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Original Article

Concept and Implementation of River Corridor to Ensure Environmental Sustainability of Citarum River, Indonesia

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ABSTRACT
The river corridor is literally a spatial passage that runs along the riverbanks. The corridor's width varies significantly depending on its intended function, land-use designation, and the associated ecological and socio-economic benefits. In this study, the river corridor is defined in terms of its role in sustaining the river ecosystem, particularly as a water source and in preserving the integrity of its hydrological substance. The primary objective of this study is to examine both the conceptual framework and the practical implementation of river corridors in promoting environmental sustainability, using the Citarum River in Indonesia as a case study. The research area covers the entire stretch of the Citarum River, from its upstream origin (km 0) to the Citarum River, Indonesia. Key parameters analyzed include river morphology, land use patterns, geospatial technology applications in land-use monitoring, anthropogenic activities, and the physical condition of the river from the thalweg (deepest channel) extending 1 km laterally on both the left and right banks. Data were collected through an integrative approach combining literature review, field observation, photographic documentation, and in-depth interviews with local residents living along the river corridor over the past two years. The study identifies both conceptual insights and implementation cases of the river corridor framework within the study period. These findings lead to the formulation of evidence-based recommendations rooted in nature-based solutions aimed at ensuring the sustainable management and restoration of river ecosystems.

KEYWORDS
Citarum; Concept and Implementation; Environmental; River Corridor; Sustainability;

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INTRODUCTION

Rivers are, by nature, dynamic systems that shape landscapes and support both human communities and surrounding ecosystems. However, they also harbor potential hazards, such as bank erosion and flooding (Wohl, 2021). Naturally flowing rivers exhibit spatial and temporal variability in water, sediment, and wood fluxes, which both trigger and respond to geomorphic heterogeneity within the river corridor system (Marshall et al., 2024). Historically, river corridors have played a central role in transportation and communication networks, facilitating social cohesion and economic prosperity across regions (Downes et al., 2025). Unfortunately, mounting pressures from urbanization, land-use conversion for economic purposes, and climate change have disrupted these vital functions, rendering aquatic ecosystems increasingly vulnerable (Tomsett & Leyland, 2019; Lawler et al., 2020).

Within the framework of sustainable river management, the river corridor concept has emerged as a key approach that emphasizes the interconnectedness between fluvial elements, hydrogeomorphic processes, and water flow exchanges with the surrounding landscape (National Research Council, 2002). A river corridor is understood as the minimum spatial area required to sustain the river's essential functions, including channel and floodplain formation (Nelson et al., 2024), and constitutes part of the unique and complex critical zone (Ward, 2023). The interplay between dynamic processes and geomorphic forms within the corridor governs the development and spatial distribution of geomorphic units (Fryirs & Brierley, 2022). Nevertheless, in practice, river corridor management still faces significant challenges, including stakeholder conflicts, ecosystem degradation, and weak intersectoral integration (Garcia et al., 2017).

Addressing this complexity calls for a paradigm shift one that advances the conceptualization of river corridors beyond localized boundaries, fixed scales, and technical mechanisms, toward an understanding rooted in dynamic socio-ecological systems (Ward et al., 2022). This study aims to examine the river corridor concept from the perspective of environmental sustainability and to investigate how this approach is being implemented in adaptive and holistic ways across various geographic contexts. Drawing upon the disciplinary evolution of river corridor science over the past century from flow control-based models to multifactorial and socio-ecological frameworks (Ward, 2023) this research seeks to provide both conceptual and practical contributions to future spatial planning and river ecosystem conservation, specifically for the Citarum River. Findings from a two-year investigation (2023–2024) will serve as the foundation for policy recommendations, both for the Citarum River and potentially for the development of river corridor guidelines in other regions, positioning this study as a critical state-of-the-art contribution.

METHOD

Research Location

In addition to formulating a sustainable conceptual framework for river corridors, this study also incorporates empirical field investigations conducted over the past several years as a replicable model for sustainable river corridor development. The Citarum River, located in Bandung, Indonesia, serves as the primary case study site for this investigation.

Research Approach

A mixed-methods approach was employed in this study to comprehensively address the overarching research objectives. The qualitative component was utilized to formulate the conceptual framework of a sustainable river corridor, while the quantitative component was applied to identify and analyze field phenomena related to the implementation of the previously established concept. The research methods included surveys and an extensive literature review, drawing upon studies conducted in various countries.

Research Procedure

The research procedure involved multiple stages over an extended period. The conceptual framework and field investigations began in early 2023, focusing on exploring the empirical relationship between land-use practices and water quality. As the study progressed, several significant findings emerged particularly regarding the sources of pollution affecting the Citarum River. In response, the 2024 phase of the investigation was refined to focus more sharply on identifying and formulating sustainable land management strategies within the boundaries defined by the river corridor concept. This targeted area was found to be a critical contributor to water quality degradation during the previous year.

Data Analysis

A descriptive analysis was employed to elaborate on prior field findings, serving as the basis for formulating a comprehensive grand design of sustainable river corridors both in terms of conceptual framework and practical implementation.

RESULT AND DISCUSSION

Our Concept River Corridor

(The A Concept, Functions, and Key Parameters of River Corridors)

The science of river corridors has undergone significant evolution over the past century. This development reflects a transition from linear, sectoral approaches to more holistic and integrative frameworks that incorporate hydrological, geomorphological, ecological, and socio-economic dimensions (Ward, 2023). River corridors are now viewed as critical landscape elements that enable pathways for the exchange, dispersal, and migration of materials and organisms (Liu et al., 2018). As dynamic systems, river corridors encompass active channels and floodplains, which are naturally bounded by topographic constraints, mesic vegetation (distinct from xeric types), and physical evidence of ongoing fluvial erosion and deposition processes (Wohl & Scamardo, 2022). Consequently, these features directly influence the morphodynamic behavior of river corridors, which is central to the understanding of river system processes (see Figure 1).

However, in practice, technical approaches adopted by watershed hydrologists often overlook critical elements such as lakes, reservoirs, and small ponds, under the assumption that water transit occurs solely through the main river channel (Kirchner et al., 2001; Lindgren & Destouni, 2004; Knapp et al., 2019). In reality, recent studies have demonstrated that reservoirs have become major contributors to the expansion of surface area within river corridors over the last century (Harvey & Schmadel, 2021). This expansion has substantially altered key parameters, including surface area coverage (ΔD) and residence time scales (ΔRw).

$$\Delta D_i = \frac{D_{pres,i} - D_{his,i}}{D_{his,i}} \, x \, 100\% \quad \text{.............................. (1)}$$

$$\Delta R_{w,i} = \frac{R_{wpres,i} - R_{whis,i}}{R_{whis,i}} \, x \, 100\% \quad \text{.............................. (2)}$$

Where D pres dan D his [%] represent the present and historical surface areas of river corridors, respectively—comprising both lentic and lotic water bodies; and Rwpres and Rwhis [TL^{-1}] denote the surface area-weighted residence time scales of the present and historical river corridor systems.

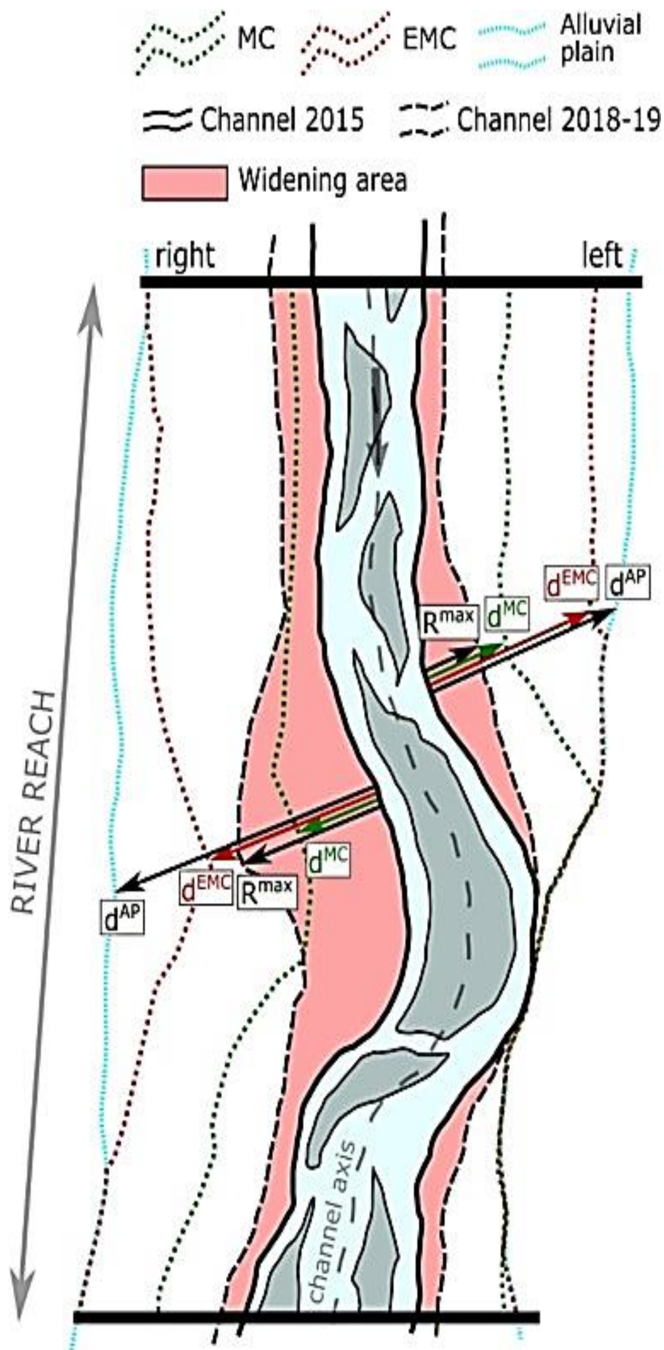
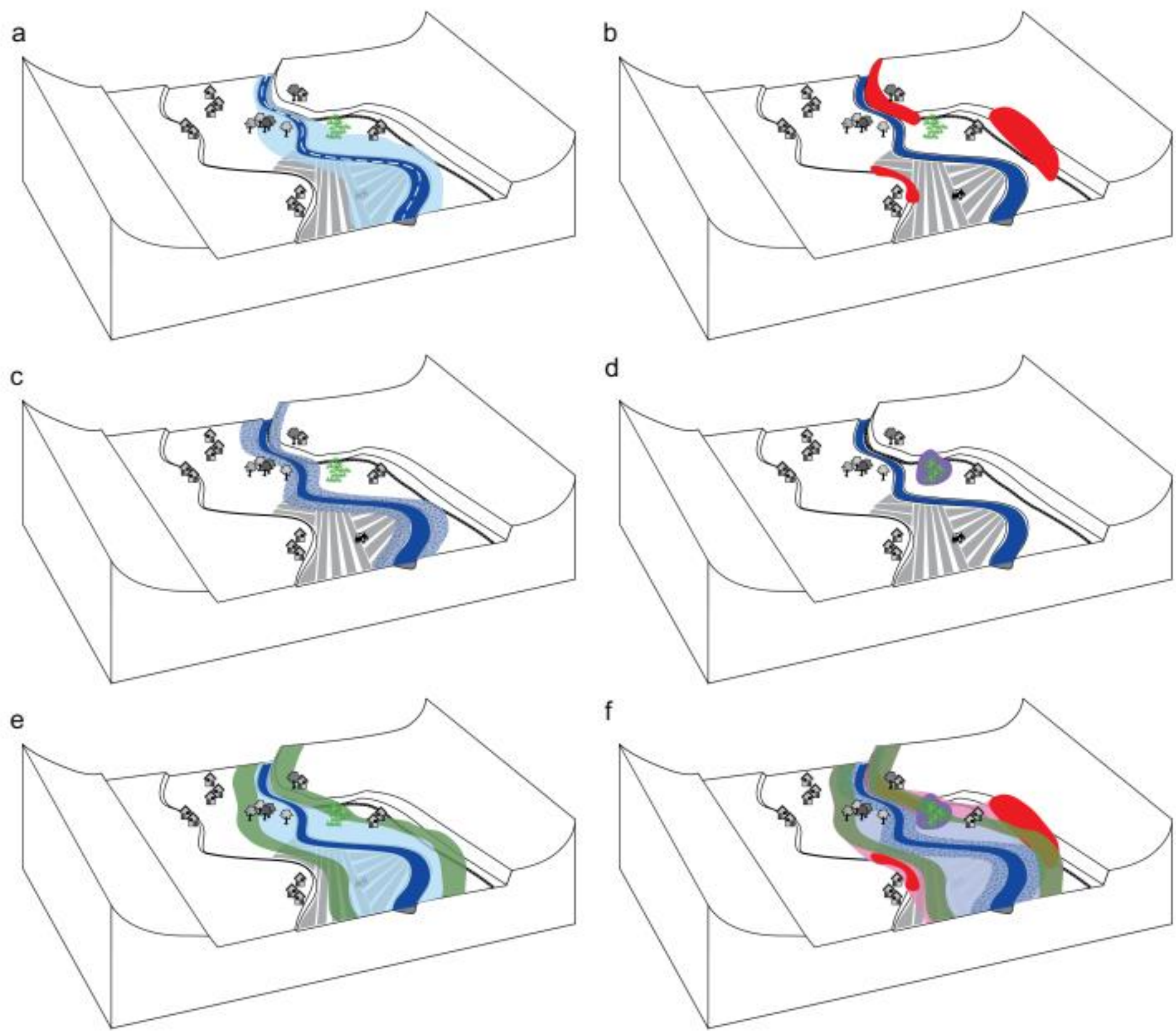


Figure 1. The Morphodynamic Widening Process of River Corridors (Brenna et al, 2024)

In the geospatial context, information, metadata, and global mapping of river corridors are now openly available to support scientific research and sustainable planning (Kaufman et al., 2023). These resources can be accessed through various platforms that provide integrated spatial data for river systems, enabling researchers, planners, and policymakers to assess, monitor, and manage river corridors more effectively https://data.ess-dive.lbl.gov/view/doi:10.15485/1971251

The ecological processes within river corridors are shaped by the interactions among surface water, dissolved substances, and the longitudinal flow of energy from upstream to downstream, which together influence water quality and habitat availability (Wondzell & Gooseff, 2014; Ward et al., 2019). At the landscape scale, river corridors act as ecological arteries that connect fragmented habitats, facilitate species mobility, enhance genetic exchange, and reduce population isolation (Fontoura et al., 2022; Qu et al., 2024; Hilty et al., 2020).



Schematic representation of how the five Process Units theoretically might appear on a generic floodplain as part of the River Process Corridor Modular Assessment Method (RPC). (a) Flood Process Unit. Note that this light blue inundation area barely extends beyond the banks of the deeply incised channel toward the top of the diagram, (b) Steep Terrain and Landslide Process Unit (red), (c) Channel Migration Process Unit (stippled blue), (d) Wetland Process Unit (purple), (e) Riparian Ecological Process Unit, and (f) the total River Process Corridor (RPC; pink)

Source: Gartner et al (2019)

Beyond their role as geographic features, river corridors function as complex ecological and social connectors. Their internal dynamics give rise to ecologically valuable zones characterized by high biodiversity, spatial and temporal heterogeneity (patch dynamics), diverse riparian habitats, and their role as ecotones between aquatic and terrestrial ecosystems (Naiman et al., 1993; Pickett & White, 1985).

In the context of climate change and increasing land disturbances, the adaptive role of river corridors becomes ever more critical for sustaining ecological resilience and supporting long-term landscape connectivity (Bennett, 2003; Paul et al., 2015; Belote et al., 2016; Lawler et al., 2020).

In several regions such as North America and Europe, species like beavers have been shown to play a significant role in shaping hydrological functions and ecosystem structures within river corridors (Larsen et al., 2021). Accordingly, the existence of river corridors is not only of ecological interest but also a critical consideration in engineering planning, policy development, and disaster mitigation efforts (Tomsett & Leyland, 2019; Shih & Lee, 2024).

In addition to beavers, this study also investigates the relationship between natural riverbanks and the confinement ratio of river corridor boundaries. This relationship is illustrated in Figure 2.

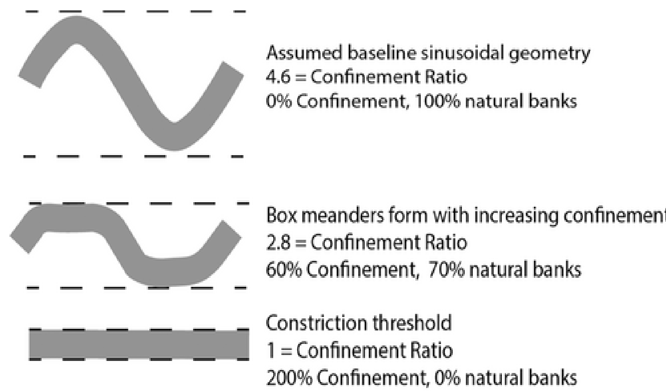


Figure 2. Relationship Between Natural Riverbanks and the Confinement Ratio of River Corridor Boundaries
Source: Nelson et al. (2024)

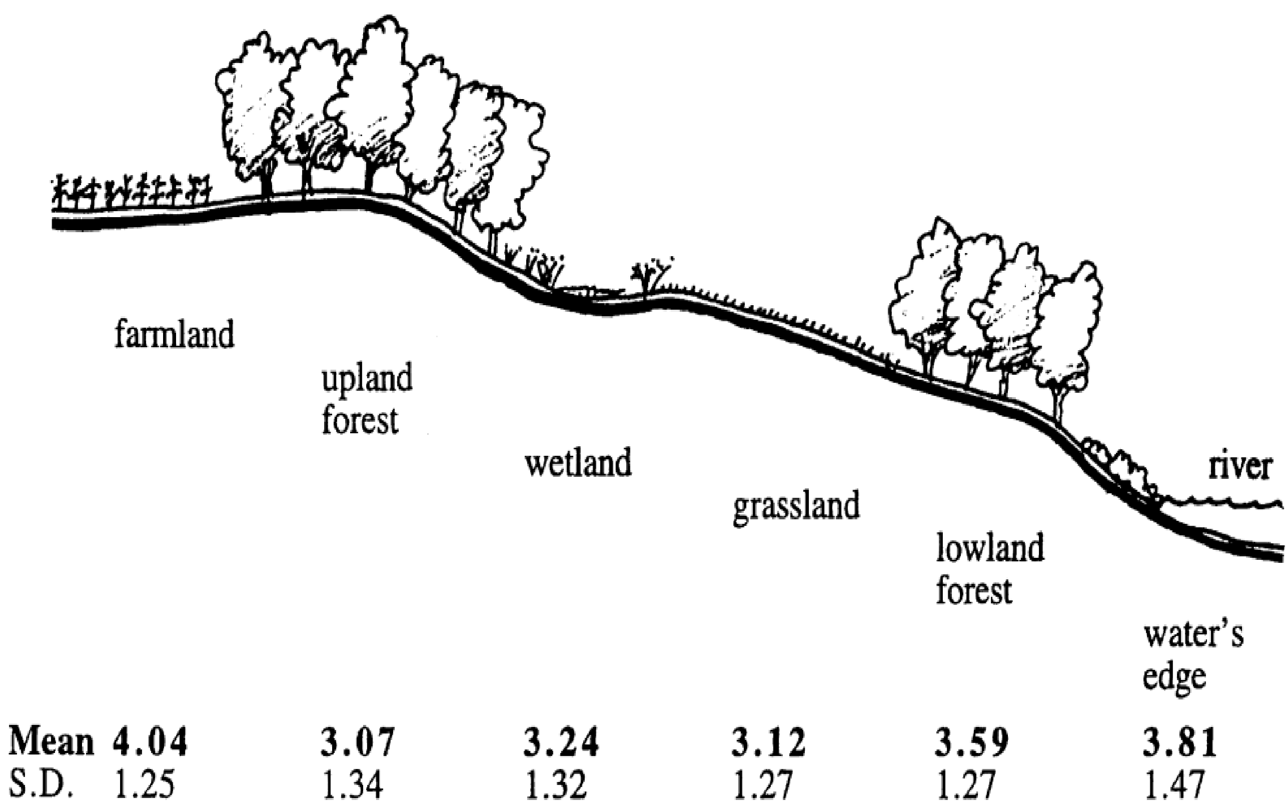


Figure 3. River corridor diagram results

In light of the changes and spatial confinement of river corridor boundaries, there is a need for a rational conceptual framework one that is not only ecologically sound but also encompasses significant social dimensions (Ward, 2023). Local community perspectives on the functional boundaries of river corridors can be explored using a grounded theory approach, as developed by Ryan (1998), which has been operationalized into a diagrammatic model representing the river corridor outcomes (Figure 3). Within these corridor areas, rivers play a crucial role in environmental, economic, and social systems. At the same time, they represent one of the most hazardous natural forces globally, underscoring the necessity of consistent monitoring to enhance our understanding and safeguard vulnerable communities (Tomsett & Leyland, 2019).

Our Implementation River Corridor

Case Studies and Sustainable Practices of River Corridors

River corridors are inherently complex environments that play a vital role in large-scale nutrient and organic matter cycling (Turetcaia et al., 2021). However, in this study, we conducted an investigation into the contribution of land-use culture to water quality along the Citarum River corridor. In this context, the planning of a healthy river corridor requires the integration of flood conveyance needs, channel migration dynamics, and riparian buffer zones (Nelson et al., 2024). Specifically, we carried out an investigation into the issues and complexities of the Citarum River corridor, as outlined below:

Year 1 Investigation

In the first year, the investigation scheme focused on identifying the empirical relationship between land-use culture and water quality. This was achieved by analyzing physical, organic and inorganic chemical, and biological parameters along the length of the Citarum River corridor (Figure 4). The detailed findings of this investigation are presented in Table 1.

Table 1. Investigation Results: The Contribution of Land-Use Culture to Water Quality

Parameters	Indicator's	Land use	Contribution (%)
Physics	Water Turbidity	Forest	19,12
		Agriculture	0,38
		Built-up Area	1,70
		Scrub	57,27
Inorganic Chemistry	pH	Forest	7,59
		Agriculture	25,77
		Built-up Area	31,01
		Scrub	3,00
	T-phosphat	Forest	18,32
		Agriculture	78,57
		Built-up Area	77,76
		Scrub	0,90
	Nitrate	Forest	53,84
		Agriculture	64,75
		Built-up Area	69,74
		Scrub	12,35
	Dissolved iron (Fe)	Forest	60,44
		Agriculture	29,82
		Built-up Area	36,67
		Scrub	25,38
	Dissolved Manganese (Mn)	Forest	0,42
		Agriculture	21,84
		Built-up Area	38,34
		Scrub	13,36
	Dissolved Zinc (Zn)	Forest	0,00
		Agriculture	0,00
		Built-up Area	0,00
		Scrub	0,00
	Kadmium (Cd)	Forest	0,00
		Agriculture	0,00
		Built-up Area	0,00
		Scrub	0,00
	Sulfate (SO42-)	Forest	16,08
		Agriculture	82,80
		Built-up Area	52,92
		Scrub	0,46
	Flourida (F)	Forest	2,73
		Agriculture	44,53
		Built-up Area	43,88
		Scrub	8,05
	Clorida (Cl)	Forest	0,20
		Agriculture	37,01

Parameters	Indicator's	Land use	Contribution (%)
		Built-up Area	5,64
		Scrub	3,35
Organic Chemistry	BOD (Biochemical Oxygen Demand)	Forest	87,84
		Agriculture	61,00
		Built-up Area	81,93
		Scrub	56,31
	COD (Chemical Oxygen Demand)	Forest	49,86
		Agriculture	97,79
		Built-up Area	65,97
		Scrub	20,25
	DO (Dissolved Oxygen)	Forest	22,20
		Agriculture	34,40
		Built-up Area	78,09
		Scrub	5,21
	Detergen Total	Forest	91,62
		Agriculture	63,73
		Built-up Area	56,03
		Scrub	55,81
Microbiology	Fecal Coliform	Forest	99,36
		Agriculture	50,94
		Built-up Area	51,24
		Scrub	85,40

Source: Rohmat et al (2024)

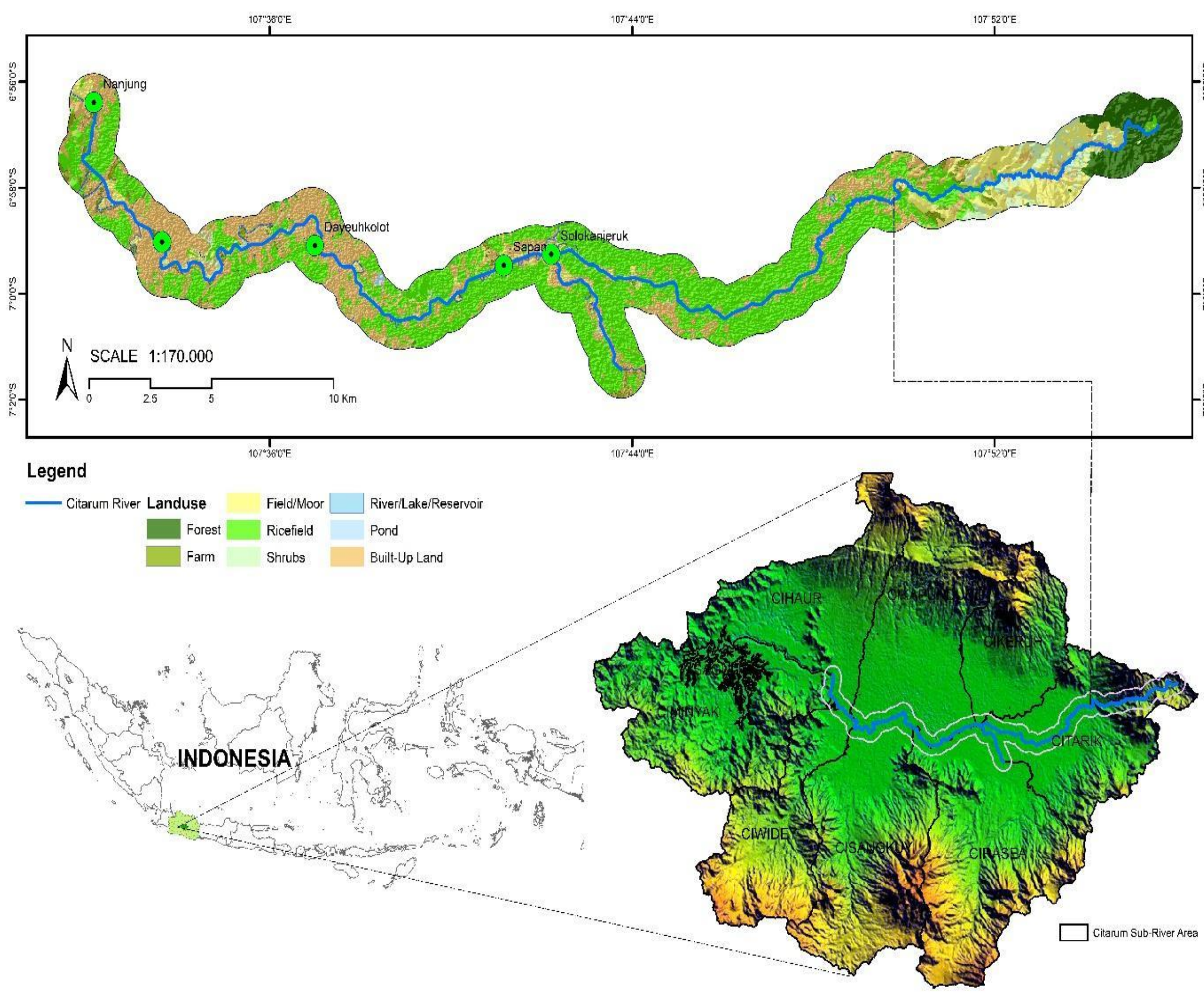


Figure 4. Along the Citarum River Corridor (First-Year Investigation)

The findings of this investigation were previously reported in a publication highlighting that land-use culture along the river corridor has a significant impact on water quality (Setiawan et al., 2024). These two parameters serve as the foundation for formulating strategic approaches to the sustainable preservation of the Citarum River. Additionally, we have published these strategic insights in a book entitled River Corridors: Between Land-Use Culture and Water Quality Parameters in the Citarum Watershed (Rohmat et al., 2024).

Second-Year Investigation

In the second year of investigation, we focused on identifying the relationship between land-use culture and the regional spatial planning framework along the Citarum River corridor. This approach aimed to reveal gaps between the two variables, providing a basis for formulating an appropriate land-use model surrounding the river corridor.

A Sample (Sector 1)

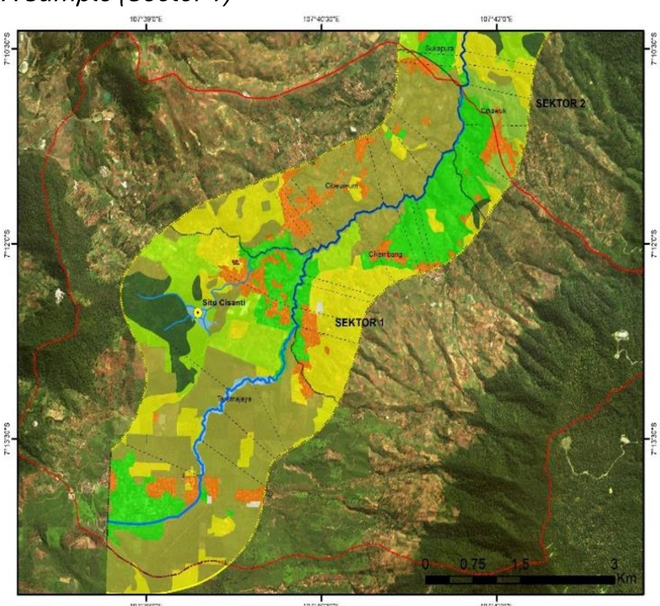


Figure 5. Identification of Land-Use Culture Along the River Corridor (Sector 1)

The results of this identification are visualized in Figure 5 and reflect the implications of the river corridor concept itself. One of the sample locations was situated in the Cibereum area, Bandung Regency, Indonesia, within Sector 1 of the Citarum Harum program. At the initial stage of the investigation, we sought to classify land-use culture by mapping land-use areas (in hectares) along the corridor. The findings from one of the identified sample sites are presented in Table 2.

Table 2. Land Area of the Citarum River Corridor by Land-Use Culture in Citarum River

Land use	Hectare	%
Settlements and Places of Activity	179,37	8,16
Plantations/Gardens	898,11	40,87
Fields	404,33	18,40
Industry	0,67	0,03
Rice Fields	374,84	17,06
Rainfed Rice Fields	14,22	0,65
Empty/Bare Land	3,74	0,17
Jungle	102,00	4,64
Bushes	194,24	8,84
Water Bodies	26,05	1,19
Total Land Area	2197,56	100,00

Source: Investigation Results (2024)

The identified land-use patterns were overlaid with the spatial planning map of Bandung Regency, revealing areas of inconsistency. This mismatch phenomenon was observed across Sectors 1 through 4. The results of this land-use discrepancy are interpreted and visualized in Figure 6.

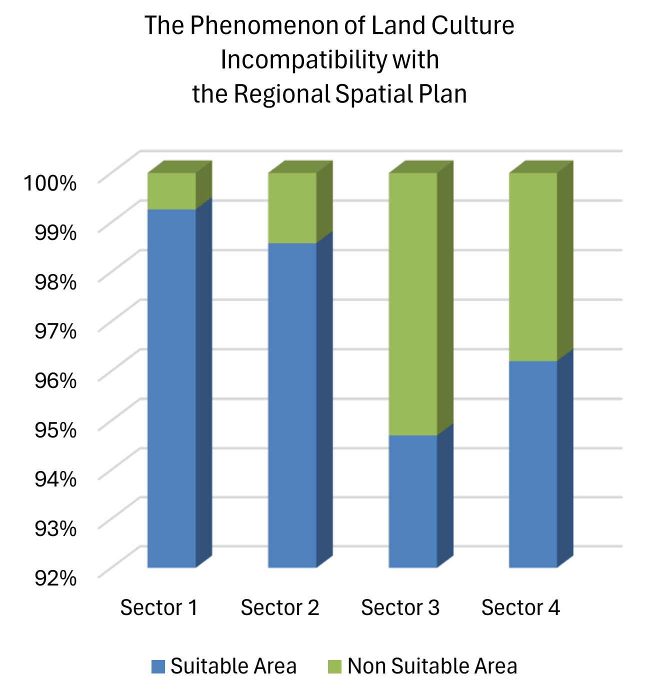


Figure 6. The Mismatch Between Land-Use Culture and Regional Spatial Planning

The gap analysis conducted across the four sectors revealed a consistent trend: from Sector 1 (upstream) to Sector 3 (midstream), land-use inconsistencies increased progressively downstream within the area of interest. Although Sector 4 (downstream) exhibited a slightly different pattern, the degree of mismatch remained comparable. Overall, these discrepancies are largely driven by anthropogenic activities such as urbanization, industrial expansion, and residential development.

A focused investigation was conducted in Sector 4, located in Majalaya, Bandung Regency. One notable mismatch was the conversion of wet agricultural land into settlements, covering approximately 9.11 hectares. This discrepancy is visually confirmed through aerial imagery, as shown in Figure 7.

Figure 7. The Land-Use Discrepancy Case in River Corridor Citarum - Majalaya, Indonesia

Nature-Based Solutions (NbS) for River Corridors

Nature-based solutions (NbS), as promoted by the International Union for Conservation of Nature (IUCN), encourage practical projects that prioritize biodiversity and habitat diversity as core considerations (Shih & Lee, 2024). Vegetation within river corridors plays a vital role in stabilizing channel banks and floodplain surfaces, dissipating flow energy, and facilitating sediment deposition during overbank flows along riverbanks or within the broader corridor zone (Wohl et al., 2022).

River corridors are designed to accommodate the dynamic behavior of rivers, such as lateral migration and sediment deposition, without posing risks to human settlements or economic activities. This approach, which integrates principles of ecological engineering, is widely recognized under the umbrella of nature-based solutions (Palmer et al., 2015; Cohen-Shacham et al., 2016). NbS scenarios are increasingly effective in times of uncertainty, particularly in the face of climate change and natural disasters that pose severe threats to human life and ecosystems.

Cohen-Shacham et al. (2016) proposed a hypothesis illustrating NbS scenarios that integrate infrastructure development with protected area conservation. This framework is illustrated in Figure 8. Ruangpan et al. (2020) further illustrated NbS across varying spatial scales, from large-scale to small-scale interventions. In their framework, NbS A represents large-scale solutions in mountainous regions (e.g., reforestation, slope stabilization); NbS B refers to large-scale river corridor interventions (e.g., river widening, retention basins); and NbS C includes large-scale solutions in coastal areas (e.g., sand dunes, levees, protective seawalls). Examples of small-scale NbS include green roofs, green walls, rain gardens, permeable pavements, swales, and bio-retention systems (Figure 9).

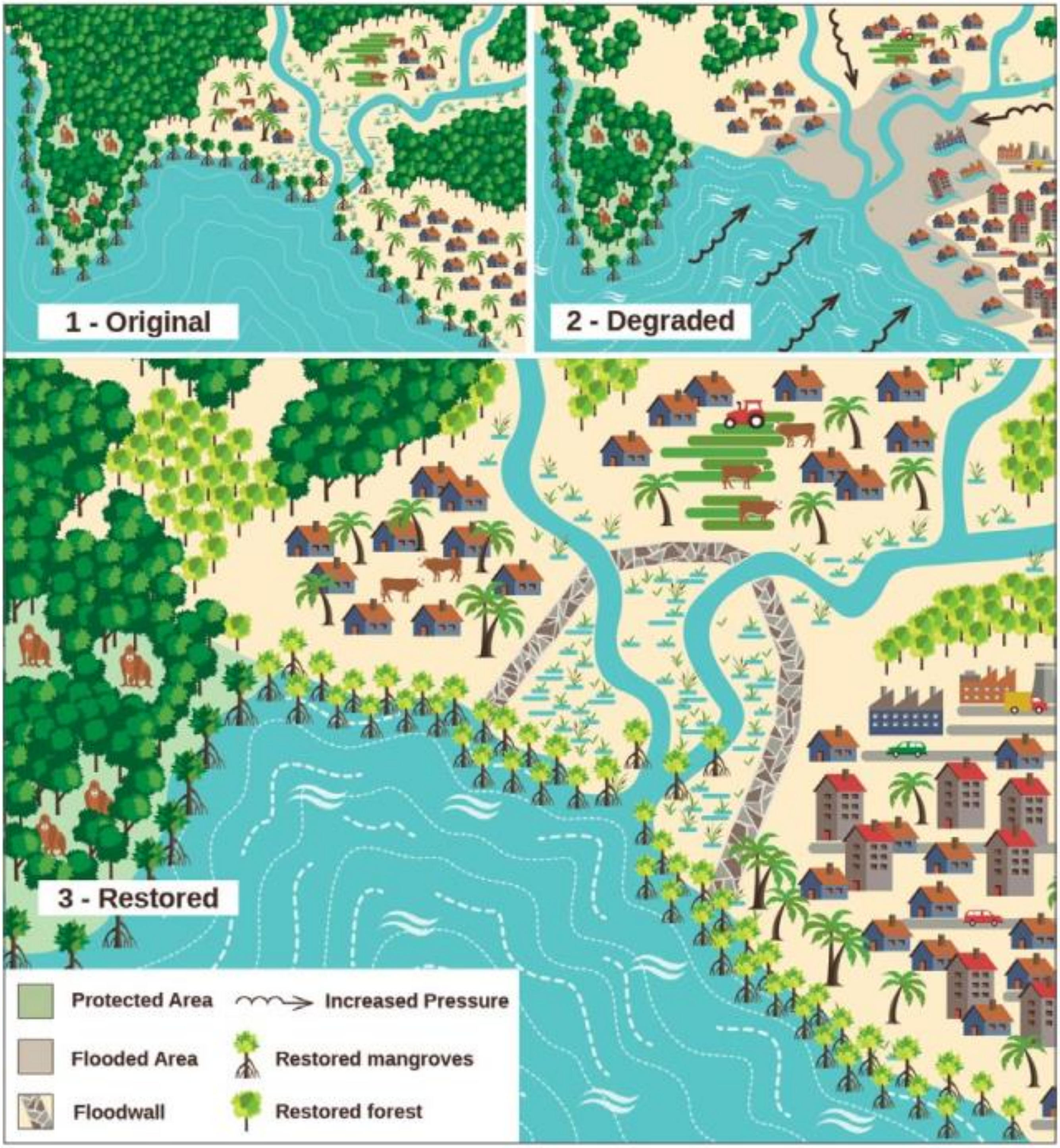


Figure 8. Hypothetical scenario of Nature-based Solutions being used in conjunction with infrastructure development and protected area conservation (Cohen-Shacham et al. 2016)

NbS strategies are urgently needed within watershed systems, which represent fundamental land surface units of the Earth. How these systems will respond to disturbances in the coming decades remains highly uncertain. This uncertainty must be reduced to enable effective decision-making that supports environmental health and the sustainable functioning of ecosystems (Stegen et al., 2024). In this regard, river corridors—often referred to as "blue-green infrastructure"—have emerged as critical systems supporting urban sustainability in contemporary societies (Shi et al., 2024).

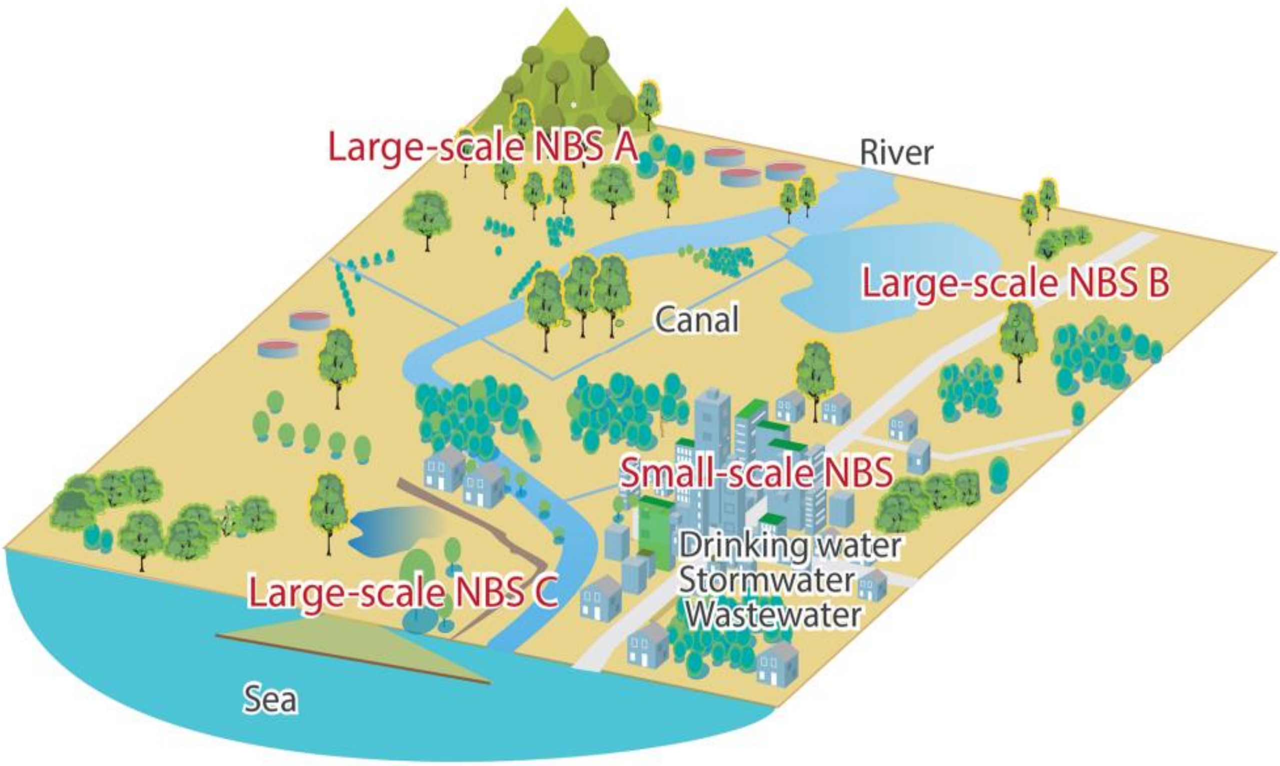


Figure 9. Illustration of Large- and Small-Scale Nature-Based Solutions (NbS)
Source: Ruangpan et al. (2020)

Practice NbS 1

In this NbS initiative, vegetation planting was implemented around the reservoir area. It is important to note that reservoirs have been major contributors to the expansion of river corridor surface areas over the past 100 years (Harvey & Schmadel, 2021). The planting practice, commonly referred to as a "greenbelt", was carried out along the banks of the Saguling Reservoir, which is part of the Citarum River system. Vegetation selection and planting were based on contour analysis and local ecological conditions, and were conducted with the consent and participation of the local community.

As Mazzorana et al. (2018) note, contemporary river corridor management is characterized by the involvement of multiple stakeholders with differing perspectives and interests, operating within complex institutional frameworks and legal landscapes. The effectiveness of this NbS-based management strategy was represented spatially through mapping grids of 20 meters by 20 meters (Figure 10). These measurements were applied conditionally, adapted to the actual topographic conditions observed on-site.

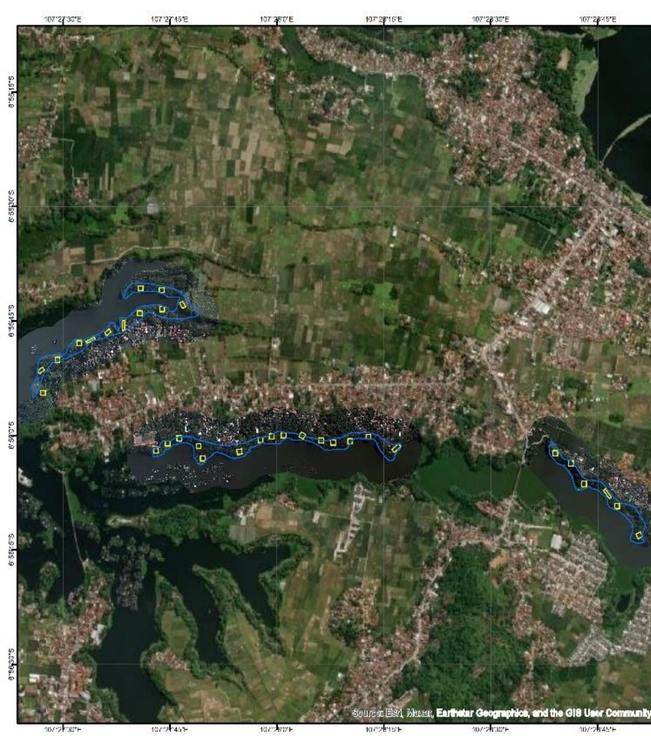


Figure 10. Greenbelt Mapping at Saguling Reservoir, Cihampelas, West Bandung Regency, Indonesia

Evaluation of Green Belt Program

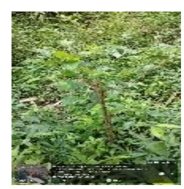
Table 3. Determination of Investigation Sample Plots

AOI	Wide (m^2)	Sample Plot Area (m^2)	Number of Plots	Rounding Result	Location Length (m)	Distance between plots (m)
1	23200,96	2320,095787	5,80	6	609	101,50
2	66508,65	6650,865444	16,63	17	1100	64,71
3	46778,30	4677,829862	11,69	12	1150	95,83
Total	136487,91	13648,79109		**35**		

Source: Field Investigation (2024)

NbS Samples - Green Belt Practices

Data Description: Sample Data from 2024 Crop Condition Survey (Location - Plots : 1 – 2)

Plot	Plant Type/Name		Height (cm)	Plant Stem Diameter (cm)		Plant Condition	Pest/ Disease Type/ Name	Land Condition		Condition
	Local Name	Latin Name		Circumference (cm)	Diameter (divided by 3.14)			Slope	Soil Solum	
2	Gamelina	Gmelina Arborea	232	18	0.06	Healthy	None	14%	Deep(>60 cm)	
2	Nangka	Artocarpus Heterophyllus	81	3	0.01	Healthy	None	5%	Middle (30-60 cm)	
2	Salam	Syzygium Polyanthum	111	4	0.01	Perforated	Caterpillars	18%	Middle (30-60 cm)	

Source: Field Investigation (2024)

Practice NbS 2

An example of river corridor management based on Nature-based Solutions (NbS) involves land management scenarios aligned with contour-based planning along the river corridor. In this approach, vegetation must be selected in accordance with the site's topography. Mazzorana et al. (2018) acknowledged that effective river management and restoration require addressing complex socio-ecological problems through integrated strategies. Additionally, the economic value of the planted vegetation must also be considered to ensure broader benefits such as planting avocado, banana, and petai (stink bean) trees.

It is therefore unsurprising that many scholars now agree that community-based restoration is essential for resilient river management, enabling both ecosystems and dependent communities to adapt sustainably in the face of future challenges (Poeppl et al., 2017; Parsons & Thoms, 2018; Bouska et al., 2019; Agnew & Fryirs, 2022).

In this NbS-based practice, we conducted an investigation along the Citarum River corridor in the

Cihauk region, Bandung Regency, Indonesia. We identified strong local cultural practices and community awareness in river corridor management, particularly through the planting of supportive vegetation such as mala trees, kaliandra, and cajuput (Melaleuca) (Figure 11). This investigation reinforces the notion that programs implemented solely through governmental approval without meaningful community engagement tend to experience reduced effectiveness and long-term impact.

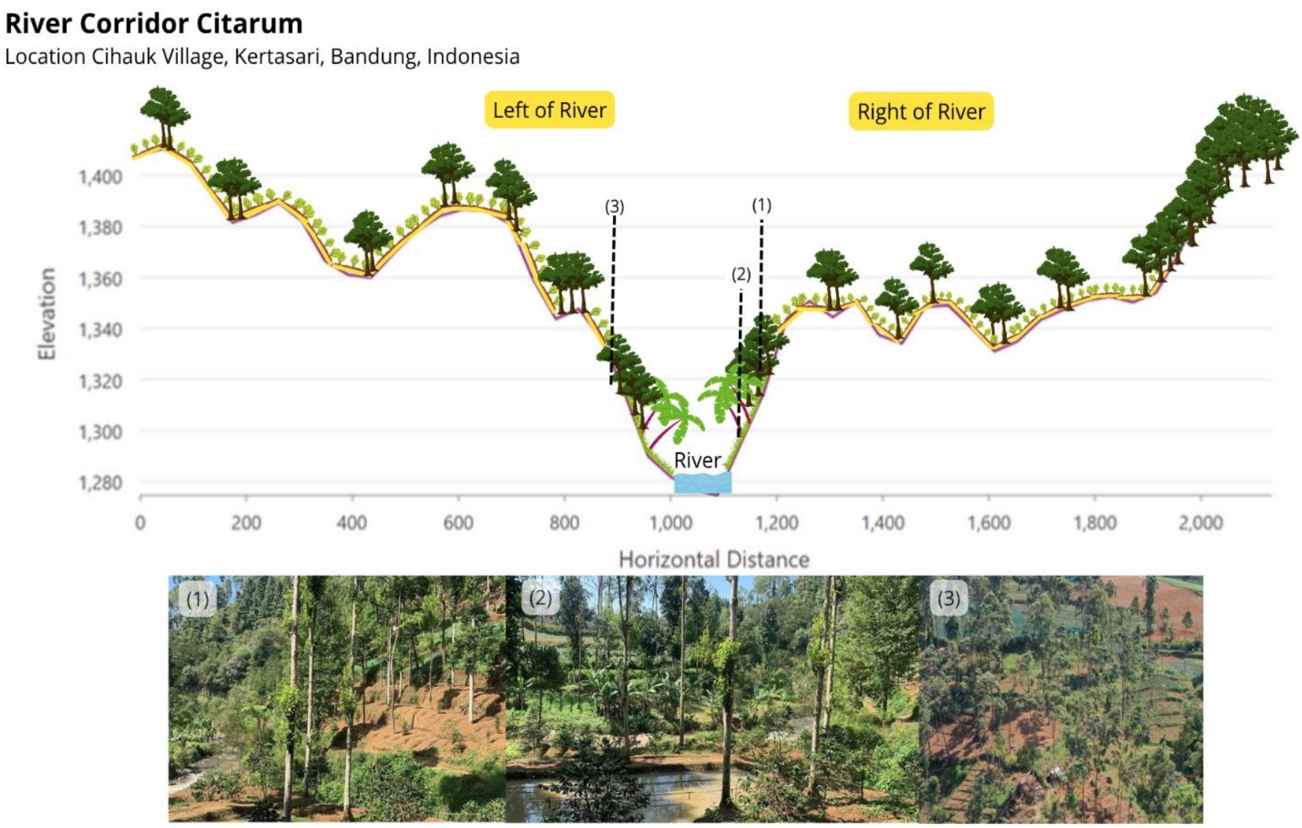


Figure 11. Practice NbS in Mangement of River Corridor

CONCLUSION

The concept of river corridors is essential for ensuring environmental sustainability, particularly in maintaining water quality and mitigating disaster risks in riverine areas. Rivers play a fundamental role in human life, serving purposes such as water consumption, irrigation, energy supply, and more. The reconstruction of river corridors offers significant opportunities for local governments to better manage land use along these critical zones. Over the course of multiple years, we conducted a series of investigations to understand local land-use cultures, assess water quality, and formulate strategies for land management along the Citarum River corridor. These efforts represent an academically grounded form of ecological restoration aimed at supporting practical implementation by regional stakeholders in the sustainable rehabilitation of the Citarum River.

However, this study is not without limitations. Specifically, it is constrained by the lack of historical geospatial data to support a more comprehensive understanding of river corridor dynamics. Furthermore, the empirical component of the study focused primarily on the upstream areas due to time and budget constraints. These limitations offer key insights and directions for future research, which should aim for broader spatial and temporal coverage. It is our hope that the findings presented here will contribute to informed policymaking. Importantly, effective river management requires a well-articulated strategy and impactful implementation that support river health and align with global climate change objectives outlined in the Sustainable Development Goals (SDGs).

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Conflict of interest The author has no competing interests to declare that are relevant to the content of this article.

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