Bio-retention Systems for Storm Water Treatment and Management in Urban Systems

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Abstract Among different anthropogenic activities, urbanization has greatly influenced the hydrological cycle. Due to increased impervious surfaces, the amount of infiltration has been reduced, thereby increasing the runoff volume leading to flood conditions even for low rainfall events. Storm water flow along these impermeable surfaces finally ends up in surface water reservoirs. Urban systems are fundamentally responsible for a lot of pollutants by different sources: vehicle, industries, atmospheric deposition, soil erosion, etc., which may release various types of pollutants such as metals, organics, nutrients, oil and grease, detergents, surfactants, etc., into the atmosphere. With the storm water runoff, these pollutants may end up in surface waters. This indicates the importance of storm water treatment. Although there are several storm water treatment methods available, low-cost environmental-friendly methods (e.g., bio-retention systems) will be more sustainable with urban systems. Bio-retention systems can manage storm water and improve water quality through containment and remediation of pollutants within the urban system. However, the limitation of these systems is its finite capacity to hold contaminants. Hence, suitable plants grown along the bio-retention systems will be an effective phytoremediation option to address the challenges encountered in these remedial systems.

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1 Introduction

Storm water generally originates during precipitation processes and melting of snow or ice [1]. It can soak into the soil by infiltration or runoff and end up in nearby water bodies or be held on the surface and evaporate. If a man-made construction occurs in a watershed, the area of impervious surfaces typically increases and, therefore, a corresponding decrease in the area of naturally porous surfaces could result in an increase in storm water runoff volumes with a degradation of runoff quality. The degradation of runoff quality can be observed in increased concentrations and total mass loads of nutrients, organics, metals, chlorides, hydrocarbons, bacteria, viruses, etc. [2]. Conventional storm water management systems collect storm water runoff and drain it from the city or into surface waters. These systems have been improved over time and cities are being heavily relied on them. In return, it reduces groundwater infiltration and lowers groundwater recharge rates.

Landscape architects, environmental scientists, engineers, urban designers, planners as well as local government play a vital role in managing the urban water cycle as it is supported by key sustainability principles of water recycling, consumption, environmental protection, and waste minimization [3]. In order to support these issues, sustainable storm water practices in the world such as Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD), Best Management Practices (BMP), Integrated Urban Resource Water Management (IURWM), Decentralized Rainwater Management (DRWM), and Green Infrastructure (GI) have been demonstrated by employing the ecosystem processes to offer numerous water quantity and quality benefits to soil and vegetation [4, 5]. They also require concept designs and strategic planning that are underpinned by sound engineering practices to carry out multiple treatment processes of storm water. Hence, bio-retention systems have been introduced as a mitigation management practice to promote infiltration and absorption of storm water runoff around the world [6, 7].

Bio-retention system which can also be named as ‘rain garden’ is used to control water at its sources, and it is the most adaptable method applied throughout many regions [8]. Bio-retention system can retain and treat urban runoff using vegetation before it flows into the main storm drain system. It is commonly made up of an excavated basin or landscape depression consisting of plants, ponding area, a mulch layer, several layers of planting soil, and an optional underdrain [9]. These systems are capable of removing pollutants from the runoff via physical, chemical, and biological processes, including sedimentation, filtration, and sorption on mulch and soil layers, plant uptake, and biodegradation by soil microorganisms [10].

Since the bio-retention systems enhance the storm water infiltration capabilities, the groundwater can be polluted over a period of time. Therefore, it is important to remediate dissolved pollutants in storm water within the bio-retention system to avoid further cycling within the ecosystem. In that case, phytoremediation using suitable plants or plant–microorganism combination can be used to minimize pollution in an environment-friendly manner in contaminated soils, sediments, water, and air [11, 12]. The phytoremediation process includes mitigation, transformation, stabilization, and/or degradation of undesirable substances [13]. In this process, it is possible to remove and/or mineralize heavy metals (HMs), organic compounds, nutrients, and even radioactive elements [14]. Hence, phytoremediation can serve as an integrated process in the bio-retention systems for storm water treatment.

In this chapter, a focused attempt has been made to discuss the relevance, feasibility, and effectiveness of bio-retention systems for storm water treatment and the use of phytoremediation technology to remediate different types of pollutants in storm water.

2 Pollutants in Storm Water

As the urban areas release various pollutants from its vast sources of pollution, the storm water that wash-off impervious surfaces has been considered as a primary pollutant source and a reason for the degradation of waterways [6, 15]. It is composed of all sediments, metals, organic compounds, microorganisms, oils, surfactants, and nutrients that finally end up with surface water bodies [6, 15]. These pollutants can easily deteriorate the water quality and disturb the biodiversity [15]. Major sources of these pollutants are motor vehicles, construction activities, soil erosion, industrial pollutants, spills and leachates, atmospheric deposition, and domestic pollutants [16].

The sediments carried by the storm water mainly consist of materials from soil erosion, particles by construction sites, vegetation debris, particulates that release from vehicles, and atmospheric deposition. It is a fact to be considered that most of the microorganisms, viruses, bacteria, and protozoa are transported along with the sediments. Among HMs, Cd, Cr, Zn, Cu, and Pb found in storm water are significant toward human and ecosystem health. The sources of these HMs could be vehicle emissions, vehicle ware, tire wears, industrial wastes, and atmospheric deposition [15, 17]. Oil, grease, and surfactant are one of the groups of contaminants that can be easily found in storm water. Since they are accumulated in roadways, parking lots, and service stations, it can largely be accumulated in urban storm water and finally surface and ground water systems [15]. The nutrients especially nitrogen and phosphorous can be found in storm water at great concentrations [16]. Organic matter, soil, fertilizers, vehicle exhausts, domestic organic wastes, detergents, animal waste, and leachates are the sources for nutrients [15, 16]. Fig. 1 illustrates general sources of pollutants in storm water. Due to their ready availability, they may create eutrophic impacts in water streams [15]. Especially phosphorous as a most prioritized nutrient for increased eutrophication, controlling of phosphorous accumulation is a

Fig. 1 Major sources for pollutants in storm water

key factor in a bio-retention system [13]. These may create eutrophication in surface water bodies. Also, the nitrogen may result in excessive growth of algae and some other aquatic weeds. The build-up of nitrates in drinking water creates health hazards to human and animals [13, 18]. The WSUDs are focusing on reuse and treatment of storm water, to meet the water quality measures and toxicity limits [15].

In the past, the biggest contributor of nitrogen and phosphorus in urban waters has been the wastewater effluent [19, 20]. During the last decade, strict regulations and improvements in wastewater management technologies have been applied to reduce the input. Attention has shifted to nutrient loading from untreated non-point sources of nutrients such as urban runoffs as concentrations of nutrients in wastewater discharges have been reduced [21]. Up to one-third of total phosphorous loading has been attributed to the urban runoff in some lakes [22]. Often pollutant concentrations found within storm water runoff exceed levels that are considered both acutely toxic and chronic to aquatic biota [23]. The economic cost of eutrophication on freshwater bodies alone within the United States is estimated to exceed 2.2 billion dollars a year [24]. Table 1 summarizes the different pollutants and their concentrations that have been reported in storm water.

3 Different Storm Water Management Methods in Urban Systems

Urban storm water management is not a new concern. However, conventional storm water management still raises many associated issues. At the beginning, priority has been given to maintain runoff volume, but with the negative impacts on the

Table 1 Different pollutants and their concentrations in storm water in the world

Location	TSS (mg/L)	TN (mg/L)	NH_4^-N (mg/L)	NO_3^-N (mg/L)	TP (mg/L)	PO_4-P (mg/L)	Zn (mg/L)	Pb (mg/L)	Cu	Reference
Charlotte, NC	49.5	1.68			0.19		0.072			[103]
College Park, MD	34				0.61		0.107			[104]
Haddam, CT		1.2			0.012–0.019					[105]
Greensboro, NC		1.35			0.11					[60]
Louisburg, NC		1.70			0.29					[106]
	375						0.659	0.212	37 μg/L	[107]
									2.12 g m^{-2} yr^{-1}	[108]
									1.0–3.9 g m^{-2} yr^{-1}	[109]
									8.6 g m^{-2} yr^{-1}	[110]
Into Sed Basin, Brisbane, Australia		1.27	0.1	0.83	0.11	0.09				[111]
Wetland 1, Brisbane, Australia		1.01	0.12	0.47	0.11	0.08				
Wet land 2, Brisbane, Australia		0.92	0.09	0.25	0.09	0.03				
Bypass, Ecosol Brisbane, Australia		1.75	0.09	0.53	0.15	0.07				
Urban areas, New Hampshire					0.15					[112]
Residential areas, New Hampshire					0.4					

environment, efforts have been taken for improving water quality as well [6, 15]. Although there is a reduction in groundwater infiltration and lowering of the groundwater recharge rates, conventional storm water systems are beneficial as they rapidly drain storm water from surfaces. Moreover, it can limit available drinking water in cities due to decreasing groundwater recharge rates [25]. Present conventional storm water management systems to a large extent are neither adaptable nor sustainable to developing conditions or changing climates. As infiltration and evaporation are reduced, conventional systems have negative effects on local climate. The climate of the cities becomes warmer and dryer compared to the surrounding areas where this phenomenon is also known as the 'Heat Island Effect' [26].

During uncertain conditions as a result of increased city development and resultant climate change, conventional systems cannot adapt to unmanageable storm water runoff. Adaptation to these changes requires higher running costs and investments in return [25]. It is important to consider about the hydraulic loading capacity and the pollutant size range in storm water and the available space [15]. In addition, there should be a widespread collective responsibility toward the water with increased awareness of water resources. If visible water systems can promote intelligent use and change of attitudes, inhabitants are likely to appreciate and understand storm water management. It has now become a necessity to reform storm water management while initiating a paradigm shift in urban water management [16, 27].

3.1 Combined Sewage and Storm Water Management System

To avoid flooding of storm water from paved areas, many cities have implemented sewage systems to drain water as well as to regulate domestic and industrial wastewater. Here, the storm water and wastewater are collected in one pipeline of the network. This mixed water is taken to the wastewater treatment plant, cleaned and then it is discharged into the water bodies [28].

3.2 Sustainable Storm Water Management Systems

In conventional urban development, storm water management has been driven by a view which reflects that storm water runoff has no value as a useful resource. Also, it is environmentally benign and adds little to the amenity of an urban environment. As a result, conventional storm water management systems are used to collect storm water runoff rapidly and drain it with a focus on highly efficient drainage systems. These systems kept storm water runoff 'out of sight' and consequently 'out of mind' [29]. Hence, this practice is considered out of touch with the environmental values of the society while it impedes the broader pursuit of advancing comparatively sustainable urban environments [30–32].

Yet, there has been significant development of new management approaches and techniques to improve the sustainability of urban storm water management since 1980s [33, 34] and advanced legislation has also been introduced. The storm water runoff treatment is no longer considered in isolation to the urban designing and planning of a particular area, as it is a part of an emerging new paradigm in urban management. Management of storm water is considered at all stages of the urban planning and design process by ensuring that architecture, site planning, landscape architecture, and engineering infrastructure are provided in such a way that supports the management of storm water as a valuable resource and the improvement of storm water quality, however not in the case of developing world [29].

However, in some cases, storm water management can be seen as unusual and messy when it is not properly designed or poorly maintained. In return, people may not use sustainable storm water management practices as they do not vividly see an added value for the extra cost [35]. In addition, there are identified impediments to sustainable urban storm water management, uncertainties in performance and cost, insufficient engineering standards and guidelines, fragmented responsibilities, lack of institutional capacity, lack of legislative mandate, lack of funding and effective market incentives, and resistance to change [6].

3.2.1 Storm Water Management Through Best Management Practices

As there was a perceived conflict generated between the environment and the existing drainage systems, new concepts and proposals came on to the surface with both considerations on public health and the environment. The main idea behind the proposals presented for urban storm water management is the use of structures to mimic some of the processes of the hydrological cycle while maintaining natural water flow mechanisms. Both structural and non-structural BMPs [36] gained popularity as a method to treat nonpoint sources of pollution such as urban runoff and as a part of an international trend driven by a public demand for integrated water management and sustainable development [33]. Best management practices are agronomically sound practices that protect or enhance water quality and are at least as profitable as existing practices [37].

The term BMP usually refers to structures that mimic natural hydrological processes of a stream network but it can include educational programs and policy changes. The choice depends on the land use, public perceptions, available space, funding, and intended function. Some structural BMPs range from ponds to surfaces for infiltration. Even, they can be designed to be multifunctional by providing green spaces for wildlife and recreation at the same time by improving storm water quality and reducing flood risks. Consequently, storm water has truly become a liquid asset in the suburbs [38].

3.2.2 Integrated Urban Storm Water Management

In response to the knowledge that rapid conveyance of storm water has led to environmental degradation in receiving water bodies, Integrated Urban Storm water Management (IUSM) is another management concept that has evolved over the last three decades [32]. However, the significance of IUSM varies between places while getting more attention in places like New Zealand, Australia, and many parts of United States as the storm water drainage system network is typically a separate system from the wastewater network unlike many places across Europe. Overall, it is concerned with enabling more sustainable management of urban storm water environments [39]. Reducing storm water pollution for protecting the urban environment in addition to reusing and harvesting rainwater and storm water locally have become equally integral parts in the flood protection focus of IUSM initiatives. However, due to separate administration of water quality management, flood management, environmental protection, and urban design, these aspects are not always synergistic [40]. Entrenched implementation processes, intergovernmental relations, the current institutional framework, and historical low political profile of urban storm water have been revealed as barriers to IUSM [39].

3.2.3 Sustainable Urban Drainage Systems

Another supportive stance by United Kingdom which has been referred to as Sustainable Urban Drainage System (SUDS) is designed in such a way by allowing water to either by retaining in devices to imitate the natural disposal of surface water or infiltrating into the ground to manage the environmental risks from urban runoff [41, 42]. Therefore, SUDS objectives are to maximize biodiversity and amenity opportunities and to minimize the impacts from the development due to the quality and quantity of the runoff [43]. As preferred solutions of storm water management, SUDS have been constantly in the usage. For example, the Town and Country Planning Assessment of Environmental Effects Regulations [44] determine that in mitigating negative impacts on the environment, SUDS should be used. Uncertainties about operational factors and long-term maintenance have slowed down the widespread adoption of SUDS. However, as an addition to traditional systems, many local authorities, developers, and environmental regulators are keen to implement SUDS [45].

3.2.4 Water-Sensitive Urban Design

To provide a broader framework for sustainable urban water management, WSUD in Australia has evolved from its early association with storm water management. It provides a unified and common method for integrating the interactions between the urban water cycle and the urban built form including urban landscapes. Four major inter-related issues that have been identified as essential elements in advancing the concept of WSUD include: Regulatory Framework, Assessment & Costing, Technology & Design, and Community Acceptance and Governance [29].

In other words, WSUD is the interdisciplinary cooperation of urban design, landscape planning, and water management. With principles of urban design, it combines the functionality of water management. WSUD develops integrative strategies for economical, social, ecological, and cultural sustainability [25]. Storm water acts as a key element, both as a resource and for the protection of receiving water bodies though WSUD considers all parts of the urban water cycle [46].

3.2.5 Low Impact Development for Storm Water Management

The Department of Environmental Resources in Prince George's County, Maryland, introduced a comprehensive approach to sustainable storm water management called LID and described in detail [47]. It opened up a new way of approaching storm water management as a potential resource as its main goal is to replicate or maintain the predevelopment hydrological regime using evapotranspiration and enhanced infiltration to reduce off-site runoff and ensure adequate groundwater recharge by minimizing the impact of development, especially for impervious surfaces [47]. Multiple purposes can be seen in LID practices such as improving habitat, enhancing management of runoff, improving groundwater recharge, improving surface water quality, and enhancing the aesthetics of the community [47].

In recent years, one structural LID practice that has gained attention is the bio-retention system. Research on bio-retention systems is an active field, particularly in terms of treatment and mix design despite its widespread usage [48]. Since the introduction of the first bio-retention manual in 1993 by Prince George's County, it has rapidly become one of the most widely used storm water BMPs throughout the world [8]. Bio-retention systems have been also referred to as rain gardens and these BMPs use the chemical, biological, and physical properties of plants, microbes, and soils to improve water quality. Bio-retention system contains a shallow vegetated depression to detain or retain storm water [49]. In addition, it provides canopy interception, water quality control, evapotranspiration, runoff volume and peak flow discharge control, and groundwater recharge [50]. Yet, there are many aspects in design and implementation of which active research challenges remain to the widespread adoption of this practice.

4 Bio-retention Systems for Storm Water Treatment and Management

Bio-retention systems are important since it requires low-tech and low-cost. In a typical bio-retention system there are several processes to improve the storm water quality and to reduce the runoff volume; evaporation, evapotranspiration,

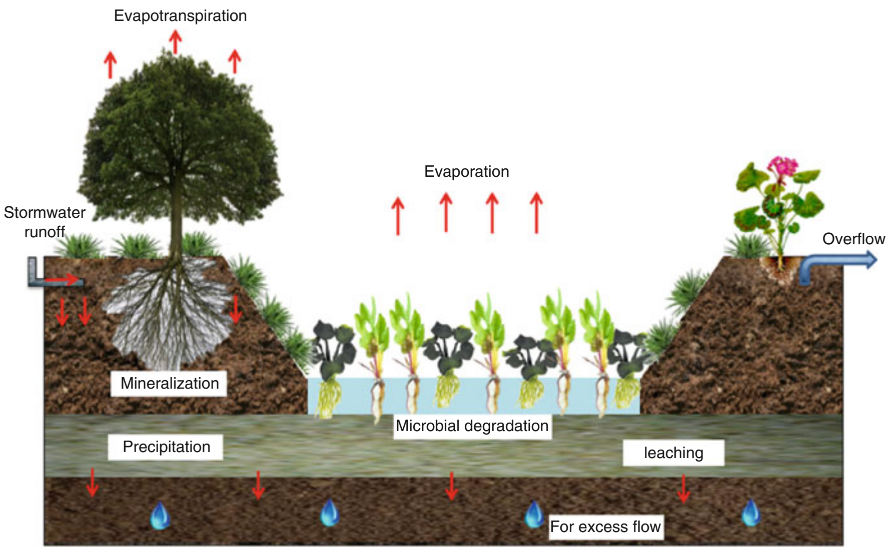

Fig. 2 Typical bio-retention system and general pollutant removal mechanisms

sedimentation, filtration, sorption, and enhanced denitrification as well [8, 15, 51]. The remaining water will be absorbed by subsoil or collected by subsoil pipes. Further water quality treatments and reuse of storm water will be facilitated thereafter [15, 52]. Rain gardens, swales, and porous pavement can also be incorporated into the bio-retention system to increase the infiltration [53]. The major objective of bio-retention system is the reduction of runoff volume by enhancing infiltration and evapotranspiration as well as for increasing the urban biodiversity [53]. Since the storm water bearing quite a number of pollutants in considerable quantities, it should have a clear way to improve water quality as well. Fig. 2 illustrates a typical bio-retention system and major mechanisms within the system.

5 Design of Bio-retention System

In recent years, there have been many engineering manuals with design recommendations for a bio-retention system. Some manuals originate in Maryland [54], North Carolina [55], and Washington [56] of the United States, North Shore City's Bio-retention Guidelines from New Zealand [49], and The Toronto Region Conservation Authority's Low Impact Development Storm Water Design Guide from Canada [57]. The basic design is same though there may be specific recommendations for design on different regional levels. Yet, depending on the site characterizations, design variations could be observed. For instance, an underdrain to allow water to drain from the system in a certain period of time is needed to areas where very low permeability is associated with native soils. Also, an overflow or bypass to a sewer drain is needed to accommodate a large flow of water in areas where flooding is not acceptable [57].

A typical design of a bio-retention system includes a sloped grass buffer strip, a ponding area with vegetation, a three-foot deep soil planting layer, and a one-foot deep sand layer. Some systems contain gravel and underdrain piping below the sand layer when soils are not appropriate for groundwater recharge (Fig. 2). The soil planting layer acts as a primary filter to attenuate pollutants. Also, it provides rapid infiltration of storm water runoff, complete infiltration within 72 h to avoid mosquito breeding. It sustains healthy vegetation at the surface too. To achieve infiltration requirements, the soil planting bed consists of a high sand content. The sand layer acts as a secondary filter and transition between the soil planting bed and underdrain system or the underlying soil. A thin mulch layer can be applied to the top of the planting substrate to retain moisture. The underdrain system can be connected to a storm water sewer system, which eventually discharges into surface waters. For systems without an underdrain, ground water is recharged through infiltration [58]. Simply a bio-retention system can be viewed as a landscaped depression which consists of vegetation, several filter media layers, an overflow weir, optional under drain and receives runoff from upgradient impervious surfaces [48].

6 How Do Bio-retention Systems Work?

Bio-retention process starts by routing storm water runoff into such landscaped depressions where they are designed to remove pollutants in a similar manner to the ecosystems. Larger storm runoffs are diverted to the storm drain system. The remaining runoff filters through the soil mix. It can either be collected in an under drain or can be designed to enhance groundwater infiltration and later be discharged according to local storm water management requirements [48]. Though runoff is filtered through each layer, the soil media layer does the main filtration [10]. The vegetation layer traps sediment and slows down the runoff velocity [59]. In this system, the pollutant removal treatment from urban runoff is performed by a variety of unit processes which make use of the biological, chemical, and physical properties of soils, plants, and microbes [8].

Bio-retention facilities are used to capture and infiltrate rainwater runoff from the ‘first flush’ of a particular rain event. Storm water that is infiltrating may recharge groundwater or can be collected in subsurface perforated pipes and then conveyed to traditional storm drains [10]. To control the initial volume of runoff by implementing adequate bio-retention gardens may have the potential to remove the majority of mobilized pollutants during a precipitation event [54]. In addition by storing, detaining and infiltrating storm water, bio-retention gardens are able to reduce runoff volumes as well as peak flows [60]. The usage of bio-retention facilities can also increase runoff time of concentration. A typical time of concentration value would be in the range of 5–10 min for a parking lot 0.2–0.4 ha in size draining directly to a storm drain.

In contrast, the placement of a bio-retention facility in front of the drainage outlet will increase the time of concentration, or time for the runoff to discharge, from a quarter hour to several hours [61], depending on the flow rates through the treatment media. Up to 31 % of runoff entering the bio-retention cells was lost through this exfiltration, and up to 19 % was lost to evapotranspiration [62]. Apart from that, there have been numerous studies of low nitrogen and/or phosphorous removal rates and even leaching of these nutrients in bio-retention systems [60, 63, 64]. Some studies have also reported on factors influencing bio-retention system treatment performance, such as the presence of vegetation [65, 66], the filter depth [10, 65] or the type of filter media [66–68]. Hence, use of phytoremediation integrated into bio-retention systems may enhance the treatment of storm water toward minimizing the pollutants.

7 Phytoremediation Integration into Bio-retention Systems

Bio-retention systems are designed in such a way to facilitate the chemical, physical, and biological processes, which naturally occurs in a terrestrial ecosystem. Some of the natural processes contributing to water quality improvement are sedimentation, adsorption, filtration, volatilization, ion exchange, decomposition, phytoremediation, and bioremediation [69]. Among different pollution removal methods, the urban systems require remediation method that has low cost, environmentally friendly as well as the easy maintenance. Phytoremediation is such a concept that can be easily adopted to the bio-retention systems. Briefly, the phytoremediation is a method of exploiting plants to extract contaminants from soil [70].

In the process of phytoremediation, there are few different ways that activate the plants and microorganisms: phytoextraction, phytodegradation, rhizofiltration, phytostabilization, and phytovolatalization. The phytoextraction acts to remove metals or organics from the soil by allowing them to concentrate on harvestable parts. The phytodegradation is there to degrade pollutants in association with microorganisms. During rhizofiltration process, the plant roots may absorb pollutants from water and aqueous water streams. The process that uses the plants to reduce the mobility of pollutants in the environment is called as phytostabilization. Phytovolatilization involves in uptake of the pollutants by plants and release later as volatile substance through transpiration process [15].

8 Selection of Plants for Phytoremediation in Bio-retention Systems

Plants in a bio-retention system often consist of native grasses, shrubs, and trees that are intended to adapt well to the soil and climate of the region. They must also tolerate pollutants and varied depths of water. The plants are intended to uptake water contaminated with excess nutrients. However, plant roots may also provide pore spaces that will provide a habitat for microorganisms, thus promoting biological degradation of some pollutants and predation of other bacteria [8]. Bio-retention systems are intended to remove the typical pollutants found in storm water such as suspended solids, nutrients, metals, hydrocarbons, and indicator bacteria [15].

Therefore, plant selection for a bio-retention system should be conducted in a careful manner. The selected plants should have a great scale of tolerability to various pollutants. Also, the water requirements and water tolerability are there for consideration [71]. In a bio-retention system, there are three layers; lower elevation, middle elevation, and the outer edge [71]. For the lower elevation, the selected plants should have tolerability for higher water level fluctuations. For middle elevation, the plants can be selected based on their ability to grow on normal soil media and also have tolerated flood stress up to some extent. The plants selected for the outer edge should be adopted for drier conditions [71].

It will be more efficient if plant species of different root systems are selected. The roots spread in different soil depths, will filter and absorb pollutants in an efficient manner. The overall root density should be higher to ensure an efficient filtration and absorption processes [71]. Also, it will suppress the weed growth and increase the evapotranspiration ability. Since the bio-retention system also employs large canopy trees, the plants selected for the ground cover should have the capability to thrive under low sunlight [71]. Table 2 depicts the different pollutants and phytoremediation plants that can be used in an urban bio-retention system.

9 Phytoremediation of Pollutants in Bio-retention Systems

9.1 Potential Plants for Phytoremediation of Organic Pollutants

Various plants have been tested for phytoremediation of different organic pollutants. Poplar plant is one such and has been identified as a plant that has the ability to remediate halogenated organic pollutants such as trichloroethylene [14, 72]. Not only in the soil, there are evidences that the poplar tree has the ability to remediate pollutants even in ground water. The *Myriophylum aquaticum* (parrot-feather) has been successfully tested for remediation of perchlorate, 2,4,6-trinitrotoluene, trichloroethylene, chlorinated pesticides, and Atrazine [73]. Bermuda grass, rye grass, white clover, and fall fescue have the ability to remediate total petroleum hydrocarbon [74]. *Juncus subsecundus* is a plant that has an ability to remove polycyclic aromatic hydrocarbons (PAHs) from the contaminated soils [75].

Hence, it can be easily used in bio-retention systems to remediate PAHs in urban storm water. Incorporating PAH degradation bacteria into the system will enhance the process of PAH removal with higher efficiency [75]. Removal of endosulfan, a persistent and toxic organochlorine compound, has been successfully tested with tomato, sunflower, soybean, and alfalfa plants; however, sunflower showed significant phytoremediation capabilities [76]. *Medicago sativa* (alfalfa), *Panicum*

Table 2 Different plant species that can be used for phytoremediation of pollutants in bio-retention systems

Pollutant type		Plant species	Common name	Reference
Nutrients (N, P, NO_3^-, NH_4^+)		*Acalypha wilkesiana*	Copperleaf	[71]
		Arundo donax	Carrizo	
		Sakura variegata	Bougainvillea	
		Bulbine frutescens	Orange bulbine	
		Chrysopogon zizanioides	Vetiver grass	
		Codiaeum variegatum	Croton	
		Complaya trilobata	Yellow creeping daisy	
		Cymbopogon citratus	Serai	
		Dracaenaceae reflexa	Song of India	
		Ficus microcarpa	Indian laurel fig	
		Galphimia glauca	Shower of gold	
		Ipomoea pes-caprae	Beach morning glory	
		Leucophyllum frutescens	Barometer bush	
		Loropetalum chinense	Chinese loropetalum	
		Melastoma malabathricum	Indian rhododendron	
		Nerium oleander	Oleander	
		Ophiopogon jaburan	Lilyturf	
		Osmoxylon lineare	Green araliya	
		Pennisetum alopecuroides	Swamp foxtail	
		Pennisetum advena	Rose fountain grass	
		Phyllanthus myrtifolius	Ceylon myrtle	
		Sanchezia oblonga	Zebra plant	
		Serissa japonica	Japanese	
		Carex rostrata	Bottle sedge	[113]
		Carex appressa	Tall sedge	[114]
			Creeping juniper	[10]
		Aronia prunifolia	Chokeberry	[105]
		Ilex vertiallata	Winterberry	
		Ilex compacta	Compact inkberry	
	N	*Eichhornia crassipes*	Water hyacinth	[115]
	NH_4^+	*Eichhornia crassipes*	Water hyacinth	[116]
	NO_3^-	*Eichhornia crassipes*	Water hyacinth	
	P	*Eichhornia crassipes*	Water hyacinth	
	PO_4^{-3}	*Eichhornia crassipes*	Water hyacinth	
Toxic metals		*Carex appressa*	Tall sedge	[114]
			Creeping juniper	[10]

(continued)

Table 2 (continued)

Pollutant type		Plant species	Common name	Reference
		Betula nigra	River birch	[60]
		Juncus effuses	Common rush	
		Iris pseudacorus	Yellow flag iris	
		Magnolia virginiana	Sweetbay	
		Iris virginica	Blue flag iris	
		Labelia cardinalis	Cardinal flower	
		Juncus effuses	Common rush	
		Hibiscus spp.	Hibiscus	
		Acer rubrum	Red maple	
		Clethra alnifolia	Sweet peperbush	
		Itea virginica	Virginia sweet-spire	
		Chasmanthium latifolium	Wild oat grass	
		Lythrum salicaria	Purple loosestrife	[92]
		Iris pseudacorus	Yellow flag iris	
		Vinca minor	Periwinkle	
		Hippophae rhamnoides	Sea-buckthron	
	Hg	*Jatropha curcas*		[82]
		Eichhornia crassipes	Water hyacinth	[117]
	Pb	*Avena sativa*	Oat	[118]
		Helianthus annuus	Sunflower	
		Elodea canadensis	Canadian Waterweed	[85]
		Potamogeton natans		
		Carex panacea		[119]
		Juncus conglomeratus		
		Phalaris arundinacea		
		Eichhornia crassipes	Water hyacinth	[120]
	Cd	*Avena sativa*	Oat	[118]
		Helianthus annuus	Sunflower	
		Juncus subsecundus		[75]
		Elodea canadensis		[85]
		Potamogeton natans		
		Potamogeton pectinatus		[121]
		Lemna polyrhiza		[122]
		Carex panacea		[119]
		Juncus conglomeratus		
		Phalaris arundinacea		
		Eichhornia	Water hyacinth	[120]
	Cr	*Avena sativa*	Oat	[118]
		Helianthus annuus	Sunflower	
		Eichhornia crassipes	Water hyacinth	[123]

(continued)

Table 2 (continued)

Pollutant type		Plant species	Common name	Reference
	Cu	*Elodea canadensis*		[85]
		Potamogeton natans		
		Dunaliella tertilecta (algae)		[124]
		Carex panacea		[119]
		Juncus conglomeratus		
		Phalaris arundinacea		
		Eichhornia crassipes	Water hyacinth	[125], [120]
	Zn	*Elodea canadensis*		[85]
		Potamogeton natans		
		Fucus vesiculosus		[126]
		Carex panacea		[119]
		Juncus conglomeratus		
		Phalaris arundinacea		
		Eichhornia crassipes	Water hyacinth	[127], [120]
	Ni	*Eichhornia crassipes*	Water hyacinth	
	Fe	*Eichhornia crassipes*	Water hyacinth	[128]
	Mn	*Eichhornia crassipes*	Water hyacinth	
	As	*Eichhornia crassipes*	Water hyacinth	[129]
Organic pollutants	PAHs	*Juncus subsecundus*		[75]
	Naphthalene (PAH)	*Avena sativa*	Oat	[118]
		Helianthus annuus	Sunflower	
	Phenanthrene (PAH)	*Avena sativa*	Oat	
		Helianthus annuus	Sunflower	

virgatum (switch grass), and *Schizachyrium scoparium* have been tested successfully for the removal of PAHs [77]. Hence, these plants may incorporate together with other plants which may improve the efficacy of the bio-retention system for phytoremediation of organic pollutants.

9.2 Phytoremediation of Nutrients

Regarding nutrient removal, the priority has been made for the phosphorus and nitrogen since they are high in concentrations. The plant species used for nutrient removal should have a great ability to uptake higher amounts of dissolved nutrients [78]. Because of the biofiltration process, the salinity conditions can be increased within the bio-retention systems. Therefore, it is important to consider about the salt tolerability of plants before establishing the plants. It is an important factor because salinity can result in growth retardation in affected plants and it can play a negative effect on the whole bio-retention system [78]. Most importantly, halophytes (salt-tolerant plants) have the ability to maintain a great nitrogen and phosphorus removal efficiency, even at salt concentrations similar to sea water [78]. Therefore, it is important to incorporate halophytes into the bio-retention system [78]. *Canna x. generalis* could be an effective plant for phytoremediation of nitrogen and phosphorus and it has a promising ability to remove phenolic compounds. Not only the particular plant, but also the *Canna x.* genera have the ability to improve physical characteristics: color, turbidity, and odor of the water [13]. Table 2 depicts several plant species that can be used for phytoremediation of nutrients in bio-retention systems.

9.3 Phytoremediation of Toxic Metals

Chemical, physical, and biological methods are there to remove different toxic metals from storm water and contaminated soils. Mainly in urban areas, the major source for metals is vehicles and vehicle-related sources [79]. Vehicle emission, vehicle leakage, tire ware, and discharges from service stations are responsible for that. Runoff that generated by roads, parking lots, and service stations bear a number of heavy metal types as well as higher heavy metal concentrations. Vanadium (V), Ni, Fe, Mg, Ca, Cu, Zn, Pb, Cr, Ni, and Cd are mostly found metals with road and parking lot runoff [80, 81]. Due to the presence of various metals, the plant selection should be conducted carefully [46]. For different metals, there are different plant species. Most of the plant species have the ability to remediate several metals. Table 2 depicts the different plant species that can be used for phytoremediation of different toxic metals.

However regarding cost and the environmental impact, the phytoremediation is considered as far more effective in terms of bio-retention [82]. The metal accumulating plants have the ability to remove metals from the soil up to 100 times higher than non-accumulator plants. Studies show that the use of hyper-accumulating plants may enhance the removal rates of metals as 10 mg kg^{-1} for Hg, 100 mg kg^{-1} for Cd, 1000 mg kg^{-1} for Co, Cr, Cu, and Pb, and 10,000 mg kg^{-1} for Zn and Ni [83]. *Jatropha curcas* plant which commonly known as a physic nut has been successfully tested for removal of Hg from contaminated soils [82]. *Jatropha curcas* roots have higher phytoremediation ability than all other plant tissues and the plant has low translocation factor and higher bio-concentration factor. Therefore, it has been recommended as a remediation material for Hg-contaminated soils and water [82]. Although it can be used as a fuel source [84], it may be harmful to use as a fuel source after it has been used for Hg removal.

Juncus subsecundus is a plant that has been used for the removal of Cd from the contaminated soils [75] so that it has a potential to be used in bio-retention systems to remove HMs. *Elodea canadensis* and *Potamogeton natans* are two submerged plant species that have the ability to uptake Cu, Zn, Cd, and Pb [85]. The submerged plants are important in bio-retention systems considering storm water management aspects. An area with overflow water to be stagnated as a modification to the bio-retention system may allow a place for the submerged plants, however this must be managed in a way prohibiting mosquito breeding. Submerged plants are far important due to their ability to uptake metals directly from storm water [85]. This may increase the aesthetic value of the bio-retention system as well. Yet, the management of such water retaining area needs quite a good attention and management.

9.4 Phytoremediation of Other Pollutants

Rather than toxic metals and nutrients, there are many other pollutants present in storm water, however most probably in low concentrations. Textile dyes, surfactants, and detergents are some of them [86]. *Alternanthera philoxeroides* plant has been successfully tested for removal of highly sulfonated textile dye called as Remazol Red. The removal rate is significantly high with *Alternanthera philoxeroides*. There are some identified wild plants: *Phragmites australis, Blumea malcolmii, Typhonium fagelliforme*, and *Ipomea hederifolia* for removal of textile dye from water [87]. Also some common ornamental plants: *Aster amellus, Glandularia pulchella, Portulaca grandifora, Petunia grandifora, Zinnia angustifolia*, and *Tagetes patula* have potential to remove textile dye from contaminated soil [86]. Aquatic macrophytes also reported for their capability to remove dyes and other pollutants. Because of their habits and stress tolerance characteristics, the phytoremediation capabilities are strong [86].

10 Advantages and Limitations of Phytoremediation in Bio-retention Systems

Bio-retention systems are proving to be a promising technology as it relies on the ecological interactions to provide storm water retention and removal of pollutants in a natural system. One of the major advantages in integrating phytoremediation into bio-retention systems is, it is low cost than other remediation methods [14]. It should be noted that the cost on phytoremediation is less than even half of any other remediation method [14]. Also do not need specific dump sites to dispose of these plants. Some are long-term plants while others are mineralizing the pollutants. This mineralization has the ability to cut down the cycling of pollutants. Since the plants enhance the biodiversity, the public acceptance is also high. Therefore, do not need extra awareness programs. Due to its applicability on a far range of pollutants, this approach does not need several remediation methods to remove all the pollutants in storm water [14]. However, a limited number of studies in the tropics, arid and semi-arid regional plants on phytoremediation may be a restraint when a phytoremediation integrated bio-retention system is to be used in such areas.

Due to the high tolerance toward changing hydrological regimes of bio-retention vegetation, these flexible and adaptive systems have the potential to be used in a wide variety of environments and it has been viewed as an attempt to maximize every available physical, biological, and chemical removal processes found in the plant and soil complex of a terrestrial forested community [69]. They can be integrated with urban development while providing at-source treatment.

Bio-retention systems are most often used as an initial runoff treatment system as they detain runoff while contributing to pollutant removal during short pulses associated with precipitation. This may be considered as a limitation as plants may react slowly. Biotechnological advances may provide input to increase the potential of plants to react fast during such pulses. Apart from the storm water quantity and quality benefits, bio-retention systems with phytoremediation integration host other benefits such as improved air quality, reduced noise, increased real estate values, shade and wind cover, as well as the creation of habitat for native wildlife and plant species by improving site aesthetics and the pride of the community [57, 88].

Some identified obstructions to the implementation of sustainable practices are inadequate engineering standards and guidelines; a lack of legislative mandate and institutional capacity; uncertainties in performance and cost and inadequate funding and effective market incentives [6]. As most contractors are not familiar with bio-retention system construction with an integration of phytoremediation, it has led to poor vegetation establishment and improper soil mixture selection or placement [89, 90]. Hence poor construction practices have also been an implementation concern. Though current bio-retention design guidelines require storm water drain within 72 h to minimize mosquito breeding [54], there are certain risks to public health regarding the breeding of mosquitos and other vector diseases as well.

Also, there is a lack of knowledge in the performance of bio-retention systems and the process of phytoremediation in tropical, arid, and semi-arid climates compared to the studies carried out in cold climates [91–93]. Sufficient studies are needed to be performed to generalize the observations under various climates. In comparison to conventional practices, bio-retention systems experience lower marginal costs as these systems promote proactive maintenance [94]. Due to characteristics of a given site and design objectives, construction costs of bio-retention system vary significantly. The costs can even vary, depending on the conducted activities as maintenance requirements are still being established [8]. In addition, the opportunity costs of the space occupied by a particular bio-retention system are substantial but is an often overlooked component [95, 96]. Unless implementation is targeted on a small watershed scale, measuring of the performance enhancements will be very difficult. The inseparable relationship of cost and performance was highlighted through watershed scale implementation. As a result, further research is needed to identify specific cost drivers and proper tools for cost prediction in the long run with an aim to gain extra knowledge on the life cycle costs for bio-retention and phytoremediation.

In recent years, well-developed computer models have provided to develop appropriate guidance by modeling various aspects of bio-retention gardens. Some of the introduced mainstream storm water models are Model for Urban Storm water Improvement Conceptualization (MUSIC) [97] and Storm water Management Model (SWMM) [98, 99]. The used model inputs may often not be suitable as there is a lack of detailed bio-retention performance information for many regions other than the limitations of the models themselves [8]. The United States Environmental Protection Agency (US EPA) developed a decision-support system called SUSTAIN in 2003 for the selection and placement of BMPs at strategic locations in urban watersheds as they have recognized that there was no comprehensive modeling system available to systematically evaluate the location, cost, and type of storm water BMPs [100]. Yet, there is still a need for additional modeling tools to verify the suitability of current guidelines and accurately predict the hydrologic and water quality performance of bio-retention system designs integrated with phytoremediation [88].

11 Summary

Bio-retention systems are one of the most recognized methods at source structural BMP under LID practice that has been utilized to improve the quality of water and mitigate hydrologic impacts due to urbanization. This was first developed in the early 1990s by Prince George County, Maryland, United States. It provided as a mean for treating the 'first flush' runoff from a particular urban area. Over the years, extensive research had been carried out to assess its performance and applicability in the urban storm water treatment and management. Quite a number of field scale studies have been carried out to provide a light in design architecture with an emphasis on water quality goals and hydrological performance [60, 101, 102]. Considering water quality goals and environmental quality, phytoremediation is an important consideration to remediation of pollutants. As the phytoremediation is a low-cost method, it can easily implement into bio-retention systems.

One drawback has been the current design guidelines which are inconsistent across various demographical regions. It is quite evident that geographical factors and the climate influence the performance of phytoremediation in bio-retention system in addition to treatment objectives which also vary with jurisdictions of a particular location. Although there is a wide usage of computational models for simulating the functions of phytoremediation in bio-retention, there has been a noted short coming in each case while aiming for perfection. Hence, there is a growing need for advanced modeling tools to verify the applicability of current guidelines, accurately predict hydrologic performance, and provide suggestions to water quality improvements with an emphasis on pollutant removal. Identification of alternative and favorable conditions for nitrification, denitrification, and phosphorus sorption is also needed. Even there should be an attempt in the bio-retention systems to the optimization of nutrient removal processes beyond field monitoring.

In fact, bio-retention systems are complex structures where there is a replication of natural ecological processes within the system. It has been proven to be applicable as a sustainable and cost-effective treatment practice among the urban storm water treatment and management techniques around the world. As improved performance and design specifications are evolving with continuous research, bio-retention systems and phytoremediation within bio-retention systems should enable learning culture that values integrated urban storm water management while acting as a guidepost for improving urban management practices.

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