HARNESSING NATURE: INTEGRATED MANAGEMENT FOR URBAN FLOOD MITIGATION USING NATURE-BASED SOLUTIONS IN EAST KOLKATA WETLANDS, INDIA

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June, 2024

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ABSTRACT

Wetlands serve as the most valuable ecosystem services in the world. The East Kolkata wetlands are no exception regarding the varied services they provide to the city. The city's population of 4.5 million residents generates almost 1.1 m3 of wastewater, which is channelled towards the east Kolkata wetlands due to the natural slope of the city from west to east. This wetland ecosystem recycles 50% of the wastewater received in the ponds of the wetland ecosystem. The rate of urban expansion throughout the globe has been alarming and the development of paved surfaces starkly contrasts with the ecosystem services. The increase in hard and impervious surfaces adversely affects the infiltration capacity of the wetlands by shrinking them in size, aggravating problems such as urban flooding. Urban floods are often concomitant to the reduction of urban greens and reckless exploitation of valuable ecosystem services such as wetlands and natural water bodies.

The urban expansion of the metropolitan city of Kolkata has resulted in the planning of urban areas in Rajarhat in east Kolkata, where two urban centres named Salt Lake and Newtown have attracted people from various parts of the state and the country, providing employment opportunities and increasing demand for land. The further expansion of the concrete landscape has had detrimental effects on the ecological services that were once available in these areas. The city Salt Lake derived its name because the area where it is located at present was a conglomerate of multiple saltwater lakes in a saucer-shaped low-lying area. In the 1960s, the growing need to provide housing for Kolkata's teeming middle-class population gave birth to the planned city, which was built over the saline water bodies by filling them with a mixture of sand and mud obtained from the river Ganga. Since then, the urban area has been sensitive to precipitation, resulting in urban floods.

The countries in the global north have started to adopt "Nature-based Solutions" (NbS) as a panacea to tackle wicked problems in urban areas, such as waterlogging. These solutions work synergically with nature and provide urban flood mitigation measures that do not have any adverse effect on the natural environment. This study tries to delve into the different possibilities of mitigating urban floods in the areas surrounding the east Kolkata wetlands, which is a Ramsar convention site and should be immune to urban development. The study identifies specific target areas that are highly susceptible to flooding by NbS measures, which can help in reducing the intensity of urban floods and possibly mitigating them in the long run. The target areas identified by a systematic Spatial Multicriteria Analysis (SMCA) have been recommended area-specific NbS measures like bioswales, rain gardens, community gardens, rainwater harvesting channels, and the like. Besides recommending these measures, the study also takes into account the needs of the local citizens. It fosters discussions at administrative levels regarding the feasibility of integration of NbS into the spatial planning and flood mitigation schemes of the Bidhannagar Municipality, East Kolkata Wetland Management Authority, and the Newtown Kolkata Development Authority (NKDA).

The study found that the rapid increase in paved impervious surfaces is the prime factor increasing the likelihood of urban flooding in the study area, which can potentially be dealt with by NbS. Effective flood mitigation can be realized by developing area-specific nature-based solutions, which need not be the same in all cases, depending on the socio-economic and physical potential of the areas. Furthermore, the study also proposed implementing measures that complement the engineering solutions and can reduce urban runoff and inundation, fostering future research on the development of existing NbS in the study area for urban flood management.

Keywords: Wetland ecosystem, Urban expansion, nature-based solutions, impervious surface, urban floods, urban flood mitigation, urban flood management, spatial planning.

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"Educate and raise the masses, and thus alone a nation is possible"- Swami Vivekananda.

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1. INTRODUCTION

1.1. Background and Justification

Urbanization is a global phenomenon occurring at a pace that is making policymakers think of ways to prevent the negative consequences it has on ecological services. 2050 is the milestone year when 68% of the global population is estimated to be living in urban areas, 90% of this growth will predominantly be from the Global South (United Nations, 2022). The growing urban population also demands land for housing. This, in turn, poses a pressure and grave threat to the natural environment. A key ecological service offered by the natural environment is the wetlands, one of the key ecological services provided by nature, helping sustain biodiversity and ecological equilibrium(Roy-Basu et al., 2020). Besides providing a habitable environment for marine life and sustaining riparian vegetation, wetlands also decarbonize urban areas and act as sinks, filtering wastewater and preventing floods in urban areas. Wetlands have an immense potential to treat organic waste and replenish groundwater resources (Roy-Basu et al., 2020). However, wetlands, while being the valuable assets of nature, have lost their existence by more than 50% worldwide solely due to the detrimental effects of urbanization (Dasgupta et al., 2013; Mondal et al. et al., 2022; Paul et al. 2021). The present century has brought with itself an immense conversion of 30 million km^2 of wetlands to impervious, manmade surfaces, in which the last 20 years have contributed to a 6% decline in wetlands (Faso et al., 2002; Mondal et al., 2022).

The consequences of shrinkage of porous surfaces lead to critical problems like urban flooding, loss of biodiversity and non-renewal of the groundwater. This can directly impact the environment and the lives of the people.

According to several studies, urban expansion and the loss of natural landscapes increase the vulnerability of urban expansion-induced urban flooding. In the present decade, the problem of urban flooding has become a more serious concern in many cities(Bassi et al., 2014; Ghosh et al., 2023; Ghosh & Das, 2020; Mondal et al., 2017; Mondal et al., 2022).The process of shrinkage of valuable natural land is anticipated to be widespread even in future due to the growing demand of land shrinkage of valuable natural land is anticipated to be widespread even in the eats posed by urban floods has already been implemented in the global north, encouraging the recovery of the lost natural landscapes (Kabisch et al., 2016). Initiatives of Nature-based solutions (NbS), such as green roofs, green walls, and pollinator planting, have yielded promising results in Liverpool, UK, and many other cities in the European Union (Mell et al., 2023).

The effects of urban expansion are felt worldwide, mostly in developing countries such as India. India is home to 17.76% of the world's population, where a small plot of urban land can determine the livelihood of a user (worldometer, 2023). The metropolitan region of Kolkata, the capital of the Indian state of West Bengal, has also witnessed substantial urban growth in the past years (Mondal et al., 2022). A part of this population has also been contributed by political events such as the partition of Bengal in the decade of 1960s and 70s, when West Bengal witnessed a huge inflow of refugees from Bangladesh, creating acute stress on the housing infrastructure of the Kolkata City (Rumbach, 2011). Besides this factor, rural-to-urban migration is also a major contributing factor to the growing population and land demand in urban areas. The urban development which was undertaken thereon had been at the cost of natural resources by converting them into paved impervious surfaces. Kolkata has a population of 15.5 million (World Population Review), making it India's third most populous city (Chakraborty et al., 2021). Increasing population pressure and demand for scarce urban land resources lead to the Geographical expansion of metropolitan areas, encroaching on areas of ecological significance.

Nature-based Solutions (NbS) is a relatively new term introduced in 2015 in the scientific publication of (Eggermont et al., 2015), where the term was first used to refer to an environmental planning measure. Nature-based solutions are defined by the European Union (2019) as cost-effective actions inspired and supported by nature to address several social, economic, and environmental challenges sustainably (Hawxwell Tom et al., 2019). Before nature-based solutions became a flagship term promulgated by the European Commission, different stakeholders used to refer to this planning policy using other terms like green infrastructure, sustainable infrastructure, blue-green infrastructure, eco-engineering, etc. (Eggermont et al., 2015). NbS emerged as a research policy in the documents of the European Green Deal, addressing critical societal and environmental challenges (European Union, 2019). Despite being promoted as a policy concept in Europe, NbS continues to be highly relevant in countries worldwide, including tropical countries like India. The loss of natural resources and the use of technical flood mitigation methods by the government and local authorities still undervalue the diverse benefits that NbS can offer to solve environmental and societal problems, such as decarbonization and vulnerability reduction.

Since its initiation, NbS has been widely studied worldwide for various purposes, such as addressing societal issues such as biodiversity loss, climate change, disaster risk reduction, and resilience. NbS also advocates promoting a green economy by providing societal and environmental benefits by caring for economic growth. However, these activities are primarily concentrated in European countries and some parts of America (Kabisch et al., 2016). The nations in the global north have implemented solutions like green roofs and walls, planting exotic fast-growing grasses, and permeable pavements, which are gaining popularity worldwide (Kabisch et al., 2016).

NbS provides several co-benefits that synergically work with nature. Chausson et al., (2020), in their publication, mention the effectiveness of NbS applications in different parts of the world, starting from Greenhouse gas (GHG) emission reduction, ecological restoration, and biodiversity enhancement. The current state-of-the-art engineering solutions can be complemented with NbS to achieve effective results for local problems such as urban floods and landslides (Raymond et al., 2017). However, NbS has significant research and knowledge gaps that must be considered. Determining an appropriate time scale for implementing and successfully operating NbS is one of the prime gaps (Kabisch et al., 2016). Considering all the pros and cons of the concept, appropriate area-based measures need to be pointed out in a collective way. For choosing the right NbS for an area, stakeholder participation is of great importance (Daniere et al., 2022). This research aims to highlight how different stakeholders envision the potential implementation of NbS in East Kolkata for flood mitigation (Ratnam & Owuor, 2020) . These insights from stakeholders shall help identify the opportunities and barriers to NbS applicability in the study area. This will help in thinking in an innovative way by putting the 'one-cap-fits-all' notion aside (Woroniecki et al., 2023).

1.2. Research Problem

. Shrinkage of wetlands, urban expansion, and consequent urban flooding are significant problems in countries worldwide (Mondal et al., 2022). In the developing and underdeveloped countries of Asia, the problem is more pressing. Urban flooding is, for instance, a common problem faced by most prominent cities in India, like Mumbai, Kolkata, Delhi, Chennai, Bangalore, and so on (Dasgupta et al., 2013; De et al., 2013). These cities, being in coastal areas or the catchment area of major rivers, receive high precipitation and are prone to urban floods. However, NbS has not yet gained much predominance in the planning system, which is still mainly dominated by conventional measures and engineering infrastructure construction (Banerjee, 2018; Bhattacharya et al., 2012; Gupta & Singh, 2017). For instance, the measures taken for flood mitigation in the city of Kolkata and its urban agglomerations are limited to traditional methods like construction and maintenance of log gates, de-siltation of rivers, lakes, and canals to increase their capacity during monsoons, making new drains, underground sewage channels, cleaning the drainage

systems which get clogged due to inefficient solid waste disposal systems and other factors (Dasgupta et al., 2013). These measures are often inefficiently undertaken due to the lack of dialogue between the different hierarchical departments working autonomously.
The extant papers discussing urban flood reduction with NbS have a finite scope to address the challenge (Raymond et al., 2017). Nature-based solutions, being manmade/artificially introduced infrastructures made with technical or engineering techniques, can help tackle the severe problem of urban flooding but can never surpass the efficiency of ecological services provided by the natural environments. For the areas of Salt Lake and New Town, the Kestopur and Bagjola Canals play a crucial role in drainage. However, they are often choked and unable to handle heavy rainfall, inundating the surrounding areas (Rumbach, 2014). Salt Lake's development pushed urbanization towards the hazard-prone low-lying land without proper planning of the drainage or flood mitigation. This exclusionary approach has led to urban floods in these areas (Mitra & Banerji, 2018a; Rumbach, 2011). The master plans have also overlooked the need to conserve the valuable east Kolkata wetlands, which led to rampant growth of built-up around these riparian areas. In some places the natural flow of water towards the wetlands has been restricted by concrete barriers.
The city planning culture in India is dominated by Master Plans (Baud et al., 2014). The master plans are often stringent in nature, with pre-defined zones delineating land cover, following which cities are planned. In the case of cities like Salt Lake and New Town, the situation is the same. Generally, the reality seldom aligns with the plan in certain aspects due to multiple factors (Tošković, 1964). Spatial planning has a significant role in urban flooding (its causes) and mitigation (Makita, 2020). The existing urban flood reduction and mitigation measures taken by the government are insufficient to prevent urban floods, which have become more frequent in recent decades (Dasgupta et al., 2013; De et al., 2013).
The existing studies on NbS dwell at great length upon the holistic approach of the concept to tackle issues like urban floods, mainly in geographic regions such as Europe, followed by America (Kabisch et al., 2016). However, research on NbS applications in the global south is also gaining momentum (Asare et al., 2023; Daniere et al., 2022; Ratnam & Owuor, 2020; Torres et al., 2023; Woroniecki et al., 2023).

This research focuses on *why* urban floods are occurring in cities like Salt Lake and Newtown, *where* in these cities can NbS be applied, *what* are the best-suited NbS services that can be provided in the areas having the most impact by floods, *how* can NbS find a place in the existing spatial plans for flood mitigation with respect to land ownership. These solutions will be provided based on area-based requirements, such as bioswales, permeable pavements, rainwater harvesting systems, percolation pits, etc., with the involvement of citizens and stakeholders. This research also aims to assess the feasibility and potential of nature-based solutions to be implemented with eastern Kolkata's existing flood mitigation schemes. Incorporation of the stakeholder's perspective plays a key role in the solution stage of the research. The participation of stakeholders will aid in understanding the dialogue between different sectors and envisioning the key requirements for future urban development with NbS. Besides this, a critical reflection on which NbS are needed to compensate for the reduced functionality of the wetlands will be discussed with different stakeholders. Adequate urban flood mitigation strategies will then be provided based on the outcomes of the surveying and interview process.
Frameworks to assess the existence of NbS in municipal plans by developing frameworks are being undertaken by researchers by involving stakeholders and local citizens (Daniere et al., 2022). Despite the ongoing research in this field, significant knowledge gaps remain (Seddon et al., 2020). Among these gaps, identification of the barriers and costs involved in NbS implementation, roadmaps for future research and collaboration, and assessment of the effectiveness of NbS are some of the prime ones (European Union, 2019; Frantzeskaki et al., 2019; Viti et al., 2022).

This research aims to address these gaps and explore the potential of NbS as a possible flood mitigation strategy in the cities surrounding the East Kolkata wetlands, which are losing all their greens (Banerjee, 2018).

1.3. Research Objectives and Questions

1.3.1. General Objective

This research aims to assess "the potential realization of" area specific NbS to reduce the impacts of urban floods due to the depletion of wetlands in east Kolkata, incorporating the perspectives of stakeholders.

1.3.2. Sub-objectives and Questions

1. To determine the relationship between urban expansion and urban flooding.

a. How and to what extent has East Kolkata Wetlands' land cover changed in the last two decades (2001-2021)?
b. Is there a relationship between urban expansion (impervious surface development), rainfall, change in slope and shrinkage of wetlands, and urban flooding?
c. What is the frequency of flood events from 2001 to 2021 (Hazard patterns)?

2. To explore the suitable NbS measures for the identified target areas based on their socio-physical characteristics.

Questions related to the characterization of the target areas.

a. Which areas can be fit for NbS measures with regard to their physical characteristics?
b. What are the land use and ownership characteristics of the target areas? (to identify the areas fit for NbS)
c. What are the existing NbS measures in the study area?
d. Which NbS measures shall be appropriate in the target areas to reduce the impact of urban floods?

3. To investigate the awareness of the study area's stakeholders of NbS and their willingness to invest in NbS.

a. What are the existing NbS measures (if any) taken by the government/local governing bodies and why they are taken? (Awareness)
b. To what extent are the residents of the study area aware of Nature-based solutions?
c. What is the perspective of the governing bodies regarding integrating NbS in existing spatial plans (perceived benefits and drawbacks)? (Willingness)
d. How much are the residents willing to invest in Nature based solutions?

4. To assess the effectiveness, feasibility, benefits and drawbacks of NbS for flood mitigation in the East Kolkata Wetland region.

a. How do the governing bodies perceive the effectiveness and feasibility of implementing NbS in flood-prone areas?
b. What are the potential benefits and drawbacks of implementing NbS in east Kolkata, and how do they compare to conventional flood management strategies?
c. What are the key factors influencing the adoption and acceptance of NbS among stakeholders in the context of urban flood management?

1.3.3. Hypothesis

The expansion of urban areas in the East Kolkata wetland region is gradually shrinking the wetlands and their infiltration capacity, consequently leading to urban flooding. The flood-affected parts of the urban area need area-specific NbS measures to mitigate urban floods, which will be suggested based on the inputs of the stakeholders.

1.4. Contribution to the Research Problem

The present research contributes knowledge that can inform urban flood management by addressing urban flood challenges through nature-based solutions in several ways, starting from the identification of knowledge gaps to providing practical solutions. The research expands the geographical focus of the concept of nature-based solutions, which are mostly popular in the countries of the Global North. (Kabisch et al., 2016; Raymond et al., 2017; Seddon et al., 2020). By focusing on the context of urban areas in Eastern Kolkata experiencing heightened flood issues, the research addresses significant global challenges related to urbanization and environmental degradation(Kabisch et al., 2016). The research identifies the existing knowledge gaps in NbS implementation, including the identification of barriers (Raymond et al., 2017; Seddon et al., 2020; Viti et al., 2022). The study's emphasis on involving stakeholders and local communities can generate knowledge that NbS solutions can be tailored to meet the specific needs and contexts of the affected populations, enhancing their effectiveness and acceptance (Frantzeskaki et al., 2019). Through a comprehensive assessment of NbS interventions and exploring possibilities of their integration into existing spatial plans, the research suggests practical solutions for mitigating or impacting the reduction of urban floods in areas like the East Kolkata wetlands facing ecological degradation, taking stakeholder's perspectives into account (Kalantari et al., 2021).

1.5. Thesis Structure

The thesis work is divided into six chapters, comprising the introduction (Chapter 1), dwelling on the problem, research gaps, objectives of the research, and contribution of the research to the problem. Chapter 2 consists of the literature review of the main concepts of the research, such as urban expansion, wetland shrinkage, urban floods, nature-based solutions and their integration into spatial planning. Chapter 3 Highlights the study area's further description, research design and strategy, materials and methods of data collection and analysis, and ethical considerations and contingencies. Chapter 4 delves deep into the results obtained from the analysis and answers each research question. Chapter 5 presents an interpretation and discussion of the analysis, which deals at great length with the results, research findings and limitations. The final chapter (Chapter 6) deals with the conclusions obtained from the study and the recommendations and future roadmap for further research.

2. LITERATURE REVIEW

This chapter of the research deals with a concise explanation of the key concepts associated with the study. It elucidates the link between the development of impervious surfaces and the occurrence of urban floods in the East Kolkata Wetland region. Each concept is introduced systematically, particularly emphasising Nature-based Solutions (NbS) as a viable mitigation measure for urban floods. Besides reflecting upon the existing urban flood management practices in the study area, the research also elaborates on concepts such as spatial planning and integrated flood management.

2.1. Urban Expansion

Urban expansion refers to the process of spatial growth and development of urban areas, often characterized by the outward extension of built-up areas into previously underdeveloped or rural land (Chakraborty & Banerji, 2016; Pfeffer, 2023). This phenomenon is driven by factors such as population growth, economic development, and infrastructure expansion (Angel et al., 2005; Mondal et al., 2017). As cities expand, they encroach upon surrounding natural landscapes and agricultural land, changing their ecological structure, functions, and land use patterns(Jiao et al., 2021).

Rapid urban expansion can also result in the occupation of wetlands and other flood-prone areas, increasing the vulnerability of populations to flood hazards (Mandarino et al., 2023). This process of physical growth of the city often converts the previously underdeveloped areas into urban areas. Urban expansion also happens by depleting or completely covering natural waterscapes. This is a commonly observed scenario in Kolkata (Chakraborty & Banerji, 2016). Natural landscapes, including wetlands, are often a part of this conversion.

2.2. Wetlands and their Shrinkage

Wetlands are vital ecological resources that recycle wastewater and infiltrate it (Paul et al., 2021). They are swampy tracts of land, maintaining the groundwater table by recharging it and balancing the hydrological equilibrium of the area. Urban expansion leads to the degradation of these natural ecosystems, having a negative impact on biodiversity and the riparian ecosystem, which is also a thriving ground for marine life (Mitra & Banerji, 2018b). This shrinkage leads to alteration of landscapes, change in land use, and encroachment upon the natural belts, posing a challenge to sustainable land use planning and flood risk management. Urban expansion often drives wetland shrinkage as urban areas expand into previously untouched wetland territories, leading to habitat loss, fragmentation, and degradation (Dey, 2018). Wetland shrinkage refers to the reduction in the extent and size of the wetland area, often attributed to human activities. Although natural causes like droughts also play a role, they are seldom observed. (Dey, 2018). East Kolkata wetlands, recognized as a valuable wetland resource and tagged as a Ramsar site, are rich in natural waterbodies, where canals bring wastewater from the metropolitan city of Kolkata, thus enabling them to receive it and naturally recycle it. The natural freshwater resources of the area are diminishing due to encroachment and construction activities, aggravating pluvial flooding (Chakraborty & Banerji, 2016). This intersection of processes highlights the complex relationship between urbanization and wetland dynamics.

2.3. Impervious surface development

Hard/impervious surface development involves constructing and implementing rigid, non-permeable surfaces in urban and architectural contexts. These surfaces include concrete, asphalt, and paving stones for roads, sidewalks, buildings, and other urban infrastructure (Ghosh & Das, 2019).

The concept of impervious surface development is integral to urban planning and design. As it dictates the spatial organization and functionality of built environments. This approach contrasts with the other softer alternatives like green infrastructure and nature-based solutions, prioritising natural elements such as vegetation and permeable surfaces to enhance sustainability and ecological resilience (Hawxwell Tom et al., 2019). Developing impervious surfaces poses challenges like stormwater runoff and the urban heat island effect. However, due to impervious surfaces' durability, ease of maintenance and cost-effectiveness, they are quite popular in urban environments (Ramachandra et al., 2014).

2.4. Urban Floods

Urban floods refer to flooding events within urban areas, often resulting from heavy rainfall, inadequate drainage systems, and urbanization processes (Mandarino et al., 2023). The concept of urban floods underscores the complex interplay of various factors, including land use, hydrology, infrastructure, and climate change (Sumi et al., 2022).

Such floods pose significant disruptions to daily life, leading to blocked roads, transportation challenges, economic damages, and threats to public safety. Cities are particularly vulnerable to floods due to their high population density, concentration of assets, and proximity to rivers and coastal areas (Arinabo, 2022). Understanding urban floods involves analyzing contextual factors such as urban development patterns, drainage capacity, and climate conditions. Addressing urban flooding requires comprehensive strategies that integrate land use planning, stormwater management, and infrastructure improvements. Enhancing urban flood resilience involves mitigating flood risks, building adaptive capacity, and promoting sustainable urban development (Sumi et al., 2022).

Urban flooding can be either fluvial, pluvial, or a combination. Fluvial flooding occurs when all natural water bodies, like rivers, lakes, and ponds, overflow their banks due to heavy rainfall. It leads to prolonged inundation and poses significant threats to communities living in flood-prone areas (Chen et al., 2010). Pluvial flooding is typically known as surface water flooding (waterlogging), resulting from intense rainfall that overwhelms the drainage infrastructure and causes water accumulation in a short duration. Pluvial flooding is more localized than fluvial flooding but can significantly impact urban areas with inadequate drainage infrastructure, hampering smooth mobility and other urban functions (Andrikopoulou, 2020; Chen et al., 2010). The metropolitan areas surrounding the East Kolkata wetlands experience pluvial flooding due to the natural slope of the city from west to east, automatically channelling the runoff waters towards the East Kolkata wetlands. The concretisation of these natural sponges is leading to an aggravating problem of pluvial flooding in the area (Mitra & Banerji, 2016).

2.5. Changing Hazard Patterns

In the wake of climate change, the hazard patterns have been altered. Lately, the world has witnessed irregular patterns of hazards. These consist of increased frequency and intensity of extreme weather conditions. Warmer temperatures across the Indian subcontinent have intensified the water cycle, resulting in increased strengths of the low-pressure systems developing over the landmass. This leads to heavier rainfall and increased flood risk in many regions. The intensity of tropical storms has also been amplified in the country, resulting in more destructive storm surges and record precipitation rates (Ghosh et al., 2023; Singh et al., 2021). Understanding the nature of these changing hazards is crucial for effective climate adaptation and urban flood mitigation. Often, the marginalized sections of society are the ones who are worst hit by these natural hazards (Singh et al., 2021).

2.6. Nature-Based Solutions (NbS)

Nature-based solutions, according to the EuropeanUnion, (2019) p.5, are "*solutions that are inspired or supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience.*"

Nature-based solutions encompass strategies that utilize natural processes and ecosystems to address various societal and environmental challenges (Daniere et al., 2022). They often complement or serve as alternatives to "grey infrastructure" solutions, which typically involve man-made structures like concrete infrastructures (buildings, dams, barriers, etc.) (Chausson et al., 2020).

NbS ensures strives for sustainable management, restoration, and protection of ecosystems to provide benefits such as climate change mitigation, urban flood mitigation, biodiversity conservation and improved water quality in urban areas. Nature-based solutions like bioswales and rain gardens have immense potential to mitigate the problem of pluvial urban flooding. These solutions harness the inherent resilience and adaptive capacity of NbS to foster societal well-being and environmental sustainability (Eggermont et al., 2015).

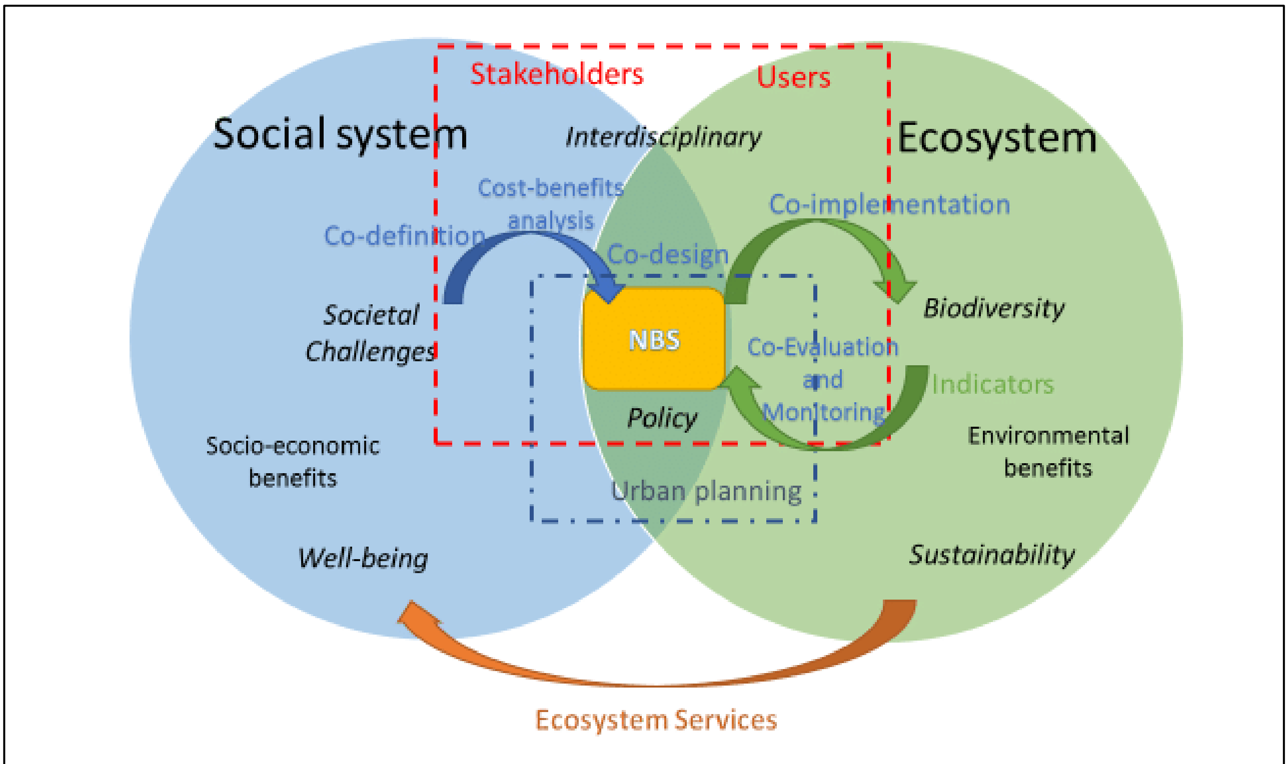


Figure 1 Conceptual understanding of Nature-based solutions. Source:(Ferreira et al., 2020)

2.7. Nature-Based Solutions typology

Interventions based on nature-based solutions are suitable for areas with different socio-physical characteristics. The interventions provided in this study primarily address the prevalent problem of waterlogging in the study area. These solutions go synergically with nature and provide cost-effective solutions complementing engineering solutions. Nature-based solutions have three typologies (Eggermont et al., 2015).

NbS type-1 primarily deals with interventions related to the capacity enhancement of existing waterbodies/ blue spaces, such as streams, brooks, lakes, ponds, etc, enhancing the existing capacity of the available green and blue spaces.
NbS type-2 deals with the upgradation or modification of existing green spaces such as parks, gardens, farms, community green areas and open spaces, ensuring sustainable practices in agriculture and allied sectors, prioritising nature.
NbS type-3 mainly explains the innovations introduced in a particular area. Typical examples of these solutions are rooftop gardens, green roofs, rain gardens, and community gardens. These nature-based solutions are man-made and are highly dependent on stakeholder engagement.
These typologies are often interrelated to each other, contributing to the enhancement of urban greenery. They involve effective planning and co-creation among the different stakeholders. A detailed insight into these typologies has been provided in Fig.2 below.

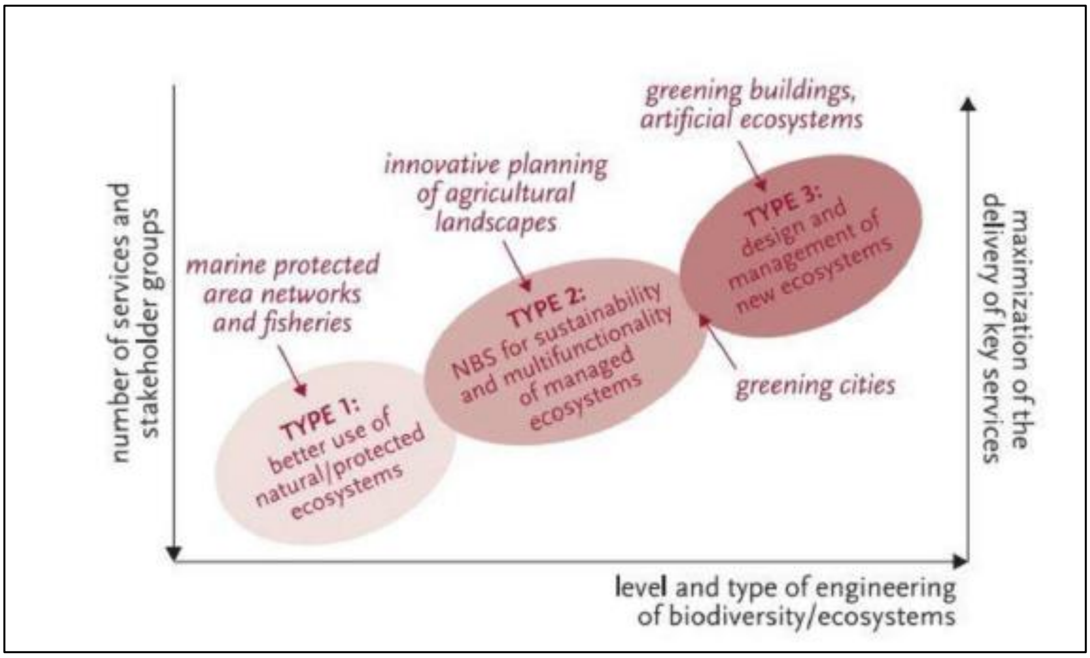


Figure 2 Nature based Solution Typologies, Source: (Eggermont et al., 2015).

To localize these interventions, area-specific maps have been made for all the target areas identified in the research.

2.8. Nature-based Solutions for Urban Flood Mitigation

Nature-based solutions are sustainable solutions recognized as cost-effective interventions for urban flood mitigation. Nbs offer several benefits to urban landscapes, starting from stormwater management and providing biodiversity and ecosystem services. This enhances a city's urban planning, fostering ecological resilience and mitigating the adverse effects of urban flooding (European Union, 2019).
The Urban expansion of Rajarhat Salt Lake and Newtown has had detrimental effects on the riparian vegetation nurtured by the East-Kolkata wetlands. The protection of the existing expanse of wetlands and implementing Nature-based solutions will play a pivotal role in maintaining the environmental equilibrium and mitigating urban floods (Tanana Valley Watershed Association, 2008).
The dense growth of indigenous plant species in and around the marshes will stabilise the soil, preventing erosion due to runoff, and also act as natural sponges absorbing excess flood water and enhancing the infiltrating capacity of these wetlands, which are known as the kidneys of Kolkata city. NbS being a natural flood mitigation measure not only protects the environment, but also aids in protecting the vulnerable

communities and marginalized sections of the society by generating income and employment opportunities. Besides these advantages, NbS also reduces the burden on the critical infrastructure by reducing the intensity of flooding. NbS acts as a sink, infiltrating the sediments, pollutants and nutrients carried by the flood water. This research aims to promote context-specific nature-based solutions, sustainable flood management in the area, and resilience by advocating for the restoration and conservation of riparian zones in high-risk flood areas of East Kolkata Wetlands.

2.8.1. Bioswales

Bioswales are public green spaces aiding in stormwater management by reducing runoff and subsequent flooding. Bioswales are man-made nature-based solutions that gently slope sides filled with vegetation such as grasses, shrubs, and trees (Fig.3). The vegetation helps absorb and filter pollutants carried by stormwater, improving water quality. The bioswales' porous soil and deep plant roots also facilitate water infiltration, reducing the runoff volume and mitigating flood risks. The porous soil of the bioswales does not allow water to stay stagnant for more than 24 hours, preventing risks of vector-borne diseases in the surrounding areas (Pathak et al., 2022).

Bioswales have several benefits, including effectively managing stormwater, improving water quality through natural filtration, and recharging groundwater. Bioswales also contribute to the aesthetic appeal of the urban environment, enriching its biodiversity and providing habitat for wildlife. Bioswales can be classified as Type-3 Nature-based solutions, which involve the participation of stakeholders, including the local government (Eggermont et al., 2015).

Bioswales represent a promising solution for sustainable urban flood mitigation, which is cost-efficient and does not require high maintenance, except for watering the vegetation in summer months when rainfall is less than usual. Integrating nature-based solutions like bioswales in urban infrastructure can significantly contribute to flood mitigation, water quality improvement, groundwater recharge and create resilient and liveable cities (Asare et al., 2023).

Figure 3 An example of a bioswale. Source: (Blankenship,2015)

2.8.2. Rain Gardens

Rain gardens are sustainable (rain-fed) stormwater management systems designed to capture, absorb, and filter runoff water from impervious surfaces like rooftops, roads, and sidewalks. Rain gardens are characterised by shallow depressions with indigenous vegetation resistant to wet and dry conditions (Zhang et al., 2020).

Rainwater is temporarily stored as it flows into the garden, allowing sedimentation and settling down of pollutants, while the plants absorb the excess water and nutrients brought by the rainwater (Fig.4). This natural filtration process helps improve water quality, reduce erosion, mitigate urban flooding, and recharge groundwater (Pathak et al., 2022). Besides these benefits, rain gardens enhance biodiversity and improve urban aesthetic beauty. Rain gardens are a mixture of sand, compost, and native soil, which helps with water infiltration and prevents erosion (Fig.5). Rain gardens effectively retain moisture and provide organic material for the vegetation, immunising the soil's health (Rain Gardens for Soil Health, n.d.; Zhang et al., 2020).

Figure 4: An example of a Rain garden. Source: (US EPA, 2015)

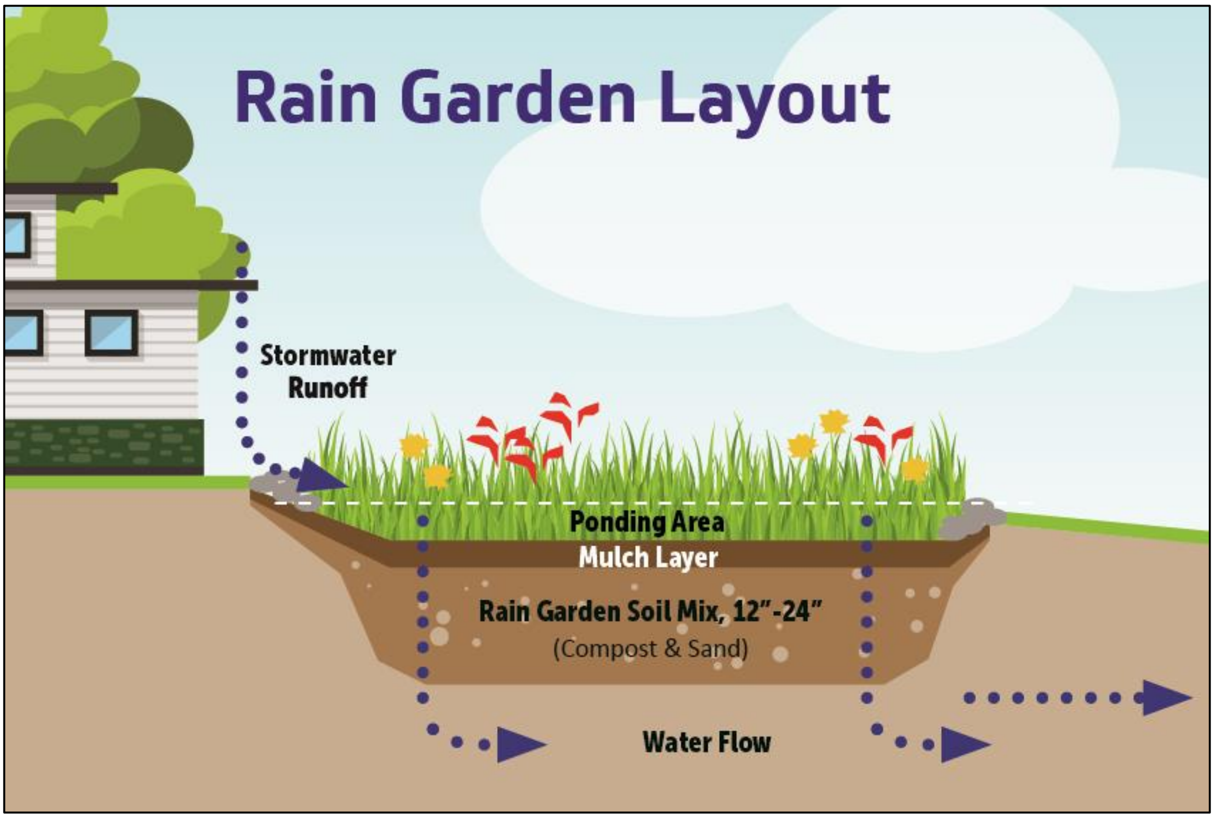


Figure 5 Layout of a rain garden. Source: (Staff,2022)

2.8.3. Balcony Garden

Urban flooding poses significant challenges in densely populated areas. Innovative solutions like balcony gardens in areas dominated by built-up areas can have an impact on reduction of urban floods. Though a bit unusual, the concept of balcony gardens is promising in small-scale interventions. While all traditional flood mitigation techniques often focus on large-scale infrastructure projects, balcony gardens are nature-based solutions complementing their bigger counterparts. Acting as mini green spaces in urban environments, balcony gardens absorb rainwater directly, preventing them from flowing as runoff and overwhelming the drainage capacity. By incorporating permeable materials in the vegetation, balcony gardens facilitate infiltration into the soil and retain moisture (Qin, 2020).

Another strong benefit of the balcony gardens is community engagement and awareness. All communities can jointly get involved in these flood resilience initiatives by creating and maintaining these gardens. This fosters a sense of collective ownership and responsibility for dealing with the problem of urban flooding. Incorporating greenery also helps in regulating temperature in urban landscapes, and implementing balcony gardens can contribute to green infrastructure development in urban landscapes. By harnessing the potential of balcony gardens, it is possible to diversify urban flood mitigation measures (Pathak et al., 2022; Qin, 2020).

Figure 6: (*Left*) Balcony Garden. Source: (The,2023) (*Right*) Balcony Barrel. Source: (Spargo,2017)

2.8.4. Rooftop Garden

Rooftop gardens, which have also been implemented as green roofs (dominated by grass) in the current decade in many cities of the global north, are a sustainable nature-based solution for mitigating urban floods. Rooftop gardens effectively absorb rainwater and help retain stormwater, reducing runoff volume during heavy rainfall events. Nature-based interventions like rooftop gardens allow rainwater to infiltrate into the soil, retarding the rate at which the rainwater enters the drains and alleviates the pressure on drainage systems. Besides reducing the surface temperature of the buildings and the surrounding areas, rooftop gardens also reduce the risk of flash floods (Qin, 2020).

The vegetation on the roofs acts as an interception for the rainwater, reducing the amount of water reaching the ground and ending up being runoff. The integration of rooftop gardens in urban areas can reduce the amount of water entering directly into the drainage system and improve the resilience of the local area, reducing the impact of urban floods and mitigating them in the long term (Pathak et al., 2022).

Figure 7: An example of rooftop garden. Source: (Dubbeling et al., n.d.)

2.8.5. Street trees

Street trees also play a crucial role in urban flood mitigation by interception of rainwater and reducing runoff. Street trees often complement "grey surfaces", which are impervious. These nature-based solutions help in enhancing soil permeability and act as natural sponges to infiltrate the accumulated rainwater. The canopy of street trees helps intercept rainwater, minimizing surface runoff and erosion. Additionally, their far-reaching roots help improve soil structure and bind the soil (Pathak et al., 2022). The overall impact of street trees in urban flood mitigation is significant when integrated into planning strategies for dealing with intense heat and heavy rainfall. However, the effectiveness of street trees greatly varies depending on factors such as species selection, planting density and maintenance of the existing street trees (Kumar et al., 2021).

Figure 8: Example of street trees as seen in the field. Source: Author, (2024)

2.8.6. Community Garden

Community gardens are effective nature-based solutions that absorb excess rainwater and reduce runoff. The cultivation of vegetation such as trees, shrubs, and grass in the community gardens enhances the permeability of the soil, allowing infiltration and preventing the accumulation of water on impermeable surfaces. Increased vegetation in the gardens intercepts stormwater and reduces the water flow into the drainage systems (Pathak et al., 2022).

This type of nature-based solution also aids in carbon sequestration and improves soil quality, facilitating groundwater recharge. Besides their implications in urban flood mitigation, community gardens promote self-help urbanism and encourage community participation in maintaining these common plantations, reducing the burden on the government to execute flood mitigation solutions (Hawxwell et al., 2019).

Figure 9: Community Garden. Source: Author, (2024)

2.8.7. Rainwater harvesting

Rainwater harvesting profoundly impacts the alleviation of pressure from the drainage systems during heavy rainfall. It is an easy-to-implement and economical solution that can vary from small- to large-scale rainwater harvesting projects. Varying from an individual household to community rainwater harvesting projects, this nature-based solution is all-round for using rainwater for potable and non-potable purposes (Campisano et al., 2017).

Rainwater harvesting systems can collect rainwater from rooftops, pavements, and other surfaces, diverting it to storage tanks to underground reservoirs for future use of recharging groundwater by infiltration. The augmented use of rainwater for non-potable uses such as irrigation, reduced use of municipal water, lower dependence on groundwater, etc, can save gallons of water from draining out as runoff. This harvesting of rainwater has the highest potential to mitigate urban floods (Amos et al., 2021; Campisano et al., 2017; Dhoble, 2006).

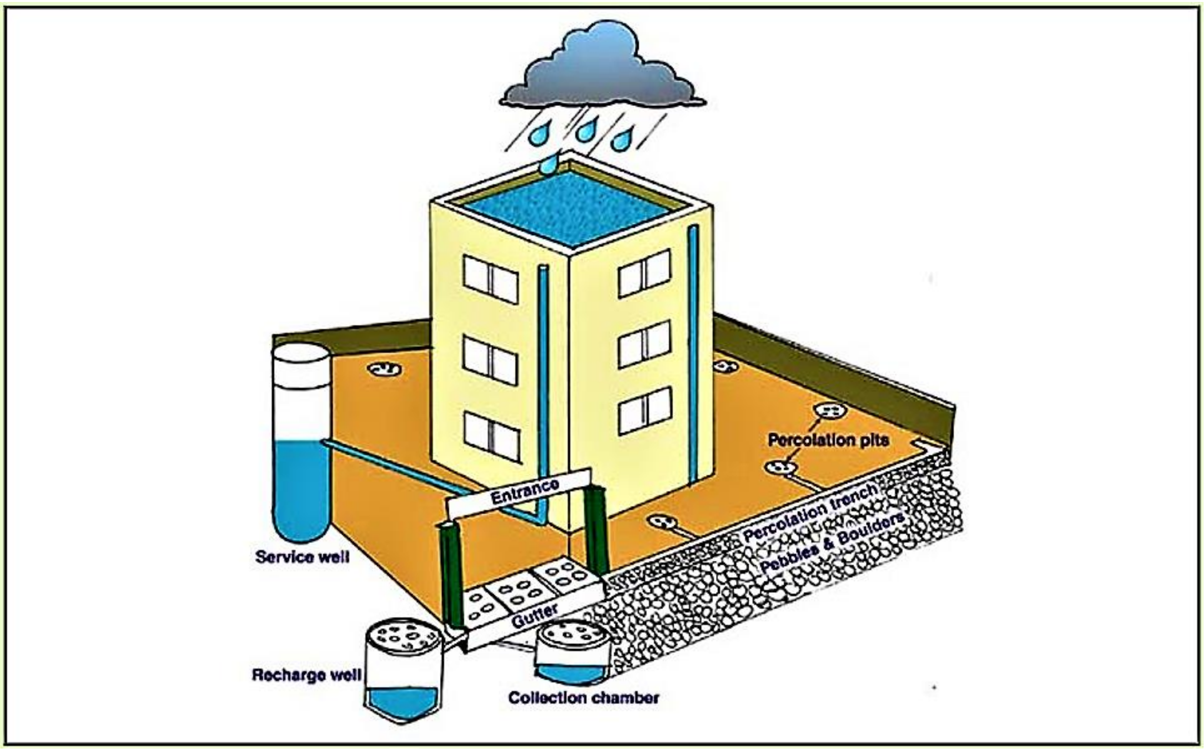


Figure 10: Example of a rainwater harvesting system. Source: (Gupta et al., 2015)

2.8.8 Porous Pavement

Porous Pavements are integral components of low-impact development strategies for urban areas. These cost-effective measures prevent complete concretisation and impervious development of urban sidewalks, parking spaces and common areas used by pedestrians. This also applies to areas in front of offices or residential buildings, often characterized by fully paved courtyards (Pathak et al., 2022).

Porous pavements allow water to infiltrate through the surface into underlying layers and decrease runoff volume during heavy rainfall. Porous pavements can be an effective solution for preventing urban pluvial flooding/ water logging in urban areas. Furthermore, porous pavements also contribute to sustainable stormwater management, aligning with nature-based solutions for urban flood mitigation and resilience (Asare, 2021).

Figure 11: Example of a Porous pavement. Source: (Wikipedia,2024)

2.8.9 Percolation Pits

Percolation pits are very simple and efficient interventions to collect rainwater and facilitate groundwater recharge. Percolation pits are trenches dug in the ground, not larger than 60 x 60 cm, covered by an iron cover or a concrete slab. They are easy to maintain and must occasionally be filled with river sand and pebbles. Small green spaces can easily accommodate many of these pits, significantly contributing to infiltration and reducing urban flooding (Dhoble , 2006).

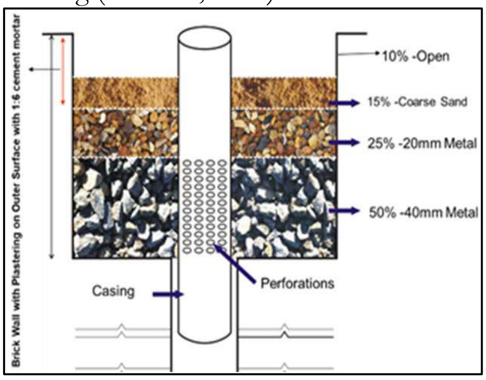


Figure 12: Percolation Pit. Source: (Swamy,2019)

2.9. Relation between different NbS measures

The different NbS measures mentioned in this chapter can be used together to mitigate urban floods in east Kolkata.

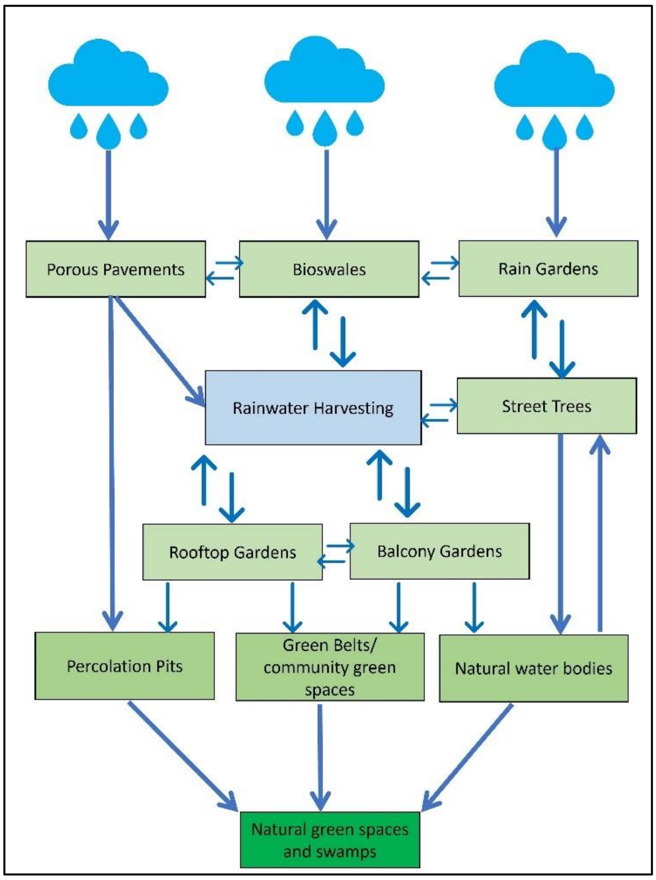


Figure 12: Interconnectivity between different NbS Interventions. Source: Author, (2024)

Fig.13 shows the interconnectivity between different NbS interventions obtained from literature (Amos et al., 2020; Andrikopoulou, 2020; Campisano et al., 2017; Daniere et al., 2022; Dhoble, 2006; Pathak et al., 2022). A porous pavement, bioswale, or a rain garden can aid in rainwater harvesting, besides infiltration. Rainwater can also be harvested from balcony gardens and rooftops. The harvested rainwater can then be used for the maintenance of the greens. Excess water will flow into percolation pits, green belts, and natural water bodies, which directly contribute to the water slowly finding its way to the natural green spaces and wetlands, ensuring a healthy ecosystem and biodiversity. Implementing a combination of NbS interventions can make the infrastructure significantly self-sustainable and be an economical and feasible choice for the committees or governing bodies.

2.10. The Concept of Spatial Planning

Spatial planning involves systematically organising and allocating land, infrastructure, and resources within a geographical area to achieve specific goals and address various societal needs and challenges (Campbell, 2016). According to Ran & Nedovic-Budic (2016), spatial planning encompasses the coordination of different demands and interests on land, considering factors such as economic development, environmental conservation, social equity and disaster risk reduction (Greiving & Fleischhauer, 2006). The goals of spatial planning are to maximize the use of available space, encourage sustainable development, and strengthen community resilience to various hazards, such as flooding(Ran & Nedovic-Budic, 2016). To direct land use decisions, infrastructure development, and urban growth in a coherent and sustainable manner, policies, regulations, and strategies must be developed (Howe et al., 2010). Cities can improve their flood resistance and lessen the adverse effects of inundation events by combining spatial planning and flood risk management. When it comes to spatial planning in the context of the global south countries, the plans are highly influenced by the spatial plans incorporated in the global north, specifically the European and North American countries (Asare et al., 2023; Eggermont et al., 2015).

2.11. Integration of NbS with spatial planning

Spatial planning is a rational and systematic approach to guiding public and private actions in urban areas. These plans have an influence on future outcomes, and they are accountable for alternative solutions to the problems that result (Ran & Nedovic-Budic, 2016). Reckless urban expansion has seriously impacted the valuable ecological services, which are the biggest environmental assets of these regions. In planning and governance, flooding is a common problem encountered by almost every Indian coastal city (Mitra & Banerji, 2018).

Several practical obstacles impede the application of modern flood mitigation techniques, like nature-based solutions. One of the prime reasons for this is the insufficiency of dialogue between the different governing bodies. In most hierarchical governments, governing bodies are unaware of the initiatives taken by the other departments or the local governments. Inadequate communication and population pressure in urban areas result in the construction of impervious structures that cover natural water bodies or wetlands, disrupting the hydrological equilibrium of the area. In East Kolkata, the spatial planning structure is characterized by a decentralized and autonomous mechanism. This involves multiple governing bodies, each with specific roles. These governing bodies are the Nabadiganta Industrial Township Authority (NDITA), the New Town Kolkata Development Authority (NKDA), the West Bengal Housing Infrastructure Development Authority (WBHIDCO), and the Bidhannagar Municipality. NDITA oversees industrial townships in Salt Lake City, ensuring infrastructure development and civic amenities, including drinking water. NKDA looks after the development of New Town, focusing on land acquisition and essential services. WBHIDCO handles the housing and infrastructure projects in the entire East Kolkata, while Bidhannagar Municipality ensures urban development in Salt Lake aligns with the overarching broader metropolitan strategies (Roy-Basu et al., 2020). The development of impervious surfaces in the past decades cannot be undone and has severe consequences like waterlogging and land subsidence. Illegal encroachment into the wetlands and other natural areas is also sometimes unmonitored, leading to shrinkage and depletion of valuable natural resources (Chakraborty & Banerji, 2016; Mitra & Banerji, 2016).

While decentralization allows tailored solutions at a local level and faster decision-making, the lack of dialogue between these bodies hampers effective urban flood management, which is a common problem for all urban clusters. Leveraging the common roles of the governing bodies and integrating nature-based solutions with spatial plans, which will be flexible and multifunctional considering the local variabilities of urban environments, the problem of urban flooding can be mitigated, or the impact can be largely reduced (Quagliolo et al., 2023; Ran & Nedovic-Budic, 2016).

2.12. Urban Flood Management in the East Kolkata Wetlands

The East Kolkata Wetlands (EKW) play a crucial role in urban flood management through their natural ecosystem services. Acting as a natural sponge, absorbing excess rainfall runoff and mitigating urban floods by regulating water flow, the wetlands have saved the city of Kolkata since its origination. Besides carbon sequestration, the EKW also acts as a flood buffer, storing excess rainwater during extreme rainfall events. The wetlands are managed and governed by stringent regulations ensuring their protection against urban sprawl and degradation. The local government has taken many engineering initiatives to control urban floods in the adjacent areas of Salt Lake and Rajarhat Newtown by increasing the capacity of the old pumping stations and making new pumping stations with enhanced technology (Mitra & Banerji, 2016). The engineering initiatives also include occasional dredging of the canals and waterbodies and making concrete embankments around the canals, to prevent inundation. The canals and clogged drains are the major causes of urban floods in these areas with heavy rainfall (Mukherjee et al., 2019).

2.13. Conceptual Framework

The major concepts dealt with in this research are described in the previous sections (introduction and literature review). The conceptual framework (Fig.14) illustrates the relationship between the different concepts and NbS. It also consists of the basic questions about why, where, what and how.

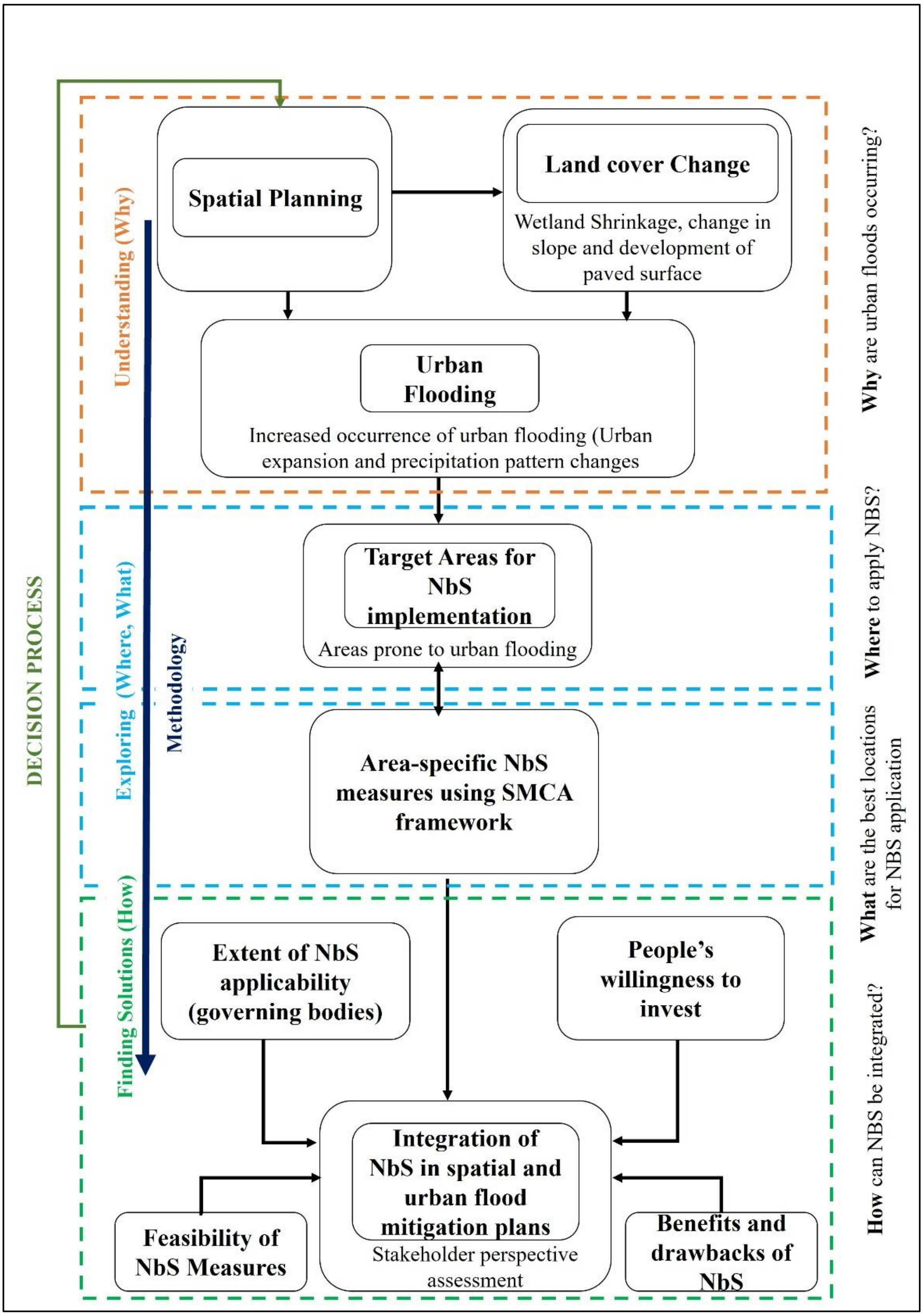


Figure 13: Conceptual Framework of the research

3. RESEARCH DESIGN AND METHODS

This chapter elaborates on the research design and the methodology that has been followed to achieve the results pertaining to the research questions. After describing the locational setting of the study areas, this chapter delved deep into the research design, followed by the methodology. The sub-sections below have also covered the data sources and the type of data used for the different analyses.

3.1. Study Area

Kolkata's urban expansion has significantly impacted the East Kolkata Wetlands (EKW), a Ramsar site and one of the world's largest natural sewage treatment systems (Chakraborty et al., 2023). These wetlands are situated on the eastern edge of Kolkata. They reach the junction of the Vidyadhari and Matla rivers, acting as a basin that absorbs contaminants draining into it from the whole city. The east Kolkata wetlands are a protected area with a stretch of 125 km^2 and provide land for agriculture, sewage-fed fisheries (for recycling sewage water), horticulture, and aquaculture (Mondal et al., 2022c). The existence of the east Kolkata wetlands is being threatened by land encroachment for residential and commercial buildings as well as agriculture and aquaculture activities due to the expansion of Kolkata's metropolitan area. Uncontrolled urban expansion inversely affects the natural capacity of the wetlands to filter and recycle wastewater. This hinders the smooth flow of wastewater to the sewage-fed fisheries and eventually hampers the lifestyle and occupation patterns of the local inhabitants (Nadella & Sen, 2021). Adding to this problem, the southern part of Bengal has also been experiencing severe tropical cyclones in recent years, increasing the vulnerability of the area and making it more susceptible to urban flooding (NCRMP,2023).

The conversion in the land surface has significantly impacted the free flow of water and the natural infiltration of groundwater into the soil. The reckless runoff of rainwater is the major cause of pluvial urban flooding, affecting the Central Business District (CBD), Special Economic Zone (SEZ), and the IT Hub of Kolkata city which are located adjacent to the east Kolkata wetlands. The primary satellite cities of Kolkata viz. Salt Lake and Newtown are situated next to the East Kolkata wetlands. Kolkata's inner city has more than 4.5 million residents, generating 1.1 million m^3 of wastewater channelled towards the east Kolkata wetlands without treating it in the sewage treatment plants (STP). This water is recycled up to 50% by the ponds in the wetland ecosystem (Bunting et al., 2010). This flow of wastewater and the water level of the ponds in the east Kolkata wetlands are controlled by gates that regulate the flow and hold back water during the monsoons in order to prevent inundation in the area. The existing technical flood mitigation measures comprise seasonal dredging of the canals and other water bodies, making high embankments around the lakes and canals, and pumping out water by installing pumps out of the urban areas. These measures have not been highly successful in coping with the urban floods caused by the recent problem of frequent tropical cyclones and urban expansion (Ghosh & Das, 2020; Mondal et al., 2017). Hence, there is a need to introduce measures that can synergically work with the existing measures for impact reduction and mitigation of the problem.

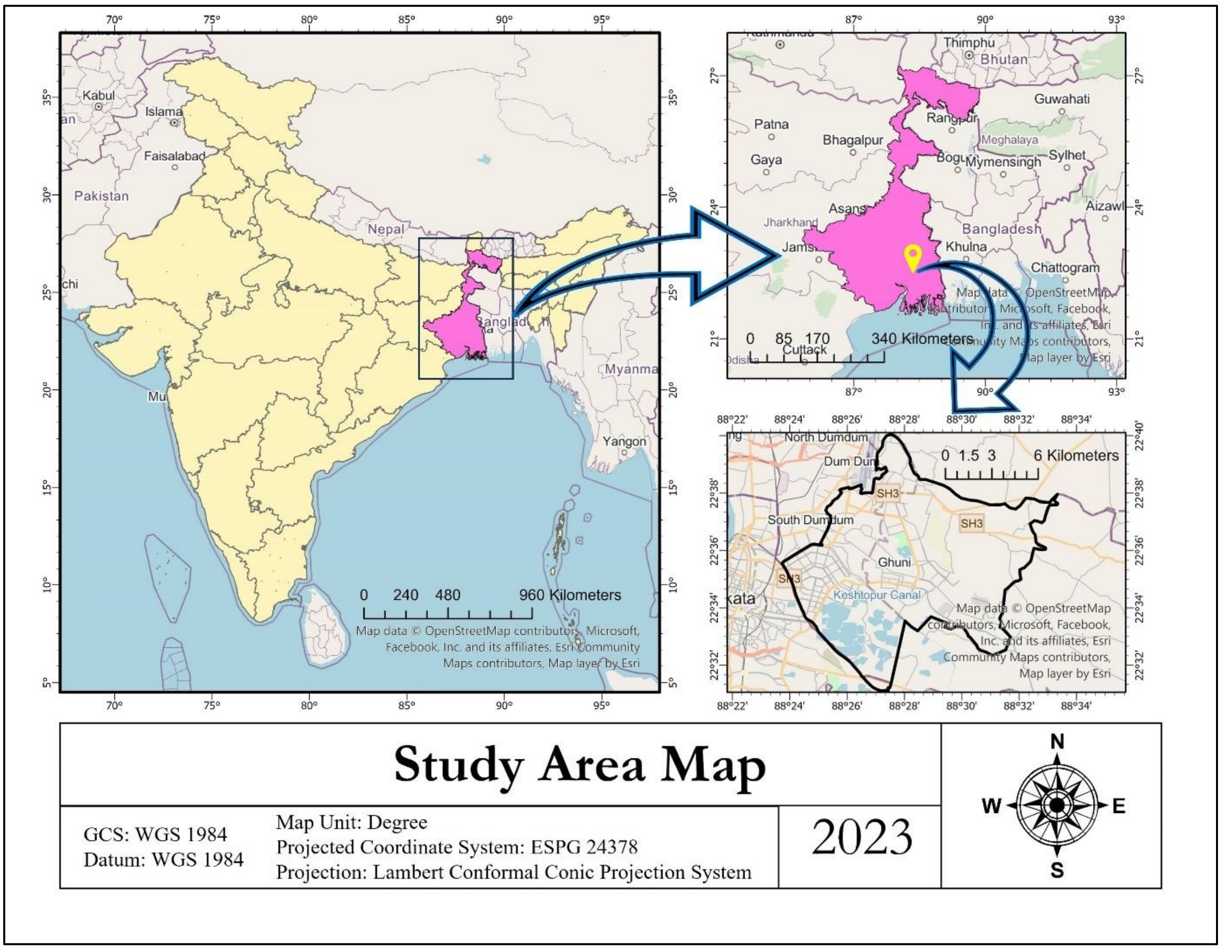


Figure 14: Map showing the location of the study area. Source: Author, (2023)

Located between 22 ˚25 ' N to 22 ˚40 ' N and 88 ˚20 ' E to 88 ˚35 ' E, The East Kolkata wetlands is a thriving wetland ecosystem spread across 125 km². The East Kolkata wetlands are popular as the 'kidney of Kolkata' due to their immense potential to filter wastewater generated from the city (Mondal et al., 2022). [Aw] (Sahana et al., 2022, p.131). Being situated on the lower deltaic plain of the Hooghly River, the region has a maritime influence, experiencing precipitation up to 2000mm and a temperature ranging from 10-42ºC. Due to an increased frequency of tropical cyclone occurrences, the study area has witnessed urban floods almost on an annual basis in the present decade, which hampers the smooth mobility of goods and services (Ghosh, 2023). For this research, the extent of the study area selected is 132.13 sq.km., which consists of the major fragment of the East Kolkata Wetlands, along with the two cities of Salt Lake, New Town and parts of Rajarhat, whose origin traces back to low lying wetlands currently most affected by urban expansion (Bhattacharya, 2021, 2023; Mondal et al., 2017). A map showing the locations of the three major urban areas, Rajarhat, Salt Lake and New Town, is provided below (Fig.16).

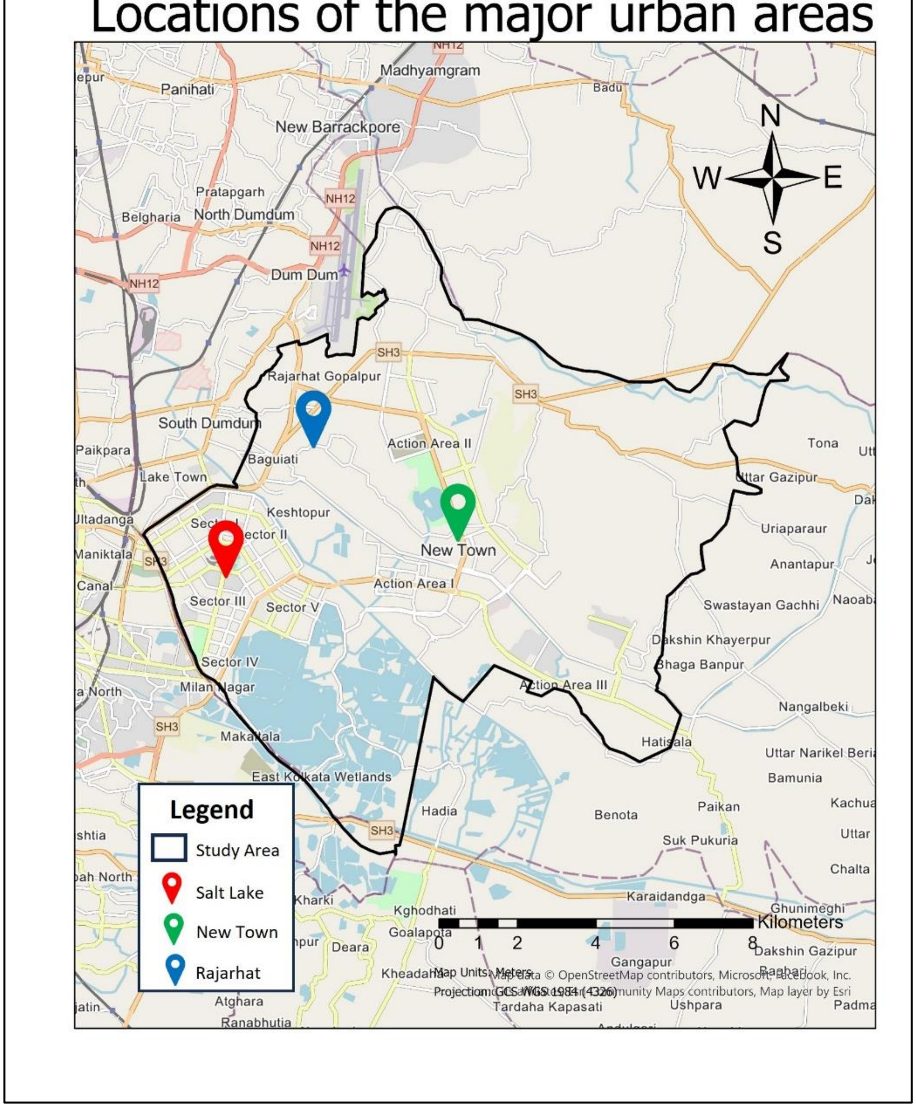


Figure 15: The location of Rajarhat, Salt Lake, and New Town is within the study area. Source: Author (2024)

The study area is intersected by different administrative boundaries, which comprise boundaries of the Airports Authority of India (AAI), The Bidhannagar Municipal Boundary and the boundaries of the North and South 24 Parganas, respectively. To reduce the complexity, the area of interest has been chosen for this study by aggregating the municipal boundary of Bidhannagar Municipality and the boundary of north 24 Parganas.

3.2. Research design and approach

The research is intended to investigate the relationship between urban expansion and shrinkage of the east Kolkata wetlands and suggest NbS measures to prevent urban flooding in the area caused by impervious surface development. A case study approach has been employed in this research to examine the specific challenges of urban flooding in the study area. This research blends spatial, qualitative, and quantitative data to provide an understanding of the efficacy and applicability of NbS in addressing urban floods. Spatial multi-criteria analysis (SMCA) has been conducted to identify suitable locations for implementing NbS interventions, integrating various factors such as physical features and socio-economic and ownership characteristics. Diverse data collection methods have been employed, encompassing field surveys and other methods to acquire primary and secondary datasets providing qualitative and quantitative information about the study area.

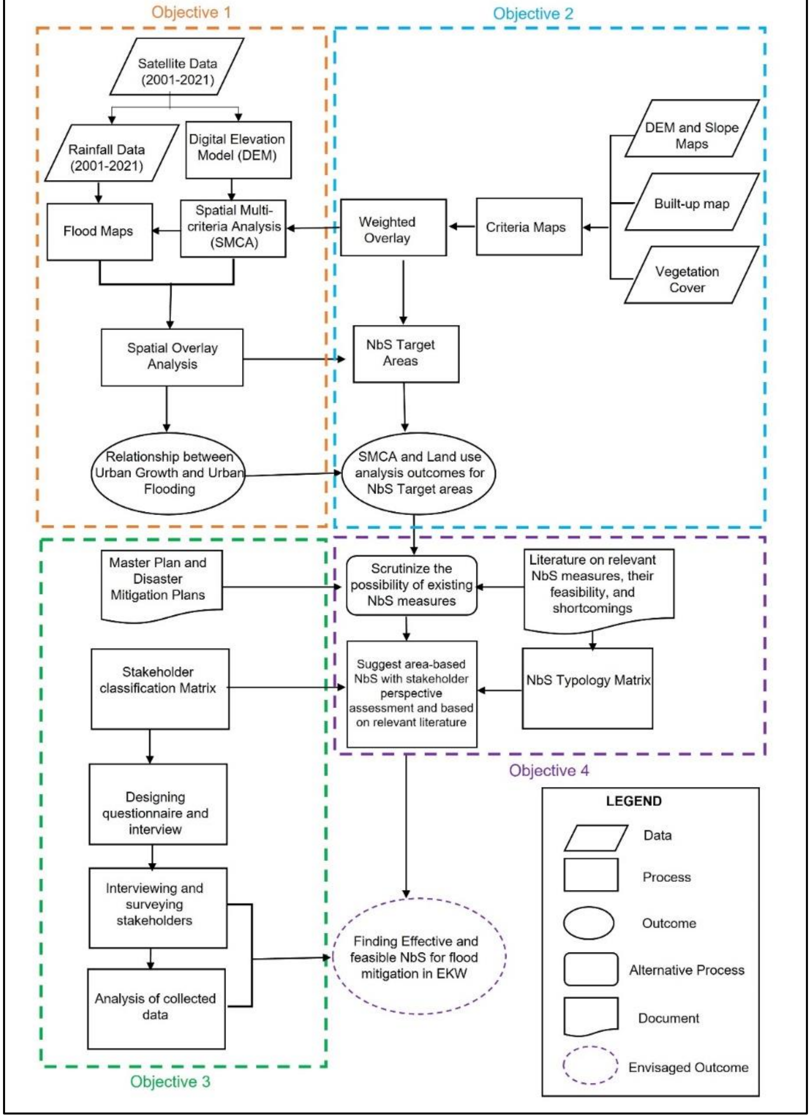


Figure 16: Methodological flowchart of the research. Source: Author (2024)

3.3. Data Sources

Primary and secondary data sources were combined to accomplish the research objectives. Primary data collection involved conducting surveys and semi-structured interviews to gather firsthand insights from respondents in the field. This primary data acquisition enabled the direct capture of relevant information pertinent to the study's focus on understanding the impact of urban expansion on the wetland ecosystem and the reasons behind urban flooding. The secondary data sources included satellite imageries from Landsat spanning the period from 2001 to 2021, obtained from USGS Earth Explorer. Rainfall data was sourced to provide a meteorological context, while a Shuttle Radar Topography Mission (SRTM) image of the study area was utilized to generate a digital elevation model (DEM) and a slope map. By integrating both primary and secondary data sets, the research has a comprehensive approach, combining firsthand observations with existing information to offer a nuanced understanding of the research topic. The primary data complements the secondary data by validating the results of the analyses with the facts obtained from the field. For instance, the locations of flood areas obtained from the questionnaires and interviews were geotagged on the SMCA map to validate them. This methodological blend facilitates analysis, enabling the exploration of multifaceted aspects and supporting informed conclusions. An overview of the data is provided in Table 1.

Table 1: Data used for the research.

Data Type	**Data Format**	**Year**	**Data Source**	**Purpose/ Rationale**
Landsat Images	Raster	2001-2021	USGS Earth Explorer	Land use-Landcover change analysis
Rainfall Data	Raster	2001-2021	Centre for Hydrometeorology and Remote Sensing https://chrsdata.eng.uci.edu/	Making Rainfall Maps (Precipitation pattern analysis)
SRTM	Raster	2001-2021	USGS Earth Explorer	To identify flood-prone areas based on their undulation by creating a DEM and using it to create a slope map and as an indicator in SMCA.
Flood management Document	text	2001-2021	Annual Flood Reports, Rainfall Statistics of India, West Bengal State Disaster Records, India Meteorological Department (IMD) rainfall and flood Reports and Newspaper Archives.	To gain insight into the rainfall patterns and past flood events.
Existing knowledge	Text	After 2010	Scientific Literature	Scopus, web of science, etc.
Built-up Surface	Raster	2020	Global Human Settlements	Indicator for SMCA
Proximity to surface waterbodies	Vector	2023	Open Street Maps	Indicator for SMCA
Land Cover Map	Raster	2001-2021	Landsat Images	Indicator for SMCA
DEM	Raster	2001-2021	SRTM Data	Indicator for SMCA
Vegetation Cover	Raster	2001-2021	TanDEM-X	Indicator for SMCA
Transcription and Audio recordings	Text and audio	Primary Data (fieldwork)	Stakeholders and key informants	Understanding the awareness, willingness, feasibility, benefits and drawbacks of NbS. Suggesting appropriate area specific Nbs interventions.

3.4. Data Collection

Primary data used in the study were collected from the field using two data collection methods, namely, the general questionnaire and the semi-structured interviews. The secondary data used in the study along with their formats and respective sources, have been represented in Table 1.

3.4.1. General Questionnaire

The general questionnaire used to gather data from the local residents consisted of questions aimed at gathering relevant information related to the people's experiences, perceptions, and concerns regarding urban flooding and nature-based solutions. The major components of the questionnaire were the demographic information (age groups) and aggregate locations. Enquiries about past experiences of waterlogging and the inundation sources were included as counterparts of the previous section. Following this, the perceptions of the residents regarding NbS were analyzed with queries regarding their awareness, attitudes and opinions regarding the effectiveness, feasibility and acceptability of NbS for urban flood mitigation. There were open-ended questions to solicit further ideas for NbS interventions. Lastly, the questionnaire comprised feedback about the survey and recommendations for improvement. The questionnaire can be found in *Annexe 3*. 102 local inhabitants took part in the survey and provided valuable information about the study area.

3.4.2. Semi-Structured interviews

The semi-structured interviews targeted key informants, including government officers, planners, researchers and policymakers. To gather in-depth insights and technical expertise related to urban flooding and NbS implementation.

The opening questions of the semi-structured interview were designed to establish rapport and familiarity with the interviewee, explaining the purpose and confidentiality of the interview. The subsequent questions delved into the professional background, knowledge, experience and expertise with NbS and flood mitigation. The second section of the interview dealt explicitly with the inquiries regarding the current NbS projects, challenges and successes. The semi-structured interview also opened up an arena for feedback and suggestions from field experts. A total of six key informants were identified for the detailed semi-structured interview. However, responses were obtained from four. The details of the 4 semi-structured interviews have been provided in Table 2. Due to time and availability, the other two interviewees could not appear for offline/online interview sessions. The interviewees were contacted by email with details about the research, the reason for the interviews, ethical aspects, and the duration of the interviews, complemented by a fieldwork cover letter provided by Faculty ITC. Based on the convenience and availability of the key informants, the meetings were conducted online (in MS Teams Work and School). Increasing the comprehensiveness of the research and gathering sensible data, the semi-structured interview was a great tool for primary data acquisition and analysis. The script of the semi-structured interview can be found in *Annex-3*.

Table 2: Information about the Institutions of the Key informants and the dates of interviews

Interviewee No.	Institution	Number of Interviewees	Date
1	Block Development Office (Rajarhat & Salt Lake)	1	12th March 2024
2	ERM Environmental Consultancy	1	17th March 2024
3	East Kolkata Wetland Management Authority	1	21st March 2024
4	Presidency University, Kolkata	1	06th March 2024

3.4.3. Sampling technique

In this study, a "purposive sampling technique" has been used. Purposive sampling involves selecting individuals or groups based on specific characteristics relevant to the research objectives, goals and context (Creswell, 2009). In this case, the stakeholders were chosen based on their expertise, involvement in flood mitigation activities, and geographical location within the EKW to obtain information about urban floods and discuss NbS interventions. The stakeholders are those who have a vested interest in the decision-making process or are impacted by the outcomes of the decisions and policies. Hence, the key informants and the local inhabitants are considered stakeholders in this case. The sample size was adequate to give the collected data significant depth and richness (Campbell et al., 2020; Valerio et al., 2016). According to study materials and literature, a sample size sufficiently large to reach saturation occurs when more data collection does not yield new findings or understandings (Creswell, 2009; Valerio et al., 2016). There is no universally recognized formula for determining the ideal sample size in purposive sampling. For this thesis, which has a limited time, the stakeholders have been classified into groups:

1) The key informants (the government officers, planners, researchers, policymakers, etc.) who have a level of technical expertise, knowledge and experience at the ground level and can provide reliable information that will enrich the data with authentic technical information.
2) The second stakeholder group is the residents of the study area, who are the people experiencing the floods. The inputs gathered from 1% of the total population of the total population (i.e.,1% of 1500000=15000) is not a feasible choice with the limited time and resources. Hence, a sample size with a diverse response that prevents bias has been undertaken.

When a certain level of saturation in the data was reached, the survey was analyzed. The saturation of the survey data was estimated by analysing the answers to certain questions present in the general questionnaire, like the source(s) of inundation, ownership of property, types of Nbs interventions (existing and suggested), etc. The collection of responses through the survey was stopped when not many new responses were obtained, and the general trend of responses was clear. These distinct groups of stakeholders were addressed using two distinct kinds of data collection methods: questionnaires and semi-structured interviews. The study area residents participated in the former, and the stakeholders with technical understanding participated in the latter. The stakeholders were classified based on their importance and influence using the stakeholder classification matrix (Boerboom, 2023) provided below.

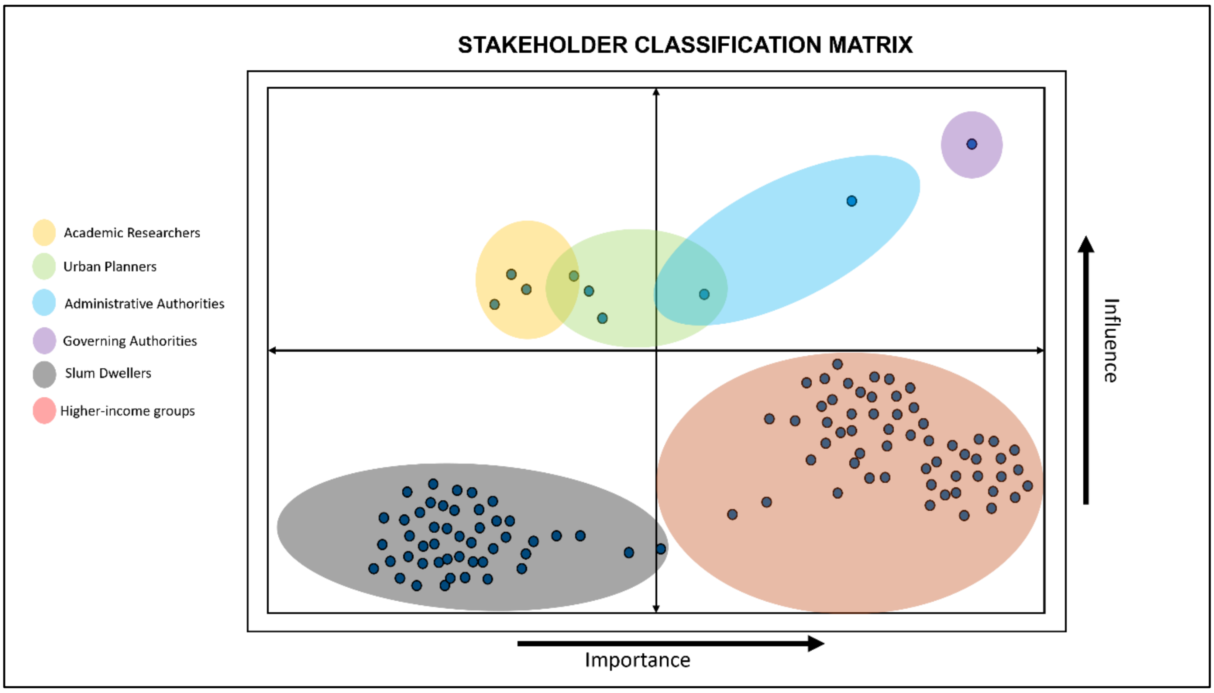


Figure 17: Stakeholder Classification Matrix. Source: Author, (2024)

3.5. Data Analysis Tools

This section deals with the methodology applied to answering the different research questions. To achieve this goal, both primary and secondary data obtained from the field have complemented each other. The Satellite images for the three years (2001,2010 and 2021) were obtained from USGS Earth Explorer. The month of the acquisition was kept the same for all three images to avoid biased results. After this, a land use/ land cover analysis was performed for the study period. This step was subsequently complemented by a change detection to quantify the area covered by built-up, vegetation and other distinct land cover classes. The process ends with visualising the flood-affected areas (obtained from the SMCA) and landcover change map and deriving a visual comparison between the two. The SMCA map was shown to the key informants, aiding in primary data collection. Appropriate NbS interventions were suggested based on the field data and outcomes from the literature.

The data analysis for the present study has been done using various methods and diverse tools. Methods of analysis differed based on the objectives and their aims. The SMCA was also used as a data analysis tool to aid in the identification of suitable areas for NbS implementation. This research stage was followed by the second objective, which delved into a deeper layer to explore suitable NbS measures and the appropriate locations that fit the same. Suggestions based on the fieldwork outcomes and relevant literature have been provided. The table provided below (Table 3) shows the research matrix.

Table 3: Research Matrix

Research Question	**Methodology**	**Data required**	**Software/tool**
***Sub-objective 1: To determine the relationship between urban growth and urban flooding*.**			
How and to what extent has the land cover (exposure) of East Kolkata	Land cover change analysis (Digital Image	Landsat images (2001-2021)	Arc GIS Pro, Arc Map 10.7, ENVI

Wetlands changed in the last two decades (2001-2021)?	Classification)		
Is there a relationship between urban expansion (impervious surface development), rainfall, change in slope and shrinkage of wetlands, and urban flooding?	Overlay Analysis of Land Cover Maps and Flood Maps	Land cover change, DEM, and rainfall maps	Arc GIS Pro, Arc GIS 10.7
What is the frequency of flood events from 2001 to 2021 (Hazard patterns)? (measure: Observed by the public authorities and registered in the information system) (remove the question from the questions)	Represent the major rainfall and cyclone events over the last 2 decades.	Rainfall data, SRTM Data for DEM, and Disaster records from the West Bengal Disaster Relief Plan (WBDRP)	Arc GIS Pro, Q GIS
Sub-objective 2: To explore the suitable NbS measures for the target areas based on their socio-physical characteristics.			
Which areas can be fit for NbS measures with regard to their physical characteristics?	Spatial multi-criteria analysis	DEM, water bodies, land cover analysis results, building height, population density, vegetation cover	Arc GIS Pro, Arc GIS 10.7. Q GIS
What are the land use and ownership characteristics of the target areas? (to identify the areas fit for NbS)	Land use analysis	Building type	Arc GIS Pro, Q GIS, Google Earth
According to the literature, what are the existing NbS measures that the area has?	Overlay analysis	SMCA and Land use analysis outcomes	Arc GIS Pro, Q GIS,
Which of the suitable NbS measures shall be appropriate in the target areas to reduce the impact of urban floods?	Literature review	SMCA and Relevant literature	
Sub-objective 3: To investigate the extent of NbS applicability by using a participatory planning approach.			
What are the existing NBS	Document review	Master Plans, flood	Atlas.ti

measures (if any) stated in the master plan/ flood		mitigation/ disaster mitigation plans	
Who are the information providers?	Designing a Stakeholder classification matrix	Participatory planning decision framework for stakeholder selection	Excel
What is the perspective of the stakeholders and the governing bodies regarding the integration of NbS in existing spatial plans (perceived benefits and drawbacks)?	Qualitative analysis	Primary Data	Microsoft Word, Atlas. ti
How to measure people's ownership of Nature-based solutions (priorities of stakeholders versus citizens' needs)	Online Questionnaire Survey and Qualitative analysis by integrated assessment method	Analysis of the citizen's responses as well as the interviews/ Discussion transcripts	Microsoft Word, Atlas.ti, Survey responses and Audio records
Sub-objective 4: To assess the effectiveness, feasibility, benefits and drawbacks of NbS urban flood mitigation in the EKW region.			
How do stakeholders perceive the effectiveness and feasibility of implementing NbS in flood-prone areas, considering socio-economic factors?	Survey and qualitative analysis by integrated assessment method	Analysis of the citizen's responses as well as the interviews/ Discussion transcripts	Survey responses and Audio records
What are the potential environmental and social benefits and drawbacks of implementing NbS in east Kolkata, and how do they compare to conventional flood management strategies?	Literature review, survey and qualitative analysis by integrated assessment method	Literature review, analysis of the citizen's responses as well as the interviews/ discussion transcripts	Relevant literature, Survey responses and Audio records.
What are the key factors influencing the adoption and acceptance of NbS among stakeholders in the context of urban flood management?	Survey and qualitative analysis by integrated assessment method	Analysis of the citizen's responses as well as the interviews/ Discussion transcripts	Survey responses and Audio records
How can the insights from stakeholders be integrated	Survey and qualitative analysis	Analysis of the citizen's responses as	Survey responses and Audio records

into decision-making processes to enhance the effectiveness and acceptance of NbS implementation?	by integrated assessment method	well as the interviews/ Discussion transcripts	

3.5.1. Sub-objective 1: To determine the relationship between urban expansion and urban flooding.

To find solutions to the first objective, a land use/ land cover analysis and a landcover change detection on a decadal interval were done during the study period.

3.5.1.1. Land use /Land cover Analysis

The land use/land cover classification was done using Landsat 5 images for the years 2001 and 2011 and Landsat 8 images for 2021. Landsat satellites are widely used for remote sensing in academic fields due to their long-term multi-spectral imagery acquisition capability. The images are open source and downloaded from the United States Geological Survey's Earth Explorer portal (USGS). The choice of Landsat 5 images for 2001 and 2011 and Landsat 8 images for 2021 was made because of the duration of these missions. Landsat 5 mission was launched in 1984 and ended in 2013, providing an image for 2001 and 2011, which are important years in the study period. Landsat 8 mission was started in 2013 and continues to date, from which the images for 2021 were acquired (USGS,2024). The details about specific bands and their wavelength and resolution have been provided in Tables 4 and 5. Table 6 provides insights into the dates of image acquisition and the number of bands used in the land use/land cover analyses.

Table 4: Landsat 5 Thematic Mapper TM Spectral Band Characteristics

Band	Band Name	Wavelength (µm)	Spatial Resolution (m)
Band 1	Blue	0.45-0.52	30
Band 2	Green	0.52-0.60	30
Band 3	Red	0.63-0.69	30
Band 4	Near Infrared (NIR)	0.76-0.90	30
Band 5	Shortwave Infrared (SWIR1)	1.55-1.75	30
Band 6	Thermal	10.40-12.50	120 (resampled to 30)
Band 7	Shortwave Infrared (SWIR 2)	2.08-2.35	30

Table 5: Landsat 8 OLI-TRS Spectral Band Characteristics

Band	Band Name	Wavelength (µm)	Spatial Resolution (m)
Band 1	Coastal Aerosol	0.43-0.45	30
Band 2	Blue	0.45-0.51	30
Band 3	Green	0.53-0.59	30
Band 4	Red	0.64-0.67	30
Band 5	Near Infrared (NIR)	0.85-0.88	30
Band 6	Shortwave Infrared	1.57-1.65	30

	(SWIR1)		
Band 7	Shortwave Infrared (SWIR 2)	2.11-2.29	30

Table 6: Image Details

Date of Acquisition	**Path/row**	**Satellite**	**Sensor**	**Spatial resolution (m)**	**Total number of Bands**
13/02/2001	138/044	Landsat -5	Thematic Mapper [TM]	30	7
09/02/2011	138/044	Landsat-5	Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	30	11
13/2/2021	138/044	Landsat-8	Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	30	11

Two image classification techniques were used to classify the images of 2001 and 2011, 2021 respectively. The processes are Maximum Likelihood and Support Vector Machine (SVM) classification. The process started with image processing, followed by training data selection using the traditional parametric technique. Each class was represented by a statistically significant number of training samples with a normal distribution of the number of training samples representing each class being similar. To ensure statistical significance, the chosen samples were checked if they were enough to cover the variability within each class and avoided biases. The parametric method of image classification was employed in this case due to its simplicity, effectiveness and efficiency. Parametric models, being more robust to noise and outliers compared to more complex models, are commonly used in Image classification (Deilmai et al., 2014). Finally, supervised Maximum Likelihood Image Classification (MLIC) or Support Vector Machine (SVM) were used on the three images based on the different accuracies provided in the final outcomes. These methods were employed to delineate Landcover categories based on spectral signatures derived from Landsat Imagery (*Research question 1. a*).

3.5.1.1.1 Methods of Classification and their significance in this study

Maximum Likelihood Classification

The maximum Likelihood Classification method uses probability models and statistical techniques to classify images based on the likelihood of the observed data assuming a Gaussian distribution of classes. It calculates the probability of a pixel belonging to each class. Maximum Likelihood classification is a widely used classification and is typically used for multi-spectral data with known statistical properties (ESRI, 2024). In this study, the 2001 Landsat 5 image was classified using this method and gave the highest accuracy compared to other methods. When applied to the images for 2011 and 2021, the same method did not give high accuracy and consisted of many misclassified areas. Hence, a uniform method could not be employed to classify all the images.

Support Vector Machine

Support Vector Machine (SVM) is an approach suitable for classification based on the Likelihood of observed data. Unlike Maximum Likelihood classification, this technique uses a hyperplane to separate classes in feature space, maximising the margin between them. This classification method is useful for classification tasks where classes are not normally distributed or when class separation is complex (ESRI,2024). In this case, the second reason stood valid and yielded more accurate results for the years 2011 and 2021 compared to the Maximum Likelihood Classification. Compared to Maximum Likelihood Classification, SVM is computationally less extensive and minimizes the number of misclassifications (Deilmai et al., 2014). However, when applied to 2001, to ensure uniformity, the accuracy was lower due to the less distinguishable distribution of classes of the multi-spectral image of Landsat 5.

Through these steps, the Land use/land cover classification facilitated the change detection of the study area over the study period of twenty years (2001-2021). The Limitations leading to the low accuracy of the Land use/ Landcover map 2001 have been elaborately discussed in the discussions (*Section 5.1*). The land use/land cover maps for each year have been provided in the results section to provide comprehensive and comparative insight into each map with progressing time. The confusion matrix showing the accuracy, kappa value, errors of omission, and the commission has been provided in *Annexe 4*.

3.5.1.2. Land Use/ Landcover Change Detection

The land use landcover maps were further developed to separate change detection maps from quantifying the percentage area covered by different land use/landcover types. This step was done in ArcGIS Pro using the Change detection wizard, where the individual classified raster layers were overlaid, and the land cover change maps were obtained. The change detection process employed in this study is categorical change detection, which computes a pixel-wise change between two thematic maps (ArcGIS,2023). In this process, 2001 was taken as the base year, on which the 2011 LULC map was overlaid, and subsequently, 2011 was taken as the base year for analysing the landcover change for 2021. During the change detection process, the class configuration was set to 'changed only', and the colour transition method was set to average, ensuring a smooth transition of colours between the different classes and avoiding sharp colour contrasts. No smoothing of the neighbourhood was applied to the existing extent because of the reasonable spatial extent of the study area. This is how the Land use/Land cover change for the entire timeframe was calculated. The output was derived as a map, and the quantitative change was obtained in the attribute table, with the details of the classes and the area of change in square metres (default), which was later converted to Hectares. The different Landcover change maps have been provided in the results section with interpretations (*Research question 1. a*).

3.5.1.3. Flood event mapping

The major flood events between the years 2001 and 2021 were obtained from government records, annual flood reports, relevant literature, and newspaper articles. The names of the areas affected by floods in the period of study were obtained from public records and newspaper archives (*Research question 1. c*). These points were located using Google Earth Pro. Places such as Salt Lake Sector I and V, New Town's Action Area 1, Rajarhat's Hatiara and Chinar Park area and some places near the Kestopur canal were identified.

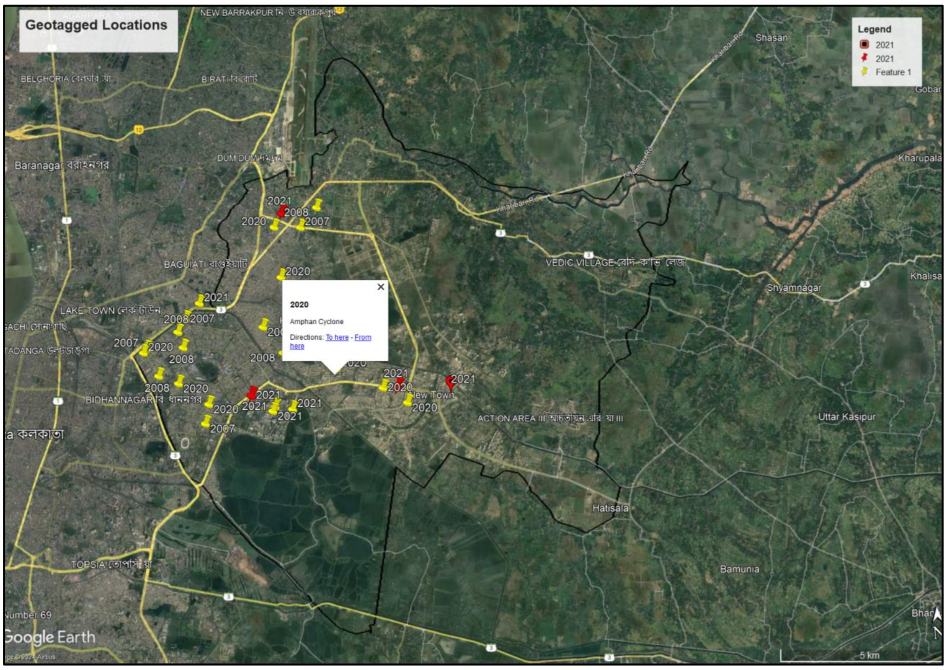


Figure 18: Locations geotagged by years of water logging according to public records and news archives.

The relationship between the distinct yet closely interrelated processes of urban expansion, rainfall, change in slope and the shrinkage of wetlands and their causal connection to urban flooding has been established by overlaying the flood map derived by the SMCA and interpreting it based on all the distinct indicators and the government records of major flood events (*Research question 1.b*). Further elaboration of these processes has been provided in the next chapter (*Results*). An attempt has been made to analyze the annual rainfall (in mm) for the study period and note the major events which witnessed high precipitation in 24 hours.

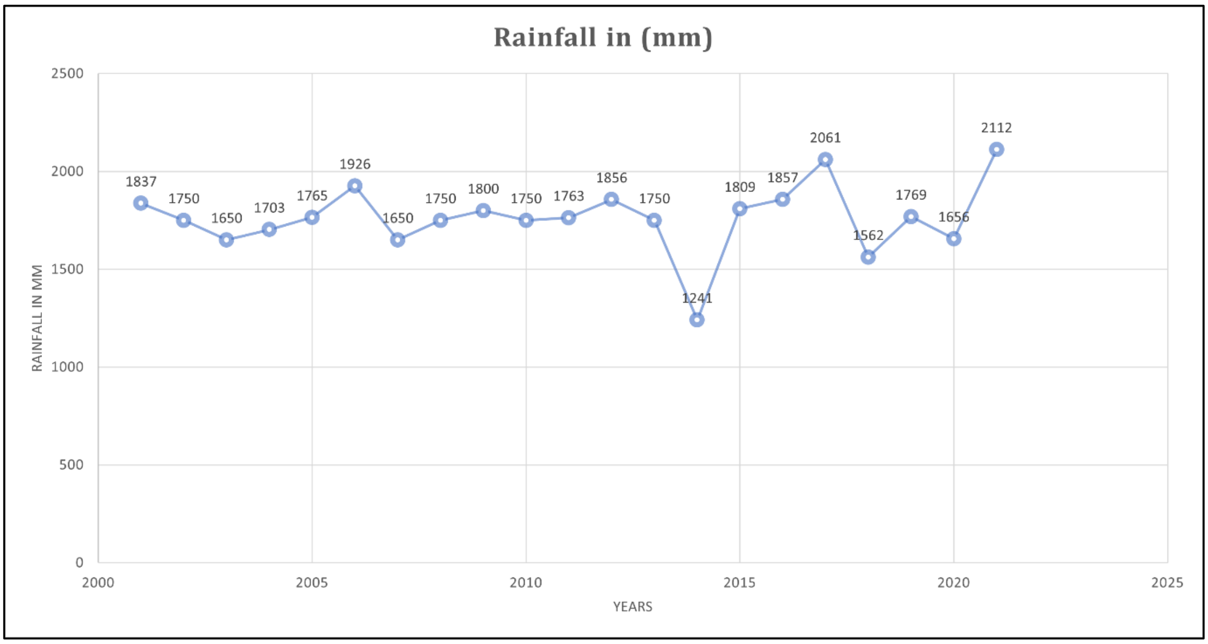


Figure 19: Annual Rainfall (in mm) from 2001-2021. Source: IMD

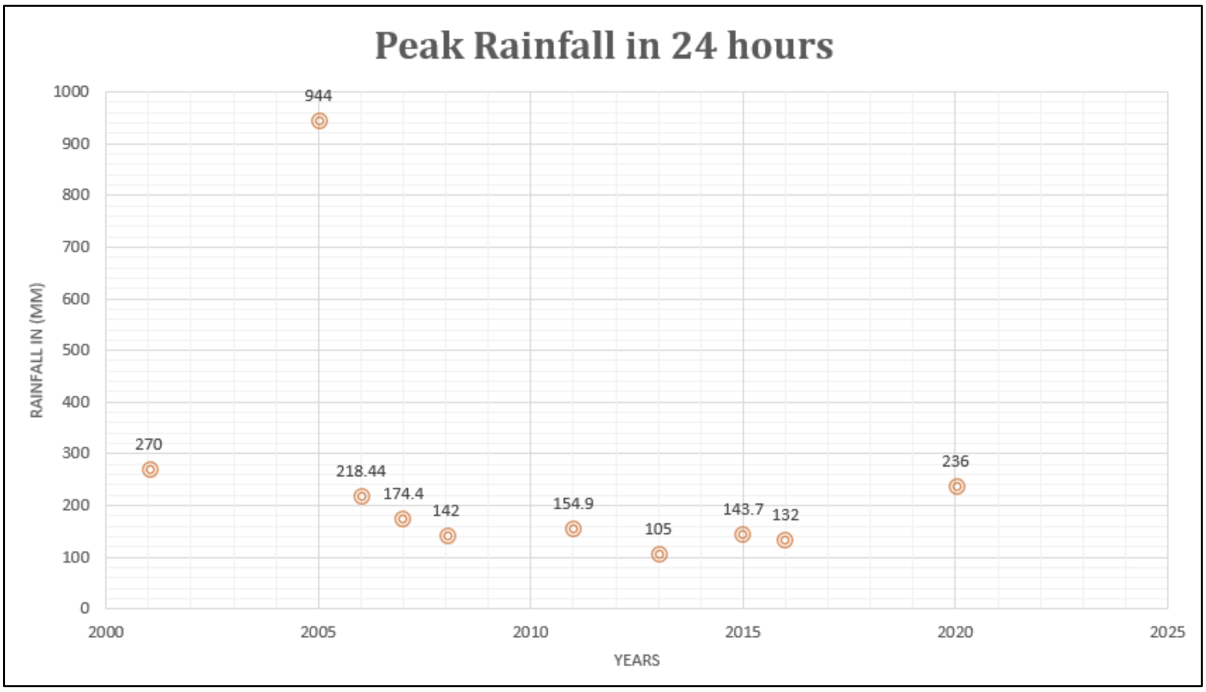


Figure 20: Peak precipitation (in mm) from 2001-2021. Source: IMD

Table 7, with the summary of annual rainfall and major flood events, has been provided (India Meteorological Department). It is also noteworthy that although Salt Lake and Newtown are quite susceptible to flooding, public records and newspapers do not explicitly mention them in their published records. Hence, the years provided in the map of waterlogging records (Fig.35) are slightly different from the above graphs (Figures 20 and 21).

Table 7: Years, annual rainfall, peak (24 hours) and dates. Source: Annual Flood Reports (2001-2021); Rainfall Statistics of India (IMD) (2014-2021)

Year	Rainfall in (mm)	In a Day Peak	Date
2001	1837	270	18th September
2002	1750	--	20th September
2003	1650	--	--
2004	1703	--	--
2005	1765	944	26th July
2006	1926	218.44	22nd September
2007	1650	174.4	25th September
2008	1750	142	September
2009	1800	--	August
2010	1750	--	--
2011	1763	154.9	18th June
2012	1856	--	--
2013	1750	105	25th October
2014	1241	--	--
2015	1809	143.7	10th July
2016	1857	132	6th September
2017	2061	--	--
2018	1562	--	--
2019	1769	--	--
2020	1656	236	20th May
2021	2112	--	--

3.5.2. Sub-objective-2 To explore the suitable NbS measures for the target areas based on their socio-physical characteristics.

3.5.2.1. Spatial Multi-criteria Analysis

This research undertook a spatial multi-criteria analysis as a preliminary step before the fieldwork. The aim of this method was to create a spatial index composed of multiple indicators for mapping urban areas susceptible to flooding in the study area. This step was informed by a detailed literature review on the structuring of the research problem and selecting a set of relevant indicators. After the selection, individual maps for each indicator were produced. The value of each indicator was expressed between 0-1. Fig. 22 highlights the SMCA concept in GIS environments (Rikalovic A & Cocić I, 2014).

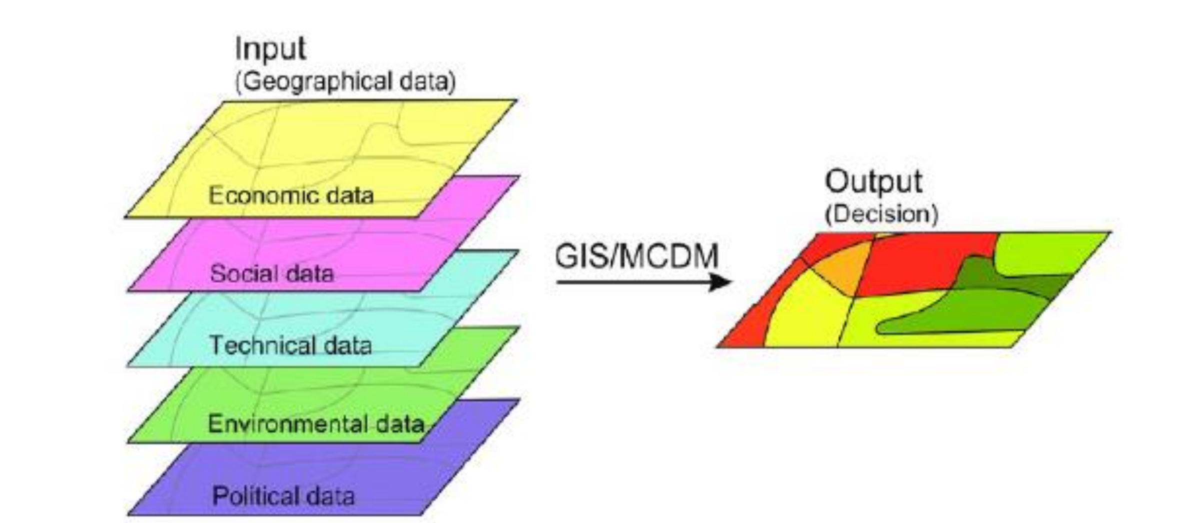


Figure 21: A demonstration of Spatial Multi-criteria Analysis. Source:Rikalovic A & Cocić I, 2014

The Individual indicator maps were derived from the remotely sensed data obtained from various sources. The SMCA workflow provided in Fig.23 shows the different indicators used for the SMCA analysis and the maps obtained therefrom.

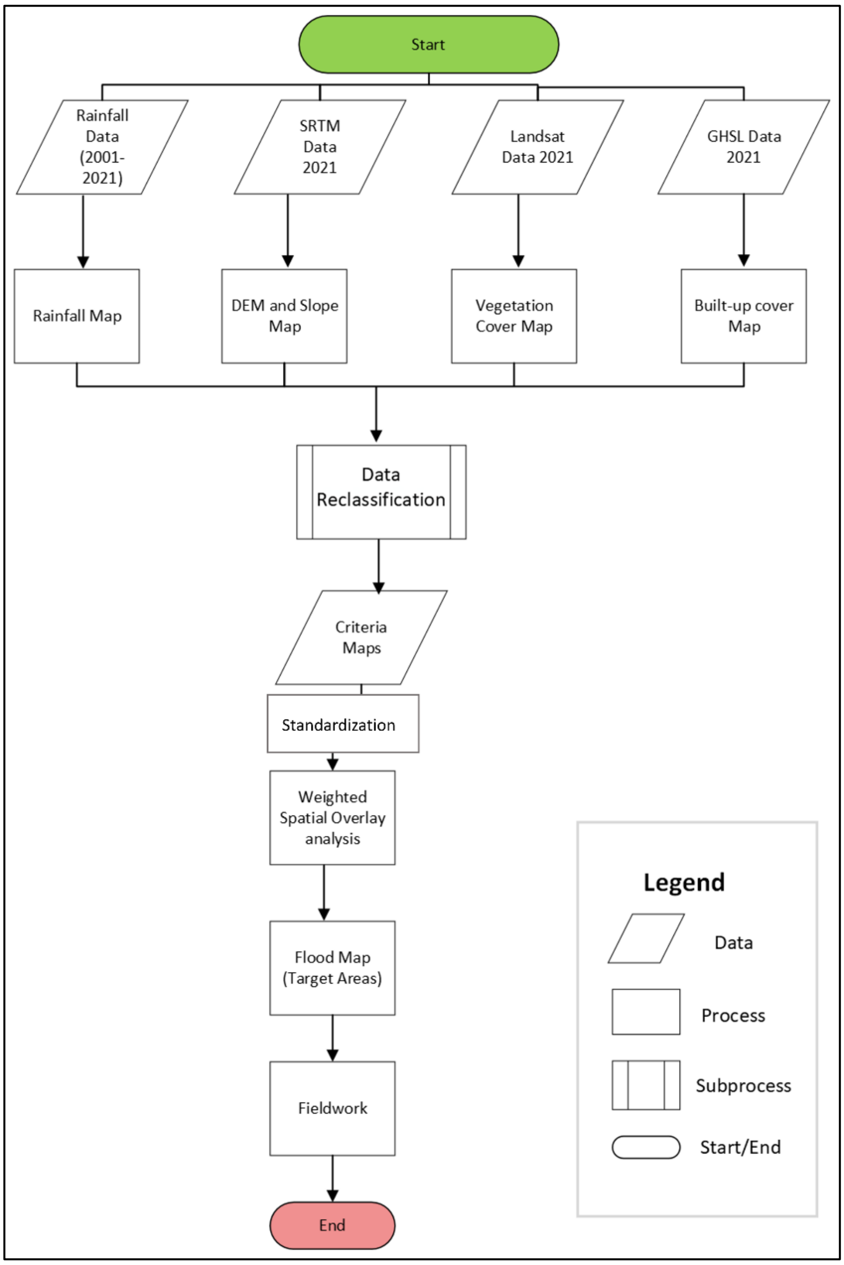


Figure 22: SMCA Workflow. Source: Author, (2024)

3.5.2.2. Data classification, reclassification and standardization

The data in all the maps were classified using the quantile method. All the maps have five classes ranging from high to low. This method has been used to ensure that there are no empty classes or classes with huge differences in values. The maps were tailored to be compatible with the overlay by reclassification. This process was initiated to convert all raster values into integers before carrying out the standardization. The step followed after reclassification was standardization. In this study, each indicator was categorized either into cost or benefit. The cost or benefit was determined based on the variable's influence on urban flooding. The list of indicators, classification (cost/benefit), and rationale are provided in a detailed table in *Annexe 1*. As represented below, different calculations were done for costs and benefits using the formulas for the standardization method (Flacke, 2023, p.6):

Cost Criterion

$$X = 1 - \frac{Score - Lowest\ Score}{Highest\ Score - Lowest\ Score}$$

Benefit Criterion

$$X = \frac{Score - Lowest\ Score}{Highest\ Score - Lowest\ Score}$$

Source: Flacke Johannes, 2023, p.6.

3.5.2.3. Weighted Sum

The weighted sum method constitutes a fundamental technique within spatial analysis and modelling, renowned for its function of overlaying various spatial predictor maps and their associated classes. This method, as expounded by Kayadibi & Aydal (2017), entails the allocation of weights to each spatial predictor map and combining them by weighted summation. This culminates the generation of comprehensive weighted predictor maps. In this research, weighted sum technique was deployed for the purpose of making an urban flood map, indicative of its versatility across multi-faceted spatial analyses(Rikalovic A & Cocić I, 2014). Following a standardization process, each indicator received uniform weight, thereby ensuring equal representation in the model. The adoption of ArcGIS tools, such as weighted sum, facilitated the seamless execution of the weighted summation. The concept of weighted summation, when the cell values are multiplied by their weight factor, is represented in Fig.24 below.

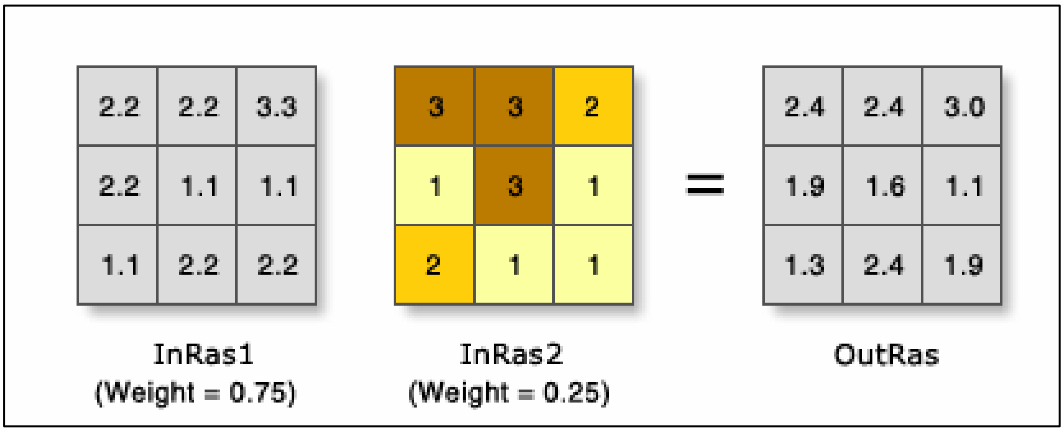


Figure 23: Illustration of weighted sum. Source: (ESRI,2021.)

3.5.3.1 Identifying areas fit for NbS interventions

The areas fit for Nbs interventions were identified through SMCA and flood event mapping, complemented by fieldwork data. Ten areas that are susceptible to flooding were identified using variables such as rainfall, built-up, elevation, slope, and vegetation cover. Areas with high susceptibility to flooding and a record of past urban flood events were identified (*Research question 2. a*). This approach provided a clearer insight into the physical characteristics of highly vulnerable local areas, aiding in effectively identifying target areas. Out of the ten identified target areas, three (Flood Areas 1,2, and 8) were excluded from the study due to greens, stakeholder inputs and ongoing political disturbances in some areas during the fieldwork. The target areas had diverse land use and ownership characteristics. Although concrete cadastral data was unavailable, the data obtained from the field and interviews of the local experts proved to be helpful. Land ownership is a critical component in urban planning research, as stakeholder involvement and the scale of the project depend on clear ownership knowledge. Land ownership considerations were integrated into the NbS recommendations provided in this study, which relied on local knowledge and stakeholder inputs due to data limitations (*Research question 2. b*). Data on existing NbS measures were collected through general questionnaires and semi-structured interviews, providing a broad spectrum of existing practices (*Research question 2. c*).

Local socio-physical characteristics, including building types, availability of open spaces and roof types determined suitable Nbs measures for each target area. These interventions were tailored to the specific typologies of NbS, indicating the degree of stakeholder engagement. Acknowledging the socio-economic diversity of the study area, the interventions aim to cater to the local needs, promoting inclusivity, equity and sustainable development (*Research question 2. d*).

3.5.3. Sub-objective 3: To investigate the awareness of the study area's stakeholders of NbS and their willingness to invest in NbS.

To investigate the awareness and willingness of the stakeholders of the study area, both general survey and the semi-structured interviews played a crucial role. This dual approach of data collection provided a comprehensive understanding of the stakeholders' knowledge and engagement with NbS. While the surveys provided a broader view, the interviews allowed a nuanced analysis. The combined quantitative and qualitative data (Quan+qual) enabled a richer understanding of the awareness and willingness levels across different stakeholder groups (*Research questions 3. a and b*).

The stakeholder awareness was also measured by asking questions related to existing government initiatives on NbS or their involvement in Nbs-related activities (*Research question 3. a*). Semi-structured interviews were conducted to understand the perspectives of the local governing bodies on integrating Nbs into spatial plans and urban governance frameworks (*Research question 3. c*). These interviews facilitated a broad understanding of their willingness to adopt and invest in NbS for urban flood mitigation. The willingness of the local residents to invest in NBS measures was assessed using various methods such as questions on the Likert Scale, informal discussions and open and close-ended questions about existing greens in homes and neighbourhoods (*Research question 3. d*).

3.5.4. Sub-objective 4: To assess the effectiveness, feasibility, benefits, and drawbacks of NbS for flood mitigation in the East Kolkata Wetland region.

A multifaceted approach was employed to understand how the governing bodies perceive the effectiveness and feasibility of implementing NbS in areas with high flood susceptibility. A literature review was done along with the data collection using the general survey and semi-structured interviews (*Research question 4. a*). During the semi-structured interviews, the stakeholders were presented with the SMCA mao, followed by detailed discussions, providing comprehensive insights into NbS feasibility and effectiveness. Visual aids such as pictures of NbS interventions helped the interviewees have a clearer understanding. The audio recordings and transcripts of these interviews were analyzed in Atlas.ti software, extracting meaningful information through text search, sentiment analysis, and correspondence analysis, which were then coded with relevant keywords. The semi-structured interviews targeted the technical audience (key informants) to explore the benefits and drawbacks of NbS interventions in East Kolkata (*Research question 4. b*). These discussions, stored as transcripts and audio records, were analyzed in Atlas.ti software using multimodal conventional content analysis methods (Hsieh & Shannon, 2005; Serafini & Reid, 2023).

3.6. Ethical Considerations and Risks

The present research deals with human participants and ensures complete abidance with the rules formulated by the ethics committee of the University of Twente, Faculty ITC, concerning the research (University of Twente, 2018). A written introductory document provided by the university had been shared with all relevant human participants, stakeholders, and organisations taking part in the research. The research had a mixed methodology of qualitative as well as quantitative data collection, which was achieved by the following ways:

1. The qualitative data obtained from the semi-structured interviews, which were elaborated and had detailed information, were recorded with consent of the participants after making them aware of the data protection and strict anonymity. The audio and transcripts of the interview were recorded in MS Teams, using the University's business subscription, which has a higher encryption and data protection. This data can only be accessed by the researcher and the supervisors (upon sharing). The device in which the data was stored, was protected by a strong password. The device also had access to 'P' Drive, where the data was stored. The 'P' Drive is a storage provided by the University of Twente for staff and students, protected by a strong password.
2. The quantitative data, using which the statistical analyses were carried out, were obtained from a survey made using Kobo Collect software, a General Data Protection Regulation (GDPR) compiled software. The GDPR, laid down by the European Privacy Law, ensures that the data obtained from people, which has the potential to trace back to the person's name or identity (which falls under GDPR), is dealt with lawfully and responsibly (University of Twente2018). Kobo toolkit software has been approved by this law and has hence been used to collect data from the field. The data subjects (participants) were transparently informed about the data processing and usage. The introductory letter and the informed consent form used during the fieldwork are in *Annexe-3*.

The researcher took full responsibility for lucrativeness and practicability in data without harming the social, political, or human rights of the individual or group (APSA Council, 2020). The work was carried out by providing clear information to all the people participating in surveys or other data collection purposes. Adherence to all ethical protocols, including the dissemination of relevant information to all human participants, was carefully taken care of (Kapiszewski & Wood, 2022). F.A.I.R (Findable, Accessible, Interoperable, Reusable) use of data collected from the field was of paramount importance. To ensure findability, the folders and the data containing them were named in a way so that the name itself describes the data it contains (e.g. Thesis> Data> Satellite Images> Landsat 2001>LT05…). For ease of accessibility and interoperability, the metadata was named in an understandable, formal and broadly applicable language (English). The data complies with all the rules laid by the University and has a clear usage licence, providing accurate information and fostering reusability. Safeguarding the privacy and anonymisation of all interviewees' profiles was duly considered and observed by renaming the transcripts with interviewee numbers instead of names and designations.

The risks and impacts that might be a byproduct of this research are the reduction of land value in the areas that are identified as areas susceptible to urban flooding and similar ones. However, one of the mitigation strategies to prevent this kind of risk, the level of spatial detail, has been adjusted by providing aggregate locations of the flood areas in the maps.

Data reusability has also been ensured in this study by storing the data for a period of ten years, accessible only to the researcher and the supervisors. According to the Data Policy of the University, the data will be stored in password-protected cloud storage provided by UT-ICT Services (LISA), Known as the Research Information System (RIS), which is an ISO 27001 and NEN 7510-certified facility (University of Twente, 2018). If the data is stored in personal cloud storage, Surf Drive was used, as it is approved by the Dutch and European privacy legislation. The data has been kept in cloud storage (MS Teams) for extra personal safety.

The research was completed within the stipulated time of six months, with the decision of the topic, the proposal submission, effective communication with the supervisors, timely completion of the fieldwork, and a well chalked-out work plan. (Association for Project Management., 2004).

4. RESULTS

This chapter presents the findings of the research on the shrinkage of the east Kolkata wetlands and the occurrence of urban floods. The results derived from the land use land cover analysis, SMCA analysis, and the information obtained from the fieldwork are provided in different sections. The results inform possible ways of integrating nature-based solutions in the study area, which has the potential to reduce the impact of or mitigate urban flooding.

4.1. Sub-objective 1: To determine the relationship between urban expansion and urban flooding.

The first objective focused on determining the relationship between urban expansion and urban flooding. The following sections present the findings on land use and cover changes, flood occurrences, how they change over time, and whether they are associated with land use/land cover changes.

4.1.1 Research question 1. a. How and to what extent has the land cover of east Kolkata Wetlands Changed in the last two decades (2001-2021)?

4.1.1.1. Land use /Land cover Analysis.

The land use/land cover of the study area was analysed for 2001, 2011 and 2021, respectively. Before the cities were planned, the land cover of the study area was dominated by swamps, farmlands, and water bodies. A staggering amount of built-up growth and concretization has been observed with the passage of each decade. In the land use/ land cover map of 2001 (Fig.25), it is observed that Salt Lake City was the only city situated on the western part of the study area, adjacent to the East Kolkata Wetlands. Parts of Rajarhat comprise a sparse built-up largely connected to and radiating from Salt Lake. The land use land cover classification accuracy for 2001 was 79.5% using Maximum Likelihood Classification. The accuracy of 2011 and 2021 are 91.5% and 96.3%, respectively, using the Support Vector Machine Method. Five classes were used for land use/ land cover classification: vegetation, built-up, agriculture, water, and open land. The confusion matrix with kappa values has been provided in Annexe 4. The Table provided below (Table 8) explains each land cover class and their descriptions according to Adeola Fashae et al. (2020) and Molla (2018)

Table 8: Land cover classes and their description. Source: (Adeola Fashae et al., 2020)

Land cover class	Description
Vegetation	Densely vegetated areas
Built-up	Buildings, roads, pavements and other concrete surfaces
Farmland	Agricultural areas, areas with less vegetation (grasses, small plants and shrubs)
Water	Waterbodies, swamps (which have water during some periods of the year)
Open land	Bare land with minimal vegetation or exposed soil

The outcomes of the land use/ land cover analyses (2001-2021) are provided in Fig.25,26 and 27. A comparative image of the three years is provided in Fig.28.

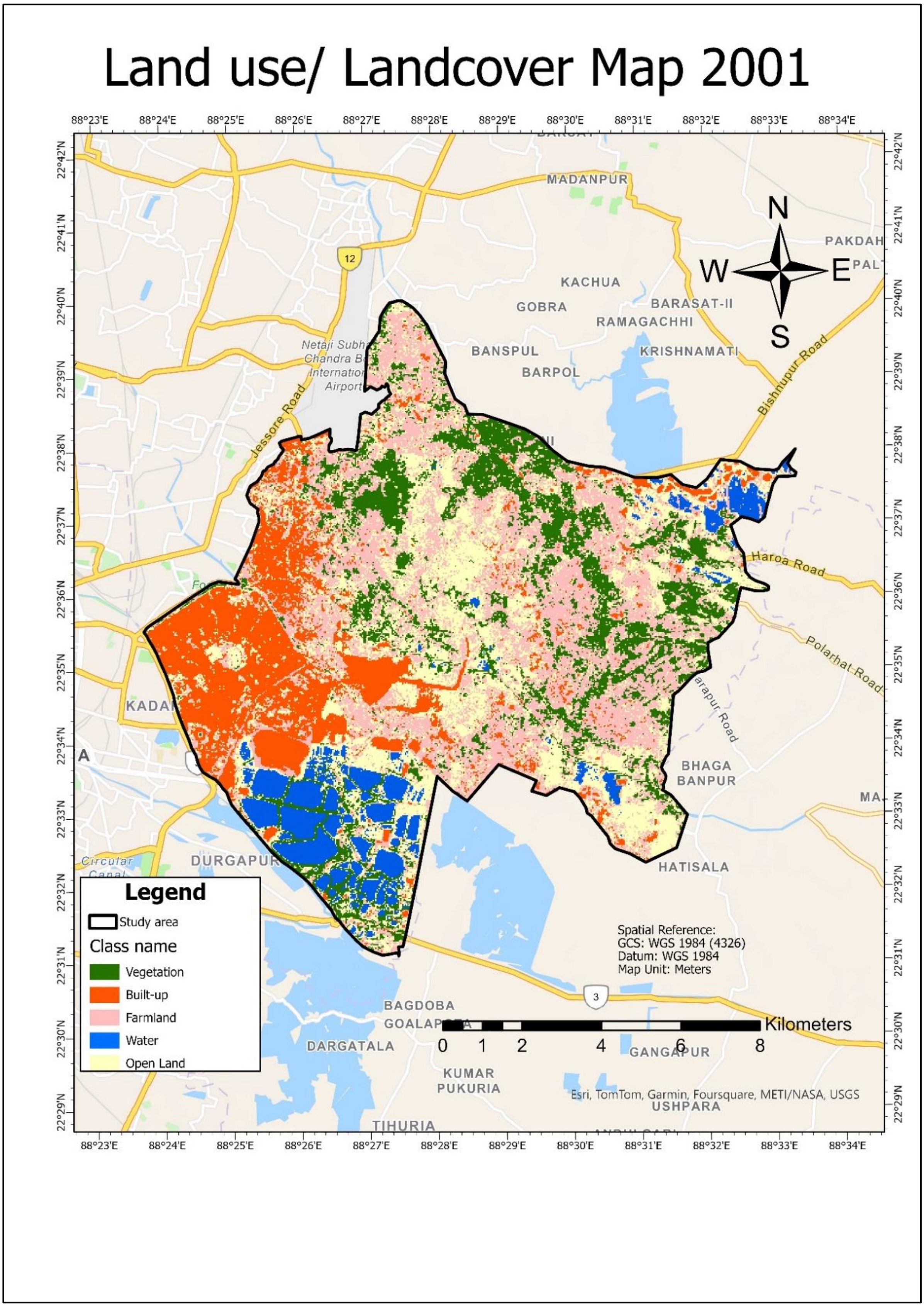


Figure 24: Land use/ Landcover Map 2001. Source: Author,(2024)

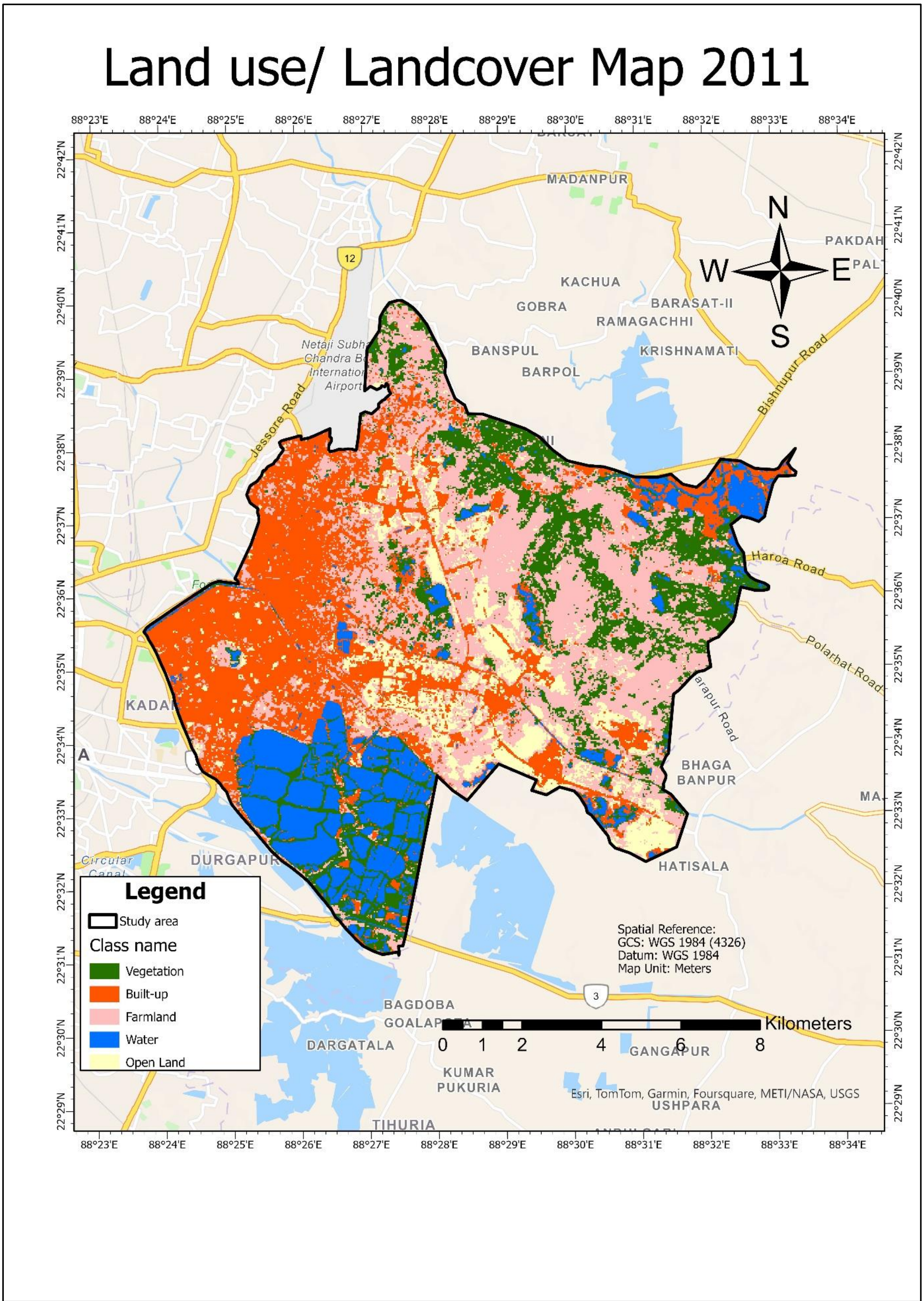


Figure 25: Land use/ Landcover Map 2011. Source: Author, (2024)

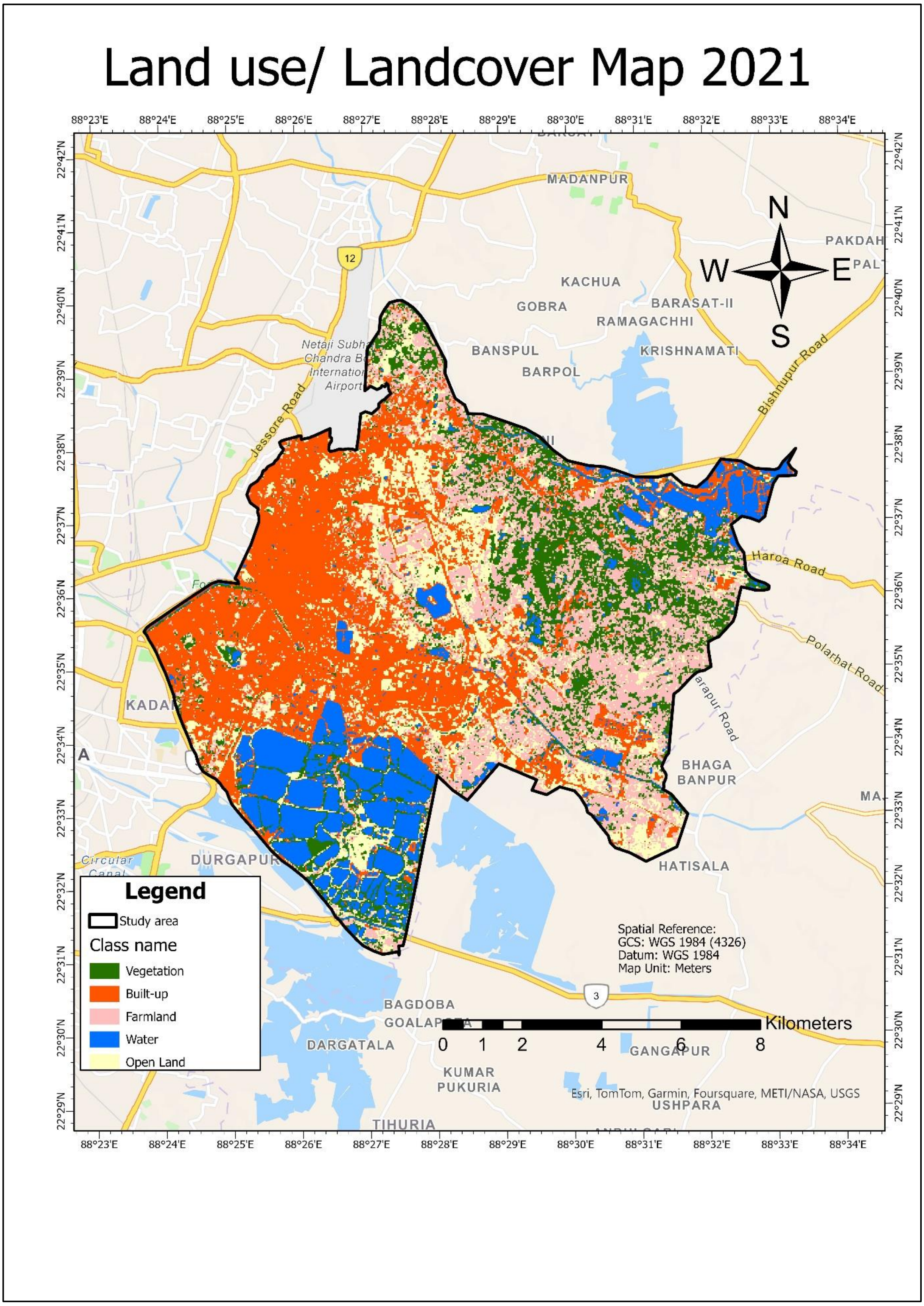


Figure 26: Land use/ Landcover Map. Source: Author,(2024)

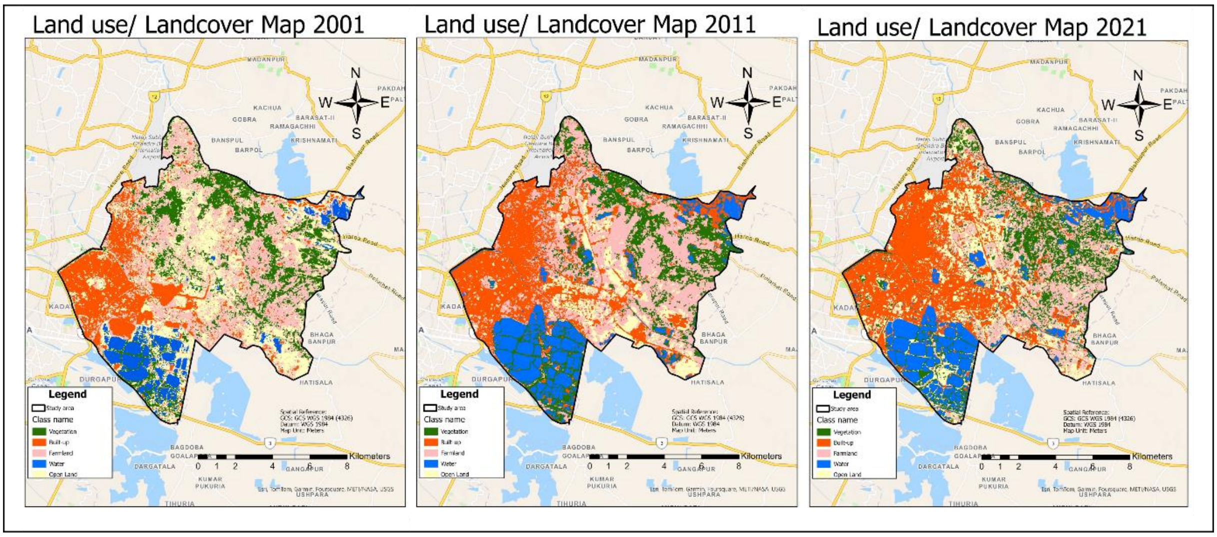


Figure 27: Comparative picture of Land use/ Landcover Maps 2001-21. Source: Author,(2024)

In the Spatial pattern, it was observed that built-up growth and concretization are among the most dominant factors. Unplanned growth of the peripheral areas of the planned cities, which are mostly inhabited by the marginal sections of the society, often encroach into the natural spaces. The map of 2001 shows the built-up concentration in Salt Lake City, which was planned under the supervision in the 1960s by the then Chief Minister Dr Bidhan Chandra Roy with a Dutch engineering firm, NEDECO, to build a city in the low-lying, saucer-shaped land in the north-western end of the East Kolkata wetlands (Rumbach, 2011b; Tošković, 1964). This city was planned to cater to the acute housing crisis in the city due to the inflow of migrant refugees during the British partition of Bengal in the late 1940s and early 1950s. Salt Lake, referred to as Dr Roy's Wonderland, was planned with the sole motive of providing housing to middle and low-income families by elevating the low-lying marshy land and brackish (Salt lakes) by "cut and fill method" where land from other areas was dug and filled in these areas. The soil was also obtained by dredging the Hooghly River. The land was elevated by mixing it with water pumped from the Hooghly River to the wetlands by a process called Hydraulic filling (Rumbach, 2011b). This was followed by the rise of New Town, which was planned between 1999 and 2006 (West Bengal Housing Infrastructure Development Corporation(WBHIDCO), 2012). The plan was executed well, resulting in an urban cluster observed in 2011 and gradually expanding in 2021, strengthened by a road network connecting the surrounding patches of clusters. The urbanisation processes within these two cities and Rajarhat are ongoing processes that are taking more of the green and blue spaces into the built-up land cover type. As evident from the above maps, if the built-up growth continues unplanned, the cities will keep growing outward, engulfing more natural areas, and increasing the vulnerabilities and urban flood-associated risks (Rumbach, 2011).

4.1.1.2. Land Use/ Landcover Change Detection

The land cover change for the study period was computed using GIS tools and standard statistical techniques. This process involved the change detection analysis of the land use/land cover images obtained from the previous analysis. This step gave quantitative results related to the land cover change in the study area. The specific classes that changed to built-up were considered while analysing the land cover change for the study period. Hence, the land cover change detection map presents four major land cover classes and their changes. The four classes of land cover change are farmland to built-up, open land to built-up, vegetation to built-up, and water to built-up. The class named Water to Build-Up shows the reason behind the diminishing water bodies in the study area. The map showing the different land cover changes is provided below in Figures 30 and 31 respectively.

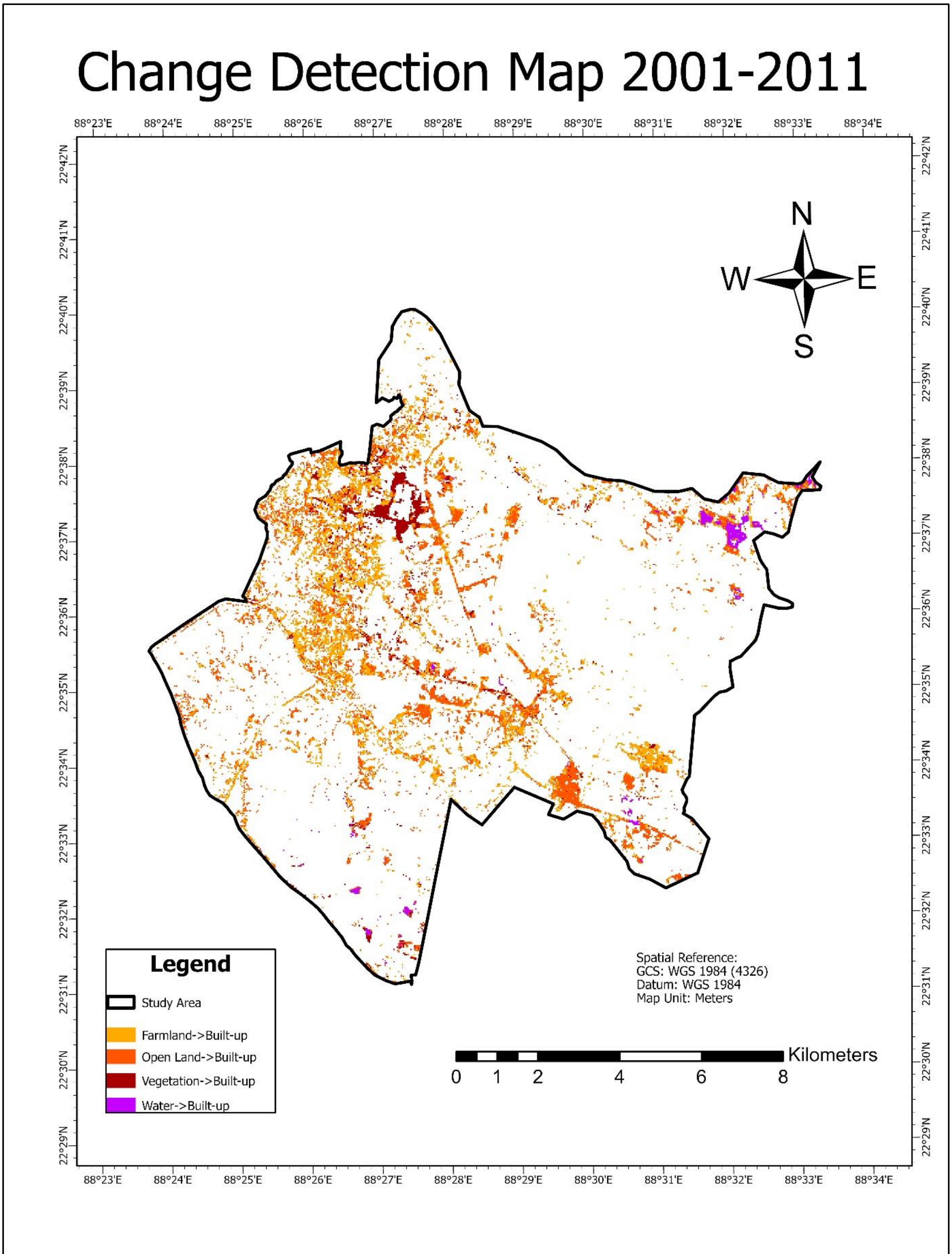


Figure 28: Land use/ land cover change detection Map 2001-2011. Source: Author, (2024)

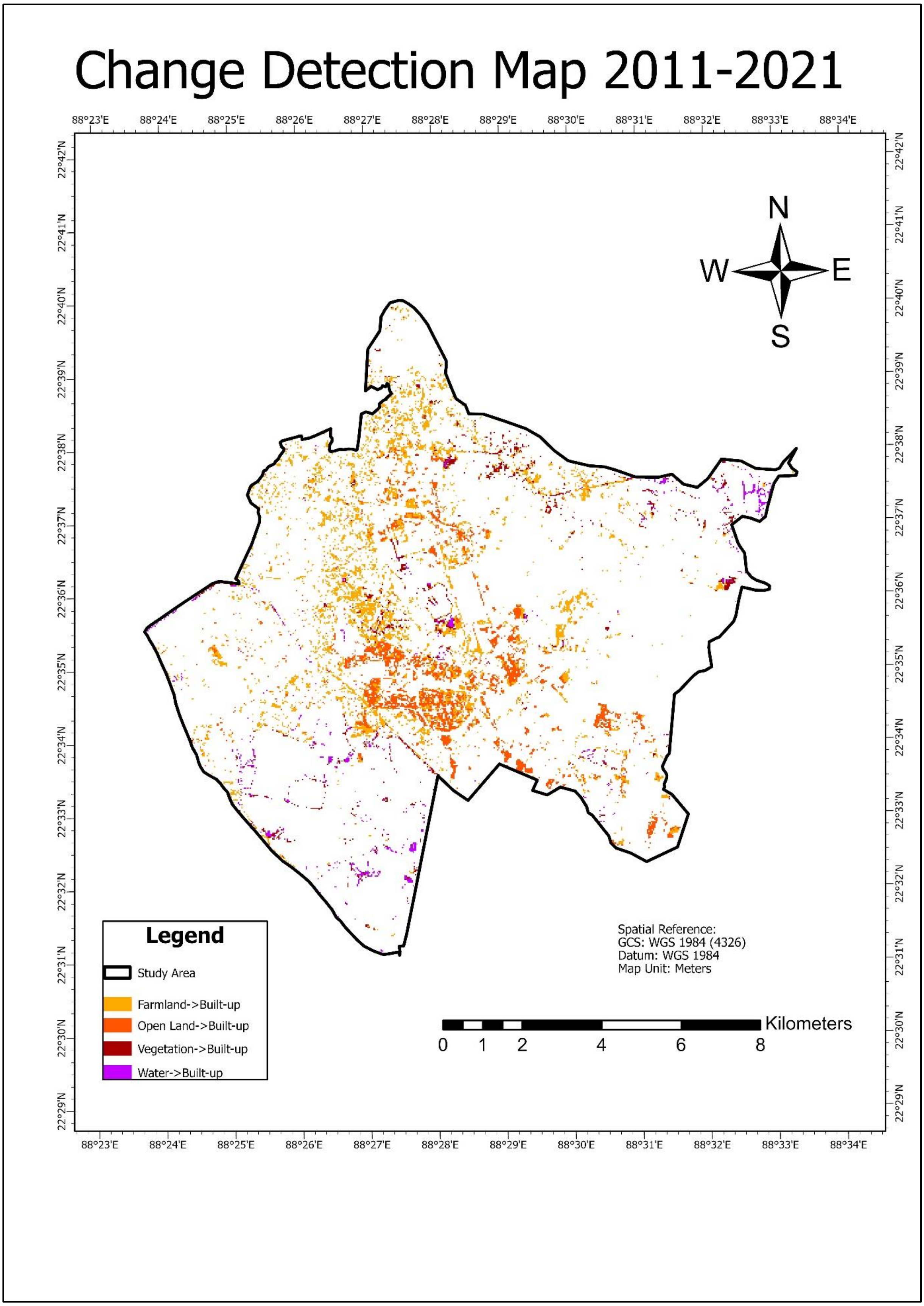


Figure 29: Land use/ Land cover change detection map 2011-2021. Source: Author, (2024)

In the Change detection maps for the study period, it is observed that in the year 2011, there was an overall built-up growth of 13.36% of the area, where the development of built-up was dominant in Salt Lake, Rajarhat (areas near the Kolkata International Airport), and Newtown. On the map for 2011-2021, the conversion from agricultural to open land is observed in the central part of the study area (New Town) and parts of the Southeastern regions. Salt Lake, however, witnessed land cover change mostly due to open lands and agricultural landscapes. This change in the overall land cover contributed to 24.5% of the total study area built-up land. The maps, when compared, also reveal the shifting focus of development with the growing demand for land. Salt Lake and parts of Rajarhat dominated the conversion of land and water bodies into built-up in 2001, and Newtown was added to this development, complemented by parts of Rajarhat and Salt Lake in the decade of 2011-2021. The graph showing the land cover classes and the changes is shown in Fig 32.

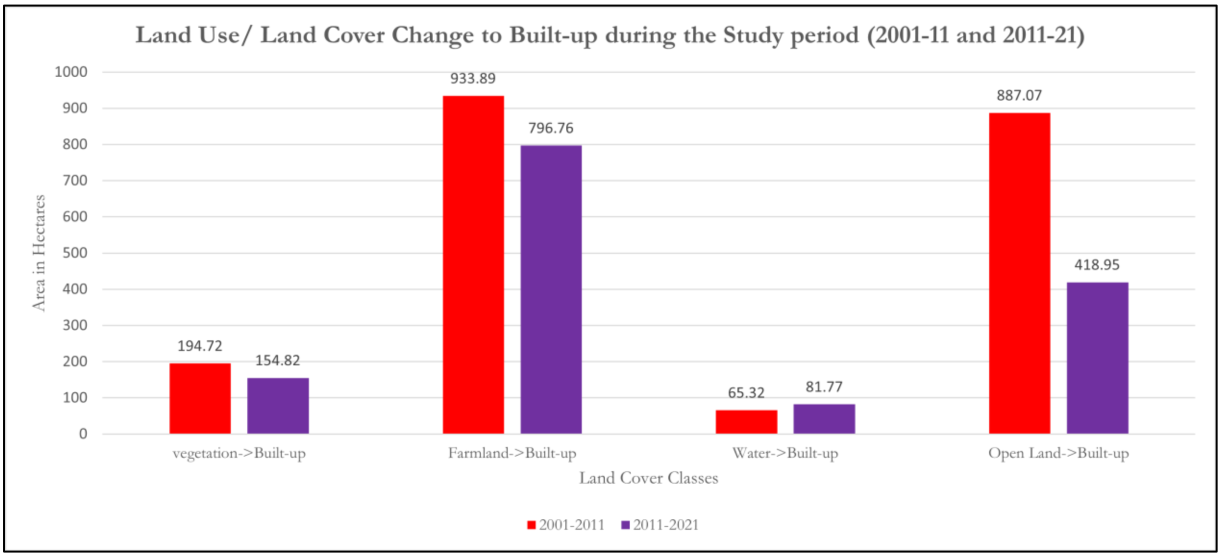


Figure 30: Land Cover Change in Hectares in the study period. Source: Author, (2024)

As seen in Table.9, the total built-up growth in the study area is 2081 Hectares from 2001-2011 from Vegetation (194.72 hectares), farmland (933.89 hectares), open land (887.07 hectares) and water (65.32 hectares). The area occupied by built-up in the study area is 13.36%. This number went up to 24.5% between 2011- 2021, i.e., an additional 1452.3 Hectares. Where built-up and concrete landscapes engulfed Vegetation (154.82 hectares), farmland (796.76 hectares), open land (341.54 hectares) and water (81.77 hectares). The study observed that the small ponds and natural water bodies, which have existed in the study area for centuries, were loaded with soil, sediments and building waste to make them fit for development(Banerjee, 2018; Biswas & Singh, 2017; Rumbach, 2014). The practice has been rampant across Kolkata and its surrounding areas, where the study area is no exception (Ghosh et al., 2023; Rumbach, 2011).

Table 9: Land Cover Classes and their changes. Source: Author, (2024)

Land use/ land cover Classes	2001-2011	2011-2021
vegetation->Built-up	194.72	154.82
Farmland->Built-up	933.89	796.76
Water->Built-up	65.32	81.77
Open Land->Built-up	887.07	418.95
Total Change	**2081**	**1452.3**

4.1.2. Research question 1. b. Is there a relationship between urban expansion (impervious surface development), rainfall, change in slope and shrinkage of wetlands, and urban flooding?

The spatial multi-criteria analysis (SMCA) helped identify the areas susceptible to flooding due to urban expansion, in which different indicators such as rainfall, built-up, vegetation, slope, and elevation were considered and segregated as costs and benefits. Fig.33 shows the SMCA outcomes, where green represents low flood susceptibility, yellow means moderate, orange represents high and red represents very high flood susceptibility. This analysis was done by combining the different variables and shows that urban expansion and anthropogenic modification of the areas' natural undulation, changing slopes and elevations, and encroaching on the natural ecosystems have aggravated urban floods.

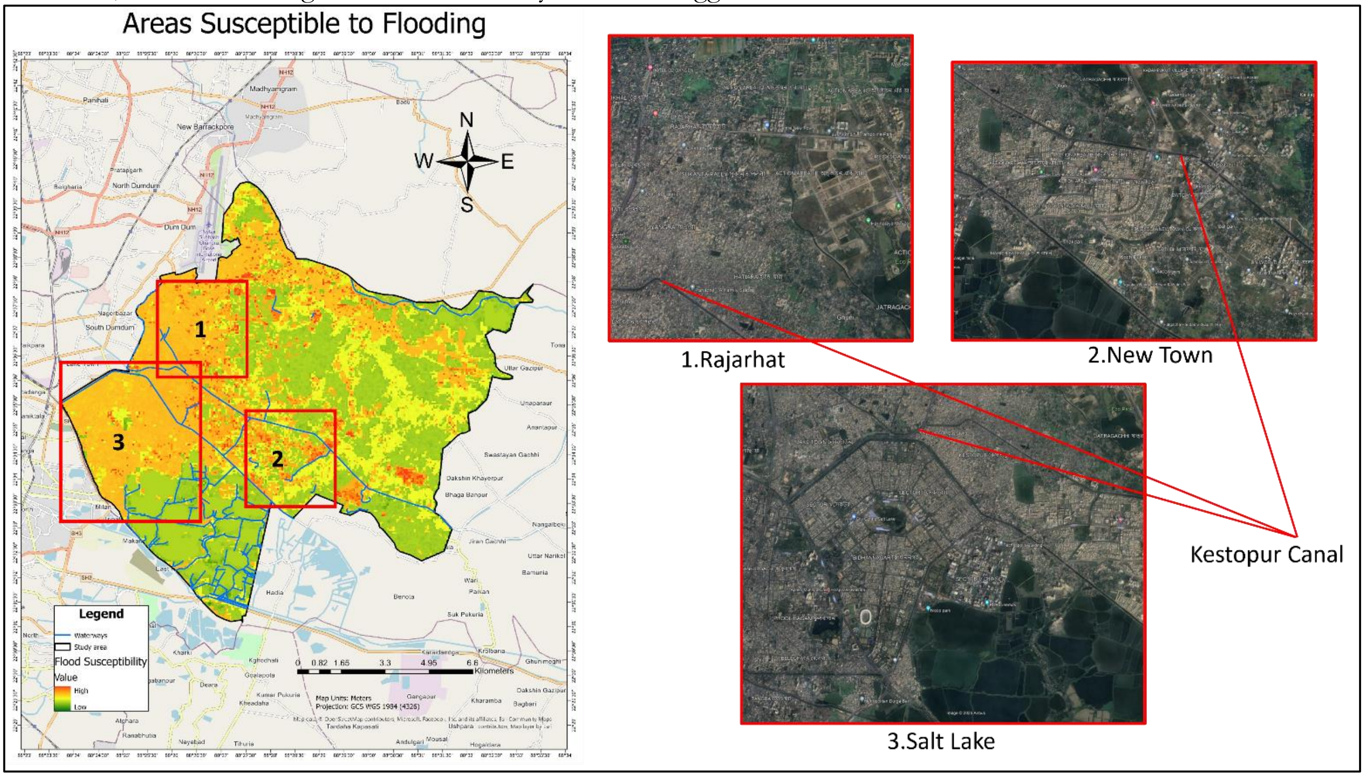


Figure 31: Areas Susceptible to Flooding based on SMCA. Source: Author, (2024)

The areas with high occurrences of floods have a high built-up cover and impervious surface. Moreover, these areas are also the low-lying areas where runoff water accumulates and causes waterlogging. Besides that, the vegetation cover is inadequate to infiltrate water or act as a sponge to provide any ecological service. Some of the areas in Salt Lake and Newtown are inundated by the Kestopur Canal (pointed out in Fig.33), which receives huge amounts of sewage and runoff water. In this study, ten target areas have been identified based on the SMCA. The data obtained from field, public records and news archives were thoroughly considered to verify the accuracy of these identified areas. The target areas identified through the SMCA and stakeholder inputs (Fig.33) have been provided.

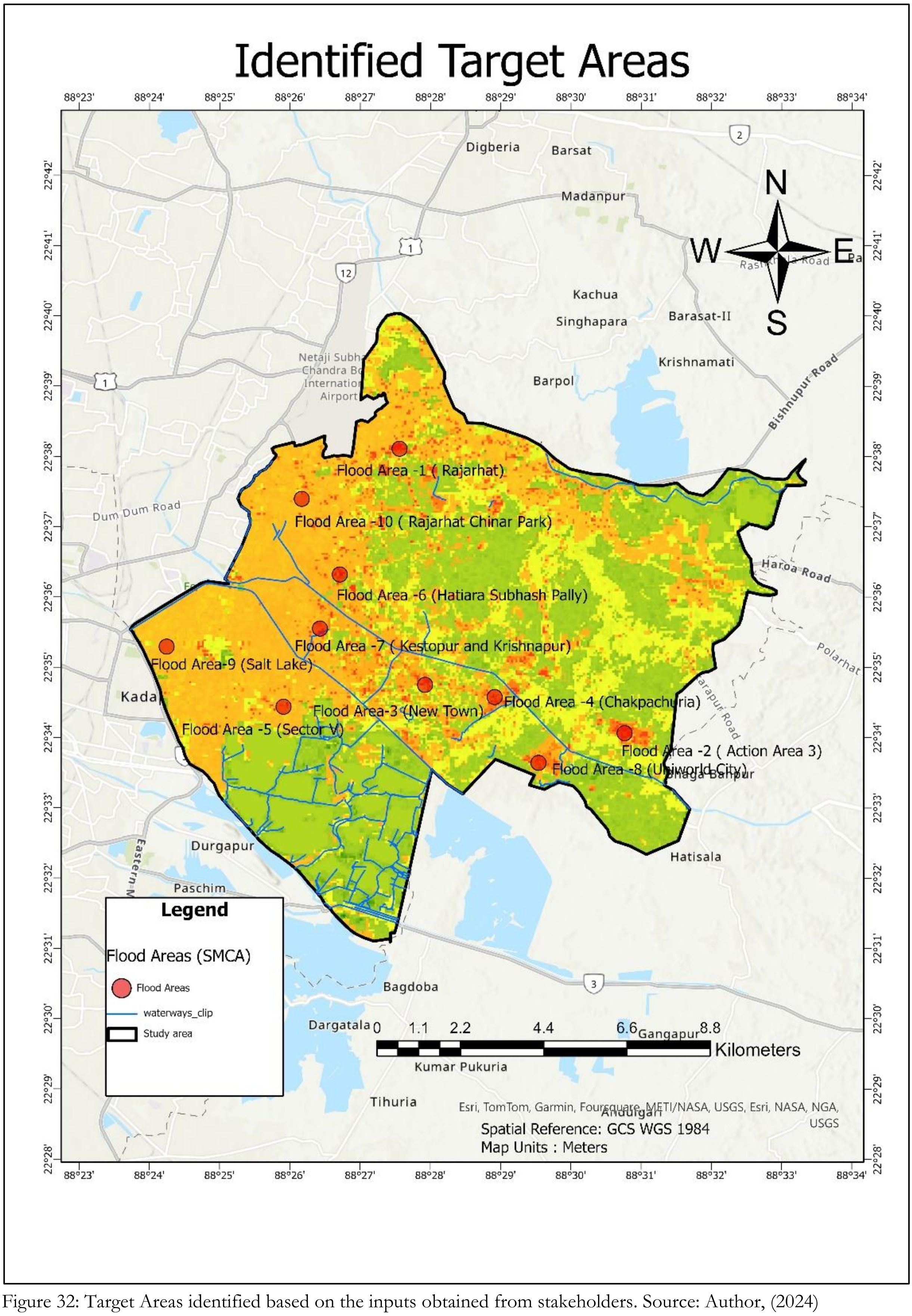


Figure 32: Target Areas identified based on the inputs obtained from stakeholders. Source: Author, (2024)

The target areas consist of Salt Lake, Rajarhat and New Town. The areas with high built-up and low elevation are the ones most likely to be flooded when there is precipitation. Parts of Salt Lake's sector -I and V, Action area 1 of Newtown, areas near the Kestopur canal, and parts of Rajarhat (Chinar Park and Hatiara) are the ones which are most affected by urban floods due to high rainfall. Hence, the interventions have been provided specifically focussing on seven major flood-prone areas, as Flood Area-1(Rajarhat) is not recorded in any secondary literature, and the impact of urban floods is not very high in that area. Similarly, flood areas 2 and 8 (Action Area 3 and Uniworld City) have also been excluded for the same reason. One of the additional reasons is the lack of direct accessibility to these two regions lying in the southeastern corner of the study area during the fieldwork due to political instability. As per the interpretation of the SMCA map, ten locations susceptible to flooding were selected.

4.1.3. Research question 1. c. What is the frequency of flood events from 2001 to 2021?

After field observations, the facts were further verified through secondary sources such as public records published by the Government (e.g., Annual Flood Reports, Natural Disaster records, Rainfall Documents, and India's Flood Atlas). However, although the years of flood occurrences were obtained from the public records, the locations were provided at different scales in different documents (e.g., Natural disaster records provide data at a municipal level, whereas the rest of the documents provide data at a district level), which makes it challenging for this kind of a study which aims at providing local area-based interventions. The newspaper archives provided detailed pinpoint locations, shown in Fig.32 below.

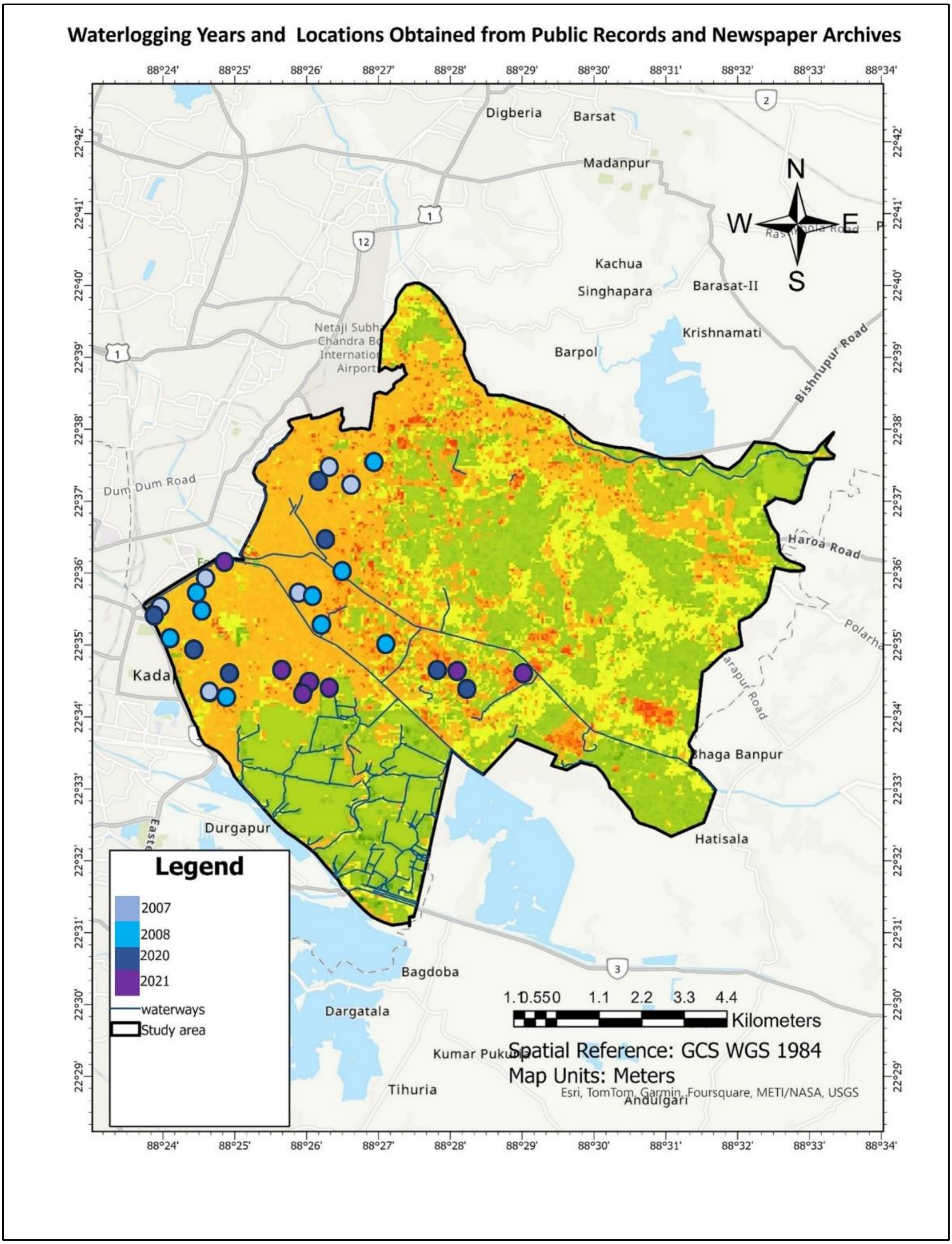


Figure 33: Waterlogging records. Source: Author, (2024)

As observed in Fig.35, the Salt Lake and Rajarhat areas were inundated in 2007 and 2008. At this time, the Newtown project was not yet completed. The problem of waterlogging started in Newtown in the present decade when it started existing as an urban landscape, preventing the natural infiltration of water in the area. However, Kolkata and its surrounding areas received severe rainfall in 2001, followed by a mega flood event in 2005, in which Kolkata received 944 mm rainfall on July 26th. This was the highest ever rainfall recorded in one day in any Indian city, which broke the record of 1978 floods caused by 380mm rainfall in 24 hours (Times of India, 2008). However, data specific to the study area for these events were not found. 2007 and 2008 witnessed normal rainfall, where the peak rainfall in a day was in the month of September (174.4mm and 142 mm, respectively). However, the waterlogging caused by this rainfall has been found in news archives. Hence, it is shown on the map. 2020 witnessed the supercyclone Amphan on 20th May, during which the peak rainfall in a day was recorded for the year (236 mm). This supercyclone caused immense damage and waterlogging and took longer than usual to drain. The high tides in the Hooghly River, which was flowing at its full capacity, aggravated the urban floods. The year 2021 witnessed high annual precipitation, a significant part of which was contributed by cyclone Tauktae (14th -19th May), cyclone Yaas (23rd -28th May) and Cyclone Gulab (24th – 28th September), among which Tauktae was the strongest tropical cyclone of the season. The annual precipitation of 2021 (2112mm) was the highest among all years in the study period (India Meteorological Department, 2021). Clogged water systems are one of the prime reasons behind the frequent water logging in Salt Lake and Newtown. When asked in the survey, 57.84% of the local inhabitants mentioned clogged water systems and manholes (50%) as the main cause of water logging. This is due to the improper solid waste management in the city (Bunting et al., 2010; Das & Das, 2019). A graph denoting the number of responses for each cause of urban floods has been provided herein.

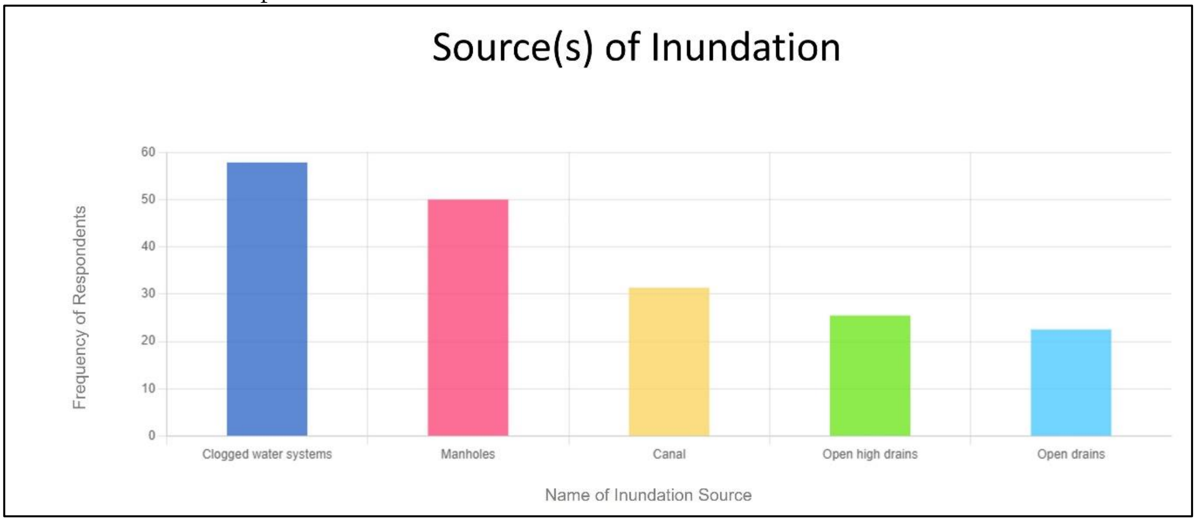


Figure 34: Bar chart showing the frequency of respondents by sources of inundation in the study area. Source: Author, (2024)

The respondents also pointed out some inundation sources, a photograph of which has been provided below.

Figure 35: Clogged drainage system, causing inefficiency and reduced capacity during the rainy season. Source: Author, (2024)

4.2. Sub-objective 2: To explore the suitable NbS measures for the target areas based on their socio-physical characteristics.

Various factors have been considered to explore suitable NbS measures for the identified target areas. These include the socio-physical characteristics of the target areas and the ownership types of different places to suggest appropriate NBS interventions for urban flood mitigation.

4.2.1. Research question 2.a. Which areas can be fit for NbS measures with regard to their physical characteristics?

The areas where NbS can potentially be implemented to reduce the intensity of urban floods are identified based on the areas identified in the SMCA Analysis, as they perfectly align with the existing records and accurately identify the areas susceptible to waterlogging. Hence, the target areas obtained from the SMCA, validated by the stakeholders, have been considered fit for NbS suggestions. The physical characteristics of the area, such as elevation, slope, building morphology and proximity to waterbodies, have been considered when NBS interventions were suggested. The NbS interventions have been provided in section 4.2.3. The Figures 38 to 48 elaborately represent the NbS interventions suitable for each identified location.

4.2.2. Research question 2.b. What are the land use and ownership characteristics of the target areas? (to identify the areas fit for NbS)

Among the 106 participants who took part in the general questionnaire survey and the semi-structured interviews, three major property ownership characteristics in the study area, namely, privately owned properties, rented properties, and government-owned properties, were identified. Among the three property ownership classes, the respondents belonged to different categories. The categories and their shares among the respondents have been provided in Fig.37.

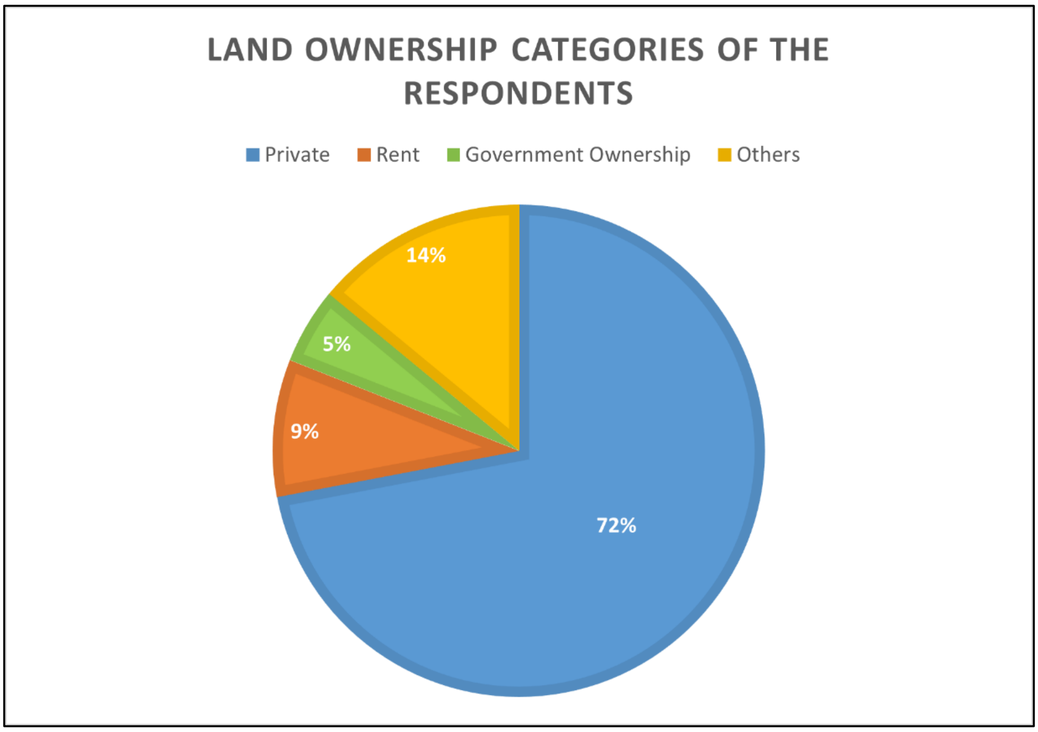


Figure 36: Pie chart showing the land ownership categories of the stakeholders. Source: Author, (2024)

As observed in the pie chart, the majority of the respondents owned properties, followed by other ownership types occupying the second most significant share in the pie chart. This other ownership category is for the people dwelling in slums and shanties without any land tenure security or legitimate documents. The slum inhabitants have been intentionally kept as the target audience to answer the general questionnaire and to analyze the contrast between the socio-economic strata and the applicability of NbS measures.

4.2.3. Research question 2.c. What are the existing NbS measures in the study area?

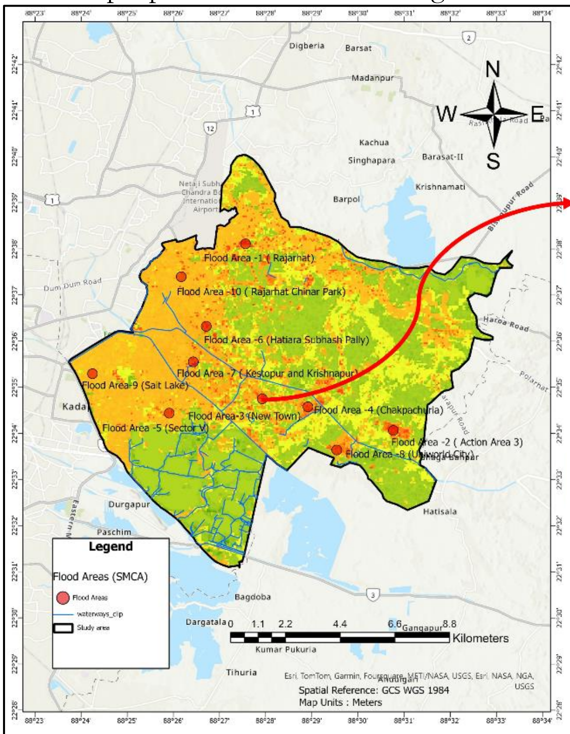
As it has been observed from the general questionnaire and interview transcripts, the local government has been actively working on increasing greens in Salt Lake and Newtown. However, these greens are mainly street trees, porous pavements and green belts in certain places. These interventions are really beneficial and aesthetically appealing. However, interventions that, besides increasing the greens, can also contribute to the groundwater table of the area are what the survey respondents and interviewees are looking forward to (Interviewees 1,2,3 and 4).

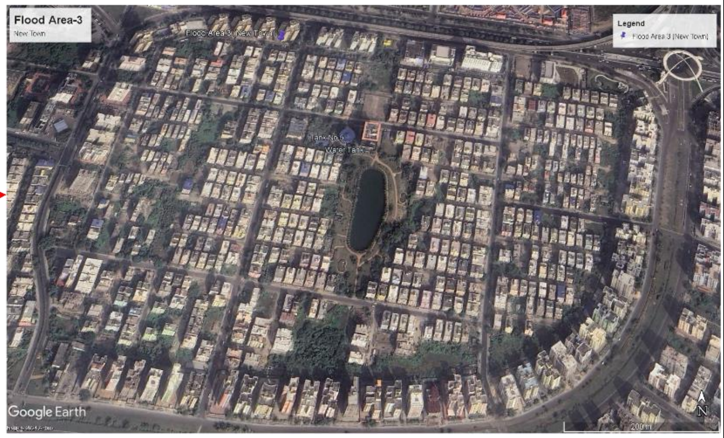
4.2.4. Research question 2.d.Which of the suitable NbS measures shall be appropriate in the target areas to reduce the impact of urban floods?

Some of the suitable NbS measures, based on the responses obtained from the study area and relevant literature, have been provided in this section for the major target areas. The NBS typologies and the degree of stakeholder engagement have also been provided along with each intervention map. Flood areas 1,2 and 8 have been omitted in this section for reasons already stated (3. Methodology, 3.5.3.1). The remaining seven areas have been investigated in detail, and the outcomes are provided in sequential order.

4.2.4.1. Flood area-3 (Newtown)

For Flood Area-3, interventions like Bioswales, porous pavements (NbS type 3), rain gardens (NbS type 2), percolation pits and rainwater harvesting systems (NbS type 3) can be very useful. Newtown, once a land covered by wetlands, after being developed into an urban area, has witnessed reckless extraction of valuable groundwater resources. In the present decade, the area once rich with water-laden aquifers is facing acute groundwater contamination and low groundwater table. This problem not only aggravates the hydrological disequilibrium of the study area but also leads to land subsidence and associated problems. Urban Floods can act as catalysts for these detrimental issues and cause significant damage to life and property. Hence, interventions which, besides greening the landscape, can also recharge groundwater are what the people of the area are looking for.

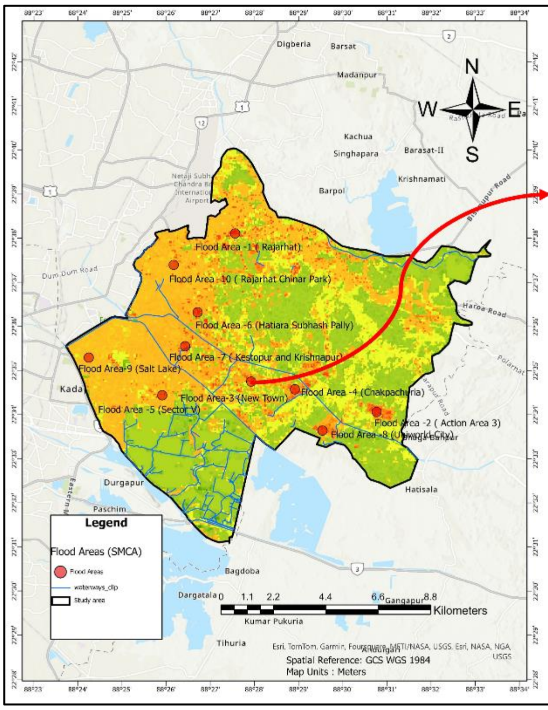




NbS Intervention	Typology	Stakeholders
Bioswales and Porous Pavements	Type-3	Government, Engineers and Municipality
Rooftop Gardens	Type- 3	Local Inhabitants
Rain Gardens	Type- 2	Local Inhabitants and Municipality

Figure 37: Map showing NbS interventions for target area-3 (New Town) suggested by Stakeholders.

As seen on the map, New Town, being a planned urban area, has well-defined blocks of residential and commercial land. All the buildings have big, open and flat rooftops, and some buildings have the extra advantage of open spaces on the ground floor to provide parking spaces and community gathering spots. These areas can be used for rooftop gardening, rainwater harvesting and balcony gardens (NbS type 3), which do not require additional intervention from the municipality (except for constructing concrete tanks on the rooftop for rainwater harvesting) and can be obtained by individual or collective efforts within the housing society. An example of some probable potential interventions has been provided below.



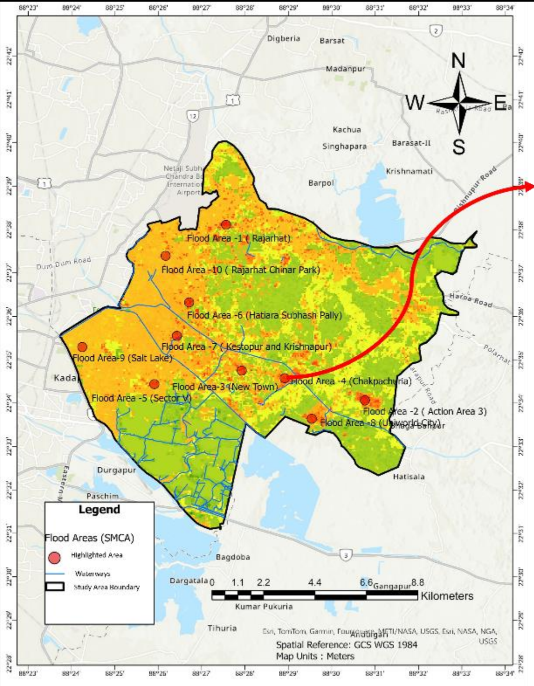
NbS Intervention	Typology	Stakeholders
Bioswales and Porous Pavements	Type-3	Government, Engineers and Municipality
Rooftop Gardens	Type- 3	Local Inhabitants
Rain Gardens	Type- 2	Local Inhabitants and Municipality

Figure 38: NbS Intervention map for Flood Area-3 (Small scale). Source: Author, (2024)

As per Fig.34, the multi-storeyed buildings in Newtown can effectively reduce runoff is adequate NbS interventions can be implemented. It can serve as an effective tool for urban flood mitigation, rainwater storage and nurturing small-scale community gardens or rain gardens in the backyards or available open spaces. In a decade, severe heat stress has become a serious problem in India. Increased greenery on the rooftops can help people reduce temperatures of the building and make the roofs aesthetically more appealing.

4.2.4.2. Flood area-4 (Chakpachuria)

The area of Chakpachuria holds special significance in the study area, as one of the Special Economic Zones (SEZ) is in this area. Besides being a hub of technology and software, Chakpachuria also has University Campuses, training institutes and critical infrastructure (hospitals). Although not explicitly termed as NbS, this area has dedicated significantly to urban greenery by planting and maintaining street trees and making structures resembling Bioswales on the major roads. However, the low-lying road near the end of the Kestopur Canal flyover gets waterlogged, reducing the mobility of goods and services in this main arterial road connecting the SEZ to New Town.



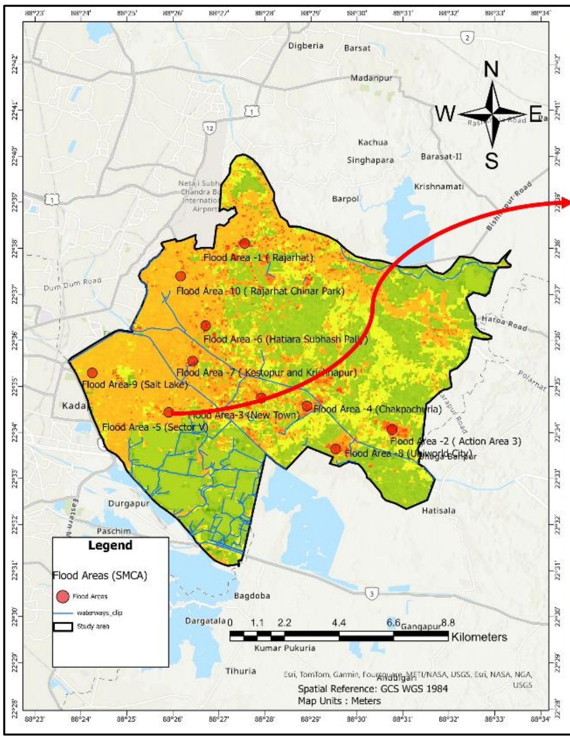
NbS Intervention	Typology	Stakeholders
Bioswale	Type-3	Government, Engineers and Municipality
Percolation Pits	Type-2 and 3	Municipality, Engineers, water management authority (NITA) Authority and Locals
Porous Pavement	Type-3	Private Owner and Engineers

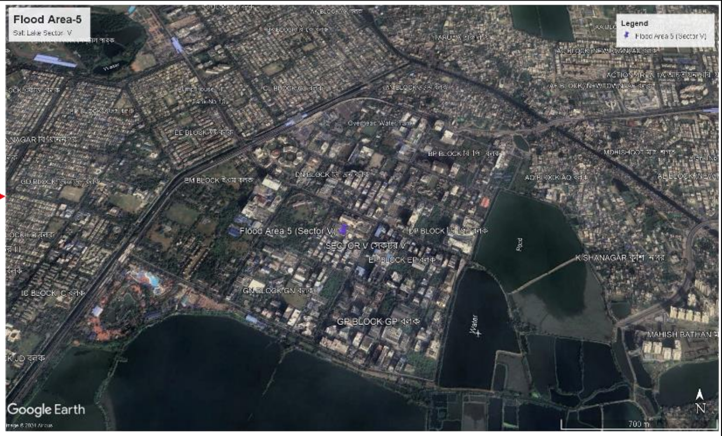
Figure 39: NbS Intervention Map for Flood Area-4. Source: Author, (2024)

The map shows that some of the NbS interventions useful for this area are Bioswales, percolation pits, and porous pavements (NbS type 3). Majority of the concrete land available in this area is privately owned. Hence, additional acceptance and adoption of NbS is required from the private Multinational tech companies and Universities in this area. The large, concretised compounds of the private buildings can also be used for making simple interventions like percolation pits (NbS type 3).

4.2.4.3. Flood Area-5 (Salt Lake Sector-V)

When it comes to urban floods in the eastern part of Kolkata city, Sal Lake Sector-V is one of the major areas covered by news agencies and newspapers. Located in very close proximity to the wetlands, the area's low elevation and the city's natural slope allow water to accumulate in the area. The drainage system often fails to cater to the needs of draining the water because of its utilization at full capacity. Being the office and commercial area of the city, maintained by the Nabadiganta Industrial Township Authority, this area has Government and Private office buildings. The Government tackles the problem of water logging in this area by pumping the water into the canals and natural water bodies of the EKW. Besides that, NbS measures include street trees and porous pavements. According to the respondents to the field survey, these interventions have curbed the problem of waterlogging significantly by reducing the problem of frequent floods. However, a little more exertion can potentially completely mitigate the flooding problem.





NbS Intervention	Typology	Stakeholders
Bioswales and Porous Pavements	Type-3	Government, Engineers and Municipality
Rooftop Gardens	Type- 3	Local Inhabitants/ Companies
Rain Gardens	Type- 2	Companies and Municipality

Figure 40: NbS Intervention Map for Flood Area-5 (Salt Lake sector-V). Source: Author, (2024)

Due to the unique land use and physical characteristics of the area, which is mostly occupied by buildings made of glass exteriors, solutions like balcony gardens may not be an appropriate solution. An example of the building type in the area has been provided below.

Figure 41: Examples of Building type in Flood Area-5. Source: Author, (2024)

Hence, some of the solutions can be bioswales, rooftop gardens (NbS type-2) and rain gardens (Nbs type-3) in some available open spaces or building premises. Other interventions that can be undertaken in this area with the help of the office building companies are rainwater harvesting and percolation pits (Nbs type 3). Community gardens with individual plots can also be an effective intervention to ensure community participation (the working community in this case) and contribute to the overall well-being of the employees (Raymond et al., 2017a) and biodiversity enhancement in the urban area (Donati et al., 2022).

4.2.4.4. Flood Area-6 (Hatiara)

Hatiara, a part of Rajarhat, is a densely populated area with mixed types of households. The houses seen in this area are mostly not more than 4 storeys because of the proximity to the Kolkata International Airport. Another typical characteristic observed in the houses of this area is the covering of tin sheds on the roofs, which makes it difficult to implement rooftop gardens in these houses or apartment buildings. However, this kind of roof with a slope can effectively contribute to rainwater harvesting systems, or drained water can be channelled to rain gardens. Tin roofs are ideal for harvesting rainwater for domestic purposes.

Figure 42: (Left) Example of the type of houses in Hatiara, Rajarhat. Source: 99acres.com (2023) & (Right) Rainwater Harvesting Mechanism with sloped roofs. Source: (Campisano et al., 2017)

Due to the dense population and closely spaced houses, the area's landscape is not ideal for providing potential for large-scale NbS, which was not the case with the planned cities of Salt Lake and Newtown. However, an attempt has been made in this research to provide some potential Nbs interventions to prevent waterlogging in the area. The NbS intervention map has been provided below with an interpretation complementing it.

NbS Intervention	Typology	Stakeholders
Porous Pavements	Type-3	Government, Engineers and Municipality
Rooftop Gardens (only for flat concrete roofs)	Type- 3	Local inhabitants
Rain Gardens	Type- 2	Municipality and Local inhabitants

Figure 43: NbS Intervention Map for flood area 6. Source: Author, (2024)

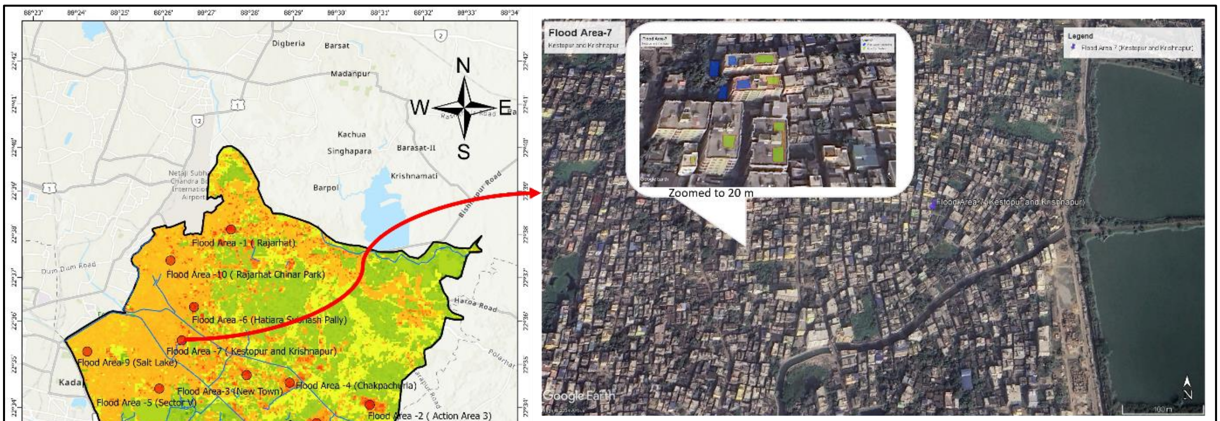
The map provided above shows the location of the flood area in the western part of the study area, aligning with the path of flight arrivals and departures to and from the Kolkata International Airport. This is the reason why the houses and buildings in this area are not high-rise. The prevention of vertical growth has led to continuous horizontal build-up, leading to a mixed physical and socio-economic landscape. The houses in this area are typically characterized by concrete-flat roofs, along with houses having tin/ asbestos roofs or roof sheds. Due to the population pressure on land, houses have been built along the region's ponds and swampy areas. An example of such a construction with an elevated foundation has been shown in Fig.36. In this kind of landscape with narrow streets and dense built-up, porous pavements, rooftop gardens (for flat concrete roofs) (NbS type 3), small rain gardens (NbS type 2) for available back/front yards, percolation pits and rainwater harvesting tanks (NbS type 3) can be some of the effective solutions (Campisano et al., 2017; Daniere et al., 2022; Hawxwell Tom et al., 2019; Pathak et al., 2022).

4.2.4.5. Flood Area-7 (Kestopur and Krishnapur)

Kestopur and Krishnapur are places located near the Kestopur canal, which faces the problem of waterlogging due to both pluvial and fluvial factors. The pluvial cause is the concrete landscape, and the fluvial cause is the inundation of the Kestopur canal due to reduced capacity during rains. The settlement pattern of the study area is dominated by apartment buildings. However, the areas near Kestopur Canal have a vast stretching slum area continuing in a linear fashion along the canal all the way to Salt Lake. The photographs of the slums provided herein were taken during the field visit.

Figure 44: Slums along the Kestopur Canal. Source: Author, (2024)

During the rains and tropical cyclones, even though the people inhabiting the concrete buildings are less likely to be affected, the vulnerability of these settlements to these hazards is very high (Rumbach, 2011a). These slums are made of tin and bamboo, which is not a durable material to withstand weather extremes. A map highlighting the physical morphology of the target area, obtained from Google Earth is provided below.



NbS Intervention	Typology	Stakeholders
Porous Pavements	Type-3	Government, Engineers and Municipality
Rooftop Gardens (only for flat concrete roofs)	Type- 3	Local inhabitants
Rain Gardens	Type- 2	Municipality and Local inhabitants

Figure 45: NbS intervention Map for flood area 7. source: Author, (2024)

The flood area is located on the eastern side of the Kestopur canal. The Newtown Lake is a massive natural waterbody restricting the growth of the urban settlements in the east. Porous pavements, rooftop gardens (NbS type 3) and rain gardens (NbS type 2) are general NbS interventions applicable to the target area. The existing high-rise buildings in the area can be great places to install rainwater harvesting systems, where the runoff water from the concrete roof can be channelled through pipes stored in underground storage tanks and used for multiple purposes, including gardening on the rooftops and balconies. These area- specific interventions have been shown in the 20m scale image. Besides these interventions, which mostly need the involvement of local inhabitants, porous pavements can be made by modifying the existing pavements, as the streets are wide enough to accommodate these pavements.

4.2.4.6. Flood Area-9 (Salt Lake Sector-1)

Salt Lake's Sector 1 is yet another low-lying area prone to waterlogging. Unlike Sector-V, which is characterised primarily by office buildings, this part of the city is dominated by residential buildings. The area has street trees planted on all the major roads. However, this intervention, unaccompanied by other ones of its kind, cannot contribute much to mitigating urban floods. The NbS intervention map of the target area has been provided below.

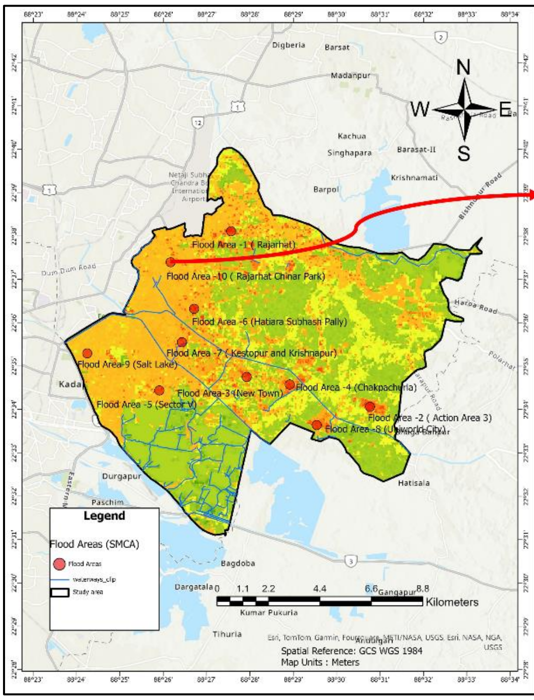
NbS Intervention	Typology	Stakeholders
Percolation Pits	Type-3	Government, Engineers and Municipality
Rooftop Gardens (only for flat concrete roofs)	Type- 3	Local inhabitants
Rain Gardens	Type- 2	Municipality and Local inhabitants
Rainwater Harvesting System	Type-3	Local inhabitants and Municipality

Figure 46: NbS Intervention map for Flood Area-9. Source: Author, (2024)

Some NbS interventions that can be applicable in this area are percolation pits in the local playgrounds and open spaces, rooftop gardens and rainwater harvesting systems (NbS type 2). Interventions like Rain gardens (NbS type 3) can be executed by local inhabitants and can gain much more acceptance if the municipality encourages the implementation of these interventions.

4.2.4.7. Flood Area-10 (Rajarhat Chinar Park)

Rajarhat Chinar Park has developed as an essential central area connecting Kolkata, the airport, Salt Lake, and New Town, with major roads crossing this area. The major reason behind this area's waterlogging is the unplanned and haphazard development of the concretized landscape, making it susceptible to waterlogging. Being an area prone to heavy traffic flow and congestion, this area does not have street trees. However, they might be implemented once the ongoing metro railway project is completed. However, by zooming into one of the main arterial roads of Chinar Park at a 20 m resolution using an Airbus image obtained from Google Earth Pro, some appropriate area-specific NbS interventions have been pointed out. The map below represents the same.



NbS Intervention	Typology	Stakeholders
Percolation Pits	Type-3	Government, Engineers and Municipality
Rooftop Gardens (only for flat concrete roofs)	Type- 3	Local inhabitants/ Housing Committees
Rain Gardens	Type- 2	Municipality and Housing committees
Rainwater Harvesting System	Type-3	Housing Committee and Municipality
Bioswales	Type-3	Government, Municipality

Figure 47: NbS Intervention Map for Flood Area 10. Source: Author, (2024)

The NbS interventions which can possibly be implemented in this small segment of the big area show the vast diversity of NbS interventions which can be implemented in the entire area either solitarily or in combination (e.g., rainwater harvesting system and rain garden). Some of the NbS interventions suggested for this segment of the flood area are percolation pits, rooftop gardens, bioswales, rainwater harvesting systems (NbS type 3) and rain gardens (NbS type 2).

4.2.4.8. General Synthesis

These urban areas of Rajarhat, Salt Lake and New Town had large tracts of wetlands (swamps and riparian vegetation), which were converted into cities to accommodate people of middle-income groups and make the area emerge as another SEZ. The demand for land and the creation of new employment opportunities led to an influx of people from the main city and rural Bengal, further driving the housing demand. The transit routes connecting these areas also started to become inhabited by people. The increase in these impervious surfaces led to the encroachment of the natural wetland resources and reduced their capacity to filter and infiltrate runoff and sewage water from Kolkata and these new urban townships. The sub-sections above have suggested A few nature-based solutions to address this flooding issue. Due to the diverse land types prevalent in different parts of the study area, generalisation of NbS interventions like "one cap fits all" would not be possible. However, in this section, an attempt has been made to provide a general synthesis of the NbS interventions. Table 10 provided below highlights the NbS interventions, their benefits, and the rationale behind implementing them in a specific area.

Table 10: Area-specific NbS interventions and their relevance.

Nature Based Solution	Areas	Rationale	Wider goals
Bioswales, Porous Pavements, rain gardens, percolation pits and rainwater Harvesting systems	Salt Lake, Newtown, Kestopur, Rajarhat	These interventions are particularly effective in mitigating urban floods by recharging groundwater. These interventions can reduce runoff in these areas dominated by built-up landscapes. These interventions can specifically benefit Salt Lake and Newtown, which have significant groundwater depletion.	Ground Water recharge and prevention of runoff.
Rooftop gardens and balcony gardens	Salt Lake, New Town, Kestopur and Rajarhat	These interventions can be implemented in privately owned homes or housing societies managed by a housing committee, where, with individual or collective efforts, greenery capable enough to store rainwater can prevent overwhelmed drains if implemented at a large scale. However, these two interventions are only applicable for owned flats or houses and rooftop gardens, depending on whether the roofs are flat concrete roofs. Closed or shaded roofs are not ideal for rooftop gardens.	Reduction of runoff, storage of rainwater and increase greenery.
Street trees and community gardens	Salt Lake and Newtown	Salt Lake and Newtown cities are planned areas, and they have dedicated spaces for greens, which can enhance community participation by implementing community gardens.	Infiltration of water, and Greenery development.

		Street trees, which are commonly observed in these areas, can be increased further to infiltrate water into the ground.	
Mixed interventions	Hatiara and Chinar Park (Rajarhat)	Rajarhat, being very densely populated, can accommodate sophisticated NbS interventions like bioswales with a very limited scope due to the dense built-up. However, the mix and match of NbS measures like percolation pits, rooftop gardens, small rain gardens and rainwater harvesting systems (on roofs with tin shades) can significantly contribute to the reduction of waterlogging.	Rainwater harvesting and infiltration
Prevention of inundation from canals	Areas adjacent to Kestopur and Bagjola Canals	For areas adjacent to the Kestopur and Bagjola canals, porous pavements, percolation pits, and large-scale rainwater harvesting systems can be effective measures. Additional measures such as greenery enhancement can contribute to biodiversity enhancement.	Rainwater storage and infiltration.

4.3. Sub-objective 3: To investigate the awareness of the study area's stakeholders of NbS and their willingness to invest in NbS.

This section delves deep into the awareness of the stakeholders about NbS interventions and their willingness to invest in such initiatives. The section also highlights the socio-economic contrasts when implementing NbS in an area like East Kolkata Wetlands is concerned. Before delving deep into the responses obtained from the stakeholders, a profile showing the distribution of the stakeholders from different housing types is provided in Fig.49.

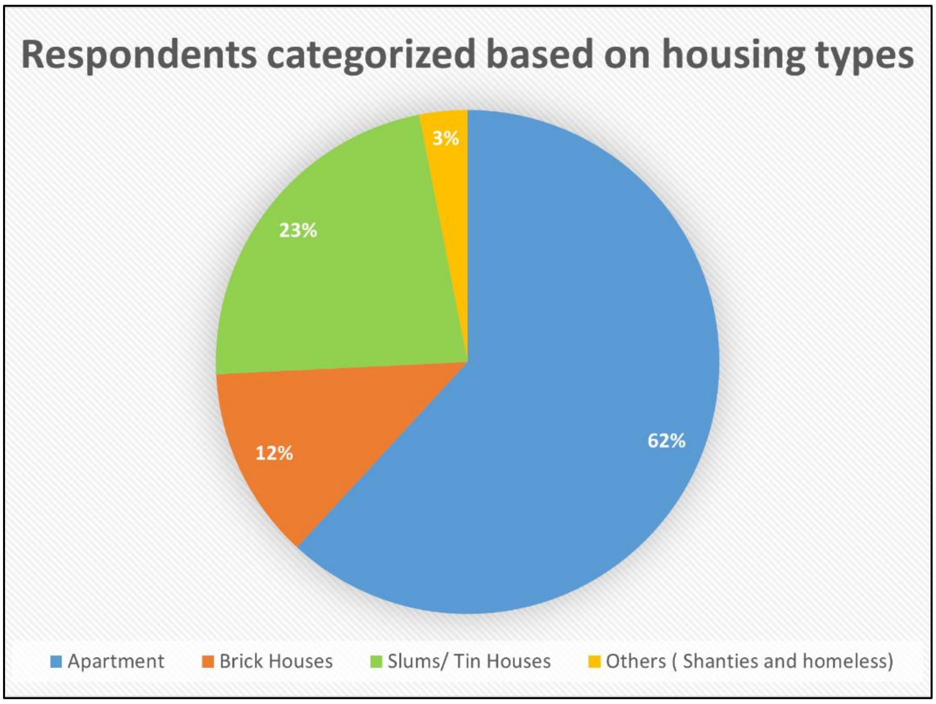


Figure 48: Distribution of responses across different housing types. Source: Author,(2024)

As seen in Fig.49, the distribution of the respondents is not even across the different types of houses due to reasons such as:

- Dominance of multi-storeyed apartment buildings in the study area.
- The study area, being a gated community, had fewer respondents among the owners of private brick houses.
- Lack of awareness about government interventions or NbS among the people living in slums and government rehabilitation colonies (Tin houses).

Hence, the graphs provided in the following sections have a higher trend toward respondents living in apartment buildings.

4.3.1. Research question 4.a. What are the existing NbS measures taken by the government/local governing bodies, and why are they taken?

In the context of Kolkata, although not explicitly termed NbS, some of the measures the government has undertaken are in some areas, particularly in Newtown and Salt Lake cities. These measures include planting street trees and green belts akin to community gardens and rain gardens, installing porous pavements, and creating public green spaces (Interviewee 3). The government took these measures as a measure to compensate for the greenery of the urban areas, which was compromised during the making of these cities and had impacts on the biodiversity of the wetlands as well (Karmakar, 2022; Paul & Bardhan, 2017; Sen, 2020). The establishment of these green spaces also aims to mitigate of the adverse effects of urban flooding and heat stress by enhancing urban biodiversity in these concretised environments. This approach aligns with the overarching government initiative of the Green City Mission, which focuses on integrating sustainable practices within the spatial planning frameworks(Karmakar, 2022; Mukherjee, 2022; Sen, 2020). Some examples of green city initiatives are provided in Fig.50.

Figure 49: a) Street Trees, b) Public Green Space, c) Unpaved Walkway, d) Porous Pavement, e) Green Belt. Source: Author, (2024)

The general questionnaire gave insights into the accessibility of green spaces and its relation to the socio-economic status of the respondents. The accessibility to these public green facilities varied greatly based on the type of houses and the socio-economic strata of the society, as shown in Figure 51.

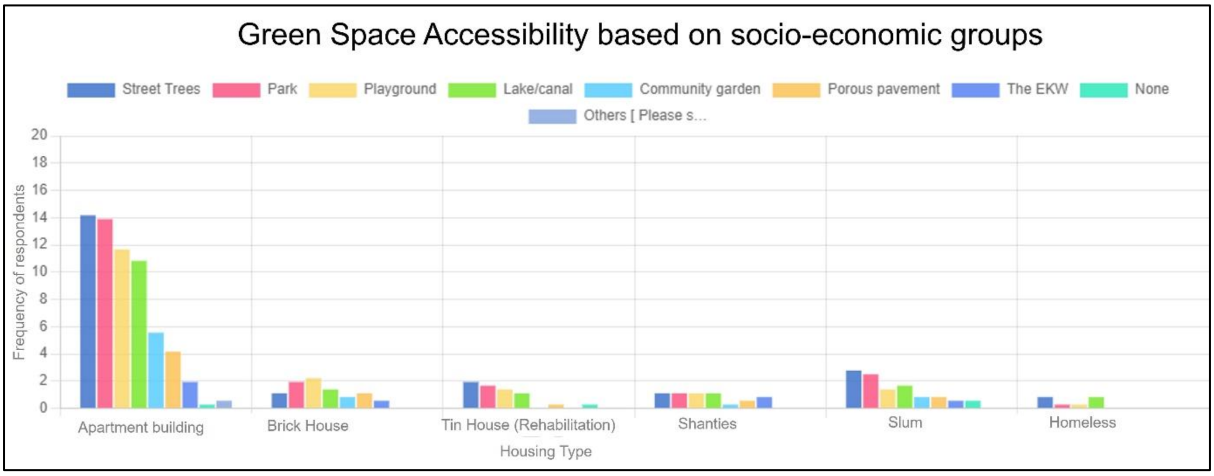


Figure 50: Green Space Accessibility Graph. Source: Author, (2024)

This analysis of the general questionnaire reveals a stark difference between the accessibility of green spaces when it comes to the socio-economic status of the inhabitants. The inhabitants of apartments, which are the dominant built-up types near these green spaces, have the highest accessibility and benefits derived from these initiatives compared to the people living in slums, shanties, and streets.

4.3.2. To what extent are the residents of the study area aware of Nature-based solutions?

Semi-structured interviews aided in finding the answer to this research question. The initial phase of the interviews facilitated discussions by querying stakeholders about Nature Based Solutions (NbS). The stakeholders mentioned that although the term NbS is relatively new and novel, they could find synonymous terms such as sustainable infrastructures, green infrastructures, or green and blue scapes. These terms were either a part of their previous works or are widely popular terms often used in spatial plans. However, when asking people from the administrative bodies and providing examples of NbS interventions, they mentioned that similar kinds of initiatives have been implemented in some places but on a very small scale, which is insufficient to tackle the problem of urban floods comprehensively (Interviewees 1,2 and 3). Hence, more investment in this field is desired by the stakeholders, who are intrinsically motivated to use NbS interventions of all typologies (type 1, type 2 and 3) in the urban spaces of east Kolkata and contribute to a better future for residents of the area by enhancing their living conditions and contributing to the urban aesthetic of the area. The study area's residents also identified similar concepts and terms associated with NbS. Fig.52 shows the overall awareness of the stakeholders.

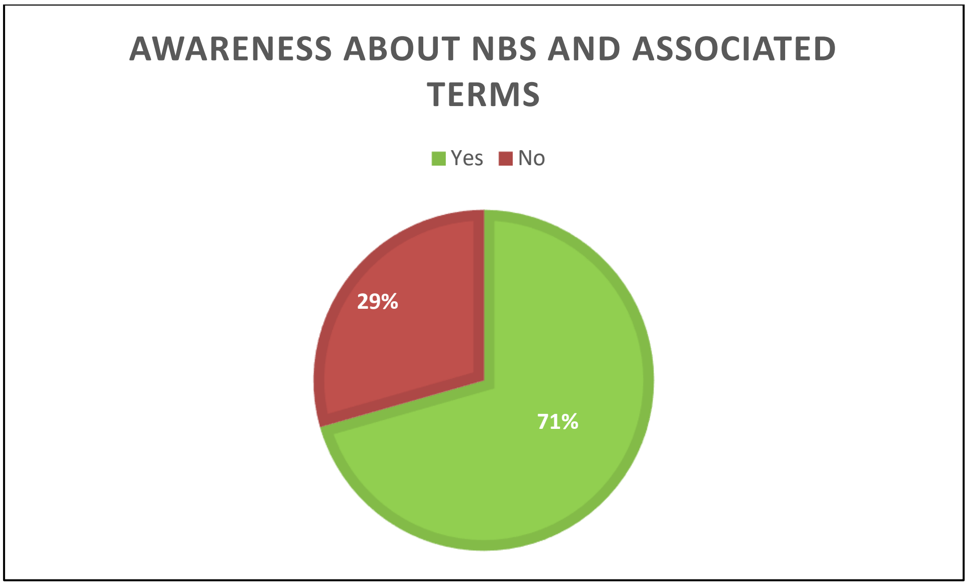


Figure 51: Stakeholder's Awareness about NbS and associated terms. Source: Author, (2024)

The stakeholders from different professions were aware of the need to conserve green and blue spaces to protect the environment. They readily admitted about the awareness of NbS and associated terms. The population which was unaware of these sophisticated terms were the deprived section of society dwelling in the slums. However, explaining the concept in vernacular language helped gather data from these respondents. The semi-structured interviews served as an effective methodological tool to assess the awareness of the stakeholders within the study area.

4.3.3. What is the perspective of the governing bodies regarding integrating NbS in existing spatial plans (perceived benefits and drawbacks)?

The Governing bodies have already started considering the importance of implementing Greens and protecting the existing natural spaces which provide valuable ecological services. With the help of the semi-structured interviews, it was found that besides the Greenery development in the study area, the government is ensuring strict vigil over the EKW to prevent illegal encroachment. However, the development of urban areas in the east Kolkata wetlands, which is known to have received runoff water from the Kolkata City since the colonial era, posed a serious risk of urban floods in these cities (Mitra &

Banerji, 2018b). Rapid urban development has also brought another drawback: loading ponds and freshwater bodies with mud and constructing buildings. The Urban expansion also encroached on some parts of the East Kolkata Wetlands, which were environmentally protected areas identified as RAMSAR convention sites. However, the government attempted to compensate the big and small filled water bodies, which comprised 20,950,000m². This venture has been able to excavate and replenish 1,130,000 m² of water bodies (Ghosh P et al., 2023). As a part of NbS typology 1, the prime focus is maintaining the existing natural expanses, such as riparian vegetation and waterscapes (Alves et al., 2024; Hawxwell Tom et al., 2019). The governing bodies are laying their primary focus on this aspect, as they are aware of the immense contribution of the East Kolkata Wetlands in filtering the waste waters (Banerjee Sarmila, 2017; Bunting et al., 2010; Rumbach, 2011a). Although the spatial plans mention about compensating the lost greens and blues, the reality is different, where the pace of built-up has overpowered and suppressed the replenishment of natural resources and exploiting other land use zones such as agriculture and aquaculture (R. Paul et al., 2021). Despite these drawbacks, the government is willing to invest in NbS interventions, which, according to the stakeholders, can work synergically with the engineered solutions and help in impact reduction and mitigation of urban floods. The stakeholders mentioned that NbS could provide enhanced resilience to urban flooding, it can be a cost-effective measure to implement, and also foster community well-being. It is noteworthy to mention that the stakeholders consider NbS interventions to be a multifaceted approach that provides several potential benefits to tackle the challenge of urban floods.

4.3.4. How much are the residents willing to invest in Nature based solutions?

The residents of the study area were willing to invest in nature-based solutions, as they were the ones experiencing the waterlogging directly, and supported implementing NbS interventions to reduce and mitigate the impact of urban floods and mitigate them. The willingness of the stakeholders was measured in the Likert Scale. This data was then grouped with the Housing types to understand the distribution of responses across different house types (Fig.53).

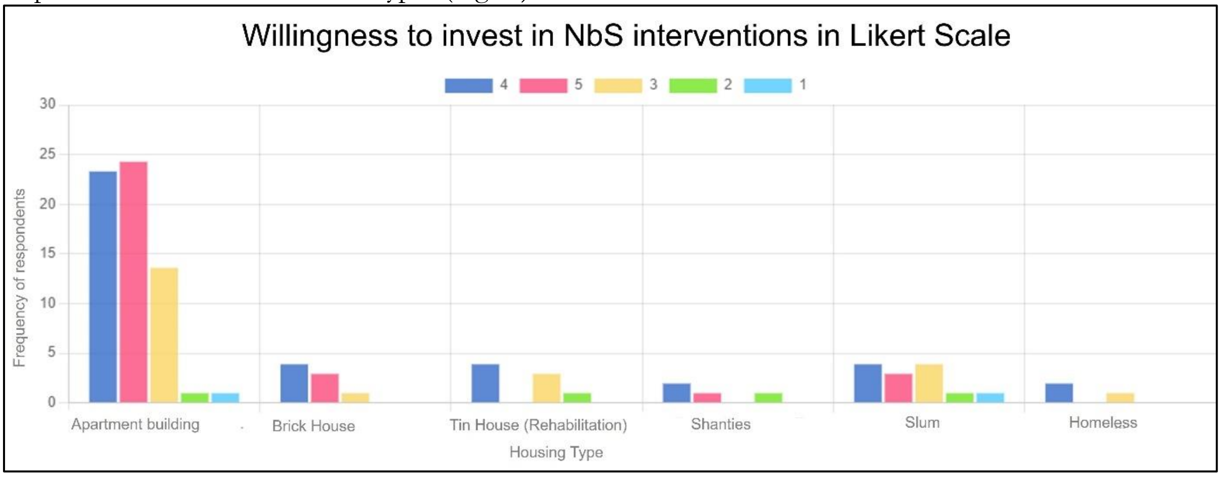


Figure 52: Willingness of the people to invest on NbS interventions measured in Likert scale. Source: Author, (2024)

When the locals were asked about their willingness to invest in NbS, they mentioned that they were highly motivated to implement these interventions, but mostly at an individual level, which comprised mainly balcony and rooftop gardens. However, this willingness also had limitations on ownership of the property. Some inhabitants live in rented apartments, where they do not have the right to change or retrofit some apartments with plants or rainwater harvesters. As the statistics reveal, the willingness of the local inhabitants was very high when measured on a Likert scale. Fig.54 denotes the same.

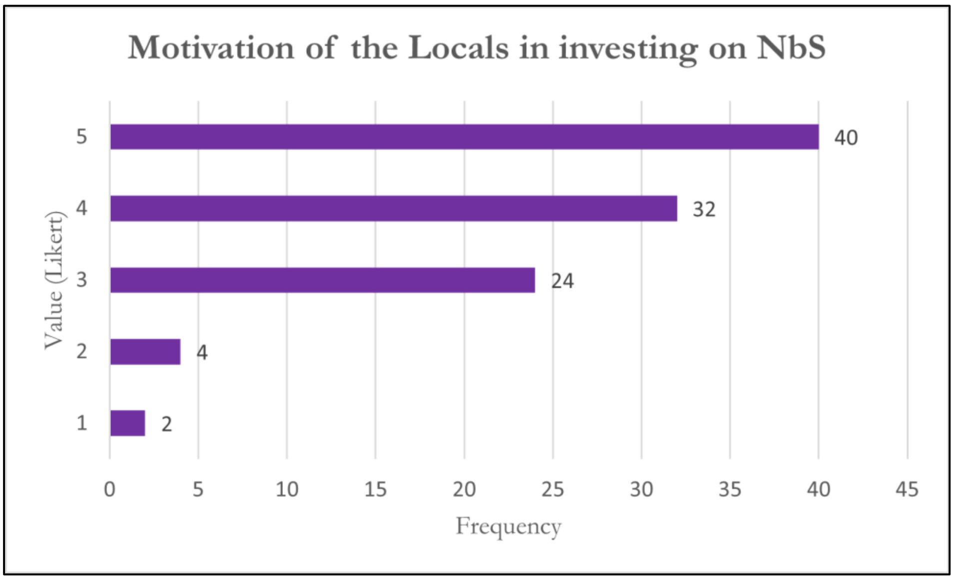


Figure 53: Individual willingness to invest in NbS interventions. Source: Author, (2024)

The graph (Fig.54) depicts that with changing socio-economic status, the willingness to invest or implement NbS at an individual level greatly changes. This result displays the real trend despite the skewness of the samples toward apartment dwellers, as the people who have their ownership of property (Fig.37) were mostly the ones who had the space and resources to invest in NbS interventions such as balcony gardens, yard gardens, green roofs (NbS type 3) and rain gardens (NbS type 2). Whereas the people living in slums and shanties do not have enough space or resources to implement these resources. When asked about other ideas for NbS interventions, the stakeholders also came up with some nice ideas as shown in Fig.55.

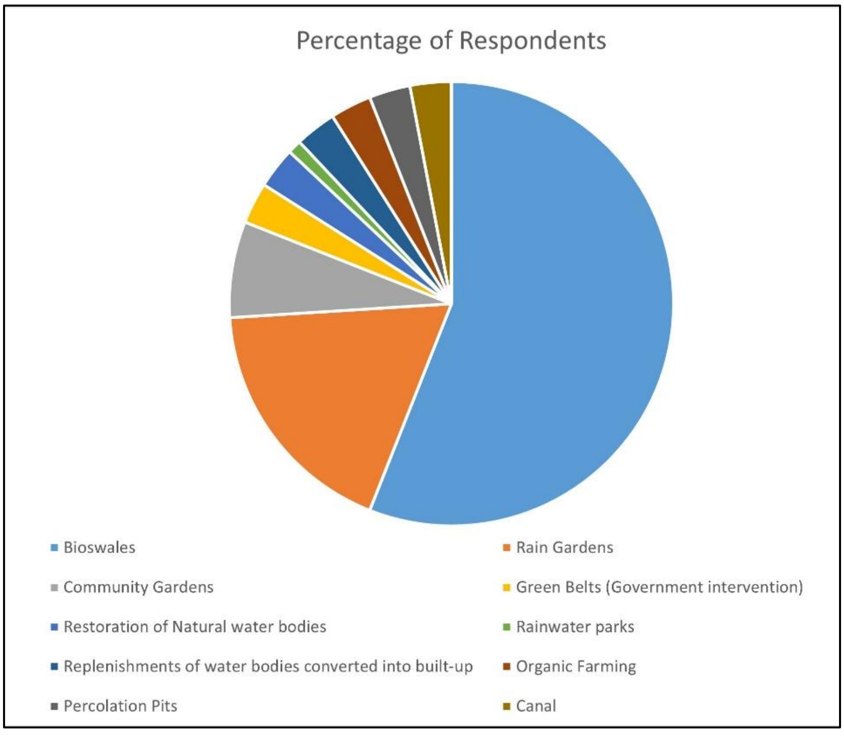


Figure 54: Suggestions obtained from the residents of the study area. Source: Author, (2024)

4.4. To assess the effectiveness, feasibility, benefits and drawbacks of NbS for flood mitigation in the East Kolkata Wetland region.

The information regarding this question was derived from the stakeholders who participated in the semi-structured interview. When asked about the feasibility of implementing NbS in the East Kolkata Wetland area, unanimous positive responses from all the stakeholders were obtained.

When asked about the benefits and drawbacks of NbS, the stakeholders mentioned the various benefits of NbS interventions, starting from maintaining ecological balance, groundwater recharge, urban flood mitigation and cooling the temperature of the area during summers. Additionally, the interviewees also mentioned the capability of NbS to improve the aesthetic appeal of the city, foster well-being, and generate employment for the marginalized sections of society in the care and maintenance of these interventions.

Some of the drawbacks that the stakeholders pointed out were related to the lack of maintenance post-implementation of NbS. The key informants also mentioned potential diseases that could affect these artificial ecosystems and impact the overall success of NbS. Some stakeholders are of the view that if more NbS interventions capable of infiltrating groundwater are implemented, they can tackle the grave problem of reducing the groundwater table and reduce the impact of Urban floods to a great extent. The NbS interventions supported most by the stakeholders are Bioswales and Rainwater Harvesting systems, which, according to them, can work most efficiently in the overall physical landscape of the study area. However, when questioned about their opinion regarding the efficiency of the existing engineered infrastructure to mitigate waterlogging, a different perspective was obtained from the two distinct groups of the society.

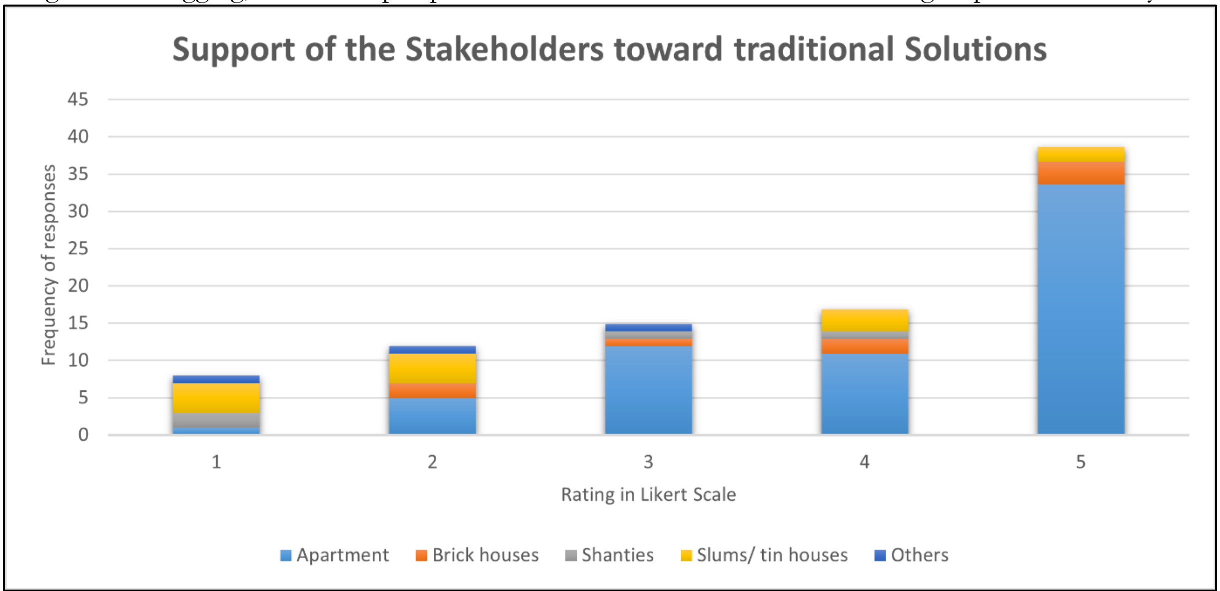


Figure 55: Graph showing the support of the stakeholders living in different households toward traditional flood mitigation methods. Source: Author, (2024)

In Fig.56, it is observed that there is a sharp contrast in the support toward engineered solutions by the inhabitants of concrete houses or buildings situated within the cities, who have mostly given a 3, 4 or 5 rating to engineered solutions on the Likert Scale. Although Fig.56 is influenced by the number of samples, it shows the trend effectively. When it comes to the people living near the drainage systems, who are mainly slum dwellers, live in shanties or are rehabilitated by the government (tin house dwellers), have a strong indentation towards alternative solutions, as the water drained by the physical drainage infrastructure is directed towards the areas where they live, causing a prolonged period of water logging. This period of water logging in the slum areas varies from 3-4 days up to a week. The sample

4.4.1. How do the governing bodies perceive the effectiveness and feasibility of implementing NbS in flood-prone areas?

The governing bodies and key informants are of the view that NBS interventions can be a very good addition to the engineered solutions that help prevent and tackle waterlogging. While no other artificial greening can be as effective as the protection of the existing expanse of the East Kolkata Wetlands (NbS type 1). In this context, the stakeholders suggested an adaptive co-management model to manage the ecological transformations. The involvement of private companies in funding and maintenance of the green and blue spaces is welcomed by the governing bodies. NbS is stated to be effective in preventing further degradation of the EKW and mitigating the effects of storms and floods, enhancing resilience in urban landscapes. The stakeholders specifically acknowledged NbS as a mechanism capable of complementing engineered solutions and bolstering urban resilience against urban flooding. Conversely, the stakeholders also reflected on the limited awareness, resource constraints, lack of maintenance by governing bodies, and lack of post-implementation monitoring and care as drawbacks to NbS interventions

When it comes to the feasibility of implementing these solutions, there are no specific initiatives or guidelines concerning NbS in the study area. While the stakeholders agree with the variety of benefits obtained from NbS if they work synergically with the existing flood mitigation measures, they lay more emphasis on awareness enhancement and collective efforts from the local housing societies, committees, clubs, and NGOs. The governing bodies support co-management of this kind of initiative rather than being solely responsible for planning and implementing these interventions. One of the best solutions they can think of, after getting some insights from the residents of the study area, is a participatory and inclusive planning approach, which involves multiple stakeholders and works towards a successful and wise utilization of finite monetary resources.

4.4.2. What are the potential benefits and drawbacks of implementing NbS in east Kolkata, and how do they compare to conventional flood management strategies?

Compared to the conventional flood mitigation strategies, the NbS can be an effective way to infiltrate the stormwater instead of focusing on draining out all the runoff water, which involves a lot of costs and takes a lot of time as high and low tides impact the water levels in the Hooghly River, which sometimes flows in its full capacity (Interviewee 4).

Rather than pumping the water out of the area, it can be kept within and used for multiple purposes. This will not only help the inhabitants have access to clean freshwater resources but will also improve the hydrological equilibrium of the area. According to the stakeholders, the benefits of NBS interventions outweigh their drawbacks. Hence, it can be a great solution to the problem of urban floods in the East Kolkata Wetland region (Interviewees 3 and 4).

4.4.3. What are the key factors influencing the adoption and acceptance of NbS among stakeholders in the context of urban flood management?

The vast benefits provided by NbS interventions are one of the dominating factors intrinsically motivating the stakeholders to implement them. Besides that, the increasing hydrological problems (pluvial flooding and the decline in the groundwater table) and the reduced capacity of the wetlands have made the local inhabitants and administrative bodies serious about solutions (Interviewee 4).

The failure of the drainage systems during heavy rains can be dealt with successfully if NbS interventions are adequately implemented. If the NbS interventions can successfully infiltrate water and act as a sponge to store water in structures such as bioswales and rain gardens, water will not be flowing out of the study area as runoff and can be used for multiple purposes (Interviewees 2, 3 and 4). Rainwater harvesting systems, if widely implemented, can significantly reduce the changes of urban flooding. A higher density of vegetative cover can effectively intercept water and transfer it directly to the soil (Interviewees 3 and 4).

The Stakeholders don't want to depend on any single method of tackling the problem of urban flooding (the engineering solutions in this case) (Interviewees 1,3 and 4). Rather, they want something to enhance the efficiency of these engineering solutions. The amount of runoff discharge that is directed towards the Kestopur and Bagjola canals can be significantly reduced with the help of NbS and by decreasing the pressure on the drainage infrastructure. The dependency of the governing bodies on engineered solutions has retarded the research and implementation of natural and cost-effective alternatives (Interviewees 3 and 4). According to the key informants (Interviewees 1,2, and 3), further research on NbS and increased awareness of the same among the different governmental and non-governmental organizations can facilitate informed decision making for the bright future of NbS in the city.

The cost-effective implementation of NbS is yet another factor that has encouraged the administrative bodies to accept the NbS measures (Interviewees 1 and 3). The government has already witnessed the success of the interventions which were a part of the Green City program. The effectiveness of their first step towards sustainability and urban greenery has further encouraged them to explore other possibilities for mitigating urban floods, working synergically with nature rather than exploiting it. Through the interviews, it was also found that the ecological importance of NbS, the potential socio-economic benefits provided by it, and stakeholder engagement and collaboration are some of the factors which are acting as forces driving the governing bodies to implement NbS. The discussions also highlighted the relevance of NbS in providing ecosystem services and also livelihood opportunities to the marginalized section of the society.

5. DISCUSSION

In this chapter, the results of the research are discussed in detail. This section of the thesis critically reflects on the urban expansion, the shrinkage of the East Kolkata wetlands and the resultant waterlogging. Besides that, the target areas and the applicable NbS interventions will be dealt with elaborately. Furthermore, this section will give an overview of the existing NbS interventions and the awareness and willingness of the stakeholders to invest in interventions like NbS for flood mitigation. The limitations encountered during the course of the study are also provided in this chapter.

5.1. Relationship between Urban Expansion and Urban flooding

The first objective of the research was to find out the relationship between urban expansion and urban flooding in East Kolkata, which comprises Rajarhat, Salt Lake and Newtown, which are the urban areas which were large tracts of swamps and riparian ecosystems till the late 20th Century (M. Chakraborty & Banerji, 2016). To deal with the acute housing crisis in Kolkata city, the Government of West Bengal decided to make the stand-alone city of Salt Lake to provide affordable and good quality houses to the teeming upper middle-class population, which had been added to the city population during the partition of Bengal (Deilmai et al., 2014). However, as future events showed, the area became characterized by the dwellings of the urban elites.

The growing demand for land and opportunities in these areas led to a huge inflow of population from the main city and the rural areas of Bengal, generating further housing demand. This population, in turn, gave rise to yet another isolated city named New Town in the last decade. Gradually, the transit routes connecting these cities were also inhabited by people, mostly characterised by a mixed socio-economic structure. This rapid urban expansion in the last three decades has given rise to the potential risk of urban flooding to the inhabitants of the area, which may be specific even to a particular community of society (Rumbach, 2014). The land use/land cover of the area was mapped for the study period in a decadal order for the years 2001,2011 and 2021, respectively. The accuracies obtained from the maps were 79.5% for 2001, 91.5% for 2011 and 96.3% for 2021. Generally, the accepted level of accuracy for classifying images with five classes is 80% and above for academic research, with no individual class having an accuracy of less than 70%. Accuracy levels of 90% and above are considered indicative of well-performed image classification (Tilahun, 2015; Van Thinh et al., 2019). However, in this case, for the year 2001, the accuracy is lower than in 2011 and 2021 Land use/ land cover maps due to the coarse resolution of the image despite being of the same spatial resolution and factors such as misclassified classes, having a significant impact on the accuracy. An example of a class which has been classified differently due to differences in reflectance during dry and wet conditions is provided in Fig.57 below.

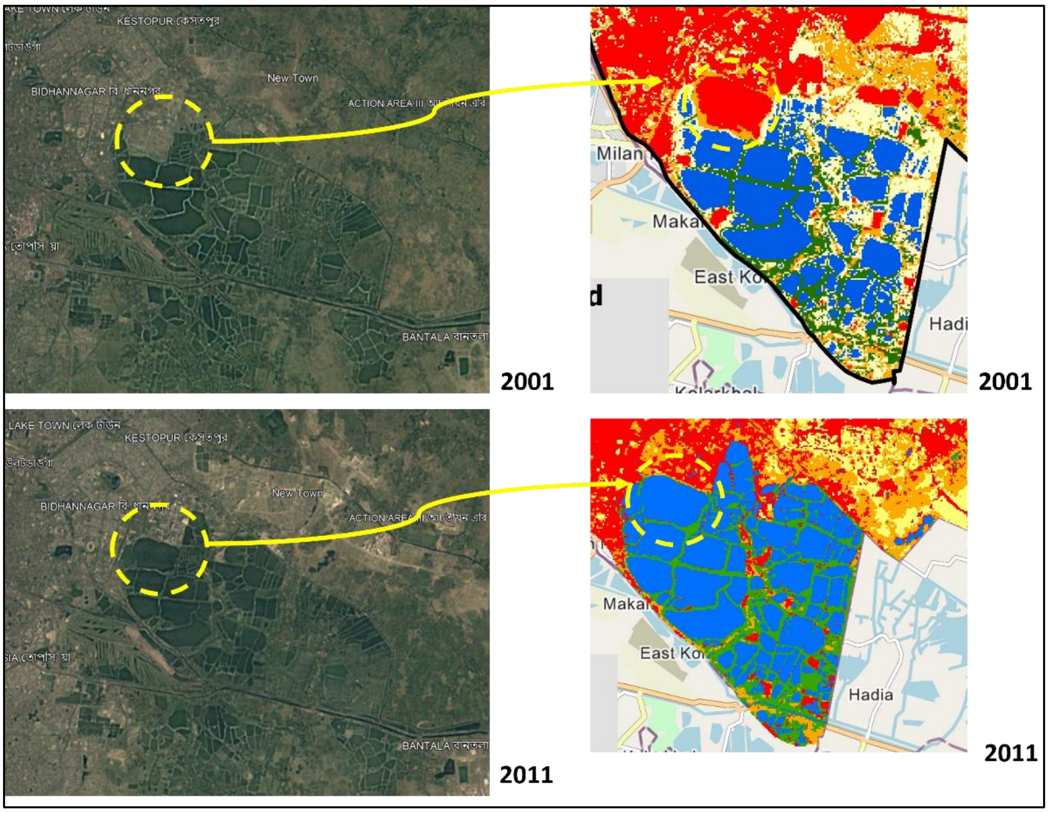


Figure 56: Image showing misclassification of a waterbody as built-up in 2001 due to the absence of water. Source: Author, (2024)

The above image (Fig.57) shows a waterbody of the East Kolkata wetlands being classified in 2001 as built-up due to the absence of water. However, in 2011, it was classified accurately. As a precautionary measure, to prevent potential biases and inaccuracies caused by seasons or cloud cover, the images used for the classifications were acquired for the month of February for all years, during which the skies are relatively less cloudy, and the natural resources remain the same. Another noteworthy observation that was made during the analysis was the low accuracy for 2011 and 2021 using the Maximum Likelihood Classification method, which was used for the 2001 image. When the images of 2001 and 2021 were again classified using the Support Vector Machine (SVM) method, the accuracy was quite high and matched with the ground truth. When the same method (SVM) was applied in 2001for, maintaining uniformity, the accuracy was quite low compared to the 79.5% obtained from Maximum Likelihood. Upon studying about the possible reasons behind the discrepancies, it was found that because SVM uses a hyperplane model to separate classes, it yielded good results for 2011 and 2021. However, since the class distinction of the 2001 image was relatively unclear compared to 2011 and 2021, Maximum Likelihood Classification, which uses Gaussian distribution to identify pixels belonging to each class, gave more accuracy (Deilmai et al., 2014; Van Thinh et al., 2019).

The existence of Salt Lake and Newtown has changed the land cover of the East Kolkata wetlands, directly impacting the exposure of these areas to different natural hazards, urban flooding being the prime among them. As observed in the public records of disasters released by the government for the time frame of 2001-2021 (study period), there has been a notable increase in urban flood events. Indian monsoons are very unpredictable, producing varied amounts of precipitation in different years. The development of hard surfaces had reduced the capacity of the East Kolkata wetlands to infiltrate and filter waste waters, which is received from Kolkata city as well (due to its natural slope from west to east) (Mitra & Banerji, 2016, 2018b; Rumbach, 2011b).

The impervious surfaces have contributed significantly to the urban floods, as the area, being a low-lying area, naturally receives water from all directions. The stormwater, after flowing through the drainage systems and overwhelming them to their full capacity, inundates the urban landscapes. This pluvial flood water is drained out of the urban areas using traditional engineering approaches such as pumping and dependency on drainage by increasing the capacity of the canals by dredging them before the onset of monsoons (Ghosh et al., 2023; Ghosh & Das, 2020; Mitra & Banerji, 2016). The inhabitants of the cities living in concrete buildings get a safe shelter during the monsoons and extreme events such as tropical cyclones. However, the strata of society which is worst affected by these events are the people living in slums and shanties in different parts of the cities and their peripheries in small clusters.

As seen in the results of the Land use Land cover maps of the study period, it is evident that there has been a significant increase in built-up, including the birth of the New Town city, which is well captured in the maps. The study area witnessed 24.5% built-up growth in the last 20 years, which is attributed to approximately one-fourth of the study area's total area. Most of the areas susceptible to flooding obtained from the SMCA analysis, field surveys and the public records and new archives identify the areas having high built-up concentration and relatively lower elevation and slope compared to the surrounding landscapes, causing the accumulation of runoff water flowing into these places from the surrounding impervious landscape. The SMCA pointed out a total of ten target areas using variables like built-up, vegetation, slope, elevation, and rainfall, which accurately coincided with the secondary data. This shows the direct linkage between urban expansion, the proliferation of impervious landscapes and urban floods.

5.2. Exploring suitable NBS Interventions for the identified target areas

In this part of the thesis, appropriate area-specific NbS measures have been suggested. The target areas derived from the SMCA map have been studied carefully, considering their socio-physical characteristics. The physical characteristics are the types of houses, available open spaces, available space in the streets, open spaces in front or back of the buildings and existing green spaces. These parameters helped us understand the feasibility and availability of land for NbS interventions. The socio-economic characteristics of the areas were analysed based on the location of slums and local knowledge of the study area. The seven areas that were finalised for NbS interventions have been critically analysed using field data (Survey and interview responses), local knowledge, and Google Earth images.

In the course of this analysis, the existing NbS measures were taken into consideration, and further suggestions for their efficiency enhancement and new NbS interventions were given along with maps of each area in the results section. Out of the ten target areas, three target areas were omitted for further research due to the proper balance between greens and built-up land, the lack of public data, and the inaccessibility of the field visit due to political reasons.

The suggestions for the different NbS interventions are not only based on the inputs obtained from the field but also based on the different literature, such as Alves et al. (2024) mention about the implementation of multi-functional Nbs Interventions which serve more than one purpose. Besides that, literature like Hawxwell et al. (2019) and Pathak et al. (2022) mention incorporating NbS interventions in spatial planning to mitigate wicked problems such as waterlogging. The different NbS measures suggested for different target areas consider the building typology and delve a level deeper into a nuanced understanding of the overall land use/ ownership type (residential or commercial). Based on this understanding, it will be simpler to identify stakeholders who need to be involved in implementing these interventions.

5.3. Investigating the awareness and willingness of stakeholders to invest in NbS

The third objective of the study was to understand the awareness and willingness of the stakeholders to invest in NbS interventions. To get answers to this broad question, the questionnaire, and the semi-structured interviews were the primary sources of answers. The existing NbS measures taken by the

Government consist of the initiatives laid down by the Green City mission. These initiatives include increasing the greens in the planned cities of Salt Lake and New Town by making dedicated green belts, recreational facilities with green and blue spaces, street trees and porous pavements. Although NbS is not a term many people have heard, it is explicitly available in the planning documents or the master plan. However, when explained to the stakeholders with pictorial references, they could relate them to similar initiatives they had either seen or read about. Hence, as far as the awareness is concerned, the term NbS is something new to the stakeholders (Interviewees 1, 2, 3 and 4), but terms like green infrastructure, rainwater harvesting, and sustainable infrastructure, which are parts and parcels of NbS were quite popular among them.

To foster further discussion regarding awareness and willingness and gain insights into the key factors influencing the stakeholders, questions related to their willingness and intrinsic motivation to implement NbS were also asked. The key informants and the local inhabitants said they were highly motivated to invest in NbS at an individual level. The key informants mentioned that this is something that the government can implement by introducing new initiatives like incentives and subsidies and supporting the people who implement NbS interventions in their own houses or as a committee in the apartment buildings (Interviewees 1,3 and 4). As a result of implementing NbS interventions, which require maintenance, many people will get employment opportunities (Interviewee 2).

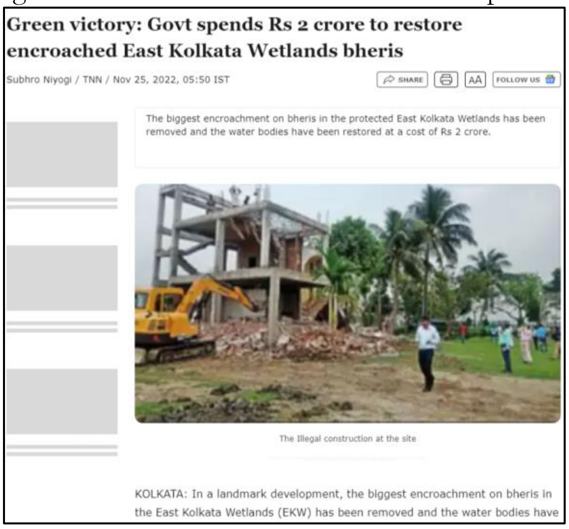
When asked about the potential realisation of the NbS measures to the inhabitants of the area as well as the key informants, they unanimously agreed that they were intrinsically motivated to invest in NbS. Besides that, the key informants mentioned that piloting the interventions can be done in flood-prone areas to assess their effectiveness and plan further whether it is needed at a larger scale (Interviewees 1 and 3). Furthermore, the stakeholders also highlighted the importance of government interference by raising awareness among the local inhabitants and different committees about the importance and requirement of these interventions (Interviewees 3 and 4). Moreover, through the municipal and local governing bodies, the government can establish laws about the mandatory implementation of rooftop gardens or rainwater harvesting tanks on roofs or lawns of the multi-storeyed buildings that dominate the built landscape (Interviewee 4). Top-down measures ensure effective implementation and a sense of obligation among the citizens. If they can be further added with incentives, subsidies or building norms, then they can yield the best results (Interviewees 1,3 and 4). Since there is a higher trend of acceptance and willingness to invest in NbS Interventions, the government can encourage this and collectively, with the local inhabitants, make an impact on reducing urban flooding. Nature-based Solutions can be successfully implemented if legitimised by the local governing authorities to implement at an individual level and committee level (Interviewees 1,3 and 4).

5.4. Effectiveness, feasibility, benefits and drawbacks of NbS

The fourth objective of the study dealt with the assessment of the feasibility of implementing NbS in spatial planning, its effectiveness, perceived benefits, and drawbacks. In this section, the information was solely obtained from and enriched by the key informants, who were also experts in the subject matter besides being the local experts. The key informants mentioned that the NbS interventions could be effective if implemented adequately and at an appropriate scale (Interviewees 2 and 4). Although there are no well-defined frameworks to assess the effectiveness of NbS interventions in the Global South, literature such as Alves et al. (2024), Chausson et al. (2020), Kumar et al. (2021), and Viti et al. (2022) can give an elaborate overview on the policy, further research, and assessment of the effectiveness of NbS interventions.

When asked about the perceived benefits and drawbacks of NbS, the benefits of NbS outnumbered the drawbacks. The benefits consisted of groundwater recharge, which could potentially mitigate the problem of acute groundwater contamination and groundwater table recession (Interviewees 2 and 4). This was followed by greenery enhancement of the study area, which would act as a sponge to prevent runoff through intercepting and water absorption in the soil (Interviewee 3). Moreover, interventions like rainwater harvesting can be effective in storing rainwater, reducing dependency on scarce groundwater resources and enabling reuse of rainwater, which can prevent the overwhelming of the manmade drainage system and the rivers and canals receiving water from this catchment area (Interviewee 4).

When asked about the drawbacks of NbS, the stakeholders agreed on the problem of lack of aftercare once projects like Nbs are implemented. However, this is a problem that can be solved. The stakeholders were also concerned about the immunisation of plant species from diseases, the prevention of parasite growth, and introducing plant species that are native and resistant to heat and have higher interception (Interviewees 2, 3 and 4). When it comes to mitigating urban floods, it is impossible to mitigate only through nature-based solutions. NbS interventions need to be complemented by engineering solutions, and then the combined measures can yield the desired results (Interviewees 1,2,3 and 4).
The spatial planning mechanism in India is primarily top-down and hierarchical. Due to this, if NbS as a flood mitigation measure needs to be implemented, it needs to have the government's involvement. By strengthening the vigilance of protection of the natural ecosystems, the existing riparian vegetation, the lakes and ponds of the existing expanse of wetlands, the cities can be saved from future aggravation of the problem (Interviewee 3). Making obligatory laws for the development authorities and private builders to use NbS in the buildings constructed after 2015 can work very well and significantly contribute to the reduction or even mitigation of urban floods in the study area. Preventing illegitimate encroachment of the EKW and strengthening the law enforcement bodies to take strict actions such as demolition of illegitimate houses can be one of the best steps to restore occupied swamp lands.

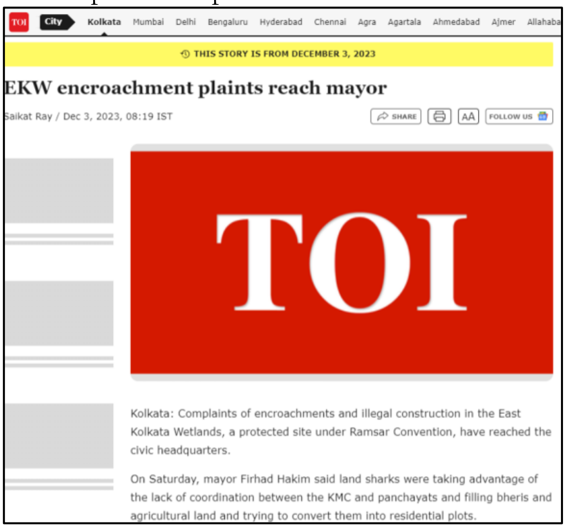
a)

Green victory: Govt spends Rs 2 crore to restore encroached East Kolkata Wetlands bheris

Subhro Niyogi / TNN / Nov 25, 2022, 05:50 IST

The biggest encroachment on bheris in the protected East Kolkata Wetlands has been removed and the water bodies have been restored at a cost of Rs 2 crore.

The illegal construction at the site

KOLKATA: In a landmark development, the biggest encroachment on bheris in the East Kolkata Wetlands (EKW) has been removed and the water bodies have

b)

THIS STORY IS FROM DECEMBER 3, 2023

EKW encroachment plaints reach mayor

Saikat Ray / Dec 3, 2023, 08:19 IST

Kolkata: Complaints of encroachments and illegal construction in the East Kolkata Wetlands, a protected site under Ramsar Convention, have reached the civic headquarters.

On Saturday, mayor Firhad Hakim said land sharks were taking advantage of the lack of coordination between the KMC and panchayats and filling bheris and agricultural land and trying to convert them into residential plots.

c)

EAST KOLKATA WETLANDS

'East Kolkata Wetlands is our pride and we must conserve it': Bypass boards for wetlands

Encroachments, illegal constructions and even buying and selling of land are threats to the wetlands, said state environment officials

SUBHAJOY ROY | PUBLISHED 25.11.23, 05:41 AM

Figure 57: a) Prevention of Illegal Construction in the East Kolkata wetlands. Source: Times of India, 2022; b) government actions monitoring and protecting the EKW. Source: Times of India, 2023. c) Policies passed by the Government to prevent selling or buying lands in the EKW. Source: Telegraph India, 2023.

The government of West Bengal has already taken the matter of encroachment with utmost seriousness and is preventing further exploitation of the valuable ecological asset. This, however, can be more efficient and organised if there is proper dialogue and communication between the different government departments and housing and infrastructure development authorities with the law enforcement bodies (Police). The government has also taken landmark steps in demolishing a few houses that were illegally constructed in the RAMSAR zone. However, this is just the tip of the iceberg (Interviewees 1 and 3). The success of the Green City initiative has created further avenues for investing in the field of NbS. It guarantees a good future for the initiative if implemented at a broader scale, with the cooperation and collaboration of different governmental and non-governmental organizations.

5.5. Limitations

Some of the limitations that were encountered during this study are as follows:

1. Overlapping Boundaries of the study area was one of the primary challenges faced at the onset of the work. The area of interest was identified and delimited after considering the municipal boundaries, the two district boundaries, and the boundary of the Kolkata Airport Authority, which passed through the study area.
2. Time constraints are one of the major limitations of the study. Since the research had a fixed total time period of six months. within these six months, there were major milestones and deadlines to meet, which restricted a very elaborate or long-duration data collection process.
3. Data unavailability was yet another limitation. The lack of land ownership data (one of the most critical factors required for this kind of research) in any published source caused a significant time spent in its pursuit. Besides that, inaccessibility to certain areas in the study area due to political disturbances going on during the fieldwork restricted the data collection only to the major urban areas, and the absence of data from the identified flood areas in the southeastern part of the study area (flood area 2 and flood area 8). Lack of Area-specific flood event data is another problem encountered while searching the public records, published government disaster records and rainfall statistics.
4. Incompatibility of certain data formats was also one of the prime limitations, which took considerable time to resolve. For example, the waterbodies are available as vector files, whereas the other variables used in SMCA were in raster format. Other examples of the rainfall data obtained earlier were found incompatible with being opened or analyzed in GIS software and replaced with the current one.
5. The availability of the key informants for the interviews also took significant time to get confirmed due to their busy schedules. The study area, being a gated community and highly secured area caused significant accessibility issues to the residential areas. The limited number of responses obtained from the study area was possible due to local connections and NGO cooperation.
6. Biasness of statistical data due to the dominance of the landscape by apartment buildings and a vast majority of respondents belonging to this class. The respondents could have been distributed evenly, but time constraints and lack of access created hindrances to this endeavour.
7. Time constraints put another limitation in the study's chosen method. With more time, the methods could have been more fine-tuned. For instance, the indicators used for the SMCA could have been divided into social, physical, and environmental classes with some more variables. A sensitivity analysis could have been done to check the accuracy of the SMCA that has been done to identify the areas susceptible to flooding.
8. Given that the research had more time, its scope could have been wider, where other aspects of urban floods, such as vulnerability (social, physical, and environmental), risk could have been assessed and mapped. This would provide richness and concreteness to the work.

6. CONCLUSION AND RECOMMENDATIONS

This chapter concludes the research with future recommendations about area-specific NbS interventions to reduce the impact of urban floods due to the diminishing wastewater filtering capacity of the EKW considering the viewpoint of the stakeholders.

6.1. General Conclusion

The study identifies that impervious surfaces have exacerbated the waterlogging problem in the low-lying, flood-prone areas with a wetland origin. This poses hazard risks and affects the livelihoods of the local inhabitants. The land use/ land cover of the area is gradually being dominated by concretized surfaces. This expansion of impervious surfaces has even encroached on small water bodies previously thought immune to urbanization. Illegitimate constructions have also paved the way due to the buying and selling of land in these protected wetland areas. The transformation of the natural landscapes into hydraulic filled, topographically altered areas increased flood susceptibility. This paved the way for exploring NbS to mitigate urban flooding. Effective implementation of NbS interventions requires multi-stakeholder involvement and integration into future spatial planning (*Sub-objective 1*).

In this research, an SMCA analysis, whose outcomes were validated by stakeholders, was used to identify ten flood-susceptible areas, out of which seven high-built-up and high flood-susceptibility areas were identified and targeted interventions were suggested. These interventions were based on stakeholder inputs and literature, considering the socio-physical factors of the study area, including land ownership. Type 1 NbS interventions, such as protection of the existing expanses of wetlands and green spaces, were suitable for the areas near the natural areas. For the concretized flood-prone areas, type 2, and type 3 interventions such as bioswales, rain gardens, porous pavements, community gardens, street trees, percolation pits, rooftop gardens and balcony gardens, which are man-made infrastructures, were suggested. These interventions have the potential to foster community participation and effectively address urban flooding challenges (*Sub-objective 2*).

The assessments of the stakeholders' awareness and willingness to invest in NbS showed that the stakeholders were familiar with many interventions although not explicitly termed as NbS. The stakeholders recognized rainwater harvesting, rain gardens and bioswales as some of the most efficient and cost-effective solutions. These discussions with the stakeholders also highlighted the importance of land ownership in NbS implementation, as it determines the degree of stakeholder engagement and investing individuals or groups of stakeholders. It was also concluded in this investigation that the high-income stakeholders, having the space and resources, had a higher awareness and willingness to invest in NbS, while the marginalized communities, despite having intrinsic willingness, lacked the resources to implement these measures (*Sub-objective 3*).

The stakeholder interviews also revealed a broader understanding of the feasibility, perceived benefits and drawbacks of NbS. The benefits included enhanced resilience against urban flooding by implementing large-scale interventions like rainwater harvesting, bioswales and rain gardens. NbS provides multi-functional benefits and complements traditional flood mitigation measures in a cost-effective way, fostering community well-being. The general awareness about NbS among the public and governing bodies was found to be limited. Other challenges associated with financial and human resources and challenges in maintaining NbS infrastructure post-implementation were also noted when the discussion delved deeper into the drawbacks (*Sub-objective 4*).

Baseline studies to understand the current urban flood mitigation infrastructure and plans of the governing bodies and the current capacity of the existing drainage system need to be done to implement

NbS measures. After which, pilot projects can be run to assess their effectiveness. The interventions yielding successful results can then be scaled up.

6.2. Recommendations and future research

The present research focuses on the need for and significance of NbS as an urban flood mitigation measure and the protection of the EKW from shrinkage. The research recommends that the governing bodies focus on developing NbS interventions along with the capacity enhancement of the drainage systems, which easily become overwhelmed in evens of high precipitation. In the course of the research, it was identified that there is a lack of communication between the different autonomously operating governing bodies, focussing on individual needs and requirements based on jurisdiction. The problem of urban flooding, which is an overarching problem experienced by the inhabitants or commuters of all the major governing institutions, can be collectively solved with the help of the higher authorities (Government of West Bengal).

Another notable observation from the research was the seriousness and the effect of laws and regulations imposed by the governing bodies. The building norms, urban planning, and governance are controlled by governing bodies like WBHIDCO, NKDA, and Bidhannagar Municipality. If legitimate reforms or incentives are introduced for the existing buildings or the builders constructing buildings in Salt Lake or Newtown (which are facing acute groundwater contamination problems) regarding the integration of NbS measures and their maintenance as a housing committee/ society, can be an effective and significant step towards the pace of development of Nbs infrastructure and promote public-private partnership to share the cost and maintenance responsibilities. The disparity between the urban elites and the urban poor can be mitigated by introducing equitable measures for both sections of society.

The NbS interventions suggested in this research, or the related ones can be considered by the governing bodies and urban policymakers for implementation in future spatial plans and to make the urban landscapes resilient to urban floods and other climate challenges. The revealed outcomes of this research can be reproduced, and further in-depth research can be undertaken in the future with additional data such as land ownership. The NbS intervention suggestions can be revised based on further observation over time. Moreover, the research can also foster similar kinds of research works in urban governance using NBS in India. The future research roadmap aims to build on the current findings of the study and develop comprehensive, sustainable, equitable and resilient flood management strategies using NbS. There is a need for identifying gaps and fostering collaboration among stakeholders. This research will contribute significantly as a first step to making urban areas resilient to flooding and other environmental challenges. Effective urban planning and sustainable and resilient flood management systems like NbS interventions are crucial to mitigating this risk and ensuring the safety and resilience of East Kolkata's diverse population.

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APPENDICES

Appendix 1: Indicators used for the SMCA and their rationales.

Table 11: Indicators list with rationales, cost/benefit criterion and sources

Factor	Indicator	Rationale	Dataset source and type	Cost/Benefit	Weights
Environmental	built-up change	The land use of an area aids in the effective decision-making process when it comes to Spatial Multi-criteria Analysis. Land use and Land cover of an area play a pivotal role in making effective area-specific measures for the implementation of sustainable solutions (Amjad et al., 2021). The higher the built-up growth, the higher the propensity of Urban flooding (Ghosh & Das, 2019).	Landsat images (30 m) Raster	Benefit	25%
	Land Surface Elevation	The low-lying areas in floodplains and coastal areas have a higher susceptibility to flooding due to differences in elevation levels. The lower the elevation, the higher the propensity of the area to get inundated due to precipitation (Gao et al., 2007). The areas with a higher elevation, on the contrary, are less likely to get inundated due to rainfall.	India SRTM data (30 m) Raster	Cost	25%
Chance of Over counting	Vegetation Cover	According to Gao et al., (2007), vegetation cover in an area significantly impacts the infiltration, water retention, soil erosion, etc. It has been evident that areas with high vegetation cover have lower susceptibility to	TanDEM X (Raster)	Cost	25%

		flood. In this context, the shrinkage of the wetlands, which are invaluable green ecosystems can lead to the aggravation of urban flooding.			
	Rainfall data	The rate of precipitation is one of the key components to be considered when analyzing waterlogging or floods. The intensity of rainfall determines the swelling of waterbodies and the capacity to which the drainage system of an area can discharge water. Fielding & Burningham (2007) mention in their paper the importance of considering precipitation as an indicator to assess physical causes of flooding.	Raster Data (TIF format)	Benefit	25%
Physical	Proximity to Hydrological systems	Olatona et al., (2018), in their paper, mentioned the importance of considering the proximity to water bodies in order to assess flood susceptibility of an area. The literature points out, that the closer an area is, to the hydrological system, the higher the probability of the area being inundated.	Vector data	cost	0

Appendix-2: Individual indicator maps

Built-up Change Map

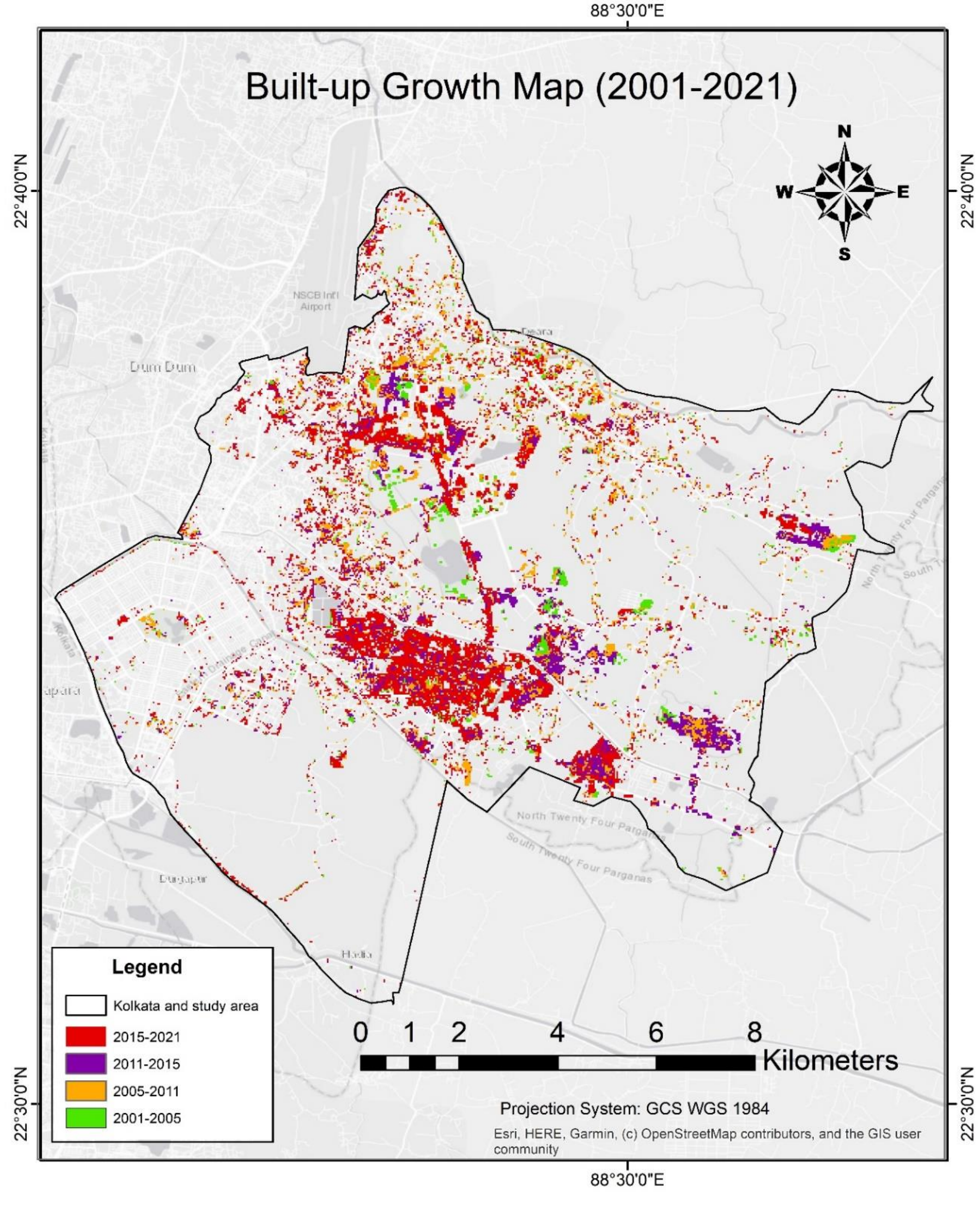

Figure 58: Built-up change map (2001-2021). Source: Author, (2024)

Digital Elevation Model (DEM)

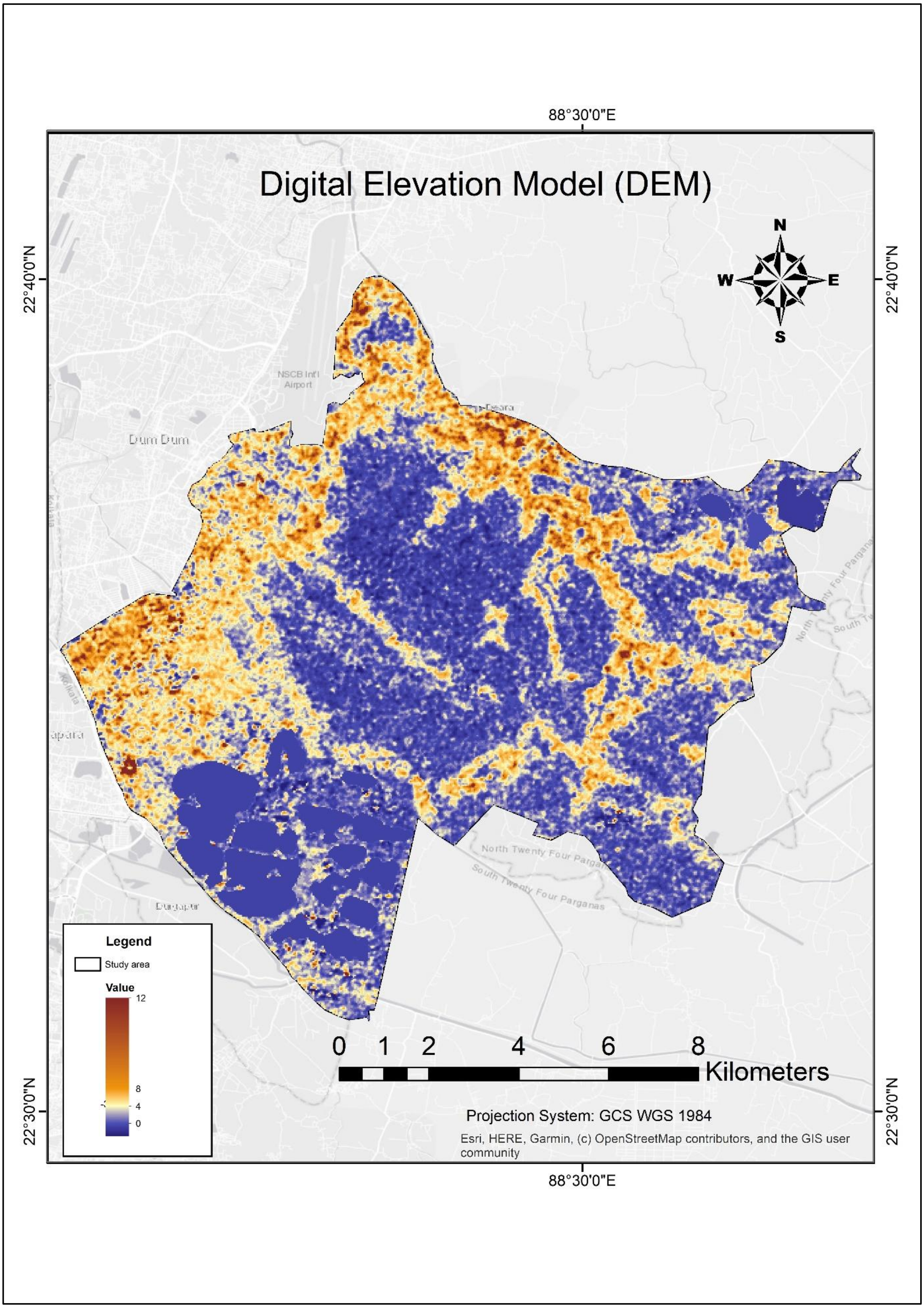

Figure 59: Digital Elevation Model of the study area. Source: Author, (2024)

Slope Map

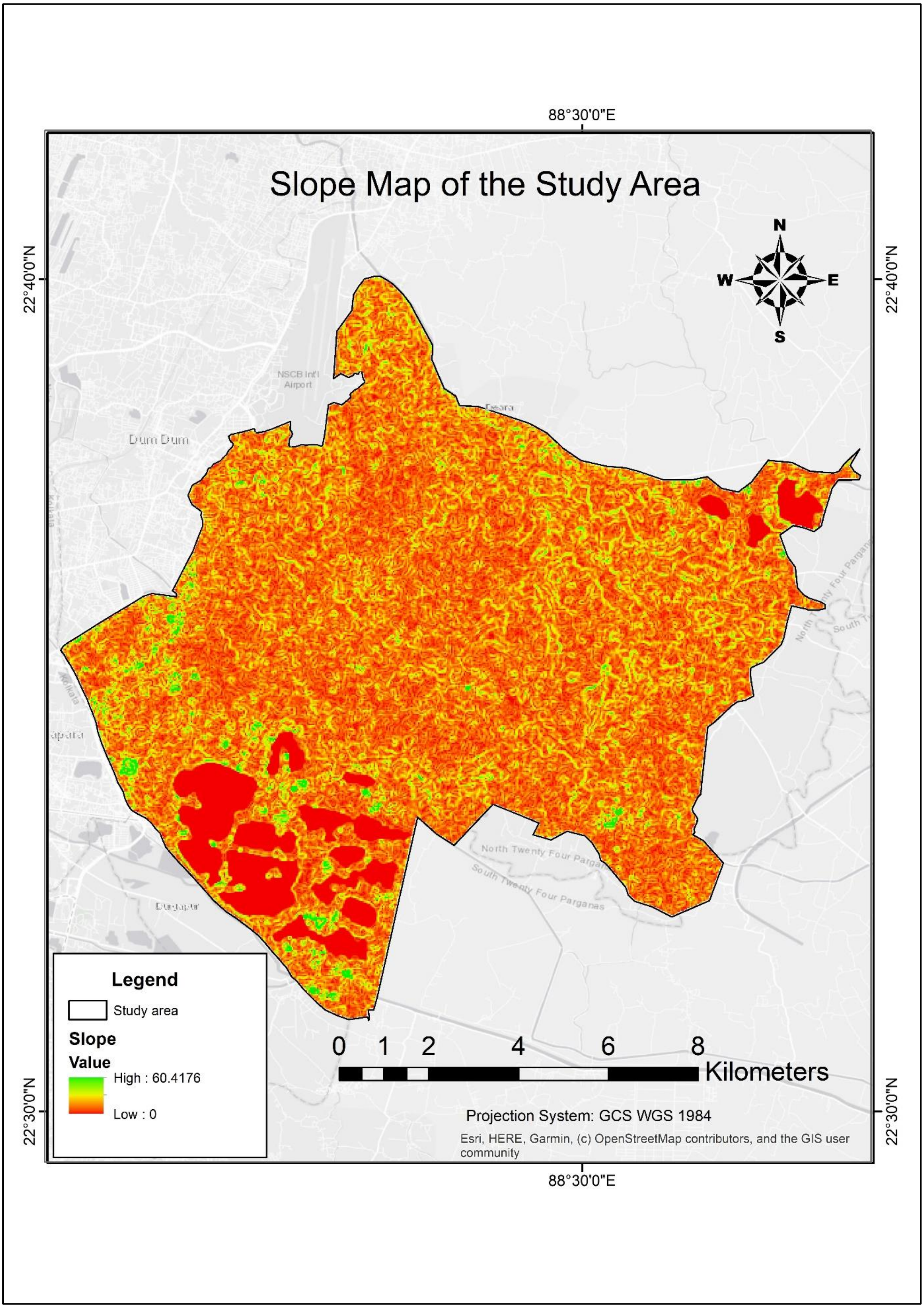

Figure 60: Slope map of the study area. Source: Author, (2024)

Vegetation Map

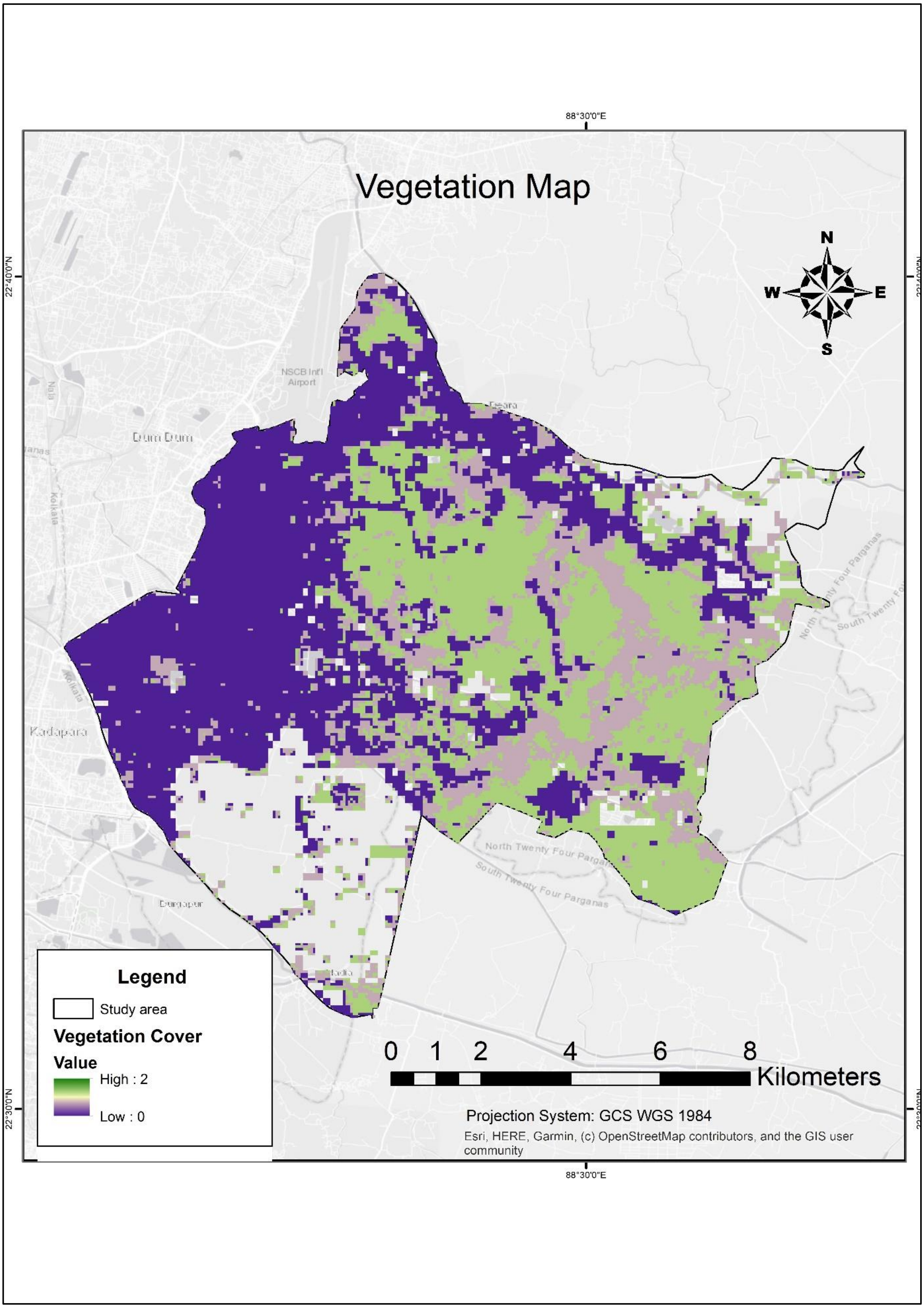

Figure 61: Vegetation map of the study area. Source: Author, (2024)

Average annual Rainfall Map (2001-2021)

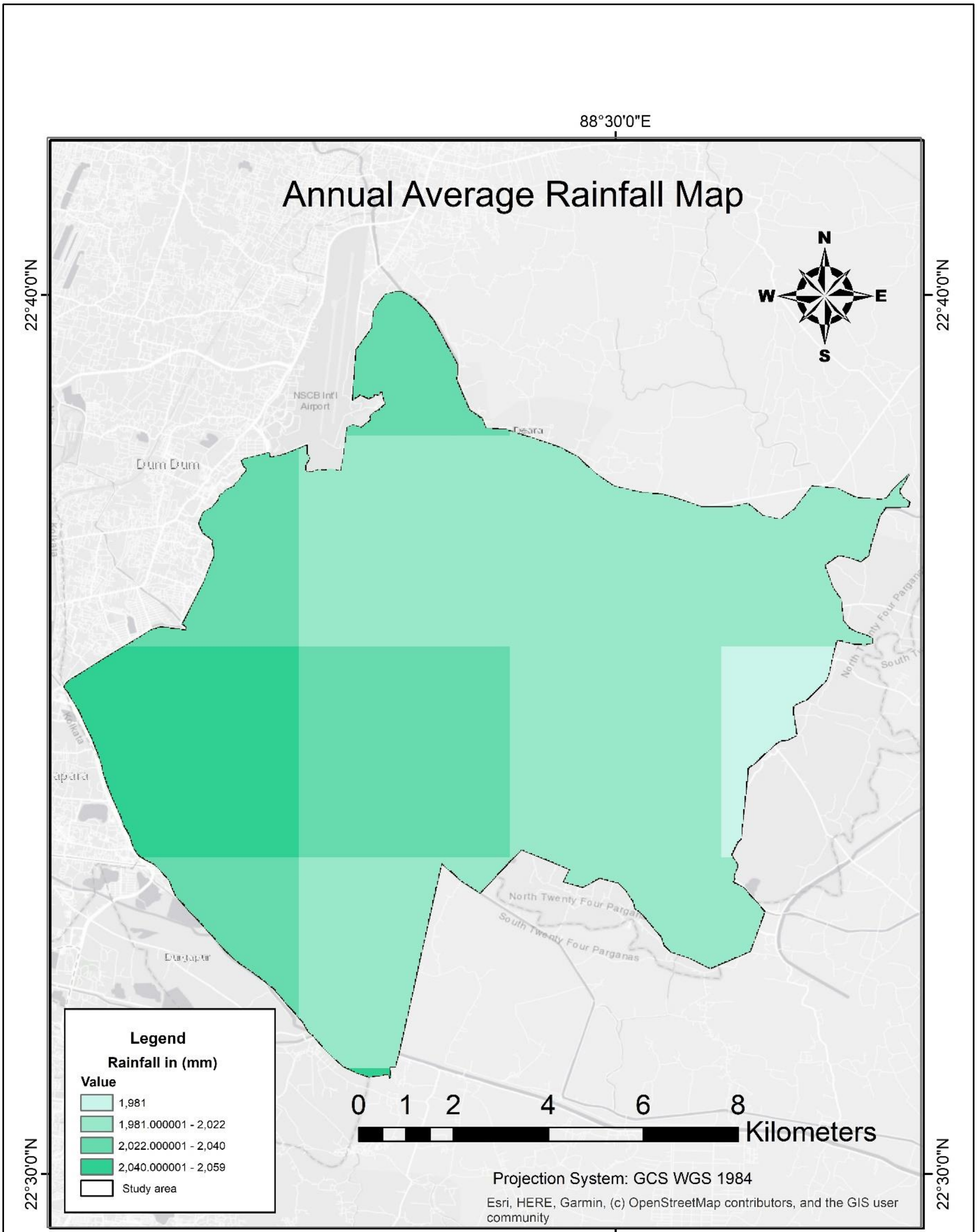

Figure 62: Average annual rainfall map between 2001-2021. Source: Author, (2024)

Annex-3 (Fieldwork)

Consent letter for field survey

CONSENT LETTER

HARNESSING NATURE: INTEGRATED FLOOD MANAGEMENT FOR URBAN FLOOD MITIGATION USING NATURE BASED SOLUTIONS IN EAST KOLKATA WETLANDS,INDIA

Dear Participant,

I am researching the frequent urban flood occurrences in the Rajarhat and Salt Lake areas, which are located near the East Kolkata wetlands. The study identifies areas affected by the urban floods and suggests Nature based solutions as mitigation measures. I would like to interview you for this study to help me understand the opportunities and challenges associated with urban floods. This interview will not take more than 30 minutes of your valuable time. With your due permission, I can also reach out to you later at your convenience (online) in case of any additional information.

Your participation in this interview is completely voluntary, and you are free to say no if you do not wish to participate. It's not mandatory to answer questions you don't wish to. If you feel like stopping at any point in the survey/interview or don't wish to start at all, you may do so. With your permission, I would like to use the MS Teams recording feature to record an audio version of our conversation, which would aid me in deriving the words accurately and highlight major points covered, for my research. If you do not wish your voice/audio to be recorded, I can transcribe the conversation.

The content derived from this conversation might be used for publication or presentation purposes maintaining strict anonymity and restricting any kind of identifiable information. Your information is safe and will not be shared with anyone beyond myself and the people who are associated with this project, who are trustworthy and will maintain confidentiality. I will try to protect the confidentiality to the best of my ability. I will provide my card/contact information with details. If you need to get in touch with me regarding the research at any point of time, please do not hesitate to do so.

The interview can be conducted in English or Bengali.

Your contribution to this project is Highly appreciated.

Thanks and best regards,

Pritam Ghosh,

For questions or concerns regarding the research, or notifying someone of a complaint, please contact.

Name: Pritam Ghosh
University of Twente
Email: p.ghosh@student.utwente.nl
Phone number: +31 647440266

Please email the University of Twente's Geo Ethics Committee at geo@utwente.nl if you have any questions about your rights as a research participant, would like more information about this study, or would like to discuss any concerns with someone other than me, the researcher.

Harnessing Nature: Integrated Management for Flood Mitigation using Nature based Solutions in East Kolkata Wetlands

General Questionnaire

Good morning/ afternoon, Sir/ Madam; I am Pritam Ghosh, an Urban Planning and Management Student at the Faculty ITC at the University of Twente. I am a Bengali, currently studying in the Netherlands. My master's thesis is based on investigating the problem of urban floods and the feasibility of introducing Nature Based Solutions (NbS) to the urban area of Rajarhat Newtown as a measure to mitigate the problem. In order to assess it, I would appreciate the cooperation of the local inhabitants of this area because you, being the residents of this area, have greater community knowledge and are the first-hand informants from this study area. I will ask you a few questions regarding the same, which will take around 15-20 minutes to complete. Be assured that no personal questions will be asked, and the data obtained will be solely used for academic purposes. If you agree to participate in this survey, do you grant permission to use this data for this research?

- Yes
- No

1. What is your age group?

   i. 18
   ii. 19-30
   iii. 31-50
   iv. 51-65
   v. >65

2. Is there a waterlogging problem in this area?

Yes

No

3. If yes, what do you think is the water source inundating the area?

i. Canal

ii. open high drains

iii. open drains

iii. manholes

iv. clogged water systems

6. What type of settlement do you live in?

i. House-tin shed

ii. House-brick

iii. Apartment-ground floor

iv. Apartment-1st floor to upper floor

v. Slum

vi. Other [Please indicate………………………………….]

7.What is your ownership of the property?

i. Own

ii. Rent

iii. Living without rent

iv. Government ownership

v. Others [Please indicate…………..] (Lease etc.)

8. Do you have any empty space in your home to implement green elements capable of absorbing/ storing rainwater?

i Balcony
ii Rooftop
iii Yard
iv Apartment building front
v None

9. What are the green elements you already have in your house, that can be effective for storing/ absorbing rainwater?

i Trees
ii Yard garden
iii Rooftop garden
iv Balcony garden
v Other [Please indicate……………]
vi None

10.Which green and blue elements do you have within 1 km distance from your home?
i Street trees
ii Park
iii Playground
iv Community garden
v Porous pavement
vi Lake/ canal
vii The EKW
viii Other [Please indicate……………..]
ix None

11. Do you feel it is important to have green or blue spaces in close proximity to your house?
Yes
No

12. The Canals or water bodies around me are occasionally dredged to prevent waterlogging.
Yes
No

13. Do you agree to the following sentences?

Statements	Yes	No
I participate in the events organized by the local governing bodies for environmental protection		
The local government has implemented nature based solutions to mitigate urban floods, in my neighbourhood.		

14. What green elements do you want to implement in your home capable of mitigating logged water? Select from the list (Tick)
- Trees
- Yard garden

- Rooftop garden
- Balcony garden
- Green roof
- Rain Garden
- Others [Please indicate………..]
- None

15. What kind of green and blue elements do you want to have access to in your community? Select from the list

- Street trees
- Park
- Playground
- Community garden
- Porous pavement
- Lake
- canal
- Others [Please indicate……….]
- None

16. Your general perception about NbS, EKW, lakes, and river restoration and installation. How much do you agree with the following statements?

Statements	Agree	Neither Agree nor Disagree	Disagree	No idea
I believe that green and blue spaces have the capability to reduce and mitigate the urban flooding problem				
The city corporation is installing green and blue elements for flood mitigation in my neighbourhood.				
The local administration is working for the restoration of the EKW.				
The local Government is monitoring and actively working for the protection of the existing expanse of the EKW				

17. Give the statements a rating from a scale of 1 to 5 based on your opinion. (Where 1 means the least and 5 means the highest agreement).

	1	2	3	4	5
Personal statement					
I am intrinsically motivated to contribute and care for NbS in my surroundings.					
Social Statements					
Political parties work on restoring the EKW and making the urban					

infrastructure greener.					
NGOs are working on restoring EKW and taking initiatives to make the community green.					
There is a lack of environmental conservation measures in urban areas.					
Engineering solutions are helping to cope with the problem of waterlogging sufficiently.					
The local government and civic bodies take necessary actions when there are floods.					

Before Submitting: Please note that all the data you provided above will be used strictly for educational purposes with utmost confidentiality and anonymity. We do not assure you of any kind of action or implementation regarding the NbS ideas discussed above. Hence, please indicate below whether you still agree with the collection and processing of this data.

- Yes
- No

https://kc.kobotoolbox.org/revivingresilience

Harnessing Nature: Integrated Management for Flood Mitigation using Nature based Solutions in East Kolkata Wetlands

Semi-Structured Interview Script

Good morning/ afternoon, Sir/ Madam, I am Pritam Ghosh, an Urban Planning and Management Student at the Faculty ITC at the University of Twente. I am a Bengali, currently studying in the Netherlands. My master's thesis is based on investigating the problem of urban floods and the feasibility of introducing Nature Based Solutions (NbS) to the urban area of Rajarhat Newtown as a measure to mitigate the problem. In order to derive information about the approaches that can be taken to mitigate urban floods, and whether NbS can be a step that can be taken to reduce the impact of urban floods to a certain extent. I need your kind cooperation to collect information about the steps that the local government or the civic bodies are taking against the shrinkage of the East Kolkata Wetlands and protecting the wetlands. Subsequently, there will be a few questions on how Nature Based can solutions complement Engineering solutions to mitigate urban floods. I will ask you a few questions regarding the same, which will take around 30-35 minutes to complete. Be assured that no personal questions will be asked, and the data obtained will be anonymized and solely used for academic purposes. If you agree to participate in this short interview, do you grant permission to use this data for this research?

- Yes
- No

General Questions

1. Which local governing body are you representing?
2. Do you think the hazard patterns (frequency of flood occurrences) have changed?
3. What comes to your mind when you hear Nature based Solutions?
4. What are the current flood mitigation measures extant in the EKW region (awareness)?
5. Why do you think the current flood flood mitigation measures are in place?
6. Can you elaborate on your organization's role in the implementation of NbS for flood mitigation?
   i. Research
   ii. Direct implementation
   iii. Indirect implementation
   iv. Others

7. Which areas do you think can be better to invest for implementing NbS measures? (A Map with the target areas shall be produced)
8. Are there other organizations working on the problem of water logging and wetland management?
9. What challenges does your institution face when it comes to implementing NbS for flood mitigation?

About NbS

10. Which among the provided examples of NbS measures is suitable in context of the EKW?
11. What steps are the local governing bodies taking to protect the existing riparian vegetation?
12. Is NbS a feasible solution for urban flood mitigation in this area?
13. What are the traditional, easy-to-implement, top-bottom or bottom-up approaches and community projects associated with NbS available for flood mitigation?
14. Do you think NbS surpasses the efficiency of engineered solutions for flood mitigation?
15. What do you think are the advantages of NbS? (e.g.- environmental, social)

16. What are the drawbacks of NbS? (e.g.- economic, temporal)
17. Compared to other flood mitigation strategies, how sound do you think nature-based solutions are?

Annex-4 (Post fieldwork)

The data obtained from the semi-structures interviews were analysed using Atlas.ti, where a text search analysis, sentiment analysis, correspondence analysis and code redundancy analysis were done. Snapshots of all the analyses cannot be provided, as they have the names of the interviewees displayed on the screen. In this appendix, a snap of the correspondence and code redundancy analysis can be found, along with a word cloud of the most frequently used words during the discussions.

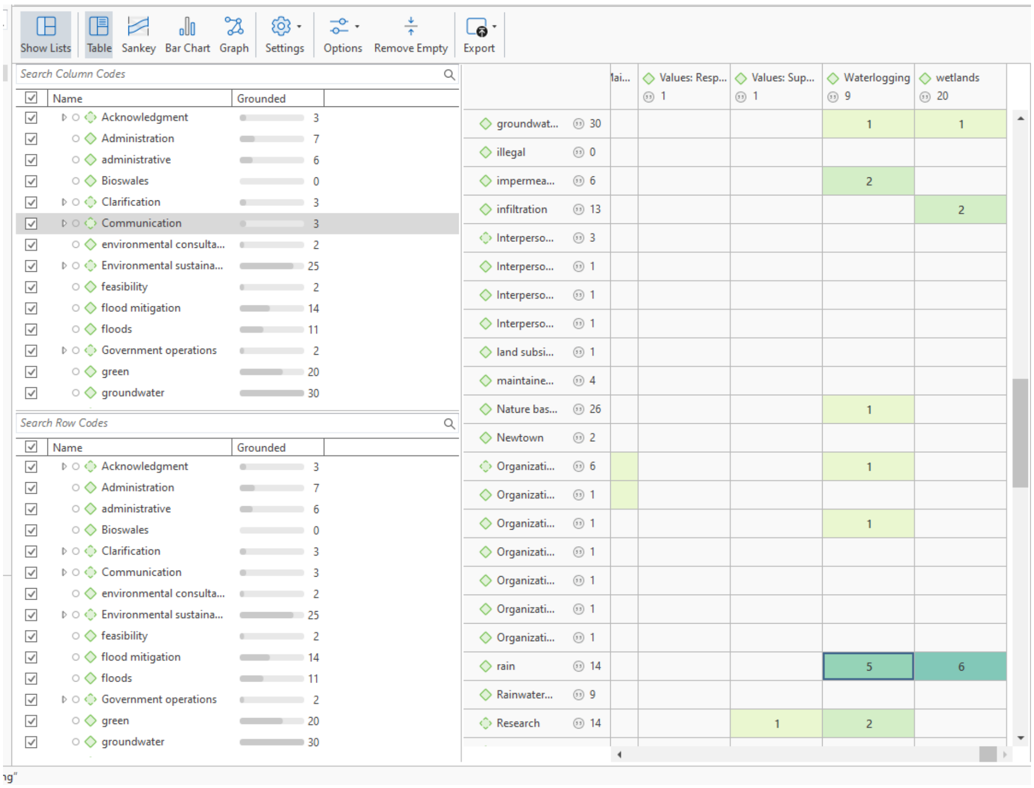

Figure 63: Correspondence analysis (post-coding) in Atlas.ti. Source: Author, (2024)

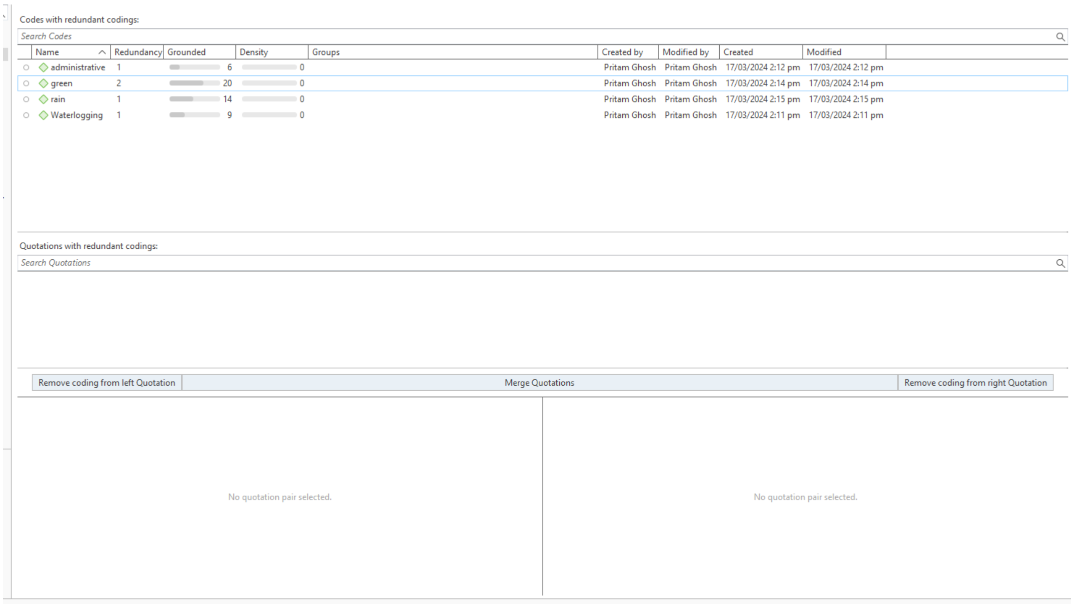

Figure 64: Code redundancy analysis of codes in Atlas.ti. Source: Author, (2024)

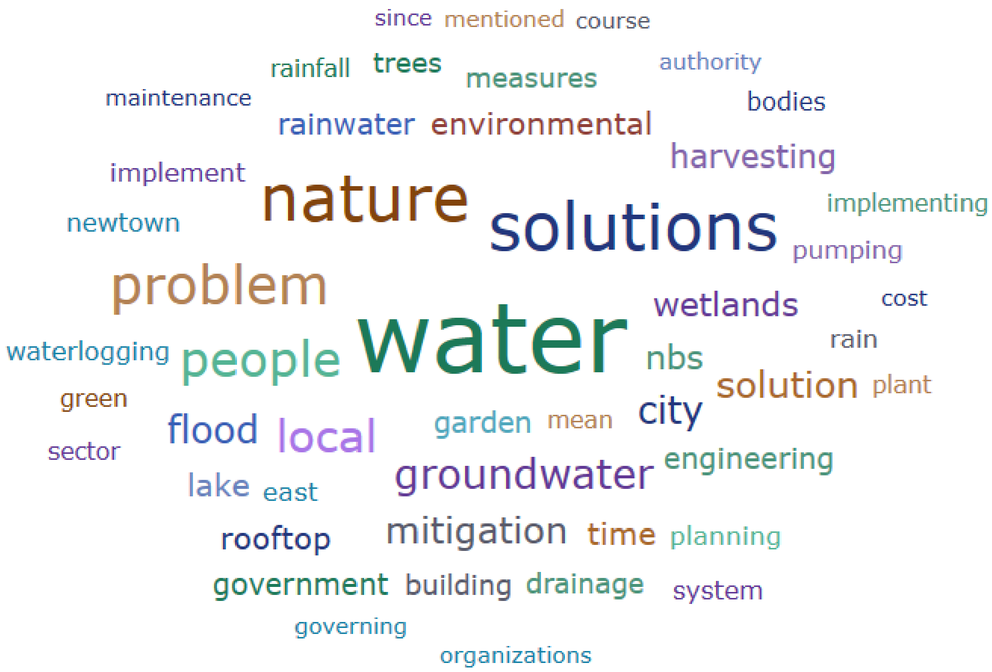

Figure 65: Word cloud obtained from Atlas.ti, after analysing the most used terms. Source: Author, (2024)

Confusion Matrix of the Land use/ Land cover analysis (2001-2021)

2001- Maximum Likelihood Classification

Class Value	Vegetation	Built-up	Farmland	Water and Marshes	Open Land	Total	User's Accuracy	Kappa	Commission Error (%)
Vegetation	12	0	0	0	0	**12**	100%	0	0%
Built-up	0	12	0	0	0	**12**	100%	0	0%
Farmland	0	0	11	0	10	**21**	52%	0	48%
Water and Marshes	0	0	1	9	0	**10**	90%	0	10%
Open Land	0	0	1	0	19	**20**	95%	0	5%
Total	**12**	**12**	**13**	**9**	**29**	**75**	0	0	0
Producer's Accuracy	100%	100%	85%	100%	65%	0	**84%**		**63%**
Kappa	0	0	0	0	0	0	0	80%	**0.7951575**
Omission Error (%)	0%	0%	15%	0%	35%	**50%**			

Figure 66: Accuracy assessment confusion matrix for 2001. Source: Author, (2024)

2011- Support Vector Machine Classification

Class Value	Vegetation	Built-up	Farmland	Water and Marshes	Open Land	Total	User's Accuracy	Kappa	Commission Error (%)
Vegetation	12	0	0	0	0	12	100%	0	0%
Built-up	0	20	0	0	0	20	100%	0	0%
Farmland	0	0	18	0	5	23	78%	0	22%
Water and Marshes	0	0	0	10	0	10	100%	0	0%
Open Land	0	0	0	0	10	10	100%	0	0%
Total	12	20	18	10	15	**75**	0	0	0
Producer's Accuracy	100%	100%	100%	100%	66%	0	93%		22%
Kappa	0	0	0	0	0	0	0	**91%**	**0.915101**
Omission Error (%)	0%	0%	0%	0%	44%	44%			

Figure 67: Accuracy assessment confusion matrix for 2011. Source: Author, (2024)

2021- Support Vector Machine Classification

Class Value	Vegetation	Built-up	Farmland	Water and Marshes	Open Land	Total	User's Accuracy	Kappa	Commission Error (%)
Vegetation	9	0	0	0	0	9	100%	0	0%
Built-up	0	28	0	0	0	28	100%	0	0%
Farmland	0	1	20	0	1	22	91%	0	9%
Water and Marshes	0	0	0	8	0	8	100%	0	0%
Open Land	0	0	0	0	8	8	100%	0	0%
Total	9	29	20	8	9	**75**	0	0	0
Producer's Accuracy	100%	97%	100%	100%	88%	0	97%		9%
Kappa	0	0	0	0	0	0	0	**96%**	**0.963908**
Omission Error (%)	0%	3%	0%	0%	12%	15%			

Figure 68: Accuracy assessment confusion matrix for 2021. Source: Author, (2024)