International experience in water resource management and dam safety and lessons learnt for Viet Nam

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Vietnam is one of the vulnerable countries that are impacted by climate change and natural disasters, including floods, droughts, saltwater intrusion, and fluctuation of river flows. Specifically, with the distribution of a variety of dams and lakes from the North to the South, Vietnam has been facing challenges regarding dam safety, sustainable water management and coping with climate change. In the current context, the risk of water resource degradation, water conflicts, and dam collapses tends to increase because of the development of hydroelectric power projects by China and the countries within the Mekong River basin [1].

Two factors leading to several droughts during the dry season and catastrophic floods during the rainy season are the imbalance of two seasons and the upstream dam effect. With the agricultural economy of the country and the millions of citizens' lives involved in the rivers, ensuring dam safety, sustainable water source management, and solving climate change risks is dramatically necessary [2]. This article analysed water management and dam safety from the international experience and particular countries, thereby proposing solutions to develop sustainably, manage dam safety and restrict the adverse impacts of natural disasters in Vietnam.

1. INTERNATIONAL EXPERIENCE IN WATER RESOURCE MANAGEMENT AND DAM SAFETY

Japan and Norway: Both nations have global expertise in dam safety management, particularly in the harsh conditions and the risks of disasters. These experiences could provide valuable lessons for enhancing safety monitoring and management systems.

In Japan, to ensure the safety of the earth-fill dams, the Japanese government has conducted regular seepage, deformation, and surface leakage measurements. Besides checking the dam's administrator, experts have performed recurring inspections three times per year to investigate the dam's safety level and operational ability. Japan's standard systems are also strict in dam design, construction, and maintenance. Independent experts have performed periodic testing and maintenance systems cyclically. Japan's dams were designed against natural disasters with solid intensity and high risks of earthquakes and floods [3]. The real-time dam safety monitoring system, which uses sensors to detect risks such as cracks, vibrations, or abnormal water pressure, was also improved by Japan. This system provides continuous updates to management agencies, enabling timely interventions to prevent potential incidents.

In Norway, artificial intelligence (AI) was used to analyze data from the dam observing sensors and give early warning for potential failures. This system effectively reduces dam failure risks and optimizes maintenance and inspection activities [4]. In addition, Norway has an effective system for managing the risk of collapse, including emergency scenarios and well-trained rescue teams. Local communities near dams are also educated and equipped with knowledge and skills to respond to emergencies.

The United States is a pioneer country in establishing the early emergency system, especially for natural disasters such as floods, hurricanes, and dam failures. The system has been implemented on a large scale, leveraging advanced technologies with integrated real-time data and predictive models. A network of monitoring sensors that analyze real-time data from dams and reservoirs has been established. These sensors, strategically installed across the dam system, monitor critical parameters such as water levels, pressure, and structural conditions. When anomalies are detected, the system immediately alerts authorities and the public via text messages, mobile applications, and radio broadcasts [5]. The United States also employs meteorological forecasting models combined with hydrological data. This system is not only based on the data from the dams but is also tightly integrated with meteorological data from weather forecasting models. Therefore, the authorities can forecast the rainfall and flood conditions, allowing them to adjust reservoir discharge rates proactively to minimize flood risks.

Additionally, community involvement is a key factor in the success of early warning systems in the United States. The government frequently organizes flood response and dam failure evacuation drills for residents. Communities living near major reservoirs are equipped with knowledge about safety processes, evacuation skills, and emergency response measures.

The Netherlands: The Netherlands has almost land below sea level and has developed a highly advanced system for flood management and response. This includes the design of flood barriers, early warning and crisis management systems. Furthermore, a dikes and water control system network was constructed modally and extensively, including storm surge barriers and powerful pumping stations, to safeguard the nation against flooding risks. Additionally, "water retention areas" have been created where floodwaters can be stored and gradually released without causing severe flooding in residential areas [6]. The Netherlands has a highly advanced early warning and rapid response system that employs sensors to monitor water levels and pressure on dikes. When signs of a potential issue are detected, the system immediately triggers emergency response scenarios, ranging from adjusting water pumping stations to notifying residents in flood-prone areas. An integrated flood forecasting model has been developed in the Netherlands, utilizing meteorological and hydrological data to predict upcoming floods. This enables the government and management agencies to prepare proactively before floods occur, including planning for the evacuation of residents and implementing measures to protect dikes [7].

Israel: As one of the most efficient nations in managing and regenerating water resources, Israel has developed innovative solutions to address its limited freshwater supply. In particular, drip irrigation technology, which minimizes water waste in agriculture, delivers water directly to the root of plants, reducing evaporation and conserving water usage. Regarding wastewater reuse, over 85% of wastewater in Israel is recycled, primarily for agricultural use. This is the world's highest rate of water reuse, highlighting Israel's ability to optimize its water resources. Vietnam could learn from this model, particularly in building wastewater treatment systems for reuse in agricultural and industrial production. This approach helps mitigate freshwater scarcity and reduces water pollution caused by untreated wastewater [8]. Additionally, a key component of Israel's water management strategy is desalination, providing water for domestic and industrial purposes. With its long coastline and abundant saline water resources, Vietnam has significant potential to develop desalination technology, especially in regions like Ninh Thuan, Binh Thuan, and the Mekong Delta, where freshwater is becoming increasingly scarce.

2. CURRENT STATUS OF WATER RESOURCE MANAGEMENT AND DAM SAFETY IN VIETNAM

Vietnam has over 7,000 operational irrigation and hydropower reservoirs, which play an important role in flood control, agricultural irrigation, and electricity production [1]. However, these facilities also present significant safety challenges, particularly in the context of climate change and inadequate management. Large reservoirs such as Hoa Binh, Son La, and Thac Ba in the northern region are crucial for regulating the Red River's water flow and electricity supply but pose significant risks if not properly maintained, inspected, and strictly managed. Many dams and reservoirs in Vietnam were constructed decades ago and are now severely degraded. According to the Ministry of Agriculture & Rural Development, hundreds of reservoirs face a high risk of dam failure due to insufficient investment in regular maintenance and periodic inspections. Furthermore, the lack of effective incident management protocols and early warning systems exacerbates community risks near these facilities. Additionally, the impact of climate change on water resource management has led to significant changes in rainfall patterns and river flows across Vietnam. The rainy seasons are becoming increasingly extreme, with heavy downpours leading to heightened flood risks, while dry seasons are lengthening, resulting in dwindling freshwater supplies. This not only affects river ecosystems but also poses direct threats to food security, human health, and socio-economic development.

According to previous research, both average temperatures in Vietnam and sea levels are rising. The Mekong Delta, Vietnam's largest rice-growing region, faces severe saltwater intrusion, impacting millions of hectares of agricultural land. Meanwhile, northern and central Vietnam are encountering heightened risks of flash floods and severe flooding due to intense rainfall concentrated over short periods. Most recently, Typhoon Yagi (Typhoon No. 3) was the strongest typhoon in the South China Sea in 30 years, making landfall in northern provinces with immense intensity. The storm's circulation caused widespread rainfall across provinces from Thanh Hoa northward, with total precipitation ranging from 200–400 mm and 400–600 mm in mountainous regions, with some areas exceeding 700 mm. Many hydropower reservoirs in the Northern Midlands and Mountainous regions had to release water urgently to ensure structural safety. For example, Thac Ba Hydropower Reservoir (Yen Bai Province) experienced critically high upstream water levels, with inflows exceeding the reservoir's designed discharge capacity. Additionally, downstream water levels in rivers of the Red - Thai Binh river system reached dangerous levels, with some locations surpassing Alert Level 3 or historical records, threatening the integrity of dike systems and causing flooding in residential areas, schools, hospitals, and essential infrastructure. Typhoon No.3 and its aftermath had a wide-reaching impact, affecting 26 provinces and cities across northern Vietnam and Thanh Hoa, which accounted for over 41% of the country's GDP and 40% of its population. Combined with upstream dam

▲ *Song Cai Lake has been developed with detailed scenarios to respond to floods*

discharges, prolonged heavy rainfall led to significant flooding, flash floods, landslides and extensive damage in many areas. On September 15th, 2024, the Department of Dike Management and Disaster Prevention (MARD) reported the Typhoon No.3 damage, including 281 fatalities and 67 missing persons, over 231,851 houses damaged, more than 305 dike-related incidents and estimated economic losses exceeding 31,596 billion VND. To restrict the harmful about dam problems, it is essential to strengthen the management and operation of water reservoirs. This includes reviewing and amending deficiencies in the operational procedures for interconnected reservoirs within the Red River - Thai Binh river basin, particularly during the flood season, regulations on early water storage, and emergency response protocols. Measures should also reinforce and upgrade dam and reservoir safety, establish a flood discharge warning system for reservoirs, and ensure the efficient and safe operation of reservoirs and downstream areas. In compliance with regulations, particular attention should be given to key reservoirs, such as Son La, Hoa Binh, Thac Ba, and Tuyen Quang. Repairs and upgrades should prioritize critical structures, especially those damaged during recent floods. Coastal dikes should also be reinforced and upgraded to withstand powerful storms, such as Typhoon No.3. Additionally, inspecting and reviewing plans for addressing weak points in critical dike sections and other areas affected during the recent flooding is necessary.

3. LESSONS FOR VIETNAM

Vietnam has faced significant challenges in dam safety, water resource management, and climate change adaptation. The experiences of countries such as the Netherlands provide valuable lessons, particularly in addressing increasing risks of drought, saltwater intrusion, and flooding. For instance, Vietnam could construct infrastructure to prevent flash floods and landslides in critical areas, install automated flash flood warning stations in high-risk zones, and establish water retention zones to mitigate flooding... One of Vietnam's biggest challenges is managing major transboundary rivers, particularly the Mekong and Red Rivers. Upstream water control directly impacts Vietnam's water flow and resources, especially from China and other countries in the Mekong River Basin. To solve this problem, Vietnam could learn from the European Union's approach to transboundary river management [2]. For instance, a system for managing shared water resources has been successfully developed to establish rules for water discharge, monitoring water quality and managing flood risks by the International Commission for the Protection of the Danube River (ICPDR). Enhanced commitment and cooperation from all involved nations are essential for addressing water-sharing issues and impacting upstream hydropower projects. A key solution is promoting international agreements for data and information sharing on water flow, reservoir levels and climatic conditions from upstream hydropower dams. Based on international experience, the following are vital proposals to improve water resource management and dam safety in Vietnam:

International cooperation mechanisms for managing transboundary water resources should be continued, particularly in the Mekong and Red River Basins. Agreements on data and information sharing among basin countries are essential, alongside commitments from upstream nations such as China and Laos for sustainable water discharge practices. Furthermore, Vietnam needs to develop response scenarios for water shortages in the dry season and flood risks during the rainy season. Investment in flow and water quality monitoring technologies and the application of flow forecasting models will enhance forecasting capabilities and water management.

(2) Enhance dam safety standards and maintenance

Significant improvements in safety standards for constructing and operating hydropower dams in Vietnam are necessary. The Ministry of Agriculture and Rural Development and the Ministry of Industry and Trade should update technical standards and regulations related to dam safety, as learned from countries like Japan and Norway. Regular inspections, maintenance, and upgrades of ageing dams are mandatory to ensure nearby residents' safety. Using real-time monitoring systems and artificial intelligence to analyze data from monitoring sensors will enable early detection of risks and minimize potential threats.

(3) Develop early warning systems and disaster response

Vietnam needs to invest in building early warning systems for floods and dam failures, drawing on the experiences of the U.S. and the Netherlands. These systems should integrate weather forecasting models, flow data, and pressure monitoring at dams to provide accurate and timely information to authorities and the public. The government should also organize regular drills for flood and dam failure preparedness to raise awareness and equip communities near dams and dikes with essential skills. These measures will strengthen emergency response capabilities during critical situations.

(4) Promote water-saving technologies and water reuse

With climate change and increasing water scarcity, advanced water-saving technologies, such as drip irrigation systems and wastewater treatment, should be adopted for reuse. Israel's experience developing water-saving solutions for agriculture and industry can serve as a model, reducing pressure on natural freshwater resources.

(5) Develop natural water storage areas and protect watershed forests

Vietnam should establish natural water storage areas, similar to "water retention areas" in the Netherlands. These areas can be used to store floodwaters during the rainy season, reducing pressure on rivers and reservoirs while protecting residential areas from flood risks. Protecting and restoring watershed forests is also vital for safeguarding water resources. Watershed forests regulate water flow, prevent soil erosion, and mitigate flood risks. The government should strengthen policies on forest protection and encourage local communities to participate in managing and preserving natural resources.

4. CONCLUSION

With its complex system of dams and water resources, Vietnam has to learn from international experiences in dam safety management and water resource protection. The practices of countries such as the United States, the Netherlands, Israel, and others highlight the effectiveness of applying modern technological solutions to water resource management and dam safety. To safeguard water resources and ensure dam safety, many cutting-edge technologies should be invested in, such as monitoring technologies, early warning systems, water reuse practices, and protection of upstream ecosystems. These efforts will contribute to building a sustainable water resource management system for the future ▪

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