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Flood Management and Biodiversity Conservation in Urban Watersheds of Johor Bahru, Malaysia: Towards the Implementation of Nature-Based Solutions

Gestion des inondations et conservation de la biodiversité dans les bassins versants urbains de Johor Bahru, Malaisie : Vers la mise en œuvre de solutions fondées sur la nature

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RÉSUMÉ

La réduction des risques de catastrophe et la conservation de la biodiversité sont des défis mondiaux, avec un besoin croissant de gestion des bassins versants basée sur des solutions fondées sur la nature (SfN). Cependant, en Asie monsoonique, les méthodes de planification ne sont pas encore bien établies. Cette étude se concentre sur les bassins versants urbains en Malaisie, confrontés à des inondations et à la dégradation des écosystèmes dues au développement. À partir d'observations hydrologiques et d'enquêtes sur la biodiversité, l'objectif est d'évaluer les impacts des changements d'utilisation des terres sur les inondations et la biodiversité. En examinant les cartes topographiques, on observe qu'en 1926, les zones urbaines n'existaient pas, mais que l'urbanisation rapide a transformé les zones humides en zones urbaines, réduisant les forêts. Un modèle d'inondation a été développé, reproduisant les inondations passées. Des enquêtes sur les poissons ont montré que les espèces exotiques dominent en aval, tandis que des espèces indigènes rares sont présentes en amont. Ces résultats suggèrent que la restauration des espèces de zones inondables pourrait être facilitée par la réhabilitation des zones humides. Le modèle d'inondation permettra d'évaluer l'efficacité des stratégies de gestion des risques d'inondation et leur impact sur la faune piscicole, soutenant ainsi la conservation et la restauration de la biodiversité.

ABSTRACT

For sustainable development, reducing disaster risks and conserving biodiversity are global challenges, with increasing demand for watershed management that includes ecosystem conservation based on Nature-based Solutions (NbS). However, planning methods for such approaches are not established in monsoon Asia, a region of high temperatures, humidity, and population density. This study focuses on urban watersheds in Malaysia, which face flood damage and ecosystem degradation due to development. Using hydrological observations and biodiversity surveys, it aims to clarify the impacts of land use changes on flood runoff and biodiversity. The goal of this study is to propose watershed management strategies to mitigate flood damage and conserve biodiversity. Land use changes were examined through topographic maps, revealing that in 1926, no urban areas existed, but rapid urbanization transformed wetlands into urban areas, reducing forests. An RRI-based flood model was developed, accurately reproducing past flood extents. Fish surveys captured 2,727 individuals across 19 species from 13 families, revealing dominance of exotic species downstream and rare native species upstream. These findings suggest that restoration of floodplain species could be achieved through retention ponds and wetland rehabilitation. The flood model will help assess the effectiveness of flood risk management strategies and their impact on fish fauna, aiming to clarify flood mitigation measures that support biodiversity conservation and restoration.

KEYWORDS

Fish fauna, Flood inundation model, Flood management, Land use change, Nature-based solution

Faune piscicole, Modèle d'inondation des crues, Gestion des inondations, Changement d'utilisation des terres, Solution fondée sur la nature

1 INTRODUCTION

For sustainable development, reducing disaster risks and conserving biodiversity are global challenges. There is growing recognition of the importance of integrated approaches that consider climate change adaptation, natural environment conservation and restoration, as well as the Climate-Nature Nexus, Nature-based Solutions (NbS), and Ecosystem-based Disaster Risk Reduction (Eco-DRR). These approaches highlight the critical intersection of climate change adaptation, disaster risk reduction, and environmental conservation. Many of the 15 Sustainable Development Goals (SDGs) are closely related to sustainable watershed management, particularly in areas such as disaster mitigation, sustainable resource use, and ecosystem restoration. Common solutions to these challenges require not only watershed management focused solely on flood control but also a more integrated approach (Itsukushima et al., 2021). Tailored solutions, adapted to each climate zone and ecosystem, are essential. However, in monsoon Asia, a region characterized by high temperatures, humidity, rich biodiversity, and extremely high population density, planning and evaluation methods for such integrated approaches are not yet well-established.

The study area, Malaysia, is entirely located in Sundaland and is a global hotspot for freshwater biodiversity, home to over 1,000 fish species. However, the rapid and large-scale conversion of tropical rainforests into agricultural land and urban development has led to the degradation of freshwater habitats, resulting in a loss of biodiversity (Wilkinson et al., 2018). While Borneo has made significant strides in biodiversity conservation efforts, the Malay Peninsula, which is the focus of this study, has experienced the most significant biodiversity decline in Sundaland, making it a high-priority area for conservation (Chua et al., 2019). Additionally, the risks of water-related disasters have increased due to climate change and land use changes. Since 1975, the Malay Peninsula has seen a rise in extreme precipitation events (Syafrina et al., 2015), and flooding has become more frequent in recent years. However, urbanization driven by economic growth and land use changes, such as the conversion of tropical rainforests into plantations, have worsened the situation. This study aims to quantitatively assess the impacts of human activities on flood runoff and biodiversity.

This study focuses on urbanized watersheds in Malaysia, where the impacts of development activities, such as increased flood damage and ecosystem degradation, are particularly severe. Using high-temporal and high-spatial resolution hydrological observations and biodiversity surveys, the study aims to elucidate the effects of human activities, including land use changes, on flood runoff and biodiversity. The ultimate goal is to propose watershed management strategies that can reduce flood disaster damage and contribute to the conservation of the natural environment.

2 METHODOLOGY

2.1 Regional setting

The study area is the Masai River watershed in Johor State, located at the southernmost tip of Peninsular Malaysia (Figure 1). In 1926, the watershed had no significant human activities, except for plantations; however, it has undergone rapid urbanization in recent years, leading to the loss of wetlands and the expansion of forest development. By 2024, 54% of the watershed will have been urbanized. Additionally, much of the forested area has been converted into oil palm plantations, resulting in significant changes to both land use and the water cycle of the watershed (Figure 2). Flooding has become more severe in recent years, with multiple flood events occurring consecutively. With the increase in rainfall due to climate change, there are growing concerns about the expansion of flood inundation damage.

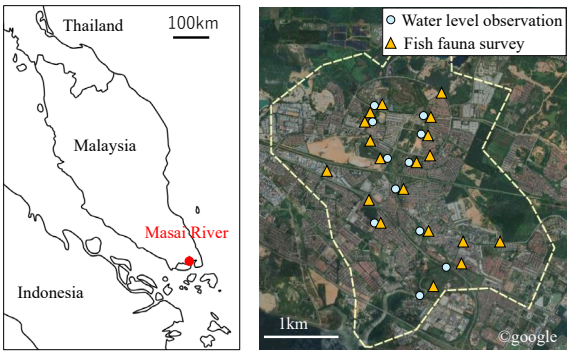


Figure.1 Location of the study area (Masai River Basin)

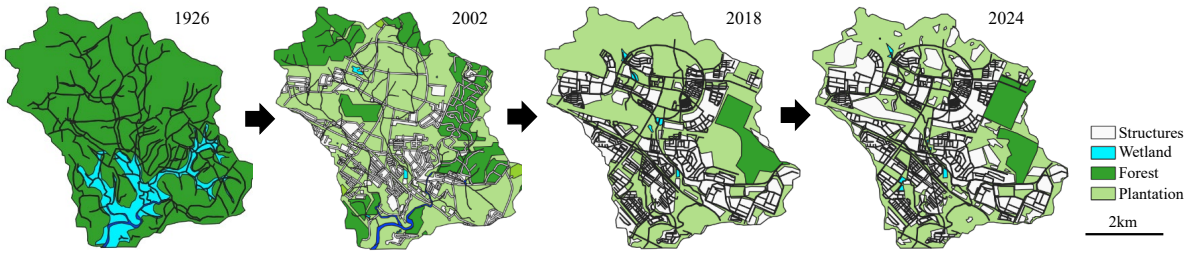


Figure 2 Changes in land use in the Masai River Basin

2.2 The construction of a flood inundation model based on hydrological observations

A flood inundation model capable of reproducing flood events in the target watershed was developed using the Rainfall-Runoff-Inundation (RRI) model. The RRI model is designed to simulate the relationship between rainfall, runoff, and flood inundation dynamics. For model calibration, water level observations were conducted at 11 locations within the watershed using fixed logger gauges and ultrasonic sensors, while flow velocity measurements were taken using trail cameras. These data collection efforts began on June 28, 2024 (Figure 1).

2.3 Survey of biodiversity within the watershed

To examine flood mitigation strategies that include biodiversity conservation and restoration, a comprehensive biodiversity survey was conducted within the watershed. The survey was carried out between November 28 and December 2, 2024. Fish surveys were conducted at 19 sites within the watershed, where each habitat (riffles, runs, pools, and glides) was sampled using a hand net and cast net over a reach (approximately 10 times the width of the river). To maintain consistent effort, two investigators conducted survey with 10 casts of the cast net and a 30-minute sampling period using the hand net.

3 RESULTS AND FUTURE CONSIDERATIONS

The constructed flood inundation model and the overlay of flood prone area are shown in Figure 3. The model closely aligns with the observed inundation locations, confirming that an accurate flood inundation model has been developed. Moving forward, the model will be used to quantitatively analyze the impact of land use changes on flood runoff and to investigate the relationship between urbanization processes and the increased flood risk. Based on the findings, flood mitigation strategies that allow for inundation, such as the construction of retention ponds and the wetlands restoration, will be examined for their effectiveness in reducing flood damage.

Additionally, the fish fauna survey resulted in the capture of 2,727 individuals across 19 species from 13 families (Figure 4). In the downstream areas, non-native species such as Pterygoplichthys disjunctivusm, Mayaheros urophthalmus, and Poecilia reticulata were dominated, while in the upstream floodplain environments, species listed on the IUCN Red List, such as Parambassis siamensis, Trichopsis vittate, and Monopterus albus, were identified. This suggests that the restoration of floodplain environments may facilitate the recovery of these rare native fish species.

In the future, a model will be developed to explain the relationship between physical environmental factors and the occurrence of fish species. By integrating this model with the flood inundation model, we aim to clarify how flood management strategies that allow for flooding can influence biodiversity, particularly in terms of controlling the spread of exotic species and promoting the recovery of floodplain fish species.

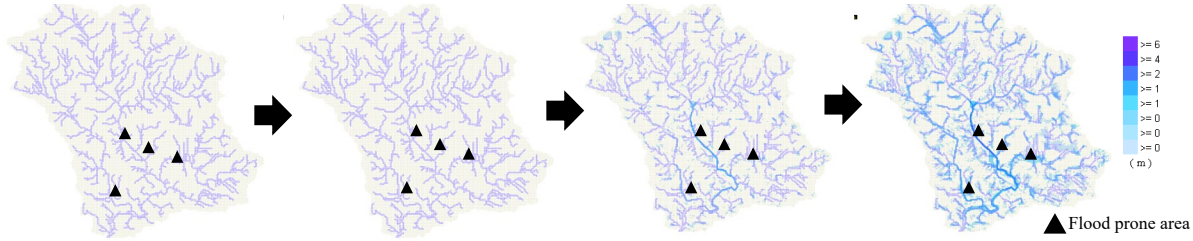
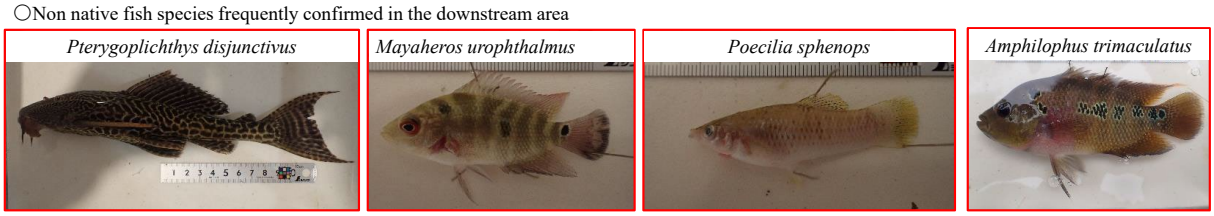


Figure 3 Flood calculation results using the RRI model and flood-prone areas

○Non native fish species frequently confirmed in the downstream area



○IUCN Red List species found in stagnant water environments

Figure 4 Non native fish species and IUCN Red List species confirmed in the Masai River Basin

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