BLUE-GREEN NATURE-BASED SOLUTIONS FOR URBAN WASTEWATER - ENABLING A CIRCULAR ECONOMY

Sanghamitra RATH
Research Scholar, Department of Architecture, Veer Surendra Sai University of Technology, Burla, India, Associate Professor, Piloo Mody College of Architecture, Cuttack, India, e-mail: sanghamitrath@gmail.com

Bharati MOHAPATRA
Associate Professor and Head of the Department, Architecture, Veer Surendra Sai University of Technology, Burla, India, e-mail: hod_architecture@vssut.ac.in

Abstract. Climate change implications are a major concern for urban areas. They are vulnerable to major disasters and pandemics for the sheer number of people depending on the limited infrastructure in a confined area. Responding to this conundrum will require directing significant investments and resources towards the right solutions in the coming years. It is also imperative for us to consider whether our current infrastructure investment strategy is adequate. Governments and urban planners have so far favoured grey or traditionally engineered infrastructure for wastewater treatment. These legacy systems need to change to cater to current needs. Nature-based solutions (NbS) and blue-green infrastructure (BGI) are an alternative to restoring and managing a diverse integrated ecosystem, with the least amount of construction or interference with nature. They are a multidisciplinary, integrated approach towards a regenerative urban system that enables a healthy environment and has significant ecosystem benefits. The incorporation of circular economy criteria for evaluating NbS solutions in the urban domain is vital to ensure its sustainability. The paper will assess the NbS applications and blue green infrastructure concerning wastewater in urban areas and their effectiveness and scope towards promoting a circular economy.

Key words: urban wastewater management, ecosystem services, wetlands, blue-green infrastructure, sustainable urban ecosystem

1. Introduction

The International Union for Conservation of Nature (IUCN) defines nature-based solutions as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (Cohen-Shacham *et al.*, 2016). The Covid 19 pandemic highlighted the vulnerability, susceptibility, and adaptability of cities to unforeseen health disasters. By adopting nature-based solutions (NbS), decision makers can help cities deal better with the effects of climate change, reduce urban heat island effects, provide for cooling needs in buildings through natural methods, provide a cleaner environment and manage the urban water system better while maintaining a sustainable ecosystem (Liu *et al.*, 2021; Seddon *et al.*, 2020).

There are various uses of NbS in managing wastewater starting from the residential unit level to the macro, and city levels. Despite the advent and obvious benefits of NbS solutions, urban wastewater management remains heavily dependent on traditional grey infrastructure (Marlow *et al.*, 2013). Findings suggest that blue-green interventions instead of traditional grey infrastructure yield the maximum tangible and intangible benefits in the usage and management of urban water (Table 1). NbS solutions need to be implemented in a more systematic and broad-based manner for the effects, and gains from a climate change perspective, to be visible.

The urban environment uses two-thirds of the energy produced while producing 70% of global carbon dioxide emissions, despite comprising just 3% of the earth's surface area. Over 60.4 % of the world's population will belong to cities by 2030 increasing to 68% in 2050 (Oginga-Martins and Sharifi, 2022). With cities consuming almost three-fourths of the world's natural resources, there's going to be more scarcity ahead in cities as more people and facilities vie for these resources and raw materials. As a result, this puts an increasing strain on rural and suburban communities to ensure adequate supplies of water, energy, food, and waste management in urban areas (Oginga-Martins and Sharifi, 2022). NbS is an effective way to manage stormwater and wastewater while enabling a sustainable urban ecosystem (Krauze and Wagner, 2019).

The objective of this paper is to assess the effectiveness of nature-based solutions and blue-green infrastructure in terms of their ability to manage urban waste water. The paper looks to understand the benefits and co-benefits of different blue green infrastructure, their potential of enabling a circular economy and the corresponding opportunity to derive economic benefits. Further the study seeks to assess the impacts and circularity potential of nature-based solutions and blue green systems empirically by examining solutions adopted in the cities of Kolkata and Bhubaneswar.

Table 1. Tangible and intangible benefits of blue-green NbS infrastructure (Source: Vause *et al.*, 2022).

Habitat /Ecosystem	Urban water bodies	Urban forests
Description	A project in Philadelphia to assess stormwater management	Analysis of potential impacts of investing in tree planting in Beijing
Investment	$2.4 billion over 25 years	$2.9 million per year
Impact	Flash flooding reduction: net benefits worth $3 billion (compared to less than $100 million for grey alternative)	Air quality improvement; Reduction in fine particulate matter (PM 2.5) of between 1µg/m3 and 10µg/m3
Co-benefits	Health and well-being; Biodiversity	Health and well-being; Biodiversity

2. Methods

The research consisted of identifying a range of NbS and blue-green infrastructure interventions that are commonly used for urban waste water management, like constructed wetlands, green roofs, urban forests, urban water bodies through literature review. Further review helped to understand the scope of blue-green infrastructure and its application in urban waste water management, to identify the benefits and co-benefits and limitations. The circular economy possibility of blue-green nature based solutions as well as their economic impact were identified. It led to selecting two Indian based case studies to evaluate the implementation and effectiveness, benefits and potential benefits of these nature based solutions and blue green infrastructure. Their performance in terms of waste water management, their contribution to circular economy were analysed from data collected from secondary sources and unstructured conversation with experts. The selected case studies are a) the East Kolkata Wetlands that serves as a sink for wastewater in Kolkata, India. It is recognised because of its unique ecosystem and proven role in wastewater management b) the Lake Neutral project based on lake Zone 3, a lakefront development project in a heavily populated area of Bhubaneswar, India. The Bhubaneswar project is in the implementation stage and potential benefits and limitations have been analysed from the project plan as well as conversation with project officials. It has been selected based on its relevance to the subject under discussion, the local context and the opportunity for a detailed observational study of the existing ecosystem. The last section consists of recommendations and discussions based on the case study analysis and literature review. Suggestions for specific interventions and potential areas for further research are included in the paper.

3. NbS in blue-green infrastructure

Blue-green infrastructure is a strategic system of “constructed” natural spaces in cities, integrating water bodies with the urban ecosystem. They are a NbS designed around water. To access the full benefits and attendant intangible gains in NbS approach in the urban water sector, capacity building and interventions can be applied in rainwater harvesting, afforestation / reforestation in catchments, groundwater recharge, resilient crop planning, urban wetlands restoration, river basin conservation and rejuvenation, stream renaturation (Brown *et al*., 2009).

Blue-green infrastructure (BGI), starting from the very basic, low impact development (LID) and green infrastructure (GI) has evolved over the years from the principles of urban water management (UWM) towards sustainable urban drainage systems (SUDS) (Fletcher *et al.,* 2015). Other variations in the nomenclature of blue-green infrastructure are water-sensitive settlements or the highly evolved sponge cities in China (Radcliffe, 2019). Blue-motivated planning looks at water solutions (Pochodyła *et al.,* 2021), while green motivated interventions look at vegetation and the like (Well and Ludwig, 2020).

Blue-green infrastructure in urban water management can help in dealing with the challenges endemic to urban areas like urban heat islands, urban floods, wastewater, stormwater management, drought-like conditions affecting food provision, a variety of health risks, etc. (Pochodyła *et al.,* 2021). Urban water includes ponds, drains, water runoffs, stormwater, rooftop rainwater, treated or untreated sewage water, constructed or natural water storage like sumps or basins, rivers, estuaries, lakes, natural or artificial streams, groundwater, treated drinking water, etc. Blue-green systems make use of water-sensitive design techniques to increase efficiency in water usage and also reduce the need for external water (Furlong *et al*., 2018). The urban water ecosystem encompassing these, includes artificial or living streams, constructed urban wetlands, revived estuaries, waterways, etc. at the macro level. Often a single comprehensive implementation for wastewater management can have multi-functional benefits, especially in limited urban spaces (Nguyen *et al*., 2019). Natural management of stormwater can happen through other BGI provisions like drainage swales, permeable pavements, rain gardens, which effectively reduce storm water run-off and recharge the subsoil. These are the features that make the sponge cities of China (Lancia *et al*., 2020) so effective.

3.1. Traditional grey infrastructure vs blue-green nature-based solutions

Nature-based infrastructure provides multiple benefits for a single solution (Nesshöver *et al*., 2017). For instance, urban forests and parks have many direct and cyclical benefits such as reducing flood risks, preserving soil, providing shade, to providing space for relaxing and de-stressing (Oral *et al*., 2020) while giving forest produce, creating jobs which help the economy and in turn enable their sustained maintenance and upkeep. They aim to reduce the impact of climate change in urban areas and create a sustainable ecosystem. Even when created for a singular purpose (e.g. stormwater management), blue-green systems provide other ecosystem benefits simultaneously (e.g., recreation, cooling the environment, biodiversity). An element, like a wet roof, which acts as a heat envelope for a structure can also double as a wastewater treatment unit. These are multiple benefits of one NbS solution, something that traditional grey infrastructure lack (Atanasova *et al.,* 2021; Nika *et al*., 2020). They are linear in their usage and serve just a singular function.

4. The concept of circular economy

Circular economy (CE) is a broad concept or an economic system that aims at reducing waste to a minimum and using resources to the full (Langergraber *et al*., 2020). Circular economy strives to change a linear resource flow that ends in the removal of the resources or waste after a single use, by creating a loop through the management of the waste by reusing and recycling (Fig. 1). Circular economy is a change of “paradigm” of man’s relationship with nature. It aims to move society away from unlimited use of resources to recovering resources through innovation, at the same time enabling a sustainable environment (Prieto-Sandoval *et al*., 2018).

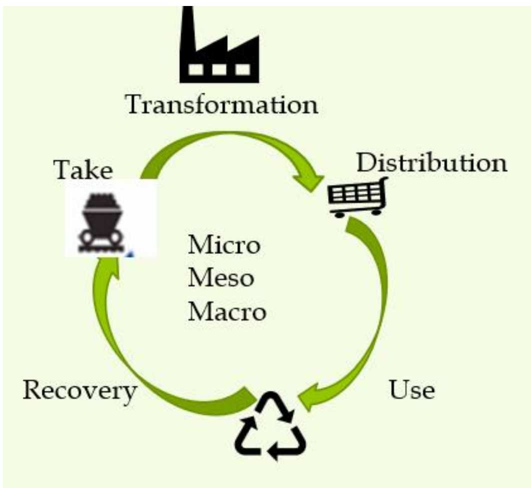

Fig. 1. Circular economy - where resources are recovered through innovation and distributed (Source: Prieto-Sandoval *et al*., 2018).

It requires a regenerative environment in policies, production and consumption. It is important to innovate to “recover and enrich" the used resources through re-processing instead of disposing of them after a single use (Stahel, 2016). Achieving Sustainable Development Goal 12 on responsible consumption and production requires a shift from the linear use of resources to the management of resources to maximize benefits. Implementation of a circular economy can open up opportunities in the recycling and reuse sector while aiding in the combat to mitigate the damages of extreme climate change. One other aspect of a circular economy is to build efficient metabolisms and systems, instead of new installations (Kakwani and Kalbar, 2020; Smol *et al*., 2020). A circular economy process would include optimizing existing assets and installations, building efficient metabolisms and systems, saving resources, contributing to the economy. Thus, in a circular economy resources like products, materials, and energy are reused and stay in the loop of the ecosystem as long as possible and keep contributing to the economy.

4.1. Blue-green infrastructure and circular economy

In wastewater management, the recovery of nutrients, salts and minerals from water, further used in blue-green interconnected systems, is an example of circularity. As per Pauliuk (Pauliuk, 2018), some indicators like Life Cycle Assessment (LCA) can be used to assess five main characteristics of water circularity, i.e., restore, regenerate, maintain utility, maintain financial value, and maintain nonfinancial value and some additional values like resource efficiency, climate, energy, and sufficiency. The three core principles while designing a blue-green infrastructure with water circularity are designing for external benefits or externalities, and keeping resources in use for as long as possible, which helps to "regenerate natural capital" (Tahir *et al*., 2018).

The circular economy theory is grounded on the basis that the existing production and consumption model is no longer viable because of its environmental load, resource use inefficiency and social inequity. However, there is the need for identifying the financial return on investment, to encourage companies and investors to invest and ensure that the new nature-based ways sustain.

4.2 Economics of blue-green infrastructure

Estimating the financial returns on blue-green infrastructure is complicated. As per a World Economic Forum report, the annual potential benefit of applying nature-based solutions while providing safe drinking water for 1.4 bn people by 2030, is $140 billion (World Economic Forum, 2022). NbS will also lead to significant carbon sequestering as also avoidance of the release of carbon dioxide into the atmosphere (Ariluoma *et al*., 2021). Environmental externalities ranging from loss of biodiversity to pollution to greenhouse gas emissions have a very high economic cost estimated at $ 4.7 trillion (World Economic Forum, 2022). The paper tries to make a case for implementation of blue-green infrastructure in an urban context and studies it's role as an enabler in reducing these externalities.

5. Application of NbS in urban areas

Rapid urbanization and urban density and the need for quality spaces can make giving over sufficient spaces to nature-based solutions and green spaces in cities difficult. Thus, cities are becoming hotter with more grey areas and decreasing ecosystem services. Green areas with their multiple benefits are the life and key to harmony for cities, their inhabitants, and biodiversity (Armson *et al.*, 2013; Langergraber *et al.*, 2020). Below are certain blue-green NbS solutions with their multiple tangible and intangible benefits.

5.1 Urban forests

Urban forests are the lungs of a city. They are also a part of blue-green infrastructure of a city, leaning towards the green. Benefits from urban forests in urban wastewater management include control of stormwater run-offs and flooding (Szota *et al.*, 2019) as well as subsoil and aquifer recharge. Other benefits include mitigation of the urban heat island effect (Pataki *et al.*, 2011), reduced air pollution, providing a critical habitat for different species, providing shade, etc. Open green spaces, green corridors are other ways a city's topography can improve, with their attendant benefits. Co-benefits are from health, livelihood diversification, tourism, building resilience to climate change, carbon sequestration, regulating water cycles through retention, infiltration and evapotranspiration (Shadman *et al.*, 2022), positive contribution to the physical, mental, social, and economic wellbeing of urban societies. Contribution to the circular economy is from the reuse of nutrients for resource production like fruits, vegetables, flowers, etc., generating livelihood, and economic benefits from tourism. In wastewater management, the recovery of nutrients, salts and minerals from water and their reuse in agriculture ensures circularity.

5.2 Constructed or treatment wetlands

Benefits include the treatment of industrial effluents, managing stormwater runoff, and sewer overflows (Masi *et al.*, 2018). Co-benefits include a plethora of ecosystem services provided by urban wetlands, like, as a rich habitat, storage of water, scope for recreational activities, green areas in a concreted built environment, evapotranspiration and thus cooling (Masi *et al.*, 2018). Contribution to the circular economy is from using recycled water for farming, industry, cleaning streets, flushing household toilets, etc. An increase in biomass creation, cleaning of surface and ground waters by natural processes, and a decrease of atmospheric carbon dioxide from non-renewable energy sources are other circular economy benefits (Meerburg *et al.*, 2010).

5.3 Green roofs

The benefits of green roofs are energy savings, lowering of the temperature of the building, and management and disposal of stormwater. Another type of green roof is the rooftop treatment wetland, which combines the characteristics and benefits of both treatment wetlands and green roofs. It brings together urban sanitation and urban agriculture to maximize the use of resources and bring about self-sufficiency (Langergraber *et al.*, 2020). Co-benefits come from rooftop production and include improved aesthetics, reduced urban heat, wastewater treatment, quality of life and health benefits. The contribution to the circular economy is from the reuse of water, savings on energy, wastewater treatment and reuse, organic rooftop produce from wastewater reuse and using extracted nutrients.

5.4 Renaturation of rivers, streams and water bodies in urban areas

Benefits of renaturation of urban waterbodies include preservation and protection of existing watercourses and hydrological systems of rivers, slowing down water flow, providing shade, soil stabilization, promoting biodiversity, protecting cities from riverine floods, with better-regulated city stormwater runoff treatment. Co-benefits include place regeneration, social interaction, recreation, contribution to the city's identity, economy, health and well-being (Raymond *et al*., 2017).

Contribution to circular economy here is from lower repair costs from less riverbank erosion, less water pollution, better heat regulation, resources from tourism, lower water treatment costs, reusing water for irrigation; reduction of adverse health effects of water pollution and reduced water treatment costs for the city and downstream areas. A riparian zone protects water quality by capturing sediments and pollutants and prevents direct stormwater runoff from streets from entering and contaminating a watercourse (Burdon *et al.*, 2020).

6. Case studies

Case studies of nature-based solutions for managing wastewater using blue-green infrastructure were undertaken to find out the related environmental impacts and assess the systems potential ecosystem benefits, circularity, their success and limitations in managing wastewater, their benefits and co-benefits.

6.1 Case study of Lake Neutral project at Bhubaneswar, India

The proposed Lake Neutral project at the BTCD (Bhubaneswar Town Centre District) is a lakefront development project right in the heart of the city and is part of the capacity-building and infrastructure development initiatives of the smart city project (Fig. 2). It is likely to have an immense impact on the area. The project is based on lake zone 3 and is a deemed net zero project, planned in a heavily populated area of the city with high land values. Lake zones 1 and 2 have their development schemes and are not part of this analysis.

All three zones are to be eventually integrated upon execution. The plan includes a lakefront development zone of 38 acres with recreational amenities for the residents and ecological remediation through rainwater harvesting, productive landscape, and green infrastructure all synergized with the lake. The scope of the project includes a systems approach integrating the lake with the entire neighbourhood (Fig. 2) and providing a suite of solutions not limited to just stormwater management (Bhubaneswar Smart City Limited, 2017).

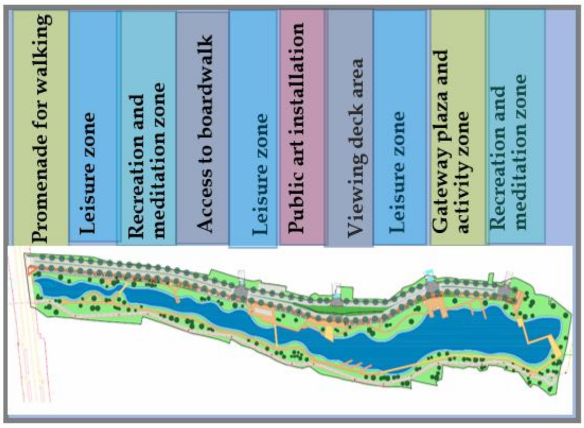

Fig. 2. Lake Neutral proposed activities (Source: Bhubaneswar Smart City Limited, 2017).

As per the project plan, 70 % of the 38-acre area will be taken up by green space and the water zone and will include 12 acres of green area (cited by project officials) and 14 acres of water spread area. The solution proposed is a hybrid of nature-based and traditional solutions (Fig. 3). The cost of the project including the road, the street furniture, lake development and beautification, the retention pond development, and planting comes to approximately Rs 35 crores (Bhubaneswar Smart City Limited, 2017). The project is estimated to cater to 10000 people in the locality. The already delayed construction is projected to be spread over 2 years, and initial work like removal of encroachment, and clearing of the area has already started (Fig. 4).

Fig. 3. Lake Neutral proposed intervention (Source: Bhubaneswar Smart City Limited, 2017).

Fig. 4. Lake Neutral site, Bhubaneswar, India - dredging in progress (Source: Authors).

6.1.1 Estimated ecosystem services for the proposed blue-green infrastructure

At the outset, the project will restrict encroachment on an inner-city watershed that is degrading rapidly (Fig. 5) and it will save the area from being consumed by developers eventually, because of high land values. The intervention will give the heavily populated area of the city some necessary breathing space. The proposed planting palette includes native trees and shrubs, fast-growing meadows, and floaters that will help in phyto-remediation. A riparian buffer of palms and reeds is also proposed (Fig. 6). The buffer landscape will guard against erosion, flood control, water purification, and runoff. Wetlands with fast-growing vegetative growth act as significant carbon sinks (Valach *et al*., 2021).

Fig. 5. Lake Neutral site, Bhubaneswar, India - existing condition (Source: Authors).

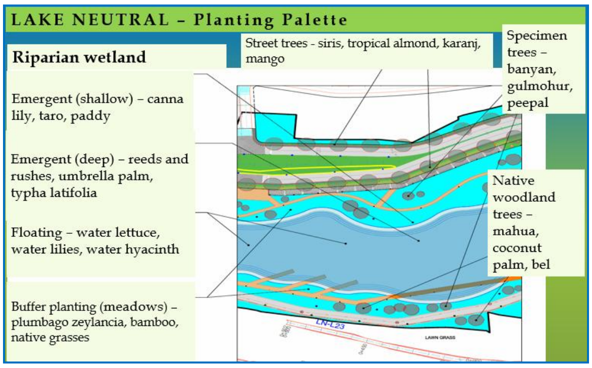

Fig. 6. Lake Neutral proposed planting scheme (Source: Bhubaneswar Smart City Limited, 2017).

The benefits, co-benefits and circular economic impact of the proposed lakefront development are likely to be in the following areas (Table 2).

Benefits are expected from wastewater management with respect to erosion and flood control, water purification from buffer plants, runoff control, use of the public realm through lakefront beautification and urban placemaking. Co-benefits are likely to be from improved biodiversity, impact on the health of the designated user group, carbon sequestration, and improved ecotourism potential. It could provide a livelihood to a section of people involved in maintaining the area. The circular economy benefits are likely to come from the reduction of runoff and the reuse of stormwater for irrigation, from food production from shallow water root vegetables and aquatic life planned for maintaining water balance, and from other vegetative produce like fruits, herbs, etc.

Ecosystem services value includes both conventional economics and human benefits. Ecosystem benefits calculations are aimed toward human well-being which is a result of the optimal interaction of human, social and built capital with natural capital (Costanza *et al*., 2014). The uses for this valuation could be in deciding payment of ecosystem services, raising awareness, planning for ecosystem services, urban land use planning, etc. (Costanza *et al*., 2014).

An initial approximation of ecosystem benefits from this site can be garnered from the extrapolation of data and inferences from other similar ecosystems where assessments have been done, based on value transfer across regions. Some adjustments have to be made considering the local scenario, especially in health care. The ecosystem services and impact of the proposed lakefront development are likely to be in the following areas.

Carbon sequestration values are in a constant state of flux and depend on the type of vegetation, and existing forest management practices (Mitsch *et al*., 2012). Vegetation cover in wetlands is similarly a great source of carbon uptake and older systems and naturally colonized wetlands are more efficient in carbon sequestering than newly restored wetlands (Mitsch *et al*., 2014).

Table 2. Expected benefits and co-benefits of the proposed Lake Neutral project at Bhubaneswar, India (Source: Authors).

Main Benefits	
Wastewater Management	From stormwater drains, runoffs, linkage with other upstream lakes
Lakeside Development	From beautification and plantation programs around the lake including blue-green infrastructure
Urban Placemaking	Creating a public realm from wasteland and dry basin within the city
Co-Benefits	
Carbon Sequestration	From green and blue vegetation, wetlands can act as significant carbon sinks over a period
Health Impact	From air quality improvement; from citizen's use of amenities for exercise, cycling, walking and fresh air
Biodiversity	From increased vegetation on the land and water-scape; replenishment and maintenance of the lake
Ecotourism Potential	From recreational activities available
Food Production	From shallow water root vegetables; aquatic animals; other vegetative produce like fruits, herbs, etc.
Circular Economy Benefits	
Circularity and other eco-services	From reduction and reuse of run-off water; from reuse of stormwater for irrigation; all of the above

Wetland ecosystem services have a positive relationship to the depth of the water body (Chunming and Li, 2019) and depend on the diversity of the waterscape, the type of vegetation, soil, the type of wetland (coastal, mangrove, salt marsh, inland, etc.), the value of wetland products. Biodiversity value is a complex value that depends on the type of forest cover, forest produce, biodiversity, and recreational values which are relational to biodiversity.

Health cost is an indirect ecosystem service value and depends on the number of local users the wetland will cater to. In a crowded urban area, the ecosystem services from health will be significant. For example, a crude approximation of ecosystem services from health in this project will be Rs 2000 (approximate per capita healthcare spending per year in India) X 10000 (user group the BGI services will regularly cater to) = INR 20 million per annum (approximately). This is a significant number in comparison to the other services in terms of monetary value.

Approximate ecosystem services for a lake project (Bassi *et al*., 2019) = $981 per hectare / year (2007 values). Extrapolating these figures in the local context to get an approximate value:
The area under consideration:
12 acres of the urban green area - 4.8 hectares
14 acres of wetland water spread - 5.7 hectares
Total ecosystem - 10.5 hectares

While calculating the ecosystem services value for 10.5 hectares, it has been adjusted with the Indian GDP growth from 31st December 2007 till 31st Dec 2021 by multiplying it with the equivalent GDP growth factor. The USD to INR conversion rate has been taken as Rs 80 based on approximate current values.

Ecosystem services value per year equivalent today = 981*10.5 (hectare)*2.61 (growth in GDP) *80 (USD to INR)

= INR 2.15 million.

This value has a lot of limitations, in terms of the periods, area under coverage, the region in which it is based, the type of vegetation in both the wetlands and surrounding urban green coverage, the maintenance of the area, etc. It can at best be a very basic indicator of the possible ecosystem services. The actual ecosystem value for the proposed project will need to take all local conditions into factor and is a subject for further research.

Fig. 7. Lake Neutral site, Bhubaneswar, India: existing condition of stormwater drain feeding the system (Source: Authors).

Fig. 8. Lake Neutral site, Bhubaneswar, India: approach to the site (Source: Authors).

6.2 Case study of a successful NbS - East Kolkata Wetlands, Kolkata, India

The East Kolkata Wetlands on the fringes of Kolkata is a prime example of using natural processes to treat the city's wastewater over the years while promoting a healthy circular economy in the process. The wetland has provided sustenance and livelihood to 150,000 people by creating opportunities in pisciculture and agriculture (Table 3), as also retrieving resources from waste. It has reduced the cost of disposing of waste through traditional processes (Bunting *et al.*, 2010). The East Kolkata Wetlands retrieves the nutrients from waste and reuses the treated water for pisciculture and agriculture, all in a natural manner. The water flows through fish ponds covering about 4,000 hectares, the fish grow on nutrient-rich plankton which grows through photosynthesis from exposure to the sun, and the ecosystem thrives with the help of solar energy (Kundu *et al.*, 2008).

The East Kolkata Wetlands is a successful example of nature-based solutions (NBS) for wastewater management in India treating 900 million litres of sewage daily. Some of the key reasons why the East Kolkata Wetlands is successful include:

Its design and management: The East Kolkata Wetlands are designed and managed to optimize the natural processes and systems that are used for wastewater treatment. The wetlands are divided into a series of interconnected ponds, channels, and canals, which provide a range of microclimates and habitats for different plants and animals. The wetlands are also managed by a network of local communities, who are involved in the operation and maintenance of the wetlands, and who benefit from the ecosystem services provided by the wetlands.

Table 3. Benefits and circularity from the nature-based solutions in waste water management in East Kolkata Wetlands (Source: East Kolkata Wetlands Management Authority and Wetlands International South Asia, 2021).

NbS Ecosystem Description	East Kolkata Wetlands 12500 hectares of wetlands on the fringe of East Kolkata where the wastewater and sewage of the city is discharged
Economic Benefits	Rs 4680 million saved annually in terms of treatment cost of 65% of the city's sewage Cultivation - 20,000 MT of fish, 50,000 MT of vegetables and irrigate 4700 hectares of paddy land 1.5 lakhs jobs creation
Co-benefits with Unassessed Economic Value	Carbon Sequestration - 60 % of carbon from wastewater is locked up Controls and regulates soil erosion; Flood control Cools the temperature Biodiversity - 380 major flora including 93 plant families, 10 amphibians, 29 reptiles, 123 birds, 79 fish, 24 crustaceans and 13 mammal species
Circular Economy	Reuse of nutrients recovered from wastewater in horticulture, pisiculture Waste recovery and reuse provides jobs to 1.5 lakhs people and other opportunities Recreational Avenues from harnessing of resources in the region, for tourists and visitors

Its location: The East Kolkata Wetlands are located in a densely populated area, which provides a large and constant source of wastewater for treatment. The nearness to Kolkata provides easy access to markets, services, and infrastructure.

Its social and economic context: The East Kolkata Wetlands are embedded in a social and economic context that supports their success. The wetlands are supported by a range of institutions and organizations, such as the East Kolkata Wetlands Management Authority and the East Kolkata Wetlands Development Society, which provide technical and financial support for the operation and management of the wetlands. The wetlands also provide a range of benefits to the local community, such as clean water, food, and income, which support their social and economic well-being.

7. Discussion

Overall, the East Kolkata wetlands are a successful example of how BGI and a circular economy can support sustainable urban development. By providing a range of ecosystem services and supporting a thriving local economy, the wetlands demonstrate the potential of nature-based solutions to address the challenges of urbanization.

Threats endemic to the wetlands: Regular monitoring and maintenance is a major cause for concern to prevent wetlands degradation. Invasive species, metal contamination, sedimentation are other regular threats to the water basin that need constant monitoring. Workforce of municipality are used for other resources by over burdened administration. Encroachment is a cause of concern. High land value, as the wetland has become a pert of the city, threatens presenvation of wetland area (East Kolkata Wetlands Management Authority and Wetlands International South Asia, 2021). Investors are more keen to invest in projects that show near term results.

The Lake Neutral project at Bhubaneswar is a small part of the total lake zone project encompassing 38 acres. The greywater is being treated offsite and the project is not linked to the sewage drainage system. The proposed retention pond will be wholly dependent on storm water for replenishment. However, eventual linkage with the lakes in zones 1 and 2 may keep the wetland replenished. There is a proposal in the offiing to have a sewage treatment plant upstream which may replenish the stream. Provision of natural filtration and cleaning of the lake water is likely through planned plantation. While lake zone 3 will be fed by the lakes in zones 1 and 2, and the storm water run-off of the area (Fig. 7), the proximity to crowded residential areas (Fig. 8) and unplanned mass housing in the vicinity might create debris in the lake. The proposed vehicular road through the site will improve connectivity but may prevent the site getting the full ecosystem benefits due to vehicular pollution. The payback structure from the project is not clear. It will be many years before the blue-green infrastructure implementation starts achieving its full potential benefits. These limitations are pointers to issues faced by other wetlands and urban water management projects. The detailed analysis of the economics of the proposed Lake Neutral project at Bhubaneswar, India is a case for future research. Tracking the project and its benefits through it's implementation and working phases is a case for further study.

A comprehensive cost benefit analysis which includes benefits from ecosystem services and the net present value of future services will increase the feasibility of the projects discussed in the case studies and enable their implementation in larger water basins and across regions.

Studies reveal the long-term potential of urban water management projects. For example, the Upper Tana-Nairobi Water Fund (World Economic Forum, 2022) project monitoring revealed a 15% decrease in sedimentation, with Nairobi's water supply achieving World Health Organization turbidity standards for the first time in 2016. It has been estimated that an investment of $10 million in the Water Fund will return $21.5 million in economic benefits over 30 years.

The various ways NbS can create a circular economy, mitigate climate change and benefit society, as assessed from the study are: save costs on expensive engineered solutions for wastewater management; create jobs like in the Kolkata wetlands; recharge the aquifers; recover and reuse of resources like soil nutrients; less reliance on non-renewable resources and energy through innovation; the blue-green NbS facilities like urban forests can rejuvenate the urban areas, sequester carbon dioxide, control urban flooding, soil erosion and help the atmosphere; alleviate urban stress and reduce urban health issues; improve public realm through urban placemaking.

8. Conclusions

The paper tries to find a link between blue-green nature-based solutions, their role in creating a circular economy and the need for NbS to be adopted in a consistent broad-based manner over a long period to have any significant impact on climate change. Economic valuation of each of the aspects of NbS discussed is a subject for further detailed study. The benefits accrued from NbS also cannot be determined linearly like in traditional infrastructure.

One has to choose between immediate economic benefits and convenience versus the larger good of climate change mitigation, urban health, and getting the entire benefit of ecosystem services in the future when choosing between investing in NbS or a traditional system in wastewater management in urban areas. The aim should be to close the cycle moving from singular use and disposal towards reusing and recycling resources, for long-term environmental and economic benefits. Heavy engineering and grey infrastructure which have a linear model, are the inherited systems and need to be reworked, leveraging their technical expertise and adapted as NbS models, promoting circularity.

Once the benefit-to-cost aspects of NbS are established and policies are made to support it, more private players and government agencies are likely to come forward to implement NbS. This needs to be done in a broad-based manner as well as project-wise.

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