Chapter 5
Water Sensitive Urban Design (WSUD) for Treatment of Storm Water Runoff

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Abstract Limited water availability and steadily increasing urban population have resulted in higher water demand, particularly in urban areas. Water scarcity or poor quality can lead to adverse health effects, water-borne diseases, and even casualties if the event is acute. For effective water management, the treatment of wastewater and its reuse plays a crucial role. A substantial volume of water received as rainfall runs off unutilized, contaminating the receiving water bodies in many cases. The first rain scavenges pollutants and flushes contaminants from the catchment making the water non-usable without treatment. Some treatment units like gross pollutant traps (GPT), wetlands, rain-garden, vegetated swales, etc., are the significant components of Water Sensitive Urban Design (WSUD) and can be used to remove the physical-chemical impurities from storm water runoff. These units have been used to remove the suspended/floating impurities, organic load (BOD), nutrients (nitrogen and phosphorus), heavy metals, hydrocarbons, and even pathogens (coliforms). There has been a wide application of WSUD in developed countries, but it is relatively less popular in developing/poor countries due to several factors. India, the second most populous country of the world with only 2.4% of geographical area, receives non-uniformly distributed precipitation (3880 BCM) mostly during 3–4 months of monsoon, and requires a strong and effective WSUD for conserving water. Suitable technique of WSUD can be applied individually or in combination depending upon the quality of runoff and feasibility of treatment. Design considerations such as type of vegetation and hydraulic conductivity of filter needs attention initially before its application. The lower operation and maintenance cost, no energy input, and formation of non-toxic metabolites make it sustainable. An effective

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WSUD not only conserves water, it also favours improved urban hygiene, better air quality, carbon sequestration, and healthy ecology.

Keywords Stormwater · Runoff · Water sensitive urban design · Urban water management

5.1 Introduction

A very limited quantity of freshwater is available to us, hence, it is said that the water will become as valuable as crude oil in the present century, forcing us to think of its efficient management and usage so that water of acceptable quality is available to all and not only to specific group of population (Rezaei et al. 2017). The usage of fresh water is increasing everyday with the increase in population and demand, and when fresh water once used becomes wastewater and it cannot be reused until it is given some treatment. This causes the scarcity of the water for humans, animals, and plants. In past, several studies were also done to estimate the world's water budget. It was estimated that 1338×10^6 km^3 of water is stored in ocean which is salty; and freshwater lakes, rivers, and streams have approximately 0.0072% of world's total stock of water (≈93,000 km^3) while the precipitation on land is of the order of 119×10^3 km^3/year (Shiklomanov 1993). India is the world's second most populous country with approximately 2.4% of the geographic area, and receives annual precipitation of about 3880 BCM (Billion Cubic Metre) (Extraction of Groundwater 2020). The precipitation is not received uniformly in India, making few places receive excessive rainfall and others receive scanty/scarce rainfall. Hence, it can be said that water is deficit in India because of the limited resources of freshwater. Also, the rainfall which is received on earth, first satisfies the infiltration capacity (leading to interflow) of ground, fills the undulations (pits and ditches) on ground and it is affected by land use/cover before it become storm water surface runoff (Wang et al. 2021). Although rainwater is the purest form of water, during the path traversed by runoff, it takes along the impurities and gets contaminated (Pipil et al. 2022). Despite being contaminated, the strength of impurities in storm water runoff is far less than the domestic/municipal wastewater. Therefore, the surface runoff can be treated to make use of storm water most efficiently to reduce the load on the existing water resources and bridge the gap between the demand and supply of the freshwater. Moreover, the annual average temperature is increasing, resulting in the change in the climate and disturbed pattern of rainfall. There is an urgent need to design the water sensitive mechanisms and techniques in order to treat and reuse the contaminated storm water runoff. For this purpose, several techniques and methods are being used in developed countries like United States of America, New Zealand, and Australia, which include gross pollutant trap (GPT), vegetated swales, rain garden wetlands, tree pits, etc. Such techniques have been implemented locally or as a centralized unit in these countries (Beza et al. 2018). These techniques and methods can also be used in India depending upon the prerequisites and requirement of the individual method are satisfied (Hoban 2018).

5.2 Water Sensitive Urban Design (WSUD)

In last few decades, a new method for sustainable water cycle management was introduced in many developed countries, known as Water Sensitive Urban Design (WSUD), and since then, it has been modified by professionals in many other parts of the world till date to achieve more efficiency towards removal of the impurities from stromwater runoff (Argue 2004). There is a wide gap between the developed and developing countries in terms of the development and functioning of such treatment units. The techniques and the methods can be combined with each other to achieve the desired level of pollutant removal. In addition to this, guidelines have been developed over a period of time to plan and design these WSUD units depending upon the local climate, catchment characteristics, environmental and local community considerations, etc. Considering the above mentioned scenario, WSUD can be broadly classified depending upon the functionalities and scale as Household Scale, and Urban Development Scale.

These WSUD can have one or more functionalities and it can also have one or more configurations. Its functionalities include, but not limited to, storm water quality management, flood control, rainwater harvesting, biodiversity, etc. These treatment units can be configured as a stand-alone unit, or combination of one or more units in either series or parallel, or sequences can also be inter-changed, since, it was observed that single WSUD unit are not able achieve the targeted or desired degree of treatment of storm water runoff (Sharma et al. 2018). The storm water quality management and flood control can be achieved by filtration, sedimentation, adsorption, rainwater harvesting, flow volume attenuation, biodegradation and uptake by plants, detention, retention, etc. so that it can find its utility for the purpose of domestic or industrial use, irrigation, ground water recharge, etc. (Argue 2004).

The quality of treated storm water from WSUD units can be classified (Lewis et al. 2015) on the basis of effectiveness and application of treatment as:

- Primary: Removal of floating, suspended ($d > 0.1$ mm) impurities through sedimentation tanks, gross pollutant tank (GPT), trash rack, etc.
- Secondary: Removal of relatively finer suspended impurities by sedimentation and filtration through swales, infiltration basin, porous pavement, etc.
- Tertiary: Removal of dissolved and micro impurities through adsorption and biological degradation, uptake by plants through bio-retention system, wetlands, etc. (Table 5.1).

The criteria on the basis of which a WSUD is selected depends upon the following (Fewkes 2012):

Table 5.1 Functions of various WSUD techniques

WSUD technique	Various functions performed				
	Flow rate reduction	Water quality management	Flood management	Rainwater harvesting	Biodiversity improvement
Gross Pollutant Trap		✓			
Trash Rack		✓			
Swales	✓	✓	✓	✓	✓
Raingarden	✓	✓		✓	✓
Wetlands	✓	✓	✓	✓	✓

– Reduction in total suspended solids (TSS), removal of total nitrogen (TN), and removal of total phosphates (TP).
– Prevention of mixing of storm water runoff with sewer water.
– Groundwater recharge.
– Development of amenities along the WSUD treatment units.
– Prevention of flood by WSUD in urban area.
– Enhancement and improvement of ecosystem and biodiversity with WSUD.

The WSUD methods that have been used in many developed countries along with the mechanism involved, advantages and the limitation are discussed below:

5.2.1 Primary Treatment Unit

5.2.1.1 Gross Pollutant Trap (GPT)

Gross Pollutant Trap (GPT) is a WSUD treatment method in which the floating impurities such as plastics, leaves, branches, and other anthropogenic litter, suspended impurities like sand and silt are removed from the stromwater runoff. The selection of size or number of GPTs depends upon the catchment area from where the runoff will be received by it. Hence, GPT helps in retaining the floating litter and debris from the storm water runoff through screening and it can remove the solids of dia $d > 5.0$ mm through impaction/gravity settling. GPTs can be installed on the existing drainage system that conveys storm water with the objective to prevent the entry of litter into the waterways at the initial stage. Hence, it can also be used as the pre-treatment unit for many other treatment units, such as wetlands (Hoban 2018).

There are various types of GTPs and they all have different mechanisms for the removal of impurities from storm water runoff. They come in various style and configurations such as Trash Racks, Litter Control Devices, Baffled Wall (Fig. 5.1), Circular Screens or Hydrodynamic Deflective Separation (HDS) Devices, Catchpit Grates, etc. Few of these GPT work on sedimentation for removal of suspended impurities through gravitational force, other work on the physical screening

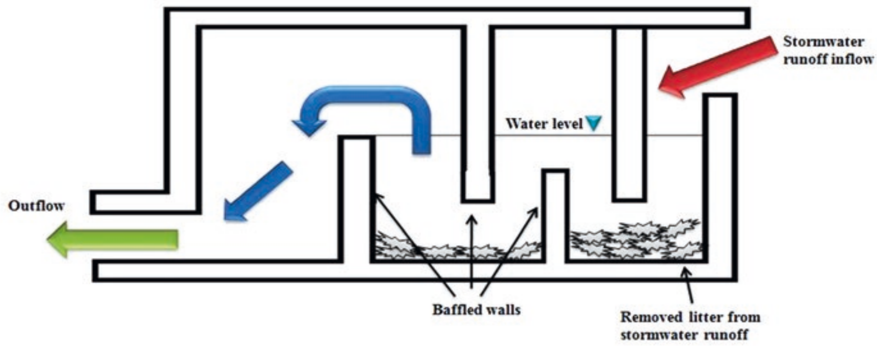

Fig. 5.1 Sectional view of a baffled wall type Gross Pollutant Trap (GPT)

separation, while, HDS works on hydrodynamic of physical impurities using centrifugal force.

5.2.1.2 Trash Rack

It is a type of GPT in which coarse metal screens facing towards the flow of storm water runoff are provided. The screens are made of parallel vertical metal bars with design specific centre-to-centre spacing. It can also be provided with a built-in trash collection unit. It physically removes the floating anthropogenic impurities/ litter like plastics, bottles, paper, newspapers, etc. since, the clear opening between the screens are kept smaller than the trash in storm water runoff, and thus, prevents them from further entering and going downstream into the treatment system. Hence, they are recommended in high litter area and it results in storm water quality management (Hoban 2018) (Fig. 5.2).

5.2.1.3 Hydrodynamic Deflective Separation (HDS)

Hydrodynamic Deflective Separation (HDS) is also a type of GPT is used to separate out the sediments, debris and litter from the storm water runoff through its continuously deflecting system. The incoming storm water runoff is allowed to pass through a system of screens provided at the centre of HDS to separate out the debris and litters, and it is collected at the sump at the centre from where it is removed later on. The incoming storm water runoff is acted upon by the centrifugal force, making a vortex, and treated storm water runoff exits the outlet (Hoban 2018).

Hence, GPT can prevent a significant portion of impurities to enter the downstream treatment units such as wetlands. They do not increase the water level in upstream side since they do not block the flow of storm water runoff. However, it cannot remove the sediments having dia smaller than 5.0 mm. When it reaches the maximum capacity, the trapped debris can be remobilized. Poor maintenance

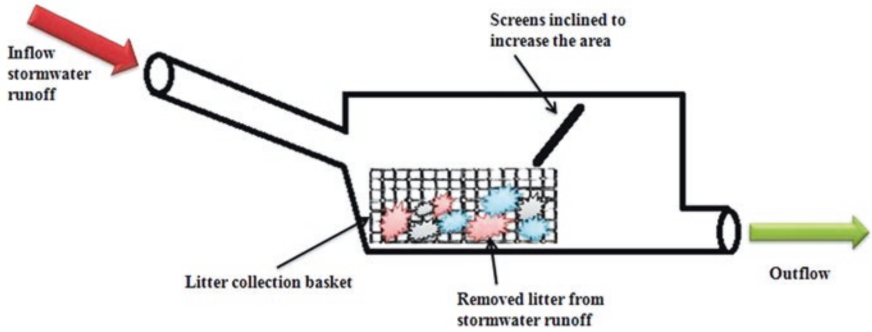

Fig. 5.2 Sectional view of a trash rack

reduces the working efficiency of the trap system and it can increase the pollutant such as phosphorus, nitrogen, COD and TSS in downstream side (Walker et al. 1999). They are usually unattractive and can cause odour problem due to poor maintenance that leads to decomposition of the wet organic litter and anaerobic conditions (Abood and Riley 1997). Its performance depends upon rainfall and runoff characteristics. It can also cause health hazards to the workers handling the waste. In order to prevent these limitations, it is recommended to clean the GTP fortnightly or after 10 mm downpour (Hunter 2001).

5.2.2 Secondary Treatment Unit

5.2.2.1 Vegetated Swales

Instead of providing the pipes to convey the storm water runoff, vegetated swales or bio-swales or swales can be provided along the side of the road. The road acts as the catchment area from where the storm water runoff is received into the swales. They are provided with a longitudinal bed slope of 1–4% in order to carry the runoff to the next treatment unit through a system of underlying perforated pipes or it can infiltrate the storm water runoff to ground through its sides that reduces the cost of laying storm water drains (Bligh Tanner 2014). Flatter slopes can cause water logging, thus, steeper slopes are preferred as they can convey the storm water runoff more easily. The steeper slopes can be balanced with the natural ground slope by providing the drop structures within the swale. They are provided with the bed of sediments and gravels with a suitably selected vegetation species. They can be provided in the road median or next to road shoulder, reducing the cost of land allocation (Fig. 5.3).

The pollutants that are present over the surface of the road over a period of time are flushed with storm water runoff due to cross slope (camber) provided on the road. These impurities enter the vegetated swale where the suspended impurities are removed by filtration due to small voids present between sediment particles

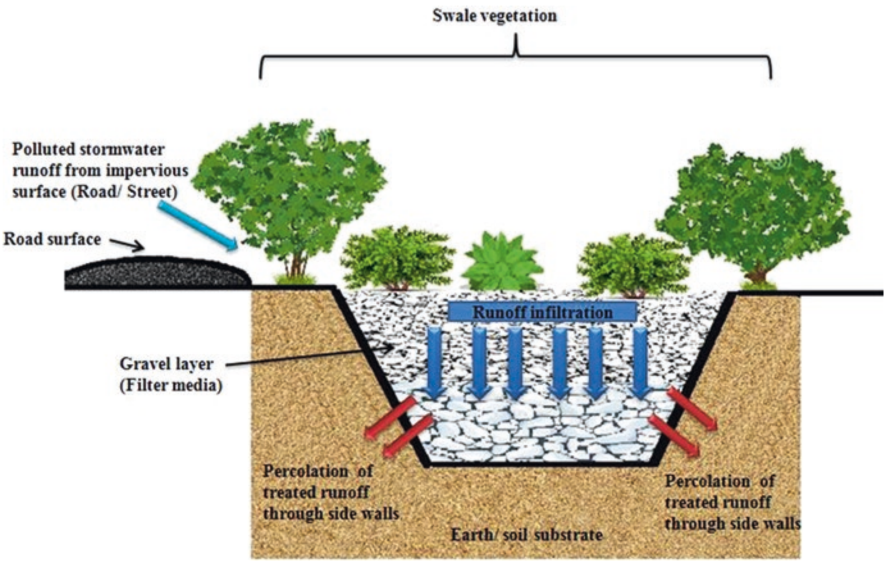

Fig. 5.3 Sectional view of an established Vegetated swale

in substrate bed. Once the voids traps suspended impurities, the filtration is enhanced as the void size further decreases and helps in removal of further finer suspended impurities. The sediments also remove the impurities through adsorption. Vegetation species up takes the dissolved impurities from storm water runoff for their metabolic activity and translocate them in various parts of vegetation (Haritash at el. 2017).

It provides better aesthetics, landscaping and increases the green cover along the roads and streets due to vegetation. They are passively getting irrigated through strom water runoff. The green cover helps in reducing the temperature of the urban area. Its operation and maintenance cost is low (Hoban 2018). It can effectively remove the TSS and TP from storm water runoff (Barrett et al. 1998). In addition to this, it takes more time (≈5 years) for treatment system to get well established and till then it requires more maintenance cost. It generally fails in removing the total nitrogen (TN) from the storm water. Wilting of vegetation can be seen in case of limited supply of the storm water runoff during dry seasons (Lloyd et al. 2002).

5.2.2.2 Raingarden

Raingarden is a type of storm water treatment technique in which the strom water runoff is allowed to enter this system which performs filtration through the media made up of sand and gravel layers; sorption, and denitrification (anaerobic conditions at bottom), etc. Nutrient uptake by plant takes place which has vegetations to suit the local climate (Hoban 2017). The filtered runoff is collected at the bottom of

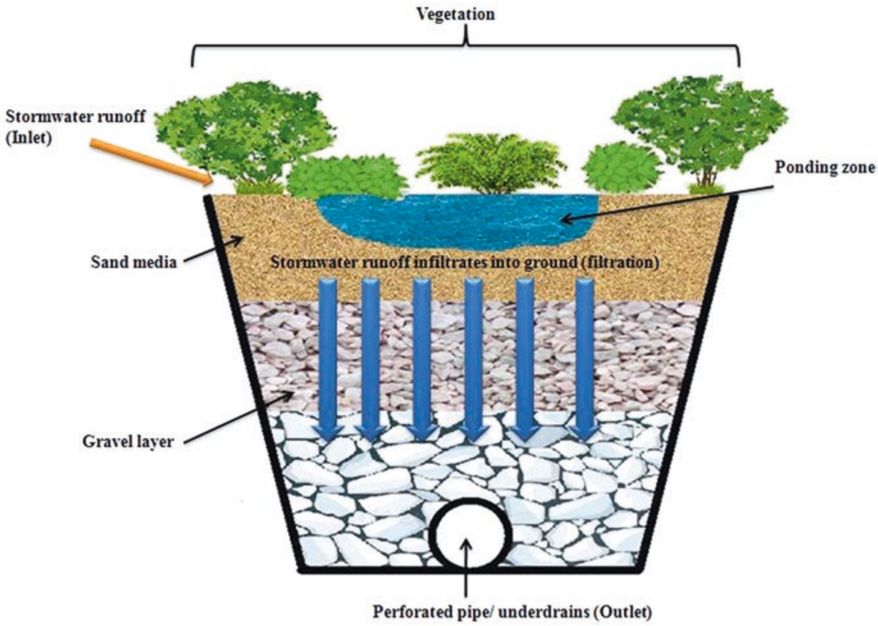

Fig. 5.4 Sectional view of a Raingarden

raingarden through perforated pipes, allowing it to further go downstream towards the next treatment unit. Also, the ponding above the raingarden provides additional treatment to runoff (Fig. 5.4).

The vegetation prevents erosion of the media and breaks media through its growth, thus, preventing the clogging. The vegetation survives with the residual moisture in the filter media during extended dry periods. The filter media allows the percolation of the runoff into ground and prevents flooding and adds to attenuation of flow. Thus, the filter media shall be so selected keeping in mind that its hydraulic conductivity reduces with time and it should be able to hold the water for vegetation growth.

Due to the presence of different type of vegetation, it enhances the aesthetics and landscaping of the urban area, helps in restoring the ecology, and augments the biodiversity. Vegetation prevents the soil erosion caused due to storm water runoff. In addition to this, it removes the pollutants such as phosphates, TSS, and heavy metals from the runoff satisfactorily (Fletcher et al. 2007). However, the filter media gets clogged with time, thus, the hydraulic conductivity of the raingarden reduces significantly with time. Water loving weed herbs can also infest which is unavoidable, and thus, use of weedicide and herbicide can cause further pollution due runoff. The vegetation can experience wilting due to long dry periods and lack of storm water runoff (Hoban 2018).

5.2.3 Tertiary Treatment Unit

5.2.3.1 Wetlands

Wetlands are unique type of ecosystem that remains submerged for most of the time in year, retains the storm water runoff over a relatively larger area and releases the treated water slowly in the downstream direction for further treatment and use. It has shallow depth of water having a wide variety of vegetation which include emergent, floating, or submerged type vegetation. The variable concentration of pollutants enters the wetland with storm water runoff where wetland vegetation acts upon it for its metabolic activities, and also, adsorption of pollutants takes place by sediments present in wetlands. Pollutants are acted upon by removal mechanisms such as sedimentation, filtration, adsorption, biodegradation, and plant uptake (Fisher and Acreman 2004). This helps in reducing the suspended impurities, dissolved impurities, reduces biochemical oxygen demand (BOD) from the domestic and storm water runoff.

Constructed wetlands can be used to remove the pollutants and they have provided the promising pollutant removal efficiency. It has shown upto 86% and 85% of phosphates and nitrogen removal efficiency, respectively, using wetland sp. *Phragmites* and *Canna lily* (Haritash et al. 2015; Nandakumar et al. 2019; Pipil et al. 2021). The nutrients present in the wastewater are taken up by the plant species, moves from root zone with the water for its metabolic activities to other parts of plant and gets accumulated resulting in translocation of nutrients (Haritash et al. 2017). This not only results in change of phase of pollutant, but also, acts as the sink for them and it is not released into the environment.

Wetland can improve the ecology of certain area and it can act as the habitat for various species flora and founa. It can be clubbed with the recreational activities like pathway, resting areas, etc., and hence, it can act as the place for enlightening the community and educate people, professionals, and provides the scope for scientific research. It can improve the aesthetics and landscaping of urban area. It can hold a very huge volume of water over large area that can be used to facilitate irrigation and ponding of water receives further treatment. This water over a large area get pretreatment and percolates into the ground helping the rainwater harvesting function. It can provide the storage at the end that acts as flood routing method and prevents flooding. It acts as the sink for pollutants, such as heavy metals and nutrients from the storm water runoff (Coleman 2007). Wetland also helps in carbon sequestration that removes the carbon from the atmosphere, produces biomass products that can be used for thatching, conserves the soil, etc. However, wetlands remain submerged in water for most of the time, thus, it is susceptible to get attacked by aquatic weeds. It has limited and poor access for maintenance as it remains submerged in water for most of the time. The upstream flow of the sediments and litter cannot be controlled and it enters the wetland (Table 5.2).

Table 5.2 SWOT Analysis of various units used in WSUD system

Type of treatment unit	Strength	Weakness	Opportunity	Threat
Gross Pollutant Trap (GPT)	Operates on gravity, centrifugal force; Does not affect the upstream flow; Expected pollutant removal performance; No energy is required;	Visually unattractive; Litter can remobilize; No removal of sediments smaller than 5.0mm; Poor maintenance leads to poor performance; Barrier to flora and fauna migration;	Better design opportunities; Research opportunity in developing countries;	Organic impurities causes odour problem; Health hazard to person cleaning the trash;
Vegetated Swales	Better aesthetics along the roads; Improved landscape; Improves water quality downstream; Prevents soil erosion; No energy is required;	Takes time to stabilize; Increased cost of maintenance in developing stage; Fails to remove total nitrogen; Reduced hydraulic conductivity causes impurities to bypass;	Various vegetation species can be used in different geographical areas; Can be used successfully in developing countries;	Difficult to retain moisture; Revegetation required after dry period; Hydraulic conductivity reduces;
Raingarden	Improved aesthetics; Attractive landscaping; No energy is required; Prevents soil erosion;	Hydraulic conductivity reduces with time; Storm water runoff can bypass them during high intensity rainfall;	Selection of new species can be identified; Can be used in developing countries;	Difficult to retain moisture in dry period; Wilting of vegetation can be seen;
Wetlands	Improves aesthetics; Augments biodiversity; Carbon sequestration; No energy is required; Improves groundwater level; Prevents flooding;	Larger area is required; Takes time to get fully established; Maintenance is difficult;	Can be used to provide water for irrigation, greenbelt and gardening on downside; Various combinations and configurations can be used in parallel, series or cascade;	Susceptible to shock from toxic impurities; Can be infested by weeds;

5.3 Conclusion

Development of urban environment needs an awakening and awareness not only among the community but also in the local law making agencies for promoting sustainable development in developing countries like India. Water is scarce and treatment of raw water for making it fit for domestic or industrial activity costs hefty money to government, even though not everyone is blessed to get safe drinking water. Along with this, the poor management of wastewater treatment is leading to pollution of freshwater resources. The dependence on freshwater resource can be reduced by making use of stromwater treatment for which the WSUD has been suggested and it is being used by many developed countries. WSUD consists of various types of methods and techniques for the removal of impurities from storm water runoff. All the methods and techniques vary in terms of its objective, application, function, mechanism of removal, and management practices. The selection of WSUD methods and techniques depend upon the local climatic condition and type of soil, slope of ground, local laws of authorities and governing bodies, presence of existing asset on site, etc. WSUD improves quality of the storm water runoff through reduction in floating, suspended, nutrient loading (phosphates and nitrates), and dissolved impurities, and it can prevent the flooding in urban area by providing detention and storage to attenuate the flow which in return helps in increasing the water capacity of the city. The storage reduces the dependence on other water resources for non-drinking purpose, such as irrigation. It also improves the green cover of urban area, helps in providing better quality of life, enhances ecology, and augments the biodiversity in terms of flora and fauna. These independent treatment techniques reduce the load on the existing conventional water treatment system and help in saving the additional cost of storm water drain laying. These techniques and methods do not need any source of energy for their operation and WSUD like wetland can act as the sink for the pollutants proves that the technique is sustainable in its approach. It has been proven effective in many developed countries, and can find a way in developing country like India in coming future.

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References

Abood M, Riley SJ (1997) Impact on Water Quality of Gross Pollutants: Research Report No. 121. Urban Water Research Association of Australia

Argue RJ (2004) WSUD: Basic Procedures for 'Source Control' of Storm water- A Handbook for Australian Practice. The University of South Australia, Storm water Industry Association and Australian Water Association. Sixth printing 2011

Barrett ME, Irish Jr LB, Malina Jr JF, Charbeneau RJ (1998) Characterization of highway runoff in Austin, Texas, area. J Environ Eng 124(2):131–137. https://doi.org/10.1061/(ASCE)0733-9372(1998)124:2(131)

Beza BB, Zeunert J, Hanson F (2018) The Role of WSUD in Contributing to Sustainable Urban Settings. In Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions. Elsevier Inc. https://doi.org/10.1016/B978-0-12-812843-5.00018-6

Bligh Tanner (2014) Review of State Infrastructure Standards. A Report for the Queensland Government Dept. State Development and Infrastructure Planning

Coleman P (2007) Do Storm water Wetlands Affect Urban Stream Health? (Honours dissertation) Monash University School of Chemistry

Fewkes A (2012) A review of rainwater harvesting in the UK. Structural Survey 30(2):174–194. http://www.emeraldinsight.com/doi/pdfplus/10.1108/02630801211228761

Fisher J, Acreman, MC (2004) Wetland nutrient removal: a review of the evidence. Hydrol. Earth Syst Sci 8(4):673–685. https://doi.org/10.5194/hess-8-673-2004, 2004

Fletcher T, Zinger Y, Deletic A, Bratières K (2007) Treatment efficiency of biofilters; results of a large-scale column study. Rainwater and Urban Design:266–273

Haritash AK, Sharma A, Bahel K (2015) The potential of *Canna lily* for wastewater treatment under Indian conditions. Int J Phytoremediation 17:999–1004. https://doi.org/10.1080/15226514.2014.1003790

Haritash AK, Dutta S, Sharma A (2017) Phosphate uptake and translocation in a tropical *Canna*-based constructed wetland. Ecolog Processes 6:12. https://doi.org/10.1186/s13717-017-0079-3

Hoban AT (2017) Facing the MUSIC: a review of bioretention performance. In: 2017 Joint IECA National Conference and Storm water Queensland Conference, 11–12 Oct 2017 Brisbane

Hoban A (2018) Water sensitive urban design approaches and their description. Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions. Elsevier Inc. 25–47. https://doi.org/10.1016/B978-0-12-812843-5.00002-2

Hunter G (2001) Storm water Quality Improvement Devices Issues for Consideration. IPWEA Conference

Lewis M, James J, Shaver E, Blackbourn S, Leahy A, Seyb R, Simcock R, Wihongi P, Side, E, Coste C (2015) Water Sensitive Design for Storm water. Auckland Council. http://content.aucklanddesignmanual.co.nz/project-type/infrastructure/technicalguidance/Documents/GD04%20WSD%20Guide.pdf

Lloyd SD, Wong THF, Porter B (2002) The planning and construction of an urban storm water management scheme. Water Sci Technol. 45(7):1–10. https://doi.org/10.2166/wst.2002.0111

Ministry of Jal Shakti (2020) Extraction of Groundwater. https://pib.gov.in/PressReleasePage.aspx?PRID=1602634

Nandakumar S, Pipil H, Ray S, Haritash AK (2019) Removal of phosphorous and nitrogen from wastewater in *Brachiaria*-based constructed wetland. Chemosphere. 233:216–222. https://doi.org/10.1016/j.chemosphere.2019.05.240

Pipil H, Haritash AK, Reddy KR (2021) Seasonal variability and kinetics of phosphate removal in a *Phragmites*-based engineered wetland. Rend Lincei Sci Fis Nat. 1–7. https://doi.org/10.1007/s12210-021-01017-w

Pipil H, Haritash, AK, Reddy KR (2022) Spatio-temporal variations of quality of rainwater and stormwater and treatment of stormwater runoff using sand–gravel filters: case study of Delhi, India. Rend Lincei Sci Fis Nat. https://doi.org/10.1007/s12210-021-01038-5

Rezaei A, Salmani M, Razaghi F, Keshavarz M (2017) An empirical analysis of effective factors on farmers adaptation behavior in water scarcity conditions in rural communities. Int Soil Water Conserv Res. 5(4):265–272. https://doi.org/10.1016/j.iswcr.2017.08.002

Sharma AK, Rashetnia S, Gardner T, Begbie D (2018) WSUD Design Guidelines and Data Needs. Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions. Elsevier Inc. https://doi.org/10.1016/B978-0-12-812843-5.00004-6

Shiklomanov IA (1993) World fresh water resources. Water in Crisis: A Guide to the World's Fresh Water Resources, P HGleick Ed. Oxford University Press. 13–24

Walker TA, Allison RA, Wong THF, Wootton RM (1999) Removal of Suspended Solids and Associated Pollutants by a CDS Gross Pollutant Trap. Cooperative Research Centre for Catchment Hydrology

Wang Y, Wang S, Wang C, Zhao W (2021) Runoff sensitivity increases with land use/cover change contributing to runoff decline across the middle reaches of the Yellow River basin. J. Hydrol. 600:126536. https://doi.org/10.1016/j.jhydrol.2021.126536