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Green Infrastructure: An Approach to Urban Stormwater Management

E. Lalitha Reddy¹, Sameer M Deshkar².

Consultant Urban Planner, M. Tech- Urban Planning, Dept. of Architecture and Planning, Alumna of VNIT,
Nagpur, India¹.

Assistant Professor, Dept. of Architecture and Planning, VNIT Nagpur, Nagpur, India².

ABSTRACT: “When there is a choice of Green, why to choose Grey”. Storm water runoff has become an unmanageable issue over the past years. As urbanization is taking its pace in the recent decades, the permeable area available within the urban areas is decreasing exponentially with the increase in built area. Changes in land use have a major effect on both the quantity and quality of stormwater runoff. If the impacts of urbanization are not planned and managed properly, natural hydrology of an area experiences a drastic change in its original form. Increased impervious cover decreases the amount of rainwater that naturally infiltrates into the soil and as a result, increases the volume of stormwater runoff. The rising rate of urban storm runoff and its management is demanding a solution to be addressed. Green infrastructure helps in answering these issues both quantitatively and qualitatively by capturing rainwater, either storing it for future use or allowing it to percolate into the natural vegetation to improve the groundwater levels. The whole research has been divided into 2 parts where the first part concentrates on deriving the parameters that can be considered while planning “Green Infrastructure” and the second part of research is on analyzing these parameters and on implementing green infrastructure on the basis of derived parameters. This paper outlines a small piece of research on arriving at the parameters that are to be considered while planning green infrastructure and various ways to integrate Green Infrastructure into present physical/grey infrastructure via Sustainable Drainage Systems (SuDS) in both policy making and designing.

KEYWORDS: Green Infrastructure, Grey Infrastructure, Urban design, Urban Planning, storm water management, Sustainable Drainage System (SuDS), Urban areas.

I. INTRODUCTION

“Cities are the summation and densest expressions of infrastructure. Or, more accurately, a set of infrastructures, working sometimes in harmony sometimes with frustrating discord, to provide us with shelter, contact, energy, water, and means to meet other human needs”(Herman 1988). Infrastructure is the backbone for survival and progression of cities. Enhancing capacity of basic urban infrastructure has always been a priority for ensuring a higher quality of living within the urban local bodies. However, much of the infrastructures in use today was designed and constructed decades ago. Many of these infrastructure systems are vulnerable to a variety of anthropogenic or natural disruptions. Among all natural disasters, Indian cities often have a problem of floods. The rainfall in India shows great temporal and spatial variations, unequal seasonal distribution and geographical distribution and frequent departures from the normal` (M. Monirul Qader Mirza 2003). As per the data of National Flood Commission of India (Rashtriya Barh Ayog), the total flood affected area in the country in 1978 as 33.516 mha, in 1980 as 40 mha and that of 2010 is 49.8 mha (Planning Commission 2011). Over the past 32 years, the area under flood affected zones has been increased by 13 million hectares. The increase in rainfall intensity demands adequate infrastructure to accommodate the excess runoff. As commonly observed, towns and cities of India are visibly deficient in the quality of services they provide, even to the existing population (HPEC 2011). The deficient urban basic infrastructure situation often leads to unhealthy and unhygienic living conditions and it also adversely affects the economic productivity and efficiency of urban centres. As

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a result of the increasing gap between the demand and supply, cities today face a severe shortage of water supply, sewerage, and drainage, housing and transportation network, and many other.

By and large, many cities in India including the metropolitans do not have a proper storm water drainage network. It is often observed that even a conventional rain can freeze the transportation network. The existing plight of the drainage system can be attributed to the unplanned expansions of the cities and often take over valuable 'water sink' regions and lakes with total disregard for the existing natural system. The city's population, housing levels, infrastructural advancements have been escalated over the past century whereas the increase in storm water network has not reached the required demand. On top of that, poor maintenance of existing infrastructure is decreasing its efficiency and unregulated construction activities resulting in storm water congestion. As a result of all the above, water-borne diseases break out during the monsoons and the low lying regions and low-income groups are the first hit. Today, management of stormwater runoff became a serious issue as the conventional methods are failing to capture the generated storm water and grey infrastructure is also failing to address stormwater runoff pollution. In spite of all these, cities are relying only on conventional techniques and making the situations even worse.

In the wake of rapidly changing natural environmental conditions, developing grey infrastructures will have long-term negative environmental impacts. Building infrastructure not only disrupts the local ecosystem but also ends up in consuming extensive physical resources and energies. This mode of development already confined cities within the loop of production and consumption for decades together. Though the concept of eco-efficiency, which is concerned with maximizing the value of goods and services while minimizing resource consumption and environmental impacts, is being advocated, the integration of eco-efficiency principles into urban infrastructure management is yet not a reality in developing nations. Urban rivers are carrying the cities sewerage and Ecologically Protected Areas are being converted into concrete jungles. Environmental management is an important aspect of urban infrastructure provisioning but most often is neglected and ignored. Under these conditions, green infrastructure at urban scale has to be considered as an alternative for the conventional grey infrastructure.

II. LITERATURE SURVEY

"Green infrastructure" is a term that is appearing more and more frequently in land conservation and development discussions around the world. Green infrastructure is defined as an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations (Mark A. Benedict 2001). Green infrastructure (GI) is a network of decentralized storm water management practices, such as green roofs, trees, rain gardens and permeable pavement, that can capture and infiltrate rain where it falls, thus reducing storm water runoff and improving the health of surrounding waterways (Joe Grant 2010). The typical elements involved in these infrastructure systems are observed to be open spaces, green roofs, tree planting, bio-retention & infiltration, permeable pavement and water harvesting.

Green infrastructure is a cost-effective and resilient approach to stormwater infrastructure needs that provides many community benefits. By incorporating "green infrastructure" practices to control stormwater runoff, communities and property developers can reduce energy costs, diminish the impacts of flooding, improve public health, and reduce overall infrastructure costs. In addition, these practices, which rely on natural processes like evaporation, infiltration, and plant transpiration, can effectively and affordably complement traditional "grey" infrastructure, giving storm water managers the ability to create integrated solutions (Odefey 2012).

2.1 Benefits of Green Infrastructures

Green infrastructure provides a multitude of economic, community and social, climate change, environmental, health/well-being and place making benefits. These benefits majorly involves Ground water recharge, Surface water purification, Stormwater retention, Reduction of combined sewer overflows, Decomposition of waste, Pollination, Soil protection, Reduction of airborne pollutants, Summer cooling of buildings, Reduced urban heat island effect, Improved energy efficiency at the building scale and community scale, Climate change mitigation, Support for biodiversity, Improved ability to adapt various impacts of climate change, Contribution to the beauty and livability of communities, Creation of green jobs, Reduced health care costs because of active recreation opportunities, air and water quality improvements, etc., Opportunities for interaction with nature and associated psychological benefits, Reduced noise pollution, Improved marketability of physical assets, Increased tax revenue from improved property values, Capital and

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operational cost savings for traditional grey infrastructure (green infrastructure investments extend the life of grey infrastructure).

Apart from the theory of benefits that Green Infrastructure is offering it is equally important to understand the practical applications of these benefits in the real world. For example, if the practice of green roofs is analyzed then there are considerable chances for reducing water treatment needs, on the other hand, it does not have any implications on the increasing or decreasing of underwater recharge. Similarly, if the case of bio-retention and infiltration is taken, it may or may not increase the available water supply but it tackles the urban heat island problems.

2.2 Challenges for GIs:

In spite of having triple bottom-line benefits offered by Green Infrastructure, the process of adoption is still slow. Using green infrastructure in urban storm water management is not a relatively new or innovative approach. There are cities that have enacted storm water regulations on a huge scale and policies long back to encourage the green solutions, many cities experimenting with the concept of GI to understand the adaptability and feasibility into the existing and new developments. Barriers can appear at various stages in various forms, depending on the scale, watershed areas, community, and socioeconomic context.

Technical barriers: Several experimentations of introducing GI into grey infrastructure have displayed convincing positive results in terms of environmental, social and economic aspects. Even after observing those results GI could not come into the lime light because of lack of sufficient technical support. Lack of proper knowledge in terms of implementation and expertise in maintenance stood as one of the major barriers to the implementation and maintenance of GI. Lack of design standards, performance sheets, precise estimation and costing details, lack of skilled man power in private and government departments and documented records in terms of maintenance guidelines are observed to be the technical barriers in detail.

Managerial barriers: Unlike Grey infrastructure, GI takes its time to integrate with the surrounding nature and there by increases the maintenance requirements till its integration. Maintenance and management activities are crucial for the success rates of GI, but it is not that easy because every site has its own potentials and a GI has to be designed for the same. Unlike grey infrastructure GI cannot be standardized and implemented where ever necessary. In addition to the designing and implementations, its maintenance also demands the expertise in the field. This barrier can simply be categorized into 2 broad spectrums:

1. Lack of expertise for the maintenance of GI.
2. Lack of organized structure within the department to take up the operational and maintenance responsibilities.

Financial constraints: GI has long term benefits and also requires continuous allocation of funds for the maintenance. Lack of sufficient funds with the government and financial crises is always a barrier to any new technological adoption. Not only funds but also lack of incentive based programs and policies also discourage the implementation of GI.

The institutional barrier: Out of all other barriers, the institutional barrier is observed to be crucial in the society than the three other categories. Some of the identified institutional barriers are like fragmented regulatory framework i.e., inconsistencies in policies and programs across multiple jurisdictions within a single watershed, fragmented regulations in agencies across central, state, local levels, and uncoordinated work between multiple government departments and agencies. Lack of public awareness, motivation, and resistance to change impede wide implementation of GI by discouraging the public and municipalities to accept the importance and reliability of GI in urban storm water management.

2.3 Integrating Grey and Green Infrastructures

When the Green infrastructure is serving all the functions of grey infrastructures effectively then why to consider concrete as an alternative to green. *“When there is a choice of Green, why to choose Grey”*. Various elements of GI can serve the purpose of fulfilling the physical requirement and in addition to that, it also helps in fulfilling various secondary benefits as it is closely connected to nature and everything is inter-related. However, when the components of GI are linked together with existing physical infrastructures additional combined benefits can be achieved at a strategic level. On disintegrating the above objective, it is important to study how the elements of GI will integrate with existing roads, paths and surrounding development i.e., either by modifying the existing or by creating opportunities for easy access to the green network including accessible paths in the right places and suitable locations. (Green Infrastructure: Design and Placemaking 2011) Making it easy to access will encourage residents and workers to use the green networks for short distances rather than using cars, helping reduce emissions and promoting active lifestyles. The

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change from grey to green is easy and can achieve transformational changes with simple and practical measures. For example, normal bollards which are used as a part of traffic slowing measures can be transformed with street trees which can serve the same purpose and they even add landscaping feature. Similarly, instead of an impervious concrete layer, footpaths can be modified with pervious members and still serves the same purpose.

SuDS is an approach to surface water drainage consisting of a sequence of water management practices and a sequence of facilities. These mimic natural drainage using natural materials and will provide a more sustainable approach than what has been the conventional practice of routing runoff through a pipe to a watercourse (Surface Water Drainage and Sustainable Drainage Systems (SuDS) 2015). Simply the system which considers quantity, quality, amenity issues are referred as Sustainable Drainage Systems (SuDS). These drainage systems are more sustainable than traditional systems as they control the flow rate of surface run-off, reduce the impact of urbanization, protect and / or enhance water quality, give consideration to the natural environment and community needs, create new wildlife habitats along the watercourses and promote natural groundwater recharge. This sustainable approach to urban drainage is a success because the systems aspire to deal with surface runoff at the point of which it occurs and to manage potential pollution at its source. The philosophy behind SuDS is to mimic natural drainage processes, remove pollutants and manage flood risk at source, whilst acting as a significant contributor to biodiversity. The SuDS approach to drainage includes a wide range of methods. As a consequence of this, there is no correct drainage solution for a site. In the majority of occasions, a combination of techniques results in best practice. SuDS techniques can be divided into four categories; Control of rainwater at the source, Infiltration trenches and filter drains, Swales and basins and Ponds and wetlands. Along with the SuDS technique, it is essential to understand their integration with various land use patterns, i.e., in a particular land use which type of technique can be installed.

Table 1: Integrating various techniques of SuDS with Land Use.

	Residential	Commercial/ industrial	High density	Retrofit	Contaminated site
Green roofs	✓	✓	✓	✓	✓
Rain water harvesting	✓	✓	✓	✓	✓
Permeable pavements	✓	✓	✓	✓	✓
Infiltration trenches	✓	✓	✓	✓	✗
Filtration drains	✓	✓	✓	✓	✓
Swales	✓	✓	✗	✓	✓
Basins	✓	✓	✗	✓	✓

(Source: Guide to Sustainable Drainage Systems, published by South Hampton City Council).

Table 1 gives the possibility of installing a particular technique of SuDS technique in a given land use. This clearly shows that the technique of Green Roofs can be integrated into a structure irrespective of its land use whereas the techniques such as Swales and Basins cannot be integrated into High-density areas as the availability of area is already minimum and these techniques require a considerable amount of area for the installation.

III. METHODOLOGY OF CURRENT RESEARCH

Methodology deals with the analysis of various parameters which helps in assessing the potentials of an area for infilling green infrastructure into storm water management. Considered parameters are Land Use, Efficiency of stormwater network, Density, Percentage of open areas and Area covered by storm water network

3.1 Land use

Pertaining to the scope of implementing GI, Land use has been categorized into residential, commercial and transportation.

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a) Residential Land Use Impervious Surface Coefficients (ISC):

Office of Environmental Health Hazard Assessment (OEHHA) under Environmental Protection Agency (EPA) has considered Impervious Surface Coefficients as a tool for environmental analysis and management. ISC is calculated by the Density (is the number of dwelling units per acre (du/acre)) is treated as a variable. In figure 1, as density increases to about 10 du/acre, IC also increases. Above 10 du/ acre, the amount of buildable land becomes limiting, and additional units are obtained by building up rather than out. This is the reason that the regression relationship begins to plateau at high-density levels. The equation used to calculate the ISC for each residential land use type is: $y = -.02304 + .04961(x)^{0.2196}$. To determine the ISC for any category, the typical densities for each Residential Land Use Categories (LUC) for x are substituted and y can be calculated accordingly, y is nothing but the impervious surface coefficient.

THE REGRESSION EQUATION TO FIND RESIDENTIAL ISC

Calculate the ISC for any residential area using equation for

$$ISC = -.02304 + .04961 (x)^{.2196}$$

Where x = density [dwelling unit / acre]

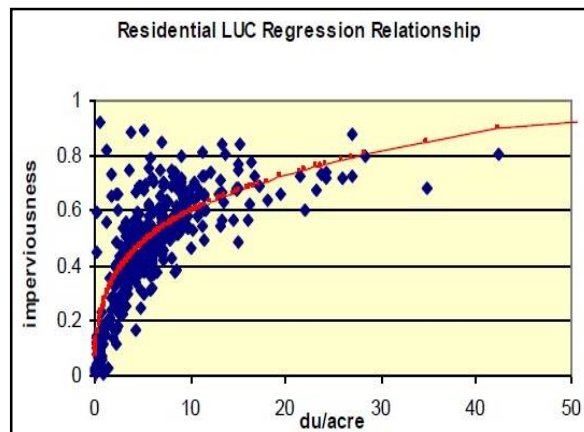


Figure 1: Residential LUC Regression Relationship(ISC Fact sheet, EPA, California)

Observation:

Figure 1 shows that the adoption of Green Infrastructure is favourable in low density. On using the above equation, for low density residential (LDR) with 6 du/acre, $ISC = -.2304 + 0.4961 (6)^{.2196} = .51$ or 51 %.

For medium density residential (MDR) with 12 du/acre, $ISC = -.2304 + 0.4961 (12)^{.2196} = .63$ or 63%.

The percentage of pervious land cover decreases as the density of dwellings increase.

b) Commercial/ General Land Use Impervious Surface Coefficients:

Commercial Land use is further classified into 10 subcategories. Such as Agriculture, Retail, Retail/Office, Office Parks, Urban office, Heavy Industrial, Light Industrial, Mixed Use, Open Space, public/Quasi-Public. Public/Quasi-Public is based on ownership, not actual land use, so there can be significantly more variability in the amount of IC on these parcels.

Of the above-listed categories, only a few categories were highlighted in Table 2.

IC can be calculated using: $IC = [\text{area of LUC}] \times ISC$

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Table 2: Land Use vs corresponding ISC.

LUC	ISC%
Agriculture	4
Open space	2
Public/Quasi- public	50
Office parks	69
Industrial	85
Mixed use	80

(Source: ISC Fact Sheet, EPA, California, 2008)

Table 2 explains the applicability in major categories along with their amount of imperviousness. This explains impervious surface coefficient in an agricultural land is as low as 4%. This shows that the agricultural fields have highest percolation rate whereas when the Industrial area is concerned, it will have very limited area accessed to natural percolation and so do the highest Impervious Surface Coefficient.

c) **Road Impervious Surface Coefficients:** The imperviousness of the three key non-highway road types: locals, collectors, and arterials, and their frequency in the 3 major development environments: urban, suburban, and rural areas, was determined.

For example: **urban ISC = [(ISC for local roads * frequency of local roads in urban areas) + (ISC collectors * frequency of collectors) + (ISC for arterials * their frequency)] / 3.**

The data from each community were averaged to arrive at a final ISC.

Table 3: ISC for various road types

Frequencies	Highways	- 50%
	Urban	- 92%
	Sub Urban	- 96%
	Rural	- 47%

(Source: ISC Fact Sheet, EPA, California, 2008)

Table 3 explains Impervious Surface Coefficients pertaining to various road types. The table shows that highways are more pervious in nature compared to Urban and Sub Urban areas. The presence of huge buffer areas along the highway stretch justifies the value of ISC for Highways. Whereas the urban and Sub Urban areas are compacted with built up spaces and public transportation network which directly decreases the amount of pervious layer within.

d) **The significance of ISC:**

ISCs are used to determine the potential impacts of new developments on the environment. With the proper knowledge of this coefficient, the area of imperviousness can be decreased and environmentally sensitive areas can be protected. The coefficient helps in reducing both air and water pollution. This also helps in achieving carbon credits if implemented at larger scale.

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3.2 Efficiency of Storm Water Network

Few parameters have been identified to understand their relations with GI. These parameters will help in understanding, resolving and choosing the places to start up the SuDS. Storm water frequency, Time of concentration and discharge, Land use, Density, Percentage of Open area, existing storm water drainage network and the relation between green and grey are the parameters considered. These parameters act as layers while designing the urban landscape. In the later stages, regression analysis is carried out to understand the influence of individual parameters on the GI.

3.2.1 Storm Frequency:

Storm water collecting drains usually have longer service span compared to any other infrastructure service. Drain lines which are laid earlier are going inefficient in handling the extra loads as their capacities are limited and designed to certain loads. Once installed, it is very expensive to augment these lines to meet the frequencies time to time. Unlike green infrastructure, grey degrades with time. Consequently, the design flood frequency for projected hydrologic conditions should be selected to meet the need of the proposed facility both now and well into the future. Most state highway agencies consider a 10-year frequency storm as a minimum for the design of storm drains on interstate and major highways in urban areas. However, caution should be exercised in selecting an appropriate storm frequency.

3.2.2 Time of Concentration and Discharge:

Time of concentration is the time taken by storm water to travel from the furthest point to the collecting point within a catchment. It is calculated as the sum of travel time taken by on ground flow and travel time of rain water in street gutters, storm sewers, drainage channels, small streams and other conveyance systems. As per ASCE Code of Practice (77, 1993), Time of concentration can be calculated by the following equation.

The equation of IDF curves is expressed as:

$I = A / (t_c + B)^c$ where I = intensity of rainfall in mm/hour

t_c = time of concentration in minutes for the cumulative drainage area to the point of interest.

It is important to notice that, Time of concentration is dependent on various factors such as size and shape of the drainage area, slope, type of surface, Land Use of a particular area, the intensity of rainfall, and whether the flow is overland or channelized.

$$t_c = \sum (t_{\text{overland}} + t_{\text{shallow}} + t_{\text{concentrated}})$$

Further, overland flow travel time, shallow travel time and concentrated travel time depend on Flow length, Rainfall rate, and Average slope.

3.3 Density and Storm Water:

The age old myth of higher densities will end up in higher imperviousness is proved to be wrong by Environmental Protection Agency. It is understood that higher density does not necessarily mean more impervious surface, multiple units in a compact arrangement may reduce the building footprints and thus result in less impervious coverage (per unit) than stand-alone units dispersed across the landscape. Similarly not all "pervious" surfaces are equal – many disturbed surfaces that appear pervious (like lawns) may be compacted, which greatly reduces their ability to infiltrate the runoff. Low - density development often requires more off – site impervious infrastructure (such as roads, parking lots, etc.). The rule of thumb says that 10% impervious cover will impair a watershed should be assessed on the scale of the watershed and not on the individual site. It is said that low-density development does not reduce impacts, it just spreads them out. From this discussion, it is clear that not always low-density development favours the installation of green infrastructure and high-density settlements offer fewer chances. The percolation of storm water or the installation of green infrastructure is dependent on the amount of pervious area that is available and not completely on the density of settlement.

3.4 Percentage of Open areas:

Percolation of the storm water in parks and open spaces depends on the amount of land available and the percolation value of the place.

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$$\text{Percolation value} = \frac{\text{(time taken to soak away)}}{\text{(Depth of water)}}$$

More the value of percolation value more will be the chances of GI installation.

3.5 Area Covered by Storm Water Network:

Within total catchment area, the area which is covered by existing physical infrastructure and not covered by physical infrastructure gives the scope of further development. Less the coverage of grey infrastructure gives more scope to integrate the green into the system. Further, the area without storm water line is dependent on the percolation/infiltration capacity of soil and that Infiltration capacity depends on the time taken to soak away and depth of existing ground water table.

3.6 The relation among Green and Grey Infrastructure:

Sizing of grey infrastructure is dependent on soil infiltration capacity. This is dependent on percolation rate of soil "**4% rule**". The favorable value of infiltration capacity of the soil is to in-between 5-10 inch/hr. This rule says that if the percolation capacity of the soil is 5inch/hr, then the grey infrastructure that to be installed is only 4% of the regular. Similarly, if the percolation capacity of the soil is 1 inch/hr then the grey infrastructure that has to be installed is 20% of the regular.

IV. RESULTS

Paper has been constructed on the basis of Dissertation study and the research has not been completed. Depending on the case studies and interpretation of data, the above following parameters have been prioritized for further analysis.

The study needs to be extended with the above parameters on a local site and there by generating the regression analysis to test the possibility of Green Infrastructure integration into storm water drainage.

V. CONCLUSION

All the metro cities have been facing the problem storm water management. After understanding the concepts of Green Infrastructure and ways of integrating SuDS into the existing system, advantages of SuDS over grey Infrastructure, it has been clearly understood that the option of SuDS can flip the existing scenario of storm water management. The concept of green infrastructure is not an alien, it has been adopted by many foreign countries and recorded appreciable success rates. But Indian cities are not as same as foreign and the conditions what we have here are different. Which makes it essential to understand, analyze and research on various parameters which are linked to Green Infrastructure. The study has been made, parameters have been identified which can be used in the implementation of Green Infrastructure both in terms of policy making and urban designing. Basing on these parameters, sites can be prioritized where the SuDS can be implemented at smaller scale. For example, let us consider a site "A" which is fully fetched with very less rainfall intensity, proper working conventional grey infrastructure, with moderate soil infiltration capacity, limited available open space within the catchment area and on the other hand, site "B" which does not have any grey infrastructure, good rainfall intensity, good soil infiltration capacity, available open spaces within the catchment. Based on above data it can be statistically said that the chances of installing Green Infrastructure in the site "B" are more favorable when compared to site "A". Depending upon the success rates in terms of physical integrity with nature and financial aspects in the policy making, this can be expanded to a larger scale.

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