Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2, 1609-1619
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i2.4848

Evaluation of drainage system and flood management in Semarang city: A case study of kali Semarang and its impact on flood and tidal flood reduction

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Abstract: Semarang City faces recurrent flooding and tidal inundation due to an inadequate drainage system, rapid urbanization, and the adverse impacts of climate change. This study aims to evaluate the effectiveness of the Kali Semarang revitalization project in mitigating flood and tidal inundation while identifying key challenges in its implementation. A mixed-method research approach is adopted, integrating hydrological analysis using a rainfall-runoff model, GIS-based spatial mapping, and stakeholder interviews. The findings reveal a significant reduction in flood inundation, from 1,281.67 hectares in 2023 to 1,228.96 hectares in 2024, along with a decrease in the number of inundation points from 522 to 466 locations. Additionally, embankment construction and river dredging improved water flow capacity, reducing inundation duration from 10 to 6 hours per event. However, challenges such as high sedimentation rates, inadequate inter-agency coordination, and limited infrastructure maintenance funding persist. Practical recommendations include enhancing drainage capacity, optimizing real-time hydrological monitoring, and increasing community engagement in urban drainage maintenance. These findings contribute to evidence-based urban flood management strategies for climate-resilient cities.

Keywords: *Climate resilience, Flood mitigation, GIS, Hydrological modeling, Semarang City, Tidal inundation, Urban drainage.*

1. Introduction

Semarang City faces significant challenges in managing floods and tidal floods due to a combination of hydrometeorological factors, land use changes, and an inadequate drainage system. With rapid urbanization, the increase in impervious surfaces has decreased soil infiltration capacity, resulting in higher surface runoff and worsening inundation risks [1]. Previous studies have shown that urban drainage systems must consider geological and morphological aspects in water management planning to minimize flooding impacts [2].

Climate change further exacerbates this issue, increasing extreme rainfall and rising sea levels intensifying tidal flooding in coastal areas such as Semarang City [3]. Research indicates drainage planning not accounting for climate change variables may increase urban flood-related losses [4]. In this context, ecosystem-based management with technological and adaptive approaches is crucial to enhancing regional resilience against hydrometeorological risks [5].

Kali Semarang plays a vital role in the city's drainage system. However, high sedimentation and domestic waste often cause water flow blockages, leading to urban inundation [6]. This issue is further compounded by infrastructure development that does not consider drainage capacity and the efficiency

History: Received: 13 December 2024; Revised: 24 January 2025; Accepted: 27 January 2025; Published: 17 February 2025
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of water disposal systems [7]. This urban inundation aligns with studies highlighting that uncontrolled urbanization without proper drainage mitigation exacerbates urban flood impacts [8].
This study aims to:

- Analyze the drainage conditions and effectiveness of the Kali Semarang revitalization project in reducing flood and tidal flood inundation.
- Identify challenges encountered in implementing drainage projects.
- Provide strategic recommendations to improve the performance of the drainage system in Semarang City.

Through a data-driven approach and comprehensive evaluation of the drainage system, this research is expected to contribute to developing more effective and sustainable urban water management strategies.

2. Research Methodology

This study employs a quantitative and qualitative approach to evaluate the drainage system in Semarang City, focusing on Kali Semarang and its impact on flooding and tidal inundation. Primary data were collected through field surveys, hydrological measurements, and interviews with key stakeholders, while secondary data were obtained from government reports and previous studies [9].

Hydrological analysis was conducted to assess drainage capacity using hydrodynamic and rainfall-runoff modeling to understand water flow patterns under extreme rainfall conditions [10]. Related studies suggest integrating hydrological modeling with risk mapping can enhance flood prediction accuracy and support decision-making in urban drainage management [11].

Additionally, GIS-based spatial analysis was employed to identify flood-prone areas and understand land use change patterns affecting the drainage system [12]. Previous research highlights that GIS technology enables more effective monitoring of hydrological changes caused by urbanization and climate change [13].

A qualitative approach was applied through interviews with stakeholders, including local government officials, community members, and hydrology experts, to understand the challenges in implementing drainage projects and assess the effectiveness of current policies [14]. Studies confirm that community involvement in drainage planning can improve project sustainability and the effectiveness of flood mitigation [15].

The findings from these various methodologies were then compared with urban drainage planning standards implemented in other cities with similar hydrological conditions [16]. Consequently, this study provides a holistic approach to evaluating the effectiveness of the Kali Semarang drainage system and offers strategic recommendations for future improvements.

3. Results and Discussion

3.1. Condition of the Drainage System in Semarang City

The drainage system in Semarang City faces multiple challenges due to climate change, population growth, and rapid urbanization. The increase in built-up areas and decline in vegetation cover has significantly altered hydrological processes, reducing infiltration capacity and increasing surface runoff [5, 17]. Previous studies have shown that high urbanization growth disrupts drainage efficiency, primarily due to decreased infiltration rates and increased runoff volume [1, 18]. Additionally, river sedimentation caused by upstream soil erosion further exacerbates urban drainage capacity issues [3]. Figure 1 presents the Drainage Map of Semarang City, illustrating the distribution of primary drainage channels in urban and coastal areas susceptible to flooding and tidal inundation.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 1609-1619, 2025
DOI: 10.55214/25768484.v9i2.4848

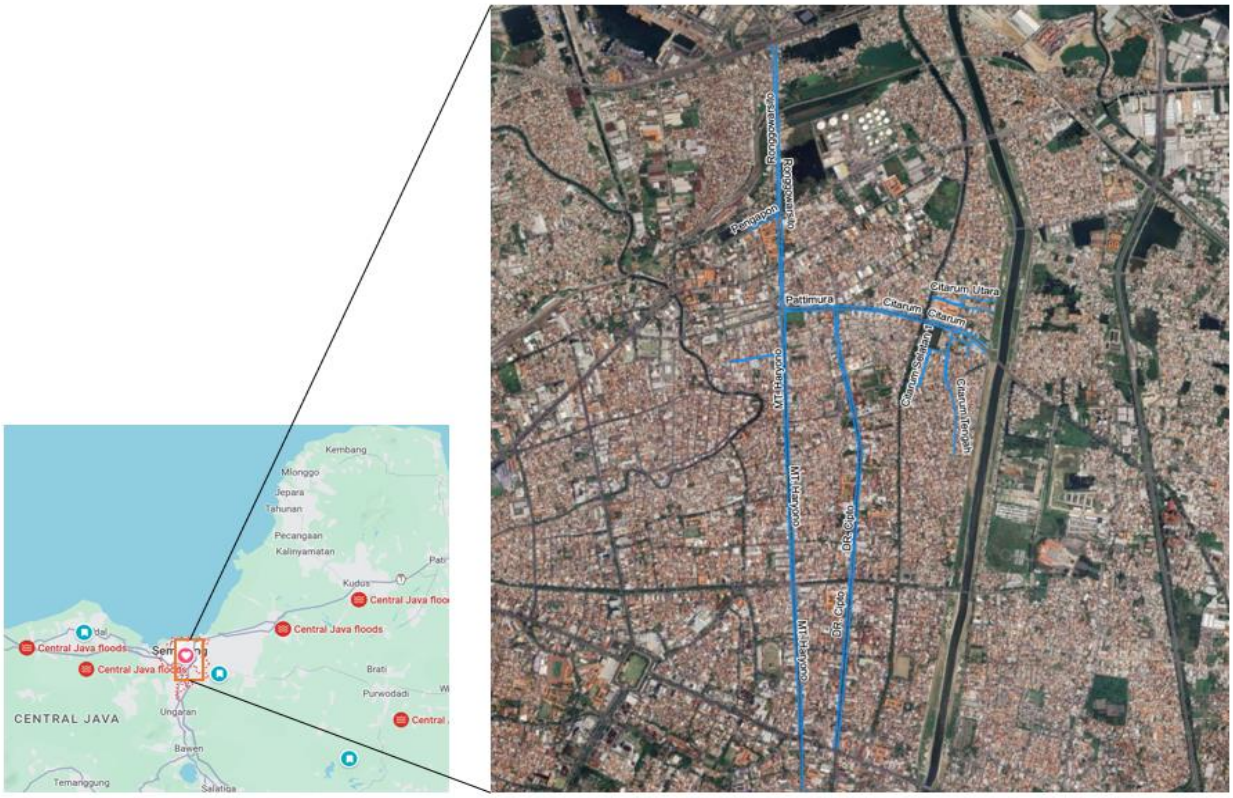

Figure 1.
Drainage map of Semarang city.

One of the main challenges in Semarang City's drainage system is the blockage of drainage channels due to the accumulation of domestic waste and plastic pollution. Plastic waste and other debris often impede water flow, exacerbating flooding in several urban areas [2, 7]. Some studies also indicate that microplastic contamination in river ecosystems negatively impacts water quality and accelerates drainage system degradation [7].

Besides internal factors, the drainage condition is also influenced by external factors, such as sea level rise and saltwater intrusion, which worsen flooding conditions in coastal areas [8, 19]. The rising sea level due to climate change contributes to the prolonged duration and increased frequency of tidal floods, particularly in areas with insufficient drainage infrastructure [6, 20]. Research in various regions indicates that the impact of climate change on urban drainage systems is further exacerbated by inadequate climate-adaptive infrastructure design [4]. Therefore, a more adaptive mitigation policy is necessary to address these challenges. Table 1 provides an overview of flood-prone areas and the effectiveness of drainage management over the years.

Table 1.
Summary of flood and tidal inundation in Semarang City (2023-2024)

No	Description	2023 (ha)	2024 (ha)
1	Total flooded and tidal inundation area	1,281.67	1,228.96
2	Flooded area	875.39	834.66
3	Tidal inundation area	406.27	394.30
4	Percentage of flooded area (%)	2.28%	2.17%
5	Percentage of tidal inundation area (%)	1.09%	1.06%
6	Number of flood and inundation points	522	466

Edelweiss Applied Science and Technology
ISSN: 2576-8484
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Relevant studies suggest that sustainable drainage management requires a systemic approach, incorporating watershed ecosystem conservation, enhancement of drainage infrastructure capacity, and effective waste management strategies [9, 13]. GIS-based technology has proven effective in mapping flood-prone areas and developing more climate-adaptive drainage systems [12]. Semarang City can adopt mitigation strategies implemented in other geographically similar cities to enhance drainage resilience against hydrometeorological risks [14].

Given the increasingly complex challenges, an ecosystem-based approach combined with drainage capacity enhancement is the key solution to improving flood and inundation management in Semarang City. Integrating risk-based spatial planning policies and public education on drainage maintenance can be a strategic step in addressing drainage system challenges in the future [10, 15].

3.2. Evaluation of the Kali Semarang Rehabilitation Project

The Kali Semarang rehabilitation project is a strategic initiative aimed at flood mitigation and reducing waterlogging in urban areas. Several interventions have been implemented, including river dredging, embankment construction, and drainage system improvements along the riverbanks. The evaluation of this project shows that these measures have enhanced water flow capacity and reduced flood occurrences in several flood-prone areas [21]. However, technical and environmental challenges remain, which must be addressed to ensure the long-term effectiveness of the project [22]. Figure 2 presents the technical framework of various strategies implemented to manage flooding and tidal inundation in several drainage subsystems in Semarang City.

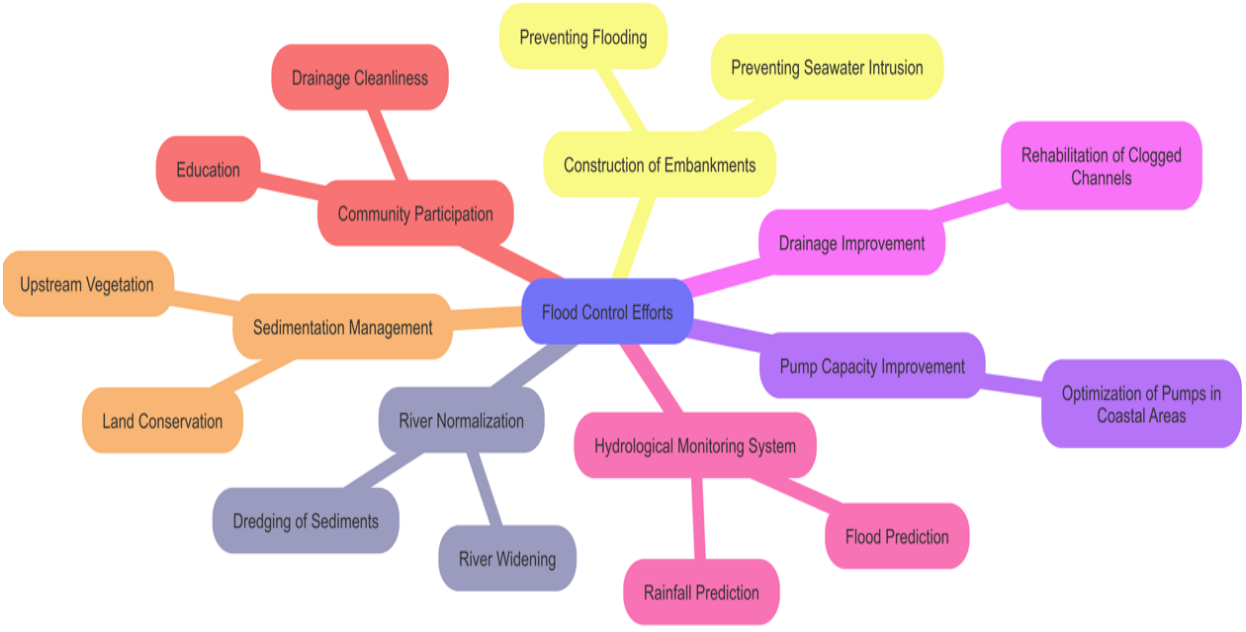

Figure 2.
Concept for flood and tidal inundation management in Semarang City (2023-2024).

One of the significant challenges in implementing this project is the high sedimentation levels caused by erosion in upstream areas. Increased sedimentation reduces river capacity, making it more challenging to contain high rainfall events, which increases flood risks [9]. Studies indicate that river dredging projects should be accompanied by upstream conservation efforts to reduce sedimentation rates [17]. Furthermore, drainage projects must integrate sustainable river ecosystem management to

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 1609-1619, 2025
DOI: 10.55214/25768484.v9i2.4848

ensure controlled ecological impacts [18]. Table 2 presents the planned river normalization and drainage capacity improvements in various drainage subsystems in Semarang City (2023-2024).

Table 2.
Planned river normalization and drainage capacity improvement (2023-2024).

No	Subsystem	River normalization and drainage capacity improvement plan
1	Mangkang River	Normalization of Plumbon River, normalization of Mangkang Kulon River
2	Bringin River	Normalization of Randugarut River, normalization of Karanganyar River
3	Siangker River	Normalization of Madukoro channel, pump capacity increase
4	Tugu River	Normalization of jumbleng river, widening of a cross drain on Jl. KAI
5	West Flood Canal	Channel normalization and inlet drain repair on Jl. Taman Siswa
6	Babon River	Pump capacity increase and development of Plamongan Hijau retention pond

Aside from technical challenges, the evaluation also found that river water pollution caused by domestic and industrial waste remains a significant concern. Microplastics and other pollutants further degrades water quality and hinders the effectiveness of drainage projects [2]. Related studies suggest that the sustainability of drainage projects requires a comprehensive approach that includes waste management and pollution control strategies [7]. Thus, the collaboration between the government, local communities, and industries is essential to maintaining water quality and river ecosystems [12].

From an infrastructure perspective, embankment construction along Kali Semarang has provided significant benefits in reducing surface runoff that causes waterlogging in surrounding areas. However, the effectiveness of embankments is still influenced by rising sea levels and saltwater intrusion, which further worsens the hydrological conditions of coastal regions [10]. This waterlogging aligns with previous studies indicating that adapting drainage systems to climate change and sea-level rise is crucial for enhancing coastal flood resilience [6].

The evaluation of this project also highlights the crucial role of community participation in ensuring drainage system sustainability. Active community involvement in keeping rivers and drainage channels clean significantly improves flood mitigation effectiveness over the long term [14]. Studies on community-based drainage management emphasize that public awareness and participation in river maintenance can reduce the risk of drainage blockages caused by household waste [8].

Overall, the Kali Semarang rehabilitation project has had positive impacts in reducing flood frequency and severity. However, long-term project success requires a holistic approach, simultaneously considering ecological, social, and technical factors. Future strategies should include drainage capacity enhancement, upstream sediment management, and strengthening community involvement to preserve river sustainability [15].

3.3. Impact on Flood and Tidal Inundation Reduction

The Kali Semarang rehabilitation project has positively impacted mitigating flooding and tidal inundation (rob) in Semarang City. The evaluation of this project indicates that increasing river flow capacity through sediment dredging and embankment construction has significantly contributed to reducing the frequency and duration of floods in affected areas [23]. Additionally, the project has allowed urban drainage systems to function more efficiently, directing stormwater runoff to the sea, thereby reducing prolonged water stagnation in coastal areas [12].

From an urban hydrology perspective, this project has proven effective in enhancing river retention capacity for stormwater runoff, especially during high-intensity rainy seasons. Improving water flow capacity has decreased the severity of waterlogging in several flood-prone areas that were previously highly impacted [13]. Previous studies emphasize that the success of flood control projects relies heavily on expanding drainage capacity and implementing sustainable river ecosystem management [4].

In addition to reducing floods, this project has also contributed to tidal flood (rob) mitigation. The presence of embankments and sediment management has significantly minimized seawater intrusion

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 1609-1619, 2025
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into urban areas. Research suggests that rising sea levels, when not accompanied by adequate protective systems, can increase the risk of tidal flooding in coastal regions [6]. Therefore, this project is a critical measure to ensure the environmental stability of urban areas vulnerable to climate change impacts [9].

One of the significant challenges in maintaining the effectiveness of this project is sustainability in infrastructure maintenance. Without regular monitoring and routine maintenance, sediment accumulation could reoccur, leading to drainage blockages that eventually reduce the efficiency of the entire drainage system [14]. Previous studies indicate that drainage projects without long-term maintenance strategies tend to experience rapid functional degradation within a relatively short period [8]. Hence, ensuring the sustainability of this project requires greater attention, particularly in the form of adequate maintenance budget allocation and policies that support sustainable urban water resource management [10].

Figure 3 illustrates the distribution of flood-prone areas and their risk reduction following the drainage project's implementation. Based on survey and field mapping results, the map visualizes the extent of flood and tidal inundation in Semarang City in 2024.

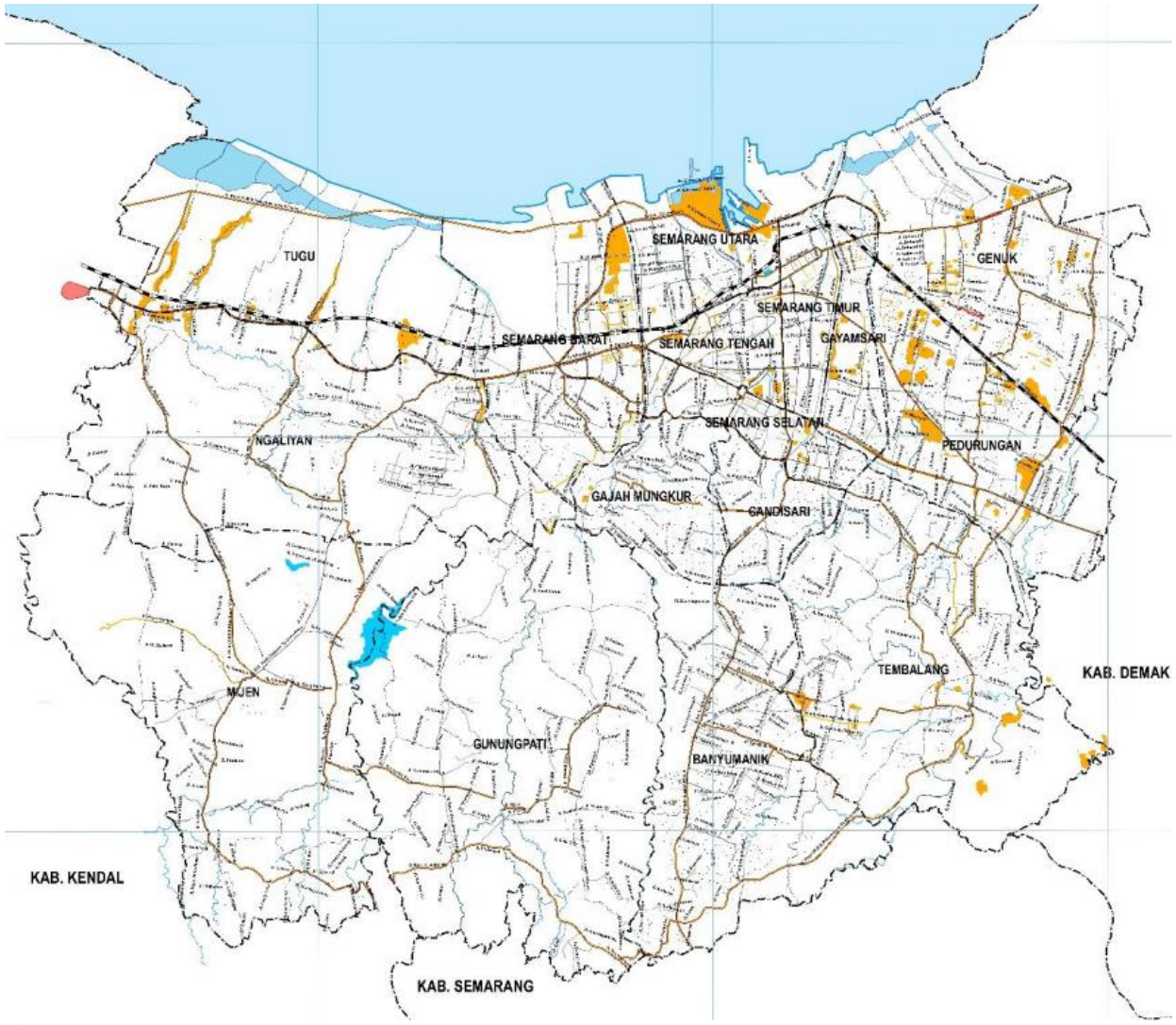

Figure 3.
Map of flood and tidal inundation locations in Semarang City (2024)

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 1609-1619, 2025
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3.4. Long-Term Strategy for Project Sustainability

Several long-term strategies are recommended to ensure continued effectiveness, including:

- Regular Hydrological Monitoring – Implement a real-time hydrological monitoring system to track rainfall patterns and river flow capacity changes for proactive flood management.
- Enhancement of Drainage Infrastructure Capacity – Increasing pumping capacity by 20% to handle stormwater and tidal floods more effectively.
- Sediment Management in Upstream Areas – Strengthening watershed conservation programs to reduce erosion rates by up to 15% annually.
- Community Engagement – Strengthening public participation in keeping rivers clean and preventing domestic waste disposal into drainage systems, which could otherwise lead to blockages and flooding [11].
- Community-Based Drainage Management Models – Encouraging localized drainage management strategies that empower residents to maintain drainage infrastructure actively [13].
- Sustainable Policy Support – Allocating a dedicated maintenance fund and policy reinforcement to ensure continuous project sustainability.

With improved infrastructure, sediment management, and community participation, the Kali Semarang rehabilitation project is expected to continue providing significant benefits in reducing floods and tidal inundation in Semarang City. The sustainability of this project should be a top priority for local governments and stakeholders to ensure that its positive impacts persist for the long term [12].

3.5. Challenges in Implementing the Drainage Project

Implementing the drainage project in Semarang City faces various technical, social, and financial challenges. One of the main obstacles is coordination between multiple agencies involved in planning and project execution. Lack of policy synchronization and institutional capacity limitations often lead to barriers to executing sustainable urban water management strategies [15]. Studies show that drainage projects involving a collaboration between the government, communities, and the private sector tend to achieve higher success rates in reducing the impact of floods and inundations [24]. Global assessment modeling has revealed significant spatiotemporal variations and socioenvironmental drivers affecting drainage system flood resilience [25]. Using integrated flood risk indices provides a framework for evidence-based planning in urban drainage systems, highlighting the role of pressure-state-response mechanisms in mitigating flood risk [26]. Furthermore, incorporating green-grey-blue coupled urban drainage strategies enhances resilience by addressing backwater effects and optimizing system performance in extreme rainfall conditions [27].

Table 3 presents the targets and performance achievements related to flood and tidal inundation reduction. It highlights the key performance indicators for flood and tidal flood mitigation in Semarang City from 2023 to 2024.

Table 3.
Key performance indicators for flood and tidal inundation mitigation in Semarang City

No	Performance indicator	2023 Target	2023 Achievement	2024 Target	2024 Achievement
1	Flood-Affected areas (%)	2.64%	2.35%	2.26%	2.23%
2	Tidal flood-affected areas (%)	1.85%	1.09%	1.08%	1.06%

3.6. Technical Challenges

The drainage project in Semarang City still faces challenges in optimizing the capacity of the existing system. Many drainage channels suffer from sedimentation and blockages due to waste accumulation and domestic pollution [1, 2]. Additionally, rapid land-use changes have caused an increase in surface runoff, placing excessive strain on the current drainage system [3]. Several studies

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 1609-1619, 2025
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indicate that uncontrolled urbanization heightens the risk of flooding in urban areas lacking adequate drainage systems [4].

3.7. Hydrometeorological Challenges

The city's drainage system is also affected by hydrometeorological conditions, including rising sea levels and rainfall patterns due to climate change. These factors have increased the frequency and intensity of tidal flooding in Semarang City [5, 6]. Prior research suggests that urban drainage systems should be designed with climate change scenarios in mind to mitigate extreme hydrometeorological risks effectively [7]. In this context, ecosystem-based approaches and adaptive technologies are essential to enhancing urban drainage resilience [8, 9].

3.8. Social Challenges

The low level of public awareness regarding environmental cleanliness presents another major challenge. Many households dispose of waste into drainage channels, leading to blockages that exacerbate flooding and inundation problems [10]. Public education programs and community participation in drainage management are key strategies to mitigate this issue [11, 12]. Several studies emphasize that community involvement in drainage projects can increase infrastructure sustainability and improve the effectiveness of urban water management [13, 14].

3.9. Financial Challenges

The limited government budget for drainage project management is another significant hurdle. Funding for infrastructure maintenance and capacity expansion is often insufficient, leading to project degradation due to a lack of regular upkeep [15, 16]. Alternative financing models, such as public-private partnerships (PPP) and international grant mechanisms, could serve as viable solutions to boost financial resources for drainage projects in the future [17].

Integrated Strategies for Overcoming Challenges

A comprehensive and integrated strategy is required to overcome these challenges, including:

- Institutional Capacity Strengthening – Enhancing coordination among local government agencies, national ministries, and stakeholders to ensure effective project implementation.
- Technology-Based Ecosystem Approaches – Utilizing nature-based solutions such as green infrastructure, bio-retention basins, and riverbank reforestation to support sustainable water management.
- Public Participation in Drainage Maintenance – Implement awareness campaigns and incentives to encourage community involvement in the upkeep of drainage infrastructure.
- Risk-Based Infrastructure Planning – Employing climate modeling and predictive analytics to design drainage systems that adapt to climate change.
- Sustainable Funding Mechanisms – Expanding PPP models, leveraging international grants, and incorporating private-sector investments to ensure long-term financial sustainability.

By adopting a more holistic and collaborative approach, Semarang City's drainage system can become more effective in reducing the risks of flooding and tidal inundation in the coming years [20].

4. Conclusion and Recommendations

4.1. Conclusion

The revitalization project of Kali Semarang has had a significant impact on flood and tidal inundation mitigation in Semarang City. Evaluations indicate that the project successfully reduced flood inundation area from 1,281.67 ha in 2023 to 1,228.96 ha in 2024, while the number of inundation points decreased from 522 to 466 points. The increased river flow capacity has shortened the flood duration from 10 to 6 hours per event, demonstrating the effectiveness of drainage infrastructure improvements.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 1609-1619, 2025
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Additionally, constructing embankments along Kali Semarang has reduced seawater intrusion, decreasing tidal inundation areas from 406.27 ha in 2023 to 394.30 ha in 2024.

However, challenges remain in the implementation of the project. High sedimentation due to erosion in upstream areas reduces the effectiveness of river dredging, while water pollution from domestic and industrial waste remains a significant concern. Furthermore, a lack of coordination between relevant agencies and limited maintenance funding has slowed drainage improvement efforts. Therefore, a more comprehensive approach is required to ensure the sustainability of this project.

4.2. Recommendations

Several key recommendations should be implemented to enhance the effectiveness of the drainage project and reduce the risks of flooding and tidal inundation:

- Increasing Drainage Infrastructure Capacity: Expanding drainage capacity by increasing the number of water pumps in coastal areas by up to 20% from the current capacity to manage tidal inundation effectively.
- Optimizing Hydrological Monitoring: Implementing a real-time hydrological monitoring system to predict rainfall patterns and river discharge, reducing response time in flood risk management.
- Upstream Sedimentation Management: Land conservation programs in upstream areas through erosion control vegetation planting, aiming to reduce sedimentation rates by up to 15% per year.
- Strengthening Regulations and Interagency Coordination: Synchronizing policies between local governments, BWS Pemali Juana, and local communities to ensure more efficient project execution.
- Enhancing Community Participation: Educational campaigns and incentive programs to increase community engagement in maintaining drainage cleanliness and preventing waste disposal into rivers.
- Diversifying Funding Sources: Utilizing public-private partnership (PPP) schemes to support drainage infrastructure maintenance budgets, which are currently limited.

By implementing these recommendations, the Semarang City drainage system can become more adaptive to hydrometeorological changes and provide better protection for the community against flooding and tidal inundation threats in the future.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Acknowledgements:

Special thanks to Nik Sutiyani as Special Staff, Semarang Mayor's Office for providing the necessary resources and facilities to complete this research study.

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Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 1609-1619, 2025
DOI: 10.55214/25768484.v9i2.4848