Sustainable Drainage System (SuDs) for Stormwater Management: A Technological and Policy Intervention to Combat Diffuse Pollution

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ABSTRACT

In urban areas management of water is very difficult. Diffuse pollution originates from the catchment area through movement of water. Planning of management strategies and application of pollution control measures can be done only after identifying the sources of diffuse pollution but it is difficult to delineate these sources. Traditional drainage has many disadvantages like run-off can increase the risk of flooding downstream containing contaminants such as oil, organic matter and toxic metals. After heavy rain, the first flush is often highly polluting. The following paper has discussed the role of Sustainable Drainage System (SuDs) for stormwater management. Sustainable Drainage techniques have been developed to collect, store and clean runoff before there release to the environment. The four general design options for SuDs are *filter strips* and *swales*; *filter drains* and *permeable surfaces; infiltration devices* and *basins* and *ponds.* Assessment of diffuse pollution can be addressed using a GIS-model. The problem with SuDs is the area constraint. Moreover rebuilding the drainage in a built-up area is a complex task. Therefore the most pragmatic solution will be mixing both conventional and SuDs. SuDs have lessened diffuse pollution and flooding in Europe, North America and UK but it has to be incorporated to developing world.

KEYWORDS

Sustainable Drainage System (SuDs); Urban drainage; Stormwater management; Filter strips; Filter drains; Infiltration devices and basins and ponds

INTRODUCTION

Unearthing of space for water in a city is important but more significant is to incorporate water in our day-to-day lives so that community can contribute to sustainable drainage. In today's world where water is becoming a scarce resource, there is an urgent need to integrate drainage and surface water management plans to skirmish the problem of diffuse pollution. In urban areas management of water has become a war between water itself, and the urban infrastructure. Some sources of diffuse pollution have been identified at the global scale. A conventional drainage system has many disadvantages. Flooding situation may arise downstream due to increase in run-off which can contaminate water bodies by pollutants like oil, organic matter and toxic metals. The first flush of rain is extremely polluting therefore it is very important to mange it at source itself. Run-off affects biodiversity, amenity value and potential water abstraction.

The following paper talks about the application of Sustainable Drainage Systems (SuDs) for stormwater management. It is an approach to manage rainfall runoff via development that replicates natural drainage along with the policy and technological interventions. The diffuse pollution persists because of the characteristic of sources which itself are distributed in nature. This type of pollution is difficult to monitor, control or regulate. Sustainable Drainage Systems (SuDs) manages surface water run-off. It reduces the risk of flood. It is applicable to rural and urban sites. SuDs techniques allow natural drainage to function in the landscape surrounding development. SuDs use natural features in the landscape to create attractive surroundings which add value to development. The paper will also highlight the need of SuDs for Delhi (National capital territory of India). The following table 1 shows a comparison between SuDs and conventional drainage system:

Table 1. SuDs vs. Conventional Drainage Systems

Sustainable Drainage	**Conventional Drainage causes**
Cost Effective Solutions	Pollution
Easily Managed	Flooding
Resilient in Use	Prevents Groundwater Recharge

Generally filter strips and swales; filter drains and permeable surfaces; infiltration devices and basins and ponds are used to establish SuDs. Assessment of diffuse pollution on a basin scale is difficult which constrains the implementation of SuDs. Development of GIS-based model is must as it can be used in urban diffuse pollution assessment and planning of SuDs. The model can be formulated in a way that it can map the critical locations for diffuse pollution. It should also identify urban or rural areas which pose the supreme peril to beneficial uses of receiving water bodies. The model must also evaluate the impact of land use changes on rainfall runoff quality. Input quality data can be obtained using volume–concentration technique to quantify pollutant loadings. Secondary data also acts as an input for the model and event mean concentration (EMC) can be used for the quantification (Mitchell, 2005).

When compared to conventional drainage system, SuDs provide space within the city. SuDs take drainage as a *disciplinary* mechanism. Combination of conventional drainage systems along with SuDs is the most practical solution to diffuse pollution problem. It will enable us to use less area as well. Other issue related to SuDs is maintenance since distribution of responsibility becomes a difficult task. It is advisable to encourage local people to be more responsive towards minimization of rainfall runoff via different methods of rain water harvesting etc. innovative structure is required to discipline and modify the behavior of water, along with the behavior of society towards water (Jones and Macdonald, 2007).

DIFFUSE POLLUTION

According to D'Arcy *et al.* (2000), non point sources (NPS) of pollution are widespread across a catchment or sub-ctachment and are mainly due to urban and rural landuse activities. Municipal sewage effluent, processed industrial effluents and other discharges do not account for diffuse pollution. Diffuse pollution arises from NPS of pollutants originating from abundant individual negligible point sources. Diffuse pollution or NPS pollution arises from return flow from irrigated agriculture, pastures of animals, run-off from range land, agricultural runoff, rainfall runoff from unsewered and impervious area, wet and dry depositions from atmosphere and runoff from roads and landfill sites. Certain activities like deforestation, wetland drainage, construction, outdoor recreation etc. enhances the extent of diffuse pollution. The extent of diffuse pollution is also affected by climatic conditions, geographic and geologic conditions and landuse type. The first flush of the rainfall is most harmful in terms of concentration of pollutants. The different pollutants arising from diffuse pollution are as follows:

- Suspended Solids: due to urban runoff from arable land and due to augmentation of solids from impervious urban surfaces.
- Nitrogenous and compounds: these compounds are carried from rainfall runoff and are emitted due to vehicles, atmospheric deposition and from agricultural fields.
- Oil, PAHs and toxic metals: arise due to urban runoff from roads etc.
- Biodegradable organic waste: arise from agricultural areas and when animal dung or human feces mixes with the rainfall runoff (Campbell *et al*., 2004).

Water logging problems in major cities of India like Delhi and Mumbai are depicted in figure 1 and 2.

Figure 1. Water Logging Problems in Mumbai, India

Figure 2. Water Pollution of River Yamuna, Delhi, India

Impact of Urbanization

Urbanization has various detrimental impacts on environment. It directly affects the water quality and the available quantity of water. The health risks due to urban run-off quality are shown in figure 3.

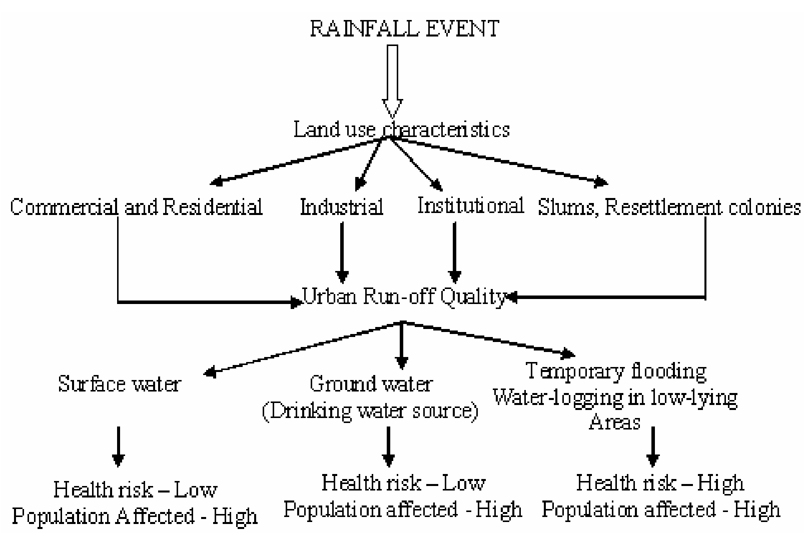

Figure 3. Urban Runoff-Quality and Health Risk (Jamwal *et al*., 2006)

Urbanization influences hydrology of a place by changing the spatial and temporal characteristics of inputs exerted by land surface. Dense urbanization and development like widening of streets, etc. directly affects the groundwater infiltration by making the land impervious. As a result rainfall is converted to runoff. In urbanized areas rainfall runoff is the main source of pollution to the receiving water bodies. In densely and unplanned cities of world like Delhi in India the diffuse pollution occurs due to mixing water from drains carrying urban runoff with the drains carrying domestic sewage before it enters the receiving water bodies.

CONVENTIONAL DRAINAGE SYSTEM

Major cities like Delhi, Mumbai, Kolkata etc in India and other parts of developing countries mainly suffer from the localized problem of flooding and water pollution due to presence of inefficient, unscientific and weakly maintained drainage system. Traditionally surface water that occurs due to rainfall or other activities in a built-up area has been removed using underground man-made pipe systems which were designed and constructed to prevent local flooding by flushing the water away immediately. These drainage systems are designed for specific flow rate of water and thus they are unable capture the fluctuations due to change in the volume the water. As a result pollutants from urban areas are washed into rivers or the groundwater like in the case of Delhi these pollutants enters the river Yamuna which is the only source of water for the city with a population of more than one million. Conventional drainage systems are unable to control poor runoff quality. Community facilities and landscaping potential have been ignored completely while constructing these drainages. Therefore they have been an unsustainable option impacting both the terrestrial and aquatic environments. Groundwater is no longer recharged since runoff is not trapped adequately. It strongly affects the water problem in city like Delhi which is greatly dependent upon the groundwater. A drainage system becomes unstable since:

- Streams are eroded due to increase in the high flow of urban runoff.
- Small streams and lakes are dried and are concentrated with pollutants due to decrease in the low flows (or baseflows) of runoff (NIPC, 1997).

Due to existing problems with the conventional drainage there is an urgent need to follow a holistic approach and to build an integrated approach shown in figure 4.

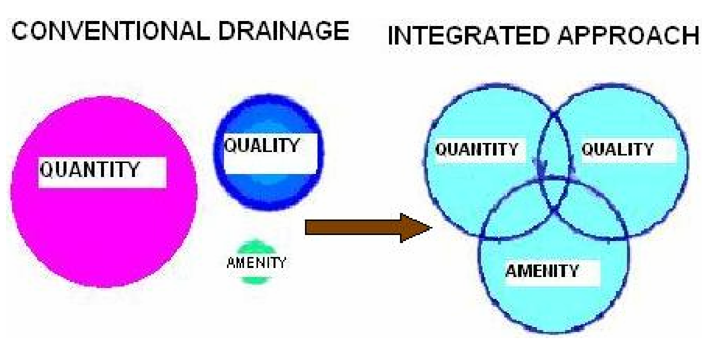

Figure 4. Difference between Conventional Drainage Systems and an Integrated Approach (CIRIA, 2005)

ABATEMENT OF DIFFUSE POLLUTION

Primarily the diffuse pollution can be minimized either by source control methods or by interception of mobilized pollutants. This can be achieved by establishing the treatment systems which includes filter strips and swales; filter drains and permeable surfaces; infiltration devices and basins and ponds. These practices (figure 5) are commonly known as Best Management Practices (BMP's).

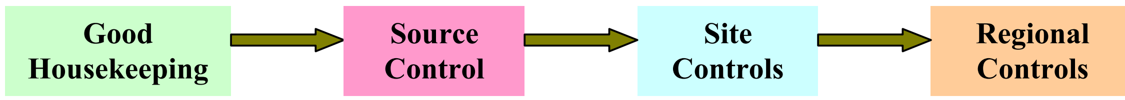

Figure 5. Flow Chart for Urban Runoff Management (Campbell *et al*., 2004)

Other methods incorporate the use of advance hydrological modeling to predict the quantity and quality of urban run-off. These models along with the GIS and remote sensing are useful to map the existing drainage patterns and establishment of the SuDs for the catchment area.

Technological Interventions to Combat Diffuse Pollution

Establishment of SuDs is essential for the densely polluted urban cities like Delhi in India. Sites for implementation of SuDs must be identified in existing built areas (Makropoulos *et al*., 1998). This must incorporate:

Filter strips and swales: Swales are either natural depression or wide shallow ditches which are used to store and route the run-off temporarily. A swale ought to be comprised of a filter strip and is mainly a source control measure. They are used to trap the transfer of pollutants moving from land to the water bodies. In case of Delhi (NCT, India) filter strips and swales can be established along the bank of the river Yamuna since the surface runoff directly pollutes the river. These filters are riparian measures to control the pollution. These strips are area of vegetation for removing sediment, organic matter and other pollutants from the runoff (Campbell *et al*., 2004)**.**

Filter Drains and Permeable Surfaces These must be applied so as to control the stormwater pollution due to urban runoff. For establishment of SuDs application of permeable pavement systems (PPS) are considered a very useful option for residential, commercial and industrial areas (figure 6). The treated storm water from PPS should be discharged into SuDs. Chiefly filter drains and permeable surfaces collect, treat and infiltrate any urban runoff to enhance groundwater recharge, reduction in pollution and recycling of water which otherwise is a waste.

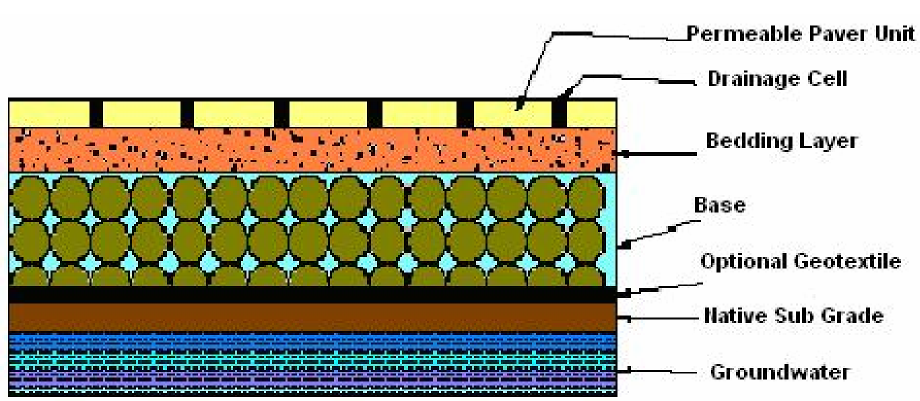

Figure 6. Permeable Pavement System (Scholz and Grabowiecki 2007)

When compared to highway gullies these technologies have high efficiency since they reduces the levels of suspended solids, biochemical oxygen demand, chemical oxygen demand and ammonia in the infiltrate water (Pratt, Newman and Bond, 1999). Mineral oil deposition and hydrocarbon pollution onto urban surfaces have been effectively and efficiently addressed by using these technologies and PPS can also be used as an in-situ aerobic bioreactor (Pindado, Aguado and Josa, 1999).

Infiltration devices and basins and ponds: These can be designed and developed for the treatment of urban runoff. It includes wetland, ditches, ponds and detention basins. Conventional wetlands for stormwater are designed by growing marshy plants and pollutants are removed by biological and physical properties like wetland uptake, retention and settling. After a storm the *detention ponds* are designed to holds water for upto 24-28 hours resulting in settlement of urban pollutants and they should be dried between consecutive storm events. These ponds are also designed to prevent clogging and re-suspension of pollutants (Campbell *et al*., 2004)**.** *Retention ponds* have long retention time (14-21 days). Here the pollutants are degraded and algae/higher plants uptake nutrients. *Stormwater wetlands* have a longer residence time. Its characteristics are similar to that of retention basins with a difference in the emergent vegetation with shallow water zone. Wetland requires larger area so constructing them in built-up area is not a feasible option. *Infiltration basins* are commonly known as 'dry ponds' since they are wet only during rainy seasons. Here pollutants are degraded in topsoil of the basins and degradation becomes slow in unsaturated zones. The area requirements for these technologies are given in table 2. Combinations of these technologies are shown in figure 7.

Table 2. Land Requirements for BMPs*(Campbell *et al*., 2004)

BMPs	Total Area Required Out Of Catchment Area
PPS	No extra land required
Swales	3m more than conventional drainage
Stormwater Wetland	
Of catchment, 50% impervious area	8.25 %
Of catchment, 25% impervious area	5.75%
Retention Pond	
Of catchment, 50% impervious area	3.5%
Of catchment, 25% impervious area	2.5%
Extended Detention Basins	
Of catchment, 50% impervious area	2.5%
Of catchment, 25% impervious area	1.75%

* based upon 60 minute rainfall with depth of 15mm on area having impermeable clay or loam soils.

Advance technologies which can be used to study the diffuse pollution are:

Hydrological Modeling

Before planning, designing and establishing the SuDs, a semi-distributed stochastic model should be used to find out the runoff volume. The *event mean concentrations (EMC)* of stormwater pollution from an urban area should be calculated. EMC is the total mass load of a chemical yielded from a storm. The modelling approach has been adopted for quite a few reasons like volume–concentration methods perform better than regression models and give more accurate load estimates as comparable to, complex build-up and wash-off models. Most common models used for this purpose are HSPF and SWMM. Predicted EMCs from such models can provide sufficient accuracy to inform SuDs planning. EMC for UK region have shown that these concentrations are not correlated with annual runoff volume, thereby simplifying the modelling exercise by ignoring the interactions between runoff volume and pollutant concentration. Many pollutants can be addressed using these models. For modeling concentrations determination of existing landuse type is very essential. The hazard mapping can be done to assess the diffuse loading exposure to receiving waters.

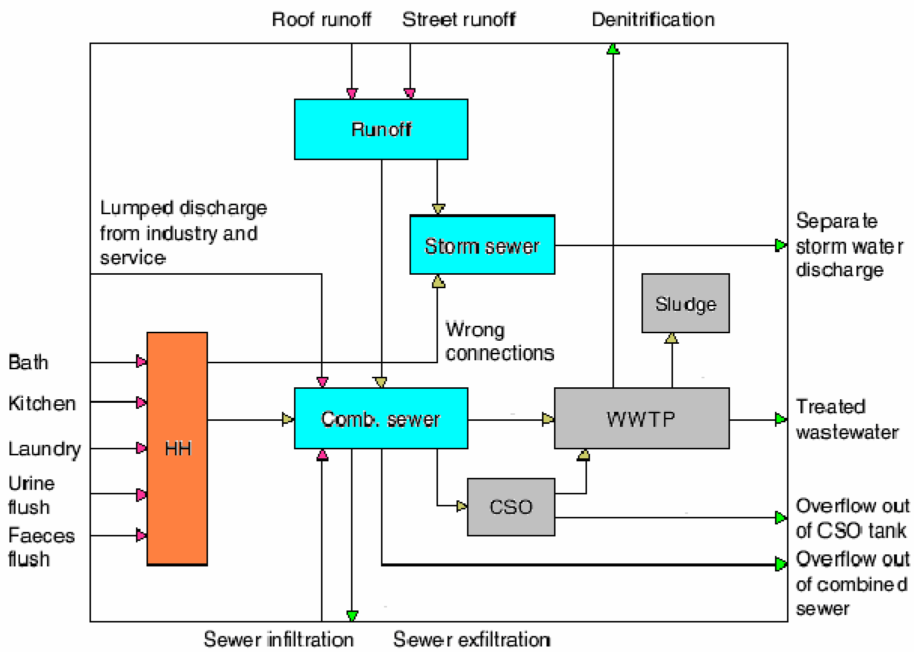

Figure 7. Proposed SuDs for Urban Areas* (Huang, D.B., et al., 2007)
*HH-household, CombSewer-combined sewer, CSO-Combined sewer overflow tank

Remote Sensing and GIS
Annual runoff volume and load modelling, requires the development of extensive GIS database for calculating the prevalent impervious area. This impermeability can be estimated using land use data. Landuse classification can be achieved using remote sensing and GIS technologies. For NCT, India the landuse classification has been done which has shown that more than 50% of the Delhi region is impervious with only 19% green cover (Delhi Development Authority, 2007). This approach is cost effective also. Soil properties also act as an input for developing the landuse pattern of the city. Physico-chemical properties of soil like permeability; infiltration capacity affects the groundwater recharge and should be mapped to find the area under each soil type. Residential density data can be calculated using GIS. Weighted *theissen polygon modelling* is required to generate rainfall maps for the river basin. Mapping of NPS can be easily achieved using GIS (Mitchell, 2005). GIS has the capability to analyze the large area with a high resolution. When choosing the model, special attention should be paid to the possibility of using a verified model which can be easily implemented (Sivertun and Prange, 2003). Management initiatives are achieved through the modeling which control emissions at source within a water quality standards framework. It also provides a basin scale assessment.

Policy Interventions to Combat Diffuse Pollution
Different number of approaches for urban runoff management has been established. Sustainable urban drainage may be achieved by defining and creating principles with limiting constraints. Sustainability must include all three elements of the SuDs, that is, water quantity,

water quality and ecology. Therefore, prime potential sustainability factors to facilitate accreditation of drainage options with regard to capital cost, resource use, performance and maintenance are technical, environmental, social and economic elements (figure 8).

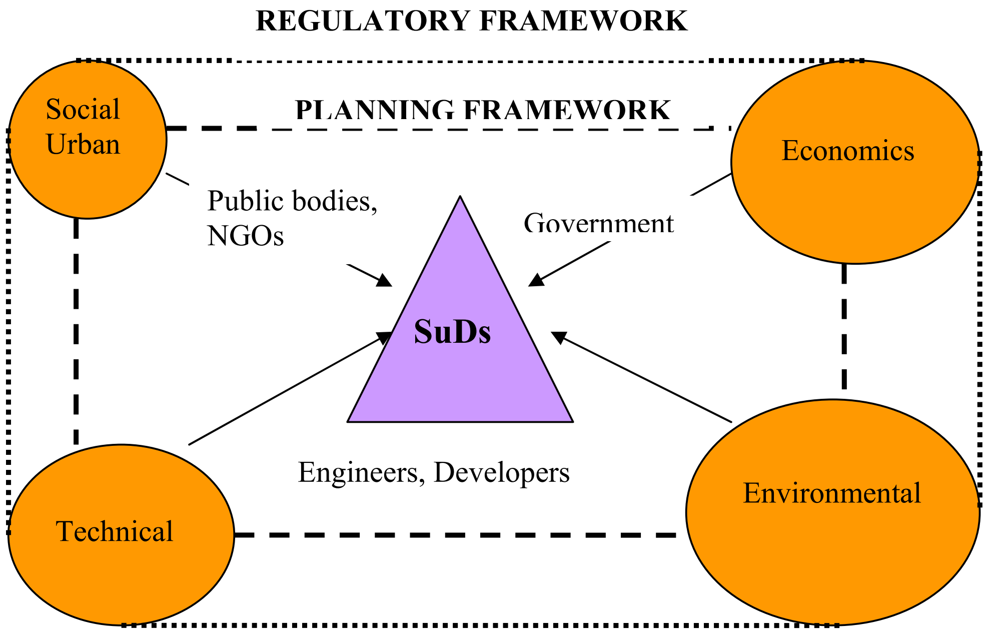

Figure 8. Sustainability and Stakeholders of SuDs (Ellisa *et al.*, 2004)

As indicated in figure 8, the implementation of SuDs involves a variety of stakeholders who are ought to work within a given planning and regulatory framework. Urban source control drainage systems must be evaluated against multi-criteria and multi-objectives placed within an overall decision support framework. Planning of SuDs requires extensive approach to build a *decision support system* commonly known as *DSS*. Table 3 provides a generic listing of criteria for the four polar categories shown in figure 8.

Table 3. Sustainability Criteria for SuDs (Ellisa *et al.*, 2004)

Category	Primary Criteria
Environmental Impacts	Water Volume Impact
	Water Quality Impact
	Ecological Impact
	Resource Use
	Maintenance
Social Benefits	Amenity and Aesthetics
	Public Information and Awareness
	Stakeholder Acceptability
	Health Risks
Technical and Scientific Performance	System Performance
	System Reliability
	System Durability
	System Flexibility And Adaptability
Economic Factors	Financial Risks
	Life-Cycle Costs

Criteria showed in table 3 define SuDs and are flexible and dynamic to be adapted and can meet the ever-changing constraints within differing organizations, regulations and customers. This approach requires a mix of quantitative and qualitative measures, along with the well defined numerical values. The study of environmental impacts using *EIA* is must. EIA lend a helping hand to the policy and decision makers to assess the impacts of establishing SuDs in a particular urban area. Assessment of social and community benefits must be taken into account before designing and establishing SuDs in any urban city of the world. The SuDs should be technically sound and must be maintained properly. Lastly cost-benefit analysis is required. SuDs economics must incorporate *operation and maintenance O&M* cost. *Life cycle assessment (LCA)* should be done before development of these SuDs.

SuDs IN DELHI, INDIA

Delhi being capital of India is a highly urbanized city with a population density of approximately 9000 person per km^2. It has conventional drainage system. It is comprised of stormwater drains along road sides which collect the stormwater and convey it to the larger drains carrying domestic sewage. Thereafter wastewater is released to river Yamuna after partial treatment. This tradition has been followed for many years and therefore has resulted in heavy pollution in river Yamuna. The treatment plants are designed for sewage capacity only and the stromwater adds extra burden to these plants. As a result the water remains either partially treated or untreated and ultimately pollutes the only source of water to the city, river Yamuna. The stormwater drains have not been maintained therefore there is a lot of infiltration of polluted stormwater into groundwater as well. Thus there is an urgent need to develop SuDs for the city.

It is very difficult to establish SuDs in an urbanized city like Delhi, India. After developing land-use pattern for the city using GIS and remote sensing it was found out that there is no space available in the city to develop a new drainage pattern. Therefore it is mandatory to follow an integrated approach where engineers and planers must develop SuDs along with the existing drainage patterns in the city. From the GIS study it was also found out that another option is to develop filter strips, ponds, basins, swales etc. near the bank of the river Yamuna since wastewater from the agricultural land pollutes the river directly. For Delhi city the EMC's of different physico-chemical stormwater pollutants have been estimated for different stations. Landuse classification using GIS and remote sensing has been done. The next step is to study in detail the existing drainage pattern of the city and to locate the hot-spots for establishment of SuDs. In NCT, India for different scale, diffuse pollution problem can be tackled using following methods:

- Source Control: constructing the filter *drains, strips, infiltration trenches, PPS, soakaways* and *swales* are required.
- Site Controls: *Detention basins, filter drains, infiltration basins, soakaways* and *swales* can be established.
- Regional Controls: The treatment facility under this type of control incorporates *retention ponds, stormwater wetlands* and *enhanced extended detention basins.*

SCOPE OF SuDs IN URBAN AREAS

It can be seen that there is a lot of scope to do work in this aspect of water pollution. The immediate task is to find out EMC's of pollutants in stormwater. Thereafter a GIS mapping of existing drainage pattern is required. NPS modeling should done using stormwater models like SWMM, HSPF, and SWAT etc. Planning and development of SuDs is to be done in a way that existing drains should be utilized as well. An integrated approach is the only solution to tackle the intense problem of diffuse pollution.

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