Integrating Wetlands as Nature-Based Solutions for Sustainable Built Environments

A Comprehensive Review

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ABSTRACT

Wetlands are ecosystems that can provide numerous services critical for sustainable development, especially in urban areas, by ensuring environmental stability. The wetlands receive increasing recognition as Nature-Based Solutions (NBSs) to environmental challenges. This review synthesizes the numerous roles of wetlands as NBSs for promoting sustainability in both rural and urban environments and highlights the potential contributions of multiple wetland services and benefits towards sustainable built environments. The review methodology involved an article search from various databases with the utilization of specific keywords in an organized framework to understand the contribution of wetlands as NBSs. The articles were reviewed to provide a comprehensive analysis of the existing research on the associated topics, focusing on specific sub titles and pre-selected themes. The findings of this review identify various parameters through which wetlands contribute to sustainable built environments, including ecological resilience, storm water management, climate adaptation, biodiversity enhancement, recreational opportunities, pollution control, and cultural values. The review also encompasses case studies of different types of wetland features such as riparian buffer zones, retention ponds, reed beds, bio swales, rain gardens, constructed wetlands, etc. in the urban environment and their contribution as NBSs. These contributions are discussed in terms of integration in urban development planning in different segments. Future work recommendations consist of a holistic integration of wetlands into urban planning and design considerations to promote more resilient, healthy, and sustainable built environments for present and future generations.

Keywords-nature-based solutions; sustainable built environment; ecosystem based adaptations; sustainable urban development; ecological resilience; pollution control

I. INTRODUCTION

Wetlands are among the most resourceful and productive ecosystems. Their value is unmatched as they support a wide range of ecological, economic, and social benefits [1]. However, urbanization, industrialization, and unsustainable development threaten these indispensable ecosystems [2]. On a worldwide scale, it is estimated that by the 1970s the number of wetlands decreased by 35% with an annual loss rate of about 1%. [3]. The degradation of wetlands affects sustainable development in a very serious way as their ecosystems meet several conservation targets such as water security, climate change adaptation and mitigation, biodiversity protection, and disaster risk reduction. Wetlands are natural water processors which can remove pollutants, sediments, and excess nutrients from water sources. Therefore, they not only serve fishing and tourism activities that depend on them, but also protect coastal communities from floods and storms to sea-level rise [4, 5]. The integration of Nature-Based Solutions (NBSs) has been manifested into urban planning and design. As stated in IUCN 2016, NBSs are the actions taken to protect, sustainably manage, and restore natural or modified ecosystems that can address societal challenges effectively and adaptively, thus providing both human well-being and biodiversity benefits [6].

Wetlands, with their versatility and ability to perform multiple tasks, and the provision of a wide range of ecosystem services, are emerging as one of the best solutions for making the built environment sustainable [7]. Using wetlands addresses cityscapes to increase resilience against environmental challenges, improving the quality of water, reducing flooding in cities, and fulfilling recreation and cultural roles for citizens [8, 9]. According to a UN report, the global urban population is predicted to increase from 55% in 2018 to 68% in 2050 [10]. This rapid urbanization will apply enormous pressure on the urban environment and resources gradually causing environmental degradation and biodiversity loss and will further lead to the rise in climate change impacts. Sustainable urban development has become imperative, therefore considering integrated approaches for integrating man-made environments with natural ones is necessary. The wetlands are a potential NBS to the problems and challenges of urbanization, while promoting sustainability. These types of ecosystems can be contributors to different aspects of sustainable development, for example, water resource management, climate change mitigation and adaptation, biodiversity assets, and human survival [7, 11]. Many urban communities are dealing with increasing problems related to water, such as water shortage, flooding, and water quality. Wetlands can be the solution to the problems of water scarcity, water pollution, and the need for water purification through their capacity to store and clean water as a perfect solution for water management. Wetlands have proved to be excellent carbon sinks and storehouses, thus rendering them as a pivotal tool in the fight against climate change [1]. Apart from this, they can also be used to improve resilience to the impacts of climate change such as sea-level rise, storm surges, and extreme weather events [4, 5]. However, despite their advantages, such as reducing the occurrences and severity of floods and water pollution or increasing the resilience of cities, the integration of wetlands in urban planning and design still faces several obstacles with contradicting priorities in the use of land, incomplete understanding of their multifunctional nature, and insufficient awareness [12]. Moreover, the involvement of all actors, including urban planners, policymakers, developers, and local communities, is necessary for the wetland's development process. They need to work together to realize the potential of wetlands as NBSs [13]. Through addressing successful case studies and highlighting the key factors needed to include wetlands in urban design and engineering, this review article aims to guide policymakers, urban planners and designers on the importance of wetlands as NBSs for urban spaces to achieve sustainability.

II. MATERIALS AND METHODS

The methodology for this literature review involved a thorough search of research articles from various database sources available online, including open-access journals, articles from periodicals, book chapters, conference proceedings, and official websites of different organizations that focus on wetland conservation. The works were identified under the following search titles: "Wetlands as Vital Ecosystems for Sustainable Development," "Wetland Services and Benefits," "Nature-Based Solutions in Built Environments," "Contributions of Wetlands to Sustainable Built Environments," "Wetlands in Climate Change Mitigation and Adaptation," "Wetlands in Stormwater Management," and "Wetlands in Biodiversity Enhancement and Pollution Control." These topics are based on a framework that emphasizes the critical aspects of wetlands as NBSs. The aspects based on these topics were formulated based on parameters identified from the literature, following an approach similar to snowball sampling. This allowed for the exploration of interconnected themes and the identification of key factors contributing to the role of wetlands in sustainable urban development (Figure 1).

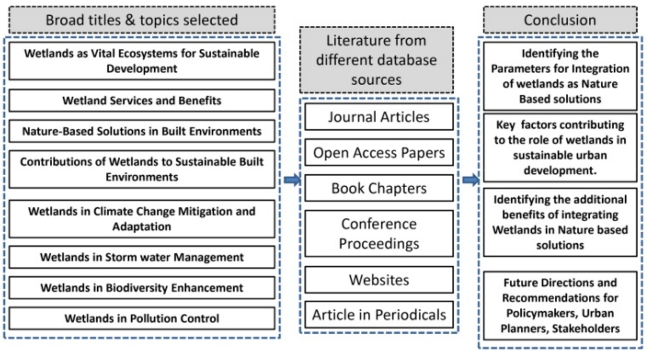

Fig. 1. Literature review methodology.

III. WETLANDS AS VITAL ECOSYSTEMS FOR SUSTAINABLE ENVIRONMENT

Wetlands are intricate ecosystems found along the land-water interface, a zone where the terrestrial and aquatic ecosystems intersect. Even though there are several different definitions of wetlands, the most widely accepted one is provided by the Ramsar Convention on Wetlands, which defines wetlands as "areas of marsh, fen, peat bog or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water that do not exceed six meters in depth at low tide" [14]. Wetlands can be categorized according to different criteria, such as process and type of hydrology, vegetation, soil type, and associated with specific geomorphic processes. Under the Ramsar Convention, wetland types have been defined to provide a very broad framework to aid rapid identification of the main wetland habitats represented at each Ramsar site. Wetland type is identified for each site on the relevant Ramsar Information Sheet [15]. There are many types of wetlands categorized by Ramsar Convention: Inland wetlands, coastal wetlands in natural wetlands and pond, aquaculture sites, and constructed wetlands as man-made wetlands [15].

The wetlands play an important role in sustainable development through the conservation of natural wetlands and the creation of artificial wetlands. Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality [16]. Constructed wetlands can also be a cost-effective and technically feasible approach towards treating wastewater. Wetlands are often less expensive to build than traditional wastewater treatment options, have low operating and maintenance costs and can handle fluctuating water levels. Additionally, they are aesthetically pleasing and can reduce or eliminate odours associated with wastewater [17] There are several types of constructed wetlands: surface flow wetlands, subsurface flow wetlands, hybrid systems, etc. that incorporate surface and subsurface flow wetlands. A surface flow (SF) wetland consists of a shallow basin, soil or other medium to support the roots of vegetation, and a water control structure. A subsurface flow (SSF) wetland consists of a sealed basin with a porous substrate of rock or gravel. Single stage systems require that all of the removal processes occur in the same space [17].

IV. WETLAND SERVICES AND BENEFITS

Wetlands offer a wide range of ecosystem services that aid human beings and sustainable development. These services can be categorized into four main types: ecosystem functions namely production, regulation, cultural, and amenity services [18].

A. *Production Services*

Wetland vegetation provides a wealth of resources such as timber, fuel wood, fibres, and construction materials. Mangroves cover a considerable spread of wood products such as poles for construction, fuel wood, and charcoal. Edible reeds, cattails, and rushes are used for crafting purposes such as thatching, weaving, and basket-making [19]. Wetlands are the habitat of fishes, crustaceans, and molluscs which constitute a major part of food security and livelihood. Rice fields – created by people to substitute the natural ones – are the second largest area after human settlement and are responsible for about 20% of the world population's diet. Ultimately wetlands are places of diversity even when it comes to food [11]. Besides their roles in maintaining water cycles, wetlands can add up to groundwater rechargeable water resources, which replenish aquifers and therefore ensure freshwater availability [19].

B. *Regulating Services*

Wetlands work as natural water storage and purification systems, controlling water flow and keeping the water quality in balance [20]. Wetlands are like natural water filters, they neutralize a variety of windblown soil and water-borne pollutants, excess nutrients, sediments, and pathogens [21]. The riparian (stream and river) wetlands act as a buffer zone that helps to maintain the water quality by trapping and filtering runoff from the surrounding areas [22]. The wetlands can absorb and store carbon, which plays a major role in the moderation of climate change and the regulation of the levels of greenhouse gases in the atmosphere [20]. Coastal areas such as mangroves and salt marshes are known for being quite effective in sequestering as well as storing large amounts of carbon under the title "blue carbon" [23]. Sea grass meadows and salt marshes stabilize sediments and lessen the impact of waves by acting as buffers, thus reducing the rate of erosion and protecting the shorelines [24].

C. *Cultural Services*

Wetlands play a vital cultural and spiritual role to many indigenous and traditional communities, whose beliefs, traditions, and ceremonies usually rely on them. A wetland can be used in scientific ecology, hydrology, biogeochemistry, geology, etc. studies [1].

D. *Supporting Services*

Wetlands have a significant role in the recycling (cycling) of nutrients such as nitrogen, phosphorous, and carbon among ecosystems that in turn facilitate plant growth. Employing reducing actions like denitrification, wetlands contribute to the removal of the excess nitrogen from the area, thereby mitigating the catastrophic effects of backwaters. The decomposition of organic matter in wetlands releases nutrients that are taken up by plants and are used for primary production and support food webs [7]. They provide habitats for species that cannot live either on the ground or in the water, including threatened and endangered species. Besides, wetlands also host many aquatic lives during the process of breeding, nursing, and feeding as a habitat for migratory birds, for example, fish, amphibians, and invertebrates [12].

V. WETLANDS AS NATURE BASED SOLUTIONS IN BUILT ENVIRONMENTS

The International Union for Conservation of Nature (IUCN)'s defines nature-based solutions as "methods of protecting, managing sustainably and restoring natural or modified ecosystems, which can alleviate social problems well and adapt to the changing environment, thus contributing to the welfare of humankind and biodiversity" [25]. NBSs and Ecosystem-Based Adaptation (EBA) are closely related concepts addressing climate change challenges. The term NBS is a broader umbrella-term encompassing various approaches, including EBA, which specifically focuses on climate change adaptation using nature [26]. Both concepts utilize biodiversity and ecosystem services to enhance resilience and adaptive capacity to climate-related hazards [27, 28]. While these approaches are considered effective for climate change mitigation and adaptation strategies, there is still a tendency for policymakers to prefer traditional engineering solutions [28]. NBSs are a variety of measures involving the protection and restoration of natural ecosystems, like wetlands, forests, and coastal habitats, to the creation of hybrid solutions that combine natural and engineered components, like green roofs, bio swales, and constructed wetlands [29]. The idea of NBSs has been accepted by various international organizations and programs, such as the World Bank, the United Nations Environment Program (UNEP), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which have promoted the adoption of NBSs as a way to solve global problems while protecting and restoring ecosystems [19]. The implementation of NBSs and EBA require consideration of social, environmental, and economic factors to optimize their effectiveness [27]. The Ramsar Convention recognizes cultural values as fundamental to wetland ecosystems, emphasizing the need for an integrated nature-culture approach [30]. Wetland technologies have been derived from the concepts taken from the functions of natural wetland ecosystems. Authors in [31] examined specific Water Quality Parameters (WQPs) in an integrated area, affirming the positive impact of Wetland Treatment Infrastructure (WTI) on water quality. WTI in urban development holds promise for enhancing water quality and strengthens sustainability [31]. Innovative solutions can also be designed for urban stormwater and runoff management.

A. Integration of Wetlands as Nature-Based Solutions in Infrastructure Planning and Design Strategies

Similar to natural wetlands, constructed wetlands manage to decrease the peak flows up to 60% and got rid of around 90% of suspended solids from stormwater runoff [32]. In the same way, the combination of wetlands and urban drainage systems potentially reduces the volume and velocity of stormwater, and so the risk of urban flooding would be reduced. Furthermore, the cost-asset of the wetland-based stormwater system compared to the traditional grey infrastructure is considerably lower [32]. The wetlands serve an extremely important function in maintaining climate change resilience and mitigation strategies in cities. The wetlands have immense significance in carbon sequestration which, in turn, can help offset greenhouse gas emissions and mitigate the effects of climate change. Authors in [33] estimated that the annual climate regulation services value of the wetlands for the globe could be in a range between 1.8 and 7.2 billion dollars. The inclusion of wetlands in the urban landscape is a step that can go a long way in conserving biodiversity and providing ecosystem services. Authors in [1] demonstrated that wetlands in urban areas, as well as the adjoining lands, can host a wide array of habitats for a diverse range of plant and animal species such as algae, crocodiles, kingfishers, and other threatened or endangered species. According [34], wetlands being part of urban green spaces can impair connectivity. However, they may form corridors for migration of aquatic and terrestrial bird species, as well as providing infrastructure during extreme weather events, which can contribute to the conservation of biodiversity. Authors in [4, 24] found the economic worth of wetlands for recreational activities, for instance, birding, hiking, and nature appreciation, which improve the happiness and quality of life of urban dwellers. Urban wetlands provide numerous ecosystem services, including reduction of water pollution, flood mitigation, and opportunities for recreation and fulfilling cultural requirements, all of which are key for people living quality and healthy life [19]. Different studies show that truly sustainable urban design principles such as Low-Impact Development (LID) and integration of Blue-Green Infrastructure (BGI) should be introduced in urban areas. Urban Green Infrastructure (UGI) and Ecosystem Services (ESs) are related concepts that can support the integration and valuation of NBSs in urban areas [26]. Wetlands, as essential infrastructural elements, can be designed with key features like micro topography, hydrologic connectivity, and planting diversity to restore ecosystem services in urban areas [35]. As opposed to the traditional grey infrastructure, NBSs, which include wetlands, are often cheaper and more sustainable in the long term, while having multiple co-benefits.

B. Case Studies of Successful Implementation of Wetlands as NBS in Development Strategies

One of the many documented case studies of the successful role of wetlands within urban areas is the Quan Li Stormwater Wetland Park in Beijing, China, which has solved the problem of urban flooding and water purification by constructing wetland as a part of green infrastructure [36]. At Staten Island, the Bluebelt project is applying the natural system to discipline stormwater, protect water quality, and provide recreation facilities [37].

TABLE I. CASE STUDY SUMMARY

Wetland type and category	**Case study**
Riparian buffer zones (natural)	• Anacostia River Riparian Buffer Project, Washington DC, USA: This project was designed to bring back and protect the riparian buffer zones of Anacostia River, a heavily urbanized watershed. By planting natives and implementing erosion control measures, the project addresses issues of water quality, biodiversity, and recreation [40]. • Don River Watershed Riparian Buffer Restoration, Toronto, Canada: The Toronto and Region Conservation Authority (TRCA) has been working ardently to restore and boost riparian buffer zones along the Don River and its tributaries for multiple years which has led to stabilization of stream banks, reduction of erosion, and improvement of the quality of habitat for different aquatic and terrestrial species [41].
Retention ponds (artificial)	• Ecopark Wetland and Retention Pond System, Beijing, China: The Ecopark project, which is part of Beijing's campaign to enhance urban water management, consist of a series of constructed wetlands and retention ponds that were designed to filter and hold stormwater runoff from the surrounding residential and commercial areas. The sustainability of the system is established by the fact that it has ensured flood control, water purification, and the creation of recreational spaces [42].
Reed beds (artificial)	• Putrajaya Wetland Park, Malaysia: Putrajaya Wetland Park, Malaysia's first and largest man-made wetland, plays a crucial role in urban ecosystem management and environmental conservation. The Putrajaya Water Wetland Park, featuring reed beds for treating urban stormwater runoff and wastewater, has improved water quality, provided recreational opportunities, and restored biodiversity, attracting various birds and plant species [43].
Bioswales (artificial)	• Portland Bioswale Program, Oregon, USA: Portland, has implemented an innovative stormwater management program featuring BGI to address flooding and water quality issues. The city has invested in over 2000 street bioswales, 600 ecoroofs, and numerous street trees, alongside extensive watershed restoration efforts [44]. • Sydney Water Sensitive Urban Design (WSUD) Program, Australia: The implemented water-sensitive designs such as bioswales in urban areas has achieved stormwater reduction, flood prevention, and offers ecosystem services including air cleaning and habitat development [45].
Rain Gardens (artificial)	• Kansas City Rain Gardens Project, Missouri, USA: This project includes construction of rain gardens within residential and commercial areas to harvest and saturate stormwater runoff. The rain gardens not only provide the possibility of cleaning rainwater but also improve the area's biodiversity and educate the community [46. • Melbourne Rain Gardens, Australia: The city of Melbourne has established a system of rain gardens in different parts of the city to deal with storm water runoff and prevent urban flooding. These rain gardens have now taken part in the process of urban greening which includes appealing view and recreational use [45].
Constructed Wetlands (artificial)	• Tianhe wetland park in China: This urban wetland park presents a chain of constructed wetlands aimed at recycling municipal wastewater and storm water runoff resulting in improvement of water resources, formation of wetland habitats for wildlife, and recreational amenities for residents. These systems utilize various plant communities, including arboreal, emergent, and submerged species, to effectively remove pollutants from water [47].

Bluebelts are ecologically rich and cost-effective drainage systems that naturally handle the runoff from our streets and sidewalks [37]. Originally implemented in Staten Island, the program preserves natural drainage corridors including streams, ponds, and wetlands, and enhances them to perform their functions of conveying, storing, and filtering runoff precipitation or stormwater. Urban design plays a vital role in mainstreaming NBSs, as demonstrated by the Bibliotec adegli Alberi park in Milan, which integrates urban ecology throughout the design process [38]. The successful implementation of NBSs in cities like Leipzig highlights their importance for sustainable urban development, providing multiple co-benefits and ESs. However, their implementation requires careful consideration of drivers, governance actors, and design options [39]. These examples illustrate the effective integration of wetlands as NBSs in urban planning, emphasizing their role in advancing sustainable development through innovative and practical applications (Table I). These case studies are examples of the broadness and usefulness of the wetland features in urban design and infrastructure. Moreover, specific location factors like local hydrology, climate, and ecology are important in the design and implementation of wetland features. Through these case studies and by adopting the best practices, cities and towns can invest to wetlands for a more liveable, durable, and resilient urban living.

VI. CONTRIBUTIONS OF WETLANDS TO SUSTAINABLE BUILT ENVIRONMENT

The current review outlines how wetlands, as NBSs, contribute to sustainable built environments through parameters such as ecological resilience, storm water management, biodiversity enhancement, recreational opportunities, pollution control, and cultural values.

A. Ecological Resilience

Wetlands as NBSs play a crucial role in climate change mitigation and adaptation, including carbon sequestration, flood and storm surge protection, urban heat island mitigation, and coastal protection and sea-level rise adaptation, as depicted in **Figure 2**. Wetlands are very good carbon sinks, with the capacity to store and sequester a great deal of carbon in their vegetation and soil. Research has shown that coastal wetlands such as mangroves and salt marshes can sequester almost four times less carbon per land area than forests [23].

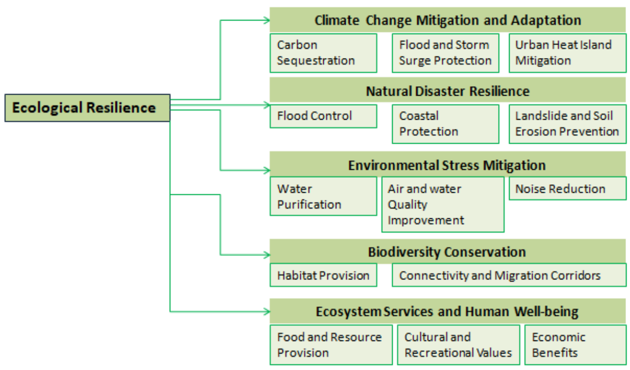

Fig. 2. Role of wetlands in ecological resilience.

By maintaining and revitalizing marshes, specifically, coastal marshes, cities have the ability to be part of climate change mitigation efforts by reducing the amount of greenhouse gasses and enhancing carbon uptake [51]. Wetlands store much more carbon per square meter than terrestrial forests, with coastal wetlands accounting for up to 50% of global carbon burial in marine sediments [52, 53]. Wetlands are natural barriers that limit the effect of flooding and storm surges, inhibiting the advance of the most severe phenomena, which are exacerbated by climate change. For instance, in [34], the value of storm protection services of coastal wetlands in the United States was estimated to be over $23 billion per year. Wetlands have a remarkable capacity to lessen the heat-island effect in urban areas using evaporative cooling and shading, thus reducing energy demand for air conditioning and improving thermal comfort [54]. Wetlands contribute to evaporative cooling using evapo-transpiration, which can be used to mitigate heat. Due to their thick vegetation and the presence of water habitats, wetlands reduce the amount of light and heat absorption, providing cooling and shielding to the city (shading and insulation) and if integrated into urban development's as part of green infrastructure, such as green roofs, urban forests, and constructed wetlands, they can play a significant role in temperature regulation and public thermal comfort [54]. Wetlands have peculiar abilities to keep their designed area unchanged even if they are faced with moderate sea level rise figures due to the continuing process of vertical accretion which has in its sediments and organic matter [55]. Wetlands act as flood control and behave like natural sponges that soak up and store excess water during heavy rainfalls, therefore, they reduce the chances of flooding in built-up areas. The flood peaks can be reduced by even 60% when flood-retentive wetlands are brought back to urban landscapes [56]. Coastal wetlands, including mangroves and salt marshes, are habitats that defend the coast from erosion, storm surges, and even tsunamis, protecting communities and infrastructure hence providing coastal protection. The dense vegetation and root systems of wetlands vegetation help in soil stabilization and prevention of landslides as well assoil erosion, thus protecting the built environments from these natural hazards [57]. Wetlands of the oceanfront, such as mangroves and salt marshes, are critically important from an ecological point of view as they protect the coastal areas from sea-level rise and surges caused by storms [4]. The benefits provided by wetlands have important economic values. This outcome, in part, can be achieved by cutting down on the cost of infrastructure and thus improving the overall resilience of cities and their economy [11]. Wetlands can increase the ability of urban areas to withstand the effects of climate change like increased intensity of precipitation and sea-level rise, by providing natural flood control and coastal protection [58].

B. Sustainable Stormwater Management

As urban areas continue to expand, the implementation of constructed wetlands for storm water management presents a promising approach to address water quality issues and flood control simultaneously [59]. Wetlands play a crucial role in integrated stormwater management by serving as Low-Impact Development (LID) solutions, incorporating BGI and functioning as flooding mitigation mechanisms while improving water quality. LID techniques include bio-retention cells, pervious pavements, rain gardens, and grassed swales [60].

BGI systems like constructed wetlands, rain gardens, and bioswales utilize natural processes for water detention, storage, and infiltration [61]. BGI leverages natural, ecosystem-based processes to manage stormwater effectively, offering multiple ecosystem services beyond the single-purpose function of traditional grey infrastructure [61]. Constructed wetlands are man-made ecosystems intended to serve as a bypass for different sources of wastewater including stormwater discharges, which are further purified using eco-friendly processes similar to those found in natural settings [21, 59]. Riparian wetlands and floodplains have the capacity to store flood water, reducing consumed energy and the likelihood of damage to the surrounding environment. Coastal wetlands like mangroves and salt marshes, act as natural barriers against storm surges, thereby protecting coastal communities and infrastructure from flooding and erosion [24]. Waterlogged swamps provide storm water filtration through sedimentation, filtration, nutrient (nitrogen and phosphorus) reduction, and chemical and biological processes (including sedimentation), and living uptake by microbes. The vegetation and microorganisms in wetlands can filter out and immobilize heavy metals, like lead, cadmium, and zinc, from the storm water runoff [62]. A summary of wetland contribution in stormwater management is exhibited in Figure 3.

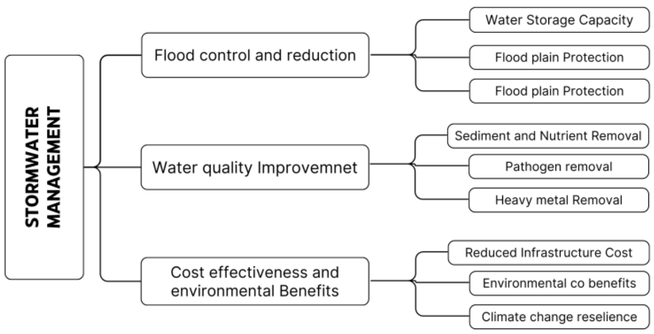

Fig. 3. Wetlands in stormwater management.

C. Biodiversity Enhancement

Wetlands support diverse ecosystems by providing habitats for endangered species, making them valuable for biodiversity conservation and enhancing the ecological integrity of urban landscapes when integrated into sustainable cities (Figure 4). This diversity in turn supposes the resistance of ecosystems and the ability to adapt to the impacts of climate change [63]. In addition, the creation of wetlands in a city's green infrastructure network contribute to its ecological connection and increases the exchange rate of genetics between the species which enhance the biodiversity and health of ecosystems [64]. Wetlands provide invaluable support for many migratory bird species [3, 65]. Urban wetland rehabilitation and maintenance targeted to reconnecting wildlife brush up with other impoundments can boost biodiversity since it facilitates species movement and averts genetic isolation [66]. Wetlands not only promote the existence of water bodies but also support the nesting and breeding grounds for aquatic species, thereby ensuring biodiversity conservation which is a vital for maintaining ecological resilience and healthy environments [7]. Wetland restoration projects have shown promising results in enhancing biodiversity and ecosystem services. Meta-analysis reveals that restored wetlands exhibit 36% higher levels of provisioning, regulating, and supporting ecosystem services compared to degraded wetlands [67]. Authors in [68] discussed the drainage pattern changes of wetlands and how they can manage stormwater and saline water intrusion in coastal cities.

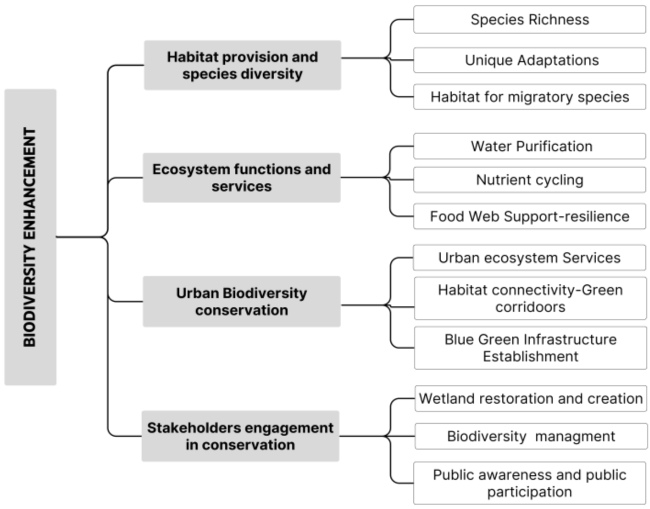

Fig. 4. Wetlands in biodiversity enhancement.

D. The Role of Wetlands Regarding Recreational and Cultural Value Provisioning

Wetland parks can be regarded as educational open-air spaces, offering educational classes and trails with interpretation that encourage the development of an environmental understanding and awareness of the natural habitat. Nature corners can induce such benefits as relief from stress and an improvement in general well-being [69, 70]. Research indicates that wetland parks can significantly reduce stress and promote relaxation. Authors in [70] demonstrated improvements in mental wellbeing, anxiety, and stress levels among the participants of a six-week wetland-based intervention. Wetland parcels within the green infrastructure of cities can offer considerable recreational activities, and provide enhanced feelings of sanctity for the urban residents [8, 71]. Involving people of the community, the indigenous group, and stakeholders in the recuperation and planning of wetland parks is an essential basis to foster the possession remains as the social events align with the requirements and preferences of a particular community [72]. Cultural aspects of wetlands include rich human values, belief systems, and practices that are integral to their conservation and management [73]. Wetlands offer recreational facilities and various kinds of ecotourism. Preserving wetlands and ecosystems that are culturally relevant to native communities may be important for social as well as cultural resilience [71]. Okavango Delta is a UNESCO World Heritage Site that draws thousands of tourists each year to admire its ecosystem and the cultural heritage of the local communities, the Bayeyi people [74]. Incorporating wetlands into urban landscapes offers numerous benefits for education, ecosystem services, and sustainable development. Urban restoration projects provide opportunities for environmental learning, enhancing participants' attitudes, awareness, and understanding of nature [75].

E. Wetlands as a Solution toPollution

Different pollutants of emerging concern in aquatic media are present in urban environments [76]. Wetlands control pollution, work as natural filters, and collect various contaminants from water such as sediments, nutrients, heavy metals, and pathogens (Figure 5). Wetlands can remove pollutants from urban runoff and wastewater through physical and vegetative mechanisms, though the interactions of species in this process are not well understood. Additionally, the use of wetlands for controlling nonpoint source pollution has gained attention, with ongoing efforts to develop guidelines and policies for their implementation [77].

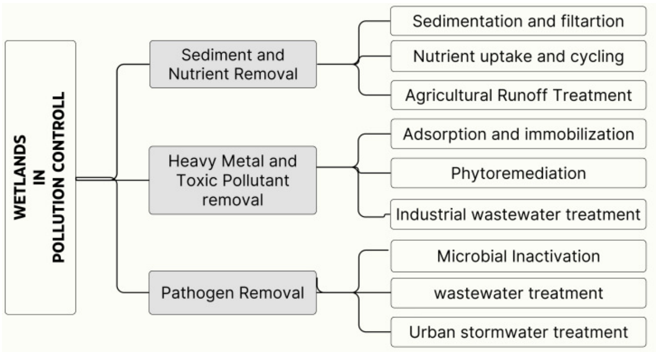

Fig. 5. Wetlands in pollution control.

1) Sediment and Nutrient Removal

The thick vegetation and low water in wetlands favour sedimentation and filtration that helps the settlement of suspended solids and sediments, thus reducing turbidity and improving water clarity. Plants and biota of wetlands are capable of effectively removing and cycling nutrients such as nitrogen and phosphorus in water sources through structural processes i.e. uptake, and microbial transformations as well as stabilizing ponds. The efficiency of nutrient retention and cycling varies depending on the wetland type and hydrological conditions [78]. Closed, ombrotrophic systems retain over 90% of inorganic nutrients, while open, rheotrophic systems retain less than 5% [79]. Plant growth forms influence nutrient turnover rates, with marshes cycling nutrients faster than swamp forests [79]. In constructed wetlands, plants can accumulate significant amounts of nutrients, but their effectiveness in removing nutrients from water may be limited due to asynchronous growth patterns and water flow [80]. Being erected around nearby water-bodies, constructed wetlands, and riparian buffer zones are successful in stopping agricultural runoff from devastating them with sediments, nutrients, and pesticides [21].

2) Heavy Metal and Toxic Pollutant Removal

Wetlands remove heavy metals and toxic pollutants through adsorption and immobilization, phytoremediation by hyper accumulator plants, and can play a crucial role in the removal of heavy metals and toxic pollutants from wastewater through various mechanisms. Authors in [81] highlight processes such as sedimentation, flocculation, and plant uptake as effective means for heavy metal removal. Additionally, authors in [82] focussed on microbial processes, including biosorption and metal precipitation, which enhance metal detoxification and retention in constructed wetlands. Wetlands play a crucial role in phytoremediation, offering an eco-friendly and cost-effective approach to pollution removal [83]. The effectiveness of wetland phytoremediation is attributed to the expansive rhizosphere of wetland plants, which provides an enriched zone for microbial activity and enhances degradation pathways [84]. While laboratory studies have shown promising results in phytoextraction and degradation, more large-scale field studies are needed to demonstrate sustained contaminant removal in natural wetland ecosystems [84]. Structural wetlands can be created to treat industrial wastewater as a cost-effective and environmentally friendly alternative to conventional treatment methods [21, 47].

3) Water Quality Improvement

Wetlands improve water quality through microbial inactivation, urban stormwater treatment, wastewater treatment, and pathogen removal. Wetlands can diminish the number of pathogenic microorganisms, e.g. bacteria, viruses, and protozoa, by different means, such as natural die-off, predation, and UV radiation exposure, thus improving water quality and reducing the risk of waterborne diseases. Urban stormwater runoff can be purified to a great extent by the natural or artificial wetlands. The result is the removal of harmful substances such as oils, greases, and toxic chemicals before they find their way into water bodies; assisting aquatic biodiversity and public health [85]. Natural wetlands can effectively cater urban and industrial waste, hence improving water quality and reducing the elective burden of municipal treatment facilities [21]. Also, using wetlands along with the urban green infrastructure contribute equally to air and noise pollution control, which ultimately lead to improvement of the environmental quality and public health [86].

VII. DISCUSSION

Wetlands, with their different ecosystem services and functions, provide NBSs that are capable of coping with the environmental, social, and economic challenges in urban and rural areas. From the comprehensive review of wetland contributions, the key parameters that wetlands offer for creating sustainable built environments were identified. These parameters could serve as a framework for planners and designers, highlighting diverse perspectives on urban sustainability by addressing environmental, social, and economic aspects.

A. Ecological Resilience and Biodiversity Conservation

Integrating wetlands into urban development is instrumental in enhancing ecological resilience and biodiversity conservation, contributing to a sustainable built environment. Wetlands are biodiversity hotspots, supporting a rich diversity of plant and animal species, including numerous critically endangered and threatened species. They provide essential habitats for migratory birds, fish, amphibians, and other wildlife, ensuring regional biodiversity and ecological balance.

As natural regulators of the water cycle, wetlands play a vital role in nutrient cycling and soil formation, which are crucial processes for maintaining ecosystem resilience and sustainability. Wetlands also function as ecological corridors, allowing species movement and promoting genetic exchange, thereby enhancing overall ecosystem health and reducing biodiversity loss. By integrating wetlands into urban landscapes, cities can bolster ecological resilience, preserve biodiversity, and foster sustainable and resilient communities.

B. Water Security and Flood Mitigation

Wetlands, either natural or artificial, are integral to sustainable urban design, functioning as natural retention systems. By acting as natural sponges, they absorb and store excess water during heavy rainfall or flooding events, significantly reducing flood risks and associated urban damages. Wetlands also regulate water flow, minimize soil erosion, and improve water clarity through their vegetation and the filtering capacity of their soils. Moreover, wetlands naturally filter out pollutants and sediments, providing a clean and reliable water supply, thereby enhancing water security in urban areas.

C. Climate Change Adaptation and Mitigation

Integrating wetlands into urban development is essential for climate change mitigation and adaptation, fostering a sustainable built environment. Wetlands act as natural buffers, reducing the impacts of sea-level rise, storm surges, and coastal erosion, thereby safeguarding urban infrastructure and communities. As powerful carbon sinks, wetlands capture and store large amounts of carbon in their soils and vegetation, contributing to the reduction of greenhouse gas emissions. Coastal wetlands, such as mangroves and salt marshes, provide natural protection against coastal erosion and rising sea levels, making their preservation vital for urban resilience. Moreover, wetlands in urban areas help mitigate the urban heat island effect through evapotranspiration and shading, improving living conditions and reducing energy demands for cooling. By incorporating wetlands into urban design, cities can enhance climate resilience, promote environmental sustainability, and create healthier, more livable urban spaces.

D. Recreational and Cultural Values

The integration of wetlands in urban planning not only supports water management and biodiversity but also enhances socio-cultural benefits by creating green spaces that connect people with nature. They can be used for bird watching, hiking, fishing, and other ecotourism activities that offer well-being to urban populations while contributing to economic development. Wetlands are often important to the native communities, particularly as when they are related to their cultural and spiritual heritage.

E. Pollution Control and Waste Treatment

Integrating wetlands as NBSs in urban environments plays a vital role in sustainable development by leveraging their natural properties for pollution control and waste removal. Wetlands, both natural and constructed, are effective in treating wastewater, serving as cost-effective and environmentally friendly alternatives to traditional wastewater treatment systems. Incorporating wetlands into decentralized wastewater management systems helps in treating domestic and municipal wastewater efficiently, reducing the burden on conventional treatment facilities, and minimizing environmental impact. Constructed wetlands are particularly valuable as they offer a durable and sustainable solution for urban and industrial wastewater treatment, enhancing the overall health of aquatic ecosystems. They act as natural filters, removing pollutants from water through processes such as sedimentation, filtration, and biological uptake, which significantly improve water quality. Additionally, wetlands contribute to air purification and noise reduction in urban areas, enhancing the living environment. By integrating wetlands into urban design, cities can promote biodiversity conservation, improve water management, and achieve a sustainable and resilient built environment.

F. Storm Water Management and Blue Green Infrastructure

Providing wetland systems as a part of green infrastructure in urban planning when devising storm water drainage solutions can reduce the burden on traditional drainage systems. Utilities of landscaping devices like bioswales, rain gardens, and water gardens include capturing and treating runoff with high water quality.

G. Socio-Cultural and Economic Benefits

Wetlands offer recreational opportunities enhancing urban well-being and potentially transforming these areas into ecotourism hotspots. Many wetlands hold cultural and spiritual significance for indigenous people, serving as sacred sites for traditions and cultural expression. The social, cultural, and economic advantages of wetlands are closely linked to biodiversity, green infrastructure, and waste management.

These various and contrasting contributions of wetlands to the sustainable built environment show their potential as NBSs that can solve different challenges at the same time. Wetlands are an underutilized resource that could be employed by urban planners and other stakeholders to create more resilient, liveable, and sustainable urban areas where natural spaces are harmoniously incorporated into the urban lifestyle. Integrating wetlands into urban green spaces and parks not only enhances the aesthetic appeal of these areas but also offers significant recreational potential, improving the residents' quality of life. Strategically incorporating wetlands into green infrastructure networks, such as greenways and riparian corridors, strengthens the connections between natural areas and promotes sustainable urban development. Integrating wetlands into BGI is essential in ensuring a sustainable built environment, as it enhances ecological resilience, supports water management, and promotes biodiversity. By understanding and addressing these factors, decision-makers can leverage wetlands as NBSs, creating vibrant, culturally rich, and sustainable environments.

VIII. CONCLUSIONS

This comprehensive review has demonstrated the vital role of wetlands in promoting sustainable built environments. Wetlands provide a wide range of ecosystem services that contribute to ecological resilience, including flood control, water purification, climate change adaptation, and biodiversity conservation. They serve as natural infrastructure that can be integrated into urban planning and development strategies. The concept of Nature-Based Solutions (NBSs) emphasizes the use of natural systems like wetlands to address societal challenges cost-effectively and sustainably. Successful case studies showcase how wetlands have been successfully incorporated into urban landscapes. These examples showcased that wetlands contribute to sustainable built environments through ecological resilience, flood prevention, climate adaptation, habitat provision, pollution control, and cultural values. To fully realize the potential of wetlands, key recommendations include policy support, incentives, capacity building, community engagement, multidisciplinary research, restoration efforts, and international cooperation. These measures can guide decision-makers in leveraging application of wetlands as NBSs for sustainable urban development.

Future initiatives should prioritize integrating wetlands as NBSs in urban planning and development to maximize their ecological, social, and economic benefits. Policymakers should create supportive frameworks and incentives to encourage the inclusion of wetlands in urban landscapes, recognizing them as sustainable and cost-effective solutions. Investment in capacity-building, community engagement, and education on wetland conservation and restoration is essential for successful implementation. Multidisciplinary research is needed to deepen our understanding of how wetlands interact with urban environments and to develop innovative management practices. Effective monitoring and maintenance are crucial to ensure that wetlands continue to provide benefits such as stormwater management, biodiversity conservation, and enhanced ecosystem services over time. Promoting awareness about the advantages of wetlands as NBSs can foster greater community involvement and support for these initiatives. Integrating wetlands into urban design and infrastructure planning can effectively address challenges posed by urbanization, climate change, and environmental degradation, offering solutions such as water purification, flood regulation, carbon sequestration, and biodiversity conservation.

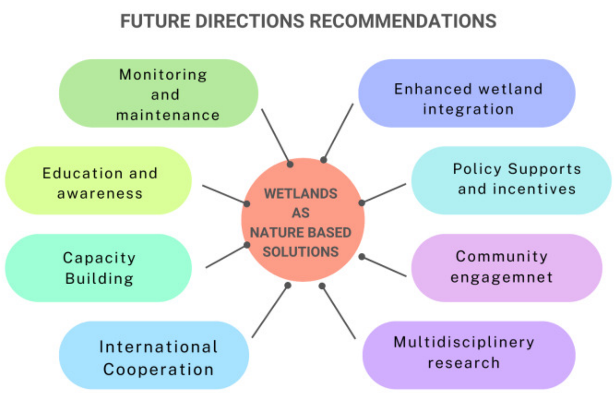

Fig. 6. Future directions for integrating wetlands as NBSs.

A holistic and integrated approach is necessary, involving collaboration among policymakers, urban planners, environmental agencies, and local communities to leverage the full potential of wetlands while preserving their ecological and cultural value. The ultimate aim is to shift the development paradigm from conventional urbanization towards a more nature-aligned approach, fostering environmentally sustainable cities and a sustainable built environment.

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REFERENCES

[1] W. J. Mitsch and J. G. Gosselink, *Wetlands*, 5th Edition. Hoboken, NJ, USA: Wiley, 2015.

[2] N. C. Davidson, "How much wetland has the world lost? Long-term and recent trends in global wetland area," *Marine and Freshwater Research*, vol. 65, no. 10, pp. 934–941, Sep. 2014, https://doi.org/10.1071/MF14173.

[3] "Ramsar wetland type classification - DCCEEW." https://www.dcceew.gov.au/water/wetlands/ramsar/wetland-type-classification.

[4] K. B. Gedan, M. L. Kirwan, E. Wolanski, E. B. Barbier, and B. R. Silliman, "The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm," *Climatic Change*, vol. 106, no. 1, pp. 7–29, May 2011, https://doi.org/10.1007/s10584-010-0003-7.

[5] S. Narayan *et al.*, "The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences," *PLOS ONE*, vol. 11, no. 5, 2016, Art. no. e0154735, https://doi.org/10.1371/journal.pone.0154735.

[6] "IUCN." https://iucn.org/.

[7] J. B. Zedler and S. Kercher, "WETLAND RESOURCES: Status, Trends, Ecosystem Services, and Restorability," *Annual Review of Environment and Resources*, vol. 30, pp. 39–74, Nov. 2005, https://doi.org/10.1146/annurev.energy.30.050504.144248.

[8] A. Ghermandi, J. C. J. M. van den Bergh, L. M. Brander, H. L. F. de Groot, and P. A. L. D. Nunes, "Values of natural and human-made wetlands: A meta-analysis," *Water Resources Research*, vol. 46, 2010, Art. no. W12516, https://doi.org/10.1029/2010WR009071.

[9] T. BenDor, T. W. Lester, A. Livengood, A. Davis, and L. Yonavjak, "Estimating the Size and Impact of the Ecological Restoration Economy," *PLOS ONE*, vol. 10, no. 6, May 2015, Art. no. e0128339, https://doi.org/10.1371/journal.pone.0128339.

[10] *The Sustainable Development Goals Report*. New York, NY, USA: UN, 2018.

[11] *The Economics of Ecosystems and Biodiversity for Water and Wetlands*. Institute for European Environmental Policy (IEEP) & Ramsar Secretariat, 2013.

[12] M. Hettiarachchi, T. H. Morrison, and C. McAlpine, "Forty-three years of Ramsar and urban wetlands," *Global Environmental Change*, vol. 32, pp. 57–66, May 2015, https://doi.org/10.1016/j.gloenvcha.2015.02.009.

[13] N. Frantzeskaki, "Seven lessons for planning nature-based solutions in cities," *Environmental Science & Policy*, vol. 93, pp. 101–111, Mar. 2019, https://doi.org/10.1016/j.envsci.2018.12.033.

[14] *The Ramsar Convention Manual: A Guide to the Convention on Wetlands (Ramsar, Iran, 1971)*, 6th ed. Ramsar Convention Secretariat, 2013.

[15] "Home page | The Convention on Wetlands, The Convention on Wetlands." https://www.ramsar.org/.

[16] O. US EPA, "Constructed Wetlands," Sep. 23, 2015. https://www.epa.gov/wetlands/constructed-wetlands.

[17] R. H. Kadlec and S. D. Wallace, *Treatment wetlands*, 2nd ed. Boca Raton, FL, USA: CRC Press, 2009.

[18] Rudolf de Groot, "Integrating the ecological and economic dimensions in," 2010.

[19] Millennium Ecosystem Assessment, *Ecosystems and human well-being: wetlands and water synthesis: a report of the Millennium Ecosystem Assessment*. Washington, DC, USA: World Resources Institute, 2005.

[20] W. J. Mitsch *et al.*, "Wetlands, carbon, and climate change," *Landscape Ecology*, vol. 28, no. 4, pp. 583–597, Apr. 2013, https://doi.org/10.1007/s10980-012-9758-8.

[21] J. Vymazal, "Removal of nutrients in various types of constructed wetlands," *Science of The Total Environment*, vol. 380, no. 1, pp. 48–65, Jul. 2007, https://doi.org/10.1016/j.scitotenv.2006.09.014.

[22] R. J. Naiman and H. Décamps, "The Ecology of Interfaces: Riparian Zones," *Annual Review of Ecology, Evolution, and Systematics*, vol. 28, pp. 621–658, Nov. 1997, https://doi.org/10.1146/annurev.ecolsys.28.1.621.

[23] E. Mcleod *et al.*, "A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2," *Frontiers in Ecology and the Environment*, vol. 9, no. 10, pp. 552–560, 2011, https://doi.org/10.1890/110004.

[24] E. B. Barbier, S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman, "The value of estuarine and coastal ecosystem services," *Ecological Monographs*, vol. 81, no. 2, pp. 169–193, 2011, https://doi.org/10.1890/10-1510.1.

[25] IUCN, *Nature-based solutions to address global societal challenges*. Gland, Switzerland: International Union for Conservation of Nature, 2016.

[26] S. Pauleit, T. Zolch, R. Hansen, T. B. Randrup, and C. Konijnendijk van den Bosch, "Nature-Based Solutions and Climate Change – Four Shades of Green," in *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice*, N. Kabisch, H. Korn, J. Stadler, and A. Bonn, Eds. New York, NY, USA: Springer, 2017, pp. 29–49.

[27] A. Oktaviani and Y. I. Masjud, "Nature based solution to climate change: Ecosystem based adaptation: How effective for climate change strategies?," *Journal of Earth Kingdom*, vol. 1, no. 2, pp. 81–90, Jan. 2024, https://doi.org/10.61511/jek.v1i2.2024.576.

[28] IUCN, *Ecosystem based adaptation : knowledge gaps in making an economic case for investing in nature based solutions for climate change*. Gland, Switzerland: International Union for Conservation of Nature, 2015.

[29] A. I. Stefanakis, "The Role of Constructed Wetlands as Green Infrastructure for Sustainable Urban Water Management," *Sustainability*, vol. 11, no. 24, Jan. 2019, Art. no. 6981, https://doi.org/10.3390/su11246981.

[30] D. Pritchard, "Culture and nature: The case of the Ramsar Convention on wetlands," in *Cultural and Spiritual Significance of Nature in Protected Areas*, B. Vershuuren and S. Brown, Eds. Routledge, 2018, pp. 182–192.

[31] A. Barman, F. Rajak, and R. Jha, "Integration of Wetland Technology for Sustainable Urban Development," *International Journal of Membrane Science and Technology*, vol. 10, no. 1, pp. 570–586, Oct. 2023, https://doi.org/10.15379/ijmst.v10i1.2620.

[32] K. Eckart, Z. McPhee, and T. Bolisetti, "Performance and implementation of low impact development – A review," *Science of The Total Environment*, vol. 607–608, pp. 413–432, Dec. 2017, https://doi.org/10.1016/j.scitotenv.2017.06.254.

[33] R. Costanza, O. Perez-Maqueo, M. L. Martinez, P. Sutton, S. J. Anderson, and K. Mulder, "The Value of Coastal Wetlands for Hurricane Protection," *Ambio*, vol. 37, no. 4, pp. 241–248, 2008.

[34] S. Cilliers, J. Cilliers, R. Lubbe, and S. Siebert, "Ecosystem services of urban green spaces in African countries—perspectives and challenges," *Urban Ecosystems*, vol. 16, no. 4, pp. 681–702, Dec. 2013, https://doi.org/10.1007/s11252-012-0254-3.

[35] C. Ahn and S. Schmidt, "Designing Wetlands as an Essential Infrastructural Element for Urban Development in the era of Climate Change," *Sustainability*, vol. 11, no. 7, Jan. 2019, Art. no. 1920, https://doi.org/10.3390/su11071920.

[36] K. Y. Turenscape, "A green sponge for a water-resilient city: Qunli stormwater park," in *Water Index: Design Strategies for Drought, Flooding and Contamination*, Barcelona, Spain: ACTAR, 2017, pp. 159–166.

[37] "The Bluebelt Program - DEP." https://www.nyc.gov/site/dep/water/the-bluebelt-program.page.

[38] J. Boros and I. Mahmoud, "Urban Design and the Role of Placemaking in Mainstreaming Nature-Based Solutions. Learning From the Biblioteca Degli Alberi Case Study in Milan," *Frontiers in Sustainable Cities*, vol. 3, Jun. 2021, Art. no. 635610, https://doi.org/10.3389/frsc.2021.635610.

[39] D. Dushkova and D. Haase, "Not Simply Green: Nature-Based Solutions as a Concept and Practical Approach for Sustainability Studies and Planning Agendas in Cities," *Land*, vol. 9, no. 1, Jan. 2020, Art. no. 19, https://doi.org/10.3390/land9010019.

[40] C. A. (Tony) Arnold, O. O. Green, D. DeCaro, A. Chase, and J.-G. Ewa, "Social-Ecological Resilience of an Eastern Urban-Suburban Watershed: The Anacostia River Basin," *Idaho Law Review*, vol. 51, no. 1, pp. 29–90, 2015 2014.

[41] G. Desfor and J. Bonnell, "Socio-ecological Change in the Nineteenth and Twenty-first Centuries: The Lower Don River," in *Reshaping Toronto's Waterfront*, G. Desfor and J. Laidley, Eds. Toronto, ON, Canada: University of Toronto Press, 2011, pp. 305–326.

[42] W. Byeon, "A Study on the Development of Design Model of Ecological Park as Stormwater Storage Facilities," *Journal of the Korean Society of Environmental Restoration Technology*, vol. 9, no. 3, pp. 1–16, 2006.

[43] C. B. Ahmad, R. A. Nasir, A. S. Ahmad, and J. Abdullah, "Visitors' Perception towards Putrajaya Wetland, Malaysia," *Environment-Behaviour Proceedings Journal*, vol. 1, no. 3, pp. 205–213, Aug. 2016, https://doi.org/10.21834/e-bpj.v1i3.365.

[44] D. Hottenroth, C. Harper, and J. Turner, "Effectweness of Integrated Stormwater Management in a Portland, Oregon, Watershed," *JAWRA Journal of the American Water Resources Association*, vol. 35, no. 3, pp. 633–641, 1999, https://doi.org/10.1111/j.1752-1688.1999.tb03619.x.

[45] J. Hoyer, W. Dickhaut, L. Kronawitter, and B. Weber, Eds., *Water sensitive urban design: principles and inspiration for sustainable stormwater management in the city of the future*. Berlin, Germany: Jovis-Verl, 2011.

[46] R. Pitt, J. Voorhees, and S. Clark, "Integrating Green Infrastructure into a Combined Sewer Service Area Model," in *World Environmental and Water Resources Congress 2010*, Apr. 2012, pp. 2950–2963, https://doi.org/10.1061/41114(371)304.

[47] L. Xiang *et al.*, "Purification effect of aquatic plant communities in constructed wetland park: a comparative experiment of Tianhe wetland park in China," *Environmental Research Communications*, vol. 4, May 2022, Art. no. 055007, https://doi.org/10.1088/2515-7620/ac6e33.

[48] "Latest news, sport and opinion from the Guardian." https://www.theguardian.com/europe.

[49] "Melbourne Water." https://www.melbournewater.com.au/.

[50] "Arcata, CA | Official Website." https://www.cityofarcata.org/.

[51] L. Wylie, A. E. Sutton-Grier, and A. Moore, "Keys to successful blue carbon projects: Lessons learned from global case studies," *Marine Policy*, vol. 65, pp. 76–84, Mar. 2016, https://doi.org/10.1016/j.marpol.2015.12.020.

[52] G. L. Chmura, S. C. Anisfeld, D. R. Cahoon, and J. C. Lynch, "Global carbon sequestration in tidal, saline wetland soils," *Global Biogeochemical Cycles*, vol. 17, no. 4, 2003, Art. no. 1111, https://doi.org/10.1029/2002GB001917.

[53] C. M. Duarte, J. J. Middelburg, and N. Caraco, "Major role of marine vegetation on the oceanic carbon cycle," *Biogeosciences*, vol. 2, no. 1, pp. 1–8, Feb. 2005, https://doi.org/10.5194/bg-2-1-2005.

[54] T. Zolch, J. Maderspacher, C. Wamsler, and S. Pauleit, "Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale," *Urban Forestry & Urban Greening*, vol. 20, pp. 305–316, Dec. 2016, https://doi.org/10.1016/j.ufug.2016.09.011.

[55] M. L. Kirwan and J. P. Megonigal, "Tidal wetland stability in the face of human impacts and sea-level rise," *Nature*, vol. 504, no. 7478, pp. 53–60, Dec. 2013, https://doi.org/10.1038/nature12856.

[56] D. Hey, J. Kostel, and D. Montgomery, "An ecological solution to the flood damage problem," in *Finding the Balance between Floods, Flood Protection, and River Navigation*, Saint Louis University, 2009.

[57] C. Giri, Z. Zhu, L. L. Tieszen, A. Singh, S. Gillette, and J. A. Kelmelis, "Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia," *Journal of Biogeography*, vol. 35, no. 3, pp. 519–528, 2008, https://doi.org/10.1111/j.1365-2699.2007.01806.x.

[58] R. Munang, I. Thiaw, K. Alverson, M. Mumba, J. Liu, and M. Rivington, "Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts," *Current Opinion in Environmental Sustainability*, vol. 5, no. 1, pp. 67–71, Mar. 2013, https://doi.org/10.1016/j.cosust.2012.12.001.

[59] P. Malaviya and A. Singh, "Constructed Wetlands for Management of Urban Stormwater Runoff," *Critical Reviews in Environmental Science and Technology*, vol. 42, no. 20, pp. 2153–2214, Oct. 2012, https://doi.org/10.1080/10643389.2011.574107.

[60] M. Shafique and R. Kim, "Low impact development practices: a review of current research and recommendations for future directions," *Ecological Chemistry and Engineering. S*, vol. 22, no. 4, pp. 543–563, Jan. 2016, https://doi.org/10.1515/eces-2015-0032.

[61] K.-H. Liao, S. Deng, and P. Y. Tan, "Blue-Green Infrastructure: New Frontier for Sustainable Urban Stormwater Management," in *Greening Cities: Forms and Functions*, P. Y. Tan and C. Y. Jim, Eds. New York, NY, USA: Springer, 2017, pp. 203–226.

[62] L. Marchand, M. Mench, D. L. Jacob, and M. L. Otte, "Metal and metalloid removal in constructed wetlands, with emphasis on the importance of plants and standardized measurements: A review," *Environmental Pollution*, vol. 158, no. 12, pp. 3447–3461, Dec. 2010, https://doi.org/10.1016/j.envpol.2010.08.018.

[63] S. Diaz *et al.*, "The global spectrum of plant form and function," *Nature*, vol. 529, no. 7585, pp. 167–171, Jan. 2016, https://doi.org/10.1038/nature16489.

[64] M. Ignatieva, G. H. Stewart, and C. Meurk, "Planning and design of ecological networks in urban areas," *Landscape and Ecological Engineering*, vol. 7, no. 1, pp. 17–25, Jan. 2011, https://doi.org/10.1007/s11355-010-0143-y.

[65] S. Alikhani, P. Nummi, and A. Ojala, "Urban Wetlands: A Review on Ecological and Cultural Values," *Water*, vol. 13, no. 22, Jan. 2021, Art. no. 3301, https://doi.org/10.3390/w13223301.

[66] J. Ahern, "Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design," *Landscape Ecology*, vol. 28, no. 6, pp. 1203–1212, Jul. 2013, https://doi.org/10.1007/s10980-012-9799-z.

[67] P. Meli, J. M. R. Benayas, P. Balvanera, and M. M. Ramos, "Restoration Enhances Wetland Biodiversity and Ecosystem Service Supply, but Results Are Context-Dependent: A Meta-Analysis," *PLOS ONE*, vol. 9, no. 4, Apr. 2014, Art. no. e93507, https://doi.org/10.1371/journal.pone.0093507.

[68] A. A. Mahessar, A. N. Laghari, S. Qureshi, I. A. Siming, A. L. Qureshi, and F. A. Shaikh, "Environmental Impact Assessment of the Tidal Link Failure and Sea Intrusion on Ramsar Site No. 1069," *Engineering, Technology & Applied Science Research*, vol. 9, no. 3, pp. 4148–4153, Jun. 2019, https://doi.org/10.48084/etasr.2686.

[69] G. N. Bratman, J. P. Hamilton, K. S. Hahn, G. C. Daily, and J. J. Gross, "Nature experience reduces rumination and subgenual prefrontal cortex activation," *Proceedings of the National Academy of Sciences*, vol. 112, no. 28, pp. 8567–8572, Jul. 2015, https://doi.org/10.1073/pnas.1510459112.

[70] P. R. Maund *et al.*, "Wetlands for Wellbeing: Piloting a Nature-Based Health Intervention for the Management of Anxiety and Depression," *International Journal of Environmental Research and Public Health*, vol. 16, no. 22, Jan. 2019, Art. no. 4413, https://doi.org/10.3390/ijerph16224413.

[71] W. J. Junk *et al.*, "Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil," *Aquatic Sciences*, vol. 68, no. 3, pp. 278–309, Oct. 2006, https://doi.org/10.1007/s00027-006-0851-4.

[72] M. Budruk, H. Thomas, and T. Tyrrell, "Urban Green Spaces: A Study of Place Attachment and Environmental Attitudes in India," *Society & Natural Resources*, vol. 22, no. 9, pp. 824–839, Sep. 2009, https://doi.org/10.1080/08941920802628515.

[73] T. Papayannis and D. Pritchard, "Cultural aspects of wetland management: An Overview," in *The Wetland Book: I: Structure and Function, Management and Methods*, C. M. Finlayson, M. Everard, K. Irvine, R. J. McInnes, B. A. Middleton, A. A. van Dam, and N. C. Davidson, Eds. Dordrecht, Netherlands: Springer, 2016, pp. 1–15.

[74] "Okavango Delta - UNESCO World Heritage Centre." https://whc.unesco.org/en/list/1432/.

[75] M. E. Krasny, C. Lundholm, S. Shava, E. Lee, and H. Kobori, "Urban Landscapes as Learning Arenas for Biodiversity and Ecosystem Services Management," in *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment*, T. Elmqvist, M. Fragkias, J. Goodness, B. Güneralp, P. J. Marcotullio, R. I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto, and C. Wilkinson, Eds. Dordrecht, Netherlands: Springer, 2013, pp. 629–664.

[76] R. M. Galvin, "Evaluating Pollutants of Emerging Concern in Aquatic Media Through E-PRTR Regulation. A Case Study: Cordoba, Spain, 2009-2018," *Engineering, Technology & Applied Science Research*, vol. 9, no. 5, pp. 4795–4800, Oct. 2019, https://doi.org/10.48084/etasr.3130.

[77] R. K. Olson, Ed., *Created and Natural Wetlands for Controlling Nonpoint Source Pollution*. Boka Raton, FL, USA: CRC Press, 1993.

[78] A. J. Twinch and P. J. Ashton, "Wetlands as Accreting Systems: Nutrient Cycling in Wetlands," *Journal of the Limnological Society of Southern Africa*, vol. 9, no. 2, pp. 104–109, Jan. 1983, https://doi.org/10.1080/03779688.1983.9632862.

[79] C. S. Hopkinson, "A comparison of ecosystem dynamics in freshwater wetlands," *Estuaries*, vol. 15, no. 4, pp. 549–562, Dec. 1992, https://doi.org/10.2307/1352397.

[80] P. Hoagland, D. M. Anderson, Y. Kaoru, and A. W. White, "The economic effects of harmful algal blooms in the United States: Estimates, assessment issues, and information needs," *Estuaries*, vol. 25, no. 4, pp. 819–837, Aug. 2002, https://doi.org/10.1007/BF02804908.

[81] S. V. Matagi, D. Swai, and R. Mugabe, "A review of Heavy Metal Removal Mechanisms in wetlands," *African Journal of Tropical Hydrobiology and Fisheries*, vol. 8, no. 1, pp. 13–25, 1998, https://doi.org/10.4314/ajthf.v8i1.1386.

[82] D. B. Kosolapov *et al.*, "Microbial Processes of Heavy Metal Removal from Carbon-Deficient Effluents in Constructed Wetlands," *Engineering in Life Sciences*, vol. 4, no. 5, pp. 403–411, 2004, https://doi.org/10.1002/elsc.200420048.

[83] P. K. Rai, "Heavy metals/metalloids remediation from wastewater using free floating macrophytes of a natural wetland," *Environmental Technology & Innovation*, vol. 15, Aug. 2019, Art. no. 100393, https://doi.org/10.1016/j.eti.2019.100393.

[84] J. B. Williams, "Phytoremediation in Wetland Ecosystems: Progress, Problems, and Potential," *Critical Reviews in Plant Sciences*, vol. 21, no. 6, pp. 607–635, Nov. 2002, https://doi.org/10.1080/0735-260291044386.

[85] M. E. Dietz and J. C. Clausen, "Stormwater runoff and export changes with development in a traditional and low impact subdivision," *Journal of Environmental Management*, vol. 87, no. 4, pp. 560–566, Jun. 2008, https://doi.org/10.1016/j.jenvman.2007.03.026.

[86] E. Alexandri and P. Jones, "Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates," *Building and Environment*, vol. 43, no. 4, pp. 480–493, Apr. 2008, https://doi.org/10.1016/j.buildenv.2006.10.055.