, Libya's disaster and climate risk management framework lacks clear institutional roles, creating confusion over mandates and responsibilities.

The flood and storm surge struck a populated coastal area with limited Disaster Risk Management (DRM) arrangements. Few weather stations in the east meant localized flood warnings were insufficient.

In Derna, the lack of proper drainage infrastructure and poor dam maintenance worsened the flooding. The city's increasing urbanization reduced natural drainage areas, allowing rainwater to accumulate instead of infiltrating the ground. Governance failures also contributed to the catastrophic collapse of Derna’s dams, which are over 50 years old and in need of maintenance. A 2003 Swiss report identified major fractures in the dams and recommended building a third dam and repairing the existing ones, but these actions were never taken. Authorities failed to warn of potential dam failures, ignoring risks highlighted by a 2022 report from Omar Al-Mukhtar University. The report urged immediate maintenance of the dams, warning that failure could lead to catastrophic consequences for the city and its residents. Moreover, during the disaster, conflicting instructions from authorities left civilians confused and insufficiently prepared to evacuate.

8. Flood response and national and international mobilization efforts

The Government authorities and humanitarian organizations have jointly launched extensive relief efforts in response to the Libya floods. The international community responded swiftly to the floods in Libya. According to the Office for the Coordination of Humanitarian Affairs, 26 foreign partners contributed to the efforts, with 800 search and rescue personnel from 12 countries assisting Libyan authorities. Civil society efforts, including collaboration between local authorities, UN agencies, and Libyan NGOs, played a key role in the relief efforts.

Several United Nations agencies—UNICEF, UNHCR, WFP, WHO, and IOM—actively provided on-the-ground support. Countries such as Turkey, Egypt, Jordan, Kuwait, the UAE, Qatar, Tunisia, Algeria, Malta, Italy, Spain, and France also participated in aiding trapped survivors (Figures 17 & 18).

Figure 17: Rescue teams look for flash flood victims in the city of Derna, Libya. Source: https://weather.com/news/news/2023-09-13-libya-flooding-derna-latest

Here’s the revised version of the paragraph with the original length maintained:

The United States also provided shipments of humanitarian supplies to Libya through USAID to support the response to the devastating floods that hit the country. The United Kingdom significantly enhanced its life-saving assistance to Libya by earmarking a substantial £1 million aid package. UK-MED, an NGO, was responsible for conducting rapid medical evaluations. In parallel with the U.K.'s efforts, the European Union committed €94.5 million for humanitarian aid, with an additional €5.7 million allocated for emergency assistance. This international support addresses both immediate needs and strengthens Libya's long-term capacity to manage such crises.

Libyan NGOs were also crucial in delivering humanitarian aid to flood victims. Citizens from various regions contributed positively to the relief efforts, sending trucks loaded with essential supplies to the affected areas (Figure 19).

Figure 18: Libyan citizens participate in the relief efforts

9. Lesson learned and recommendation

9.1 Lesson learned

The devastating floods of 2023 highlight how extreme weather events, fueled by climate change, combine with human factors to create even greater impacts, leaving more people, property, and infrastructure at risk. The disaster in Derna exposed significant weaknesses in state institutions, both in terms of disaster preparedness and crisis management. Conflicting messages to residents in areas at risk of flooding led to confusion and uncertainty about what actions to take. The floods further revealed the inability of Libyan institutions to effectively respond to major natural disasters, including organizing rescue operations and delivering humanitarian aid in a coordinated and timely manner.

9.2 Recommendations

The Libyan government must clearly define the roles and responsibilities of relevant authorities concerning environmental disaster management. This should include the installation of early warning systems in various parts of the country, particularly in disaster-prone areas, along with disaster preparedness plans to anticipate and respond to extreme weather events.

Developing robust floodplain management strategies to prevent encroachment on flood-prone areas is crucial to enhance resilience and mitigate future risks. Additionally, raising awareness among local communities about flood risks will enable them to respond quickly to instructions in the event of an actual or anticipated disaster.

10. Conclusions

The consequences of the Derna flood have exposed the depth of Libya's governance crisis. Alongside historical and structural challenges, the ongoing armed conflict and political divisions since 2011 have significantly weakened the state's ability to respond to disasters. Addressing Libya's environmental challenges requires a comprehensive approach, which includes rebuilding effective state institutions and resolving the country's political, security, and economic issues. Only through such efforts can Libya improve its capacity to manage future crises.

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5 Floods and Droughts in Myanmar from 2008 to 2024: How Climate Change and Management Gaps Amplify Loss and Damage

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ABSTRACT

From 2008 to 2024, Myanmar has faced a series of intense floods and droughts, with Cyclone Nargis in 2008 and Cyclone Mocha in 2023 marking two of the most devastating events. In addition to these floods, the country has endured severe droughts in 2010, 2016, and 2019, resulting in water shortages, agricultural losses, and heightened community vulnerability. The effects of climate change—such as increased cyclone intensity, irregular rainfall patterns, and prolonged dry seasons—exacerbate these disasters, leading to heightened socio-economic impacts. Alongside these environmental factors, gaps in Myanmar's flood and drought management—characterized by inadequate infrastructure, limited preparedness, insufficient budget and policy integration—further amplify the losses and damages. The combined result is widespread displacement, considerable agricultural losses, infrastructure damage, serious impact on livelihood, and long-term health risks in vulnerable communities. This paper explores how climate change, reflected in increasingly erratic weather patterns, amplifies the impact of these natural disasters, while weaknesses in water-related disaster management—such as inadequate infrastructure, insufficient community preparedness, and fragmented policy integration—further compound the damage. Addressing these challenges demands a paradigm shift in leadership, with a commitment to secure dedicated budgets for disaster preparedness and climate resilience initiatives with advanced technology, infrastructure development, community empowerment, and increased financial mechanism. Furthermore, comprehensive institutional reform is essential to foster effective coordination and strengthen disaster response capacity across sectors. By advancing climate-adaptive policies, ensuring strong leadership, and embedding community-centered management approaches, Myanmar can enhance its resilience and mitigate the escalating socioeconomic impacts of floods and droughts.

1. Introduction

The Republic of the Union of Myanmar is between latitudes 09°32´N and 28°31´N and longitudes 92°10´E and 101°11´E. The country shares its border with India, Bangladesh, China, Laos and Thailand. It has the largest landmass of the mainland Southeast Asian countries, with a land area of 676,552 sq.km (See Figure 1). Myanmar, situated in the Northwest Southeast Asia, is particularly vulnerable to extreme weather events that have become increasingly frequent and severe due to climate change. Since 2008, a series of devastating cyclones—including Cyclone Nargis, which claimed over 138,000 lives—has demonstrated the catastrophic impact that these events can have on communities, infrastructure, and the nation's economy. Since then Myanmar authorities and people are more aware of the water-related disasters and their impacts. The government, local NGOs, international NGOs, Universities, and few private sector entities have tried to improve the disaster preparedness, technological capability, multistakeholders participation, financial support as well as better policy recommendations. The emphasis has been shifted to before, during and after the water-related disasters, instead of traditional approaches that placed more attention on during disaster period only. The activities like information sharing, hydrological prediction, hydraulic modeling, capacity development in climate modeling, database development, integrated water resources management, integrated flood management, and multistakeholders engagement began to mobilize in the arenas of government departments, technical universities, NGOs and INGOs. Unfortunately, Myanmar's limited resources, the government's approach during that particular disaster event, and underdeveloped disaster management systems have left it inadequately prepared or even blocking the disaster management cycle (See Figure 2), to handle the onslaught of climate-induced disasters. As climate change accelerates, Myanmar faces compounding challenges from both increasingly intense storms and inadequate flood and drought management strategies. This combination amplifies the scale of loss and damage experienced by local communities, further affecting livelihoods, health, and food security. The country's recent history with cyclones like Giri (2010), Komen (2015), Mocha (2023), and typhoon Yargi (2024) exemplifies how these dual factors—climate change and weak management—continue to disrupt lives and strain the nation's ability to recover and build resilience. The major water-related disasters that have impacted Myanmar from 2008 to 2024 are listed below in the section 2.

This paper explores the interplay between climate change and the deficiencies in Myanmar's flood and drought management, examining how this convergence amplifies the country's vulnerability. By understanding the full scope of these challenges, extracting an important insight, we can identify solutions that enhance resilience and reduce the human and economic toll of these recurring disasters. Hence, few possible solutions are also suggested here.

2. A brief overview of Myanmar's Vulnerability to Floods and Droughts

Myanmar is highly vulnerable to floods and droughts due to its geographical location, climate variability, socioeconomic conditions, and political instability. The country experiences a monsoon climate, which brings heavy rains and seasonal flooding, particularly in low-lying regions and along major rivers like the Ayeyarwady. Coastal areas are also at risk from cyclones and storm surges, which can lead to severe flooding (See Figure 3).

Droughts, though less frequent, are particularly challenging for Myanmar's agricultural sector, affecting food security and livelihoods in rural communities. Climate change is intensifying these risks, leading to more unpredictable weather patterns and extreme events. Limited infrastructure, gaps in disaster preparedness, and socioeconomic factors further increase Myanmar's susceptibility to loss and damage from both floods and droughts.

This vulnerability underlines the need for resilient water management strategies, early warning systems, and sustainable development efforts to help communities adapt to the impacts of climate change. For that reason, the governments of (2011-2016) and (2016-2021) put much efforts to reform the Myanmar's Water Sector with the help of the World Bank, ADB, Governments of Australia, Germany, India, Japan, Norway, Sweden, The Netherlands, and few others especially in the areas of integrated water resources governance and management, integrated flood management, water sector institutional reforms and water legislation (See Figures 4, 5 and 6). The Myanmar Water Framework Directive and Myanmar National Water Policy were completed and recognized by the National Water Resources Committee and respective governments. The Myanmar National Water Law (the mother law) has been drafted and plans for the further details regarding the States and Divisional Laws to proceed. The sudden political change halted the drafting of the water legislation at the State and Divisional level. Current political situation in Myanmar is very fluid and unpredictable, however, one thing for sure is that the existing water policy and water law have to be revised in the light of future scenario in Myanmar. The

Water Think Tank is very much aware of that fact and currently collecting data and publications relevant to new scenario in order to craft the new water governance structure as well as new water legislation which will be suitable for the new era. All those efforts are community-based and people-centered approaches.

3. A list of Major Cyclones that have impacted Myanmar from 2008 to 2024

The following list presents the ten major cyclones and typhoon, each of these events contributed to ongoing challenges in Myanmar related to flood and storm management, underscoring the country's vulnerability to climate change and extreme weather.

1. **Cyclone Nargis** (2008) – The most devastating cyclone in Myanmar's history, causing over 138,000 deaths and widespread destruction, particularly in the Ayeyarwady Delta.

2. **Cyclone Giri** (2010) – A severe tropical cyclone that hit Rakhine State, causing extensive damage to homes, farmland, and infrastructure, displacing around 70,000 people.

3. **Cyclone Mahasen** (2013) – While it weakened before landfall, it still affected Rakhine State, where thousands of internally displaced people were living, leading to significant displacement and damage.

4. **Cyclone Komen** (2015) – Although it did not make direct landfall in Myanmar, Komen caused severe flooding across the country, affecting over 1 million people and leading to significant crop and property damage.

5. **Cyclone Mora** (2017) – Made landfall in neighboring Bangladesh but caused extensive damage in Myanmar’s Rakhine State, impacting vulnerable communities and refugee camps.

6. **Cyclone Titli** (2018) – A powerful cyclone that passed near the Myanmar coast, bringing heavy rains and localized flooding, particularly in the southern areas.

7. **Cyclone Fani** (2019) – Though it primarily impacted India and Bangladesh, Myanmar experienced heavy rains and coastal flooding, which affected communities near the border.

8. **Cyclone Amphan** (2020) – One of the most powerful cyclones in the region in recent years, Amphan led to storms and coastal flooding in Myanmar’s Ayeyarwady Region, though it made landfall in Bangladesh.

9. **Cyclone Yaas** (2021) – Although Yaas made landfall in India, it caused heavy rains, localized flooding, and evacuations in coastal areas of Myanmar, including Rakhine State.

10. **Cyclone Mocha** (2023) – The most recent severe cyclone that affected Myanmar, making landfall in Rakhine State with extreme winds and rain, leading to significant displacement, destruction of infrastructure, and substantial humanitarian needs.

11. **Typhoon Yagi** (2024) - Typhoon Yagi struck Southeast Asia in early September 2024. Heavy rains from Typhoon Yagi’s remnants caused severe flooding across Myanmar, impacting 59 townships in 9 regions. Areas affected included Nay Pyi Taw, Bago, Kayah, Kayin, Magway, Mandalay, Mon, and parts of Shan State (See Figure: 8). Widespread damage to homes and infrastructure resulted. While data verification

is challenging, estimated 631,000 people might have been affected by flooding across the country. Multiple sources indicate that hundreds of people have died, with many more missing.

4. Cyclone Events and Their Amplified Impact on Myanmar

Myanmar's vulnerability to cyclones has been repeatedly demonstrated over the past two decades, as powerful storms have struck with increasing intensity, causing severe losses and exposing gaps in the nation's disaster management systems. Beginning with Cyclone Nargis in 2008, which claimed over 138,000 lives and displaced hundreds of thousands, Myanmar has faced relentless challenges in both immediate disaster response and long-term recovery. Nargis remains one of the deadliest cyclones in the country's history, underscoring how unprepared infrastructure and inadequate management strategies can exacerbate the devastation of such events.

Following Nargis, Myanmar continued to experience destructive cyclones, including **Cyclone Giri** in 2010 and **Cyclone Komen** in 2015. Cyclone Giri struck Rakhine State with heavy rains and high winds, displacing around 70,000 people and destroying farmlands and homes. Cyclone Komen, while not directly making landfall, caused severe flooding across the country, affecting over a million people and resulting in significant economic loss. These storms demonstrated that even indirect impacts of tropical cyclones can have long-lasting repercussions on communities and the economy, particularly when there is limited preparedness and response capacity.

More recently, **Cyclone Mocha** in 2023 made landfall in Rakhine State, bringing devastating winds and rainfall that displaced tens of thousands, damaged essential infrastructure, and severely impacted vulnerable populations. Mocha's destruction highlighted ongoing deficiencies in Myanmar's management systems, from evacuation protocols to resilient building standards. The cyclone also emphasized the need for community-centered disaster risk reduction and better communication systems to warn residents in advance. Moreover, Typhoon Yagi hits Myanmar in Sept 2024, which was originated in the western Pacific Ocean, forming over warm tropical waters. It developed as a tropical depression and gained strength as it moved westward across the Pacific, eventually reaching typhoon status. Yagi made its way toward Southeast Asia, bringing heavy rainfall and strong winds to countries like the Philippines and later impacting parts of Vietnam, China, and Myanmar, where its remnants caused severe flooding.

Each of these cyclones or Typhoon has left an enduring mark on Myanmar, illustrating how climate-driven storms expose and amplify the weaknesses in flood and drought management. Without proactive planning and investment in climate-resilient infrastructure, and water education, these storms will continue to set back national progress, destabilize local economies, and threaten the lives and livelihoods of millions of people.

5. Details about the Cyclone Mocha in 2023 with its implications (Source: UN OCHA)

Cyclone Mocha, which struck Myanmar in May 2023, had a significant impact on the country, affecting over 600,000 people and resulting in approximately 48 reported fatalities. The cyclone made landfall near Sittwe, Rakhine State, with winds reaching up to 215 km/h (135 mph). This extreme weather event caused widespread destruction, including damage to infrastructure and homes, and severely disrupted essential services such as healthcare and water supply.

The NASA published on 14 May 2023 as the following. As Cyclone Mocha approached Myanmar on May 14, 2023, winds roared as fast as 175 miles (280 kilometers) per hour, enough to make it a category 5 storm (See

Figure 7). Although the storm weakened slightly during the final hours of its approach, Mocha still brought dangerous winds, downpours, and storm surge when it made landfall just north of Sittwe, Myanmar.

Early reports suggest the storm caused widespread damage in Sittwe, the state capital of Rakhine, with local news sources reporting flooded streets, downed trees and power lines, and roofs torn from homes. The evacuation of hundreds of thousands of people from vulnerable areas in both Bangladesh and Myanmar in advance of the storm may have helped limit casualties, according to some news reports. The worst of the storm surge also missed low-lying refugee camps in Cox’s Bazar that many observers feared were vulnerable.

However, aid groups also report that telecommunication interruptions have made it difficult to assess the full impact of the storm. “Early reports suggest the damage is extensive and needs among already vulnerable communities, particularly displaced people, will be high,” the United Nations Office for the Coordination of Humanitarian Affairs noted in an update on May 14.

In the aftermath, the United Nations and various humanitarian organizations mobilized to provide emergency assistance. Evacuations were carried out, with over 78,000 individuals displaced from high-risk areas prior to the storm's arrival. Unfortunately, many communities faced challenges related to access to healthcare and clean water, increasing the risk of waterborne diseases.

5.1. High Lights

- The humanitarian access situation in cyclone-hit Rakhine state has deteriorated with existing travel authorizations (TAs) for humanitarian organizations suspended this week pending new, centralized discussions in Nay Pyi Taw.
- Initial approval for humanitarian distribution and transportation plans for cyclone-affected townships in Rakhine have also been rescinded pending further Nay Pyi Taw-level deliberations. Similar plans in Chin are also pending.
- Some requests for the replenishment of relief supplies from outside the country have been approved, but with significant conditions. Others remain pending.
- The suspension of access in Rakhine brings a stop to activities that have been reaching hundreds of thousands of people.
- To date, more than 110,000 affected people have received shelter and other essential relief items.
- Food assistance had reached almost 300,000 affected people in Rakhine state alone.
- In Rakhine, partners were distributing seeds and organic fertilizers to provide families with food to eat and sell. Further scaled-up distributions of agricultural inputs are critical to combating food insecurity in affected areas over the months ahead and are now also on pause.
- Humanitarians have also been prioritizing the wellbeing of children in the response, including through the establishment of hundreds of mobile and temporary child-friendly spaces, and the distribution of critical child safety messaging to nearly 28,000 people across Rakhine and the Northwest.
- The suspension of activities in Rakhine could not have come at worse time with the monsoon arriving. An urgent scale-up of the response is needed, expanding activities that had already been underway in the impact zone and adding to assistance being distributed by a range of local authorities and civil society organizations in different areas.

5.2. Aftermath situation overview *(Source: UN OCHA)*

The monsoon season has arrived in Myanmar, further worsening the living situation facing people whose homes were damaged or destroyed by Cyclone Mocha in mid-May. Heavy rains and some flooding were observed in areas that were already heavily impacted, further hampering the recovery process for people whose coping capacities are already stretched to the limit.

Against this backdrop, access restrictions have escalated. Existing Travel Authorization (TAs) that had been facilitating assistance delivery in Rakhine have been suspended pending centralized discussions in Nay Pyi Taw through the Disaster Management Committee. Using these existing approvals, humanitarians had been reaching a growing number of people in need. More than 113,200 people in the affected areas have received shelter and other relief items, while food assistance has reached more than 293,800 people in Rakhine alone. In addition, humanitarians have been working to ensure cyclone-affected children are looked after with the establishment of 240 mobile and temporary child-friendly spaces in Rakhine and the Northwest. These spaces provide safe environments for children to engage in recreational activities and receive vital psychosocial support after the trauma and disruption they have experienced. Approximately 28,000 people in Rakhine and the Northwest have also received important child safety messages.

Humanitarians had been hoping to scale-up their operations in the coming weeks, but this centralized decision on TAs now puts that on hold. Initial approval for humanitarian distribution and transport plans across 11 townships have also been rescinded pending additional deliberations in Nay Pyi Taw. Similar plans for Chin are also not yet approved.

Some import requests have been approved with conditions. Others remain pending. Flexible imports are critical for the replenishment of supplies. Scaled-up financial support is also urgently required to facilitate the timely procurement of vital supplies.

5.3. The Losses and Damages caused by Cyclone Mocha (Source: UN OCHA)

5.3.1. Human Impact

- Displacement: Over 600,000 people were affected by the cyclone, with many displaced from their homes due to flooding and destruction. Thousands sought refuge in temporary shelters, particularly in Rakhine State and neighboring regions.
- Casualties: At least 48 deaths were reported, primarily due to drowning, injuries from falling debris, and other storm-related incidents. Many communities struggled to access healthcare and emergency services in the aftermath.

5.3.2. Infrastructure Damage

- Housing: An estimated 100,000 homes were either damaged or destroyed, leaving many families homeless. This destruction exacerbated the vulnerability of communities already facing challenges due to previous conflicts and humanitarian crises.
- Public Infrastructure: The cyclone caused significant damage to roads, bridges, and public buildings, disrupting transportation networks and access to essential services. Some rural areas became completely cut off, complicating relief efforts.

- Schools and Hospitals: Numerous schools and healthcare facilities were damaged, impacting education and healthcare access for affected populations. This raised concerns about the long-term implications for children's education and community health.

5.3.3. Economic Losses

- Agriculture: The cyclone severely affected agricultural lands, damaging crops, livestock, and fisheries. Initial assessments indicated that large areas of paddy fields and other crops were inundated, threatening food security in the region. Farmers faced not only the immediate losses from the storm but also long-term challenges in recovering their livelihoods.

- Livelihoods: Many communities that relied on fishing and small-scale agriculture faced significant setbacks due to the destruction of boats, fishing gear, and farmland. The loss of income sources placed additional stress on already vulnerable households.

5.3.4. Environmental Impact

- Ecosystem Damage: The cyclone caused soil erosion, sedimentation, and loss of coastal vegetation, which are crucial for protecting against future storm surges and flooding. This has implications for local biodiversity and the health of ecosystems that support agriculture and fisheries.

5.3.5. Response and Recovery

- Humanitarian Needs: In the wake of Cyclone Mocha, international humanitarian organizations and local agencies mobilized to provide emergency relief, including food, water, shelter, and medical assistance. However, access to affected areas was often hampered by damaged infrastructure and ongoing conflict in some regions.

- Recovery Challenges: The recovery process faced significant challenges due to the existing political and economic instability in Myanmar. Efforts to rebuild and restore services and infrastructure were complicated by funding limitations and logistical obstacles.

6. Details about the Typhoon Yagi in 2024 with its implications (Source: Local CSO)

- Heavy rains from Typhoon Yagi's remnants have resulted in significant flooding and damage in various parts of Myanmar. The flood impacted 59 townships in nine regions and states, including the state's capital, Nay Pyi Taw, Bago, Kayah, Kayin, Magway, Mandalay, Mon, and eastern and southern Shan (See Figure 9).

- While data verification is challenging, estimated 631,000 people might have been affected by flooding across the country. Multiple sources indicate that hundreds of people have died, with many more missing.

- After the Typhoo had passed, most areas remain submerged, and evacuation and emergency assistance are ongoing. Despite challenges, humanitarian partners have started reporting on the impact and planning for response wherever possible.

- **Casualties and Displacement:** Nearly **900 people have lost their lives** across the region, with Myanmar accounting for a significant number of over 400 deaths which is more than 50%. **Over 235,000 individuals have been displaced** from their homes as floodwaters continue to rise. Landslides in the Mandalay region alone have claimed 230 lives. Flooding has submerged villages and displaced entire communities, including 10,000 IDPs in Demosoe Township and 1,335 people in Shadaw Township.

Typhoon Yagi Situation Overview *(Source: UN OCHA)*

Since 9 September, heavy rains caused by the monsoon season and remnants of Typhoon Yagi have led to severe flooding in multiple states and regions across Myanmar. Central Myanmar is currently the hardest hit, with numerous rivers and creeks flowing down from the hilly Shan State. There has been significant damage to road networks, transportation, telecommunications and electricity in affected areas. Most areas remain flooded, although some townships have started to see receding water levels (See Figure 11).

Massive flooding has affected more than 300,000 people in 10 townships in Mandalay and 6 townships in Magway regions. The number of affected people ranges from 30,000 to 100,000 in each township (Kyaukse, Myitthar, Sintgaing, Tada-U, Wundwin and Yamethin) in Mandalay Region.

In the Mandalay Region, 40,000 acres of agricultural land were submerged, and 26,700 houses, 251 electric poles, 110 schools, 80 state buildings, and several bridges and road sections were damaged and destroyed. At least 30 people reportedly drowned, and more than 80 people remain missing in Yamethin Township.

In Nay Pyi Taw, more than 60,000 people in four townships were affected by flooding (The state-run media). In southern Shan State, 14 townships were affected by heavy rains and flooding. More than 80 per cent of Nyaungshwe Township has been submerged, affecting an estimated 74,000 people, including people displaced by the conflict. Heavy rainfalls and severe runoff hit the hardest in Kalaw, Hsihseng, Lawksawk, Pinlaung, and Shwenyaung townships, damaging homes and other structures. In eastern Shan, more than 18,000 people have been affected in Kengtung and Tachileik townships. In Kayin State, nearly 90,000 people in 5 townships are estimated to have been affected by flooding. Approximately 35,000 people were evacuated to temporary relief camps in Hpa-An Town. On 11 September, flooding and landslides reportedly killed five people and injured three more in Thandaunggyi Township. More than 300 temporary shelters in three IDP camps in Hpapun and Thandaunggyhi townships were destroyed.

7. DROUGHTS

A brief outline of some significant drought events in Myanmar in recent years, along with a few details are as shown below.

7.1. 2009 Drought

- **Regions Affected**: Central Myanmar (primarily the Dry Zone areas including Mandalay, Magway, and Sagaing).
- **Details**: Following Cyclone Nargis in 2008, rainfall levels remained low, leading to severe water shortages in central Myanmar.

7.2. 2010 Drought

- **Regions Affected**: Central Myanmar, especially the Dry Zone.
- **Details**: One of the worst droughts, with temperatures reaching record highs and causing agricultural losses, especially impacting rice production.

7.3. 2015-2016 El Niño-Induced Drought

- **Regions Affected**: Nationwide, with the Dry Zone particularly hard-hit.
- **Details**: An intense El Niño event caused widespread drought, affecting over 3 million people and drying out water sources. The shortage was especially dire in rural and mountainous areas.

7.4. 2018 Drought

- **Regions Affected**: Dry Zone (Mandalay, Magway, and Sagaing regions).
- **Details**: Dry conditions and erratic monsoon rains led to severe drought, impacting thousands of households and livestock. Temporary water distribution was needed in some areas.

7.5. 2019-2020 Drought

- **Regions Affected**: Throughout Myanmar, with notable impacts in the Dry Zone.
- **Details**: A prolonged dry season led to low water levels in reservoirs and significant agricultural losses, particularly in rice and pulses.

7.6. 2023 Drought

- **Regions Affected**: Central and southern Myanmar.
- **Details**: Below-average rainfall during the monsoon season led to drought conditions, especially impacting agriculture, rural communities, and drinking water supplies.

Each drought event has stressed Myanmar's water resources and highlighted the need for improved water management, especially in the Dry Zone areas.

7,7. **Specific Impacts of the Top 3 Droughts (from 2008 to 2023)**

7.7.1. 2015-2016 Drought (El Niño-Induced)

- **Water Scarcity**: Over 3 million people faced severe water shortages. Many water sources in rural and mountainous regions dried up completely.
- **Agriculture**: Crop yields dropped significantly, with rice and other staples heavily impacted. There were also notable losses in livestock due to water shortages.
- **Economic Impact**: The drought affected agricultural productivity nationwide, impacting Myanmar's GDP and food security. The food supply chain was strained, leading to increased food prices.
- **Government Response**: Temporary relief measures included water distribution and awareness programs. However, limitations in infrastructure meant many affected communities received insufficient support.

7.7.2. 2010 Drought

- **Extreme Heat and Water Shortages**: Temperatures soared to record highs, exacerbating the drought. Central Myanmar (Dry Zone) experienced severe water shortages, affecting both drinking water supplies and agriculture.
- **Agriculture**: The drought impacted critical areas like the Dry Zone, where most of Myanmar's staple foods are produced. Rice production suffered, and pulses and oilseeds were also hit hard.
- **Health Impact**: The extreme heat led to increased cases of heat stroke, dehydration, and water-borne diseases as communities turned to alternative water sources.
- **Economic Strain**: The agricultural impact increased costs for essential goods, leading to economic pressure on lower-income households.

7.7.3. 2023 Drought

- **Erratic Rainfall**: Below-average rainfall during the monsoon season led to drought conditions across central and southern Myanmar, compounding existing water scarcity issues.
- **Agriculture and Food Security**: Water shortages particularly affected the agriculture sector, impacting crops like rice and pulses, which are key staples in Myanmar. Reduced crop yields raised concerns over food security.
- **Rural Communities**: Drinking water shortages were widely reported, with some regions relying on limited water distribution efforts.
- **Environmental Impact**: The lack of water reduced biodiversity in affected areas, drying out wetlands and affecting wildlife habitats.

These top droughts have significantly impacted Myanmar's economy, health, and food security, underscoring the need for long-term water resource management, good water governance, conscious leadership, and drought preparedness in the country.

8. Impact of Climate Change on Floods and Droughts in Myanmar

Climate change has intensified the frequency and severity of extreme weather events across the globe, and Myanmar is no exception. The country's geographical location and long coastline make it especially susceptible to tropical cyclones, which have become more destructive as global temperatures rise. The warming of ocean surfaces fuels stronger storms, leading to increased wind speeds, greater rainfall, and, consequently, more severe flooding. Myanmar's dry season has also grown more unpredictable, resulting in prolonged periods of drought that threaten water resources, agriculture, and rural livelihoods.

Shifts in rainfall patterns, driven by climate change, are leading to more erratic monsoon seasons. In Myanmar, the traditional monsoon period has been marked by heavier rains, while dry seasons have become more extended and arid, contributing to both flood and drought risks. This climate variability exacerbates the challenges faced by farmers who rely on stable water availability for crops, as well as by rural communities that depend on predictable weather patterns for food and income stability.

The environmental consequences of these shifting patterns are profound. Flooding events often lead to soil erosion, degrading agricultural lands and compromising the quality of water sources. During droughts, limited water availability affects not only agriculture but also drinking water supplies, creating public health risks and leading to conflicts over scarce resources. In Myanmar's context, these climate-related stresses have intensified losses across sectors, amplifying the human, economic, and environmental costs of both floods and droughts.

By recognizing climate change as a driving force behind these worsening conditions, it becomes clear that Myanmar's resilience hinges on both addressing climate-related risks and adapting management practices to minimize the impacts of these intensifying extremes.

9. The effects of climate variability on water resources, ecosystems, and public health.

Climate change is significantly altering Myanmar's climate patterns, intensifying the risks and impacts of both floods and droughts. Rising global temperatures have led to warmer ocean surfaces, which in turn fuel stronger cyclones and extreme weather events that affect Myanmar's coastal and inland regions. The increase in cyclone intensity translates to higher wind speeds, greater rainfall volumes, and severe storm surges, all of which create compounding hazards for Myanmar's most vulnerable communities.

One of the most prominent impacts of climate change in Myanmar is the alteration of monsoon patterns. Traditionally, Myanmar's monsoon season provides consistent rainfall that sustains agriculture and replenishes water resources. However, recent years have seen erratic monsoon patterns, with increasingly intense but short-lived downpours that can lead to flash floods. These sudden and severe rain events often overwhelm Myanmar's drainage systems and cause significant river and surface flooding. The damage to infrastructure, farmland, and water supply systems has far-reaching effects, disrupting food security, public health, and economic stability.

Simultaneously, Myanmar faces extended dry spells during the typical dry season, which contribute to drought conditions across the country. Prolonged droughts strain water resources, particularly in rural regions where communities rely on seasonal rains for agriculture and household water supplies. As water availability decreases, competition for this essential resource intensifies, affecting agricultural productivity, biodiversity, and drinking water security. This scarcity is often worsened by soil degradation and erosion caused by previous flood events, creating a cycle of land degradation that affects long-term agricultural sustainability.

The environmental impacts of these shifts in rainfall and temperature patterns are substantial. Flooding causes erosion and sedimentation, which degrade soil quality, diminish crop yields, and threaten critical ecosystems. The increased runoff and water stagnation also contaminate water sources, raising the risk of waterborne diseases. In contrast, during drought periods, the reduced water flow affects river ecosystems, drying out wetlands and impacting biodiversity, while also posing challenges for hydropower generation, which relies on stable water levels.

Together, these climate-driven impacts on water availability, agriculture, and public health underscore the urgency for Myanmar to build resilience against climate change. Addressing these challenges requires not only adapting to new weather patterns but also implementing integrated flood and drought management systems that are informed by climate science and community needs (See Figure 8). By enhancing Myanmar's adaptive capacity, particularly in water management, infrastructure resilience, and community preparedness, the country can better withstand the increasingly severe effects of a changing climate.

10. Challenges in Flood and Drought Management in Myanmar

10.1. Infrastructure Limitations

10.1.1. Aging and Insufficient Infrastructure: Myanmar's drainage systems and flood control infrastructure are often outdated and inadequate. Many riverbanks lack proper reinforcement, making them susceptible to erosion and breaches during heavy rains or storm surges*Road and Transport Disruptions**: Flooding can render roads impassable, isolating communities and hindering emergency response efforts. In rural areas, the lack of all-weather roads complicates access to markets and essential services, particularly after disaster events.

*10.1.2. Barrage and Irrigation Systems**: Inefficient irrigation and water management systems contribute to both flooding and drought conditions. The limited capacity for water storage exacerbates drought impacts, as communities struggle to manage water resources effectively during dry periods.

10.2. Planning

10.2.1. Lack of Comprehensive Risk Assessment: There is often a lack of detailed assessments of flood and drought risks, which impedes effective planning and response strategies. The government's capacity to forecast and monitor climatic changes and their impacts is limited, leading to inadequate preparedness.

10.2.2. Insufficient Climate Change Adaptation: Many existing policies do not sufficiently integrate climate change projections and adaptation measures, which are crucial for anticipating future flood and drought scenarios. This gap hampers the development of resilient structure and community-based adaptation strategies.

10.3 Community Preparedness

10.3.1: Limited Awareness and Training: Community awareness of flood and drought risks, as well as preparedness strategies, is often low. There is a lack of training programs for local populations on how to respond effectively during disasters.

10.3.2. Weak Coordination among Stakeholders: Efagement requires coordination among various stakeholders, including government agencies, NGOs, and community groups. However, there are often communication gaps and a lack of collaboration, which can lead to fragmented responses during emergencies.

10.4. Socioeconomic Factors:

10.4.1. Poverty and Vulnerability: Maties in Myanmar are economically vulnerable, making it difficult for them to invest in disaster preparedness measures. This socioeconomic factor increases their exposure to the impacts of flooding and drought.

10.4.2. Political Instability: Ongoing political challenges hinder the implode disaster management policies and the allocation of necessary resources for infrastructure improvements and community training.

Addressing these challenges in flood and drought management requires a multi-facet that enhances infrastructure, strengthens planning processes, and builds community resilience. Integrating climate change considerations into all aspects of disaster management will be essential for reducing vulnerabilities and improving responses to these increasingly frequent events.

11. Locally led people-centered step-by-step solutions (from simple to advanced and holistic)

Our goal is water secure Myanmar and peaceful Myanmar. These are two faces of the same coin. Once we can promote and implement the new water resources management paradigm, fair water resources sharing, equitably shared prosperity and spiritual transformation from within, nurturing inner soul or consciousness will bring Peace and Prosperity. Individuals can control themselves not to be unfair or over greedy of power or resources or credit or mandate. When a deep-rooted consciousness is cultivated within individuals and advanced technologies are effectively applied to support transparent decision-making, society is positioned to achieve peace and prosperity. In Myanmar, however, a significant gap persists between the wealthy and the poor, as well as in intellectual capacity and moral strength, which hinders social cohesion. This challenge is further compounded by a low level of societal trust, stemming from over 70 years of complex historical experiences.

‘How can we transform these negative situations into positive outcomes?’ is an excellent question.

Transforming Myanmar’s challenges into positive outcomes requires a combination of fair governance, ethical growth, technological advancement, and reconciliation. Together, these actions can build a foundation for a peaceful and water-secure Myanmar, driven by both sustainable practices and a spirit of mutual respect. This is a kind of spiritual transformation with technological capability, humility and empathy.

A step-by-step approach has been adopted within the communities of water and climate change professionals, with the goal of expanding this approach to include a broader range of stakeholders. Especially in the context of building a water-secure and peaceful Myanmar, we first established the Transformative Water-Learning Partnership (TW-LP) consortium formally by signing an MOU among three parties. The TW-LP consortium consisted of three organizations namely; Federation of Myanmar Engineering Society (Fed.MES, https://www.mes.org.mm), Myanmar Green Building Society (MGBS, https://www.myanmargbs.com/) and the Myanmar Water Academy (MyanWA, https://www.myanmarwatersacademy.com) with total of nearly 76,000 engineers and water professionals across Myanmar. The consortium members regularly practice effective communication, team building, and transformative water learning techniques. Those techniques include both natural and social science aspects.

Therefore, it can be seen that humans are intelligent and ethical actors who can transform that huge damage into positive outcome. The consortium apply mindfulness practices as well as Hydroinformatics tools to implement the various water projects including the empowerment of successive generations and promote the team building with diverse generation such as generation Alpha, X,Y,Z, to baby boomers. Trying to provide good relationship among 5 generations is a demanding task as well as very rewarding. This is the time and place where reconciliation began to flourish. Hydroinformatics is the socio-technology which uses high performance models with possibility to practice real-time inclusive decision-making process. For example, web-based decision-support system. After having communicated with communities and digested the ideas, we took the following steps:

1. **Promotion of Inclusive Water and Flood Management Policies**: Advocating to implement a new water resources management paradigm that prioritizes fair and equitable water distribution can foster trust and strengthen social bonds. In Myanmar, such policies can help reduce the gap between urban and rural populations and between different economic classes by ensuring that all communities have access to this essential resource. On the other hand, when the water-related disasters occur, early warning information can reach-out to all people and collective disaster risk reduction community-actions can be organized swiftly. Fair access to water becomes a foundation for prosperity, promoting sustainable agriculture, health, economic growth, trust, social cohesion, and eventually attaining peace. This may be seen as a slow process, however, it is the most sure way to achieve peace and prosperity.

2. **Promotion of HELP Policy Recommendations**: The High-Level Experts and Leaders Panel on Water and Disasters (HELP) has made a number of policy recommendations to address water-related disasters, including:
    - Invest in water infrastructure
    - Develop evidence-based policies

- Build partnerships: The panel recommends building partnerships and cooperation between governments, communities, the private sector, and researchers.

- Improve disaster response: The panel recommends setting up and strengthening national coordination committees for water, sanitation, and human hygiene.

- Provide safe water and toilets: The panel recommends providing safe water and toilets quickly when a disaster or conflict occurs.

- Share hydro-climatic data: The panel recommends that national governments declare hydro-climatic data as public goods to be shared at all levels (See Figure 11).

- Establish a Large Delta States Network: The panel recommends that delta states establish a network to address the negative impacts of sea level rise.

The HLPW panel's outcome document, Making Every Drop Count, found that water-related disasters are responsible for 90% of the 1,000 most severe disasters since 1990. Such scientific and research findings are promoted by the Transformative Water-Learning Partnership Consortium. Moreover, the TW-LP Consortium further promote, discussed and disseminate the HELP proposed actions based on the Bandung Spirit. The Bandung Principles of the Asian-African Conference that was held in Bandung, Indonesia in 1955 symbolized in a phrase “live and let live”. It is a spirit of tolerance, mutual respect, sustainable growth, valuing diversity, and belief in the power of youth and next generations. Actions for Water for Peace can be activated where individuals, communities and states can engage in democratic and peaceful relations at their respective levels. Positive impact of it cannot be overstated. This environment fosters stability, cooperation, and mutual respect among nations, serving as a cornerstone for internal as well as international harmony and progress. Our spiritual transformation will switch the mind set that uses water as a weapon to water as a catalyst for peace. Therefore, building and sustaining peace through water is possible.

3. **Encouraging and Practicing Spiritual and Ethical Development**: Integrating principles of ethical leadership and spiritual growth into water management lead to a transformation from within, where individuals prioritize the collective good over self-interest. By fostering values such as humility, fairness, and restraint in the pursuit of power or resources, individuals can contribute to a culture that values equity and transparency, essential for both water security and societal peace, which we named Ecocivilisation. Replacing Ego with Eco. Replacing Greed with Courage to Share. According to UN World Water Development Reports, there is a general consensus in multiple sources about challenges in water projects' effectiveness. According to UN-Water and other global assessments, numerous water-related projects face obstacles such as inadequate management, lack of funding, and failure to address local needs effectively, which leads to a high rate of failure or underperformance in many cases. It is fair to say that those failures were caused by negative side of the human nature (greed, ego, ignorance, wish to win by all means, etc.), not only because of financial and technical constraints. That is why this step is a must to take.

4. **Leveraging Technology for Transparency**: Advanced technologies can support transparent decision-making and accountability in water resource management. Using tools such as real-time monitoring, open data platforms, and community-based water assessments can ensure that water management is equitable and resilient. This transparency helps to bridge social divides, as communities feel included in the decision-making process. Hydroinformatics play a key role in this step (See Figure 12).

5. **Address Historical Inequities with Reconciliation Efforts**: Myanmar's long history of social and economic disparities has created a low level of societal trust. Acknowledging past injustices and committing to fair resource-sharing policies can build trust within communities. Programs focused on community engagement, fair resource allocation, and reconciliation can help repair trust and create a sense of shared purpose.

6. **Fostering Education and Awareness**: Strengthening educational initiatives focused on water conservation, ethics, and social responsibility can empower individuals across all sectors of society. An informed public is better positioned to advocate for fair water use and sustainable practices, reducing resource-driven conflicts and fostering a culture of shared responsibility. Since water is everyone's business, we need to explain about water and water-related disasters to each and every citizen in Myanmar. To get everyone on board (See Figure 9), we began with a very simple technological philosophy to know about flood and drought and how to deal with them at the very basic level. We explained about the flood as the following to the grassroots participants in Myanmar language. When a river or a stream cannot carry within its bank full capacity it is overflowing over the banks and producing flooding.

(i) Water is unlike any other material, and cannot be compressed, like earth or air, to make its volume smaller. When water is frozen into the form of ICE some think the volume may shrink the volume, but it swells by 1/11 times instead.

(ii) So when Flood comes one can do 3 things to save people's lives. These are:-

(a) Either we move people from harm's way, or

(b) we move Water from the people's way, or

(c) warn the People how high the Flood will come and when.

That warning system is called the "Early Flood Warning System - EWS". The EWS sounds nice unless our forecast has enough time to make people go away or move to higher ground. But under ongoing climate change, more and more flash flood-producing rains are coming on short notice like the Japanese and Sri Lanka Tsunami cases, and the Typhoon Yagi case, we do not have enough time and people drowned. Therefore, we inform the grassroots participants to check the time available in our environment. One difficulty we faced during evacuation is that people refused to leave their own home regardless of the apparent danger. Many lost lives due to that attachment.

(d) Water education and capacity development also include exercises on both vertical and horizontal integration to understand each other's role play and portfolio and perspective. The need for infrastructure in flood and drought risk reduction is very obvious. A function of hydraulic infrastructure is to move part of excess flood water away from people. Therefore, water engineers build dry polders (temporary retention reservoirs) away from the main river course and stored some volume of water there during flood time and released them back to water after flood. Some are also build on stream flow through a gated regulator (maybe small dams, weirs, or barrage), to retain flood water upstream and release it slowly to accommodate water within the stream downstream so as not to overflow its banks thereby protecting downstream people, cities, and towns until the flood subsides. Other kind of infrastructure is building new streams or channels parallel to the main river with a milder channel slope so that the flow in that sharing channel is slower than the main river lowering the peaking time downstream.

(e) Nature-based solutions in Cities: municipalities reform and greening the private sector. This is the most difficult task among other water education and capacity development activities. Municipal rules and regulation to keep the soil surface as some percentage of the total housing plot area, however, it was rarely obeyed. The benefits of the green space (See Figure 12), and many possibilities of nature-based solutions for municipalities and riverine areas (See Figure 13) were promoted, however, people place the priority on cash income rather than the long-term health benefit for example. The yard stick of majority's decision making is based on monetary gain rather than other psychological, health and life span. It will take some time to get the message into critical mass.

(f) The last but not least part of our water education and capacity development involved AI, GIS (Geographic Information Systems), RS (Remote Sensing), and simulation models in order to enhance inclusive water governance. Science and Technology were used to

11.2. Database continuity and Decision Support System

Data is a cornerstone of Integrated Water Resources Management (IWRM) because it enables evidence-based decisions, long-term planning, and effective resource allocation. During the stakeholders consultation meetings, reliable data can convince the participants and get the negotiated agreement faster and firmer, which has led to public acceptance of the decisions. To maximize the effectiveness of IWRM, data should be collected consistently, shared among stakeholders, and analyzed regularly, promoting a responsive, adaptive approach to water management. Hence data is essential in IWRM for the following tasks:

1. **Informed Decision-Making**: Accurate data on water availability, quality, and demand allows for smarter policy-making and better management practices. Data-driven insights help in evaluating the impact of different management strategies, allowing adjustments to be made in real-time.

2. **Resource Allocation and Optimization**: IWRM seeks to balance the needs of various sectors (agriculture, industry, domestic use, and ecosystems). Data helps in assessing sectoral demands, ensuring water resources are allocated efficiently and equitably.

3. **Water Quality and Ecosystem Health Monitoring**: Data on pollutants, temperature, pH, and biological factors is essential for monitoring water quality and maintaining healthy ecosystems. Without accurate monitoring, it's challenging to identify and mitigate pollution sources or protect biodiversity.

4. **Early Warning and Risk Management**: IWRM requires robust data for flood forecasting, drought monitoring, and other risk assessments. Reliable data helps mitigate the impact of extreme weather events by enabling early warnings and coordinated responses.

5. **Stakeholder Engagement and Transparency**: Providing transparent data builds trust and promotes stakeholder participation, which is essential in the collaborative decision-making processes of IWRM. When communities and sectors have access to data, they can make more informed contributions to planning discussions.

6. **Climate Change Adaptation**: In the face of climate change, understanding patterns in precipitation, temperature, and water demand is crucial. Data supports adaptation efforts, helping managers to foresee and plan for changes in water availability and demand.

7. **Performance Monitoring and Improvement**: Data allows for the monitoring of implemented strategies and policies. By tracking key performance indicators (KPIs), water managers can measure the success of IWRM initiatives and adjust strategies as needed.

12. Conclusion: A New Water Governance / Management Paradigm

Local water professionals, indigenous peoples and international experts, professors from in and outside of Myanmar collectively possess the knowledge of Myanmar Water Resources, history in water management and governance, technology, sociology, anthropology, agriculture sector development (or otherwise), soil and water sciences, seed production, rainwater harvesting, market fluctuations, supply chain challenges, etc. etc. However, water issues and problems are extremely complicated and also sensitive. More than 60% donor funded water projects failed or struggled to achieve the pre-set goals. It was because we have not put human actors in the water resources governance equation. To be more precise, we have forgotten to include ourselves into the equation. Human are part of the climate change equation as well as water equation. Human actions caused the Global warming and Climate Change. Like-wise humans are part of the problem in water related disasters, water stress and cause water pollution. Moreover, concerning Water Risk and/or Water Security, many questions confront the World as listed below.

- How can we ensure that an adequate supply of clean water is available, both for today and for coming generations?
- How equitable will access to it be? How should it be managed, and by whom?
- What will the implications of climate change be on the quality and quantity of fresh water?
- Is clean water destined to become for the twenty-first century what petroleum was for the twentieth, a source of geopolitical power and conflict?
- Will social change concerning water use come through technological innovation or through cultural and value change, or some combination of both?

Concurrent with the ecological dimensions of the water crisis are public health dimensions, including, but not limited to, the spread of water-borne diseases, particularly in the developing world. Existing systems need to be modified, or new systems need to be created, so as to achieve more just access to clean drinking water, as well as to provide for effective societal responses to public health concerns. We as humans need to transform ourselves from part of the problem the problem to part of the solution. Hence calling for a New Water Management/ Governance Paradigm began in 2020 by awaken peoples.

The proposed new water management/ governance paradigm has three components, hardware, software, and leadership. Water technologies, water management systems as hardware and water ethics and Ecologism as software. Water Professionals are Key to success. They need to know not only interdisciplinary but also transdisciplinary! Not only about self but also the Nature!

As a conclusion, a New Water Governance / Management Paradigm (3-Ply) should be implemented, i.e. (Socio-technology + Systems Science + Spiritual transformation - begin with leadership principles). To be more specific, it can be stated as a new water governance paradigm is equal to (Hydroinformatics Tools + Systems Science + AEIOU Leadership). That is to revive human greatness and Nature together!

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FIGURES

Figure 1. Physical Map of Myanmar (Source: Worldometer)

Figure 2: Typical representation of the disaster management cycle (Water Symposium of Florida 2021 (Source; Prof. Dr. Lee Bosher, University of Leicester)

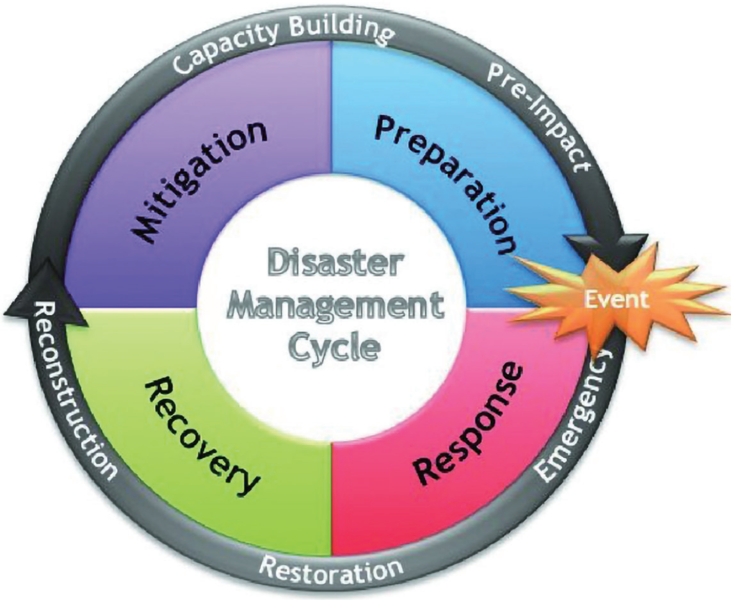


Figure 3: (a) Myanmar's three agro-ecological zones and (b) eight physiographic regions (Source NAPA 2012)

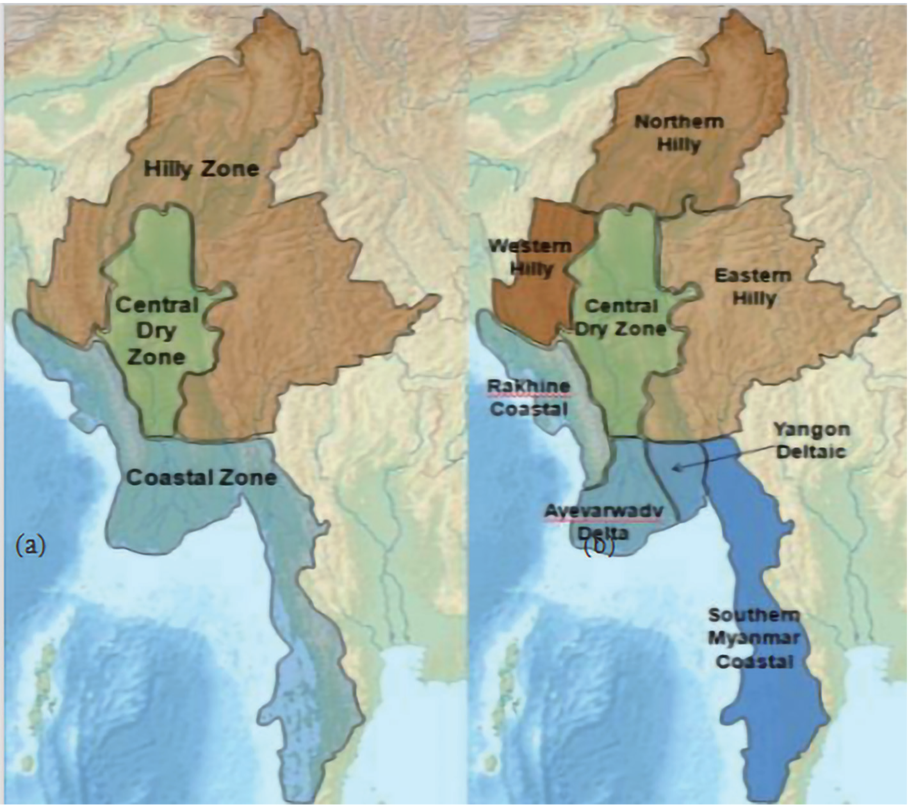
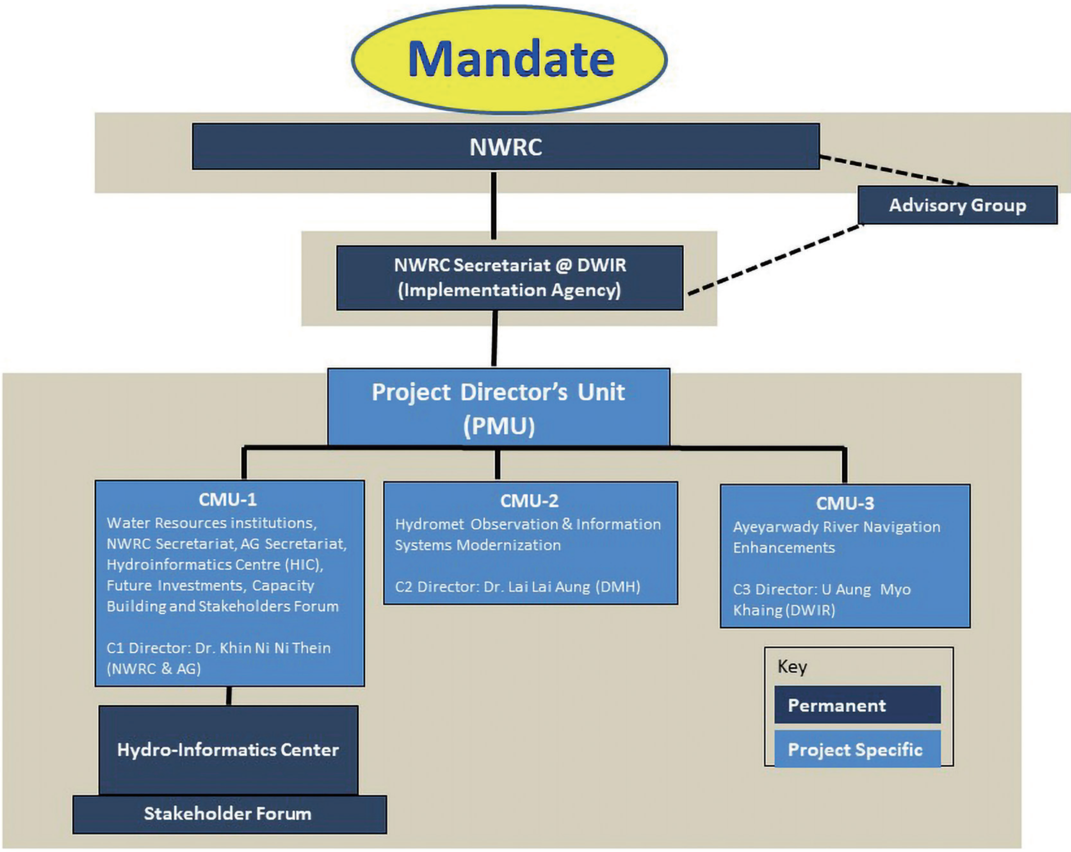
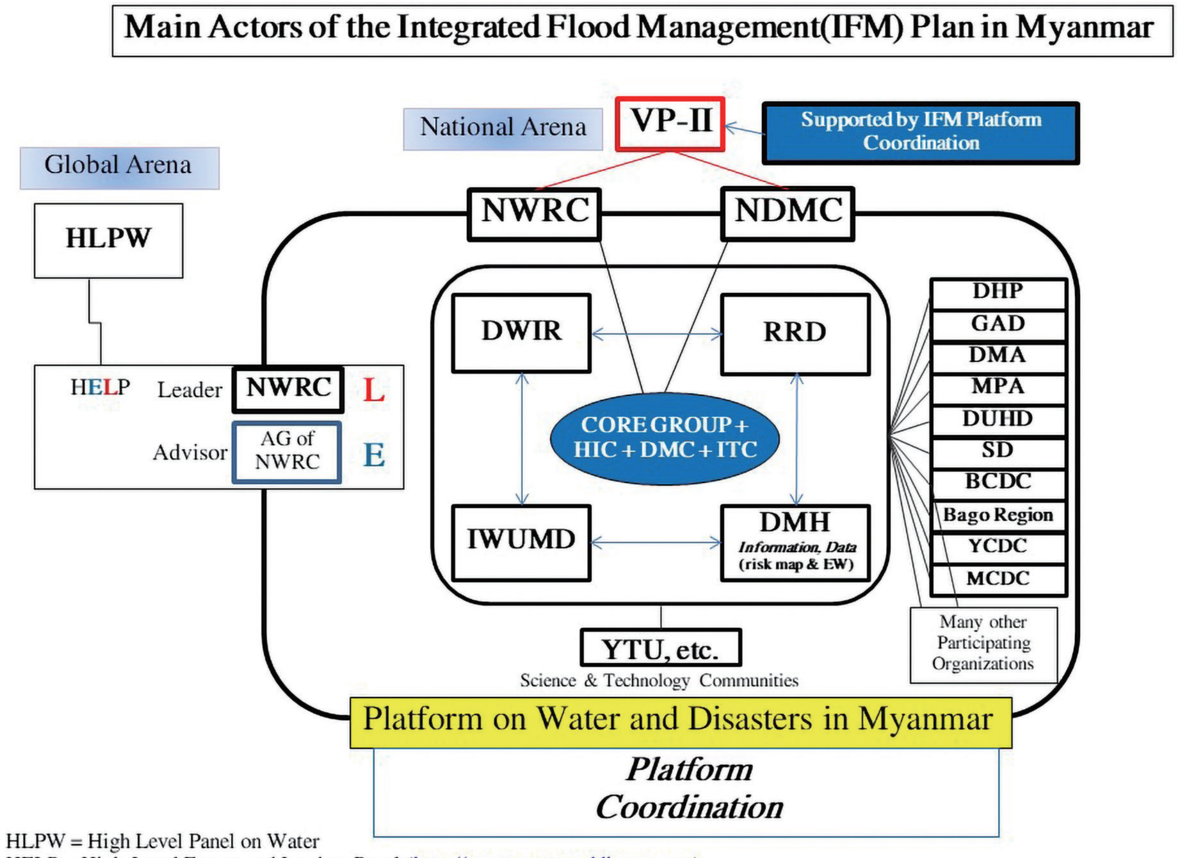


Figure 4: (Apr 2016 – Jan 2021) The government's effort to reform the Myanmar Water Sector (unfinished)



Light blue shaded area indicates the offices that are located together in the same office space.

Figure (5) The government's effort to establish the Water Disaster and Resilience Country Platform (unfinished)



HLPW = High Level Panel on Water
HELP = High-Level Expert and Leaders Panel (http://www.wateranddisaster.org)

Figure 6: Infographic of the Myanmar Water Sector Reform supported by the World Bank AIRBM Project

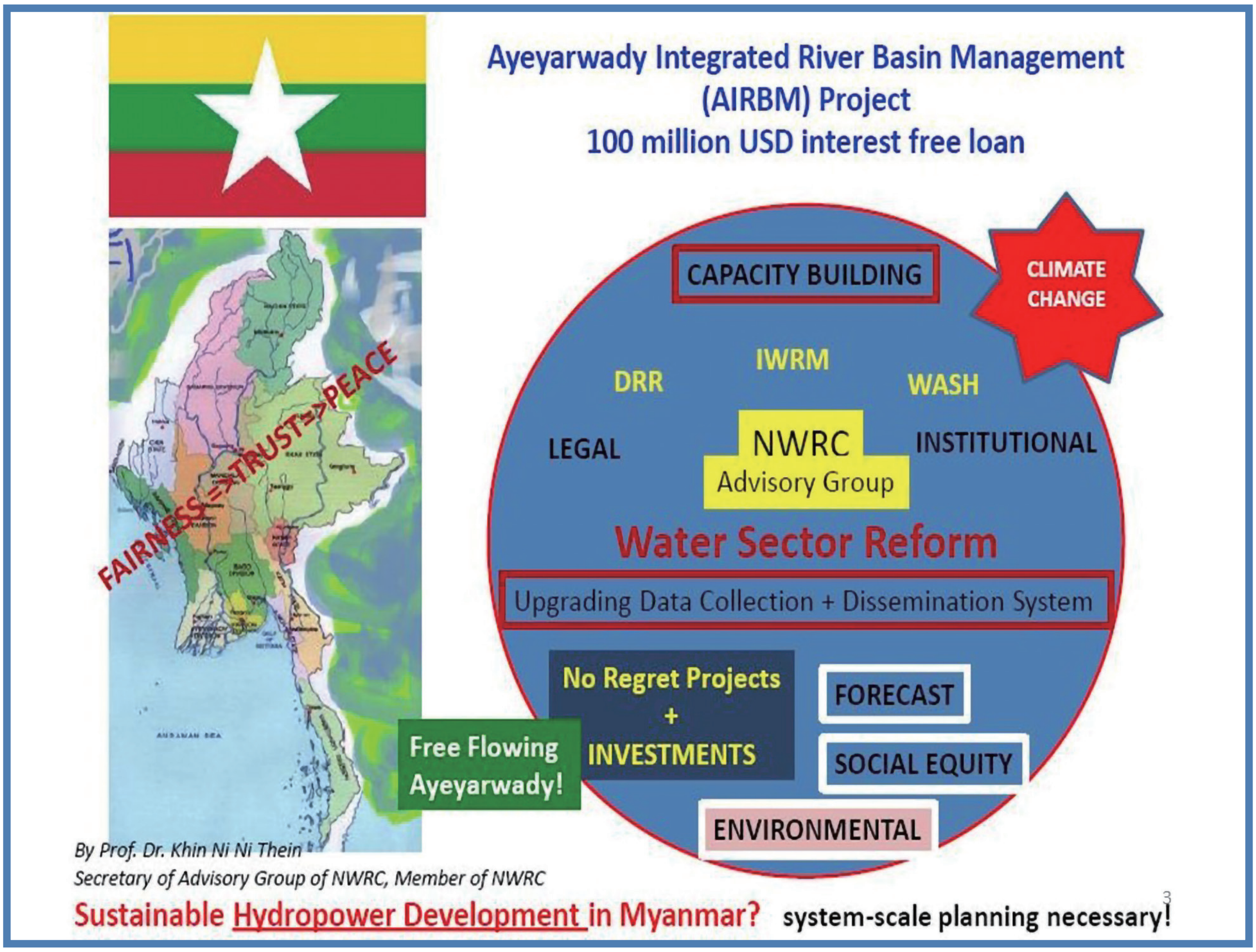


Figure-7: NASA Satellite Image on 14 May 2023 Mocha Cyclone

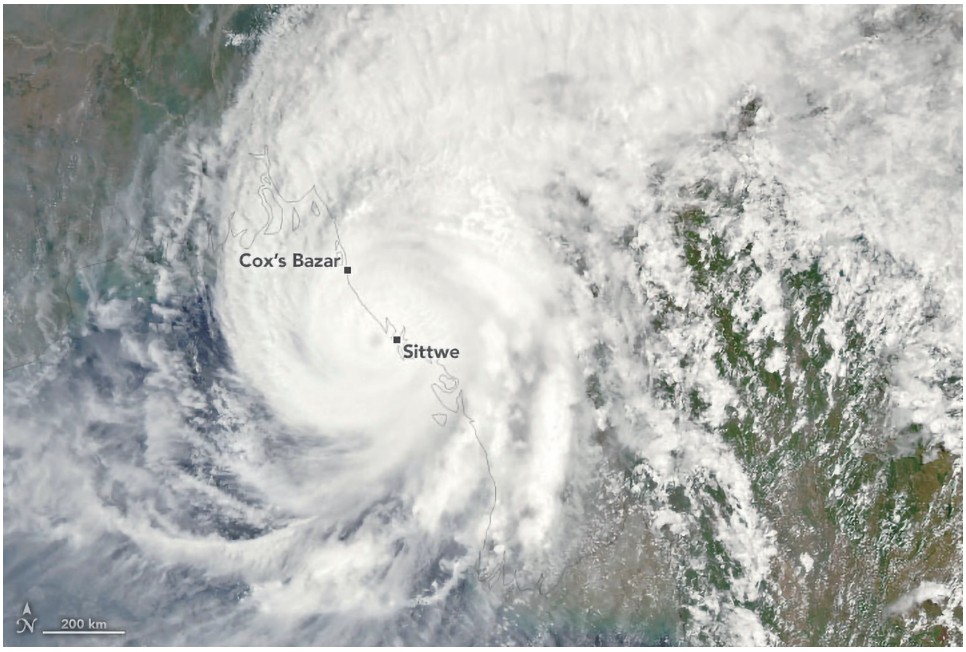


Figure-8: Workshop organized by the SANA Organisation as a Member of Myanmar Climate Action Network

Figure 9: Flood in Inlay Lake area, Sept, 2024
(Source: SANA Organisation, Myanmar)

Figure 10: Photos that depicted the situation of Typhoon Yagi affected areas in Shan State
(Source: Action Aid Myanmar)

Figure 11: Publication of ASEAN Hydroinformatics Data Center Application of Science and Technology for water-related disaster risk reduction

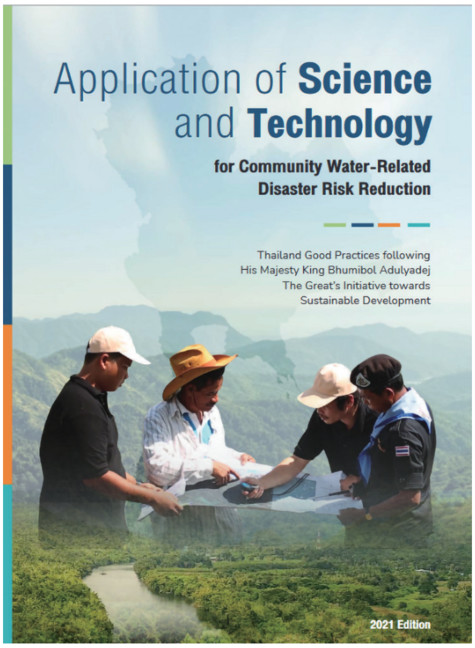
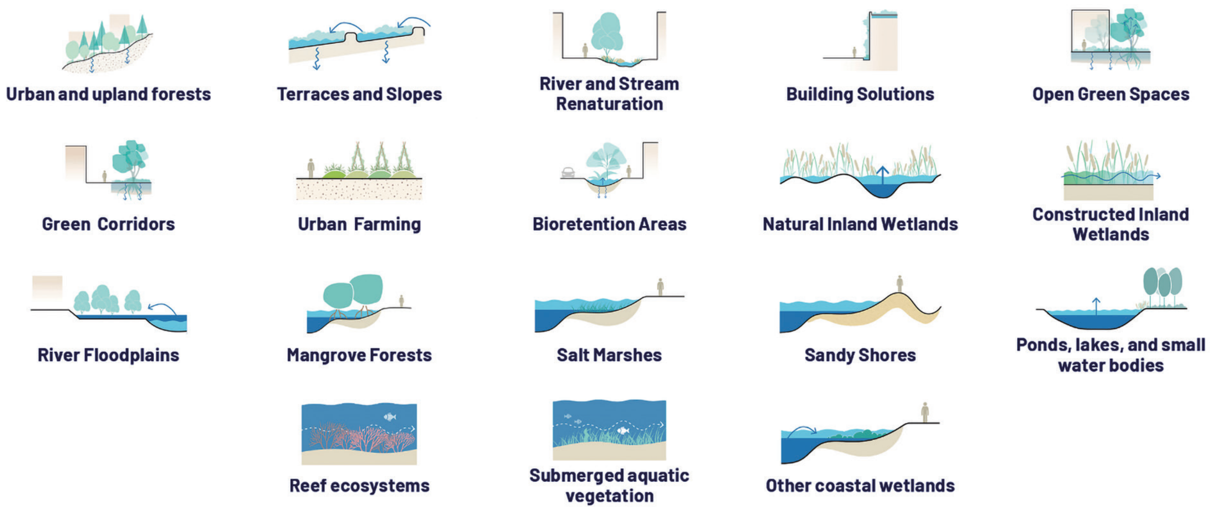


Figure 12: Benefits provided by open green spaces (as part of Nature-based solutions) Source: A Catalogue of Nature-Based Solutions for Urban Resilience, World Bank, 2021.

Figure 13: Types of Nature-based Solutions in Urban and Coastal areas
Source: Adapted from A Catalogue of Nature-Based Solutions for Urban Resilience, World Bank, 2021



HELP
Water & Disasters

HELP Principles on Gray and Green Infrastructure for Water and Disasters

HELP Principles on Gray and Green Infrastructure for Water and Disasters are a complete set of recommended actions for all stakeholders to advance gray, green and integrated infrastructure for disaster risk reduction (DRR) and water resources management. They will assist decision-makers, administrators, academia, practitioners and stakeholders to address water-related disasters and water resources management in wholistic and concrete ways. They will help, inter alia, exponential acceleration of water-related SDGs towards the full achievement of all SDGs. These principles are intended to not only guide the design of new infrastructure, but also to guide the review and climate adaptability of existing infrastructure to make it more resilient.

The Principles advocate expanded transparent benefit-costs analyses that include commensurate and non-commensurate measures. They facilitate integration of gray and green infrastructure, thereby enhancing effectiveness of basin-wide water management systems, which leads to a healthier water cycle. They can be tailored to natural, social and economic conditions based on scientific methods and proven effective experiences.

The Principles recommend integration of gray and green infrastructure in DRR and WRM as it creates co-benefits for climate change mitigation and adaptation, for enhancing biodiversity, and for progress on disaster risk reduction (DRR) and water resources management. This approach expands options for transboundary water agreements to jointly cope with difficult and recurring disasters and to ensure harmonious water sharing, which will lead to peace and prosperity in the region.

HELP is convinced that (a) governance and policies that enable integration of gray and green Infrastructure on water and disasters rather than their separation, (b) administrative mechanisms that bridge the gap between science and politics for critical decision making on gray-green-and-integrated infrastructure, and (c) end-to-end, practical approaches relaying scientific, engineering, socio-economic, and political actions for their implementation in a systematic manner will bring revolutionary change to our society from a quantity-oriented to a quality-oriented one based on quality infrastructure. The change will enable drastic acceleration of progress of the SDGs towards their full achievement.

With this conviction, HELP wishes that the Principles be proactively used by decision-makers, governments, academia, civil society, and stakeholders at all levels so that gray and green Infrastructure and their integration as a whole will lay solid foundations for the creation of the future we want without anyone left behind, via the creation of disaster resilient and sustainable basins with healthy water cycles for all.

1. **HELP's definition on green and gray infrastructure**

Beware that there are still various "definitions" on gray and green infrastructure. Practitioners must clarify, with source documentation, what definitions of gray and green infrastructure are used in specific discussions and decision-making with regards to gray and green infrastructure. Keep in mind that definition may change depending on time and stages.

- Definition of infrastructure

  Fundamental structural and non-structural facilities and systems that support functions and the operations for society. The function of water-related infrastructure consists of three components: storing the water, controlling water flow, and purifying the water.

- Definition of "green infrastructure"

  A strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to mitigate the three components of water-related disaster risks, i.e., hazard, exposure, and/or vulnerability and to improve water resources management by delivering ecosystem services.

- Definition of "gray infrastructure"

  Artificial structures or facilities, and their networks, designed and managed to mitigate the three components of water-related disaster risks, i.e., hazard, exposure, and/or vulnerability as well as water resources management by delivering non-ecosystem services.

Reference:

Definition of "Green Infrastructure" by the EU: "A strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services, while also enhancing biodiversity." Such services include, for example, water purification, improving air quality, providing space for recreation, as well as helping with climate mitigation and adaptation. This network of green (land) and blue (water) spaces improves the quality of the environment, the condition and connectivity of natural areas, as well as improving citizens' health and quality of life. Developing green infrastructure can also support a green economy and create job opportunities.

Definition of Nature-Based Solutions: The European Commission defines nature-based solutions as "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions."[1] Consequently, solutions rooted in nature should be advantageous for biodiversity and assist in providing various ecosystem services.

[1] Source: https://rea.ec.europa.eu/funding-and-grants/horizon-europe-cluster-6-food-bioeconomy-natural-resources-agriculture-and-environment/nature-based-solutions_en

2. Decision-making in policies and plans of gray and green infrastructure

- Mainstream integration of gray and green infrastructure at regional, national, district, and local levels.
- Consider wide options of green and gray infrastructure that will serve the purpose of the facilities at the outset of policy formulation, planning, building and operating infrastructure for water-related DRR and water resources management. Compare, without prejudice, benefit and cost of options, which use both gray and green infrastructure by maximizing their benefits and minimizing the costs.
- Consider integration of gray and green infrastructure in a basin-wide water resources management system, which enables creation of a healthier water cycle.
- Decide, in transparent and accountable procedures, the best set of options. Use appropriate examples and practices when explaining the decisions. Rigorously make sure that the selected gray, green, and integrated gray-green infrastructure will achieve numerical targets/functions for DRR and water resources management through certified assessment methodologies.

3. Valuing gray-green infrastructure on water and disasters

- Value gray, green, and integrated infrastructure by economic, social, financial, and environmental yardsticks.
- Conduct comprehensive cost-benefit analysis on gray and green and integrated infrastructure, which will reveal how water is valued. Options will contain various economic, social, political, and environmental benefits and costs. These benefits and costs will also vary depending on local, regional, national, and global scales.
- Use rigorous economic, social, and environmental methods in analyzing and comparing gray and green and integrated infrastructure. Methodologies of assessing cost/benefits of green infrastructure are still in development stages compared with those of gray infrastructure. It will not, however diminish the value of green infrastructure. While the measure of gray and green include non-commensurate measures of value, great progress on the methods regarding non-commensurate Benefit-Cost Analysis (BCA) is evolving. For example, keeping green areas intact may not increase their functions for DRR and water resources management. However, there are cases in which functions of green infrastructure are drastically enhanced by combining them with gray facilities.
- Evaluate the life cycle costs of infrastructure solutions, considering not only financial aspects but also local environmental and social conditions. Decisions should be context-driven and informed by a comprehensive assessment that accounts for the local factors and conditions, to ensure the most sustainable, disaster-proof, and cost-effective solutions are chosen.
- Consider also the ecological benefits, such as providing habitats for migratory birds for instance, that connects green and gray infrastructure and ecosystems.
- Consider cultural and historical factors in the assessment of infrastructure choices to ensure that they align with the unique local context and heritage.

4. **Financing gray and green infrastructure**

- Conduct dialogues with finance ministers and officials on gray, green, and integrated infrastructure so that they understand the merit of financing these. Understanding the value of a healthy water cycle in economic, social, and environmental terms, will create a policy foundation for national prosperity.
- Apply rigorous economic, social, and environmental analysis on gray and green infrastructure when deciding piecemeal large-scale green or integrated infrastructure. Use available closest examples and/or guidance/ manuals when deciding small-scale infrastructure.
- Prioritize and promote integration of gray and green infrastructure in policies, plans, and projects, particularly in those by ODA. Include assessment and evaluation on levels of integration of gray and green infrastructure in bilateral and multilateral cooperation plans and projects. Make an investment master plan for gray-green infrastructure, and include them in Nationally Determined Contributions (NDC) and Climate Adaptation Plans.

5. **Capacity building for gray and green infrastructure**

- Support planners, and practitioners to enhance their knowledge and capability to plan, design, and implement both green and gray infrastructure projects through education and training including on the job training.

6. **Proactive integration of gray and green infrastructure to address Climate Change**

- Proactively integrate gray and green Infrastructure in policies, plans, and projects on water, DRR, and climate change in a basin to enhance resilience of the basin against impacts of climate change.
- Be aware that existing gray infrastructure may not ensure the level of water security originally planned/designed and that a "gray-only" approach may not be feasible in economic, social, and/or environmental terms. Integration of gray and green Infrastructure will bring effective solutions to progressive challenges of hydrological extreme events under uncertain scenarios of climate change.
- Be aware that intricate, cascading, and structural risks that are latent in social, economic, and environmental systems may suddenly emerge and intensify to the extent that a single-handed solution by grey infrastructure cannot cope with increased variabilities of water events.
- Strategize integration of gray and green infrastructure as a core part of "quality infrastructure policy" towards building quality-oriented societies that are more sustainable, resilient, and inclusive.

7. **Promoting advancement of science and technology on gray and green infrastructure**

- Convene scientists and experts, not only those on water and DRR but also on food and agriculture, ecosystem, biodiversity, energy, climate, IT, etc., to bring their expertise and intellect to deepen the understanding of gray and green infrastructure.

- Promote scientific discussion and action on observation, modelling, analysis, and assessments of gray and green infrastructure, including those on social science and particularly in terms of quantification, which will lead to overall consilience, or fusion of sectoral intelligence, on this subject.
- Promote financing and investment in science and technology on gray, green, and integrated infrastructure to enhance scientific knowledge and broaden application on both. Financing in research on green infrastructure is of particular importance as its functions can be fully tapped by elucidating ecological services on, e.g., water resilience of green areas.
- Cultivate “facilitators” who fill gaps between science and technology and decision making, planning, and field practices. They will become catalysts to create science-based, practical solutions to water challenges.

8. Promoting science-based decisions on gray and green infrastructure

- Keep developing scientific knowledge on gray and green infrastructure that are applicable to regions, countries, districts, and communities. Create databases for geographic, geological, vegetation, and other natural conditions of basins so that they are effectively used when making plans and decisions on gray and green infrastructure.
- Create and use scientific advisors/facilitators or their panels when making critical decisions, such as:
  - Decision-making mechanisms for development, maintenance, and conservation of gray and green infrastructure
  - Decision-making for use and conservation of gray and green infrastructure during emergency and crisis
- Ask scientists to explain the current status of science and technology and innovation on gray and green infrastructure and indicate prospects for their further development.

9. Stakeholder involvement for integrating gray and green infrastructure

- Be aware that Integration of gray and green infrastructures will increase the number of stakeholders and raise their interests. While their participation/involvement process tends to be more complicated and time-consuming, it also can increase the possible areas for agreement and solidarity. Creating a well-crafted and legitimate stakeholder involvement process is key. Using an IWRM approach facilitates the process.
- Involve all stakeholders in planning, building, and operating gray, green, and integrated infrastructure in preparing, planning, implementing, operating and monitoring gray and green infrastructure. The full involvement and participation by, and collaboration with, local stakeholders will particularly augment functions of green infrastructure.

10. Using IWRM and a Basin Approach to promote the Integration of gray and green infrastructure

- Apply an IWRM approach in assessing and planning gray, green, and integrated gray-green infrastructure. Use the basin as a basic unit when making overall plans of gray and green infrastructure as it is often most productive. Implementing gray and green infrastructure in a basin should be based on IWRM concepts. Thus, create master plans of gray and green infrastructure within or in coordination with IWRM Plans.

11. Promoting gray and green infrastructure in transboundary water

- Include gray-green infrastructure in dialogue among riparian countries, which can increase the possibilities for agreements and solidarity in transboundary situations. Discuss historical examples and options of gray and green infrastructure, particularly their integration, for conflict resolution and peace building.

12. Promoting common understanding on gray and green infrastructure and their integration at global, regional, and basin levels

- Strengthen international solidarity on gray and green infrastructure and their integration by agreeing on international principles on gray and green infrastructure and their integration at global, regional and basin levels.
- Create sets of practical guidelines that are applicable for policy, plans and practices in accordance with diverse hydrological, geophysical, economic, social, environmental, cultural and other conditions. Share globally and regionally, good practices and lessons on the application of gray and green infrastructure and their integration.

1 Case Studies on the integration of the green and grey infrastructure and nature-based solutions in the water-related infrastructure in Japan

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The Japanese government has long promoted nature-oriented river improvement and has implemented a number of infrastructure projects based on the struggle to find the appropriate balance between green and grey aspects of the projects. Through these experience in Japan, the authors introduce Japan's struggles to find the right balance between green and grey infrastructure in water management. Through the lessons learned from these examples, the authors highlight the importance of community and education.

1. Details of the project

In Japan, the river and freshwater network has been closely linked to people's daily lives, including transportation, domestic water supply and laundry. The development of infrastructure systems, including railways, motoways and water supply pipes, has forced the relationship between people and rivers, to be varied, and to be distant.

Historically, based on the experience of their long history, the Japanese have a lot of indigenous knowledge about how to deal with rivers and fresh water. However, most of them have been forgotten in the shadow of economic growth and infrastructure development.

In 1990, the Ministry of Construction (now the Ministry of Land, Infrastructure, Transport and Tourism) of Japan started the nature-oriented river improvement, which is similar to what we now call "nature-based solution", by issuing a document entitled "A guideline for promotion of nature-oriented river improvement". The guideline sets a fundamental value of "paying attention to the good habitat and nurturing environment for biological organisms that rivers naturally provide, while preserving or creating beautiful natural landscapes".

On the basis of this guideline and the following documents, Japan has developed nature-oriented or nature-based solutions based on an appropriate balance, which is not easy to determine, of the green and grey infrastructure.

In this chapter, the author presents several examples in Japan that consider the balance between green and grey infrastructure in the development of water-related infrastructure.

2. Cases

2.1. Riverside forest managed by local communities for more than 400 years (Fukushima, Japan)

The Arakawa River, a major tributary of the Abukuma River in Fukushima Prefecture, is characterised by very steep gradients and large amounts of sediment runoff due to the active volcano Mt. Agatsuma at its headwaters. The Arakawa River has long been the scene of frequent disasters, and records of disasters in the basin can be traced back to at least the 17th century. In the past, local communities have been involved in the protection of residential and farmland, the construction of open and non-contiguous levees, and the planting of flood protection forests in the riverside.

The idea of a flood protection forest was legislated in the amendment of the River Act of 1997. The forest around the Arakawa River was designated as a special forest area based on the amended River Act. This combination of forest and levee is still in place today and is still a source of protection for the city of Fukushima.

Fig. 1 Arakawa River Basin

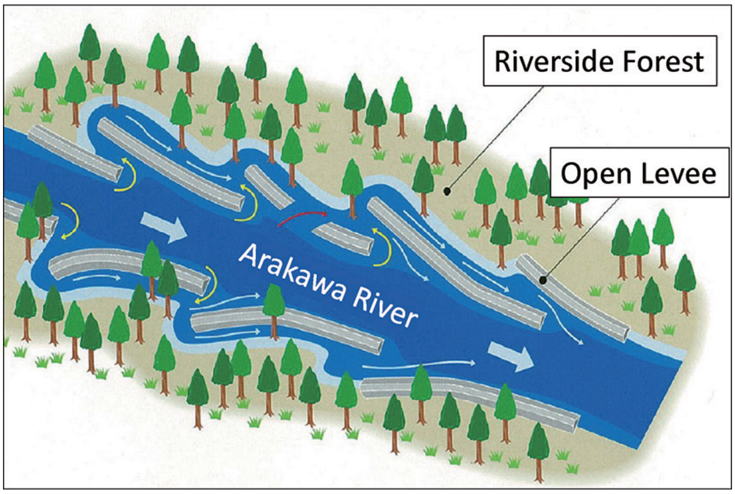

Fig. 2 Riveride flood protection forest and open levee system

Fig. 3 Riveride flood protection forest

Fig. 4 Open levee system in front of the flood protection forest

2.2. Moderation of farmland to co-benefit wetland park and flood storage (Shizuoka, Japan)

The Tomoe River basin, located in Shizuoka City of Japan, has historically experienced recurrent flooding due to the topographical features of gentle slopes and meandering channels and fragile geology in hilly areas.

Local communities have struggled with flooding for centuries. People in this basin have struggled to tackle the high frequency of flooding and have carried out various amounts of dredging and river improvement works.

The city has experienced rapid urbanisation since the 1950s, which has increased the speed and volume of flood discharges in the basin.

After a devastating flood in 1974, the Shizuoka Prefectural Government decided to promote comprehensive flood disaster risk reduction measures, including large-scale infrastructure such as the Oya Floodway, a diversion channel for the mainstream, the Asahata Flood Control Basin which is reported below, and community-based flood storage activities such as schoolyard flood storage, park flood storage and individual home flood storage.

The Asahata Flood Control Basin has been designed as a combination of green and grey infrastructure, including an urban park zone, a health promotion zone, a waterside recreation zone and a nature field zone. All these zones also have flood storage capacity and reduce flood discharge downstream.

In normal times, these zones play an important role as green infrastructure, providing citizens with nature-oriented activities and water-friendly habitats.

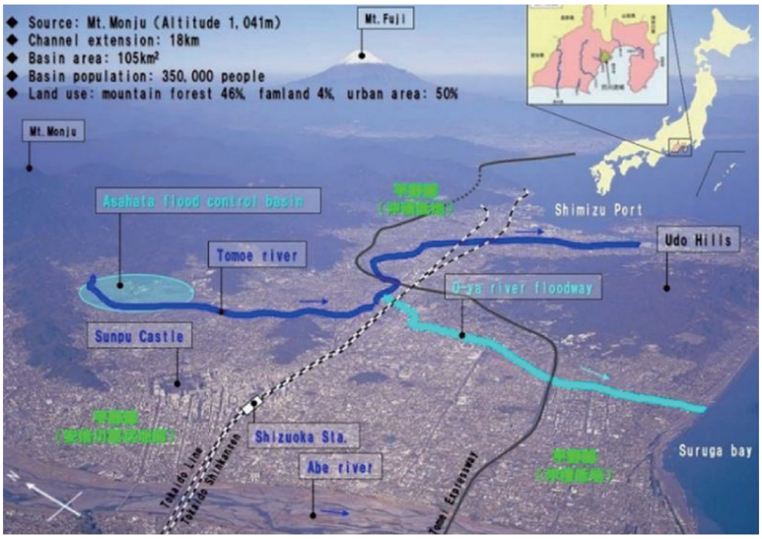

Fig. 5 Overview of the Tomoe River Basin (Source: Shizuoka Prefecture)

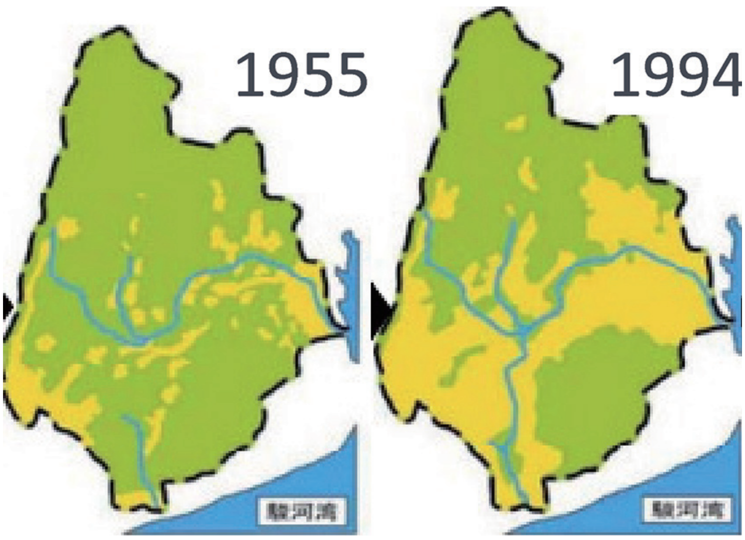

Fig. 6 Urbanization of the Tomoe River Basin (Source: Shizuoka Prefecture)

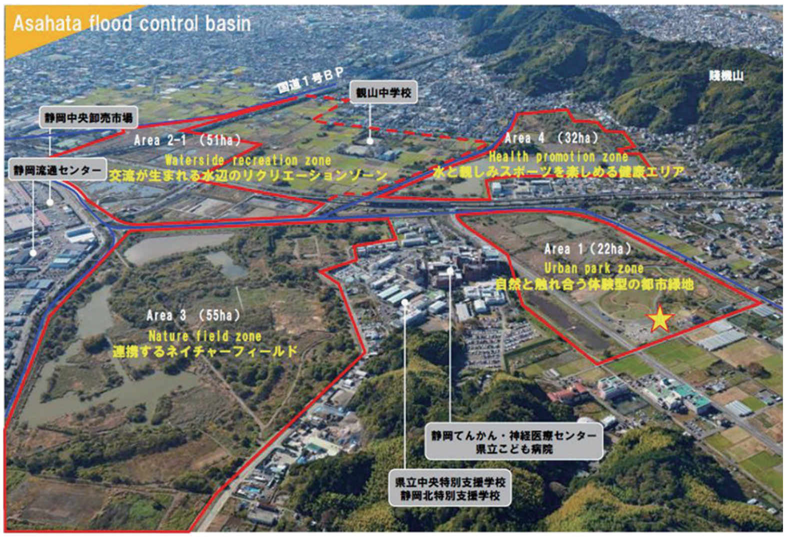

Fig. 7 Zoning of the Asahata Flood Control Basin (Source: Shizuoka Prefecture)

Fig. 8 Asahata Flood Control Basin storing floodwater in the 2022 flood (Source: Shizuoka Prefecture)


Fig. 9 Children's experience of rice planting in the Asahata Flood Control Basin (Source: Asahata Flood Control Basin Management Committee)

2.3. Great Forest Wall: Combination of multiple lines of tsunami defense facility based on the combination of green and grey infrastructure (Miyagi, Japan)

More than 15,000 people lost their lives and around 2,500 people are still missing in the devastating tsunami disaster caused by the tsunami caused by the Great East Japan Earthquake in 2011. In the aftermath of the tragedy, the Japanese government decided to build a comprehensive tsunami disaster risk reduction infrastructure along more than 400 km of the damaged coastline. The details of infrastructure development have been implemented through dialogues with local governments and local communities, which take years to reach a consensus.

Some areas have decided to plant coastal forests to reduce the risk of tsunami surges over the height of coastal levees. This comprehensive system, consisting of tsunami protection forests and levees with a reinforced surface, has been called the "Great Forest Wall".

This system is expected to provide persistent protection for coastal levees and contribute to the creation of a landscape that is integrated with the land behind it, preserving the natural environment and contributing to coastal use.

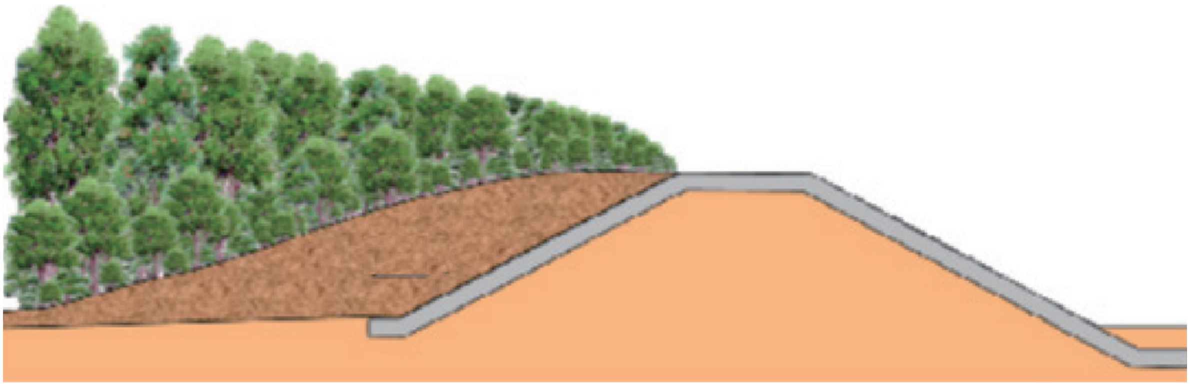

Fig. 10 Concept of the Great Forest Wall

Fig. 11 Implementation in Nakahama district

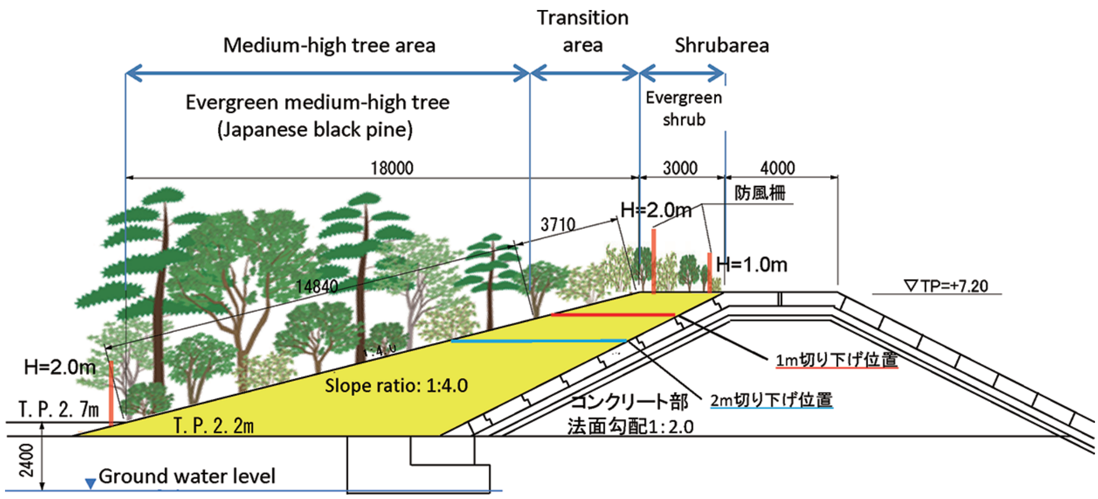

Fig. 12 Standard cross section of the levee

2.4. Kiso Sansen Park (Kiso three rivers park): The use of the river space as an urban recreation area and as a field for eco-hydrological education (Aichi, Gifu, Mie, Japan)

The Kiso River Basin is one of the most complex river basins in Japan, with a conjunction of three interrelated main rivers, the Kiso, the Ibi and the Nagara, which have complicated interactions with each other. Governors and people living in this basin have long struggled to manage the flood risks caused by the river.

In the Meiji era, from the late 19th century to the early 20th century, the Japanese government, assisted by engineers dispatched from the Netherlands on the basis of bilateral cooperation, carried out a huge river improvement plan that divided the river into three main streams to avoid complicated interrelationships between the basins.

As a result of this huge improvement work, a large amount of flat land has been created between and around the three main streams.

The Japanese government decided to utilise this space for the recreation and education of the citizens as the largest national park and named it "Kiso-Sansen Park", which means "Park of the Three Rivers". The park was inaugurated in 1987 and is divided into 13 areas, each with a different theme, such as the education of flowers and plants (area no. 1), water sports (area no. 7) or aquatic life (area no. 11).

Today, the park attracts more than 10 million people a year and more than 160 million people in total, contributing to the recreation and education of the people living around the basin, as well as tourists from all over the world.

Fig. 13 Standard cross section of the levee

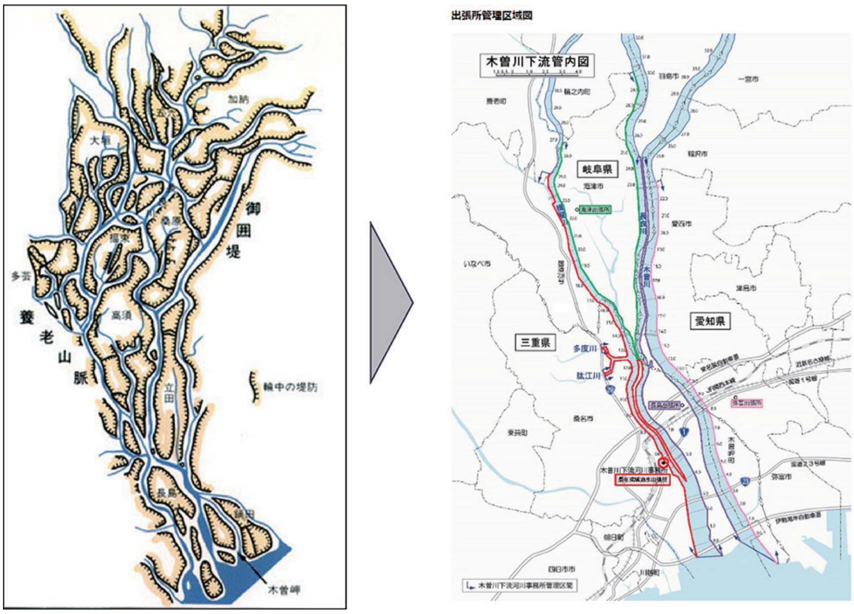

Fig. 14 Hisory of improvement of the Kiso River Basin (17c and now)

Fig. 15 A botanical garden in the flower park

Fig. 16 River environment educational park

Fig. 17 Historic river park at ancient battlefield

2.5. Nature-and-Culture-Oriented River Management (Gifu, Japan)

In the past, Japan's national land development, urbanisation and flood control measures, which did not take into account the river environment, have deteriorated the habitat, growth, breeding environment and landscape of living organisms, resulting in the disruption of the good relationship between people and rivers.

However, since the revision of the River Law in 1997, the concept of 'multi-nature river development' has been developed and applied to all rivers since 2006.

Specifically, the concept is to conserve the river's inherent habitat, growth and breeding environment for living organisms and diverse river landscapes, while taking into account the natural activities of the river as a whole and harmonising with local life, history and culture in all actions of survey, planning, design, construction and maintenance.

On the Itonuki River in Gifu Prefecture, the riverbed along the waterway and park were developed in an integrated manner. Through hydraulic analysis, the revetment was removed and the steps for approaching the waterfront were eliminated. An artificial babbling channel was created to guide people to the river.

This has encouraged children to enter the river to play.

Fig. 18 Itonuki River, before improvement

Fig. 19 Itonuki River, after completion

3. Key challenges and recommendations

Like other countries, Japan has struggled to find the right balance between green and grey infrastructure in water management. Although there are many lessons to be learned from the above activities, the authors would like to highlight the importance of community and education.

In general, green infrastructure should be well maintained to preserve its value in both infrastructure and ecosystem aspects. Community consensus and participation are essential for both purposes. In the case of the Arakawa River (2.1), the community has played a major role in maintaining both green and grey infrastructure for centuries. In the case of the Tomoe River (2.2) and the Great Forest Wall (2.3), the community has been carefully involved in the development and management of the entire infrastructure system from the very beginning, so that community members feel a sense of ownership of the infrastructure.

Education is also important, both in terms of eco-education and community involvement. In the cases of the Asahata Flood Control Basin (2.2) and the Kiso-Sansen Park (2.4), the ecosystem and biotope have been included in the curricula of local primary and/or secondary education programmes. The Itonuki River (2.5) encourages children to learn about the river. It obviously improves the quality of ecohydrological education and the commitment of the community members, who are also the grown children who have received this eco-education.

4. Conclusion

The Japanese government has long promoted nature-oriented river improvement and has implemented a number of infrastructure projects based on the struggle to find the appropriate balance between green and grey aspects of the projects. The author has presented several examples of such activities and emphasised the importance of community involvement and educational application as lessons from these experiences.

Japan will continue to improve and expand ecohydrological infrastructure development based on the balance between green and grey infrastructure, also in cooperation with the international community.

2 K-water's Integrated Gray and Green Infrastructure Development for Climate Change Response and Water Disaster Risk Reduction

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Wonho Shin,

General Manager, K-water (Busan Eco Delta Smart City)

1. Summary of the article

The integration of green and gray infrastructure presents a future-oriented approach in sustainable water management by combining the advantages of nature-based solutions and engineering systems. At the forefront of these innovative efforts, Korea Water Resources Corporation (K-water) aims to showcase exemplary cases of green and gray infrastructure integration. The goal is to demonstrate how the synergy between these two types of infrastructure can address the complex challenges of water management faced by climate change and urbanization.

This case study explores two exemplary projects in Korea : the Sihwa Lake Tidal Power Plant and the Busan Eco Delta Smart City. These projects are not only at the forefront of sustainable water management in Korea but also serve as global benchmarks for utilizing and harmonizing the functions of natural and engineering systems.

the Busan Eco Delta Smart City embodies a future vision where green infrastructure is seamlessly integrated into urban planning. This smart city demonstrates how urban landscapes can collaborate with natural processes and merge with cutting-edge ICT technologies to promote efficient water management and enhance the quality of life for its residents.

On the other hand, The Sihwa Lake Tidal Power Plant, a marvel of gray infrastructure, utilizes natural tidal movements to produce electricity, marking a significant technical achievement in the renewable energy sector. Particularly, the integration with green strategies shows a successful balance between industrial development and ecological sustainability.

By reviewing these two projects, this case study aims to provide valuable insights into the potential of integrating environmentally friendly and gray infrastructure. It highlights how such integration can lead to more sustainable, resilient, and adaptable water management practices essential in the era of rapid urbanization and climate change. Moreover, as water-related disasters increase globally, this article is confident that it will serve as a useful reference for organizations, urban planners, and policymakers striving to implement sustainable water solutions.

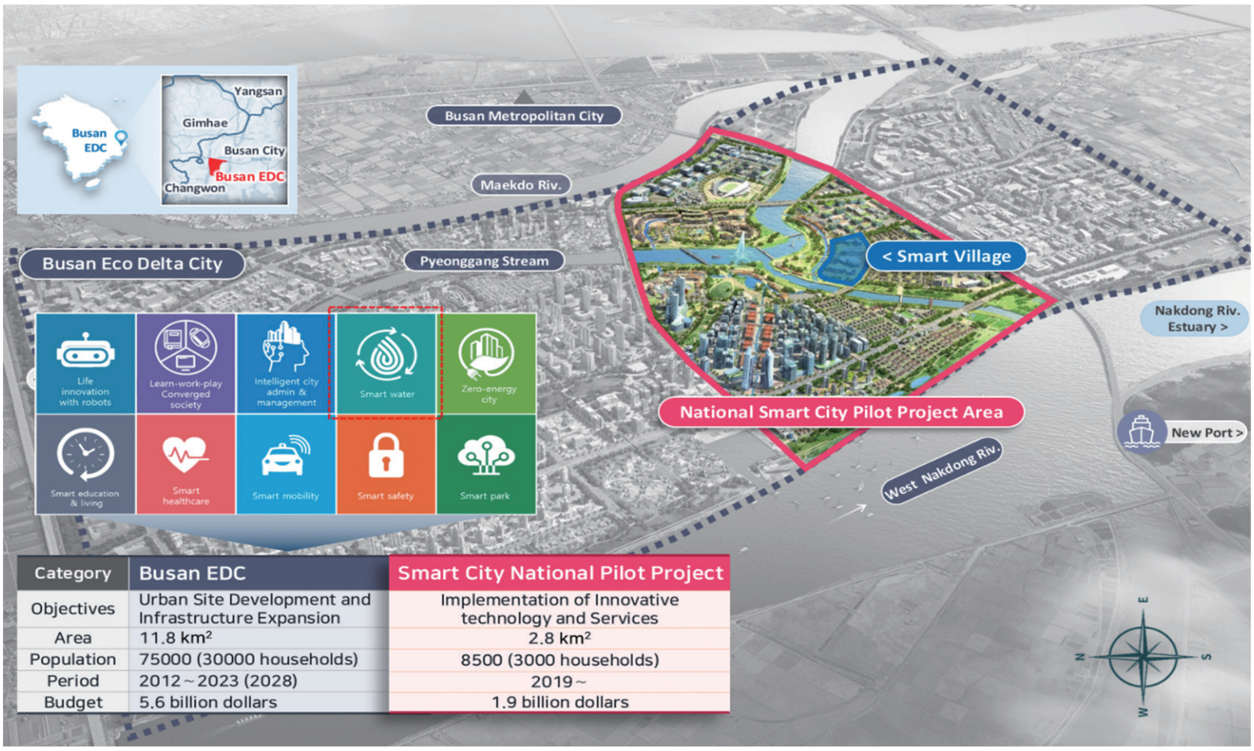
2. Details of the project

(1) Busan Eco Delta Smart City

First case is the Busan Eco Delta Smart City project. This project is part of South Korea's smart city pilot program aimed at incorporating Fourth Industrial Revolution technologies into urban development. Initiated in 2019, K-water is currently developing approximately 12 km² of urban area in the Gangseo District of Busan Metropolitan City, focusing on a central area of about 2.8 km² where ecological environments and key technologies of the Fourth Industrial Revolution converge to construct a smart city.

The project aims to implement smart technologies including smart healthcare services, smart education systems, smart transportation and safety, life innovations using robotics, intelligent urban administration and management, smart water, and a zero-energy city concept.

Notably, the city is flanked by the Nakdong River and the West Nakdong River, possessing rich water resources with three waterways at its heart, which positions it advantageously as an eco-friendly waterfront city. Based on specialized water management technologies, K-water is developing a smart water city platform that responds to climate change by applying advanced smart water management technologies and services throughout the entire urban water cycle (rainfall-river-water purification-sewage-reuse).



< View of Busan Eco Delta Smart City>

(2) Sihwa Lake Tidal Power Plant

The second case, the Sihwa Lake Tidal Power Plant, is located on the west coast near Ansan city in Gyeonggi Province, South Korea. It is part of the development plan for the Sihwa District, which surrounds Sihwa Lake. The project involved constructing a dike and land reclamation to collect fresh water from nearby rivers and turn it into a lake. Construction of the dike began in April 1987, extending from Daebudo in Ansan to Oido in Siheung, covering five sections and 12.7 km. By January 1994, approximately seven years later, the construction of Asia's longest dike, with a water surface area of 48.98 km² and a total storage capacity of 330 million tons, was completed.Tidal power generation harnesses energy from the changes in sea levels caused by tidal forces. The west coast of Korea, where tidal range differences are particularly significant—reaching up to 10.3 meters in tidal range and 7.5 meters per second in maximum flow velocity—provides favorable conditions for tidal power.

The Sihwa Lake Tidal Power Plant was built into sections of the dike blocking Sihwa Lake, with construction spanning from 2004 to 2011. It features ten 20MW Kaplan turbines, each with a rotor diameter of 14 meters and a blade length of 7.5 meters. These turbines generate a total of 254 MWh per day, which annually adds up to 552 GWh—enough to supply electricity to 500,000 people for a year.

Additionally, the natural environment adjacent to the sea has been utilized to develop renewable energy sources such as solar and wind power. The Sihwa Lake area now hosts a renewable energy cluster equipped with facilities for solar, wind, and hydrogen energy demonstration. Around the power plant, solar and wind power plants, an offshore solar power demonstration site, and energy storage systems (ESS) have been established, and there are ongoing initiatives to utilize sea thermal energy.

Category	Sihwa Lake Tidal Power Plant
Facility Capacity	254MW (10 turbine-generator)
Annual Generation	552GWh
Generation Type	Single Tide-cycle System
Period	2004~2011
Budget	0.46 billion dollars

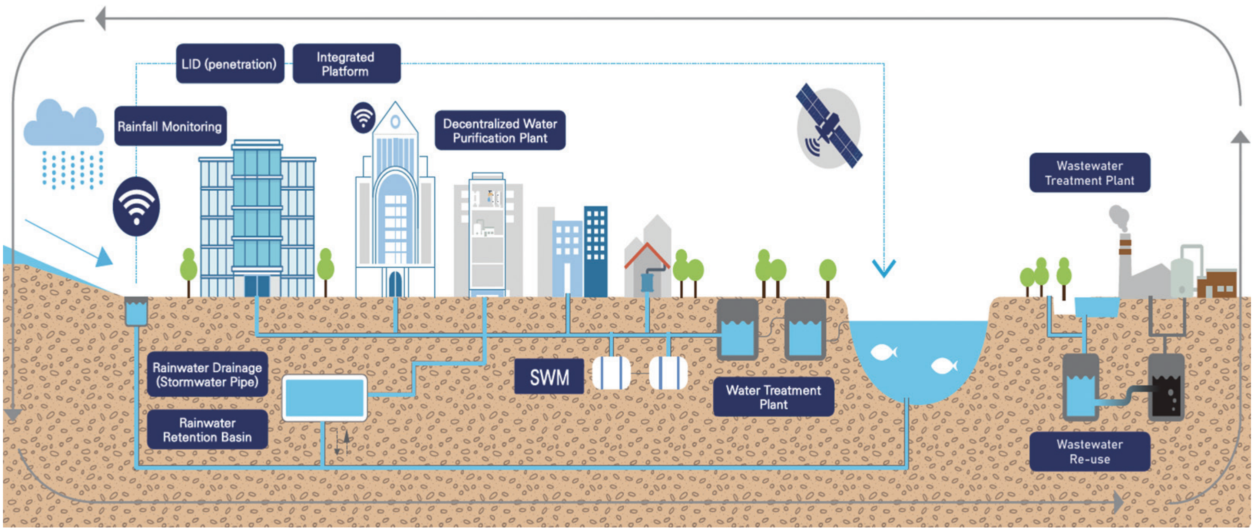
< View of Sihwa Lake Tidal Power Plant >

3. Cases

(1) Busan Eco Delta Smart City

Introduction of Specialized Water Technologies for Green Infrastructure Development and Climate Change Response

Busan Eco Delta Smart City applies advanced technologies such as Information and Communication Technology (ICT), Artificial Intelligence (AI), big data, and smart grids across the entire urban water cycle, from water sources to individual household taps. This approach enables precise management of both water quantity and quality. As a result, the city is transitioning into a sustainable water-specialized platform. Rather than merely producing, transporting, and treating water through traditional methods, this system integrates various sensors and controllers within the water movement process, creating a data-driven foundation for urban water management.



<concept of urban water circulation>

The smart water management technologies to be introduced in Busan Eco Delta Smart City include:

① Advanced Urban Flood Response System: Building a system equipped with small-scale rainfall radars and a real-time urban flood management system.

② Low Impact Development (LID): Introduction of LID practices to reduce the environmental impact of urban development.

③ Urban Stream Water Quality Improvement (Eco-filtering): Implementing eco-filtering techniques to enhance water quality in urban streams.

④ Smart Water Treatment Plants: Upgrading water treatment facilities with smart technologies for enhanced efficiency and control.

⑤ Smart Water Network Management (SWNM): Utilizing advanced monitoring and management systems to optimize water distribution and usage.

⑥ Sewage Reuse: Implementing systems to treat and reuse wastewater for various non-potable purposes.

⑦ Thermal Energy: Harnessing thermal energy from water sources for heating and cooling applications.

These technologies will be integrated throughout the entire urban water cycle to enhance the management and sustainability of water resources in the city.

Advanced Urban Flood Response System (Small-Scale Rainfall Radar, Real-Time Urban Flood Management System)

Due to the increasing trend of urban flooding and water-related disasters, there is a critical need for demonstrative rainfall observation technologies and operational techniques that can respond to localized heavy rainfall at the city level. The Busan Eco Delta Smart City is implementing state-of-the-art, high-precision small-scale rainfall radars to analyze the amount of rainfall locally and in real-time, allowing for the prediction and proactive response to potential flooding. Additionally, an urban water disaster system linked to an urban inundation prediction model based on surface terrain and network information is planned to be established.

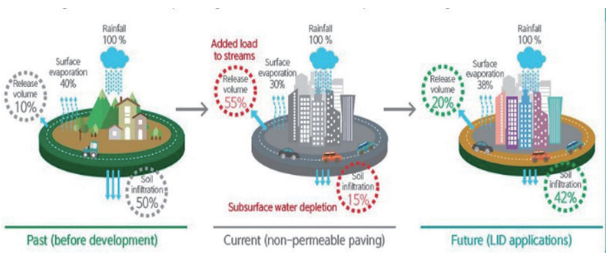
Furthermore, these high-precision small-scale rainfall radars will be installed in a central observatory within the city to create a foundation capable of responding to sudden local floods. The city plans to develop an urban flood prediction analysis model using hydrometric data, river flood information, and detailed urban flood data obtained through the rainfall radar, aiming to transform Busan into a city free from water disaster concerns.

Low Impact Development (LID)

Busan Eco Delta Smart City is currently being developed as a testbed for Low Impact Development (LID) technologies to improve the city's distorted water circulation system and enable various measures such as disaster prevention, microclimate regulation, and the health of aquatic ecosystems. Particularly, within the smart city, custom-sized green infrastructure is being constructed by applying rooftop greening, vegetative swales, rain gardens, and permeable pavements to roads, parks, and other public spaces.

Drawing from the retrospective application of LID technologies, the city plans to use a two-dimensional grid-based urban runoff model from the planning stage to analyze the quantitative effects of structural and non-structural methods. This analysis will guide the ICT-based construction and maintenance, leading to a Smart Water Balance tailored to the lifecycle of the city. Moving away from projects centered on single techniques, the city is advancing towards an integrated, multifaceted project approach to enhance urban water circulation. Ultimately, this initiative aims to contribute to the restoration of water circulation health in the Nakdong River basin and improve the quality of life for its citizens, establishing a K-water style water circulation city brand harmonized among citizens, the city, and rivers.

< ① Advanced Urban Flood Response System >



< ② Low Impact Development >

Urban Stream Water Quality Improvement (Eco-Filtering)

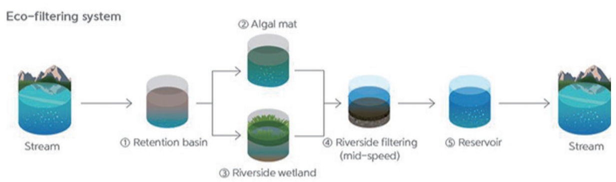
An eco-filtering system, a nature-based water purification process, is being developed along the Pyeonggangcheon and Maekdocheon rivers running through the city center to improve their water quality. This system allows water to flow naturally along the riverbanks where it is cleansed. Test beds have been operated to determine the appropriate technology and scale, including retention areas, algae mats, riparian wetlands, and riparian filtration areas. The capacity and size of the facilities have now been finalized, and installation is underway.

Smart Water Treatment Plants

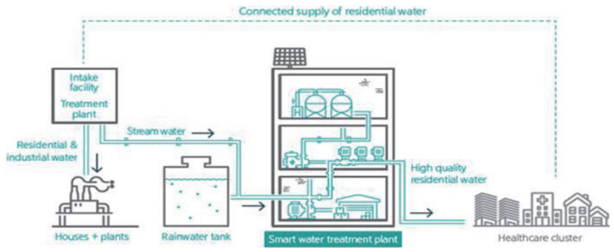
The current water supply system delivers treated water from large-scale treatment plants located near water sources to the end consumers. However, there have been several issues in the past, including leaks and water contamination during the distribution process.

To address these issues, the city has moved away from the traditional centralized, supplier-focused supply system. It has introduced consumer-centric smart water treatment plants located closer to consumers within the urban area. These plants allow residents to drink freshly treated water directly.

The plants have a capacity of approximately 1,100 cubic meters per day and utilize local water sources available in the urban area, such as rainwater, groundwater, and river water, processed through ultrafiltration methods. Additionally, the city has implemented compact vertical water treatment facilities that consider both functionality and aesthetic aspects of urban design. In the future, an automated supply system based on big data and integrated with ICT technologies is planned to enhance the efficiency and reliability of water supply.



< ③ Urban Stream Water Quality Improvement >



< ④ Smart Water Treatment Plants >

Smart Water Network Management (SWNM)

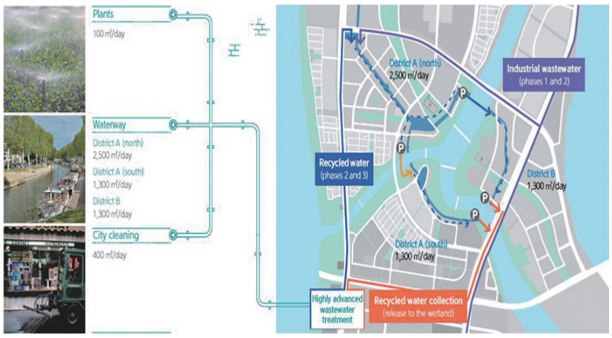
Smart Water Network Management (SWNM) is being implemented in the city, integrating Information and Communication Technology (ICT) throughout the entire process of water supply, from source to tap. This system allows for scientific management of water quantity and quality, providing real-time water quality information so that citizens can safely consume the water. For efficient network management, over 700 advanced sensing infrastructures are being installed, along with automatic drain facilities and inspection units to minimize leakage within the pipelines. Additionally, three water quality display boards are planned for installation to provide water quality information. Smart meters are also being installed in each household to provide continuous usage data, and services that detect activity patterns of vulnerable groups for enhanced living security.

Water Reuse System Development

As urban development accelerates and industrialization intensifies, the demand for domestic and industrial water is increasing, while water quality pollution and depletion of water resources are emerging as critical issues. The city of Busan plans to become a fully water-sufficient city that reuses 100% of its used water. A state-of-the-art sewage treatment plant (41,000 m³/d) is being installed underground, along with facilities for sewage reuse.

The treated water, which goes through an advanced treatment process and is of good quality, will be used as an alternative water resource for landscaping, urban water cleaning, and supplying waterways within the city for recreational water activities.

< ⑤ Smart Water Network Management >

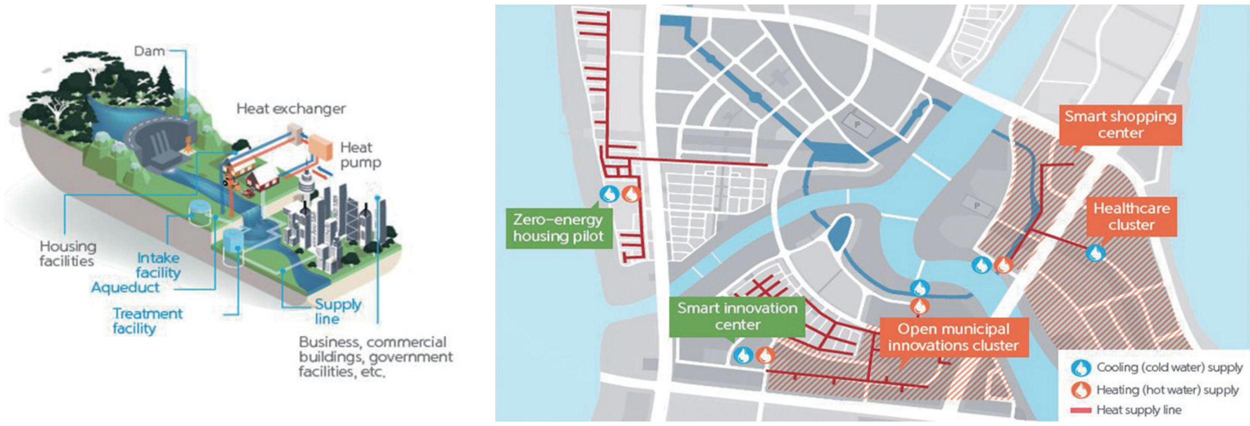


< ⑥ Water Reuse System >

Hydrothermal Energy

Busan Eco Delta Smart City is on its way to becoming an energy self-sufficient city through the establishment of a 60MW hydrogen fuel cell power plant (capable of supporting 24,500 households for a year) and the introduction of thermal energy using river water, a first in South Korea. Particularly, the city is utilizing the abundant water resources surrounding it to harness hydrothermal energy from the temperature differences between water and air, supplying this energy for heating and cooling within the city. This initiative reduces the reliance on fossil fuels and contributes to creating an environmentally friendly energy city.

Most cities in South Korea have inadequately utilized water resources as a source of energy, previously operating energy systems focused on individual buildings using tap water and seawater. However, Busan Eco Delta Smart City is the first in the nation to introduce a district-level heating and cooling system, which brings efficient energy use benefits directly to its citizens.

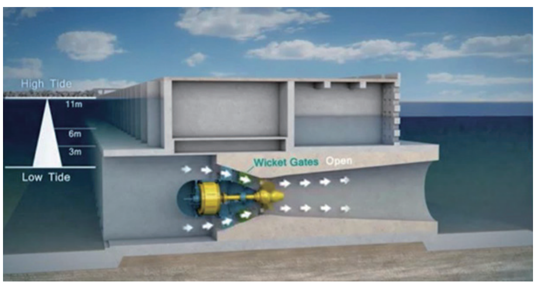


< ⑦ Hydrothermal Energy >

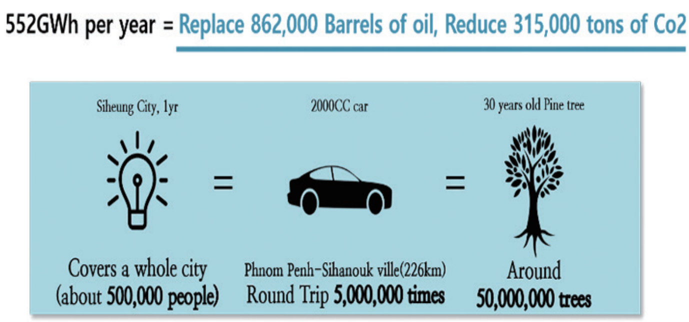
(2) Sihwa Lake Tidal Power Plant

Value as a Tidal Power Generation and Green Infrastructure Facility

Tidal power generation harnesses potential energy created by the differences in water levels during tides. Compared to solar and wind power, tidal energy is considered a more cost-effective and large-scale production option that is less affected by weather conditions, making it a reliable source of clean energy. South Korea has pledged to reduce its greenhouse gas emissions by 37% relative to its 2030 Business as Usual (BAU) projections. Through the Sihwa Lake Tidal Power Plant, K-water produces approximately 552 GWh of clean electrical energy annually, which prevents the emission of about 315,000 tons of carbon dioxide (CO2). This significant contribution to reducing greenhouse gas emissions underscores the growing importance of the Sihwa Lake Tidal Power Plant's role.



< Principles of Tidal Power Generation >



< Greenhouse Gas Reduction Effects >

Tidal Power Plant as a Hub for Renewable Energy Clusters

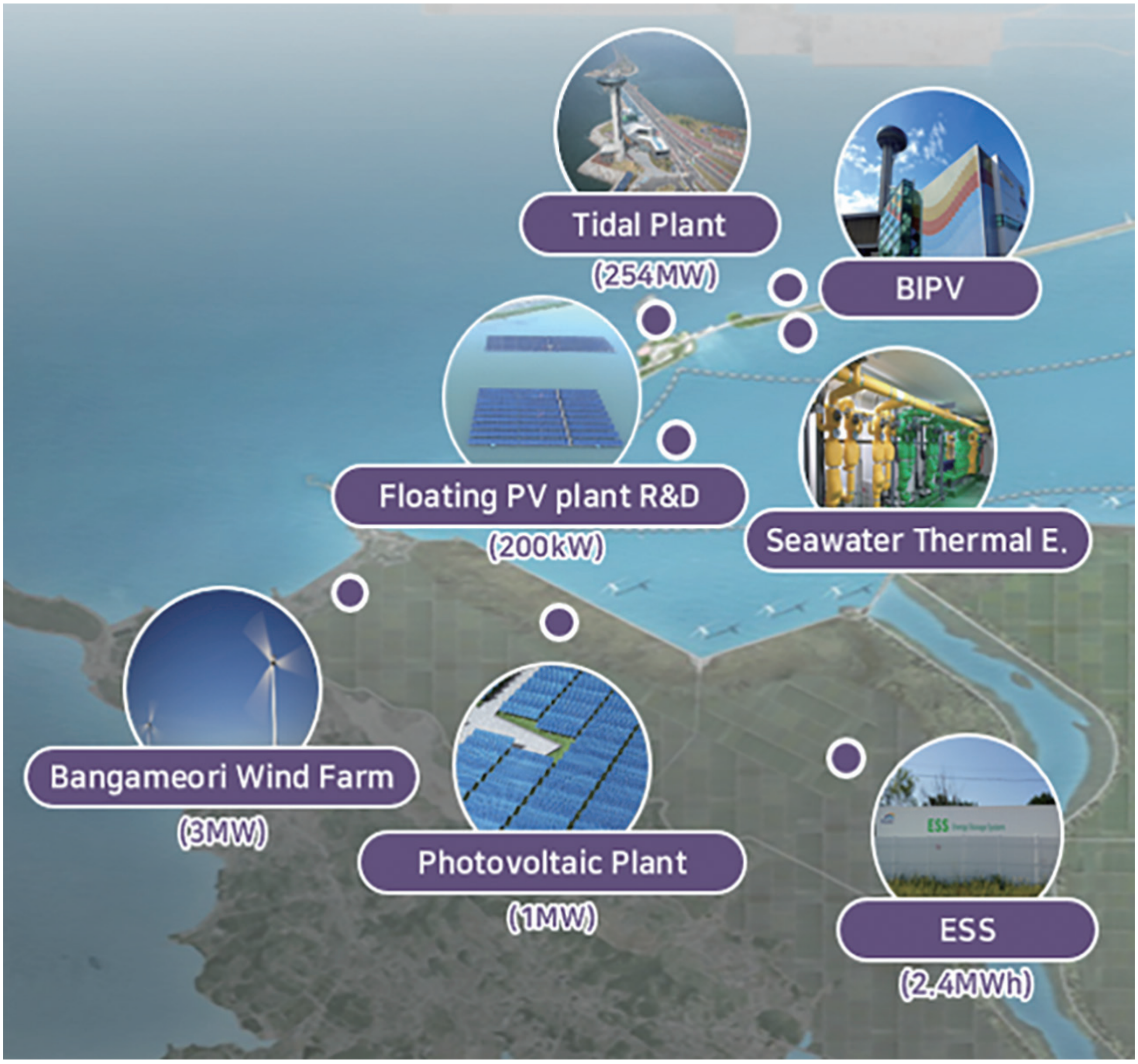
The Sihwa Lake Tidal Power Plant serves as a prime example of success in the renewable energy sector, establishing itself as a hub for renewable energy generation projects. The Sihwa Lake area boasts optimal geographic conditions for establishing a global-level self-sufficient renewable energy supply. Located adjacent to the sea, it efficiently utilizes water (tidal and seawater thermal energy), sunlight, and wind, which are abundant natural and marine resources. Geographically, its proximity to the metropolitan area also provides advantageous conditions for energy supply.

The "Bangamori Solar Power" facility, which began operation in 2016, has an installation capacity of 1MW and generates about 1.2 GWh annually. The "Bangamori Wind Power," which started in 2010, has a total capacity of 3MW and produces approximately 5.8 GWh annually. Additionally, there is an Energy Storage System (ESS) with a capacity of 2.4 MWh that can store 2.2 MWh of solar energy and 0.2 MWh of wind energy. A consortium including K-water is also conducting offshore solar R&D with an installation capacity of 200kW.

Within the management buildings of the Sihwa Lake Tidal Power Plant, a seawater thermal heating and cooling demonstration system and Building-Integrated Photovoltaics (BIPV) are being developed. The seawater thermal device uses the temperature difference of seawater, similar to hydrothermal energy, to provide heating and cooling for the facilities, currently setting up a system with a capacity of 20RT. BIPV serves dual purposes of building functionality and power generation, with plans to use solar panels installed on the exterior of the power plant building to operate heat exchangers and heat pumps during seawater heating and cooling. This system has a capacity of 27kW, with a project budget of 320 million KRW.

Furthermore, K-water plans to build a hydrogen infrastructure facility at Sihwa Bangamori in collaboration with the city of Ansan. This facility will use the 3MW from Bangamori wind power and 1MW from solar power to produce green hydrogen through water electrolysis, supplying hydrogen at a scale of 240 kg/day for experimental research and providing 300 kg/day of hydrogen to fuel 60 cars at a hydrogen refueling station, along with a carbon-neutral education and promotion center.

An expansion of the Sihwa Lake Tidal Power Plant is also under consideration. The plan includes adding four turbines and six sluice gates to increase the power generation by 112 GWh (25% increase) and enhance the seawater flow by 12.7 billion tons (26% increase), which is expected to further reduce carbon dioxide emissions by an additional 51,000 tons (25% increase).



< Overview of the Sihwa Renewable Energy Cluster >

Exemplary Case of Eco-Friendly Growth

As we enter an era of energy transition aimed at carbon neutrality, the Sihwa Lake Tidal Power Plant is being recognized as a symbol of eco-friendly renewable energy. The plant significantly contributes to the improvement of water quality and the restoration of the ecological health of Sihwa Lake by circulating 14.7 million tons of seawater daily. This activity not only helps restore the aquatic ecosystem directly and indirectly but also generates significant economic impacts, inducing production worth KRW 1.3 trillion and creating approximately 10,000 jobs, serving as a model for eco-friendly growth.

The Sihwa Lake Tidal Power Plant is at the forefront of integrating Fourth Industrial Revolution technologies and leading the Digital New Deal policies. K-water, which manages the operation of the tidal power plant, is driving change by incorporating Information and Communication Technology (ICT) into the Sihwa Lake area. They are creating a "data dam" using infinite resources and data, and advancing the application of Fourth Industrial Revolution technologies such as digital twins and artificial intelligence (AI).

A notable digital twin technology at the Sihwa Lake Tidal Power Plant is the 'K-TOP' (Tidal Power Operation Program), developed and completed in 2018. 'K-TOP' is a digital program designed to calculate the power generation under the same conditions as the actual generators installed, providing a power generation schedule that maximizes output considering the constantly changing tides. It includes features for calculating the power generation of bidirectional generation methods, which can be utilized in future tidal power constructions both domestically and internationally. Additionally, the 'Real-time Automatic Sluice Operation AI' incorporates an algorithm that predicts changes in sea level in real time, designed to automatically open gates and drain water from Sihwa Lake as needed.

4. Key challenges and recommendations

Major Challenges

Due to climate change and rapid urbanization, complex water management issues arise that demand innovative approaches. These issues are challenging to address with traditional water management methods alone, necessitating a sustainable and resilient water management system.

The integration of modern infrastructure with nature-based solutions is crucial to balance technological achievements and environmental conservation. For instance, the Sihwa Lake Tidal Power Plant simultaneously pursues renewable energy production and environmental restoration, seeking this balance. Additionally, as seen in the Busan Eco Delta Smart City project, there is a need to integrate smart technologies with water management to establish a more efficient and intelligent water circulation system. This approach optimizes water quantity and quality management and promotes water resource reuse and recycling.

Recommendations

To achieve sustainable water management and reduce water disasters, a forward-thinking approach that blends the benefits of nature-based solutions and engineering infrastructure should be adopted. This approach can respond to climate change and enhance ecological sustainability in urban environments.

Advanced technologies such as Artificial Intelligence (AI), big data, and smart grids should be integrated into water management strategies to proactively address predictable environmental changes and strengthen the capacity for disaster prevention and management.

Furthermore, engaging the community and fostering close collaboration with policymakers are essential to develop and implement sustainable water management policies. This ensures broad stakeholder participation and mobilizes a variety of perspectives and resources.

5. Conclusion

The integration of green and gray infrastructure presents a crucial solution for reducing water-related disasters, and this approach can evolve into a more effective strategy when combined with advanced water management technologies such as artificial intelligence and digital twins. As seen in the cases of Busan Eco Delta Smart City and Sihwa Lake Tidal Power Plant, this technological integration is essential to address the increasing water management challenges posed by climate change and urbanization.

Busan Eco Delta Smart City, currently being developed by K-water, applies water management solutions throughout the entire urban water cycle. This enables the city to autonomously prevent and adapt to climate change, creating an optimized urban model for eco-friendly energy production and circulation. This model is expected to enhance the city's resilience to climate change effectively.

The Sihwa Lake Tidal Power Plant has been redeveloped from its original embankment construction to incorporate environmental values into a new infrastructure facility. As the world's largest tidal power plant, it has been reborn as a structure that combines various renewable energy facilities including tidal power, solar energy, marine thermal energy, and wind power.

In conclusion, combining the ecological benefits of green infrastructure with the structural strengths of gray infrastructure and cutting-edge technology plays a vital role in maximizing the efficiency of water management, enhancing urban resilience to extreme weather events, and protecting and restoring urban aquatic ecosystems. This integrated approach is essential for building a sustainable and resilient water management system and needs to be applied more broadly worldwide to reduce water-related disasters.

3 Green solutions for disaster risk reduction and climate change adaptation in the Netherlands

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1. Introduction

The Netherlands has over 1000 years of history of water resources management and protection against floods from rivers and the North Sea. Over the centuries the Dutch have shaped the Rhine-Meuse delta by building infrastructure to manage the water, to protect land against flooding and to reclaim land from the water. This resulted in highly complex water systems consisting of a network of rivers, streams, lakes, aquifers, canals, ditches, and related infrastructure such as sluices, dams, weirs, pumps, groynes, embankments and levees. As 10 million people of the Netherlands are living in areas prone to flooding from either the sea or river and 70% of its economy located in these areas, the main priority in water management is flood protection. Flood defenses, such as dikes, dams and storm surge barriers are the most important measures in the Dutch flood safety system, providing high safety standards varying between 1/100 to 1/100,000 per year, depending on the region.

Increasingly confronted with the current and expected effects of climate change, as well as the societal changes and priorities, there is a growing awareness to include nature-based solutions in building resilience to climate change. The flooding problems of the 1990's have considerably influenced the way in which the Netherlands deals with flooding risks. Consequently, the discourse gradually changed from merely constructing grey infrastructure as flood defense (dikes, storm surges, barriers) to approaches that include building upon natural processes. Such nature-based solutions are considered to be an effective strategy to build resilience to climate change and provide a more flexible and future-proof approach to flood risk management as the ability of natural flood defenses to adapt to sea level rise reduce risks of lock-in situations that might arise from grey infrastructure solutions.

Climate change and sea level rise will have an increasing impact on flood protection and the availability of freshwater resources and the resulting implications for society, economy and biodiversity. The Dutch Delta Program was initiated to tackle the new challenges through a holistic and integrated approach to water management and to keep the Netherlands the safest the delta in the world. Recognizing that the impacts of climate change will unfold over decades, the Delta Program has a long-term perspective on building resilience through its water infrastructure to protect the Netherlands from flooding, ensuring a sufficient supply of freshwater and adapting to the impact of climate change (Van Alphen, 2015; Van den Aarsen, 2023).

This chapter presents several cases in the Netherlands where nature-based solutions are strengthening the existing flood protection infrastructure along the rivers and North Sea coast. Nature-based solutions are also implemented as a strategy to build resilience to a changing climate in rural areas (e.g., natural water retention measures as a combined floods and drought risk management strategy) and urban areas (e.g., building resilience to heat stress and extreme rain fall).

2. Nature-based solutions

In the past decades the concept of nature-based solutions ("ecosystem-based adaptation", "eco-DRR" or "green infrastructure") has developed into an alternative or complement to traditional gray infrastructure approaches (World Bank, 2017; EEA, 2021; Bridges et al., 2021b). These interventions can be completely "green" (i.e. consisting of only ecosystem elements) or "hybrid" (i.e. a combination of ecosystem elements and hard engineering approaches). Nature-based solutions are actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits (UNEA, 2022). Nature-based solutions are increasingly seen as important to mitigate the risks associated with water related disasters and reduce the impacts of climate change in combination with their ability to provide ecosystem services and biodiversity benefits (Figure 1). The growing scientific evidence demonstrates the full opportunity of nature-based solutions for disaster risk reduction and climate change adaptation (World Bank, 2017; Timboe et al., 2022; DeWit et al., 2022). Nature-based solutions are applicable in catchments and streams, large rivers, urban areas and coastal areas. In each domain the type of specific nature-based solutions might be different, but their overarching characteristics and objectives are the same, reducing the risks and impacts of water-related extreme events and additionally providing a multitude of co-benefits for society and nature. Nature-based solutions can play a key role in flood protection in river catchments (Opperman & Galloway, 2022). Nature-based coastal protection is increasingly recognized as a potentially sustainable and cost-effective solution to reduce coastal flood risk. It uses coastal ecosystems such as mangrove forests, salt marshes and seagrass beds to create resilient designs for coastal flood protection (World Bank, 2017; Van Hespen et al., 2023). In addition, nature-based solutions can also help mitigate droughts, erosion and landslide, forest fires and heath waves. The multiple benefits from nature-based solutions for disaster risk reduction and climate change adaptation are summarized in Figure 1. Nature-based solutions may also create multiple benefits to the environment and local communities. These include sustaining livelihoods, increasing biodiversity, improving food security, and sequestering carbon (Anisha et al., 2020; DeWit et al., 2022). Such solutions can be applied to river basins (e.g., riparian wetlands and floodplain forests), coastal zones (e.g., mangroves and coastal wetlands), and cities (e.g., urban parks).

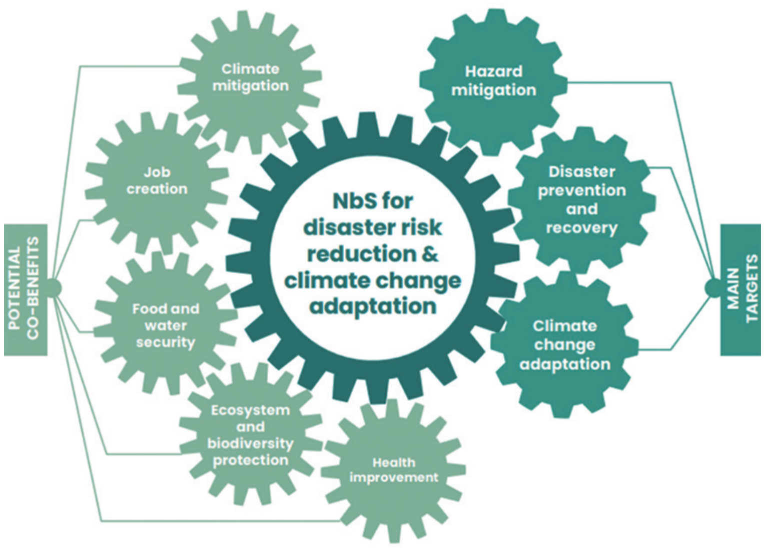

Figure 1: Multiple co-benefits from nature-based solutions for disaster risk reduction and climate change adaptation. From: DeWit et al., 2022.

3. Case studies

Green solutions for flood risk reduction need to be adapted to the ecosystem they are placed in. Consequently, different sets of potential green solutions for flood protections are available in rivers, coastal areas, and estuaries. This paragraph gives an overview of implemented large-scale green solutions for flood protection in different water-systems in the Netherlands. More and more, nature-based solutions are implemented to reduce the risks on droughts and pluvial flooding. Those solutions will be briefly introduced in paragraph 4.

3.1. Room for the river: the Meuse bordering the Netherlands and Belgium

The awareness of restoring ecological values of the main rivers Rhine and Meuse was growing in the late 1980's in the Netherlands (Van Looy & Kurstjens, 2022). Consequently, the rivers Rhine and Meuse and their floodplains were recognized as the backbone of the ecological main infrastructure in the Netherlands. This resulted in strategies and plans for ecological rehabilitation of floodplains by creating room for the rivers through lowering of floodplains, constructing lateral channels and widening of the main channel. The extreme flood events of 1993 and 1995 created strong political momentum to improve the flood resilience of the Dutch river systems and river management authorities emphasized the need for a flood risk management strategy based on increasing the discharge capacity on the one hand and improving the ecological and landscape values on the other hand (Pedroli & Dijkman, 1998; Smits et al., 2000; Duel et al., 2002). This resulted in the acceptance of creating room for the rivers as a cost-effective method to protect against floods while enhancing ecological values. A flagship room for the river project that simultaneously provide environmental, social and economic benefits and helps to build resilience is the Grensmaas project (Figure 2). The Grensmaas is a 45 km free flowing stretch of the river Meuse bordering the Netherlands and Belgium. The Grensmaas is the only gravel river in the Netherlands. Room for the river measures are implemented at both sides of the river, making this a transboundary project. The floodplain lowering of the Grensmaas is being combined with commercial gravel and sand mining. When the room for the river Grensmaas project will be fully implemented in 2027, a total volume of 54 million tons of gravel and 10 million tons of sand will have been extracted (Rijkswaterstaat, 2018). The room for the Grensmaas river project is largely funded through the commercial gravel extraction. Although not all the measures are fully implemented yet, the room for the river approach has demonstrated already its values, both in terms of flood projection and ecological restoration. The villages alongside the Grensmaas were not flooded during the flood event in summer 2021, despite the flood event of the river Meuse in summer 2021 was bigger than then the floods in 1993 and 1995.

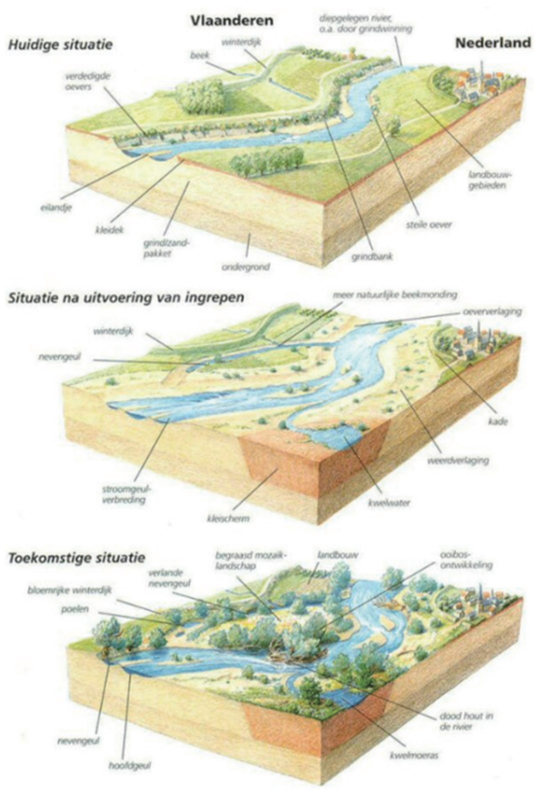

Figure 2: The Living Grensmaas concept: situation before implementing room for the river measures (above), after lowering the floodplains and creating lateral channels (middle) and in near future due to ecological processes (below). Source: Bureau Stroming[1]

[1] *https://www.stroming.nl/nl/overzicht/levende-grensmaas*

The room for the river measures also restore river ecosystems and providing habitats for endangered riverine flora and fauna. As a result, the Grensmaas is a dynamic, braided river landscape with a wide variety of habitats, instream complexes of riffles and pools habitats, sand and gravel bars, lateral channels, varied shorelines, and complexes of floodplain habitats, such as marshes, grasslands, and floodplain forests (Van Looy & Kurstjens, 2022).

3.2. The Sand Motor at the North Sea Coast

The Dutch North Sea coast consists mainly of sandy beaches and dunes. The beaches and dunes are a natural flood defense and protecting the Netherlands from coastal flooding. The beaches and dunes are also important for nature and recreation. Large parts of the Dutch shoreline is permanently eroding due to the prevailing currents in the system. To safeguard the hinterland of the Dutch coast, regular large scale sand nourishment is needed. A total volume of about 12 million m3 of sand is yearly needed to project and maintain the sandy shoreline, distributed over several sites that are sensitive for sand erosion (Brand et al., 2022). A traditional sand nourishment at a site contains a volume of 2-5 million m3 (Huisman et al., 2021). The lifespan of the nourishment is typically in the order of 5 years. This means that every 5 years the nourishment needs to be repeated, resulting in a frequent disturbance of the coastal ecosystem.

To explore alternative solutions for frequent sand nourishments along the shore, the Sand Motor Pilot Project was initiated in 2011. The Sand Motor is a mega-nourishment that supplied a much larger volume of sand in one specific location. After that, natural processes due to wind, currents and waves are redistributing the sand from the Sand Motor along the coast and towards the dunes. The mega-nourishment started as a hook-shaped peninsula of about 21.5 million m3 of sand, 1 km into the sea and 2 km alongshore (Huisman et al., 2021). The sand was dredged 10 kilometers off the coast and deposited nearshore to construct the hook-shaped peninsula. Long term detailed monitoring of the developments of the Sand Motor was carried out to better understand the dynamics and effectiveness of this mega-nourishment and showed that the concept was effective (Figure 3).

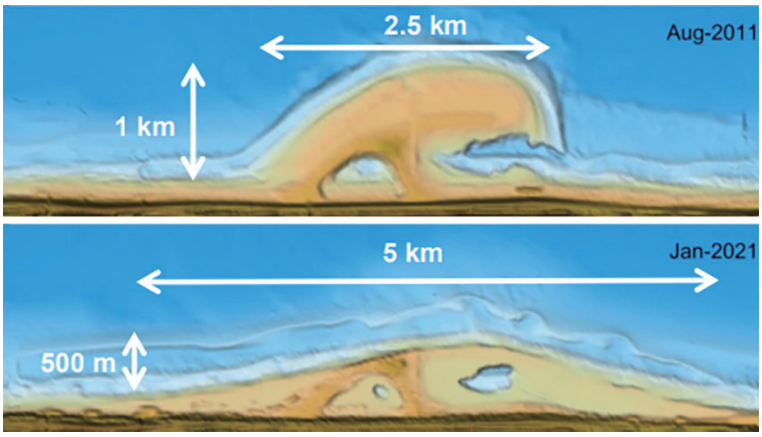

Figure 3: The development of the Sand Motor between 2011 and 2021 (Huisman et al., 2023).

This innovative approach of maintaining the shoreline limits the disturbance of local ecosystems while providing new opportunities for nature and recreation. The evaluation of 10 years of the Sand Motor showed that this innovative approach of large-scale coastal measure is very successful in terms of maintenance of the natural flood defense, ecological values and benefits for recreation. After 10 years the coastline has widened (Figure 4), and the dunes are growing well and therefore improve coastal protection. The Sand Motor will continue to develop in the years to come. The more sand spreads towards the dunes and beach, the less will remain of the original sandbank. The Sand Motor will become more and more elongated on the longer term as a result of alongshore redistribution of sediment (Luijendijk et al., 2019). The cross-shore width of the Sand Motor will decrease, while the beaches become wider. These changes will, however, take many years, meaning that the Sand Motor will be recognizable for another ten to twenty years as a seaward protrusion of the Delfland coast. Dune formation is expected to increase further in the coming years (Huisman et al., 2023). The Sand Motor has also created a wide range of habitats for species that are depending highly on the coastal ecosystems, including birds, macro-invertebrates and dune plants. Leisure visitors are valuing the landscape.

The concept of the Sand Motor demonstrates the value of large-scale coastal measures for protecting sandy shorelines and let natural processes do the work for building natural flood defenses. Additional pilots have been set up along the Dutch coast, but also internationally such as UK and Egypt.

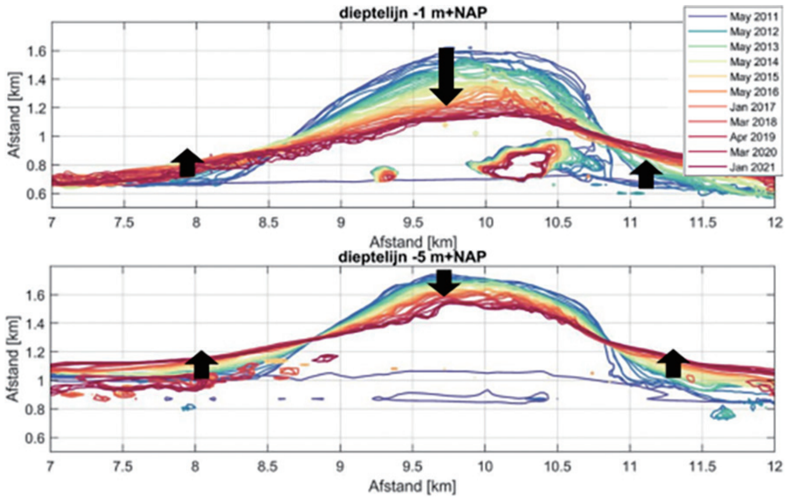

Figure 4: Coastline changes at the 1 and 5 meter depth contour (dieptelijn) of the Sand Motor between 2011 and 2021, distances (afstand) in km (Huisman et al., 2023).

3.3. Flood protection through reinforcing coastal dikes with salt marsh development

The Wadden Sea is the largest intertidal ecosystem in the world. The Wadden Sea is a large, temperate, relatively flat coastal wetland environment, formed by the intricate interactions between physical and biological factors that have given rise to a multitude of transitional habitats with tidal channels, sandy shoals, sea-grass meadows, mussel beds, sandbars, mudflats, salt marshes, estuaries, beaches and dunes. The Wadden Sea is protected by international agreements and is a designated UNESCO World Heritage site.

This case presents a pilot to improve the coastal protection through reinforcing an existing sea wall of the Wadden Sea coast near the city of Delfzijl in the Northeast of the Netherlands by artificially constructing new salt marshes (Figure 5). Coastal wetlands play important role in flood protection due to their capacity to reduce the impacts of waves (Baptist et al., 2021). The project was initiated by the municipality to explore the potential of improving coastal protection by combining nature-based solutions with reinforcing the existing grey infrastructure, while creating opportunities for enhancing ecological values and improving the water quality. The aim of the project was to investigate the best way to restore and construct salt marshes by reusing sediment from the port of Delfzijl and the Ems-Dollard estuary that is meeting the requirements for improving coastal protection while enhancing the ecological values. In total of 28 hectares of artificial salt marshes were constructed. The design of the marshes was a result of intensive stakeholder engagement processes resulting into an integrated design that was containing elements that were relevant and interesting for all parties involved, including experimental plots to better understand which initial construction choices would best stimulate the establishment of the saltmarsh. The strong stakeholder involvement has proved to be essential for the implementation and success of the project. The project was monitored between 2018 and 2020 to collect information on the morphological and ecological development of the marshes and lessons learned will be used to prepare guidance for design, construct and monitor salt marshes and use the salt marshes' ecosystem services.

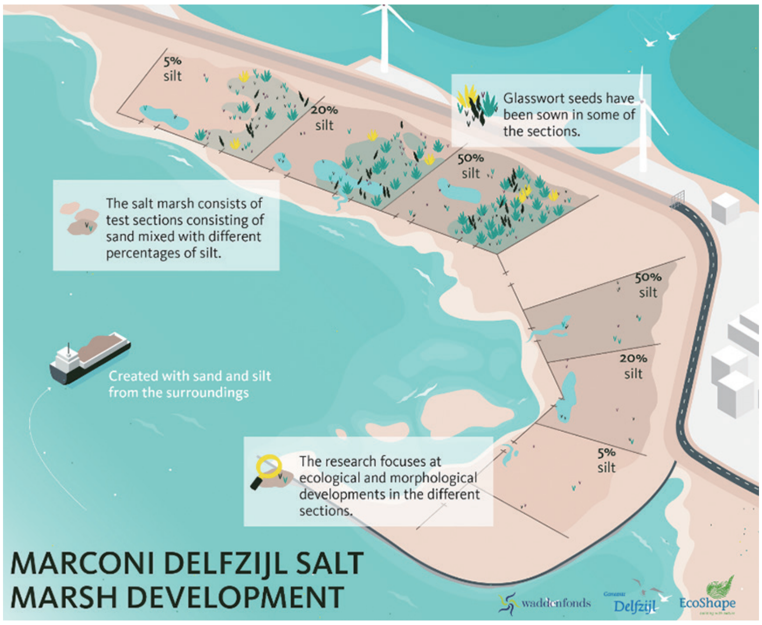

Figure 5: Design of the artificial salt marsh at Marconi near the city Delfzijl, the Netherlands (source Ecoshape)[2]

The presence of a wave attenuating salt marsh in combination with an alongshore dam forms a hybrid flood defense and provides a good basis to protect part of the town center of Delfzijl (Baptist et al., 2022). Model calculations showed that the presence of the salt marsh leads to a reduction of the significant wave height of 25% for wave overtopping over the dike at a flood level of 7 m above mean sea level and of 60% reduction at a flood level of 4 m above mean sea level, when compared to the original situation without the salt marsh (Van Lente & Vuik, 2020; Baptist et al., 2022).

Besides increasing coastal flood protection, the nature-based coastal defense is supporting nature and its biodiversity and can secure ecosystem services for human wellbeing. The Marconi constructed saltwater marshes demonstrates how large-scale natural coastal defenses can build back. To boost vegetation cover and species richness balanced mixing sand with mud is essential. Strong stakeholder engagement with key actors greatly enhances successful project implementation.

[2] *https://www.ecoshape.org/en/cases/marconi-salt-marsh-development*

The pilot salt marsh in September 2020, about two years after construction (Source Ecoshape)[3].

3.4. Wide Green - Grey Infrastructure alongside the Ems-Estuary

The fourth case presented in this chapter also combines nature-based solutions with existing grey infrastructure. Traditionally, coastal sea dikes have a sand core which is covered, on the seaward side, by a layer of clay and grass at the crest. The middle and lower part on the seaward side is covered by a revetment of stones or concrete blocks protecting the toe of the dike and sometimes a foreland adjacent to the dike (Figure 6). This cover of rocks, concrete, clay and grass protects the outer slopes against wave impact (Van Loon-Steensma & Schelfhout, 2017). The coastal sea dikes usually have steep slopes of 1:3 to 1:4. The Wide Green Dike is an innovative dike design concept to reinforce the existing traditional dikes along the Dutch Wadden Sea coast to meet current safety standards and prepare for the effects of climate change, as well as to enhance the nature and landscape values of the Wadden region. A Wide Green Dike has a grass-covered mildly sloping seaward face with a slope of around 1:7 and merges smoothly into the adjacent salt marsh. The combination of forelands (salt marshes) and gentle seaward slope of the Wide Green Dike are very effective in reducing wave impacts.

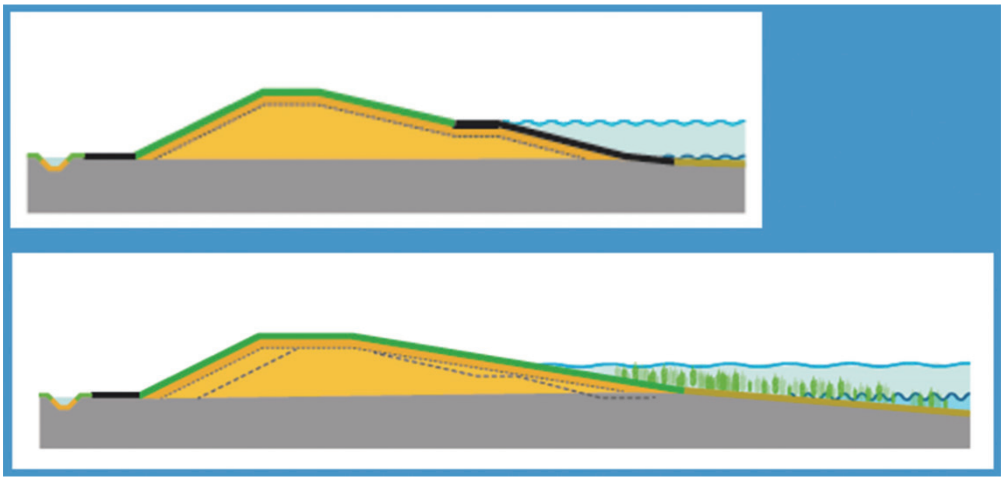

Figure 6: A traditional dike (above) and a wide green dike (below). From: Huiskens, 2016.

[3] *https://www.ecoshape.org/en/cases/marconi-salt-marsh-development/*

Alongside the Ems estuary a pilot project was started to reinforce existing embankments by reusing soft sediments (silt) from the estuary to implement to Wide Green Dike concept. This project is a collaboration between governments, environmental organisations and private sector with the aim to improve flood protection while strengthen both the economic and ecological development of the estuary. To maintain the Ems estuary large amounts of sediment are dredged yearly. To make dredged material from the estuary suitable for reinforcement clay ripening and maturation is needed. This process was taken place in specially designed clay ripening areas (“kleirijperij”) to contribute to large-scale silt extraction in a cost-effective way. In 2022, the waterboard Hunze & Aa’s has strengthened 750 meters of a flood protection dike, using 70,000 m3 of matured clay. Currently, the pilot is monitored to assess the robustness of this solution and to design guidelines for future use in dike reinforcement projects.

The reinforcement of existing coastal dikes by applying the Wide Green Dike concept are an innovative approach to meet all mandated engineering criteria for withstanding extreme conditions in the current climate, while offering additional advantages, such as greater robustness under extreme conditions in a future climate, more flexibility for adaptation and enhanced nature and landscape values. A Wide Green Dike merges smoothly into the Wadden Sea coastal landscape, which is characterized by a shallow tidal sea, sand flats and mudflats, and extensive semi-natural salt marsh along the coastline (Van Loon-Steensma & Schelfhout, 2017). The reuse of the sediments of Ems estuary offers a cost-effective approach to reinforce the dikes along the Ems estuary through the Wide Green Dike concept. In this case, the wide, gently sloping grass-covered dike is cheaper to build than a traditional steep dike with a revetment made of concrete or stones. Moreover, cyclic harvesting of sediment for periodic dike reinforcement appeared to be a sustainable option for adapting to future sea level rise.

4. Challenges for mainstreaming

The Sendai Framework for Disaster Risk Reduction (SFDRR) recognises the role of ecosystems and environment as a cross-cutting issue in disaster risk reduction, emphasising that ecosystems need to be considered in undertaking risk assessments, risk governance and investing in resilience (UNDRR, 2015). The SFDRR clearly refers to climate change adaptation and disaster risk reduction and supports the uptake of nature-based solutions: (i) 'to enable policy and planning for the implementation ecosystem-based approaches' in order 'to build resilience and reduce disaster risk', and (b) 'to strengthen the sustainable use and management of ecosystems and implement integrated environmental and natural resource management approaches that incorporate disaster risk reduction'. In addition, nature-based solutions support the implementation of the Sustainable Development Goals and the Water Action Agenda 2030 referring to the services they provide and the resilience they offer to society. Moreover, nature-based solutions are increasingly recognized to offer great potential to enhance urban resilience to climate change while bring more and more diverse nature into cities (Naumann & Davis, 2020).

Although adaptation to water-related climate risks and impacts makes up the majority of adaptation efforts worldwide (Timboe et al., 2022), well-functioning ecosystems provide important biodiversity and ecosystem services, such as flood protection, water storage, water flow and water purification. As ecosystems are also depending on water, water is also a solution for building resilience to climate change.

Successful implementation of large-scale nature-based solutions requires a systematic approach, comprehensive assessment, co-creation process with all relevant stakeholders, and carefully designed implementation processes. In the Netherlands, the concept of nature-based solutions has been applied to coastal protection and mitigation of flood risks from the large rivers Rhine and Meuse. In addition, there are also examples of nature-based solutions to mitigate floods and droughts in rural landscapes and to mitigate extreme weather events in urban areas.

In the Netherlands, more and more cities are developing green infrastructure as an approach to build resilience to climate change. The City of Rotterdam is one of the pioneers in developing innovative green infrastructure to transform pluvial flooding risk and heath stress challenges into solutions that provides communities safe, climate-resilient green spaces and at the same time boosts the local economic development through the creation of green jobs. Green urban infrastructure includes amongst other green solutions, green parks with water retention ponds, roof parks, rain gardens, urban wetlands, and green corridors for water infiltration (Tillie & Van der Heijden, 2016). The green infrastructure is also advancing social resilience, not only through protecting residents against the changing climate, but also bringing employment and providing opportunities to recreational activities and many more activities.

Nature-based solutions aiming to restore the sponge characteristics of landscapes will improve the resilience of rural areas against hydrological extreme events and reduce the vulnerability to both droughts and floods (Penning et al., 2023). Natural water retention measures to enhance the water storage potential of landscapes, soils and aquifers and foster ecosystem services for mitigating the impacts of floods and droughts have been implemented across the rural landscapes in the Netherlands in the past decades.

Despite the demonstrated values of nature-based solutions, mainstreaming these solutions is still hampered. Recently, the Netherlands has implemented a spatial planning policy that promotes natural processes of water and soil as a guiding principle for future urban development and land use and that stimulates climate resilience at a catchment level combining different types of nature-based measures into overarching strategies (Figure 7). In addition, the Government of the Netherlands has made a large fund available for piloting nature-based solutions as a strategy for building resilience to climate changing called NL2120[4].

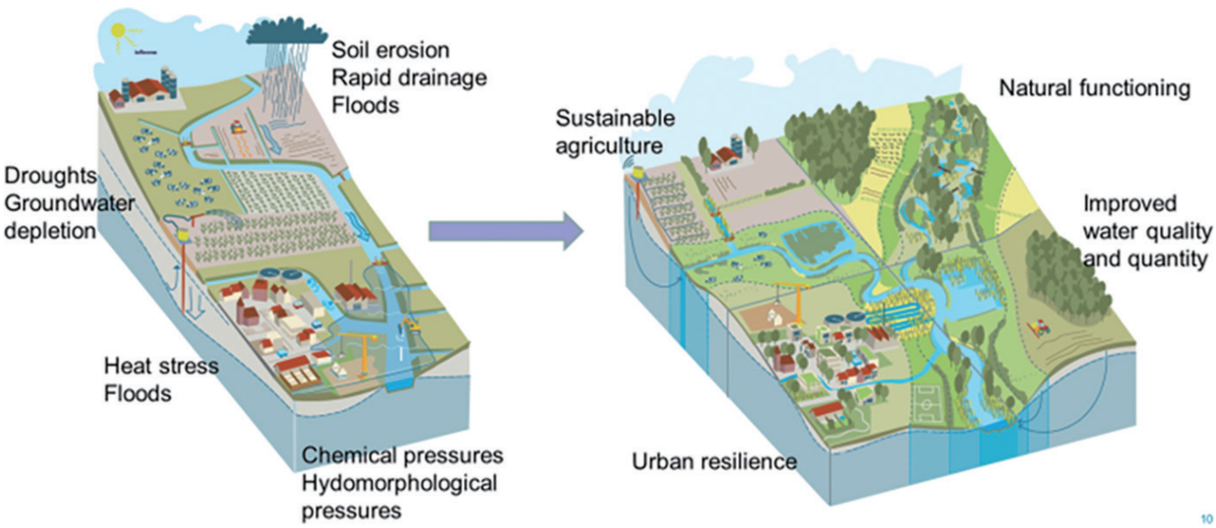

Figure 7. Nature-based solutions for climate resilient catchments (adapted from STOWA)[5]

[4] *https://www.nationaalgroeifonds.nl/overzicht-lopende-projecten/thema-landbouw-voedsel-en-land-en-watergebruik/nl2120-het-groene-verdienvermogen-van-nederland*

[5] *https://www.stowa.nl/publicaties/praatplaat-naar-een-klimaatbestendig-beekdallandschap*

Technical advancements in support of nature-based solutions are increasingly the subject of peer reviewed and other technical literature. Best practices of nature-based solutions in the Netherlands are frequently illustrating international guidance documents to inform program level action and technical practice for implementing nature based solutions (e.g., World Bank, 2017; Van Eekelen & Bouw, 2020; Bridges et al., 2021a, 2021b).

5. Conclusions

Nature-based solutions for climate change adaptation and disaster risk reduction are actions that work with and enhance nature to restore and protect ecosystems and to help society adapt to the impacts of climate change and slow further warming, while providing multiple additional benefits.

The Dutch main water systems face pressing environmental, economic and societal challenges due to climatic changes and increased human pressure. There is an increasing momentum for the use of nature-based solutions as part of resilience-building strategies, sustainable adaptation, and disaster risk management portfolios in the Netherlands. Nature-based solutions are not replacing gray infrastructure, on the contrary: combining nature-based solutions with (existing) gray infrastructure can offer additional robustness and flexibility in risk management and adaptation as illustrated by the cases in the Netherlands. Nature-based solutions are preferred where possible and grey infrastructure solutions are chosen when necessary.

Stakeholder involvement, dialogue and co-design of tools and measures are key to increase awareness, to tackle potential stakeholders' conflicts more effectively and to create social acceptance and demand for nature-based solutions. Awareness at governments, spatial planners, water managers, environmental agencies and organisations, economic sectors, society at large is growing that nature-based solutions provide cost-effective solutions for disaster risk reduction and climate change adaptation and simultaneously provide environmental, social and economic benefits and help building resilience.

Despite the showcases of large-scale nature-based solutions for mitigation flood risks from sea and main rivers, mainstreaming large-scale nature-based solutions has not used its full potential in the Netherlands yet. Key factors that will contribute to further effective application of nature-based solutions to mitigate water-related extreme events include:

- Fitting nature-based solutions into the landscape context and aligning them with natural (ecological) processes and seeking synergies across sectors is essential.
- Design of nature-based solutions is to be based on evidence of their functioning under normal and extreme conditions and knowledge of their development over time, considering the long-term perspective of changing climate.
- Integrating nature-based solutions with complementary existing grey infrastructure can provide robust future-proof solutions especially in locations where fully green options are not feasible due to e.g. a lack of space.
- Stakeholder engagement through co-designing and co-developing nature-based solutions will facilitate effective uptake and implementation of nature-based solutions.
- Strong institutional embedding through policies and regulation frameworks is requisite to support uptake and upscale nature-based solutions and requires coherence across policy domains and sectors.
- Fit-for-purpose financial instruments and approaches for implementation and maintenance of large-scale nature-based solutions help provide sound business cases.
- Nature-based solutions are based on inclusive, transparent, and empowering governance processes, where capacity building of the people involved is essential.

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4 Central and Eastern Europe: Natural small water retention measures for flood and drought management

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(1) Summary of the article

Natural small water retention measures (NSWRM), can greatly contribute to flood and drought management through improving water retention in the landscape. They present in addition multiple benefits including filtration of pollutants and biodiversity. Noting that awareness of these measures, methods and tools, and uptake, remained yet limited in the CEE region, GWP CEE started collaborating with partners in the early 2010s to advance these solutions. GWP has since supported a broad range of measures, including demonstration projects, knowledge products, stakeholder engagement, policy level work, and partnership development to support uptake of NSWRM.

(2) Details of the project

Central and Eastern Europe is increasingly vulnerable to the impacts of flood and droughts. Climate changes have resulted in an increase in the frequency and impacts of extreme climate events, including floods and droughts. At the same time, the intensification of agriculture, the unification of natural habitats, the construction of drainage systems, and urbanisation, have caused changes in the soil cover and water cycle, with more limited retention in catchments and a quicker water circulation. The population's exposure has also risen as ever more people live in flood-prone areas. Climate change models further point to a decrease of precipitation during summers, and an increase of precipitation during winters in Europe, further aggravating the cycle. Some monitoring systems and management measures are in place, but they are insufficient to protect people, infrastructure and nature.

NSWRM are taken with the aim to restore the natural water retention capacity of catchments.

- Technical Measures. Most hydro-technical and drainage works, aiming at the retardation of surface water runoff can be included in this group like construction of small water reservoirs, damming of lakes and water courses, construction of ditches and channels etc.
- Non-Technical measures (planning methods). Proper spatial planning of the catchment can play an important role in water management. This measure focuses on the creation of spatial planning that can limit the accelerated runoff of rain and snow melting waters.
- Non-Technical measures (agro-technical), often labelled now as Nature Base Solutions (NBS) These are the measures that depended on the way of land use, including the use of proper methods of arable field's cultivation in the river catchment.

All the NSWRM have positive social, economic and environmental effects. The most important benefits are:

- Changes in water outflow structure in the river, decrease of the flood wave and, in some cases, improvement of low flow conditions;

- satisfying the needs of water dependent forest and swamp ecosystems, as well as the improvement of the state of environment as a result of elevation of groundwater tables;
- increase of groundwater aquifers alimentation, which causes the increase of groundwater resources;
- fulfilling some of economic demands, for example, water reservoirs can be used as water intakes for firefighters, bathing resorts, fish ponds, water intakes for irrigation or watering holes for wild animals;
- improvement of natural values of environment, improvement of biodiversity of agricultural landscape by the restoration of wetlands, small ponds, creation of natural aquatic fauna and flora enclaves, creation of human friendly micro climate;
- protection of surface water quality, retention of suspended matter, cleaning of rainwater from nutrients (nitrogen and phosphorous).

Despite their benefits, NSWRM still have a limited uptake, with important challenges related in particular to awareness, knowledge, methods and tools, and expertise.

(3) Cases

GWP CEE took a pro-active approach to support the uptake of NSWRM, supporting demonstration projects, knowledge products, stakeholder engagement, policy level work, and partnership development.

As GWP CEE launched the regional Integrated Drought Management Programme (IDMP)[1] in 2013, it identified NSWRM among the measures to be supported for drought management in the Region. Within the IDMP, a specific project on Natural Small Water Retention Measures (NSWRM)2 was implemented by a group of experts from four CEE countries: Poland, Slovakia, Hungary, and Slovenia. The activities carried out included a compilation of case studies as well as the preparation of first Guidelines on Natural Small Water Retention Measures, published in 2015. During the course of the project, the experts identified the need to create a modern and effective tool for delivering knowledge on NSWRM. Consequently, GWP CEE collaborated with partners to develop a video lecture series on NSWRM.

An important milestone for advancing NSWRM came with the FramWat project[3], implemented over 2017 – 2020 with the support of INTERREG's Central Europe Programme. The project coordinated by Warsaw University of Life Sciences aimed at strengthening the regional common framework for floods, droughts, and pollution mitigation by increasing the buffer capacity of the landscape through NSWRM.

The starting point for the project was that the majority of water management and flood protection measures lack innovation and follow more traditional approaches, including large scale grey infrastructure investment programs or capital projects.

Within the scope of the project, GWP CEE supported stakeholder engagement, policy dialogues, development of the synthesis guidelines of the project as well as the preparation of 6 action plans for NSWRM in each of the project pilot catchments. A series of national and regional policy dialogues was conducted in 6 countries – Austria, Croatia, Hungary, Poland, Slovakia and Slovenia.

The project integrated the stakeholders most affected by droughts and floods (municipalities, forest districts,

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[1] https://www.gwp.org/en/GWP-CEE/WE-ACT/Projects/IDMPCEE/
[2] https://www.gwp.org/en/GWP-CEE/WE-ACT/Projects/IDMPCEE/Demonstration-projects/Small-retention-measures/
[3] https://programme2014-20.interreg-central.eu/Content.Node/FramWat.html

representatives of agriculture, nature protection agencies) with each other and experts, and facilitated creating ideas for in mitigating their effects. Problems and possible solutions were identified (Action plan), and tools (DSS planner) were provided to support stakeholders in the process of implementing activities (i.e. legal and technical guidelines).

In addition, national trainings were organized by project partners in 6 pilot river basins to familiarise stakeholders, particular target groups and associated partners with developed methods and to train them how to apply methodologies in river basins. Their purpose was to discuss and test the methodologies and train participants on how to use the developed GIS based assessment tool/s. National trainings were organized during the preparation of the concept plan and testing models. After creating the prototype of GIS Tool (FroGIS[4]), training of its use was conducted for all partners. Additionally, the materials from the training course of GIS tool was developed into an e-learning system. In 2018 the training was organized for several WULS students and several function demonstrations at meetings with stakeholders in various countries.

FRAMWAT tools were adapted in the next project where GWP and partners were involved (TEACHER[5]). Focus of further work was on down streaming the tools to the municipalities or regions. From the tool's perspective, the overarching platform TEACHER toolbox was created. It contained except FroGis also heavy rain assessments and mapping, flood modelling including impact of Climate Change on drinking water availability, assessment of forests vulnerability to CC as well as LocalAdapt tool supporting the local communities for CC adaptation., drought risk mapping and few tools related to River Basin Management practices. Number of activities including individual and partners training were undertaken in Poland, Hungary, Slovenia, Germany, Czech Republic and Italy. The project was led by GWP CEE partner University of Ljubljana.

At the moment FroGis is further developed and implemented on EU scale by SpongeScape[6] (2023-2027) program Horizon Europe project, which focuses on increasing the European resilience against floods and droughts by NBS retention measures and upscaling individual restoration projects. Project is implemented in Netherland, Great Britan, Poland, Slovenia, France, Germany and Greece.

The work continues also other EU project Optimal strategies to retain water and nutrients (OPTAIN)[7] funded by Horizon 2020 over 2020 – 2025 and coordinated by Helmholtz Centre for Environmental Research (UFZ, Germany). OPTAIN proposes a social and scientific journey towards the increasing and better understanding of the multiple benefits of NSWRM. In this project GWP co-leads the work package on Communication and Dissemination, aiming to be a bridge between researchers and end users/farmers.

(4) Key challenges and recommendations

FramWat developed a new set of tools for choosing the best location to improve water quality and better balance its quantity. It provided GIS-based tools and guidelines for the water authorities and decision-makers to critically approach and assess the effectiveness of nature-based small water retention measures in the river basin management context. FramWat increased the skills and capacities of water authorities and related stakeholders for sustainable use of landscape, and for better and climate-proof water resources management.

[4] https://programme2014-20.interreg-central.eu/Content.Node/FroGIS.html
[5] https://programme2014-20.interreg-central.eu/Content.Node/TEACHER-CE.html
[6] https://cordis.europa.eu/project/id/101112738
[7] https://www.optain.eu/

Partners developed innovative methods:

(1) Identifying locations in a river basin where N(S)WRM would be needed as a consequence of topological, hydrological, meteorological conditions.

(2) Supporting the evaluation of cumulative effectiveness of N(S)WRM at river basin scales.

(3) Improving understanding of small retention measures and a part of NBS for water management improvement

(4) enhancing upscaling of individual restoration and/or retention measures to the catchment scale

(5) Providing guidelines for implementation of N(S)WRM with policy options and cost analysis to mitigate negative effects of floods and droughts and prevent water pollution to preserve natural heritage in Europe.

Moreover, the methodology provided decision makers with appropriate tools to incorporate N(S)WRM into the next cycle of River Basin Management Plans and gave guidance and raise awareness about the importance of horizontal integration of different planning frameworks. All of the activities were carried out with a strong stakeholder engagement process, policy-level dialogues, and trainings, ensuring co-development and appropriation of the tools for uptake.

(5) Conclusion

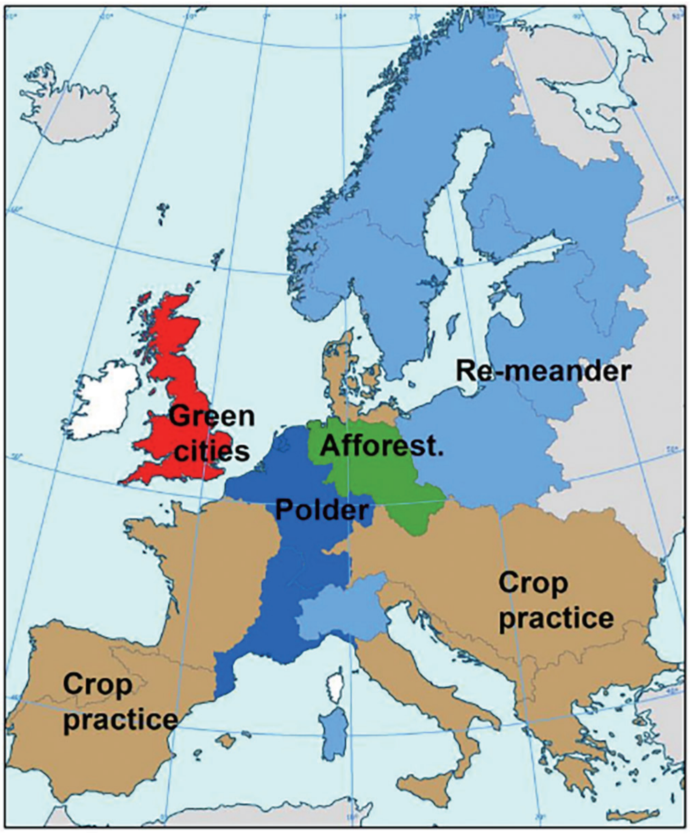
An intervention combining development of new tools and methods directly applicable by decision makers and river basin in management planners can greatly facilitate their uptake. When supported by national water management authorities, the measures can be included in river basin management planning and possibly replicated in other basins.

Table: Potential benefits expected from selected examples of NWRM

NWRM	Description	Potential primary benefits
Reconnection of oxbow lakes 	The historic straightening or canalisation of rivers resulted in the disconnection of meanders and formation of oxbow lakes. The re-connection of oxbow lakes to the main channel will restore the natural river flow conditions.	Enhanced water storage, attenuation of peak runoff, restoration of river continuity, diversifying flows and habitats, groundwater recharge
Conservation tillage 	By leaving crop residue on the soil surface, conservation tillage improves water infiltration into the soil and reduces soil erosion.	Water quality improvement, decreased runoff, soil conservation, increased infiltration potential
Installation of green roofs 	Coverage of a top of a building or structure with vegetation planted over a waterproof membrane.	Retain precipitation, provide insulation to buildings, new habitats for wildlife in urban environments, reduce peak flows, water quality improvement, soften extreme temperatures in cities, amenity space

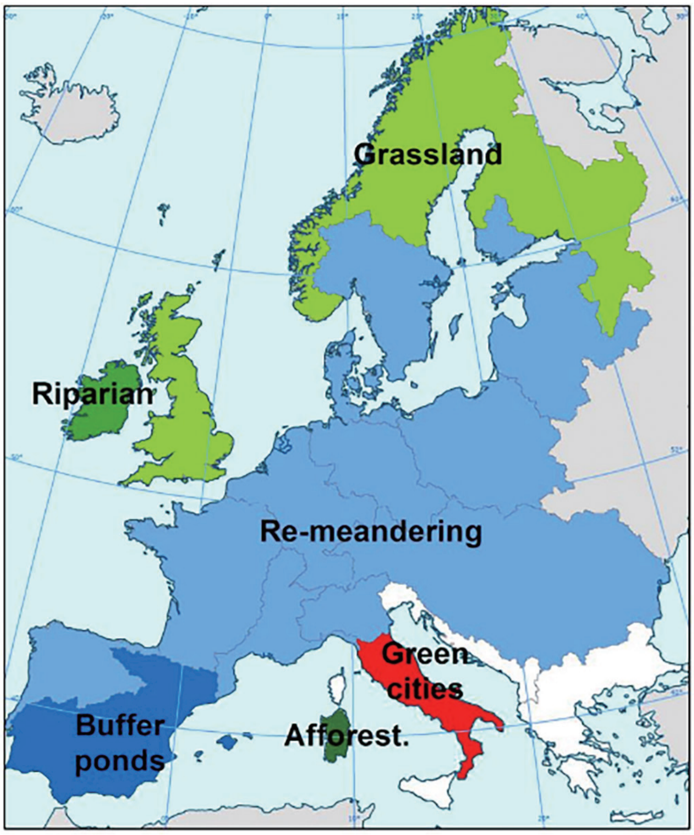
Source: 11309347 (europa.eu)

Map: Most effective regional measures to reduce flood peaks (here: 20 year return period)



Source: [Evaluation of the effectiveness of natural water retention measures - Publications Office of the EU (europa.eu)]

Map: Most effective measures to increase low flow per region (here: 10% flow)

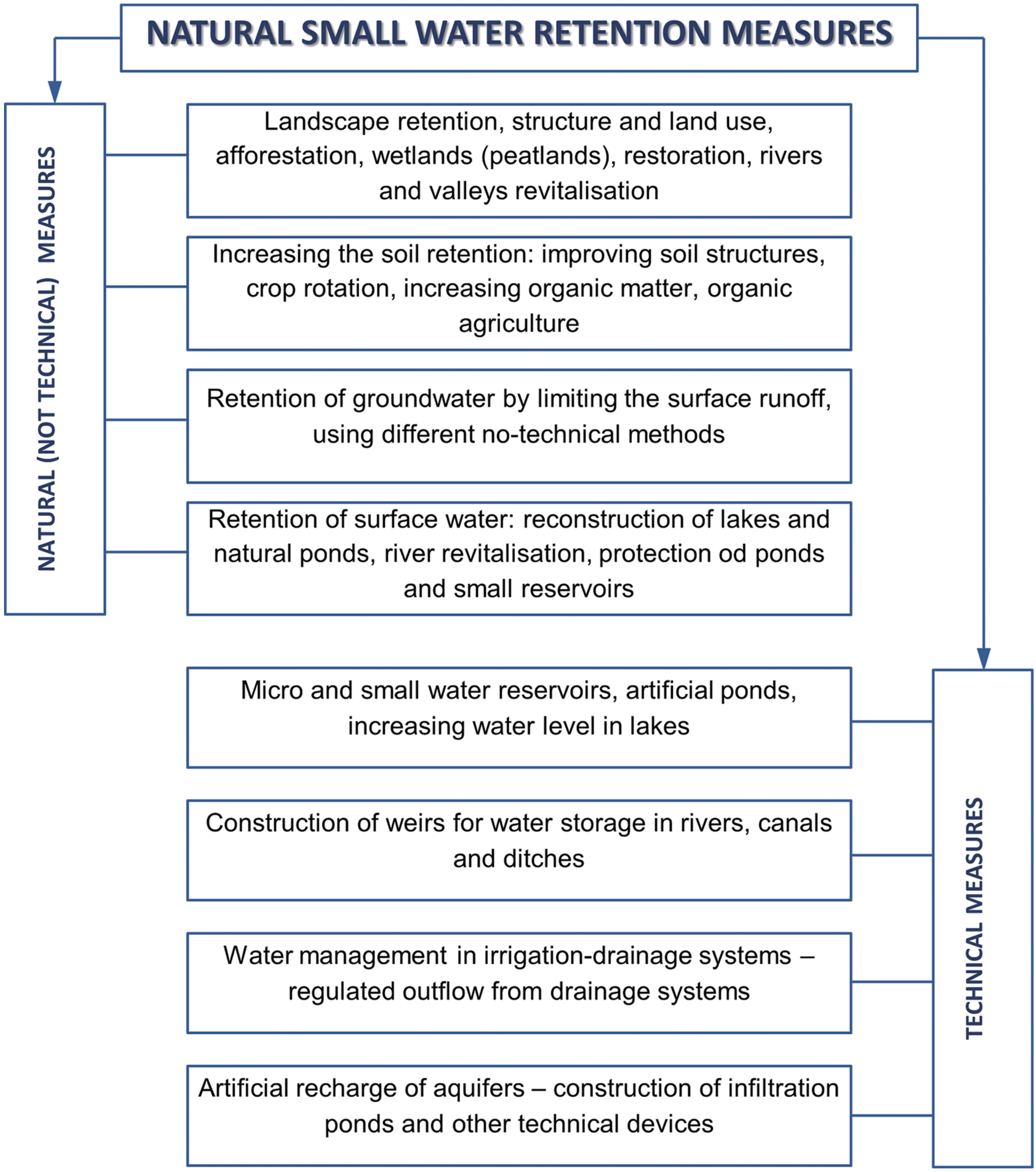


Source: [Evaluation of the effectiveness of natural water retention measures - Publications Office of the EU (europa.eu)]

Figure: Sava in Zagreb. On top: Current situation, i.e. before river restoration; below: Illustration of Sava after river restoration. Instead of monotonous reinforced banks and foothills or - even worse - planned hydropower impoundments, restoration could provide attractive recreation areas

Source: 01_SavaWhite Book Study.pdf (balkanrivers.net)

Fig: Natural Small Water Retention Measures.



Source: idmp-nswrm-final-pdf-small.pdf (gwp.org)

Table: Evaluation of the impact of small retention measures on water resources and environment

Name of the indicator	Impact on water resources			Impact on			Threats
	Surface water	Soil retention	Groundwater	Landscape	Biodiversity	Water quality	
Afforestation of agricultural lands (poorly permeable soils, hummocky area, presence of snow melting floods)	++	+/–	+/–	+++	+++	++	Disappearance of certain plants (weeds)
Afforestation of agricultural lands (permeable soils – sands, presence of snow melting floods)	+	+/–	+/–	++	+++	++	Decrease of alimentation of groundwater aquifers
Agrotechnics (soil structure improvement) – poorly permeable soils	++	+++	++	+	+	++	Excessive intensification of agriculture
Agrotechnics (soil structure improvement) – permeable soils	+++	+++	++	+	+	++	Decrease of alimentation of groundwater
Agrotechnics-field water harvesting (small dikes around field edges)	+++	+++	+++	+/-	++	+++	large impact on the loss of deposits on the floodplain valley
Buffer zones along water courses and reservoirs lands (poorly permeable soils, hummocky area)	+	+	+	++	++	+++	Decrease of the area of grasslands and arable lands
Regulated outflow from drainage systems	+	++	+++	+	+	+++	Excessive humidity of arable lands, soil degradation (reduction processes)
Active water management on a drainage system (river valleys)	+++	+++	+	+	+	+	Intensification of agriculture
Construction of micro reservoirs on ditches	+++	++	++	++	+++	++	Excessive humidity of arable lands
Infiltration reservoirs and ditches	+	+	+++	+	+	++	Pollution of groundwater
Dry reservoirs/flood polders (river valleys used for agricultural purposes)	+++	++	+	+	++	+	Periodic destruction of crops yields, excessive humidity/drying
Construction of reservoirs on outflows from drainage systems	++	+	+	++	++	+++	Loss of the area for agricultural production
Old meanders/side reservoirs on rivers (retaining water during high spring flow)	++	+	++	++	++	+	
Construction of small reservoirs on rivers (dammed reservoirs)	+++	++	++	+	++	++	Destruction of valuable ecosystem, problems with fish migration
Dug ponds in local terrain denivelations	+	++	+	+	++	+	Destruction of valuable ecosystems
Small ponds (restoration)	++	++	+	++	+++	+++	Conversion of the ecosystem into less valuable
Water course restoration (meandering)	+++	++	+	+++	+++	++	Flooding of agricultural lands
Swamps restoration (peatlands)	+++	+++	++	+++	+++	++	Excessive limitation of water courses alimentation
Anti-erosion measures (various)	++	+	++	++	++	++	Changes in ecosystems

Scale: +++ meaningful impact, ++ medium impact, + small impact, +/– negative or no impact

Source: idmp-nswrm-final-pdf-small.pdf (gwp.org)

5 Environmental protection initiatives in the Japan Water Agency.

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Background

Japan Water Agency (JWA) has a large inventory of water resources development facilities today in Japan (Fig-1) and is working to reduce the damage caused by abnormal floods and droughts due to climate change, the management of ageing facilities to extend their service lifespan through dam rehabilitation, upgrading and advanced maintenance management, using new technologies. JWA is also working hard to decarbonize its operations, as Japan as a whole has set a target of reducing greenhouse gas emissions by 46% in 2030, with the ambitious goal of actually reaching a higher target of 50%.

This report focuses on JWA's efforts to reduce the burden on the natural environment and to contribute to global environmental protection in its water resources development and management operations.

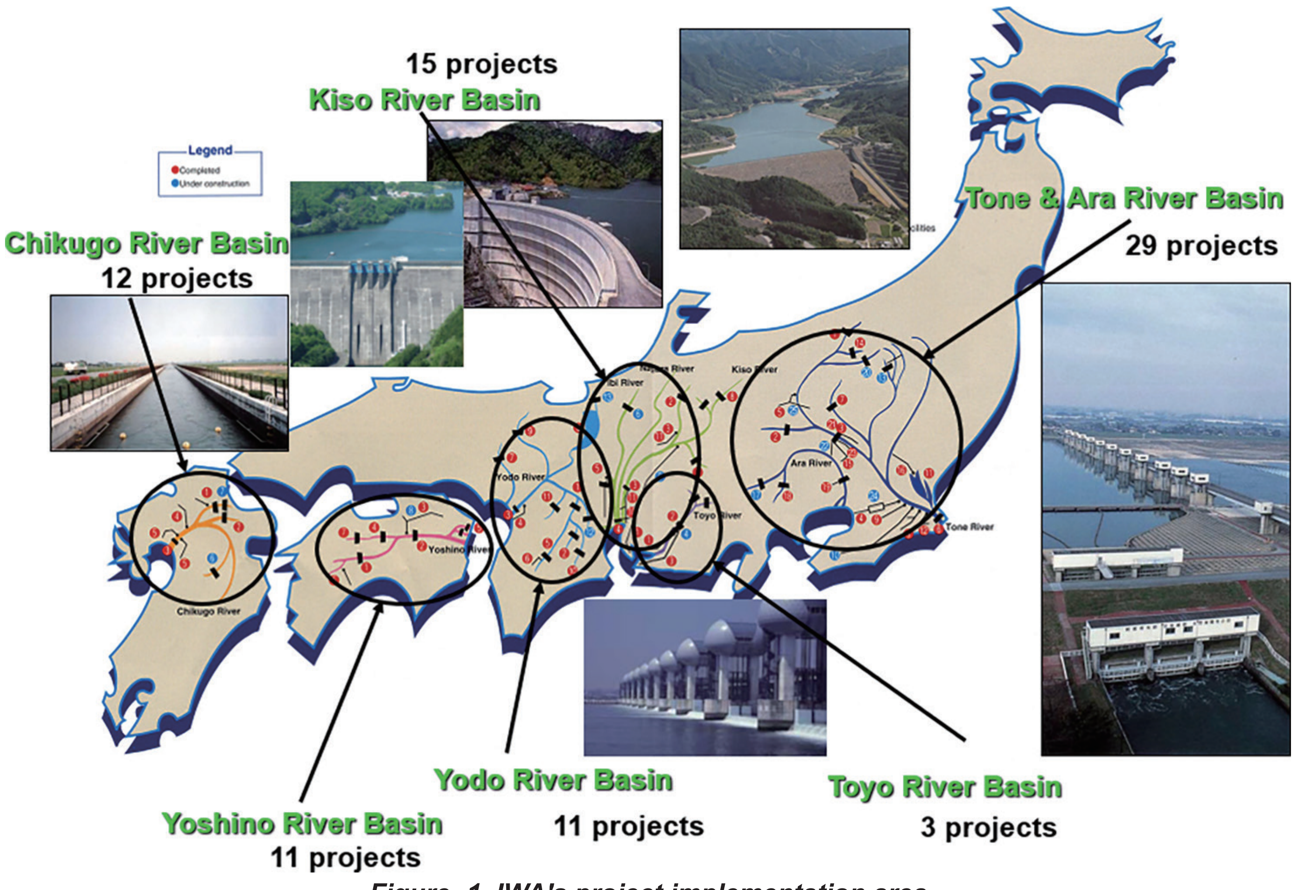


Figure- 1 JWA's project implementation area

1. Japan Water Agency's environmental conservation efforts in the implementation of its projects.

JWA has implemented big projects of water resources development. In particular, the dam projects are located in mountainous areas rich in nature and require large-scale changes to the natural environment due to the construction of the dam and ancillary facilities, the extraction of embankment materials necessary for the construction, the installation of various temporary facilities, and the replacement of existing roads submerged in the reservoirs. Therefore, it is necessary to address the implementation of construction projects, through conducting a careful environmental survey and the environmental impact assessment procedures required by the law with the occasional advice from experts in advance, in order to avoid or reduce the impact on the natural environment as much as possible. It is also necessary to maximize the utility of the project while minimizing natural resources and energy consumption during the management and operation phase after completion of the construction project.

1-1 Five basic perceptions

JWA believes that it is its social responsibility to contribute to building a society that ensures sustainable development with less environmental impact and to global environmental protection. Therefore, JWA has set the following five basic perceptions and specific action items under these perceptions to address the implementation of its projects:

① Basic Perception 1: To promote initiatives that take into account environmental protection

To ensure the appropriate environment conservation in and around the project area, comprehensive efforts will be made to ensure the design, construction and management with due consideration to environmental conservation.

- Action Item 1: Implementation of natural environmental surveys and environmental impact forecasts, and environmental conservation measures
- Action Item 2: Improvement of the river environment downstream of dams, etc.
- Action Item 3: Daily understanding of information on water quality through water surface patrols, and water quality surveys, etc.

② Basic Perception 2: Promotion of initiatives to reduce environmental load

Promotion of the control and recycling of construction by-products as well as that of greenhouse gas reduction initiatives.

- Action Item 4: Effective use of renewable energy
- Action Item 5: Reduction of electricity and fuel consumption, etc.
- Action Item 6: Reduction of paper consumption and office waste
- Action Item 7: Effective use of biomass such as driftwood and mown grass
- Action Item 8: Promotion of construction by-product recycling
- Action Item 9: Procurement of environmental goods, etc., and promotion of contracts based on Act on Promotion of Contracts of the State and Other Entities, Which Show Consideration for Reduction of Emissions of Greenhouse Gases, etc.

③ Basic Perception 3: Raising awareness of environmental protection

Raise environmental awareness and advance knowledge through environmental education and other means, so that each JWA staff member is actively involved in environmental protection.

- Action Item 10: Implementation of seminars and trainings on the environment

④ Basic Perception 4: Communication with society

Actively publicize JWA's environmental protection initiatives and environment-related information. In addition, as a member of the local community, communicate with society by participating in and cooperating with local environmental protection activities.

- Action Item 11: Dissemination of environmental information through public relations magazines, websites, events, etc.
- Action Item 12: Development of landscape-friendly facilities
- Action Item 13: Environmental conservation activities in cooperation with dam reservoir areas, etc.

⑤ Basic Perception 5: Compliance with environmental laws and regulations.

Comply with environmental laws, regulations and the guidelines set by JWA to prevent environmental pollution, and to preserve and create good environment

- Action Item 14: Compliance with relevant laws, regulations and guidelines set by JWA

1-2 Implementation of an environmental management system (W-EMS).

Furthermore, in order to convert the Basic Perceptions into practical and continuous approaches to environmental conservation, JWA established its own environmental management system (W-EMS), which has been in company-wide operation since 2016, each year managing and continuously improving environmental conservation targets through the PDCA cycle, the name being the acronym of“Plan”, “Do”, “Check” and “Act”.

W-EMS is a unique system that JWA created based on the know-how cultivated through the company-wide operation of International Standard ISO 14001 and certificate acquisition of it up to 2012 W-EMS was also developed with ensuring the same quality as the original Standard and restructured and improved in line with JWA’s business operations. Through this system, JWA can continuously monitor, evaluate and reduce the impact of the administrative and business activities on the environment, and comply with environment-related laws and regulations to bring about the conservation and creation of a good environment.

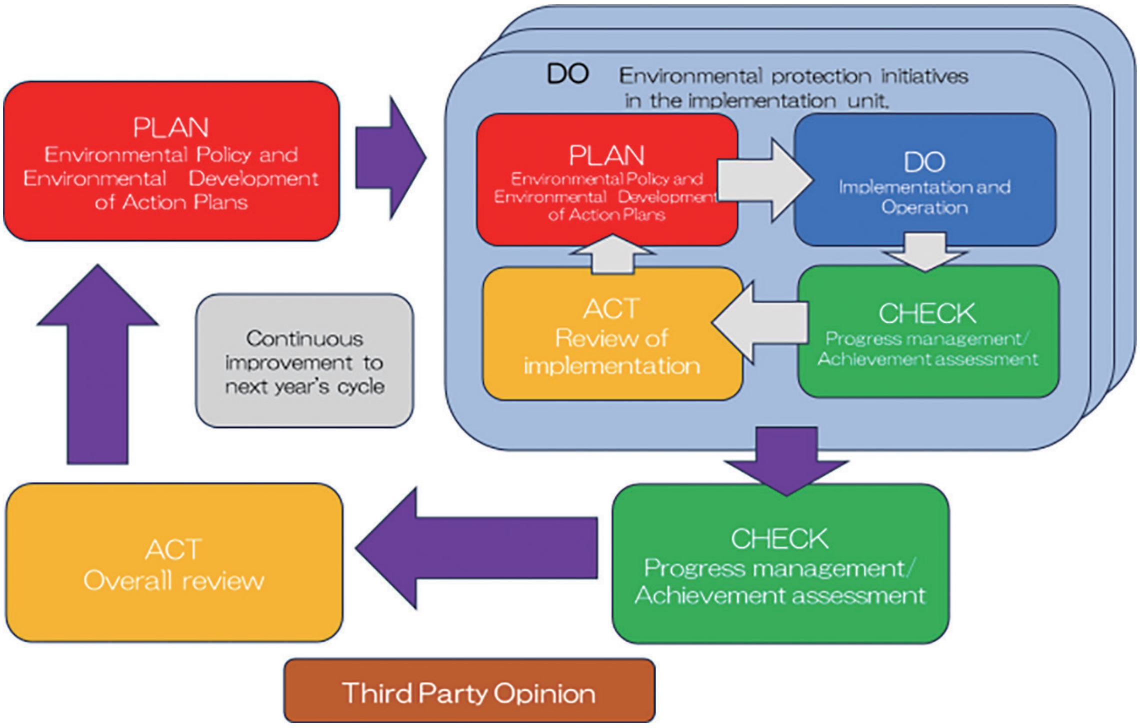


Figure- 2 Implementation of environmental protection measures through the W-EMS

1-3 Implementation system

In terms of the implementation system, the Chief Engineer, who is the chief technical officer at the head office, is responsible for overall JWA environmental management through the W-EMS as the 'Responsible Officer for Environmental Management (ROEM)', while the divisions in the head office and branch offices, and the individual construction offices and management offices are the 'Implementation Units (IUs)' for environmental conservation measures (ECM). Furthermore, each IU assigns a staff member in charge of each of the above-mentioned Action Items 1-14 to implement ECM. At the same time, 'Environmental Conservation Measures Promoter' is designated for each IU, and the staff member in charge assesses the progress and results of ECM. If any inadequacies are found, ROEM eventually instructs the relevant IU to make improvements for the following year, and sets new targets for further environmental improvements throughout JWA.

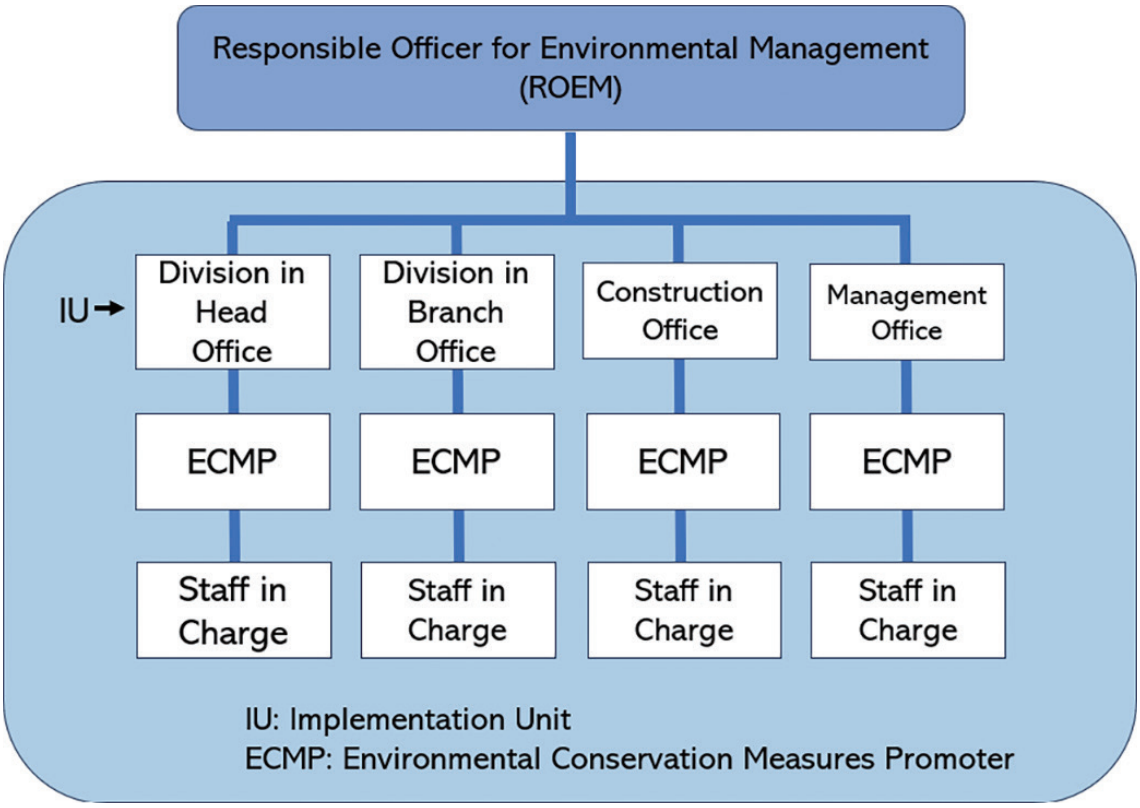


Figure- 3 Implementation system

2. Specific cases of initiatives

2-1 Natural environment studies, impact forecasts and protection measures

To protect the natural environment, natural environment studies and impact forecasts are carried out, and environmental protection measures are developed and implemented based on the results of these studies, etc.

① Conservation of Falconiformes

In general, Falconiformes are at the top of the food chain in the ecosystem. Therefore, the number is so small that the ecology is largely unknown. However, many species of hawk and eagle live in the upstream river basins of dams and planned reservoir site. JWA focuses on the mountain hawk-eagle as a rare species among Falconiformes and assumes that if its habitat can be maintained throughout the pre- and post-dam construction period by avoiding the impact of the project on its population as much as possible, the overall natural environment of the area will have been conserved.

In the research phase, the activity areas of the breeding pairs of the mountain hawk-eagles are clarified by means of fixed-point surveys. Based on the results of the surveys, nesting and hunting sites, etc. are estimated from flight density and the vegetation environment of the forest area, and these are identified as particularly important areas within the activity area of the breeding pairs.

In the stage of planning conservation measures, the particularly important areas are superimposed on the facility layout and construction scheme plans, and consequently, changes to and adjustments, including restriction of construction work during the egg-laying and nestling periods of the plans are made to avoid alteration of and less impact on these areas

After the completion of the construction, the behavior of the breeding pairs is to be monitored on a regular basis. If breeding activities are taking place or especially fledglings are confirmed around July or August, the effectiveness of the conservation measures can be proven.

Picture-1 Mountain hawk-eagle

Picture-2 Point survey

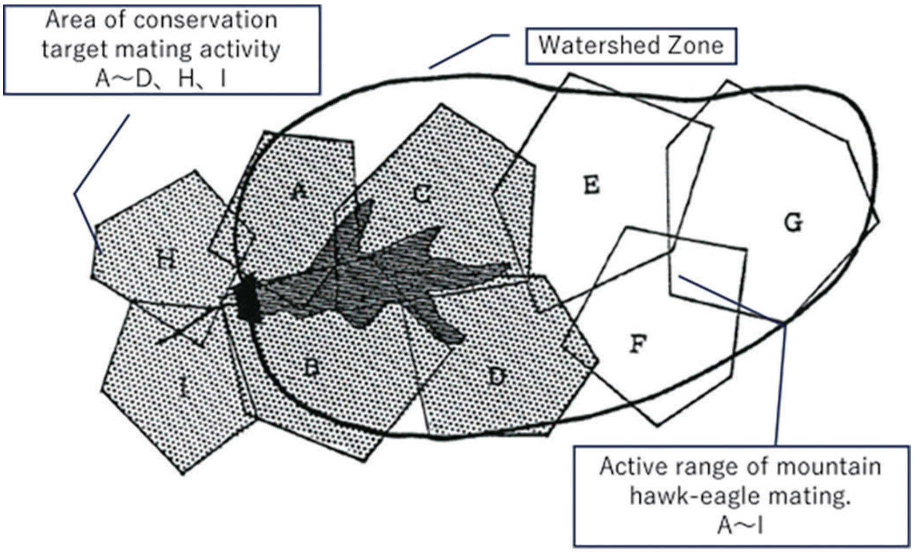


Figure-4 Distribution of the mountain hawk-eagle mating activity area.(Image.)

Multiple pairs of the mountain hawk-eagles grow at most of the dams of JWA, and in many cases, the pairs; have their activity areas without any spaces between them. In the case of the Tokuyama Dam of JWA, which reservoir is the largest in Japan, there are a total of 17 pairs around the dam site and its reservoir, all have continued to live there since the dam construction started and its reservoir was impounded after completion, and some fledglings have been observed.

② Conservation of giant salamanders

In the Kawakami Dam construction project, the conservation measures of giant salamanders have been implemented since 2016, which is to relocate them at the planned dam site and reservoir area to upstream river of the reservoir. The giant salamander is designated as the National Special Natural Monument, then it is necessary to get a permission from the Agency for Cultural Affairs for implementation of the conservation measures. In April 2018, a number of salamanders inhabiting the section in a diversion tunnel due to be constructed at the dam site were captured and released upstream.

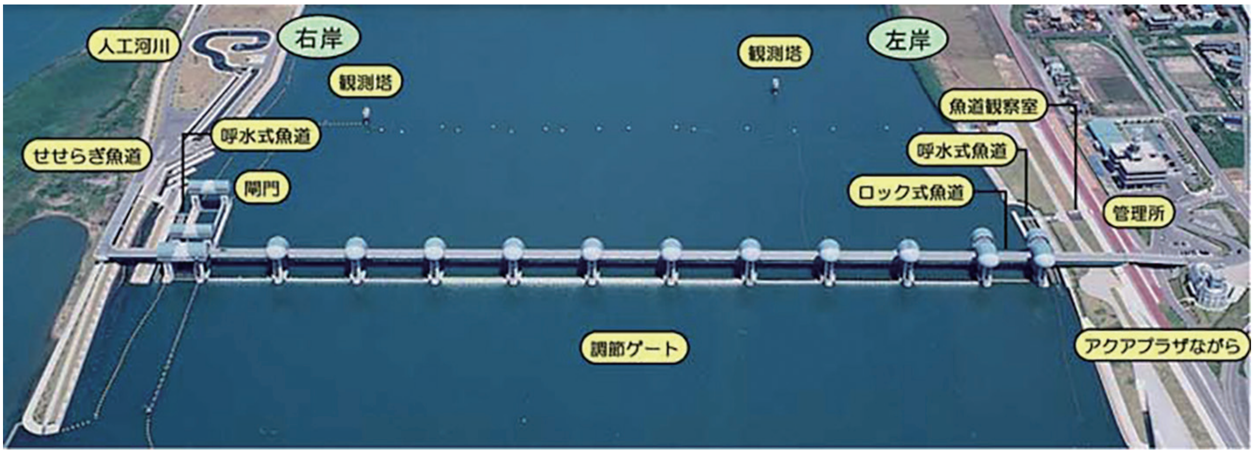
Picture-3 Giant salamander capture operation

Picture-4 Captive giant salamanders.

③ Monitoring upstream migration of fish

In certain facilities such as those in estuary weirs, fish passages are installed and gates are operated to guide fish to the passages, taking into account the fish migrations, and monitoring surveys are conducted to confirm effect of these measures. At the Nagaragawa River Estuary Barrage of JWA, five fish passages of three types (Guide-flow type, Lock type and Brook type fishway) have been installed on the left and right banks of the Barrage, and fish run surveys have been conducted. JWA has established an AI-based automatic counting system, which was used to verify the upstream migrations of 590,000 young ayu, sweetfish in early spring 2019. An observation window onto the fish passage was installed in the Barrage facility, and live video footage of young ayu running upstream through the passage is streamed on the website during their migration period, among other initiatives, so that the public can see what is going on in the fish passage.

左岸呼び水式魚道　稚アユの群れ



Picture-5 Panoramic view of the Nagara River estuary weir

2-2 Promotion of initiatives to reduce environmental impact

① Recycling of construction by-products

Based on the target values for recycling rates, etc. in the Construction Recycling Promotion Plan 2014, developed by the Ministry of Land, Infrastructure, Transport and Tourism, JWA has set the target values and been promoteing the recycling of construction by-products. In 2018, target values were achieved in all items as follows (Table-1).

Table-1 Promotion of recycling of construction by-products in 2018.

Construction By-products Target Items (Recycling rate)	Recycling rate (%) Actual / Target	Off-site emissions (t)	Recycled amount (t)
Asphalt and Concrete mass	100% / 99%以上	5,776	5,774
Concrete mass	100% / 99%以上	34,409	34,375
Construction By-products Target Items (Recycling - Reduction rate)	Recycling - Reduction rate (%) Actual / Target	Off-site emissions (t)	Recycled amount, etc. (t)
Construction generated lumber	100% / 96%以上	11,561	11,551
Construction sludge	100% / 90%以上	24,684	24,598
Mixed construction waste	98% / 60%以上	1,201	1,161
Total construction waste	100% / 96%以上	81,693	81,455
Construction By-products Target Items (Effective Utilization Rate)	Effective Utilization Rate (%) Actual / Target	Embankment backfills (m3)	Embankment peat volume other than new material (m3)
Construction soil	99% / 80%以上	10,431,737	10,350,250
Construction By-products Target Items (Emission Rate)	Emission Rate (%) Actual / Target	Annual emission (t)	Recycled amount (t)
Mixed construction waste	1.5% / 3.5% 以下	1,201	1,161

② Curb Greenhouse gas emissions from energy use

Some of JWA O&M offices generate hydrolectricity for their facility management in addition to the hydropower generated by the power generator utility. Over FY2013-17, JWA introduced and enhanced small hydropower and solar power generation facilities to further utilize the potential of the dams, canals, and other facilities. In FY2018, the effective use of these renewable energies contributed to the reduction of greenhouse gas emissions by 22,062 t-CO2.

- Actual performance of hydropower generation by O&M offices in 2018

  48,546 MWh of hydro-electricity was generated by 17 hydropower generation facilities. Of this, 5,168 MWh was used for facility management, thereby reducing JWA's greenhouse gas emissions by 2,547 t-CO2. In addition, 43,378 MWh of surplus electricity was sold to the power companies, which reduced costs and contributed to a reduction in greenhouse gas emissions by 21,371 t-CO2. In addition, 43,378 MWh of surplus electricity was sold to the power companies, which reduced costs and contributed to a reduction in greenhouse gas emissions of 21,371 t-CO2.

- Actual performance of solar photovoltaic power in 2018

  38 photovoltaic installations generated 1,435 MWh of electricity and this reduced greenhouse gas emissions by 6t-CO2, and contribut to a reduction of 691t-CO2.

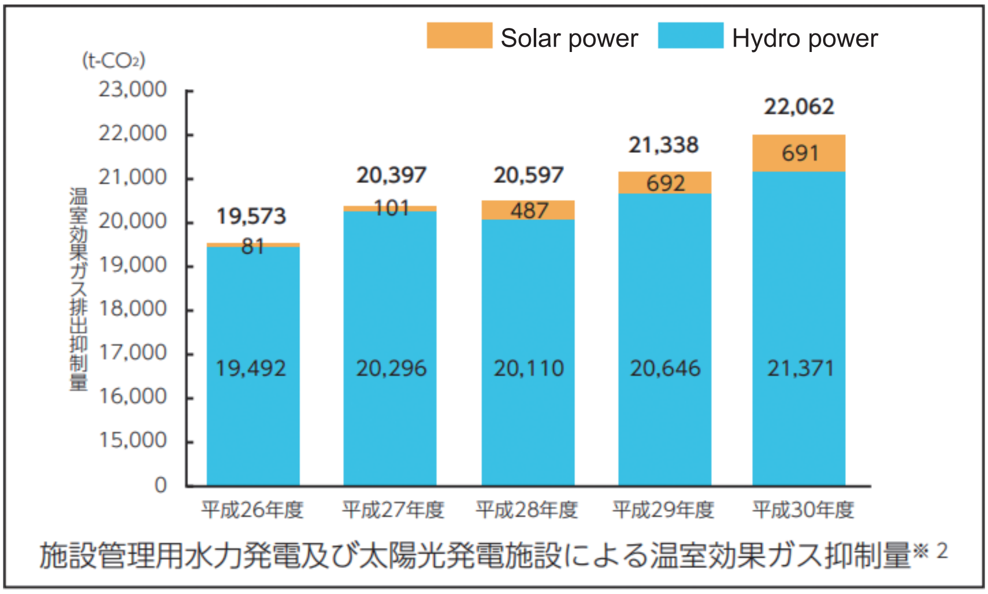


Figure- 6 Reduction of Greenhouse gas emissions by hydropower and photovoltaic facilities in O&M offices.

2-3 Communication with society Forest improvement

As a member of a local community, JWA participates in forest maintenance activities, community - in-river clean-up activities and environmental awareness-raising activities, together with local authorities and relevant organizations. The planting of broadleaved trees and thinning of cedar and cypress plantation forests in the mountains of river basins help mitigate floods and droughts, improve sediment run-off prevention functions and the growth and habitat of plants and animals. Municipalities in the basin carry out forest maintenance in cooperation with NPOs and other relevant organizations, and the Water Resources Agency also actively participates in these activities. The Tokuyama Dam office carries out a plan of protecting and nurturing the natural environment in the upper basin of the dam with local residents, by growing beech, konara (Quercus serrata), mizunara (Quercus mongolica var. crispula), chestnut and walnut trees from seeds into small seedlings, which are then donated to elementary and junior high schools (sapling home-stay activities), where the children and students grow them into large seedlings, which they later plant on mountain areas upstream of the Tokuyama Dam.

Picture-6 Planting of saplings

Picture-7 Installing posts to protect against winter snow.

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