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Reviving Surface Water Bodies with Ecological Resilience Through WSUD Approach: A Case of Rajshahi City, Bangladesh.

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Abstract
Ecological resilience is a measure of an ecosystem's ability to recover rapidly from disruption. Human interventions and urbanization dramatically affect surface water bodies over land, which are integral parts of the ecosystem. There were approximately 729 ponds and canals in 2002, but only 393 remain in 2011, which increases temperatures, waterlogging, and drought conditions. As pollutants enter water bodies through rainwater, they disrupt the ecosystem and ecology. This paper provides an overview of the research and implementation, focused on Water-Sensitive Urban Design toward ecological resilience. In line with the theory, the outcomes are impressive, and fruitful, in addition to improving ecological resilience. These can provide direction on Rajshahi's future waterbody preservation process. As the method provides a relative assessment of resilience and makes some basic assumptions, additional research is needed to explore assessment methods that account for this effect.
Keywords: Water- sensitive Urban Design, Ecological resilience, Surface pollutants, Rajshahi City.

1. Introduction

Water is one of the important elements which balances the ecological structure of nature. The capacity of social-ecological systems to deal with shocks, adapt to changing situations and transform in conditions of disaster are depending on the features of water e.g., regulating the Earth's climate, supporting biomass production, and imparting water resources to human societies. Water bodies are facing a crucial time due to the imbalance of ecology and day by day these surface water bodies are declining. Human interaction with nature is also lowering simultaneously.

Water in ecological resilience can be defined as the role of water in safeguarding and sustaining water in the particular desired state of a social-ecological system, ranging from upholding the state of ecosystems to the stability of regional weather and climate systems(Falkenmark et al., 2019). Besides that, water surface additionally plays a huge role in balancing ecological resilience. Ecological resilience has also become important to conservation practices and ecosystem management, especially because the latter has shifted its attention to the significance of ecosystem services. Such services consist of the availability of food and natural products, the mediation of climate; the removal of toxic materials from environmental reservoirs; and the cultured enjoyment that people derive from the natural world. 'Ecological resilience' is defined as the capacity of a system to undergo disturbance and reorganize to still maintain essentially the same functions, structures, and controls by not moving in a different region of the state space controlled by a diverse set of mutually reinforcing processes(*A_Retrospective_Approach_to_Complex_Syst*, n.d.).

Globally urban environments are facing challenges due to an accelerating increase in urban populations. By 2050, 68% of the world's population is expected to live in urban areas (Amen, 2021; Aziz Amen, 2022; Amen et al., 2023; Amen & Nia, 2020). Nowadays, cities, especially in developing countries like Bangladesh, are faced with an ever-increasing population and as a result of the build-up increase. Nowadays, 40% of the population of developing countries are residing in cities and this figure is expected to reach 51% by 2020(*Population Challenges for Bangladesh in the Coming Decades*, 2008). However, massive, inter-connected, human interference involving climate forcing, water withdrawal, and land-use change have significantly disturbed the water functions and induced regime shifts in social-ecological systems. Because of the drastic urbanization process by increasing populations, the surface water bodies like ponds are declining.

According to the Rajshahi City Corporation, in 2002, the Rajshahi city had an estimated 729 ponds and canals but in the year 2011, the number has declined to 393(Kafy et al., n.d.). Drought conditions in the last 5 years increased 35% in Rajshahi city. In 2008, the maximum temperature was 40.0 degrees centigrade, whereas, in 2011, it was 42.5 degrees centigrade(*Zila_Rajshahi*, n.d.). One of the major reasons for facing these problems is the shortage of water bodies and ecological imbalance.

Surface water sources are very limited and most of them, like ponds, canals, rivers, and other natural water bodies get dried up and also contaminated by wastewater. Every day huge quantities of wastewater are produced in municipal areas and discharge without treatment of this wastewater in the natural receiving bodies creates environmental hazards. This wastewater is a combination of different types of wastewaters originating from the

sanitary system of commercial housing, industrial facilities and institutions, in addition to any groundwater, surface water and stormwater that may be present(Schellenberg et al., 2020).

To control ecological resilience and health hazards, surface water bodies must immediately be treated appropriately. Different water treatment technologies are used worldwide, and WSUD is one of the most useful tools. The Water Sensitive Urban Design (WSUD) is supported by an underlying value of providing urban water services in a manner that considers the site-specific opportunities and limitations of development to provide water services in a way that protects and enhances local hydrological and ecological integrity. The WSUD concept encourages urban development with integrated urban water management as an interdisciplinary effort to minimize negative hydrological impacts on its surroundings(Sharma et al., 2016). Water sensitive urban design (WSUD) is an approach to planning and designing urban areas to make use of this valuable resource and reduce the harm it causes to our rivers and creeks.

Water Sensitive Urban Design (WSUD) is an emerging urban development paradigm aimed to minimize the hydrological impacts of urban development on the environment. In practice, the WSUD integrates stormwater, groundwater water supply, and wastewater management to

- protect existing natural features and ecological processes;
- maintain the natural hydrologic behavior of catchments;
- protect the water quality of surface and ground waters;
- minimize demand on the reticulated water supply system;
- minimize wastewater discharges to the natural environment;
- integrate water into the landscape to enhance visual, social, cultural and ecological values .

For implicating WSUD to revive the surface water bodies, case studies of other countries should be analyzed and necessary steps should be taken according to these. For this process, the analysis of the case studies and their research can be followed. But the site, climate, topography and other elements should be kept in mind according to the geology of our Rajshahi city.

The initial step involved analysing the condition of Rajshahi City in Bangladesh. The data collected from Rajshahi City Corporation, Rajshahi Development Authority, and Bangladesh Bureau of Statistics revealed a significant decline in the number of surface water bodies, such as ponds and canals, in the city. Drought conditions increased by 35% in the last five years, and there was a decrease in the number of ponds. The stormwater from rainfall mixed with pollutants on roads and fields, polluting the water bodies and disrupting the ecological balance.

Then it involved conducting a literature analysis on the WSUD approach. The study found that WSUD had been successfully implemented in various countries, including Australia, Singapore, Germany, and the Netherlands. WSUD aims to integrate rainwater into the landscape, conserve water quality, reduce runoff and peak flows, and improve urban amenity. The study also highlighted the use of wetlands, rain gardens, and swales as effective tools in WSUD.

In this step, there is a proposed problem solution process for Rajshahi City. Considering the tropical wet and dry climate of the area and the decline in water bodies due to stormwater pollution, WSUD was identified as an effective process for maintaining water quality, stormwater management, and water conservation to restore ecological balance. It is identified that three WSUD tools suitable for the area: wetlands, rain gardens (bioretention), and swales. These tools were selected based on their compatibility with the climatic conditions, site location, user preferences, authority involvement, and ease of maintenance. The proposed solution involved implementing wetlands, rain gardens, and swales in selected areas such as residential neighbourhoods and public ponds. Wetlands act as natural filters for stormwater, removing pollutants before they enter waterways. Rain gardens use vegetated soil filters to treat stormwater, and swales collect and transfer stormwater while removing gross pollutants. The researchers emphasized the importance of maintenance by the local authority and increasing awareness among the community to ensure the long-term effectiveness of these WSUD tools. The use of wetlands, rain gardens, and swales can help improve water quality, manage stormwater, and enhance human interaction with the water bodies.

2. Materials and Methods

We addressed our research question - how to revive surface water bodies with ecological resilience through the WSUD approach - by taking the three-step approach described below. The process of designing using Water Sensitive Urban Design as a tool, including the methodology and results of this three-step approach, is presented in this section. We collected data from Rajshahi City Corporation (RCC), Rajshahi Development Authority (RDA) & Bangladesh Bureau of Statistics. Figure 1. **A graphical framework to represent our methodological approach (Developed by Author).** A graphical framework to represent our methodological approach (Developed by **the** Author).

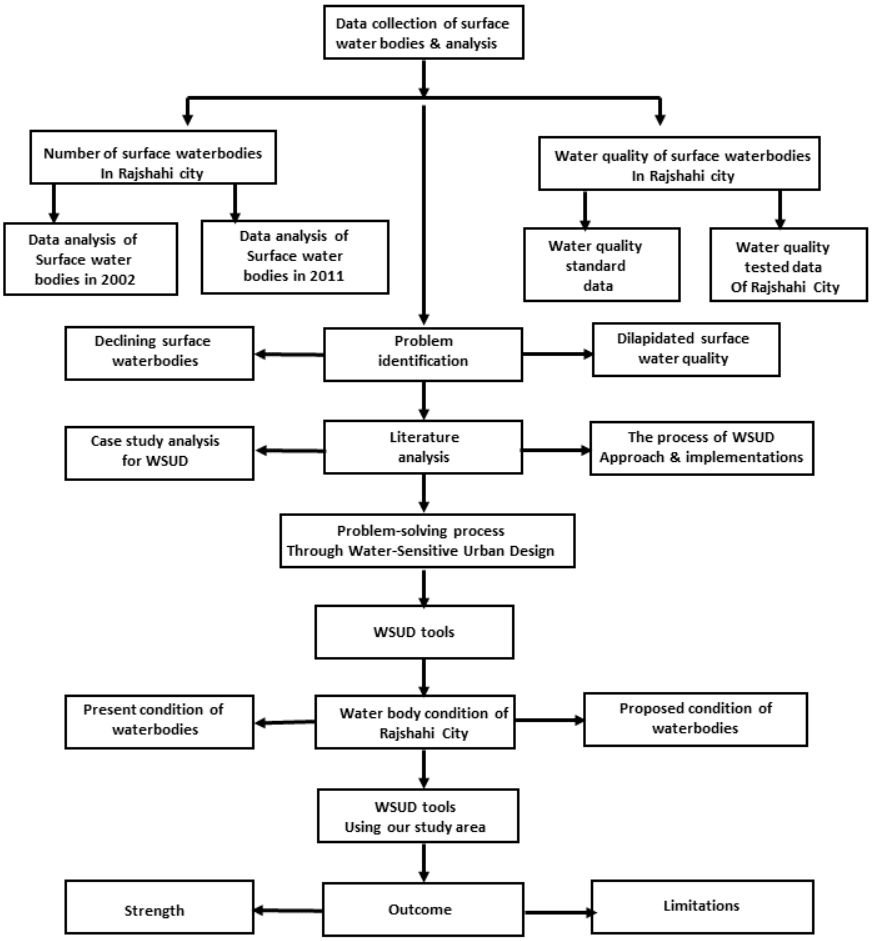

Figure 1. A graphical framework to represent our methodological approach (Developed by Author).

2.1. Analysis of Rajshahi city

According to the Rajshahi City Corporation, in 2002, the Rajshahi city had an estimated 729 ponds and canals but in the year 2011, the number has declined to 393. In the year 2016, the total number of surface water bodies in the RCC area is only 2.02 km2 which indicates almost 1.4 km2 of water bodies are being filled up in a space of only 12 years. Drought conditions in the last 5 years increased by 35% in Rajshahi city(Chowdhury et al., 2020).

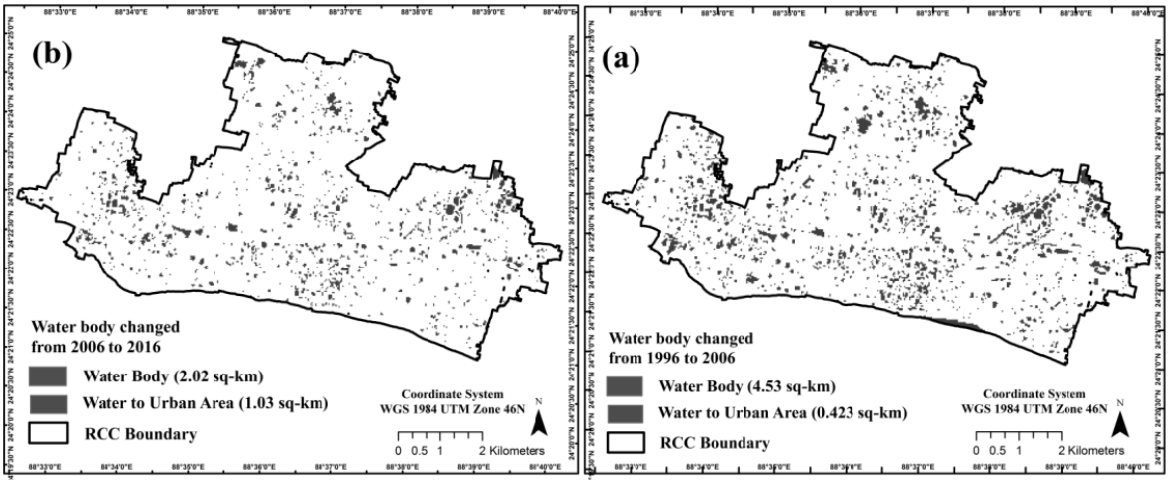

Figure 2. Association of water body fill up occurrence with urbanization in RCC a) 1996-2006 b) 2006-2016

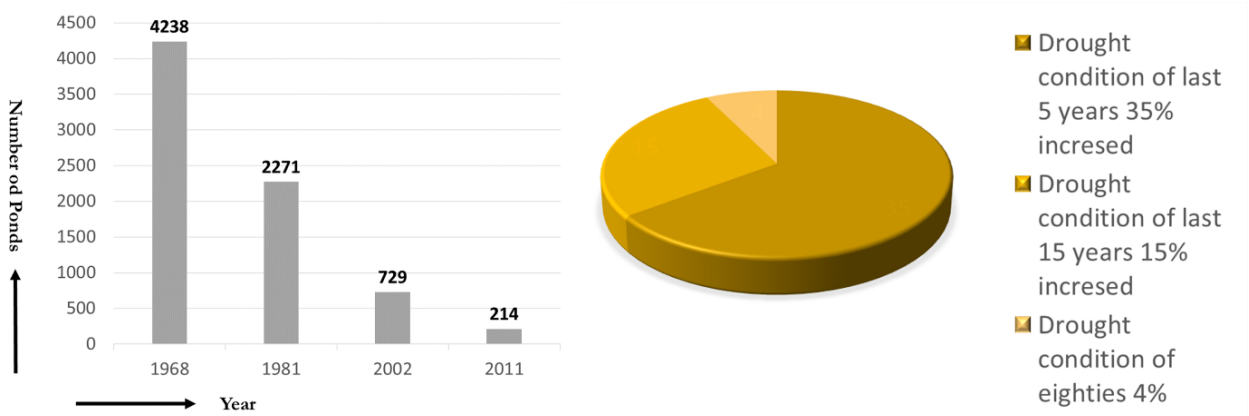

Figure 3. A graphical presentation of decreasing number of ponds and a graphical presentation of decreasing number of ponds (Developed by Author).

In 2008, the maximum temperature of Rajshahi city was 40.0 degrees centigrade, whereas, in 2010, the maximum temperature was 42.5 degrees centigrade. According to the Bangladesh Bureau of statistics in 2008, the amount of rainfall was 1629.3 millimeters & in 2011 the amount was 4637.3 millimeters. Because of rainfall, the rainwater mixes with the pollutants on roads and fields and it falls into the surface water which is called stormwater(Shamsuzzoha et al., 2014).

This stormwater pollutes the water bodies and creates an imbalance in ecology. The highest pH value of the stormwater was found at 6.93 in the residential areas, and 6.6 in commercial areas. Where it is seen that the mean pH value of Rajshahi's pond was 7.7. But the normal pH value for household activities is 7 [10].

Stormwater and wastewater pollute the surface water body which is unhealthy for the resilience of the ecology. This is also one of the reasons for pond declination. Day by day surface water bodies of Rajshahi city are declining and left water bodies are in dilapidated condition. For this reason, necessary steps should be taken to stop this carelessness towards nature and the environment.

2.2. Literature analysis

WSUD intervened in many countries and had a great impact on resurrecting the water bodies. It helped many countries to balance nature and ecological resilience. WSUD was used as a term in 1994 in Australia for the very first time and introduced the integrated management of land and water planning which grew globally later in the 1990s [11]. The objective of this technique is to incorporate rainwater into the landscape, conserve water quality and natural system and reduce runoff and peak flows. The outcomes are WSUD planning, implementation, community consultation and regulation and aimed to investigate the impediments in the mainstream uptake of WSUD approaches to conduct a post-implementation assessment of developments in the study area and to explore the community perception.

The second study is based on Water Sensitive Urban Design, especially wetlands for both stormwater management & the ABC (Active, Beautiful & Clean) for urban areas. The new master plan aims to enable water treatment as soon as the water touches the ground, enabling Singapore's water catchments, waterways, wetlands and man-made bio-swales to have good water quality, be aesthetically beautiful, attract people and enhance the community(Felipe & Gómez, n.d.).

Similarly, the WSUD concept has been successfully operationalised and applied in different climatic conditions in Germany, Singapore, the Netherlands and the presented States among others (Rosemary LeonardSayed IftekharSayed IftekharMelissa GreenAndrea WaltonAndrea Walton, 2019).

2.3. Problem solution process

Rajshahi has a tropical wet and dry climate and the Charland remains dry from May to August, generally marked with monsoons, high temperature and moderate rainfall(Shamsuzzoha et al., 2015). As we know, the number of surface water (ponds) is decreasing because the rainfall stormwater is mixing with ponds and hampering the water quality. To solve this vital problem, Water Sensitive Urban Design (WSUD) is an effective process for maintaining water quality, stormwater management, and water conservation to maintain the ecological balance. Water sensitive urban design (WSUD) is a broad area of practice, with a wide range of objectives from managing hydrology and water quality to improving urban amenity and mitigating urban heat island impacts .

Results for WSUD from one study may not always be relevant in other situations where there are differences in rainfall, stormwater quality, or treatment measure configuration. There are some approaches for WSUD. In South

Australia, the former Department of Planning and Local Government developed the Water Sensitive Urban Design Technical Manual, which guided the implementation of 12 WSUD tools in the greater Adelaide region. These are shown in Table 1

Table 1. WSUD Approach/ Tools

No.	WSUD Approach/Tools	No.	WSUD Approach/Tools
1	Demand reduction	7	Bioretention systems for streetscapes
2	Rain gardens, green roofs and infiltration systems	8	Swales and buffer strips
3	Rainwater tanks	9	Sedimentation basins
4	Previous pavement	10	Constructed wetlands
5	Urban water harvesting/ reuse	11	Wastewater management
6	Water smart street trees	12	Gully baskets

2.4. PROBLEM SOLUTION

The area selected for the proposed research is a residential neighborhood water body (Shagor para), public pond (shahmakdum mazar pond and Rajshahi college pond). The selected areas are shown below:

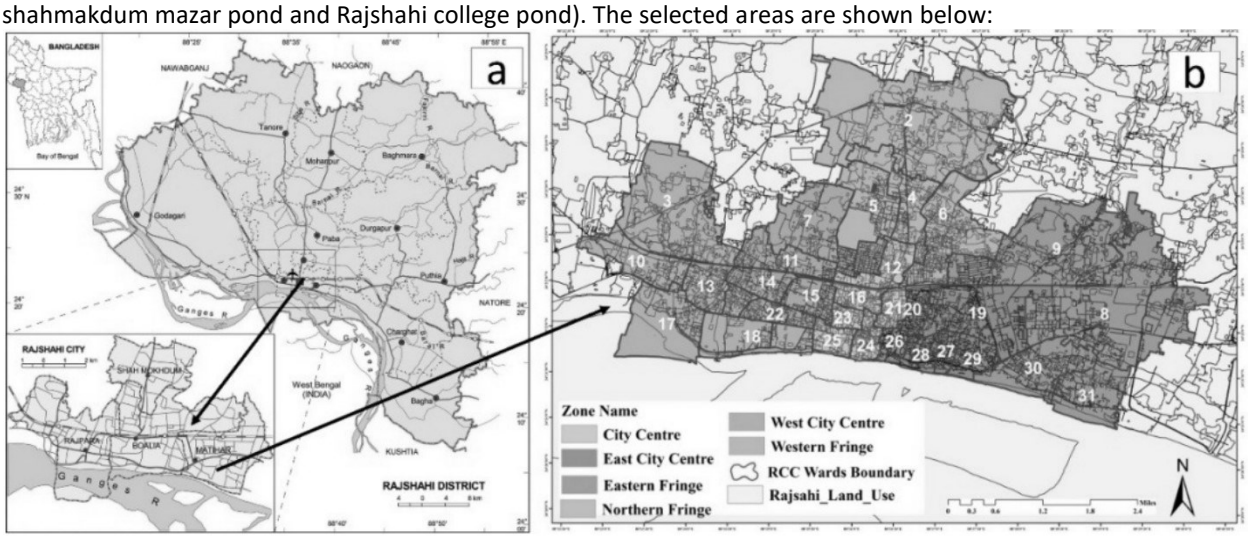

Figure 4. Location of Rajshahi City Corporation (RCC) area (a) in Bangladesh and Rajshahi District b) RCC ward boundary, Land use and Zoning boundary Source: (a) Banglapedia, National Encyclopaedia of Bangladesh, 2012, and (b) Rajshahi Development Authority (RDA),2004

Figure 5. Site area of proposed research development (Developed by Author).

2.5 The present condition of water bodies of proposed sites

Figure 6. Waterbodies of selected areas (Developed by Author).

The site of the pond area is quite devastated. Dirt piles are accumulating around the pond. The filth in this area mixes with the rainwater and then mixes with the pond water. Which also ruins the water quality. Due to this, the interaction of the ponds with the people in the vicinity is decreasing and as a result, the ponds are losing their natural interaction with human beings. By that time the pond is generally not being used for any necessary purpose and is also being destroyed.

2.6. Proposed Condition of Shagor para pond

As the proposed design condition, we use three WSUD tools, "Wetland, rain garden (Bioretention), and vegetated swales" with some infrastructures like pedestrian, ghat and playing zone for increasing human interactions.

WSUD tools are used to keep the water quality. Also, new infrastructures are introduced to enhance human interaction with the pond. Due to the scarcity of proper elements and knowledge, the present condition of ponds, and climatic conditions. There are three tools of the Water Sensitive Urban Design approach suitable for our areas.

Alignment Between Various WSUD Approaches and Different Management ObjectivesTable 1Table 2:

Table 2. WSUD Approach/ Tools for wetlands, rain gardens, swales.

WSUD Tools Names	Peak Flow Reduction	Runoff Volume Reduction	Gross Pollutants	TSS/ TP/TN	Hydrocarbons	Amenity
Wetlands	Med	Low		*	Low	High
Rain garden	Med	High	Med	Med	Med	High
Swales	Med			Med	Med	Med

NB: TN, total nitrogen; TP, total phosphorus; TSS, total suspended solids; WSUD, water sensitive urban design; *, highly variable.

These tools are used keeping in mind the climatic condition, site location, user, authority, and maintenance. These three types of tools can be managed wisely while other tools need to be maintained on daily basis. These WSUD tolls vary from site to site. Some tools are used in building like a green roof and rainwater tank. Some are hard to maintain like water-smart tress, gully baskets, urban water harvesting, and sediment basis. But for contexts like Rajshahi, these three tools are more appropriate to use and easy to maintain for the local authority and local peoples.

2.7. WSUD tools used for study area:

2.7.1. Wetlands

Constructed wetlands are a series of shallow, densely-planted, man-made ponds that help filter water through physical and biological processes. They provide a natural way to treat and remove pollutants from stormwater before it enters our creeks, rivers and oceans(*Constructed-Wetland-Factsheet*, n.d.).

The working process of Wetland

$$\text{Inlet zone} \longrightarrow \text{Macrophyte} \longrightarrow \text{High flow Bypass Channel}$$

Built wetlands normally has three elements that work collectively to help filter out stormwater. they are

Inlet zone: a sediment basin that gets rid of coarse sediment.

Macrophyte zone: a shallow vicinity densely planted with aquatic flowers and the main part of the wetland, which eliminates first-rate debris and dissolved pollution

High flow bypass channel: let's excess water float across the wetland without adverse the plants.

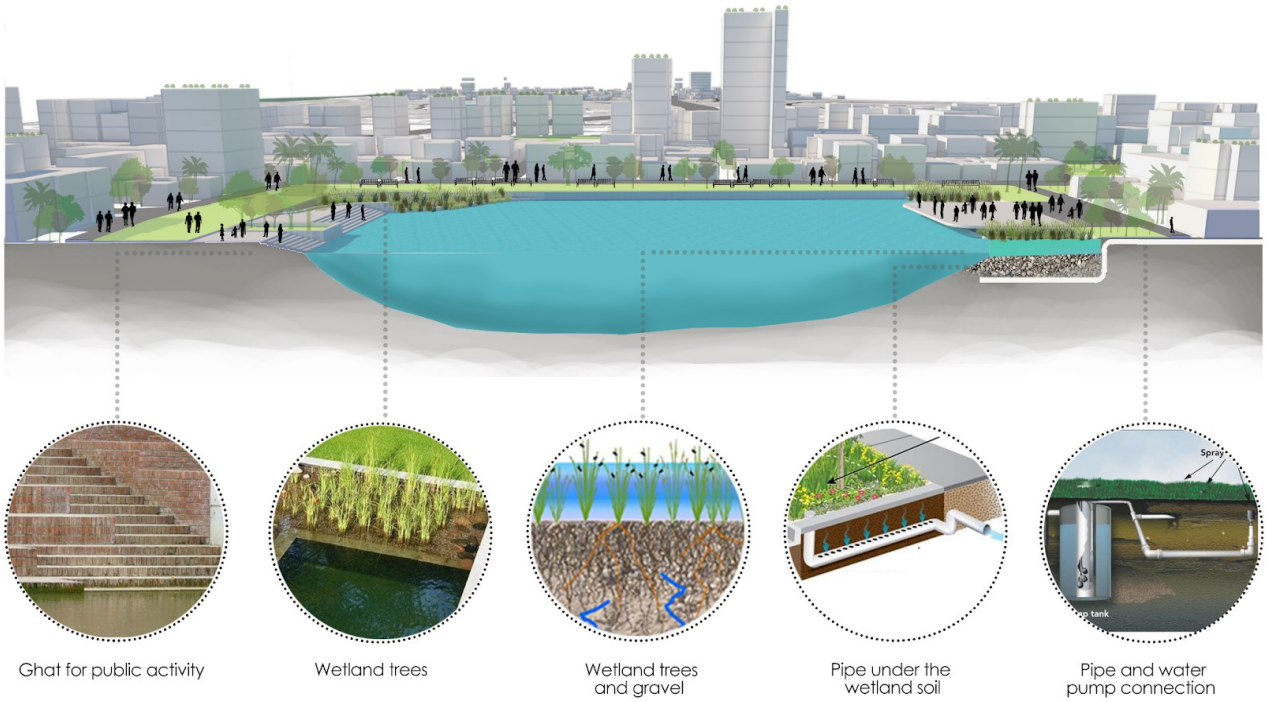

Figure 7. Usage of WSUD tools in Selected areas (Developed by Author).

Wetlands may additionally have open water ponds at the inlet and outlet, however, should in any other case be planted so densely that the water isn't always without problems visible.
For Rajshahi city, this kind of wetland can be introduced in residential and public pond areas. The local authority has to take a step and help to maintain the wetlands from time to time and awareness about ponds should be increased.

2.7.2. Rain garden

Rain gardens are vegetated soil filters that treat stormwater by vertical percolation through a soil filter media. The use of saturated zones underneath bioretention systems is likely to assist in helping plants survive extended dry periods and water quality is managed through a combination of filtration, sorption, transformation, denitrification, plant uptake, and exfiltration(Liu et al., 2014).
Working process of rain garden:

Collect water on the garden surface
↓
Water soaks through the plants, trapping rubbish, sediment
↓
Plant uses the nutrients in the stormwater soils
↓
Roots work together to remove pollutants

Rain gardens need particular plants with roots that help to keep the clear water out media absorbent and damage down the pollution. Most effective use of flora that may develop in sandy soils and tolerate dry situations for numerous weeks in among rains. There are some specific local aquatic plants named “Black-eyed Susan, hibiscus, Joe Pye weed, ginger tree, waterlily, lotus, water smartweed etc.” which are used for rain gardens. Rajshahi’s common plans can be also used for bioretention.

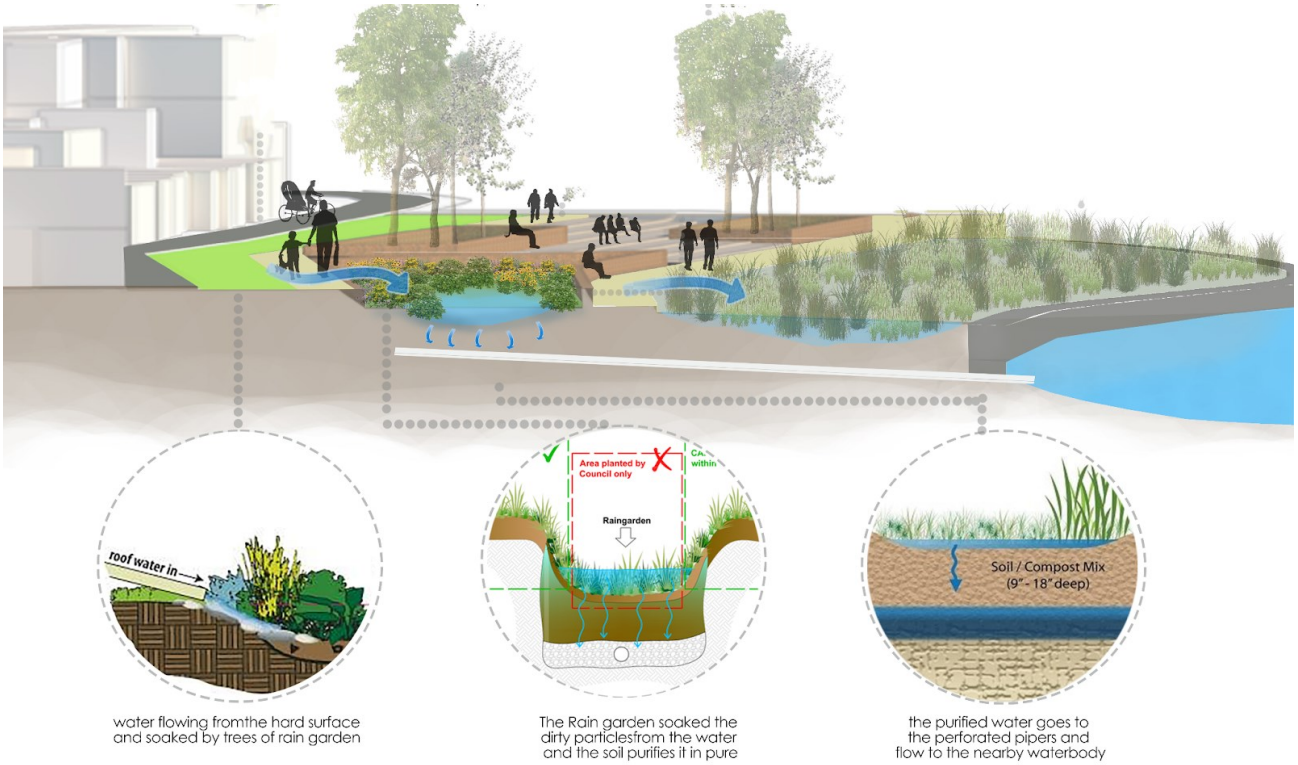

Figure 8. Usage of WSUD tools in Selected areas (Developed by Author).

2.7.3. Swales

Swales are linear, depressed channels that collect and transfer stormwater. They can be lined with grass or more densely vegetated and landscaped.

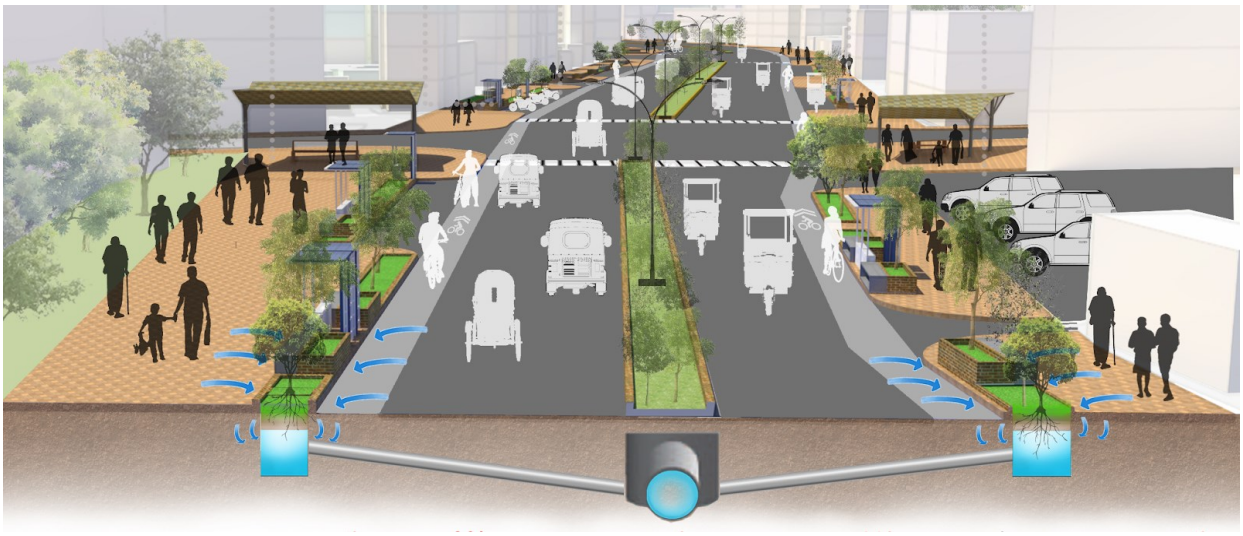

Figure 9. Usage of swales in roads (Developed by Author).

Swales can bring stormwater and display screens and remove gross pollutants, such as clutter and coarse sediment.

In urban areas, swales may be used as an alternative to

- conventional street nature strips.
- center median strips of roads.
- run-off collection points in car park areas.

2.8. Human interaction

Since our job is to revive the ponds in a new way that will control the ecological balance of the environment, the water quality of the pond needs to be improved, and increase the activity of the neighbourhood people with the

ponds. As WSUD approach emphasizes storm management with increasing interaction between humans and water body areas.
In this space, we introduce new walkable streets, create a pedestrian connection among the three ponds, create dedicated ghats and introduce a playing zone for children.

3. Result

The utilization of WSUD tools is crucial for the revival of dilapidated water bodies. These tools not only contribute to improving the water quality but also play a significant role in creating human interaction with the local community. By incorporating WSUD in the design process, awareness about the scarcity of surface water can be raised among the people. This interaction and utilization of the water bodies can foster a sense of appreciation and love for nature, encouraging individuals to take part in its preservation.
The key drivers for adopting Water Sensitive Urban Design include reducing water flow, conserving water resources, and improving water quality. Furthermore, WSUD aims to enhance human interaction by spatially connecting the surrounding areas with the water bodies, including the ponds themselves. This integrated approach facilitates the restoration and rejuvenation of the ponds while considering the ecological balance.
However, there are challenges associated with implementing WSUD systems. One of the major obstacles is the lack of clear technical and financial justifications, which often leads to reluctance from local authorities to take responsibility for the maintenance of WSUD elements. Uncertainties regarding the cost burden compared to conventional water management techniques can hinder the widespread adoption of WSUD. Moreover, the proper implementation of WSUD design elements can be impeded by the inadequate execution of construction contractors. It is crucial for those involved in the design of WSUD strategies to maintain oversight during the construction phase to ensure effective implementation. Additionally, the maintenance of WSUD components is vital for the long-term success of the approach. Neglecting maintenance can undermine the entire process and compromise its effectiveness. Overall, the implementation of WSUD tools and the proper maintenance of the designed systems are essential for the revival of water bodies, improving water quality, and fostering human-nature interaction.

4. Conclusion

The paper presented the methodology and working principles of some Water Sensitive Urban Design (WSUD) tools for stormwater management and water conservation. Its other aim is to create human activity towards the surface water bodies. WSUD is a broad area of practice. It has a vast range of objectives and an even wider set of management processes. The matching of management practices to layout targets and placement context may be very complex and calls for an interdisciplinary method of practice.
There are many tools for the Water Sensitive Urban Design approach. This paper is focused on some key tools based on a literature study and site context- to highlight the range of options available, how they function, and some of the key risks and unresolved issues. Site-precise issues consisting of soils, slope, and current property additionally play a key function in influencing the favoured outcome.
Despite over two decades of WSUD exercise in Australia, there's nevertheless a lot to be learned about the stormwater performance of the remedy technology. WSUD is an ongoing process, and this has some pros and cons. But it is proven that it plays a vital role in the hydrologic performance of bioretention systems in our society. We consider that authority will be able to follow the methodology provided in this paper to recognize the effectiveness of the WSUD tactics and the problems related to their predicted uptake by local governments, service providers, and builders.

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Conflict of Interests

The authors declare no conflict of interest.

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