Nature-Based Wetland Management for Flood Mitigation in Gorakhpur
A Case of the Rapti River

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Abstract

Introduction Rapid urbanisation coupled with climate variability has resulted in devastating urban floods in most Indian cities, causing major disruptions and significant impacts on people, the economy, and the environment. However, urban wetlands, a complex socio-economic-natural ecosystem, provide valuable ecological benefits to urban areas, including reducing flooding by acting as sponges for cities. Unfortunately, these wetlands in urban areas have been severely degraded due to anthropogenic factors such as agricultural conversion, development activities, sewage effluent encroachment, and other consequences.

Aim This research aims to utilise urban wetland ecosystems to reduce urban flooding risk focusing on the Rapti riverine wetlands in Gorakhpur to mitigate flooding using nature-based solutions.

Methods Using a case-based approach to wetland planning, the study employs a mixed-methods approach to access the Rapti riverine wetlands. It combines qualitative methods like expert surveys, case studies, and report analysis with quantitative approaches such as primary surveys and Geographic Information System (GIS) analysis to develop policy and infrastructure-based solutions.

Results The research identifies specific nature-based solutions and provides data-driven insights into the current state of the Rapti riverine wetlands and their potential for flood mitigation.

Discussion This research will assist urban planners, policymakers, and other stakeholders in developing effective flood mitigation strategies by leveraging the ecological benefits of urban wetlands. Furthermore, the findings of the study advance urban wetland planning and support sustainable environmental development in Gorakhpur.

Keywords: Wetland Management, Nature-based solution, Disaster-risk Reduction, Floods, Climate Change

1. Introduction

1.1. Urbanisation and Wetlands in Urban Ecosystems

Wetlands are the edge areas where land and water meet in one of the most productive ecosystems in nature. (Ghamandi, 2010) They serve various purposes and provide significant benefits and exceptional cultural, social, ecological, and economic val- ues. (Kiran, 1999; Russi et al., 2013) They share several char- acteristics; they vary significantly in terms of area, location, and hydrology. (Mahdavi et al., 2018) As defined by the Ram- sar Convention on Wetlands, wetlands are defined as “Areas of marsh, fen, peat, and or water, whether natural or artificial, per- manent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.”(Article 1, Ram- sar Convention on Wetlands, 1971). In addition, the Conven- tion (Article 2.1) states “may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of ma- rine water deeper than six meters at low tide lying within the wetlands”. The Ramsar definition is perhaps the broadest of all wetland definitions. However, this definition is suitable for most international purposes; most nations have their definition of wetlands created for scientific, administrative, and govern- mental purposes. (Mahdavi et al., 2018) Today, the manage- ment of wetlands depends on the growth rate of the human population and its water demands. (Craft, 2016a) The global population is expected to reach more than 9 billion by 2050 and more than 10 billion by 2100 as shown in Figure 1. (United Na- tions, 2022). With increased urbanisation comes an increasing demand for food and water to grow it. (Craft, 2016a) Accord- ing to the Ramsar Conventions, about 87% of the wetlands in urban areas have been badly damaged or lost since the 1700s. According to estimates by Wetlands International South Asia, nearly 30 percent of the natural wetlands in India have been

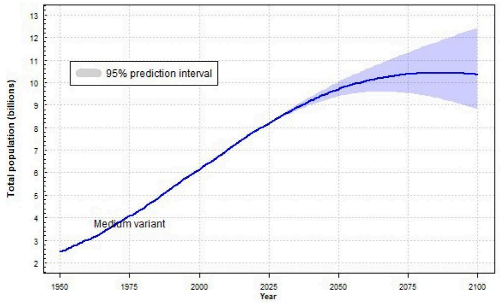

Figure 1: World Population Prospects, UN-DESA

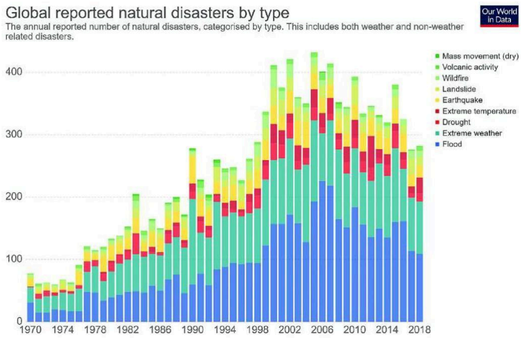

Figure 2: Global annual reported natural disasters by type, EM-DAT

lost in the last three decades. Nearly all losses result from human activity, drainage, fill placement, nutrient over-enrichment, and other waterborne pollutants. Extractive activities like har- vesting and mining sand and other construction materials also contribute to the loss. (Craft, 2016a)

On the other hand, water stress is a significant problem globally, particularly in countries like India, where the water demand has surpassed the supply. According to the World Resources Insti- tute, India is one of the 17 countries experiencing extremely high water stress. The country is home to 16% of the world's population. However, the country possesses only 4% of the to- tal freshwater resources, a situation projected to deteriorate as population growth and climate change intensify the problem, leading to water scarcity. As per estimates by UNDESA, nearly half of the world's population will live in areas with signifi- cant water stress under the climate change anticipated by 2030. Maintaining sustainable water consumption levels is expected to become even more difficult in urban areas due to increasing population pressure, poor management of water resources, changing water consumption behaviour, and climate change. (Kummu et al., 2016). In addition, urban flooding in Indian cities makes the water situation worse. Globally, around 1 billion people live in flood-prone areas and is anticipated to double by 2050. (UNDESA, 2012) Increased impermeable catchments lead to higher catchment yield in a shorter time, occasionally increasing flood up to three times as high, which causes urban inundation. (Kiran, 1999) Rapid urbanisation, climate change, land-use changes, and inadequate infrastructure contribute to more frequent and severe flooding in urban areas. (United Na- tions, 2015; T.V Ramachandran, 2009) According to the Emergency Events Database (EM-DAT) depicted in Figure 2, there has been a significant increase in water-based disasters, with urban areas experiencing 37% of flood disasters between 1980 and 2020. In recent years, India experienced devastating floods in cities like Mumbai, Chennai, Hyderabad, and Bengaluru, causing massive damage to property and infrastructure, as well as loss of life. However, it will cost global economies up to

$1 trillion per year by 2050 if left unaddressed, as per the es- timates by the World Resources Institute. High levels of water stress frequently result in inadequate water supplies for residen- tial and commercial use and increased dependence on ground- water, causing a decline in water tables. Moreover, water stress is predicted to worsen in the coming years due to population growth, climate change, and increasing demand for water from agriculture, industry, and domestic use. The lack of proper in- frastructure, such as stormwater drains, can further exacerbate the impact of urban floods by causing waterlogging and increas- ing the risk of water-borne diseases such as diarrhoea, typhoid, etc. Around 21 major cities in India are expected to run out of groundwater by 2020, affecting more than 100 million people. Thus, to curb the issue of urban flooding, wetlands should be in- corporated into a city's planning based on ecological value and establish a synergy between the execution and planning for the management of the wetlands. Furthermore, a multifaceted strat- egy is needed to handle water stress, including investment in infrastructure and addressing the root causes of climate change.

1.2. *Nature-Based Solutions in Urban Flood Management* Traditional flood management strategies such as dams, levees, and concrete channels are in place. However, relying solely on these engineered structures is no longer adequate to ad-

dress the increasing risks linked with urban flooding. More- over, they detrimentally impact the ecology of wetlands. While effective to some extent, these traditional methods are often costly, environmentally disruptive, and can lead to unintended consequences downstream. Recently, nature-based solutions (Nbs) are gaining popularity as sustainable and cost-effective alternatives to traditional flood mitigation strategies. The In- ternational Union for Conservation of Nature(IUCN) defines NBS as actions to protect, sustainably manage and restore nat- ural or modified ecosystems. These solutions address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits. In other words, nature-based solutions (NBS) are defined as actions inspired by, supported by, or copied from nature (Cohen-Shacham et al., 2016; EC, 2015) that (1) Nbs deploy various natural fea- tures and processes in a resource-efficient and sustainable man- ner; (2) Nbs are adapted to local systems into diverse spatial scales, redefining the role of nature in urban, and natural en- vironments; and (3) Nbs face social, environmental, and eco- nomic challenges, leading to multiple benefits and supporting sustainable development and resilience. The use of NBS began at the beginning of the 21st century and was adopted by sev- eral worldwide institutions. NBS have a multi-functional role, which provides great potential to address social, environmen- tal and economic dimensions of global challenges as shown in Figure 3. Additionally, nature-based solutions (NBS) for flood

Figure 3: Nature-based solutions, IUCN

management involve leveraging natural processes and ecosys- tems to mitigate the impacts of flooding. NBS aim to work with nature rather than against it, providing a range of ecological, so- cial, and economic benefits while addressing the root causes of flooding.

One of the most effective nature-based solutions (NBS) for flood mitigation involves the restoration and creation of wet- lands. These wetlands serve as natural buffers that absorb ex- cess rainwater, reduce runoff, and mitigate flood risks. Inter- ventions include re-establishing natural water flow by removing barriers such as levees and drainage systems, allowing rivers to reconnect with their floodplains. The ”Room for the River” initiative in the Netherlands exemplifies this approach, involv- ing interventions like relocating dikes and creating secondary channels to allow rivers to overflow into designated areas dur- ing high water events, thereby reducing flood risks and enhanc- ing biodiversity. Another key strategy is planting native vegeta- tion, such as riparian buffers and marsh plants, to stabilise river- banks, reduce erosion, and enhance water absorption. Along the Mississippi River, the installation of riparian buffer zones essentially protects riverbanks, reducing erosion, and improv- ing water quality by trapping sediment and nutrients. Creat- ing water storage features like ponds and channels increases the capacity of wetlands to retain floodwaters. The Everglades Restoration project in Florida showcases this strategy by restor- ing historical water levels and establishing microtopographic features that enhance the water storage capacity of the wetland, thus reducing flood risks and improving ecological health. Soil and sediment management, including replenishing eroded areas and improving soil quality, enhances the ability to store water. In the Murray-Darling Basin in Australia, efforts to replenish eroded areas with sediment and improve soil quality have sta- bilised the soil, reduced erosion, and increased the water re- tention capacity of the wetlands, contributing to more effective flood control. Managing invasive species and improving wa- ter quality through natural filtration processes are also essen- tial. Mangrove restoration projects in the Philippines showcase this strategy by removing invasive plants and replanting na- tive mangrove species, which stabilise shorelines, reduce ero- sion, and protect against storm surges while improving water quality. Engaging local communities and stakeholders, along with implementing long-term monitoring and adaptive manage- ment, ensures the success and sustainability of these projects. Maryland's Living Shorelines initiative demonstrates the im- portance of community involvement and adaptive management, using natural materials and vegetation to stabilise shorelines and reduce erosion, enhancing coastal resilience and support- ing marine habitats. These case studies highlight how integrat- ing NBS into flood management strategies can significantly en- hance flood resilience, promote ecological health, and provide multiple co-benefits for local communities. By incorporating these nature-based solutions, the urban wetlands can be man- aged to enhance flood resilience, leading to multiple benefits for the environment and society.

1.3. Need for Wetland Planning in Indian cities

Wetlands have played a major role in the development of civil- isation throughout human history. Our cities have been built along rivers, lakes, and coastlines to help develop civilized communities in the inundated and fertile floodplain environ- ments. (Craft, 2016a) Globally, wetland ecosystems cover an area ranging from 1275 million hectares (m ha), with 92.8 % of continental wetland area being inland with an annual eco- nomic value of approximately US $15 trillion (Gell et al.,2016; Millennium Ecosystem Assessment, 2005). In India, wetlands constitute 4.7 % of the overall land area. (Bassi et al., 2014a) Additionally, wetlands stabilise the catchment area's water sup- plies and water balance, thus ameliorating floods. (Mitsch et al., 2009) Wetlands are essential for managing stormwater runoff, reducing flooding, and improving water quality. (Kiedrzyn´ska & Zalewski, 2012) Therefore, wetlands are crucial in urban ecological ecosystems. (Wang et al., 2022) As per estimates by Wetland Atlas of India, Uttar Pradesh is home to significant wetland distribution, with a total of 121,242 wetlands covering 1,242,530 hectares, making it the state with the second-highest inland wetland extent in India. As cities grow, wetlands be- come infringed upon, and it becomes convenient to drain or fill the wetlands to expand. (Craft, 2016a) Furthermore, climate change has impacted the integrity of the wetlands. (Mahdavi et al., 2018) Wetlands can be considered an adaptive and yet ecologically fragile system. (Turner et al., 2000) So far, ap- proximately 57 % of the total wetlands have been transformed or destroyed. (Davidson, 2014) And, despite the substantial wetland coverage in Uttar Pradesh, severe degradation of these wetlands and the absence of wetland-specific legislation leads to an urgent need for comprehensive legal frameworks to safe- guard them. The loss of wetlands must be considered a devel- opment crisis and a biodiversity problem because it could in- crease water, food, and climate insecurity. Therefore, the need is to manage our wetlands ecosystems, which will alleviate the flooding problem in landlocked cities like Gorakhpur, and tap into other social, environmental, and economic benefits of such ecosystems to ensure long-term sustainability.

1.4. Aim and Contribution of the Study

This study aims to develop effective strategies for planning and managing these urban wetlands using nature-based solutions to mitigate the risk of urban flooding in Gorakhpur. By focusing on the Rapti riverine wetlands, the research seeks to explore and implement ecological approaches that leverage the natural flood-regulating capacities of wetlands. The study significantly contributes to academic research by enhancing the understanding of urban wetlands as natural flood mitigators and offering a robust methodological framework by integrating a mixed-method approach. It enriches the literature on nature-based solutions, providing empirical evidence from the case of Gorakhpur's Rapti riverine wetlands. Practically, the study delivers concrete policy and infrastructure recommendations to local governments and urban planners, aiming to manage wetlands effectively and reduce urban flooding risks. By involving local stakeholders, the research ensures its solutions' socio- economic relevance, promoting urban resilience, wetland con- servation, and broader environmental sustainability goals. Ad- ditionally, the study raises awareness about the ecological value of wetlands, advocates for their preservation, and serves as a blueprint for other cities facing similar challenges. Ultimately, it supports climate change adaptation strategies and fosters sus- tainable urban development practices.

2. Material and Methods

2.1. Study Area

Spread over an area of 147 sq km, Gorakhpur, situated in Uttar Pradesh, India, which lies on the confluence of the Rapti and Rohini rivers, is a region of significant importance for understanding wetland dynamics and their impact on urban resilience. According to the National Wetland Portal of India, Uttar Pradesh is home to many wetlands, and Gorakhpur plays an essential role in this extensive wetland network distribution. However, many of these potential wetlands are degraded and yet to be tapped. For example, Ramgarh Tal, a signifi- cant wetland located in Gorakhpur and one of the ten Ram- sar sites in Uttar Pradesh, has faced challenges such as pol- lution, encroachment, and reduced water quality. These is- sues highlight the need for effective management efforts to re- store and utilise these valuable ecosystems. Flooding is another challenge for the city, and degraded ecosystems only exacerbate this problem. Gorakhpur, for example, witnessed record-breaking rainfall with torrential downpours in recent years, including in 2022. (Du, 2019) Flooding in the city has been attributed to various factors, including heavy rainfall, inadequate drainage infrastructure, and encroachment on water bodies and wetlands, which leads to waterlogging. Further, the topography of Gorakhpur is characterised by low-lying areas with min- imal slope gradients. Approximately 74.29% of the total city area has a slope of 0–1 degrees, with 61-67% of the region lying at an elevation of only 80–85 meters. Research by the Gorakhpur Environmental Action Group (GEAG) on vulnerability assessment indicates that roughly 18% of the city, particularly the southern, western, and central districts, are at extreme risk of waterlogging. Water often stagnates for over three to four months, leading to deteriorating health conditions and in- creased health threats. Further, the Municipal Corporation has

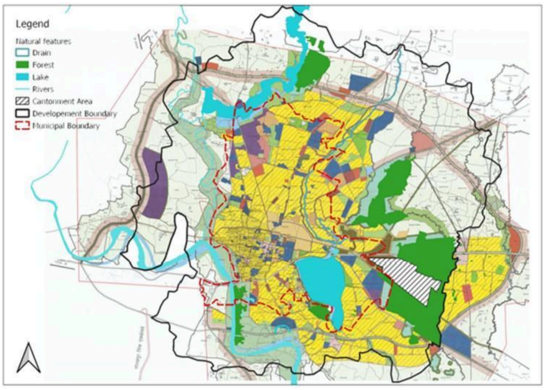

Figure 4: Study Area: Gorakhpur, Uttar Pradesh - Master Plan 2021

identified 59 spots as permanently waterlogged. The general slope of the city is from north to south, but it is not uniform. As the city has developed, its drainage system has evolved to link water flows to various water bodies, including small and large ponds. A significant impact of climate change is the expected increase in rainfall intensity over shorter periods, exacerbating the flooding propensity of low-lying areas, particularly if the wetlands that traditionally absorbed runoff are degraded or filled. Historically, the city in the Terai region had 103 small and large water bodies in the 1960s, which played an essential role in its drainage system. However, increasing land demand for housing and rising land costs have led to the encroachment and development of these water bodies. As a result, the num- ber of water bodies has dwindled to 43. Further, Gorakhpur's largest lake, Ramgarh Tal, faces the threat of extinction due to these pressures. The location of the study area and wetlands in Gorakhpur is shown in Figure. 4 Because of this, the city be- comes a breeding ground for diseases each year such as dengue fever, malaria, and Japanese encephalitis, which claimed the lives of over 500 people between 2007 and 2010 alone. (Du, 2019)

2.2. Research Questions

1. How can we delineate urban wetlands? 2. How can a wetland be utilised to prevent problems like flooding in Indian cities?

2.3. Methodology

The research methodology is structured into distinct interconnected phases designed to achieve specific objectives. The ini- tial phase involves a preliminary study aimed at identifying key indicators at the city level, including waterlogged areas, a 10 km buffer area around river Rapti, built-up areas, income levels of housing (urban poor), and wetland areas catchments which are essential for prioritising catchments within the ur- ban area boundaries of Gorakhpur city. The identification of these city-level indicators is accomplished through a combina- tion of methods such as primary surveys, interviews with local authorities, and consultations with experts. Subsequently, using the multicriteria analysis priority area mapping for the catchment zones, overlaying the sub-basin areas using Lidar Survey data to enrich the catchment prioritisation process, is carried out. This process is followed by a rigorous Pareto Analysis to further refine the focus areas. In this phase, the study leverages the stakeholder survey, experts from governmental organizations such as Wetlands International, Gorakhpur Development Authority, and Jal Nigam, as well as non-governmental organizations (NGOs) like GEAG (Gorakhpur Environmental Action Group), practitioners, and researchers such as NIUA (National Institute of Urban Affairs) and Independent Wetland Researcher. By applying the Pareto Analysis and gathering insights from diverse stakeholders, the study strategically focuses on prioritising areas where addressing just 20 % of the problems can yield solutions for 80 % of the flooding issues in Gorakh- pur. The research methodology is driven by three main objec- tives followed by three distinct sub-objectives that are outlined to specifically address the second objective. The primary objec- tive of the study is 1. to delineate the boundary of the wetland.

2. to comprehend the strategies for flood mitigation using river- ine wetlands in Gorakhpur. In the subsequent phase, this study aims to achieve the following sub-objectives in wetland plan- ning as part of the second. Firstly, the objective is to enhance the functionality of the environment by leveraging wetlands as a sustainable solution for mitigating flooding. This involves studying the potential of wetlands to absorb excess water dur- ing heavy rainfall and their role in regulating water flow within catchment areas. Secondly, the research focuses on increas- ing the availability of water within these catchments, which is essential for various purposes such as agriculture, and urban supply. Finally, the research also aims to contribute to urban development by providing recreational spaces. These spaces not only serve as leisure areas but also play an essential role in strengthening city connections, promoting community engage- ment, and enhancing the overall quality of life. Through these objectives, the study aims to address key challenges faced by ur- ban areas like Gorakhpur, thereby fostering a more resilient and sustainable urban environment. To assess these, the data collec- tion and analysis are structured into three hierarchical levels as River Level Analysis, Catchment Level Analysis, and Wetland Level Analysis. The systematic analyses culminate to form the basis for deriving the research findings, drawing conclusions, and engaging in substantive discussions. In the final phase, the study outcomes were leveraged to develop proposed strategies, which were subsequently followed by establishing robust mon- itoring and control mechanisms to ensure the efficacy of the strategies in achieving the predefined research objectives. In the last phase, these outcomes from the study subsequently inform the formulation of proposed strategies. Finally, robust mon- itoring and control mechanisms are established to ensure the efficacy of these strategies in attaining the predefined research objectives.

3. Results

The results of this study are presented in two distinct subsections, each corresponding to one of the key research questions. These subsections provide a comprehensive overview of the findings from the extensive data collection and analysis phases

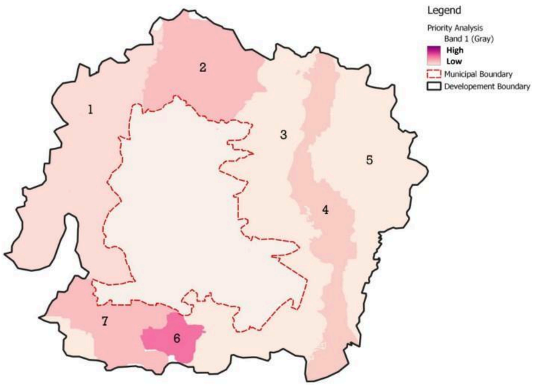

Figure 5: Delineated area of study,Author

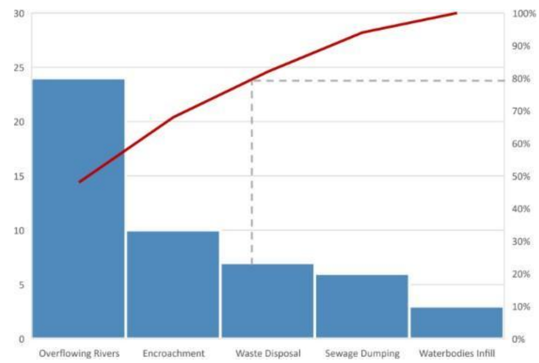

Figure 6: Major causes of flooding using Pareto Analysis

of the research, highlighting the critical insights and implications for Rapti riverine urban wetland restoration, delineation of these wetlands, and utilisation of urban wetlands in flood prevention in Gorakhpur.

3.1. Approach to Delineating Urban Wetlands

Using Sub-basin LiDAR survey data developed from the digital elevation model (DEM) and topography data prepared by IIT Kanpur, the city of Gorakhpur has been divided into seven catchment areas. Further, based on the indicators identified for the study area, including the extent of waterlogged areas, prox- imity to the Rapti River, built-up regions, housing income lev- els, and existing wetland areas, the layers are overlaid using multi-criteria analysis. This is to prioritise the catchment areas within the study area integrating various critical factors at risk of flooding and in need of intervention as depicted in Figure.5.

3.2. Major causes of flooding in Gorakhpur

Utilising stakeholder surveys, the study identified the major causes of flooding in Gorakhpur with significant impacts. The results reveal that the majority of flooding, nearly 80%, is attributed to riverine floods, primarily stemming from Rapti over- flow, followed by encroachment, and then by waste disposal as shown in Figure. 6.

Despite consistently low flood levels each year, flooding remains an annual occurrence in Gorakhpur. Adding to this concern is the looming threat of increased flooding in the coming years due to the effects of climate change on urban areas. As water-related disasters are on the rise, cities like Gorakhpur are expected to experience heightened vulnerability. projections in- dicate that floodwaters are anticipated to surpass established danger thresholds. This prediction extends up to 2035, sug- gesting that in the forthcoming years, water levels will likely exceed the danger level, leading to more significant overflows in the area.

3.3. Captilising Wetlands for Flooding Prevention

The multi-tiered approach aims to holistically address the flood- ing issues in Gorakhpur. The analysis was conducted at the river level, wetland level, and catchment level. The sub-objective of the study includes enhancing the functionality of the environ- ment by using wetlands to mitigate flooding, increasing water availability within the catchments, and providing recreational spaces that strengthen city connectivity. By leveraging nature- based solutions, the research emphasises the sustainable use of urban wetlands. These solutions not only help in flood miti- gation but also offer ecological and societal benefits, such as creating recreational areas that foster community engagement. The findings and proposed strategies bring out the importance of integrating natural ecosystems into urban planning to reduce the impact of water-based disasters and promote resilient infras- tructure. This model can serve as a blueprint for other regions facing similar urban flooding challenges, ultimately reducing the strain on natural resources like water.

3.3.1. River Level Analysis

Known as the ”River of Sorrow, the Rapti River, originating from Rukumkot in the Mahabharata Range of Nepal at an elevation of 3,048 meters, spans a total length of 25,793 square kilometres, with 56% of its area lying in Uttar Pradesh. Characterised as a meandering river, the Rapti has an active channel width of 206 meters and a net eroded area of 21.80 square kilo- metres, which is not severe in Gorakhpur. The river features the Rapti Barrage, which is 756 meters long, and the Ban Ganga Barrage, which is 385 meters long. The average discharge of water, or volume of water flowing per unit time for the Rapti, is calculated to be 136 cubic meters per second (4,800 cubic feet per second). At the city level, multiple factors exacerbate overflow issues at the floodplain level. Firstly, the discharge of a substantial 97.34 MLD of untreated wastewater from nine sewerage drains directly into the river significantly contributes to contamination and volume increase. Secondly, the presence of a 5000-meter non-continuous concretised embankment on the right bank of the Rapti River disrupts natural water flow and exacerbates flooding. Additionally, the widespread prac- tice of landfill dumping, amounting to an estimated 598 TDP of Municipal Solid Waste per day, further impedes water absorp- tion capacity. Moreover, encroachment, encompassing approximately 10% of the floodplain area, including structures like crematory grounds, exacerbates the issue, reducing the natural floodplain buffer and altering drainage patterns. This analysis highlights the significant hydrological features and challenges associated with the Rapti River. There, effectively addressing these multifaceted challenges is not just essential for managing floods and preserving the environment but it is also for safeguarding public health, sustaining ecosystems, and fos- tering resilient communities. By implementing comprehensive strategies that tackle wastewater discharge, embankment issues, waste management, and encroachment, we can mitigate flood risks and promote sustainable development along river systems.

3.3.2. Catchment Level Analysis

The population in the catchment area is noted to be 2575, with a total catchment area of 2.18 square kilometres. The poten- tial runoff in the catchment area is calculated using the ratio- nal method, resulting in a total peak discharge of 8,197 cfs (or 231,987 cubic meters per second). Regarding land use-land cover, as per MPD 2031, only 1.35% out of 17.5% is developed in favour of the proposed land use for recreational and open space. The proposal in Draft Master Plan 2031 suggests the util- isation of Rapti River Bank as a recreational zone, encouraging river bank development along the bank, allocating only 19.84% of land use for the total recreational and open spaces. However, there is no clear demarcation of the flood plains of Rapti in this Master Plan. Additionally, the soil in the area is characterised as fine silty soil that retains water well, with groundwater levels ranging from 2 to 5 meters below ground level (mbgl), further complicating efforts to capture flood water.

3.3.3. Wetlands Level Analysis

The Oxbow wetland accommodates a catchment population of 3575. The water bodies cover an area of 2.17 square kilometres, with a maximum depth of 2.6 meters, providing a water stor- age volume of 702,000.6 cubic meters. The wetland primarily sources water from rainfall and catchment runoff, with a total water demand of 487,625 litres per capita per day (lpcd). Solid waste generation stands at 1072.50 kilograms, while wastew- ater generation is estimated at 118,100.00 lpcd, mainly from domestic sources. The wetland faces pollution from domes- tic waste, with 9.25% of the built-up area within a 100-meter buffer zone. Water quality indicators reveal concerns regard- ing total coliform organisms, pH levels, dissolved oxygen, and biochemical oxygen demand, indicating a poor ecosystem sta- tus. Identified ecosystem services include provisional, regulating, cultural, and supporting functions, culminating in a total ecosystem service score of 9, indicating a poor condition. Further assessment reveals a water spread area of one hectare, with fluctuating water seasonality and occurrence intensities.

4. Discussion

The study on nature-based wetland management for flood mit- igation in Gorakhpur highlights the potential of urban wetlands to address the escalating flood problems in Gorakhpur city due to rapid urbanization and climate change. The findings empha- sise the need for innovative, sustainable solutions that leverage

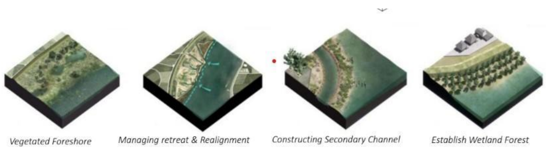

Figure 7: Floodplain Level Interventions

the ecological functions of wetlands. This discussion elaborates on the research outcomes up to the wetland level analysis, proposing strategic interventions at the floodplain, catchment, and policy levels to enhance flood resilience while providing environmental, social, and economic benefits. However, it is important to note that the city focuses on interventions at the city level and along the riverbank of Gorakhpur. Nevertheless, there is still a need for a joint effort from players in both the upper and lower catchment areas of the Rapti River Basin.

4.1. Floodplain Level Interventions

To enhance the flood resilience of floodplain areas, various environmental, social and economic strategies can be implemented.

4.1.1. Environmental Strategies

Expanding the floodplain area using nature-based solutions by removing obstructions and restoring natural landscapes can sig- nificantly enhance flood storage capacity, creating more room for water during peak flows as shown in Figure. 7. Establish- ing a 30-meter riparian buffer zone along waterways acts as a natural barrier, slowing down water flow, promoting groundwa- ter recharge, and reducing flood risks. Additionally, integrat- ing urban drains with sewage treatment plants (STPs) prevents the direct discharge of domestic wastewater into water bodies, thereby improving water quality and further mitigating flood risks.

4.1.2. Social and economic strategies

Developing multi-functional recreational spaces, such as water squares, serves a dual purpose by storing excess rainwa- ter and providing community recreational areas, enhancing urban resilience and offering social benefits. Similarly, promoting sustainable agricultural practices in floodplain areas, like rice plantations, helps manage water levels effectively. This approach not only mitigates flood risks but also provides economic benefits to local farmers, fostering a symbiotic relationship between environmental management and agricultural productivity. These strategies collectively contribute to sustainable urban development and climate adaptation.

4.2. Catchment Level Interventions

To increase water availability and enhance flood mitigation within the catchment areas, several innovative environmental strategies and community-led activities can be implemented.

4.2.1. Environmental Strategies

Constructing flow channels within wetlands is essential for pre- venting water stagnation and enhancing water storage capac- ity, thereby improving overall wetland health and functional- ity. Additionally, constructed wetland systems play a role in naturally treating wastewater, which not only improves water quality but also increases water availability for various uses. Utilising bio-soil technology for decentralised wastewater treat- ment further complements these efforts by efficiently managing sewage at the local level. This reduces the burden on central wastewater systems and helps prevent water-logging, contribut- ing to a more sustainable and resilient water management in- frastructure.

4.2.2. Social and economic strategies

Assessing the economic value of wetlands highlights their im- portance, providing a compelling case for investment in their preservation and restoration. This valuation highlights the mul- tifaceted benefits wetlands offer, from ecosystem services to flood mitigation. Simultaneously, implementing flood-resilient agricultural practices is essential for protecting crops and ensur- ing food security for local populations. These practices enhance the adaptability of agriculture to changing environmental condi- tions, safeguarding livelihoods and contributing to sustainable development. Together, these strategies promote ecological bal- ance and community resilience.

4.3. Policy Level Interventions

Effective policy interventions are essential for the sustainable management of wetlands and the overall mitigation of flood risks. Developing a comprehensive Wetland Management Mas- ter Plan for Gorakhpur, utilising the Wetland Management As- sessment Toolkit developed by NIUA, ensures coordinated and effective interventions, promoting long-term ecological sustain- ability. Incorporating flexible standardisation in land use plan- ning, with dedicated zones for floodplains, wetlands, and water bodies, protects these critical areas and promotes their sustain- able use. Additionally, integrating sub-watershed planning into the city's master plan enhances water efficiency and resilience, addressing the city's unique hydrological challenges. Imple- menting mandatory Water Sensitive Urban Design (WSUD) norms further mitigates flooding and fosters sustainable water management, creating a more resilient urban environment.

Urban planning should incorporate wetland management to en- sure the protection and sustainable use of these ecosystems. Co- ordinating wetland planning with river basin management can enhance the overall resilience of water systems while imple- menting nature-based solutions strengthens the city's resilience to flooding and other climate-related challenges. Raising pub- lic and stakeholder awareness about the benefits of wetlands encourages community participation and support for conserva- tion efforts. Advocating for stringent regulations ensures sus- tainable wetland conservation and prevents harmful activities. Additionally, collaborating with stakeholders across the water- shed, both upstream and downstream, enhances the effective- ness of flood mitigation strategies. By adopting nature-based solutions and implementing strategic interventions at the flood- plain, catchment, and policy levels, the city can boost its flood resilience while also gaining environmental, social, and eco- nomic advantages. The recommended strategies offer a com- prehensive framework for sustainable urban development, un- derscoring the crucial role of wetlands in promoting urban re- silience and maintaining ecological balance.

5. Conclusion

In conclusion, the integration of wetland management into urban planning is crucial due to the direct correlation between wetland degradation and increased flooding risks. When wetlands lose their capacity to absorb and retain excess water, urban areas become significantly more vulnerable to flooding events. The research conducted on the Rapti riverine wetlands demonstrates that well-managed wetlands can significantly reduce this susceptibility by maintaining their natural hydrological functions. This study highlights the effectiveness of nature-based interventions at the sub-watershed level, such as expand- ing floodplain areas, establishing riparian buffers, and connect- ing urban drains to sewage treatment plants. These strategies not only help in flood mitigation but also improve water quality and promote biodiversity, showcasing the multifaceted benefits of preserving and restoring wetlands. The findings from the Rapti wetlands case study provide a compelling argument for incorporating wetland conservation into urban planning to en- hance flood resilience and promote sustainable urban develop- ment. This research emphasises that strategic wetland manage- ment should be a cornerstone of urban planning efforts, particu- larly in regions prone to flooding. By adopting a watershed ap- proach that integrates wetland management with other land-use practices, cities can create more resilient and sustainable urban landscapes. Furthermore, raising public and stakeholder aware- ness about the benefits of wetlands is essential for garnering support for conservation initiatives. The exploration of Rapti riverine wetlands serves as a tangible example of the positive impact that strategic wetland management and nature-based interventions can achieve in mitigating floods. By emphasising these approaches, urban planners and stakeholders can proactively manage wetlands to enhance resilience against flooding and ensure sustainable urban development. The study proposes a methodological framework to assess the urban Wetland planning at the city level. However, it is important to acknowledge the limitations of this study. Each context and type of wetland is unique, and what works for the Rapti riverine wetlands may not be directly applicable to other wetland systems. Factors such as local climate, hydrology, soil types, and existing land-use practices can significantly influence the effectiveness of wet- land management strategies. Additionally, the specific flora and fauna of each wetland play crucial roles in maintaining its ecological balance and resilience, which need further investi- gation to develop tailored management plans. Effective imple- mentation also necessitates coordinated efforts among various upper river catchments, lower river catchments and other allied stakeholders. Additionally, the methods used rely on traditional methods alongside these nature-based solutions for optimal re- sults. Future research should focus on these contextual differ- ences and conduct comprehensive studies on various wetland types to formulate universally applicable guidelines. Moreover, long-term monitoring is essential to understand the full impact of these interventions on both flood mitigation and ecosystem health. Addressing these limitations will ensure that wetland management practices are more broadly effective and sustain- able across different regions.

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Conflict of Interest

The authors declare no conflict of interest.

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