

The Framework of Floodplain Rejuvenation Priorities for Urban Flood Mitigation: Case Study Sail River, Pekanbaru, Indonesia

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ABSTRACT

Flood has become an inevitable disaster for cities, especially those with rivers flowing through their urban areas. Urban development often encroaches upon natural river floodplain features, significantly increasing flood risk. The purpose of this study is to develop and implement a GIS-based multi-criteria decision framework to prioritize floodplain rejuvenation areas for urban flood mitigation in Pekanbaru City, Indonesia. A GIS-based analytic hierarchy process was employed to assess floodplain rejuvenation priorities based on four criteria: 1) flood, 2) environment, 3) policy, and 4) socio-economy. The framework was applied to a case study of the Sail River in Pekanbaru City, Indonesia, which faces recurrent annual flooding. The Sail River runs through densely populated areas of the city, and its floodplain was delineated using automatic methods, identifying a total of 753 ha. This study highlights that current spatial policies must be revised to preserve green open space within the floodplain. Importantly, it advocates for the adoption of a waterfront landscape paradigm, encouraging a cultural shift where rivers are seen not as waste disposal sites but as vital front-facing elements of the urban environment. Such perceptual changes are critical in promoting sustainable river management and enhancing community resilience to floods. This approach enables decision-makers to establish a mitigation plan based on three priority levels (high, moderate, low), covering a total of 584.23 ha (77.44% of the identified floodplain). The results offer practical insights for targeted and effective urban flood mitigation and demonstrate the framework's potential applicability in other cities facing similar flood-related challenges.

INTRODUCTION

Frequent flooding escalates in Indonesia's cities, pushing the government to take immediate action towards the problems (Fulazzaky 2014; Narendra *et al.* 2021). The causes vary, from natural climates to urban expansion (Neise and Diez 2019) and sea and river overflows (Buchori *et al.* 2018; Marfai and King 2008). Multiple studies have been conducted on various approaches to help decision-makers find accessible strategies regarding flood concerns (Nasution *et al.* 2022; Rohmat *et al.* 2022; Arkham *et al.* 2014).

Pekanbaru is one of the largest cities on Sumatra Island, Indonesia, that annually suffers from flood issues, which are further exacerbated by its increasing population growth rates—from 855,720 people in 2010 to 6,390,000 people in 2020 (BPS Pekanbaru 2021). Population growth causes an unavoidable increase in the built-up area in Pekanbaru, leading to chronic flood issues in the city. One factor that increases the risk of flooding is changes in the floodplain features. Studies state that floodplain-based urban flood mitigation should be able to contribute significantly to reducing urban flood risk (Khattak *et al.* 2016). However, floodplain-based urban flood mitigation has not yet been applied in research conducted in Indonesia.

The Sail River, which flows through Pekanbaru City, functions as a hydrological reservoir and primary urban drainage channel. However, increasing urban development along the Sail River Basin has exerted pressure on its ecological and hydrological functions. A recent study reported that several water quality parameters in the Sail River do not meet national environmental standards, indicating environmental degradation associated with anthropogenic activities (Yuliati *et al.* 2021). This condition reflects the declining ecological performance of the river system, which may reduce its natural capacity to regulate runoff and store floodwaters. Therefore, strengthening floodplain management and spatial planning integration is essential to restore the river's ecological and hydrological functions.

Its existence is threatened by improper infrastructure development and management along its riverside. Infrastructure development along the Sail River has unwittingly weakened the river's ecological function by not considering the floodplain layout.

A study in the Netherlands showed that one flood management strategy using periodic floodplain rejuvenation was able to maintain a safe flood level in the Waal River. Approximately 15% of the total floodplain area was rejuvenated with a return period of 25 to 35 years (Baptist *et al.*

2004). A floodplain is an area of land that extends from the river banks to the bottom of the surrounding basin and is flooded during periods of high discharge. Floodplain inundation occurs naturally during flood pulses, a process that has been shown to affect ground and surface water connectivity, biodiversity, and bioproduction in river landscapes worldwide. Floodplains have the natural function of providing essential ecosystem services, such as flood damage repair (Shankman and Smith 2004), consumption and storage of energy and materials (Valett *et al.* 2005), and maintenance of shallow aquifers that provide baseflow to rivers, as well as irrigation and drinking water. These traits stem from the complex and dynamic terrestrial and aquatic habitats (Ward *et al.* 1999) living in intact floodplains. The complexity of floodplains reflects the heterogeneity and connectivity of the environment produced by changes in the mosaic of habitats they create (Stanford *et al.* 2005).

Floodplain rejuvenation occurs naturally through channel migration or hole scouring in specific locations. Rejuvenation can also be done artificially, known as anthropogenic rejuvenation. Artificial rejuvenation should be adjusted according to its original or natural analogy (Baptist *et al.* 2004).

The pattern of landscape units in natural river systems is shaped by combining two main driving forces: succession and rejuvenation. Succession is the local transition from one landscape unit to another by changing species composition (Forman and Godron 1986), while erosion in the outer river bends and sedimentation in the inner bends rejuvenate the vegetation types to earlier stages. Naturally, continuous rejuvenation processes result in diverse landscape patterns with high biodiversity (Amoros and Wade 1996). However, semi-natural floodplains in regulated rivers generally lack natural rejuvenation mechanisms, leading to a landscape pattern dominated by key successional stages, which have relatively low biodiversity and high hydraulic robustness (Amoros and Wade 1996; Baptist *et al.* 2004).

This highlights the importance of including artificial rejuvenation measures in river management strategies (Shankman and Smith 2004). By applying suitable artificial rejuvenation measures, it is anticipated that biodiversity and flood resilience in an area can be increased (Buijse *et al.* 2005).

Based on the statements above, this research aims to provide a framework for determining the priority areas for floodplain rejuvenation as an urban flood mitigation strategy

in Pekanbaru, Indonesia. The study aims to contribute applicable methods for addressing flood problems by considering the natural conditions through floodplain rejuvenation. The methodology and framework developed in this study can be replicated in other cities in Indonesia to determine priority areas for urban flood mitigation in their respective areas.

DATA AND METHODS

Study Area

This research focuses on the floodplain area of the Sail River, located in Pekanbaru City, Riau Province, Indonesia. The target area encompasses the downstream part of the river (Figure 1) and includes the delineation results of the floodplain. Geographically, it is situated at coordinates 0°32'42.2"N and 101°28'5.7"E. The Sail River is a sub-watershed of the Siak River, which flows through the heart of Pekanbaru City. It traverses several districts, namely Sail District, Lima Puluh District, Bukit Raya District, and Tenayan Raya District. The research was conducted over a three-month period, from July to September 2021.

Natural Floodplain Area Mapping

The mapping of the natural floodplain area of the Sail River in Pekanbaru City was conducted in this study using an automatic floodplain delineation approach based on the Digital Terrain Model (DTM). This method utilizes topographic maps derived from Digital Terrain Models. The observed river area is integrated into the hydraulic model results, which serve as the primary inputs for the automatic floodplain delineation process (Noman *et al.* 2001).

The process involves creating a water surface using delineated water points, and subsequently generating a flood depth map by subtracting the Digital Terrain Model (DTM) from the water level. A positive value indicates a flood depth or flooded area, while a negative or zero value indicates a flood-free area. In this study, the floodplain was delineated by reducing the DEM (Digital Elevation Model) by a height of 9 meters, determined based on the downstream boundary area of the Sail River's floodplain (Safaripour *et al.* 2012).

For the water surface mapping, a water inundation map generated from the Modified Normalized Difference Water Index (MNDWI) was utilized (Suwarsono *et al.* 2021). The satellite imagery used in this study was acquired during the

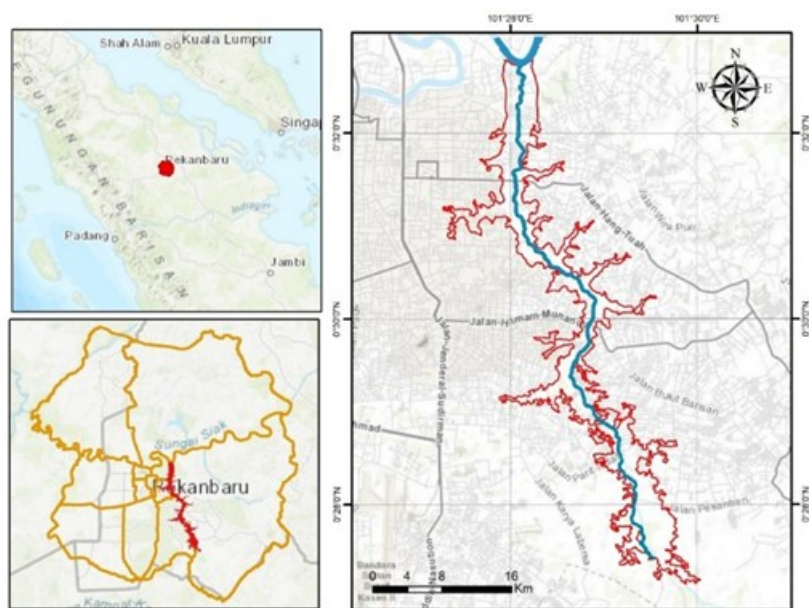


Figure 1. Study location of Sail River, Pekanbaru

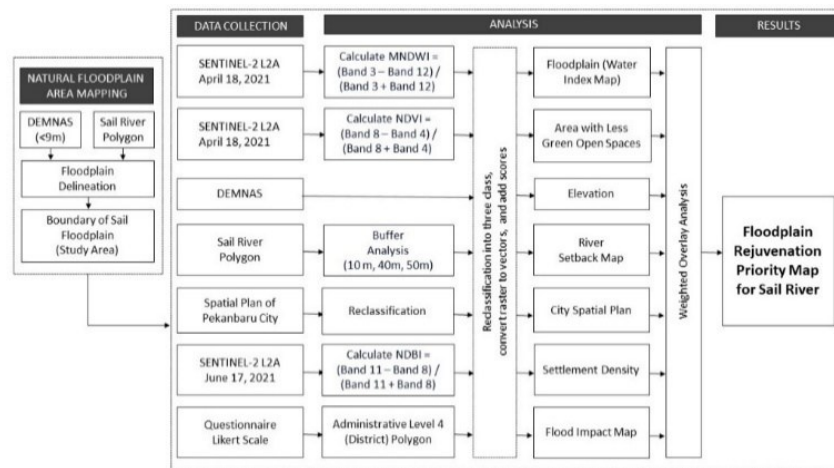


Figure 2. Research stages

flood occurrence and depended on the availability of data under visually clear, bright, and cloudless conditions. Specifically, Sentinel-2 L2A Satellite Imagery from April 18, 2021, was selected as it represented the month with the highest rainfall and coincided with the occurrence of flooding in Pekanbaru City, based on literature studies and field verification. Additionally, for elevation and hydrological analysis, DEMNAS data with a resolution of 10 x 10 meters was employed. The delineation of the river was validated through field surveys at sample points, particularly in shaded areas that required clear evidence through remote sensing observations.

Floodplain Rejuvenation Priority Framework

A framework for determining priority areas for floodplain rejuvenation in the Sail River, Pekanbaru City, was developed to guide the creation of a master plan. The methodology employed a GIS-based multi-criteria evaluation, incorporating the Analytic Hierarchy Process as one of the analysis techniques to assign weights to each criterion (Saaty 2004). Four criteria were considered in the model to identify priority areas (Li *et al.* 2020), see Table 1. These criteria are as follows:

Criteria 1: Flood - This criterion utilizes the floodplain zone map, which represents areas prone to flooding during overbank events. The floodplain zone is identified using a water index derived from the Modified Normalized Difference Water Index (MNDWI) formula. The MNDWI, specifically modified for urban areas like Pekanbaru City, was generated using Band 3 and Band 12 from Sentinel-2 L2A satellite imagery taken on April 18, 2021. Additionally, a non-flood control map based on Sentinel 2-A Satellite Imagery on June 17, 2021, depicting the water index under normal or non-flooding conditions, was used for reference.

Criteria 2: Environment - This criterion comprises two parameters: 1) areas with insufficient green open spaces and 2) elevations. Low-lying areas are more susceptible to flooding, while the density of vegetation surrounding the Sail River is assessed using the Normalized Difference Vegetation Index (NDVI) derived from the same satellite images as the MNDWI. The NDVI values indicate vegetation density and are divided into four classes: High Density, Moderate Density, Low Density, and Non-vegetation Area.

Criteria 3: Policy - This criterion consists of two parameters: 1) built-up areas encroaching upon riverbanks in violation of regulations, and 2) areas designated as non-developed based on the Spatial Plan of Pekanbaru City. Descriptive policy analysis is conducted to examine the latest regional spatial planning regulations set by the City Government and align them with the master plan in this study.

Criteria 4: Socio-economic - This criterion comprises two parameters: 1) settlement densities and 2) the impact of flooding on the community. Settlement density mapping utilizes the Normalized Difference Built-up Index (NDBI) derived from Sentinel-2 L2A satellite imagery taken on June 17, 2021. The NDBI values extracted from Band 11 (SWIR) and Band 8 (NIR) indicate the presence of built-up areas within the Sail River floodplain, categorized into four density ranges: High Density, Moderate Density, Low Density, and Non-settlement. To assess the impact of flooding on the community, questionnaires were distributed to flood-affected areas, employing a Likert scale (ranging from 1, Not Affected, to 3, Highly Affected). The questionnaire also collected demographic information, particularly ethnicity and culture, to provide socio-cultural context for the study. Data collection regarding the impact of urban flooding on communities along the Sail River involved the distribution of questionnaires using a purposive sampling method to several residential areas with a history of flooding, as identified through literature review. The questionnaires were filled out conventionally on paper or online, with a total of 181 respondents.

RESULTS AND DISCUSSION

Floodplain Area and Build-up Area of Sail River

The Sail River floodplain covers a total area of 753 hectares. Along the downstream towards Siak River, the width of the floodplain reaches up to 600 meters. However, it narrows to approximately 200 meters around Jalan H. Imam Munandar and then widens again to around 800 meters at Simpang Tiga Subdistrict. These floodplain zone boundaries serve as the study boundaries for conducting spatial analysis in this research.

Through the extraction of surface water using the Modified Normalized Difference Water Index (MNDWI), it was found that 32 hectares of land were inundated outside the Sail River area, with 19 hectares within the floodplain itself. The remaining 208 hectares exhibited a moderate water index, indicating a prone for flooding in those areas.

Results of the analysis of the build-up area within the floodplain area reveals a concerning disparity between the allocation of land for Settlement Areas and City Green Open Space along the Sail River. The area allocated for Settlement Areas greatly exceeds the allocation for City Green Open Space, with a ratio of approximately 13 to 1.

There are sizable open spaces within the study boundaries that have the potential to be designated as the city's Green Open Space area. These areas of open space are significant in size and hold great potential for creating green spaces within the city. The calculations indicate that the

designated green open space within the areas allocated for housing amounts to 307 hectares, which accounts for approximately 53% of the total area designated for residential purposes. This situation should be a matter of priority for the government of Pekanbaru City.

If the current trend continues, with housing developments encroaching upon the open spaces of the river-floodplain, the consequences could be severe, leading to increased risks of flooding in the area. It is essential for the government to recognize that Pekanbaru City encompasses a vast area, offering numerous safer locations for residential development. With the NDBI (Normalized Difference Built-Up Index) value extraction indicating that the non-built areas still dominate the floodplain area of the Sail River, comprising approximately 428 hectares, it becomes clear that these non-built areas or open spaces should be protected to maintain the ecological function of the river.

To address this issue, Pekanbaru City's government to enforce rules against converting open areas within Sail River's floodplain to built-up spaces. Preserving these areas is vital for the river's sustainable functioning, requiring a comprehensive approach involving strict land-use regulations, urban planning, and the promotion of green infrastructure. Understanding the floodplain's extent and characteristics, as delineated in this research, is foundational for implementing these measures.

River Setbacks and Spatial Plan of Pekanbaru

River setbacks play a crucial role in preserving the functions and protecting the environment surrounding the river. These setbacks are defined as virtual lines on both sides of the riverbed, serving as boundaries for river protection. Their purpose is to maintain the river's functions, enhance the value of existing resources within the river, and minimize the destructive power of river water on its surroundings (Nurisjah and Anisa 2011). The determination of river setback lines is governed by the Regulation of the Minister of Public Works and Public Housing (PUPR) of the Republic of Indonesia No. 28/PRT/M/2015. This regulation differentiates between rivers within and outside urban areas, as well as rivers with and without embankments.

In the case of the Sail River, it runs through an urban area, and therefore, the demarcation line is set at a distance of 10 meters from the left and right banks of the riverbed along the river channel. Additionally, for further protection considerations, additional lines are drawn between 50 and 100 meters from the riverbanks, as the river is unembanked outside urban areas.

Analyzing the Pekanbaru City Regional Regulation Number 7 of 2020, which pertains to the 2020 Pekanbaru City Spatial Planning, the distribution of space allotment along the Sail River is primarily dominated by Settlement Areas, covering approximately 575 hectares or 78% of the designated area.

These findings highlight the current spatial pattern of land allocation in the vicinity of the Sail River. However, it is important to assess the appropriateness of these designations in the context of floodplain management and urban flood mitigation strategies. Considering the significant percentage of settlement areas, there is a need to revisit the city's spatial plan and revise the allocation of space within the floodplain. By reducing the extent of settlement areas in the floodplain, the risk of flooding can be minimized for both existing and future developments.

To ensure sustainable development and mitigate the impacts of urban flooding, it is crucial to strike a balance between the needs of urbanization and the preservation of

natural systems. Future revisions to the city's spatial plan should consider prioritizing the establishment of buffer zones and green open spaces along the Sail River. These areas can serve as flood-resilient spaces and contribute to the overall ecological health of the river system.

Impact of Urban Floods to the Communities

The survey respondents consisted of 94 men (52%) and 87 women (48%). The age distribution revealed that individuals between 50-59 years and 19-39 years were the dominant groups. In terms of education, the majority of respondents had completed high school. The ethnic composition of the respondents was diverse, encompassing Malay, Minang, Javanese, Batak, and Chinese ethnicities, with a relatively even distribution.

The findings from the field survey and questionnaire shed light on the impact of flooding on the community. It was observed that the frequency and material consequences of flooding were categorized as high impact. The areas most severely affected were concentrated in the following settlements: Bambu Kuning ward, Rejosari ward, Sekip ward, Suka Maju ward, Suka Mulia ward, Tengkerang Labuai ward, Tengkerang Selatan ward, Tengkerang Timur ward, Tengkerang Utara ward, and Pematang Kapau ward. These regions experienced significant disruptions and damage due to frequent flooding events.

Moderate impact was reported in the Tanjung Rhu ward and Tengkerang Selatan ward. While the effects were not as severe as in the aforementioned areas, these settlements still faced considerable challenges and adverse consequences resulting from urban floods.

In terms of the community's perspective, the assessment of respondents' preferences regarding the development of the Sail River for flood mitigation in Pekanbaru City revealed a general consensus and support for such initiatives. The community recognizes the importance of taking measures to mitigate flooding and alleviate its detrimental effects.

By extending the description of the impacted settlements and emphasizing the community's perspective, the subsection provides a more comprehensive understanding of the impact of urban floods on the residents of Pekanbaru City.

Priorities Area for Urban Flood Mitigation

The Sail River rejuvenation priority map for flood mitigation in Pekanbaru City was generated using a weighted overlay analysis on the results of six parameters, includes 1) Floodplain 2) Green Open Space 3) Elevation, 4) River Borders, 5) Urban Spatial, 6) Settlement Density, and 7) Impact of Floods on Society. The weighted scores given to the seven parameters were obtained using the Analytic Hierarchy Process (AHP) method from selected expert respondents, with Consistency Ratio (CR) = 1.1%, and principal eigenvalue = 4,031 (Table 1).

Expert respondents in this study consisted of nine experts from academia and government, with expertise in floods, environment, policy, socioeconomics, as well as remote sensing and GIS fields. Apart from having expertise in the fields used as parameters in this study, the experts also understand the research location, especially Pekanbaru City.

The results of the calculation of the analytical hierarchy process (AHP) weights show that the flood parameter has the highest level of importance, followed by legal and social environmental parameters. Several additional inputs from expert respondents regarding this research varied from issues of regulatory authority, handling river pollution, to concern for the social impacts of society.

Table 1. Framework for Floodplain-based Urban Flood Mitigation Priorities

No	Criteria / Parameter	Weight	Scores	Categories	Data Source
Flood					
1	Floodplain (Water Index Map)	29	3	High Water Index (MNDWI>0.1)	DEMNAS,
			2	Moderate Water Index (MNDWI -0.2 – 0.01)	MNDWI,
			1	Low Water Index (MNDWI <0.2)	
Environment					
2	Area with Less Green Open Spaces	20	3	Low Density Vegetation (NDVI 0.4 - 0.6)	NDVI,
			2	Moderate Density Vegetation (NDVI 0.6-0.8)	Landcover Map
			1	High Density Vegetation (NDVI >0.8) and No Vegetation (NDVI <0.4)	
3	Land Elevation	12	3	Low Elevation (<5m)	DEMNAS
			2	Moderate Elevation (6-9m)	
			1	High Elevation (>9m)	
Policy					
4	River Setbacks	10	3	Close Proximity (10 m from riverside)	River Map
			2	Moderate Proximity (10 – 50 m from riverside)	
			1	Safe Distance (50 – 100 m from riverside)	
5	City Spatial Plan	13	3	Urban Open Space, Local	Spatial Plan
			2	Settlement Area	Pekanbaru City
			1	Other Area	
Socio-economy					
6	Settlement Density	8	3	High Density Settlement (NDBI >0.05)	NDBI
			2	Moderate Density Settlement (NDBI -0.1-0.05)	
			1	Low Density Settlement (NDBI <-15)	
7	Flood Impact to Community	8	3	Highly Impact – 3	Boundary,
			2	Moderately Impact – 2	Questionnaire
			1	Low Impact – 1	

Source: Modified from Saaty (2004), Edamo *et al.* (2022), Pacetti *et al.* (2022) and Sisriany *et al.* (2021)

Sail River based on PUPR Ministerial Regulation No. 4 of 2015 is included in the authority of the Sumatra III Regional Office. The decline in river quality also occurs due to activities in the downstream area in the form of household waste from settlements, also originating from activities in the upstream area in the form of sand mining and oil palm plantations.

The results of the analysis show that the priority areas for floodplain rejuvenation are a total of 584.23 ha (77.44%), divided into High Priority covering 71.91 ha (9.53%), Medium Priority covering 191.68 ha (25.41%), and Low Priority covering 320.63 ha (42.5%). In comparison, the non-priority area is 170.16 ha (22.56%). Ward with the most significant priority area compared to non-priority areas were in Bambu Kuning Ward (92.87%), Sekip Ward (90.64%), and North Tangkerang Ward (93.13%). Ward with a higher percentage of Priority is Pebatuan Ward (43.56%) and Simpang Tiga Ward (37.14%). The rest have a priority percentage of 70-90%. High Priority is dominantly in the vegetated area with trees. Moderate Priority is dominantly in an open area, low-vegetation area lacking trees. Low Priority is dominantly in the residential area.

Green Open Space and Elevation of Sail River

Green open space is an elongated/lane and/or grouped area where the space is open, a place for plants to grow, both naturally and deliberately planted (Indonesia 2007). The ecological function of green open spaces around rivers is water catchment and water basin. In addition, green open space around the river functions as a source of water, nutrients, a habitat for vegetation and animals, and filters for pollutants and toxic substances (Wardiningsih and Salam

2019; Widodo *et al.* 2012). Therefore, the availability of green open space around the Sail River is essential to reduce the risk of natural flooding due to the overflow of river water into floodplain areas (flood plains). Green open space mapping based on the vegetation index results shows that the green open spaces. Both man-made and natural, that exist in the study boundary or floodplain area of the Sail River are considerably large enough, even for 'High density,' the area is 207 ha (27.53%). The target priority is suitable mainly for areas with low vegetation density because trees do not dominate the vegetation in this area, so it needs to improve its ecological function.

The elevation or height of the floodplain area of the Sail River has the lowest point at -5.08 m and the highest at 19.03 m. In this study, the elevation was divided into three class ranges: Low Elevation, Medium Elevation, and High Elevation. Low elevations are spread widely in almost all parts of the floodplain, then low elevations spread around Tangkerang Labuan ward, Pematang Kapau ward, Simpang Tiga ward, and Pebatuan ward.

Urban Flood Mitigation Strategies for Pekanbaru

The following recommendations are systematically derived from the spatial findings and AHP-weighted priorities illustrated in Figure 4.

This framework translates the study's multidimensional data into a tiered mitigation strategy, transitioning from strict ecological conservation in high-priority zones to infrastructure resilience in high-density settlements. Each strategy, grounded in a paradigm shift toward a "Waterfront Landscape" (WFL), is detailed in the sections below.

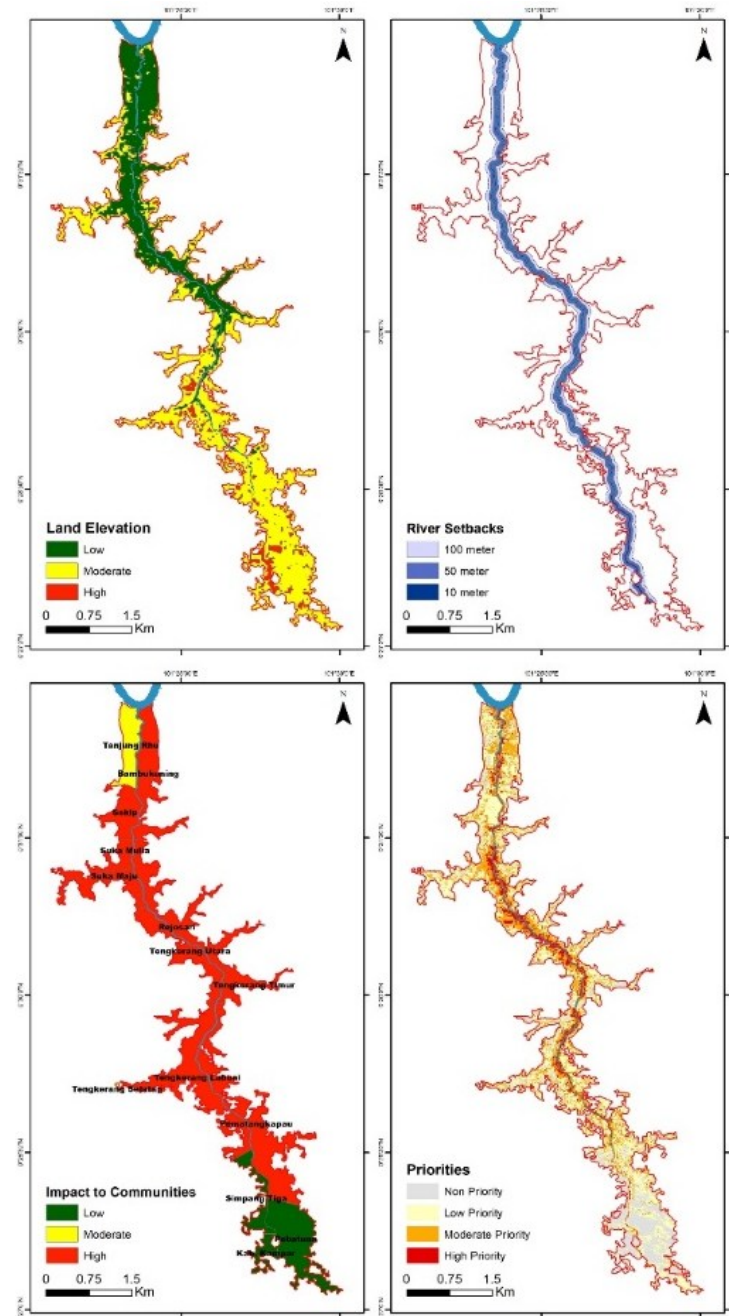


Figure 3. Layers of parameters (Water Index Map, Vegetation Density Index Map, City Spatial Plan, Built Up Area, Elevation, River Setbacks, Impact to Community) and results (The Priority Map)

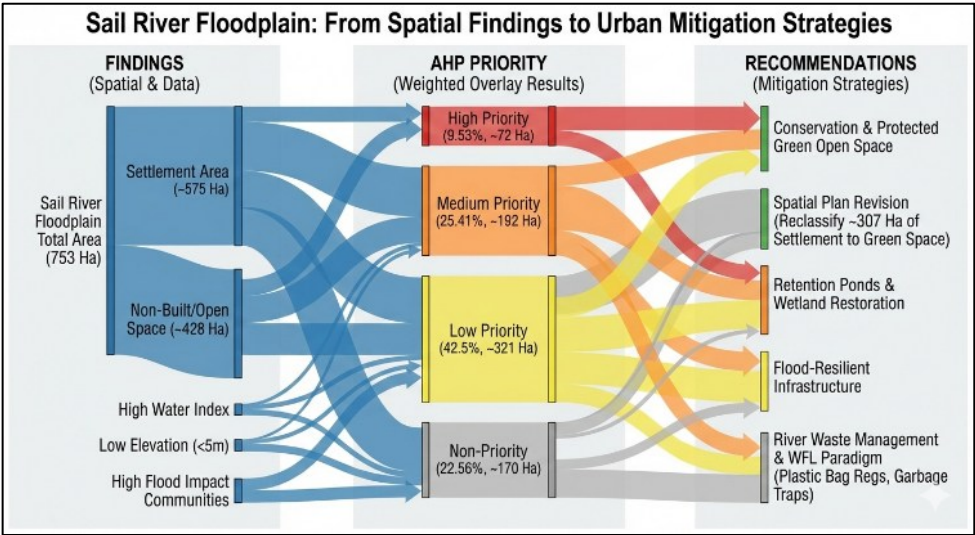


Figure 4. Strategic flow of flood mitigation priorities for the Sail River, transitioning from environmental data to localized policy and infrastructure recommendations

Revision of Pekanbaru City Spatial Plan by Reducing Settlement Area in the Sail River Floodplain

The current designated Settlement Area within the Sail River floodplain in the city plan of Pekanbaru raises concerns regarding the potential increase in built-up areas in a location prone to flooding. The existing city plan allocates a significant portion of the Sail River floodplain, approximately 307 hectares, as settlement area. However, it is crucial to recognize that these areas are naturally meant to experience flooding due to their location in the floodplain.

Strategic approach using the spatial plan is one of the key instruments to overcome the flooding issues (Chanthamas *et al.* 2017; Adjie and Santika 2021; Putri and Zain 2010). In order to mitigate the risk of flooding in both current and future built-up areas, a thorough review of the city plan is necessary. The revision of the Pekanbaru City Spatial Plan should aim to reduce the designated settlement area within the floodplain of the Sail River. By limiting the extent of built-up spaces in flood-prone areas, the city can significantly decrease the vulnerability to flooding and its associated impacts.

The revision process should involve careful consideration of the ecological function and hydrological dynamics of the floodplain. It is essential to strike a balance between urban development and the preservation of natural floodplains, which provide crucial ecosystem services and play a vital role in flood regulation. This can be achieved by identifying alternative locations for settlement areas outside the floodplain, taking into account the city's available land resources and urban expansion plans.

By reducing the designated settlement area in the Sail River floodplain, the city can prioritize the safety and well-being of its residents, while also safeguarding the ecological integrity of the river system. This strategic revision of the spatial plan will help prevent the detrimental consequences of housing development in flood-prone areas and contribute to sustainable urban planning in Pekanbaru.

Development Plan based on Priorities Areas

To effectively manage and utilize the priority areas within the Sail River region, a comprehensive development plan should be implemented. This plan should prioritize different areas based on their level of priority, considering their specific characteristics and potential for sustainable development.

High-priority areas should be designated as locally protected areas to ensure their conservation and safeguard their ecological integrity. These areas, recognized for their significant ecological value, should be designated as City Green Open Spaces. By extending their protection, we can preserve their natural features and prevent further encroachment or development that could compromise their ecological functions (Li *et al.* 2020).

Moderate-priority areas provide an opportunity to enhance water conservation efforts. These areas should be utilized to increase water retention capacity and improve overall water management around the river. Strategies may include creating water basins, constructing retention ponds, and implementing wetland restoration projects. By improving water resources and the quality of surrounding wetlands, we contribute to the overall ecological health of the Sail River region (Baptist *et al.* 2004; Rohmat *et al.* 2022).

Low-priority areas, particularly existing residential areas within the floodplain, require measures to enhance their resilience to flooding. Development should focus on implementing flood-resistant infrastructure, innovative urban planning strategies, and community-based flood preparedness initiatives. By increasing the flood resilience of these

settlements, we can minimize the risks and damages associated with flooding, ensuring the safety and well-being of the residents (Buchori *et al.* 2018; Nasution *et al.* 2022).

River Waste Management and the Role of Waterfront Landscape

Effective floodplain management should not solely focus on the riverbanks but also extend to the river water body itself. One critical aspect is the control and mitigation of river waste, a persistent issue affecting many rivers in Indonesia, including the Sail River. River waste typically includes both solid waste (mainly household garbage) and liquid waste.

However, a more profound shift is needed – not just in infrastructure, but in mindset. In many parts of Indonesia, including Pekanbaru, rivers have traditionally been treated under the Waterback Landscape (WBL) paradigm – where rivers are seen as the "backyard" of settlements, often becoming dumping grounds for waste. This perception shapes local behaviors, contributing to the degradation of river environments.

Instead, Pekanbaru should adopt the Waterfront Landscape (WFL) paradigm, where rivers are envisioned as the "front yard" – a valued and visible part of the urban environment that fosters pride, stewardship, and sustainable interaction. The WFL approach is not just about physical development, but about transforming public perception and community behavior toward the river (Ulfah 2018; Arifin H.S 2014).

To support this shift, practical measures are still essential. Installing garbage traps in the primary canal leading to the Sail River can help intercept solid waste before it enters the water body. These interventions must be complemented by public education campaigns and urban planning strategies that reinforce the WFL mindset.

For liquid waste, integrating efficient collection and treatment systems remains critical. These efforts align with Pekanbaru's ongoing initiatives to improve its domestic waste management systems. Ensuring that liquid waste does not enter the river's drainage network is vital for preserving both water quality and ecosystem health.

Ultimately, managing river waste is not only a matter of infrastructure – it is a matter of perspective. Adopting a Waterfront Landscape approach empowers residents to see rivers not as waste outlets, but as integral, cherished parts of their urban environment (Sutrisno *et al.* 2020; Kaswanto *et al.* 2023). This cultural transformation is key to reducing flood risks, restoring ecological balance, and enhancing the overall quality of life along the Sail River. Effective floodplain management should not solely focus on the riverbanks but also extend to the river water body itself. One critical aspect of floodplain management is the control and mitigation of river waste, which remains a major concern for many rivers in Indonesia, including the Sail River. River waste can be categorized into two main types: solid waste and liquid waste. Solid waste primarily consists of household garbage.

To address this issue, it is essential to implement measures such as installing garbage traps in the primary canal leading to the Sail River (Koutalakis *et al.* 2023). These traps will act as barriers, preventing waste from entering the river and ultimately aiding in the cleanup efforts. By strategically placing these garbage traps, the city can effectively manage and reduce the influx of solid waste into the Sail River.

In addition to solid waste, it is crucial to manage harmful liquid waste to prevent its entry into the river's drainage system. This approach aligns with the ongoing development of the city's domestic waste management system. By implementing proper waste management practices, such as

establishing efficient collection and treatment methods, the city can prevent the harmful effects of liquid waste on the Sail River and its surrounding ecosystem.

Managing river waste is not only crucial for maintaining a clean and healthy environment but also plays a vital role in mitigating flood risks. Uncontrolled waste accumulation can obstruct water flow and contribute to the deterioration of river ecosystems, exacerbating flood problems. By implementing effective river waste management strategies, Pekanbaru City can enhance the overall cleanliness and ecological health of the Sail River, thereby reducing the risk of flooding and preserving the natural beauty of the surrounding areas.

Plastic Bag Regulations

Plastic waste poses a significant threat to river ecosystems, including the Sail River, as it is often one of the primary contributors to pollution. In response to this pressing issue, it is recommended that the government of Pekanbaru City implements mayoral regulations to restrict the use of plastic bags. Similar regulations have already been successfully implemented in numerous major cities across Indonesia, and Pekanbaru City should follow suit.

By enacting regulations that limit the use of plastic bags, the government can take a proactive step in reducing the amount of plastic waste that finds its way into rivers, particularly the Sail River. Plastic Bag Regulations will play a crucial role in raising awareness about the environmental impact of plastic waste and encouraging sustainable practices among residents and businesses.

The implementation of plastic bag restrictions aligns with the growing global movement to combat plastic pollution and protect waterways. By adopting this approach, Pekanbaru City can demonstrate its commitment to environmental sustainability and become a role model for other regions facing similar challenges.

Reducing the usage of plastic bags in the city will have far-reaching benefits. It will help reduce the accumulation of plastic waste in rivers, preventing harm to aquatic life and preserving the natural beauty of the Sail River. Furthermore, it will contribute to a cleaner and healthier environment for both present and future generations.

To ensure the effective implementation of plastic bag regulations, it is crucial to engage stakeholders, including local businesses, community organizations, and residents. Awareness campaigns, education programs, and alternative solutions such as reusable bags can be promoted to facilitate the transition away from single-use plastic bags.

CONCLUSION

This study developed a GIS-based multi-criteria decision framework to prioritize floodplain rejuvenation areas in the Sail River, Pekanbaru, integrating flood hazard, environmental conditions, policy compliance, and socio-economic vulnerability. The analysis revealed that the 753-hectare floodplain contains 56% open space, with 9.53% and 25.41% of the area classified as high and medium priority for mitigation, respectively. Flood-related factors such as high water index and low elevation were dominant determinants of priority areas, while environmental factors (low green space) and socio-economic vulnerability (densely populated, high flood impact) further guided interventions. Policy analysis highlighted misalignment between existing spatial plans and floodplain ecological functions, emphasizing the need for spatial plan revision and stricter river setback enforcement. The study also advocates adopting the Waterfront Landscape

paradigm, encouraging rivers to be valued as integral urban spaces rather than waste-receiving areas. This integrated framework offers practical guidance for urban planners, supports culturally informed flood mitigation strategies, and provides a replicable model for other Indonesian cities facing similar urban flood challenges.

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