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Sustainable Urban Land-Water Interface Design: A Context-Sensitive Landscape Framework for Deltaic Region

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Abstract

Preservation and integration of natural water and land resources into urban areas are crucial for the long-term sustainability of a land-water relationship. In deltaic locations like Bangladesh, natural landscape features are essential for hydrological performance and biodiversity. In order to address the urban crisis, it is essential to develop context-sensitive strategies that incorporate local knowledge and natural processes. Therefore, this study aims to provide a comprehensive framework for the sustainable integration of land and water resources in urbanized areas, with an emphasis on Bangladesh's deltaic region and similar cities. The research examines spontaneous settlements along the dynamic land-water interface in the Eastern Fringe of Dhaka Metropolitan Area (DMA). In response to the environment, these settlements exhibit a natural evolution, demonstrating the potential for communities to harmoniously integrate with the water system that shapes the landscape. The study investigates land-water interactions in this area to find sustainable strategies. The research examines hydro-eco-sensitive landscapes utilizing field survey, semi-structured interviews and ArcGIS spatial analysis. The land-water interface in the research area was analyzed qualitatively and quantitatively, encompassing physiography, hydrology, soil and land use. The comprehensive findings highlight land-water integration principles, landscape features and their influencing factors. These findings are included into urban design guidelines to improve hydro-ecological performance which prioritize the preservation of natural landscapes, retaining local land-use patterns and the utilization of local knowledge. This study provides a context-sensitive, sustainable landscape framework for urban water edge design that addresses the constraints of engineering-based techniques and promotes environmentally resilient urban design in deltaic situations.

Keywords

Land-Water Interface, Spontaneous Urban Territory, Local Knowledge, Water-Sensitive Urban Design, Urban Design Guidelines, Integrated Landscape Framework

1. Introduction

Bangladesh, lying in the extensive delta formed by the Ganges, Brahmaputra, and Meghna rivers, is known for its unique, water-rich landscapes that have shaped human settlements and local ecosystems for years. The country's monsoon climate and geographic location along the Tropic of Cancer result in intense seasonal rainfall, which has created an interdependent relationship between natural resources and human habitation. This synergy between land and water resources is evident across the entire region, where human settlements have traditionally coexisted with the natural water flow and seasonal changes in the landscape.

The Dhaka Metropolitan Area (DMA), the capital of Bangladesh and the largest urban center, sits at a critical geographic junction where multiple rivers converge. It is surrounded by the Buriganga, Turag, Balu rivers and Tongi Khal rivers, and has developed on elevated highlands that gradually slope into lower flood-prone valleys to the east and west. Historically, Dhaka's landscape comprised interconnected rivers, canals, reservoirs, wetlands, and floodplains that shaped both urban and rural settlement patterns. Local settlements, positioned on flood-free highlands, relied on low-lying areas to manage seasonal rainwater, protect against floods and support agriculture during periods of inundation. These waterbodies not only contributed to ecological resilience but were also vital resources for agricultural productivity and biodiversity.

However, Dhaka's rapid and unregulated urban expansion is increasingly disrupting these critical natural systems. In the face of growing population demands, development is often driven by short-term goals, frequently leading to the transformation of wetlands, lowlands and floodplains into urban land. This demand-driven growth, common in developing regions, overlooks sustainable development principles, endangering essential natural resources (Bullock, 1993; Sim & Balamurugan, 1991). Engineering solutions—such as embankments and drainage systems—have become primary management approaches, overlooking the region's hydro-geographical characteristics and diminishing its ecological functionality. As a result, Dhaka's unique natural landscapes are undervalued and marginalized within formal urban planning, leading to heightened flood risks, resource depletion and environmental degradation.

Therefore, there is a need for research on urban development techniques that protect and incorporate the natural resources of the delta due to the disconnect between Dhaka's built environment and its natural systems. This research directly addresses this challenge by examining land-water management and sustainable urban design practices in Dhaka's Eastern Fringe. This area, characterized by traditional settlements closely aligned with natural land-water systems, provides an ideal context to explore development practices that respect and preserve the landscape's ecological integrity.

Through spatial analysis, field surveys and semi-structured interviews, this study examines key factors influencing the land-water interface in the Eastern Fringe, such as physiography, hydrology, soil characteristics and land use. These findings are synthesized into urban design guidelines that prioritize the preservation of natural landscapes, support traditional land-water interactions and leverage local knowledge in planning. By proposing an integrated landscape framework, the research emphasizes a shift from engineering-based solutions toward ecologically responsible and resilient urban design.

This study aims to promote a new urban development paradigm that integrates natural systems as core elements of sustainable design. The proposed guidelines provide practical tools for policymakers, urban planners, designers and developers to adopt context-sensitive, ecologically sustainable practices in Dhaka and other deltaic regions facing similar challenges.

2. Integrating Land-Water Interface in Sustainable Urban Frameworks

The land-water interface serves as a vital buffer zone, safeguarding waterbodies from urban impacts and mitigating the effects of human activities on natural water resources (Desfor & Laidley, 2011; Devoy, 2005; Hoyle, 1989). In advanced urban design models, this interface is envisioned as a cohesive natural landscape, where land and water resources are harmonized based on regional ecological characteristics. To foster a water-sensitive urban environment, the natural hydrological landscape acts as a foundational structure for human settlements, enhancing urban quality, development and sustainability. Rediscovering methods to integrate land and water resources for hydrological, ecological, environmental and socio-cultural benefits is increasingly advocated in the fields of "water urbanism", "landscape urbanism", and "ecological urbanism" (Corner, 1999; McHarg, 1969; Shannon, 2004; Waldheim, 2006). These contemporary approaches to urban design and planning are based on ecological perspectives and the analysis of the interactions between living organisms and their environment, as well as the processes that shape both (Hough, 1984, 2013; Lynch, 1981; McHarg, 1969). These approaches suggested for landscape analysis to identify the areas of sensitive natural resources so that the development could be appropriately sited to complement natural systems and do the least possible harm to them.

Urban land use pressures have led many cities to re-evaluate the potential of their water edges, designating these areas for sensitive redevelopment. Traditional practices of managing water edges for activities like agriculture, irrigation, transportation, flood control, and open space connectivity are being revisited, leveraging both existing and previously obscured water bodies. Water-sensitive urban design emphasizes understanding the intricate relationships between constructed and natural elements within the urban landscape. This approach aids in identifying the unique characteristics of land-water interfaces within a region, allowing for strategic frameworks and visionary plans that align with these natural dynamics (Bently, 1990; Carmona, 2009; Davies, 2000; George, 1997). To improve deteriorating urban living conditions, the integration of urban lands with natural resources is guided by a comprehensive understanding of hydro-ecological processes, forming an active basis for landscape framework development along urban water edges.

3. Methodology

This research employs a mixed-method approach to inquiry, integrating quantitative and qualitative methods to structure the research, comprehend the problem, and investigate solutions within the local context (**Figure 1**). By gathering and analysing relevant data in alignment with the study's objectives, the research formulates recommendations that are sensitive to the unique environmental and social contexts of the region.

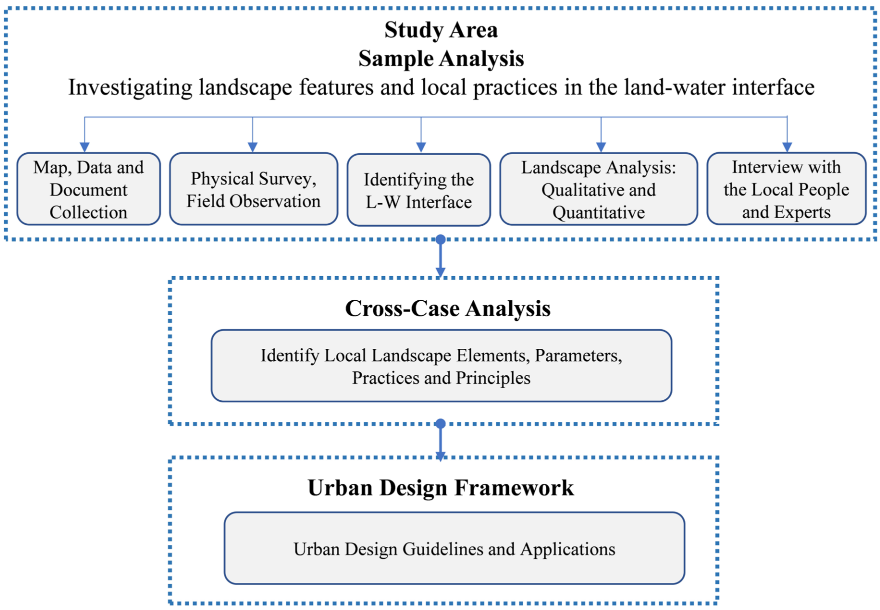

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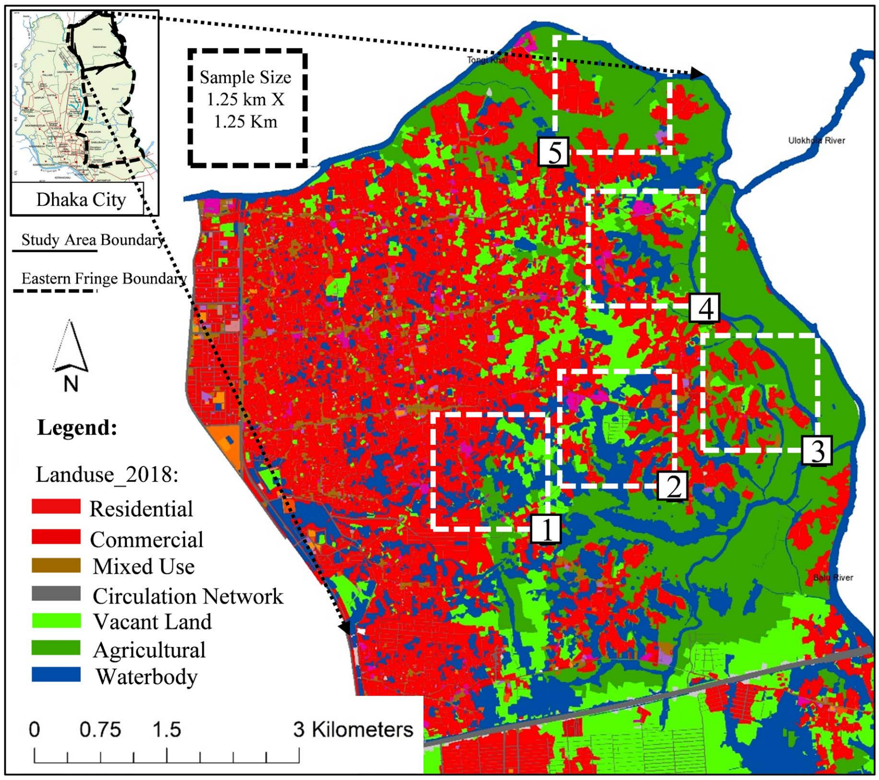
Figure 1. Methodology diagram.

3.1. Site and Sample Selection

Dhaka's rapid urbanization has progressively encroached upon its natural landscapes, with much of the city's western waterbodies and green areas already sacrificed to development. As a result, urban growth is now pushing into the eastern periphery of the Dhaka Metropolitan Area (DMA), where natural ecosystems still remain, albeit under increasing pressure. The selected study area lies in the upper northern part of this eastern fringe, covering approximately 42 km^2 (**Figure 2**).

This region is significant due to its largely preserved natural landscape, which includes vast agricultural lands and a network of natural waterbodies. Historically, local settlements have evolved in response to the region's geomorphology, forming a delicate balance between land and water, which offers an ideal setting for the investigation of sustainable land-water integration strategies.

The chosen study area showcases how traditional settlements have utilized the natural land-water interface to coexist harmoniously with their environment. Within this larger area, five specific sample locations (**Figure 2**) were selected for detailed analysis based on their representative landscape characteristics and hydrological conditions. These samples were carefully chosen to capture the diversity of land-water relationships and provide a detailed understanding of how local practices interact with the region's unique environmental features.



Source: Author.

Figure 2. Map of the eastern fringe and sample locations in the upper northern part of the DMA.

As urbanization progresses, such sample-based investigations offer crucial insights into localized practices, highlighting how settlements and landscapes evolve in tandem. The detailed examination of these sample areas is essential for identifying sustainable land-water integration techniques that can inform regional urban development strategies. Rather than applying broad, top-down planning solutions, this research emphasizes the need for site-specific approaches that respect the local landscape's hydrological and ecological nuances. The selected samples illustrate varying hydrological behaviours, settlement patterns, and landscape compositions, which provide a rich foundation for uncovering resilient urban planning and design strategies.

3.2. Investigation of Land-Water Interface

The land-water interface in any region is shaped by a variety of environmental factors, including geology, hydrology, soil composition, land use, agriculture, and climate. Depending on the context, each of these landscape features serves its purpose in a unique manner. Soil, hydrology, physiography, land use, and agriculture are some of the criteria that are investigated in the hydro-eco-sensitive landscape investigation (Figure 3). The landscape features and local activities at the land-water interface are studied using quantitative and qualitative methodologies. Along with thorough mapping, surveying, and observation, semi-structured interviews are also carried out with local residents, administrative authorities, specialists, and important personnel.

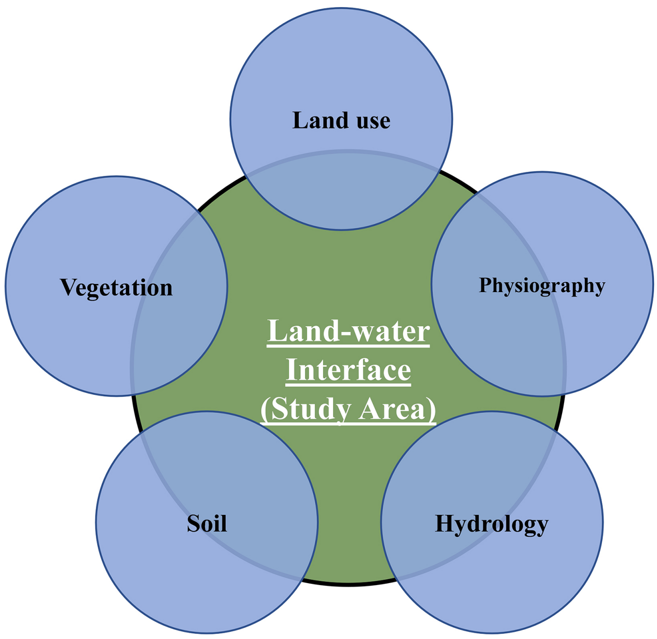


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Figure 3. Key landscape parameters for analyzing the land-water interface.

3.2.1. Quantitative Analysis

The land-water interface was thoroughly and quantitatively analysed for each landscape feature in the sample. Area, width, and slope length calculations, among other geographical analyses, were carried out using the ArcGIS shapefile that corresponded to the detected land-water interface. Using ArcGIS, a shapefile representing the detected land-water interface was created and overlaid on multiple maps, including land use maps, the Digital Elevation Model (DEM), and soil type maps. Additional layers such as the MS mouza map (Metropolitan

Survey) and the RS mouza map (Revisional Survey) were also incorporated to provide detailed spatial data on the area. The DEM data enabled further analysis of slope gradients, water flow patterns, and water volume at the interface, using ArcGIS 3D analyst tools to model the hydro-ecological behavior of the landscape. The resulting data were then extracted and analyzed using Microsoft Excel, allowing for a detailed comparison of the landscape features across the sample sites. This spatial analysis provided valuable insights into how the natural land-water interface supports ecological functions, such as flood mitigation and agricultural productivity, while also revealing the vulnerabilities posed by ongoing urbanization.

3.2.2. Qualitative Analysis

Thorough site surveys are carried out throughout the year to provide a qualitative knowledge of the site and samples. These surveys captured the seasonal variations in local agricultural activities, which are heavily influenced by the region's hydrology and climate. The year was divided into three distinct seasons: summer (March - June), rainy (July - October), and winter (November - February). The link between urban activities and natural waterbodies is studied by watching, mapping, and sketching a variety of activities near the water's edge. Locals, especially the elderly, are interviewed in semi-structured interviews to learn about their flood experiences, agricultural practices, land values, and the effects of urban activities on their environment.

The combination of spatial analysis, field surveys, and local knowledge offers a comprehensive perspective on the challenges and opportunities of sustainable urban development in Dhaka's eastern fringe. The findings have informed the creation of context-sensitive urban design guidelines that respect the region's natural systems while addressing the pressures of urbanization.

4. Identification of Landscape Elements, Practices, Process and Patterns at the Local Land-Water Interface

The investigation of the local land-water interface, through parameters such as physiography, hydrology, soil, land use, and agriculture, has revealed a variety of landscape patterns that reflect integrated practices and processes. These patterns showcase how natural and human-made elements integrate within the unique land-water dynamic.

In terms of **physiography**, the research examines critical landscape features including topography, surface relief, form, slope gradient, and the overall organization of the land-water interface. These features define how the land interacts with water, determining the layout of settlements and agricultural activities. **Land use** is another essential component, classifying the diversity of land cover types in the area. This includes agricultural lands, built environments, natural vegetation, and wetlands. Understanding land use categories provides insights into how the local community balances urban expansion with environmental preservation.

The **hydrology** of the region, encompassing water distribution, movement, and management, is a key parameter in this study. It includes the analysis of water-bodies such as rivers, canals, lowlands, valleys, and flood-plain areas. Drainage systems and natural depressions are also critical features that support water retention and flood management, particularly in this deltaic region where seasonal flooding is common. The study reveals that water management practices, including drainage and retention, are deeply rooted in local traditions and adapted to the natural hydrological cycles.

Soil characteristics, such as permeability, suitability, and classification, were systematically categorized to understand the region's capacity for supporting various land uses. This includes soil types that are conducive to agricultural productivity, specifically in areas where rice cultivation and other water-intensive crops are common. The research also examines how soil classification and suitability impact water retention and drainage at the land-water interface, further informing sustainable land management practices. **Agriculture** in the land-water interface is diverse, incorporating crop cultivation, aquaculture, and poultry farming. Crop yields are closely tied to the seasonal flooding patterns, with local farmers adapting their planting and harvesting cycles accordingly. The integration of fish farming into the floodplains is another key element of the local landscape, creating a symbiotic relationship between land and water-based food production systems. Poultry farming also plays a significant role in the economy, further diversifying the local agricultural practices.

Collectively, these landscape elements contribute to the environmental, hydrological and ecological health of the region. Their integrated functionality offers substantial benefits for local settlements, supporting agriculture, food production, flood management, and biodiversity conservation. The global recognition of such integrated land-water systems has prompted their adoption in contemporary water-sensitive urban design, advocating for sustainable development practices that align with the natural environment.

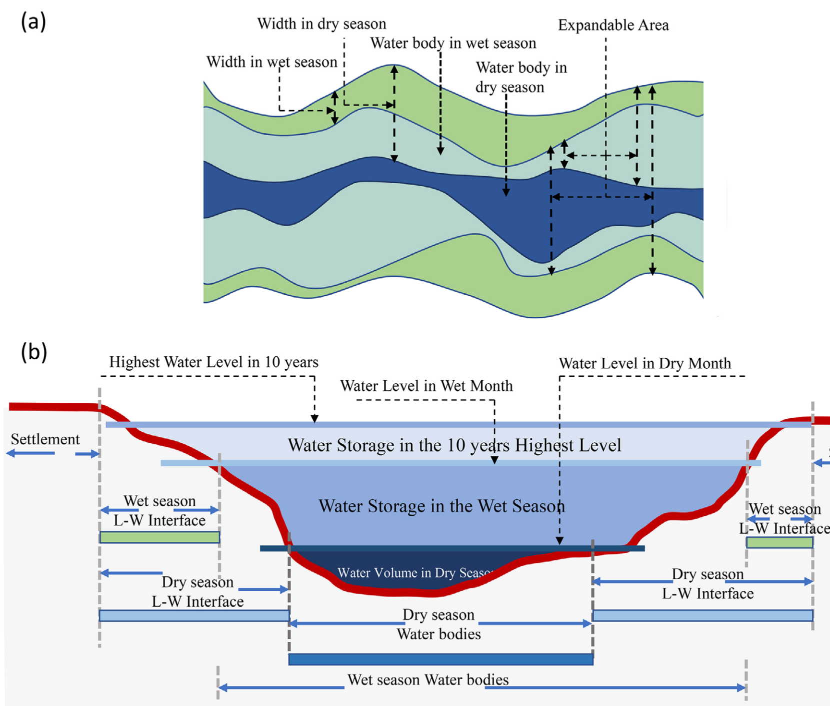
Identifying and categorizing these landscape elements according to their presence at the local land-water interface is crucial for fostering a symbiotic relationship between natural systems and urbanized environments. The findings from this study, organized systematically in **Table 1** based on analyzed landscape parameters and their associated landscape features, serve as a foundation for understanding the intricate dynamics of land-water integration. By extracting strategies from these local contexts and applying them to urban development, planners can promote sustainable practices that prioritize the preservation of natural landscapes. This approach is essential for advancing urban development models that are resilient, environmentally responsible, and in harmony with the natural water systems.

4.1. Landscape Features and Physiography

The landscape elements, features derived from the physiography analysis of the local land-water interface are outlined below, along with their general findings shown in Figure 4.

Table 1. Identified landscape features, elements extracted from land-water interface analyse.

	Physiography	Hydrology	Land Use, Soil and Agricultural Pattern	Local Techniques
Landscape Features	▪ Expandable area ▪ Variable width ▪ Slope gradient	▪ Continuous natural landscape ▪ Watercourses ▪ Water retention capacity ▪ Meanders ▪ Permeable edge	▪ Residential use in adjacent land ▪ Agriculture dominated interface ▪ Diversity in agricultural practices	▪ Local land division pattern ▪ Land utilization techniques for agriculture ▪ Circulation pattern



Source: Author.

Figure 4. Space for water in the land-water interface is managed through expandable areas, variable width, and the storage capacity of water ((a) plan; (b) section).

4.1.1. Expandable Area

The expansion of waterways in width or depth in response to changes in flow volume is a critical aspect of the land-water interface (Gregory, 2011; Wolman, 1967). The research reveals that, this expansion varies significantly between dry and wet seasons, influenced by the type of waterbodies within the catchment area. During the dry season, the land-water interface area increases by almost 100%, particularly adjacent to lowlands and marshlands. In areas dominated by continuous waterbodies like rivers or large canals, the interface area expands by approximately 250% during the dry season. Channel adjustment plays a vital role in stream function, enabling waterways to reach a balance between sedimentation-deposition equilibrium and maintain hydraulic conditions essential for aquatic ecosystems (Gurnell et al., 2007; Kondolf et al., 2013).

4.1.2. Variable Width

The width of the land-water interface fluctuates along its length and across seasons, influenced by vegetation, land slope, land use, and soil characteristics (Hawes & Smith, 2005; Zhang et al., 2015). According to the findings, the interface width varies all the way along. Interface widths range from 20 meters to 200 meters in lowland and marshland areas during the wet season, increasing to 15 meters to 500 meters during the dry season for continuous waterbodies like rivers. This variability in width is a key characteristic of the water edge in the study area, necessitating adaptive design approaches.

4.1.3. Slope Gradient

The slope and topography of the water edge play a crucial role in managing storm runoff and facilitating infiltration. In the majority of cases, a mild slope gradient ranging from 1:15 to 1:20 is observed at the land-water interface, aiding in runoff attenuation and erosion prevention. A very moderate slope of 1:100 or greater is occasionally observed, which facilitates the retention of soil moisture and the slow runoff of water for agricultural practices like paddy cultivation. Even smoother gradients are observed in parts that are adjacent to major watercourses to facilitate agricultural inundation and sediment deposition. Overall, the slope gradient and variation align with the region's topographical characteristics, contributing to hydrological management and ecological diversity.

4.2. Landscape Features and Hydrology

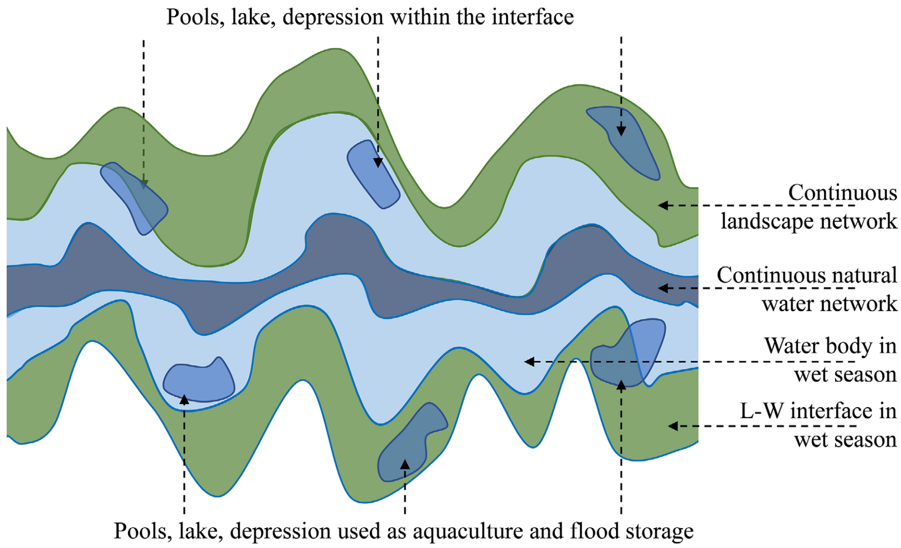
Waterbodies are subject to a variety of natural and dynamic processes, including erosion, transportation, and deposition, which influence and define the landscape along the water's edge in terms of its form, composition, and evolution (Balasubramanian, 2010; NRC, 2010). The hydro-ecological processes and the landform of any territory are significantly influenced by these water edges. Based on the hydrological analysis conducted within the study context, the following general landscape characteristics have been found (**Figure 5**).

4.2.1. Continuous Natural Landscape

The connectivity between watercourses and surrounding landscapes benefits biodiversity and facilitates the exchange of matter, energy, and habitat (Jackson & Pringle, 2010; SEWRPC, 2010b). The analysis reveals a continuous network of waterbodies, including canals, river branches, and rivers, interconnected with natural vegetated landscapes. This interconnected blue-green network contributes to a sustainable hydro-ecological environment within local settlements.

4.2.2. Presence of Watercourses

The land-water interface in each sample comprises depression areas such as pools, lakes, wetlands, and submerged areas. These watercourses store overbank floodwaters and surface runoff, enhancing infiltration, controlling erosion, and providing habitat for wildlife. These hydrological features serve multifunctional roles in supporting seasonal agriculture and aquaculture practices.



Source: Author.

Figure 5. Contentious water network, watercourses, agricultural belt, vegetation zone along the land-water interface.

4.2.3. Water Retention Capacity

Expandable areas at the land-water interface serve as vital reservoirs for excess rainwater, surface runoff, and floods, mitigating settlement inundation. The analysis confirms the flood-free status of the study area over the last decade, highlighting the retention capacity of the land-water interfaces. The natural setting of water edges, with various landscape elements such as surface undulation and vegetation, enhances their ability to cope with hydrological dynamics.

4.2.4. Permeable Edge

The vegetation along the water's edge enhances the permeability of the land-water interface, promoting water infiltration and reducing stormwater runoff. It also increases evapotranspiration rates, contributing to the region's ecological stability. Three distinct vegetation zones have been identified along the interface: highland trees near settlements, vegetable cultivation zones, and paddy fields adjacent to waterbodies. These vegetation zones play a crucial role in reducing surface runoff and increasing soil permeability.

4.2.5. Meanders

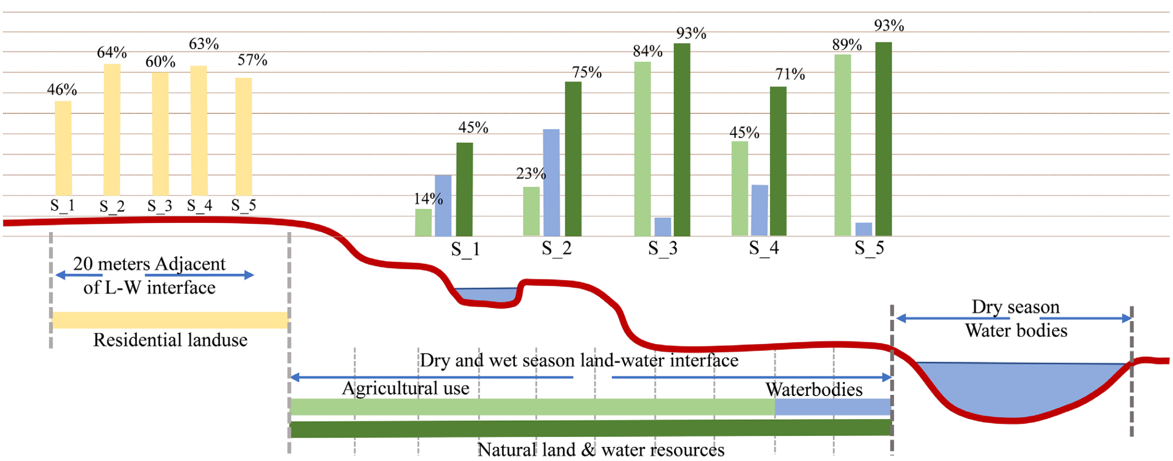
Natural waterbodies often meander across the landscape, forming meander belts where sediment accumulates around vegetated water edges (NRC, 2002). Finger-like meandering patterns are observed in the study context, guiding the movement of waterbodies and shaping the land-water interface. These dynamic meandering patterns slow stream runoff, promote vegetated landscapes, and enhance sediment infiltration, contributing to ecological protection and maintaining local identity (SEWRPC, 2010a; van Dijk et al., 2013).

4.3. Landscape Features and Local Land Use, Soil, Agricultural Pattern

The sustainable land-water interaction of every location is fundamentally determined by the long-term land use patterns along the water edge and surrounding buffer strips. Additionally, agricultural practices, influenced by soil suitability and local topography, significantly impact the hydro-ecological health of the nearby waterbodies and their interface (Enanga et al., 2010). Therefore, incorporating pre-urban land use patterns into future development processes is essential for maintaining a sustainable living environment.

4.3.1. Residential Use in the Adjacent Area

Peripheral development should align with residential land use along the edges of the land-water interface. Analysis reveals that more than 60% of the adjacent land within a 20-meter buffer of the land-water interface is used for residential purposes (**Figure 6**). This underscores the dependence of inhabitants on landscape practices surrounding the water edge. The limited presence of industrial and mixed-use developments helps control pollutant discharge into waterbodies, thus maintaining water quality.



Source: Author.

Figure 6. Land use patterns in and around the land-water interface.

4.3.2. Agriculture Dominated Land Use

Agricultural activity is a prominent feature of the water edge landscape, encompassing crop production, aquaculture, livestock, and tree plantations. Historically, agricultural activities have shaped much of the landscape and continue to occupy a large portion of the land-water interface now a days. Local agricultural practices, influenced by soil type, topography, and water content, result in year-round crop production and fish cultivation. Approximately 75% to 94% of the land-water interface is utilized for agriculture purposes, including both land and waterbodies (**Figure 6**). The diverse agricultural practices, adapted to seasonal variations and local conditions, play a crucial role in maintaining sustainable land-water relationships.

4.3.3. Diversity in Agricultural Practices

The diverse landscape and geomorphological conditions support a wide range of specialized agricultural productions, adapted to the unique features of the region, such as soil type, subsoil composition, and surface water availability. Long-term vegetation patterns define the character of the land-water interface, emphasizing the importance of incorporating these patterns into future land development processes to ensure sustainability.

The soil and subsoil specific characteristics of the study area dictate suitable agricultural production practices. Madhupur Terrace lowlands, valley soils, low floodplains, and high floodplains make up the majority of the soil type in the research area's land-water interface. These soil types lie below the seasonal flood level and are unsuitable for permanent settlement due to their propensity for inundation. Primarily used for moderate agricultural purposes, these soil types support double-cropped to tri-yielded agricultural lands. In contrast, the high-levelled Madhupur Terrace soils are less flood-prone but have lower natural fertility, making them ideal for construction purposes rather than farming.

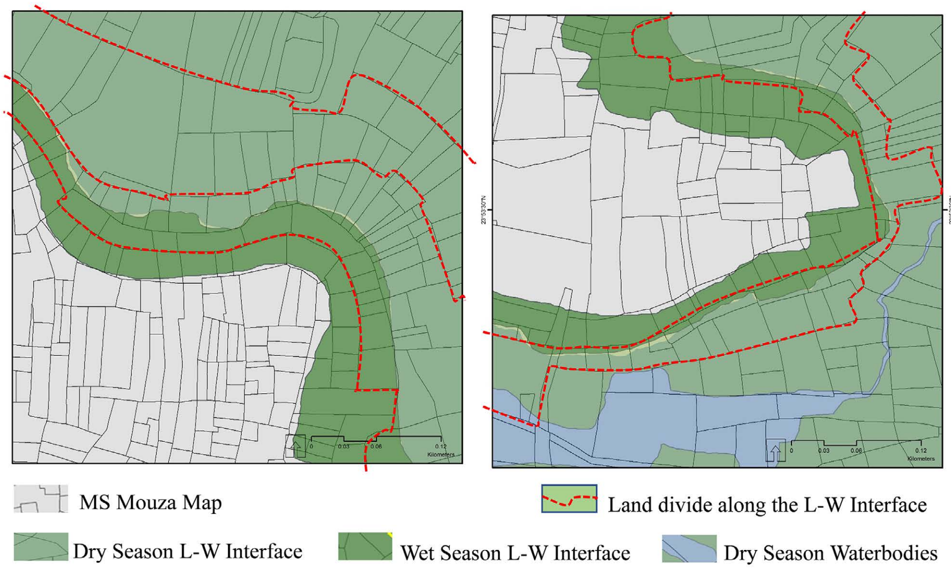
Local land use decisions are heavily influenced by soil typology. Settlements are typically built on higher ground, while the low-lying, fertile floodplains are utilized for land-water interface activities and agriculture. This strategic placement of settlements and agricultural zones ensures that flood risks are minimized and natural resources are used effectively, promoting a water-sensitive approach to urban development.

4.4. Landscape Features and Local Techniques of Land Utilization

Throughout history, land and water resources have been vital in shaping local settlements, offering various benefits. Local communities have developed unique methods to harness these natural resources, optimizing opportunities and building resilience against adversity. These local techniques of land utilization not only reinforce regional identity but also ensure sustainability by efficiently managing resources and preserving biodiversity.

4.4.1. Local land Division Pattern

The pattern of land division in these regions typically follows the slope direction of the land-water interface. Analysis of Revisional Survey (RS) and Metropolitan Survey (MS) Mouza maps reveals that plot subdivision follows the topographical contours both laterally and transversally (**Figure 7**). Unlike flat land suitable for settlement, the sloped land-water interface remains undeveloped, preserving space for waterbodies.



Source: Author.

Figure 7. Land division pattern following slope direction.

4.4.2. Land Utilization Techniques for Agriculture

Local residents employ practical knowledge that has been verified over time to enhance agricultural production by utilizing the landscape. The extensive land-water interface is exposed to multiple water sources throughout the year, providing opportunities for varied agricultural practices. To optimize the agricultural potential of the landscape around them, local residents implement a wide variety of techniques. Listed below are a few of the many locally-developed techniques for cultivating agricultural products, fish, and poultry.

- During the rainy season, when water levels are high, residents practice floating vegetable farming using platforms made from organic materials (**Figure 8**).
- In inundated lowlands during wet months, locals engage in fish farming by setting up bamboo fences and nets, a method known as “bana” (**Figure 9**).
- Residents maximize crop production by constructing earthen dams to store water during low periods and irrigate during high-water periods, cultivating crops across different topographic levels.
- The peripheral areas of waterbodies are utilized for poultry farming, with farmhouses built on stilts over the water and bamboo fencing used to control duck movement.

4.4.3. Circulation Pattern

Road infrastructures in these regions is typically constructed parallel to and beyond the water’s edge, ensuring the flow of surface runoff and debris into waterbodies (**Figure 10**). This practice not only reduces road maintenance costs but also enhances landscape connectivity and protects biodiversity. Where road crossings are necessary, structures such as bridges or culverts are designed to ensure the safe passage of fish and wildlife across the land-water interface.

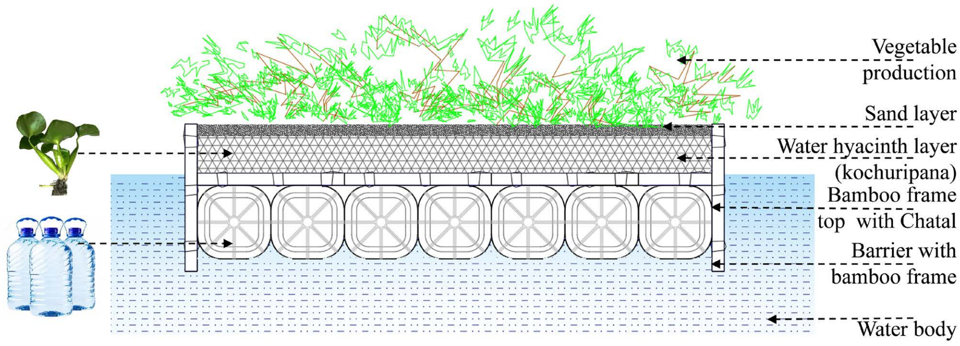


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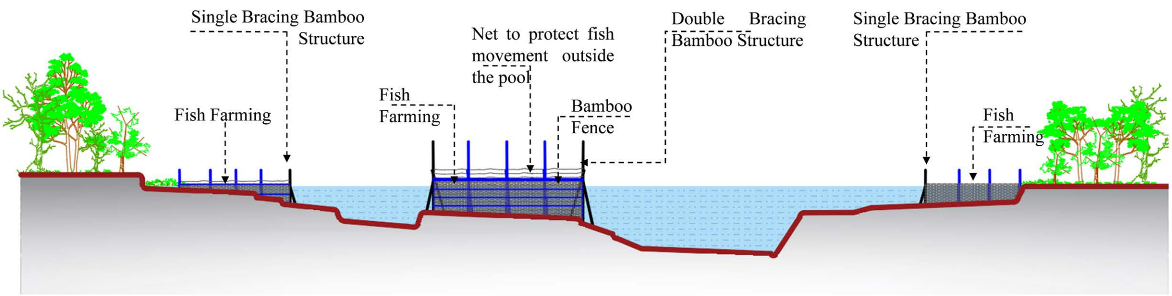
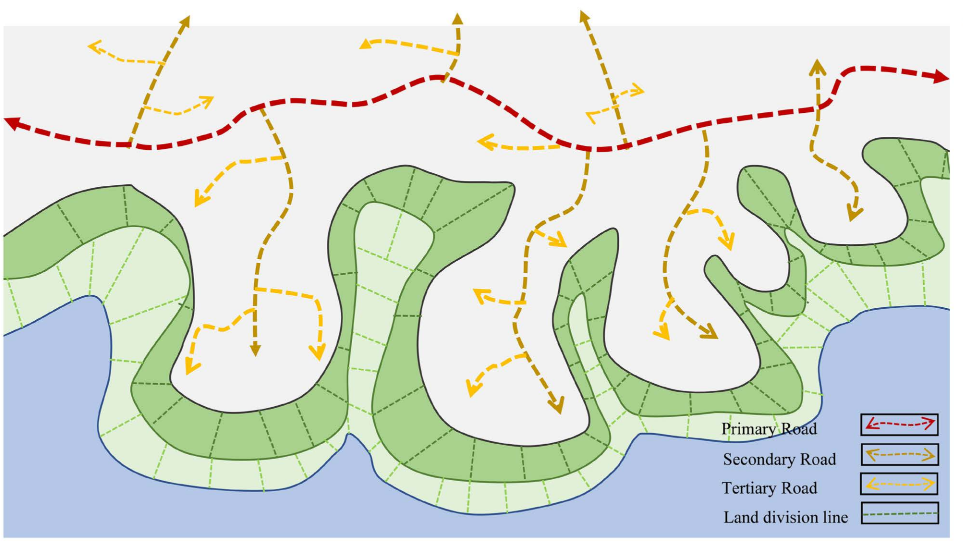
Figure 8. Local wisdom of floating vegetable cultivation.



Source: Author.

Figure 9. Traditional aquaculture techniques in the lowlands.

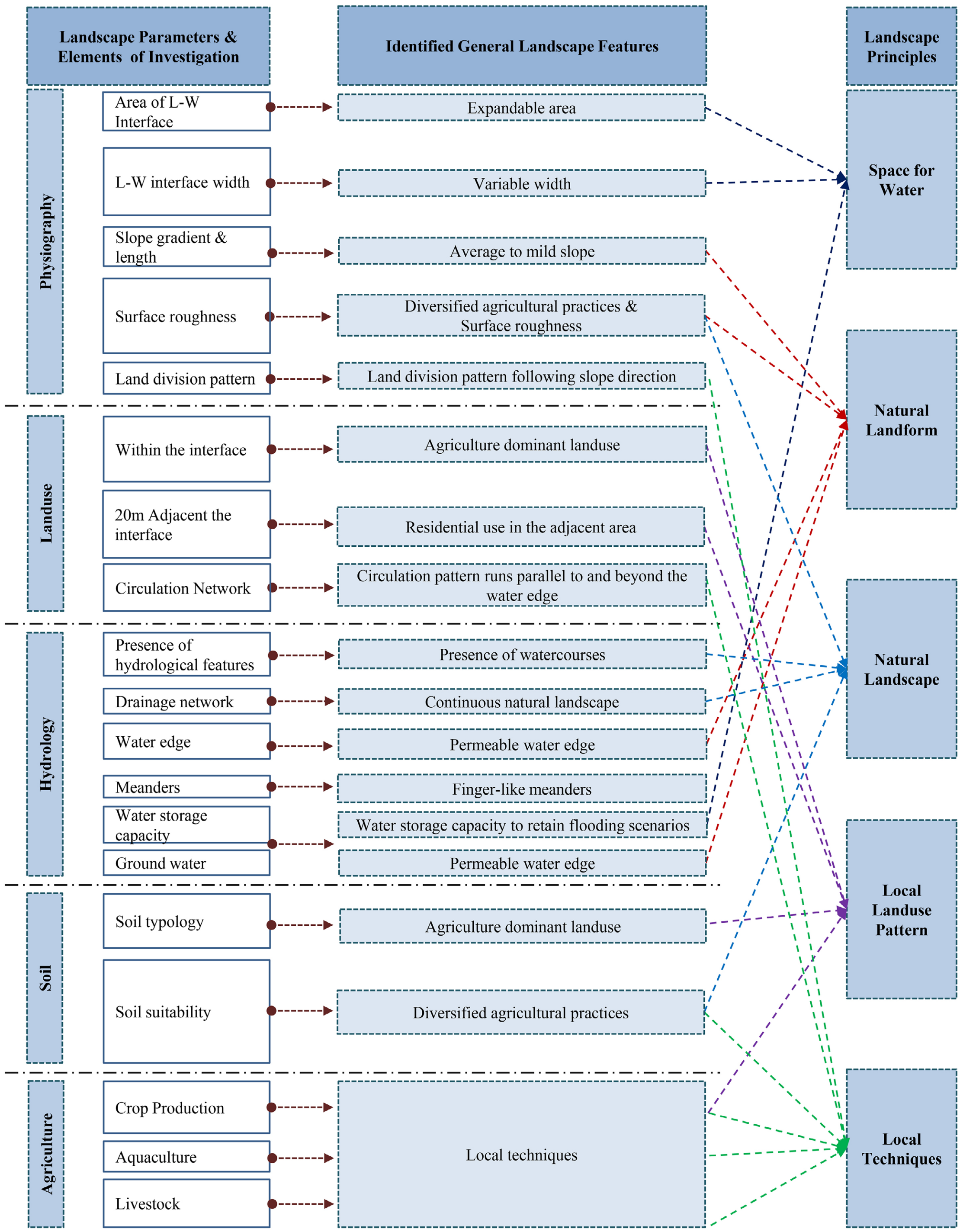


Source: Author.

Figure 10. Circulation pattern in relation to land-water interface in spontaneous settlement.

5. Result: Landscape Principle from Local Water Sensitive Land-Water Interface

The detailed observation and analysis of the study area reveal that the local settlement has effectively implemented a water-sensitive approach in managing the land-water interface. To enhance urban resilience over the long term, it is necessary to approach the land-water interface in a more adaptable and flexible manner, especially when dealing with problems linked to ecology and hydrology. Figure 11 provides a summary of the results for each sample of the landscape features



Source: Author.

Figure 11. Cross-case analysis of the samples, identified landscape features, and principles.

that were investigated, taking into account the parameters that were analyzed This observation helps to identify the relationships between landscape parameters and the corresponding samples, forming the foundation for understanding local knowledge, patterns, practices, and the key features of landscape development at the land-water interface.

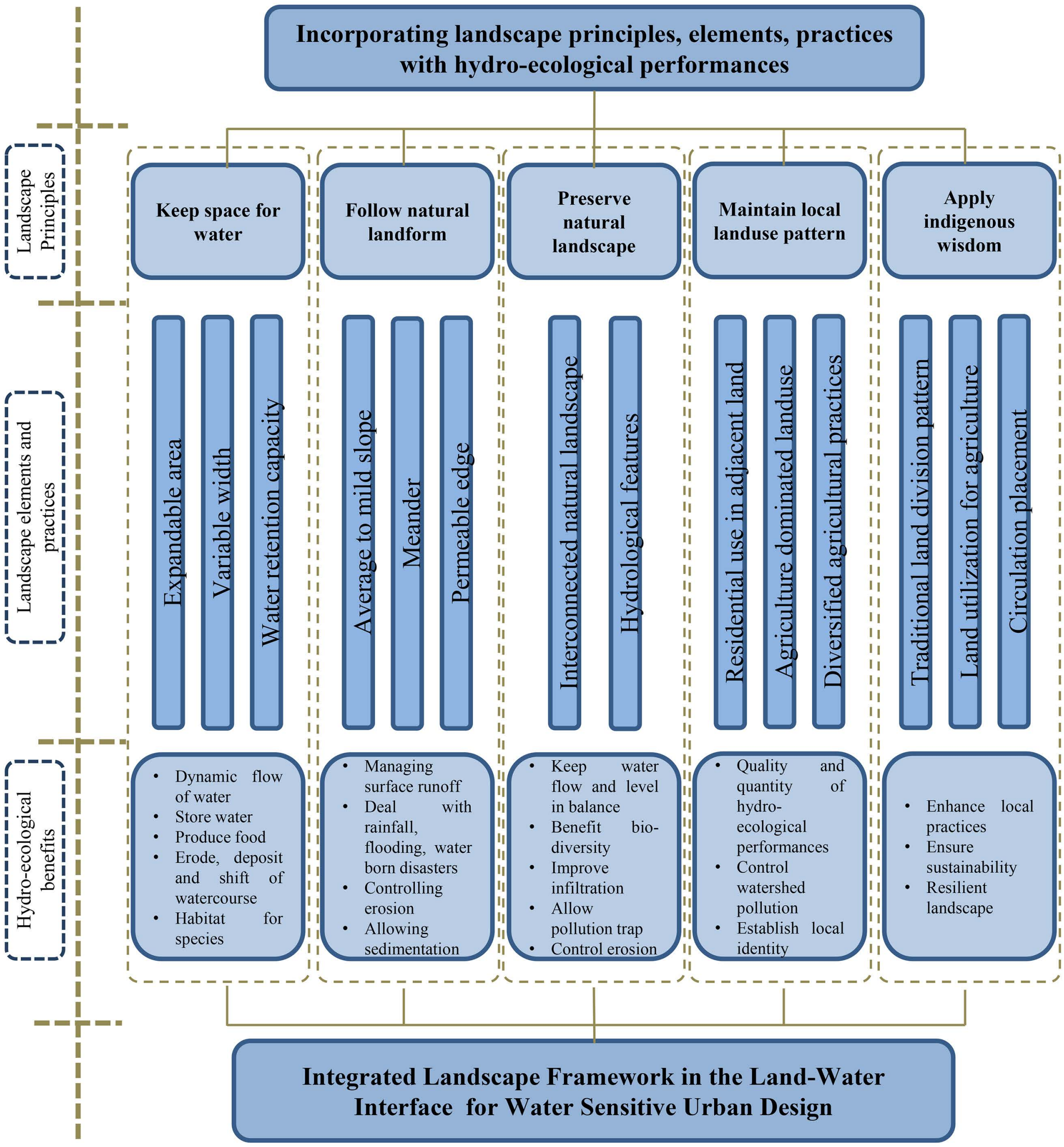
The analysis shows how different landscape outputs are interrelated, leading to the formulation of general principles that connect identified landscape components to guide future urban development strategies at the land-water interface. To meet the requirements of water-sensitive development, **Figure 11** organizes common landscape elements under specific guiding principles.

In local contexts, sustainable land-water relationships are maintained by "ensuring adequate space for the interface", "preserving natural landforms", "protecting the natural landscape", "following traditional land-use patterns", and "applying local techniques". These core landscape services contribute to the development of essential "landscape principles" that reflect the diverse characteristics of the region. To mitigate the hydro-ecological impacts of human development, these principles advocate for landscape intervention that harmonizes with nature. The principles and specific elements observed in resilient local landscapes offer valuable insights for the current design of water edges in the region. Furthermore, they can serve as a foundation for sustainable water-sensitive design solutions in future urban landscapes.

6. Integrated Landscape Framework and Design Guideline

The integrated landscape framework is a strategic tool for urban planning and design, offering a cohesive vision for future development while guiding interventions that shape open spaces, buildings and landscapes (PPN 17, 2015). A comprehensive investigation of every given site allows for the incorporation of that site's distinct characteristics and potentials into the overarching urban design framework. This framework includes guiding principles, core design concepts, action strategies, and implementation plans. The study area's landscape analysis identified key elements, parameters, and practices that are resilient and sustainable. "Space for water", "natural landform", "natural landscape", "local landscape pattern", and "local wisdom" are five principles of landscape design that emerged from an analysis of all landscape components.

Incorporating the landscape elements creates a landscape framework. An urban design framework that incorporates the identified landscape principles, features, and practices for the land-water interface has been produced by comparing and merging the concerns—context analysis, landscape investigation, and cross-case analysis (**Figure 12**). The objective of the framework is to compile a set of essential features—elements of the local landscape—that may be improved, altered, and preserved at the land-water interface and in comparable settings. Design guidelines (**Figure 12**) for water-sensitive urban development and the created landscape framework are detailed and shown below.



Source: Author.

Figure 12. Integrated landscape framework for the land-water interface.

6.1. Space for Water

For the land-water interface to work hydrologically, it is necessary to comprehend the changes in water volume over time. Analysing the hydrological characteristics of the area is required to determine the necessary amount of space along the edge of the water to support the higher water volume during the rainy season and the more productive landscape during the dry. The city's water and land management organizations need to ensure enough room along the waterfront to withstand the increased water levels that occur during the rainy season. According to the study, the land-water interface's "expandable area", "variable width", and "water retention capacity" are crucial for making sure there's adequate room for changes in water levels in nearby waterbodies.

6.2. Natural Landform

At any location, the land-water interface is heavily influenced by the natural landforms shaped by waterbodies and their flow patterns. Identifying and incorporating local landform patterns into the landscape characteristics used for land-water interface design is crucial for preserving the local hydro-ecological process. Landscape elements such as "permeable edge", "suitable slope gradient", and "finger-like meandering" have been recognized by the study as essential to the land-water interface's overall design.

6.3. Natural Landscape

Urbanization often transforms natural land and water features into built environments. To mitigate the ecological impacts of this shift, urban design and water management strategies must incorporate pre-urban landscape elements. The findings emphasize the importance of preserving interconnected natural landscapes, often found in spontaneous settlements, as structural components of future urban development. These natural elements should be retained and integrated into the design of the land-water interface to support long-term ecological resilience.

6.4. Local Land Use Pattern

Most notably, the city planning authority is quickly turning the city's periphery zones into growth management regions by turning wetlands and agricultural areas into urban areas. These activities are forcing residents to abandon their livelihoods that depend on these landscape resources and migrate. Urban planning for delta regions should take into account and include local communities that are linked to adjacent water resources and agriculture-related activities. Consequently, water edge design must take land usage into account both inside and outside of the land-water interface. The quality and quantity of adjacent waterbodies are significantly influenced by nearby land use.

6.5. Local Techniques

The study clearly examines into the topic of local intelligence in water and land resource management, which enhances the utilization of the resources in a sustainable and resilient way. It is recommended that future water edge development should incorporate the long-standing practice of land utilization for landscape generation on the land-water interface, which is based on local wisdom. The water-sensitive urban development must integrate the traditional "land division pattern", "land utilization techniques for agriculture", and "circulation pattern".

7. Application of the Urban Design Framework

Achieving sustainable urban development requires the preservation and integration of natural land and water resources within city landscapes. Ensuring a harmonious interaction between land and water systems is critical for maintaining hydro-ecological health. In urban contexts, the sustainability of these interactions is largely determined by the landscape characteristics of the land-water interface. Therefore, a thorough analysis of these landscape aspects can provide a robust framework for organizing the land-water interface and guide the design of water-edge landscapes that are resilient and adaptable.

Flood mitigation strategies in the study area must align with the principles outlined in this research. For instance, the region's **"Stormwater Drainage Master Plan"** should incorporate landscape elements that enhance floodwater retention at the land-water interface, thereby improving the area's capacity to store and regulate stormwater. This approach would also aid in flood protection by ensuring the natural landscape's ability to manage excess water during extreme weather events. Institutional policies should reflect these landscape-based strategies, emphasizing the preservation of natural hydrological features, the implementation of non-structural water management techniques, and the maintenance of interconnected natural landscape networks.

Moreover, the study underscores the need to incorporate local natural landscapes, topographies, land-use patterns, and traditional land-water management practices into policy frameworks. These elements are vital for crafting solutions that work with the natural environment rather than against it. This integration can create more adaptive and ecologically resilient urban environments.

The proposed guidelines should also be integrated into existing environmental protection regulations and legislation. Relevant authorities are encouraged to expand categories such as **"open spaces"**, **"natural wetlands"**, **"ecologically critical areas"**, **"flood flow zones"**, and **"sub-flood flow zones"** to encompass diverse waterbodies and their surrounding landscapes. By adopting this methodical conservation approach, cities can address flooding and waterlogging more effectively, fostering urban environments that are water-sensitive and resilient to climatic fluctuations.

These findings should be embedded into the legal framework through existing laws, such as the "Water Act", "Environment Conservation Act", "Playground", "Open Space", "Park and Natural Water Reservoir Conservation Act", and the "Agricultural Land Protection and Land Use Act". Additionally, rules regarding land development and inland waterway protection, such as the "Construction & Installation Control Rules on Inland Waterways and Foreshore" and the "Land Development Rules", should incorporate the landscape framework and design guidelines proposed in this study. This systematic approach can ensure that urban development aligns with environmental conservation principles and the sustainable management of land and water resources.

Lastly, the city's **Detailed Area Plan (DAP)** must adopt the proposed landscape framework and design guidelines. Integrating these elements will support the implementation of policies outlined in the **Dhaka Structural Plan (DSP)**, ensuring the creation of water-sensitive urban environments in the eastern periphery of the

Dhaka Metropolitan Area (DMA) and other regions with similar landscape features. This approach will bridge the gap between policy and practice, helping cities incorporate natural and hydrological processes into their urban planning frameworks.

8. Conclusion

Natural waterbodies and land resources in delta regions are integral to hydrological management and ecological sustainability. However, contemporary urban development practices often prioritize land conversion for urbanization over the conservation of these natural resources, neglecting the critical land-water relationships that sustain the region's ecological balance. Reliance on engineering-based solutions, without consideration of the hydro-geographical characteristics of the landscape, exacerbates urban vulnerability to floods and ecological degradation. Additionally, the failure to integrate natural landscapes into formal planning frameworks has resulted in the gradual erosion of essential environmental resources.

This research presents an alternative, context-sensitive approach that emphasizes the integration of local knowledge and natural processes into urban land-water management strategies. The study demonstrates that local land-water interfaces have the potential to form distinctive relationships where natural landscapes coexist with settlements, addressing both hydrological and ecological challenges without reliance on heavy engineering or institutionalized planning processes. This approach highlights the untapped potential of traditional land-use practices and ecological stewardship in shaping sustainable urban environments.

Incorporating these findings into institutional frameworks can strengthen land-water management systems, protect natural resources from unsustainable development pressures, and preserve the intrinsic land-water relationships that are vital for long-term ecological resilience. By integrating the principles of water-sensitive urban design into planning strategies, cities can create adaptable, resilient landscapes that enhance urban livability while mitigating environmental risks.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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