Food and Agriculture Organization of the United Nations

Charles Sturt University
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Agriculture Water Environment

BRIEF 6

Mapping river infrastructure

for improved water resource management

Next Generation Water Management Policy Briefs

Cover photo:
Ferry boats on Bogale river in Pyapon district of Myanmar.

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Next Generation Water Management
BRIEF 6

1. Introduction

Infrastructure developments that fragment river basins have profound consequences for ecosystems, biodiversity, water resources and local communities. One of the primary outcomes is the loss of habitat and biodiversity, as natural habitats are destroyed or degraded by infrastructure such as dams, road crossings and irrigation structures. This fragmentation disrupts connectivity between different parts of the river, preventing the movement of species and genetic exchange and negatively impacting fish populations, migratory species and other aquatic organisms.

Moreover, such fragmentation alters vital ecological processes. It disrupts the natural flow patterns of water, sediments and nutrients, adversely affecting species distribution, nutrient cycling and ecosystem functionality. These disruptions have cascading effects on the entire food web and ecosystem. The socioeconomic implications are equally significant. River-dependent communities that rely on fisheries for food security face reduced fish populations and restricted access to resources. Altered water flows and availability challenge sectors like agriculture, irrigation and hydropower, leading to economic strain and potential resource conflicts.

In the Asia-Pacific region, the issue of river basin fragmentation is particularly pronounced in the Mekong River Basin. The Mekong River flows for 4,800 kilometres and sustains the world's most productive inland fishery. With an estimated annual first-sale value of approximately USD 17 billion, the Mekong River underpins the economy and livelihood of the region (Nam *et al.*, 2015). Migratory species constitute a significant portion of the Mekong's catch, ranging from 40 to 70 percent, including diadromous species that move between the ocean and rivers, as well as potadromous species that migrate between various freshwater habitats (Barlow *et al.*, 2008). These migratory fish rely heavily on river connectivity for their life cycles.

Over the past 40 years, the Mekong River Basin has seen significant infrastructure development for its multiple uses, including energy, agriculture and transportation, causing a disruption to natural flows, cold-water pollution and fragmented habitats. With exponential growth in such structures, particularly in the Lower Mekong Region, river connectivity, and aquatic biodiversity that rely on such connectivity, now face significant distress.

Box 1: River connectivity

River connectivity refers to the extent to which different parts of a river ecosystem are linked together, enabling the free flow of water, organisms, nutrients and sediments from one part of the system to another.

A well-connected river system has the following features:

Longitudinal connectivity: This involves the upstream and downstream flow of the river. It allows the movement of fish and other aquatic organisms for migration, spawning and accessing different habitats. It also aids in the transport of nutrients, sediments and organic material along the river's course.

Lateral connectivity: This refers to the connection between a river and its floodplain. In times of flooding, water spills over into floodplains, creating temporary habitats and feeding grounds for many species. It also helps in nutrient exchange and sediment deposition.

Vertical connectivity: This is the connection between surface water and groundwater. It plays a crucial role in maintaining base flow in rivers during dry periods and in recharging aquifers.

Temporal connectivity: This refers to the changes over time in the other types of connectivity due to seasonal variations, climate change and other factors.

Infrastructure development can disrupt these connections, leading to what is known as river fragmentation. These barriers can impede the movement of organisms, interrupt the natural flow of water, block sediment transport, and change the timing of flows, all of which can have significant impacts on river ecosystems.

The degree of river connectivity, in essence, is a balance between the number of existing river barriers, such as dams, small irrigation structures and road crossings, and the total water need for irrigation, inland fisheries, aquaculture and energy production (Baumgartner *et al.*, 2021). Effective water management requires optimizing river connectivity without impeding the existing and future demand for water. Informed by a sound decision support system, appropriate management practices can restore the maximum ecological integrity of rivers, through context-specific assessments of the barriers and by ensuring that the presence of barriers, including unauthorized ones, do not hinder water availability for concurrent uses, thus promoting sustainable river ecosystems and resource utilization (Mardsen *et al.*, 2023).

Danao - A view of a river running through forest land

2. Spatial data and planning

Spatial planning is a key decision-making tool for managing and restoring the ecological integrity of rivers. Spatial planning leverages the power of spatial data to create, analyse and visualize diverse scenarios. The subsequent insights can guide the implementation of effective river management practices.

Box 2: Spatial data and planning definitions

Spatial data, also referred to as geospatial data or geographic information, is data that identifies the geographic location and characteristics of natural or constructed features and boundaries on the Earth. Spatial data can be used in a variety of applications, including mapping, navigation, urban planning, disaster management, transportation planning and environmental management, among many others. Tools like Geographic Information Systems (GIS) are used to store, manipulate, analyse, and visualize spatial data.

Spatial planning refers to the methods used by public authorities to influence the distribution of people and activities in spaces of various scales. It is essentially a geographical approach to public policy that includes land use planning, urban planning, transportation planning, regional planning and environmental planning. Spatial planning uses data about the location and distribution of activities in the physical space, which is referred to as spatial data or geographic information. The process involves the creation and use of spatial strategies, policies, plans and decision-making frameworks. These are usually set out in documents such as regional plans, local development plans, and neighbourhood plans.

Spatial planning enables informed decision-making by harnessing geographical data within the context of river ecosystems. For example, the mapping of habitats, identification of barriers (e.g. dams, roads, levees) and pinpointing of vital ecological corridors can guide the determination of restoration focus areas and methods of implementation, equipping decision-makers with an evidence-based foundation for decisions.

Specific to river basin barriers, spatial planning plays a pivotal role in the assessment and mitigation of barriers. By providing a detailed understanding of barriers in a river system, spatial planning can enable barriers to be identified and categorized based on their impacts on river connectivity and overall ecosystem health. This process allows for the identification of unauthorized or damaging barriers, with priority placed on their modification or removal. The ability to cater for differences is another crucial aspect of spatial planning, making it possible for context-specific planning to occur.

Given that each river system possesses unique characteristics and faces distinct challenges, it is essential that these differences are taken into consideration during planning. This adaptability allows management practices to be tailored according to the unique needs of each river system. Thus, considering the spatial distribution of species, habitats and human activities, spatial planning leads to customized and hence more effective management strategies.

However, existing methodologies for such assessments have long catered to the realities of developed countries that assume the availability of rich field data and financial resources. The realities are often different in developing countries, such as those of Southeast Asia, where both data and financial resources are constrained (Baumgartner *et al.*, 2016). In resource-constrained settings, where the availability of site data may be limited, it is crucial to develop low-cost and time-efficient methods for harnessing spatial data for public policy.

3. Spatial planning for fish passage in Southeast Asia

The need for fishery restoration efforts is growing globally. However, the allocation of resources often remains disproportionately meager in developing countries. This is particularly pronounced in Southeast Asia, where fisheries play a significant role in securing food security and livelihoods for millions of people.

Southeast Asia is recognized for its rich aquatic biodiversity, hosting numerous unique and endemic species. Many of these species are highly dependent on interconnected, healthy aquatic ecosystems to survive and thrive, making restoration efforts vital to conserve biodiversity. As the region is rapidly developing, pressures on aquatic ecosystems have escalated. Infrastructure development, such as dams for hydroelectric power and irrigation, have resulted in habitat loss and fragmentation, disrupting fish migration patterns and breeding cycles. These developmental projects require effective and efficient fishery restoration efforts to mitigate their environmental impacts.

To facilitate the successful restoration of fish populations, it is crucial to adopt fish barrier prioritization approaches based on rigorous scientific principles. However, these methodologies should be adaptable to resource-constrained settings, providing a framework for practical conservation strategies.

Leveraging advancements in science and technology, spatial planning emerges as a promising tool for such conservation efforts. This approach harnesses GIS data (Hoenke *et al.*, 2014) to rank barriers for remediation using proxy information. By integrating GIS data, local knowledge, expert assessments and field validations, a robust and valuable toolkit can be established for identifying and prioritizing fish passage barriers, even in settings that lack extensive site data.

Box 3: Proxy Information

Proxy information, in the context of spatial planning for fisheries restoration, refers to data types that indirectly provide insights into the state of the river systems and fish populations. It includes but is not limited to:

Landscape characteristics: These could include data on the slope, elevation, soil type and vegetation cover of the areas surrounding the rivers. This type of information can indicate the likelihood of barriers such as dams or irrigation structures.

Water quality indicators: Proxy data on factors such as temperature, pH, turbidity and pollutant levels can provide insights into the health of the fish populations and the impacts of human activities.

Hydrological data: Information on flow rates, water levels and precipitation can help infer the presence of barriers and their potential impacts on fish migration and breeding.

Land use data: Information about the surrounding land use, such as agriculture, urban development or protected areas, can indicate the potential impacts on the river systems.

Species distribution models: These use existing data on species presence and environmental variables to predict where species might be found. This can help infer which barriers might be most impactful.

Historical data: Past data on fish populations, barrier locations and river conditions can provide context and help assess the potential impacts of barriers over time.

All of these types of proxy information can be integrated and analysed using GIS tools to help prioritize restoration efforts and provide a comprehensive view of the river systems and their challenges.

GIS-driven spatial planning allows a compact team to field-validate approximately 200 sites per month in certain Southeast Asian regions, amassing enough data to support restoration efforts for several years (Mardsen *et al.*, 2023). With augmented resources, the scope of field assessments could be broadened, scaling the workforce across regions. When field validation and spatial planning techniques are combined, policymakers and resource managers can gain vital insights into the range and impact of barriers in river systems. These insights enable informed decision-making in water resource management, thus paving the way towards sustainable conservation outcomes.

4. Fish barrier prioritization support system

The fish barrier support system (FBPSS) was developed and tested by Tim Marsden through a collaboration between Australasian Fish Passage Services and Charles Sturt University, Australia. The replicability of the framework allows rich experiences in fish passage construction and rehabilitation work in Australia to be put into practise in other regions such as in Southeast Asia (Marsden *et al.*, 2023).

The FBPSS is a decision support tool designed to identify, assess and prioritize fish passage barriers for remediation. These barriers could be human-made structures, such as dams, small irrigation structures or road crossings, that hinder the movement of fish across rivers and other water bodies, disrupting their natural life cycles.

The FBPSS is primarily aimed at resource-deficient settings and is built to be flexible and adaptable to various objectives. This means it can be used to inventory specific barrier types at local levels or to strategize large-scale prioritization across a wide range of structures.

The core of the FBPSS incorporates scoring adjustments and attribute weightings, which can be customized according to different contexts and management priorities. This is accomplished by integrating GIS analyses, scoring and ranking techniques, and re-evaluation concepts from optimization techniques into a single system.

The FBPSS implements a rigorous, five-stage decision support framework. The stages are as follows:

Stage 1 – Potential barrier identification: This stage utilizes existing spatial data layers to pinpoint and compile an exhaustive inventory of potential fish barriers.

Stage 2 – GIS analysis of potential barriers: The potential barriers identified in the previous stage undergo an initial GIS-based ranking for further evaluation. The ranking criteria include stream order, percentage of intensive land use in the vicinity, upstream habitat, the number of downstream barriers, and the area of upstream habitat.

Stage 3 – Field appraisal of potential barriers: High-priority barriers identified in Stage 2 are field-validated. This crucial phase ensures that subsequent assessments are grounded in accurate and reliable data.

Stage 4 – Biological appraisal of the barriers: This stage involves evaluating potential gains in fisheries productivity related to the validated barriers. Evaluation parameters include barrier type, stream condition, water supply/quantity, instream habitat and the importance of the site to local fishers.

Stage 5 – Socioeconomic assessment of high-priority barriers: The final stage conducts a socioeconomic assessment of the high-priority barriers identified in Stage 4. Assessment criteria encompass the estimated construction cost, technical feasibility of construction, productivity benefits, and effectiveness of reinstating fish passage at the site.

By integrating these five stages, the FBPSS provides a systematic and robust approach for decision-making and prioritization of barrier remediation efforts, enabling comprehensive consideration of various ecological, social and economic factors.

5. Measuring river fragmentation in the Citarum River Basin

Under the NextGen Programme, Charles Sturt University is implementing an initiative to improve the ability of the Indonesian Ministry of National Development Planning to gather and use geospatial data for better-informed water resource management.

Although existing initiatives in Indonesia aim to gather and apply data for inland waterway management, the country faces a significant deficit of spatial information regarding irrigation, fisheries and hydropower infrastructures. Moreover, there is limited expertise to document the impacts of these structures and prioritize remedial efforts. This data deficiency becomes especially pertinent as the nation's irrigation policy is undergoing reform, with upgrades planned for irrigation infrastructure over the next 15 years. Enhancing data capacity for inland waterway management is fundamental to securing water, food and energy, conserving biodiversity, and adapting to climate change.

The project's objective is to bolster the national effort to collect high-quality data to generate spatial information that supports inland waterway management under existing and future climate scenarios. It aims to enhance spatial data capacity pertaining to river development, thereby informing restoration efforts for current river infrastructures and the sustainable design and management of planned ones. It will facilitate the identification of river barriers linked with illegal aquaculture developments that adversely impact water availability and quality for other activities.

By examining the cumulative effect of these barriers, the project aims to offer a holistic assessment of river connectivity and potential fragmentation. It also intends to deliver technical training programmes customized for local stakeholders to bolster their skills in mapping and validating river infrastructure and connectivity.

The project has earmarked the Citarum River watershed as a case study due to its importance to all stakeholders, including local and regional institutes and agencies responsible for river basin management. These authorities, with diverse responsibilities and authority over the river watershed, play a pivotal role in managing barriers to river connectivity, water allocation and water use.

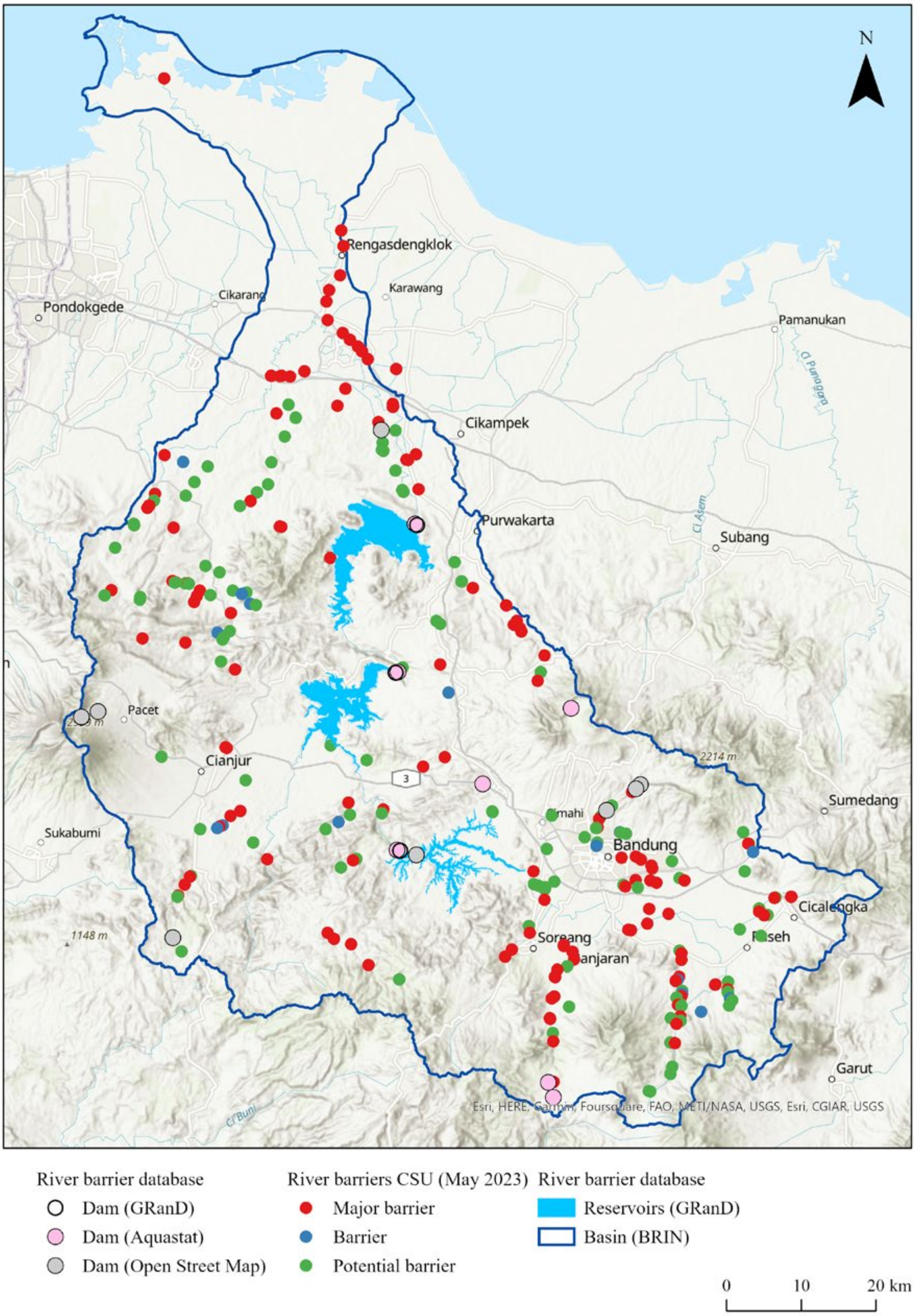
The project seeks to create an accurate location inventory of the existing river infrastructure catering to various water management needs, such as irrigation, inland fisheries, aquaculture, and energy production. Geospatial technology and analysis are crucial in informing decision-makers about threats to water security and biodiversity at a catchment scale.

To date, the project has pinpointed 545 barriers, with 145 already verified through visual assessment. The geodatabase will house the location of river barriers along with attributes like stream order, land use, slope, barrier type and passability. This information will enable a quantitative assessment of river connectivity and guide decision-making in river catchment management. To complement this quantitative assessment, a questionnaire has been prepared to evaluate stakeholders' perceptions of river connectivity and its role in effective water resource management.

The project outcomes will enhance geospatial data capacity, communication, data transferability and data updates for water resource management. It will also strengthen institutional and technical capacity, knowledge transfer and decision-making ability for strategic planning of water resources under projected climate change scenarios.

By quantifying habitat fragmentation and offering evidence-based tools, the project aims to instigate a shift in water management practices, with a focus on the Sustainable Development Goals and climate change adaptation. Ultimately, the project will contribute to the development of knowledge and capacity building in freshwater management at the catchment level, addressing present and future challenges.

Figure 1: River barrier in Citarum



Source: SPAN (Spatial Data Analysis Network). 2023. CITARUM_SHP [Shapefile]. In: Spatial Data Analysis Network (SPAN). [Cited 7 September 2023]. https://csu-span.maps.arcgis.com/, modified by Ana Horta

6. Conclusion

Contextualized spatial planning tools, such as the FBPSS, provide invaluable assistance in forming effective water management strategies, particularly in resource-limited settings. By integrating GIS data and local knowledge, these tools can efficiently and effectively assess and prioritize fish passage barriers. This can streamline the collective efforts of various agencies to strengthen data collection, ultimately leading to an accurate, comprehensive database on river infrastructure, such as dams, irrigation structures and road crossings.

Building capacity for spatial planning among stakeholders involved in water resource management is another essential aspect. Capacity-building initiatives can empower local stakeholders to accurately map and validate river infrastructure, evaluate barriers and make well-informed decisions regarding ecosystem restoration efforts. Enhancing the skills and knowledge of stakeholders can strengthen a country's ability to address water resource challenges, thus promoting sustainable development.

Moreover, adopting basin-scale strategies for fish passage barrier management can result in more efficient and effective remediation efforts. Instead of focusing solely on individual barriers, comprehensive plans should be developed that consider the cumulative benefits of addressing multiple barriers within the entire river basin. This approach considers the ecological, social and economic factors associated with each barrier, enabling decision-makers to achieve superior outcomes in terms of river connectivity and sustainable water resource management.

Spatial planning is critical in water resource management, especially regarding river connectivity and fish passage barrier remediation. Adopting tools like the FBPSS, strengthening data collection and validation efforts, and initiating capacity-building endeavors can substantially improve decision-making processes. By embracing basin-scale strategies and considering the cumulative benefits of barrier remediation, governments and water resource management agencies can ensure sustainable water usage, maintain the ecological integrity of rivers, and support the livelihoods of communities that rely on these resources. Incorporating these recommendations will catalyse positive change in water management practices, thereby contributing to the attainment of the Sustainable Development Goals in the region and globally.

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The Next Generation Water Management Policy Brief Collection

This Briefing Collection has been developed to inform policymakers of new and improved approaches to different aspects of water resources management for agriculture and food security across Asia and the Pacific. Each brief promotes cutting-edge approaches in water management that are being developed and implemented by FAO and its key technical partners. Content for this Briefing Collection draws from two major programmes led by FAO's Regional Office for Asia and the Pacific:

Asia Pacific Water Scarcity Programme (WSP): TThe WSP aims to bring water use to within sustainable limits and prepare countries for a productive future with less water. The WSP is assessing the scope of water scarcity in the region, evaluating effective management response options (primarily water accounting and allocation), supporting improvements in governance, and assisting partner countries to implement adaptive water management in the agriculture sector using appropriate and newly developed tools and methodologies. The WSP is also establishing a regional cooperative platform to enable countries to share solutions and experiences, in addition to ensuring national engagement at the highest political level.

Next Generation Irrigation and Water Management Programme (NextGen): NextGen draws on global best practices to accelerate the modernization of irrigation systems and water management in Asia and the Pacific. NextGen aims to ensure a bioeconomy that balances economic value and social welfare with environmental sustainability. The programme addresses cross-cutting issues in irrigation and water management, such as irrigation performance, food security, ecosystem health, gender equality, fisheries, and aquatic biodiversity. In this way, NextGen promotes the implementation of integrated and evidence-based policies and practices in micro and macro environments, using technological, organizational and social innovations. NextGen is undertaken in collaboration with the Australian Water Partnership, supported by the Australian Department of Foreign Affairs and Trade.

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