Nature-Based and Tech-Enabled: Thailand's Integrated Approach to Water and Climate Resilience

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Abstract

Accelerating climate change and ecosystem degradation make sustainable resource use an urgent global priority. This paper examines Thailand's Hydro-Informatics Institute (HII) and its integrated approach to advancing data-driven Nature-based Solutions (NbS) for water resilience. The framework combines traditional ecological knowledge with modern Science, Technology, and Innovation (STI), aligned with Thai Royal Development concepts, such as "Three Forests, Four Benefits" and "New Theory Agriculture."

The Mae La Oup River Basin Network Community in Chiang Mai illustrates the model's efficacy. Confronting land tenure ambiguity and water scarcity, the community adopted participatory Community Water Resource Management (CWRM) in 2009. Interventions included community-led land use maps, 394 check dams, and solar-powered greenhouses with post-harvest technologies (Hydro-Informatics Institute, 2021).

Results show improved ecological and economic resilience: diversified farming supported by smart technology raised household incomes while reducing flood and drought risks. The study concludes that converging NbS, technology, and community empowerment provides a scalable pathway to achieve the SDGs and strengthen regional climate adaptation.

Introduction

Sustainable use of natural resources has become an urgent global imperative amid accelerating climate change. Intensifying temperature anomalies, hydrological shifts, the increasing frequency of extreme weather events, and ecosystem degradation are placing unprecedented pressure on natural systems and communities, further increasing the vulnerability of societies and economies worldwide (Intergovernmental Panel on Climate Change, 2022).

These challenges highlight the need for strategies that enhance resilience while preserving ecosystem integrity. Ensuring that natural resources are managed responsibly is not only essential for environmental protection but also for safeguarding livelihoods, food security, and long-term resilience.

Within this context, Nature-based Solutions (NbS) have gained prominence as an integrated approach that leverages natural processes to address societal challenges, including climate adaptation, disaster risk reduction, and sustainable water management. NbS encompasses the protection, restoration, and sustainable management of ecosystems to generate environmental, social, and economic co-benefits (International Union for Conservation of Nature, 2020). By working with nature rather than against it, NbS offers cost-effective, scalable, and inclusive pathways toward sustainability.

To maximize the effectiveness of NbS, the integration of modern technology is indispensable. Advanced tools, such as automated telemetry stations, remote sensing, geographic information systems (GIS), hydrological modelling, and data-driven decision-support platforms, enhance the ability to track ecosystem dynamics and evaluate impacts. These technologies also improve the precision, efficiency, and monitoring capacity of NbS initiatives, helping to optimize long-term planning (UN Environment Programme, 2021).

Integrating traditional ecological knowledge with digital technologies facilitates the development of Nature-based Solutions that are not only scientifically robust and practically implementable but also precise, scalable, and cost-effective.

In Thailand, the Hydro-Informatics Institute (HII) serves as a primary catalyst for advancing data-driven Nature-based Solutions (NbS). Leveraging hydro-informatics platforms, climate resilience initiatives, and community-based water resource management, HII bolsters national endeavours to deploy adaptive, evidence-based strategies that fortify natural resource governance. The integration of NbS with innovative technologies strengthens institutional capacity, fosters regional collaboration, and delivers tangible impacts for communities. Through strategic partnerships and knowledge dissemination, HII demonstrates the efficacy of a science-based, technology-enabled, and nature-centred paradigm in enhancing sustainable resource management amidst climate change. These initiatives underscore Thailand's broader commitment to sustainability, climate adaptation, and the deployment of innovation to mitigate environmental challenges.

Conceptual framework

Nature-based Solutions

Nature-based Solutions (NbS) are underpinned by the principle that healthy ecosystems, when protected, restored, and sustainably managed, provide essential services capable of addressing societal challenges. This framework emphasizes working synergistically with natural processes—rather than relying solely on engineered interventions—to enhance resilience, support biodiversity, and deliver long-term socio-economic benefits (IUCN, 2020). To operationalize this concept within water resource management and climate adaptation, three core principles, Watershed Restoration, Wetland Utilization, and Rainwater Management, are applied.

1. **Watershed restoration:** This approach prioritizes the rehabilitation of degraded catchments through reforestation and soil conservation. By restoring natural vegetation and stabilizing slopes, these interventions improve hydrological functions, specifically infiltration and flow regulation, thereby securing water supplies and mitigating flood risks (Browder et al., 2019).
2. **Wetland utilization:** Recognizing wetlands as multifunctional assets that simultaneously provide ecological services and safeguard human settlements, this principle leverages their natural capacity for water retention and filtration. Wetlands act as critical buffers against hydrological extremes, effectively managing floodwaters and improving water quality, which offers a resilient complement to engineered infrastructure (Ramsar Secretariat, 2018).
3. **Rainwater management:** Focused on mimicking natural hydrological cycles, this principle employs green infrastructure and decentralized storage to manage rainfall. Techniques such as permeable surfaces and community-based rainwater harvesting integrate natural hydrological processes into urban and rural planning, thereby reducing surface runoff and enhancing groundwater recharge. These strategies are particularly critical in rapidly urbanizing environments to mitigate localized flooding and disaster risks, while simultaneously bolstering water availability and promoting sustainable usage (UN-Habitat, 2020).

The effectiveness of NbS is maximized by bridging traditional ecological knowledge with modern science, technology, and innovation. The integration of data-driven tools—such as hydrological modelling and Geographic Information System (GIS)—ensures that these nature-centred solutions are scientifically robust, scalable, and optimized for long-term sustainability. By aligning ecological processes with human needs, NbS provides a clear pathway toward climate resilience and sustainable water governance.

Science, Technology, and Innovation for community water resource management

HII's Science, Technology, and Innovation (STI) for Community Water Resource Management or CWRM, grounded in active participation from local villagers, strengthens local ownership and enhances community capacity to manage water resources sustainably under diverse conditions, including floods and droughts (Hydro and Agro Informatics Institute, 2016). HII works closely with local villagers by providing training in technologies that are appropriate to the local context. This approach ensures that modern scientific tools are adapted to community needs and combined with indigenous knowledge, enabling villagers to manage water resources effectively while preserving their cultural traditions.

The integration of science, technology, and information systems has enabled communities to systematically collect essential data, diagnose root causes of local water challenges, and develop planning strategies that are best suited to their circumstances (Hydro-Informatics Institute, 2021). This participatory approach ensures that solutions are not only technically sound but also socially accepted and locally relevant.

Information technology: Information technology plays a central role in strengthening CWRM. Geographic Information Systems (GIS) provide communities with powerful tools to capture, analyse, and visualize geographic information, enabling them to map resources, monitor water flows, and plan for disaster preparedness. Global Positioning System (GPS) receivers complement this by offering precise location data, which is invaluable for land and water surveys. Together with satellite imagery and land use maps, these technologies allow villagers to better understand their local context, clarify land use patterns, and create visual guides for comprehensive future planning. Automated telemetry stations further enhance local capacity by continuously measuring water levels, precipitation, temperature, and humidity, transmitting data in real time for use in water modelling, forecasting weather, and disaster warning systems (Hydro and Agro Informatics Institute, 2018).

Water data, mapping, and security: Effective community water resource management relies on the systematic use of water data, water maps, and water diagrams. These tools provide essential information for analysing local hydrological conditions and developing resource management plans. By combining quantitative data with spatial mapping and flow diagrams, communities are better equipped to cope with flood and drought risks, strengthen water infrastructure, and enhance their capacity to manage local resources (Hydro and Agro Informatics Institute, 2017). Such integrated approaches ensure that decision-making is based on a shared and accurate understanding of water availability and distribution.

Equally important is the pursuit of water security, which encompasses the reliable availability of sufficient water for consumption, agriculture, and other essential uses throughout the year. Improving water security requires increasing water capital—through measures such as storage, reuse, and conservation—and ensuring adequate water reservations to buffer against seasonal variability and climate extremes. By securing water resources in this way, communities can safeguard livelihoods, reduce vulnerability to disasters, and promote sustainable development.

Tools and innovation for water management: Practical tools and innovations for water management, such as echo sounders, are used to determine water depth and monitor reservoirs, while hydropneumatics pumping stations enable the delivery of water from lower to higher grounds over long distances (Office of Research Administration, 2024). Wastewater treatment systems, such as household grease traps and solar-powered aerators, provide low-cost solutions for improving water quality. Water balance analysis has become a crucial practice, allowing communities to calculate demand and supply, identify risks of scarcity, and plan agricultural activities accordingly. Water reuse strategies, such as circulating canal water into farm ponds and paddy fields, reduce external demand and increase water value. Visual water diagrams, which illustrate flows from upstream to downstream, help communities understand hydrological dynamics and manage resources more effectively.

Innovation in agriculture is also closely linked to water resource management. Crop calendars provide farmers with timely information on planting, sowing, and harvesting periods, supporting climate-adaptive agricultural planning. Pond networks distribute water from upstream reservoirs to downstream ponds, strengthening local storage and distribution systems. Monthly water balance analysis, combined with surveys of natural streams recorded in GIS, enables farmers to identify the root causes of water stress and adopt appropriate solutions, such as rainwater harvesting and allocation for cropping (Hydro and Agro Informatics Institute, 2017). These practices are essential for coping with seasonal variations in rainfall and extreme weather events, thereby strengthening adaptability and resilience in agricultural communities.

Thai Royal Development Frameworks on Sustainable Agriculture and Natural Resource Management: Community-driven innovations are further strengthened by the application of royal initiatives, particularly the "Three Forests and Four Benefits" principle, which entails planting three types of forests for economic, conservation, and community-use—to generate four distinct benefits: wood/fuel, food/income, environmental protection, and water security. Additionally, the "New Theory Agriculture" promotes efficient land and water use through the systematic division of farmland into functional zones. This is exemplified by the 30:30:30:10 model (30% water storage, 30% rice cultivation, 30% mixed crops, and 10% housing). Together, these frameworks provide holistic approaches that ensure water–food–income security and reduce climate vulnerability, thereby promoting economic self-reliance and sustainable resource management (Grossman et al., 2016, Grossman et al., 2017).

The innovative solutions implemented by these communities have led to reduced flood and drought risks, improved water security, and strengthened reforestation efforts. Collectively, these initiatives contribute to resilient and sustainable livelihoods, ensuring that communities are better prepared to face the challenges of climate change.

Good practice case: Mae La Oup River Basin Network Community, Galayani Vadhana District, Chiang Mai Province, Thailand

The Mae La Oup River Basin Network Community is in Moo 3, Jam Luang Sub-district, Galayani Vadhana District, Chiang Mai Province, Thailand, covering 78.35 square kilometers, of which 79.05% is forest, 20.40% is agricultural land, and only 0.05% is designated for settlement. This network consists of 221 households with a total population of 810 people, primarily from the Paka-Kyaw ethnic group, who have inhabited the area for centuries (Hydro-Informatics Institute, 2021).

Despite their long-standing presence, the Paka-Kyaw community has historically lacked formal land title deeds. This absence of legal recognition created ambiguity regarding the boundaries between arable land and conserved forests. Over time, population growth and migration intensified the demand for natural resources, leading to forest encroachment. The situation was further exacerbated by external capitalists who hired local people to clear forested areas; this accelerated environmental degradation and directly resulted in worsening water shortages (Hydro and Agro Informatics Institute, 2017). Consequently, long-term conflicts over water allocation emerged as households competed for limited resources to sustain agricultural production. These tensions highlighted the community's vulnerability to resource scarcity and underscored the need for collective management strategies

Community water resource management in Mae La Oup River Basin, Galayani Vadhana District, Chiang Mai Province, Thailand: Integrating indigenous knowledge and modern technology

In 2009, Community Water Resource Management (CWRM) was introduced to the Mae La Oup River Basin Network Community. Recognizing the importance of indigenous knowledge within the Paka-Kyaw community, the Hydro-Informatics Institute (HII) placed special emphasis on facilitating the sharing of community-led local traditions and practices, and provided training in local languages enabling them to combine their deep knowledge of the landscape with modern tools, such as satellite imagery, Geographic Information Systems (GIS), and Global Positioning System (GPS) technology, to produce community land use maps. These efforts promoted the application of cultural wisdom while simultaneously transferring modern technologies to strengthen community-based resource management (Hydro-Informatics Institute, 2021).

Through participatory surveys by representatives of the local villagers, the community mapped and delineated vivid boundaries of preserved forest, usable forest, rehabilitating forest, crop rotation areas, and arable land. The resulting maps were formally endorsed by the

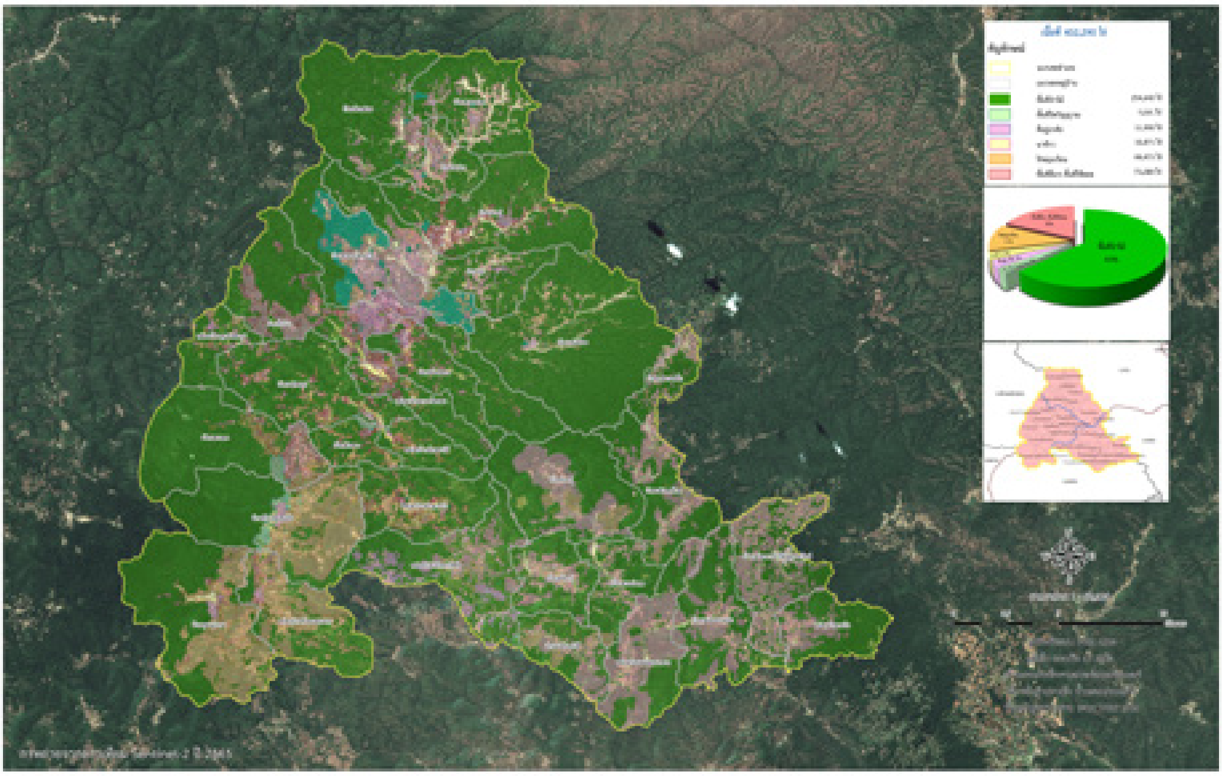

Figure 1: Example of Land-use Map in Mae La Oup River Basin, Galayani Vadhana District, Chiang Mai Province, Thailand

community and became the basis for issuing land use titles, thereby securing tenure rights and empowering collaborative upstream reforestation and sustainable land management.

Villagers were trained by HII to apply science and technology in preparing detailed water maps, conducting water balance analyses, and designing nature-based check dams and distribution systems suited to local hydrological conditions. Building on this technical capacity, the community constructed a series of three-level filter-system check dams tailored to the surrounding topography. The check dams were designed based on the location of the stream in the forest, using local materials, such as stone and wood. The primary and secondary levels function to slow water flow, trap sediment, and promote upstream reforestation, while the tertiary level enhances water storage for dry season use. To date, a total of 394 check dams have been completed, securing year-round water availability across 20 brooks (Hydro-Informatics Institute, 2021).

In 2009, the community faced severe natural disasters triggered by heavy rainfall, which caused soil erosion and landslides. These events not only damaged local infrastructure and agricultural land but also heightened awareness of the risks associated with unsustainable resource use. The experience reinforced the importance of integrated watershed management and community-driven approaches to strengthen resilience against climate variability and environmental hazards.

To address landslide risks, a 920-meter "canal street" was constructed along ridge areas. In normal conditions, it functions as a road, while during the rainy season it serves as a flood-control canal, channelling excess water to retention ponds. This innovation completely solved the landslide problem and strengthened community resilience against flash floods (Hydro-Informatics Institute, 2016). Indigenous knowledge guided the design of water storage dams and local irrigation systems, while traditions, such as the River Goddess Worship Ceremony (Natee Khunnam) and traditional rhymes, were revived to reinforce environmental stewardship.

Strengthening water security requires attention to both physical infrastructure and social governance. The installation of solar-powered pumps and storage facilities in Mae La Oup River Basin, together with pipelines extending to higher elevations, has reduced dependence on seasonal rainfall and enabled more reliable agricultural planning and crop diversification. Equally important, the project emphasized community-driven management. By entrusting the operation and maintenance of these systems to local stakeholders, the initiative fostered a strong sense of ownership that is essential for the long-term sustainability of community water resources (Yingkajohn, 2025).

From 2024, a notable technological advancement introduced through the project is the development of automated, climate-smart greenhouses designed to provide stable growing conditions year-round. Constructed with mesh roofing and equipped with comprehensive IoT-enabled control systems, these greenhouses autonomously regulate irrigation, temperature, and humidity. All operational functions are managed through the Tuya Smart application, a comprehensive mobile application that centralizes the control, monitoring, and automation of smart devices, allowing farmers to monitor and adjust environmental parameters in real time. Powered entirely by solar energy and utilizing mist irrigation to decrease temperature during summer for off-season cultivation, the system maintains ideal conditions for high-quality cultivation (Yingkajohn, 2025). As a result, farmers are able to produce vegetables and herbs consistently throughout the year, significantly increasing productivity while reducing vulnerability to climate-related impacts.

Complementing the improvements in water access, the initiative placed strong emphasis on integrating renewable energy into both water distribution systems and post-harvest agricultural processes in the Mae La Oup River Basin. By deploying hybrid systems that combine solar and hydropower, the project ensured a stable and reliable energy supply for agricultural processing and storage, which is an essential advancement for remote communities with limited access to conventional energy infrastructure. Practical applications of these systems include solar-powered electric dryers used for efficient dehydration of crops, such as chili and vegetables, as well as solar-driven cold storage units that maintain low temperatures needed to preserve product quality. These cold storage facilities reduce post-harvest losses and support off-season marketing, directly contributing to increased farmer income. Together, these innovations demonstrate how renewable energy infrastructure simultaneously strengthens environmental sustainability and reinforces economic resilience within the community. Value-added processing has lifted product worth by 1.6 times, while extended shelf life enables off-season sales that raise prices by up to 1.3 times (Yingkajohn, 2025).

With improved water resource management supported by various IoT technologies, the community transitioned from monocropping and nomadism to integrated agriculture, boosting household incomes through organic farming and agroforestry.

Outcomes and lessons learned

The implementation of these integrated interventions has yielded significant tangible outcomes, particularly regarding economic security and production efficiency. Household income from production saw an annual increase of approximately 28,800 THB (USD 893). Most notably, the strategic transition from monoculture to diversified farming systems proved highly lucrative; farmers reported an average annual income of 88,600 THB (USD 2,747), a substantial rise from the 14,400 THB (USD 446) typically generated by rice monoculture alone. Beyond primary production, value-added processing initiatives increased product value by 1.6 times, while improvements in shelf-life extension facilitated off-season sales, allowing farmers to command prices up to 1.3 times higher. These technical advancements also significantly reduced post-harvest product damage, ensuring more efficient market delivery. On a social level, the project successfully fostered community and youth engagement, expanding networks for knowledge exchange to support continuous, collaborative development (Yingkajohn, 2025).

Community empowerment was applied in Mae La Oup through training in technology, while ensuring that villagers themselves took the lead in surveying, planning, decision-making, and implementation. HII acted as a mentor, providing knowledge and financial support to foster sustainable development. As Ani et al. (2017) note, empowerment occurs when communities can identify problems, access resources, improve skills, and mobilize collective action for mutual benefit. It is a process of expanding the ability of individuals and groups to make choices and pursue common goals. Empowerment begins with individuals recognizing their own capacity and freedom, which can then be shared to build collective strength. For sustainability, empowerment must evolve from external initiation into self-reliant, internally driven actions.

Policy recommendations and scaling up

By the end of 2020, the Mae La Oup River Basin Network Community had expanded its practices to reach 8,648 people across 465.05 square kilometres, covering seven subdistricts: Jam Luang, Mae Daet, Wat Jan, Mae Najorn, Mae Suek, Ban Tab, and Tha Pha. Working Groups on Land Management and Regulation were established, alongside the "AePaWaDou" Youth Network, which now engages 105 members in 8 communities. The success of the Mae La Oup model has also extended to the Mae Jam River Basin, where good practices have been transferred to three subdistricts in nine villages (Hydro-Informatics Institute, 2021). Further scaling opportunities have emerged as visitors learn from the community's good practices, inspiring networks across Thailand to adopt similar approaches.

Since 2003, HII has initiated Community Water Resource Management (CWRM) project starting with two pilot communities in the very first year. Mae La Oup Network stands as one of the notable achievements within this journey, exemplifying how local empowerment and sustainable practices can evolve into national models. Over time, these good practices have self-expanded and multiplied. By the end of 2024, 60 CWRM core communities and 1,847 villages were established across 19 river basins, covering the entire country (Nunta & Kanyawararak, 2024).

HII has expanded its nature-based science adaptation concept not only across Thailand but also to neighbouring countries. In Lao PDR, HII partnered with the Department of Technology and Innovation, Lao PDR, to transfer knowledge and techniques on Community Water Resources Management concept to strengthen capacity of the local community in Sangthong Village, Vientiane Capital for climate-resilient adaptation. This initiative was started as bilateral project between two agencies, and further supported by the local private sector, the Coca-Cola Foundation, as part of their Corporate Social Responsibility program, demonstrating how community-based water resource management can be scaled regionally through cross-border collaboration and public-private-people partnerships.

Conclusion

The Mae La Oup experience underscores the critical role of integrating Nature-based Solutions (NbS) with modern technology to achieve sustainable development and climate resilience. By combining indigenous knowledge, scientific tools, and community empowerment, the model demonstrates how local action can reduce disaster risks, restore ecosystems, and secure livelihoods. Its success highlights that resilience is not only ecological but also social, rooted in community governance and collective capacity.

As HII's Community Water Resources Management model expands nationally and regionally, it provides a replicable framework for countries seeking to strengthen climate adaptation strategies. The convergence of NbS and technology offers pathways to achieve the Sustainable Development Goals (SDGs), particularly those related to water security, ecosystem restoration, and inclusive governance. Importantly, it shows that sustainable development is most effective when communities are empowered to lead, supported by institutions, and connected through regional collaboration.

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