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ORIGINAL ARTICLE

Water Sensitive Urban Design for Rain Water Harvesting And Groundwater Recharge

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ABSTRACT

The gradual increase in water demand along with dwindling water resources has raised the need to explore both traditional as well as unconventional water resource management techniques. Current urban water resources and infrastructure of Pakistan which heavily rely on groundwater cannot deal with growing water stresses. The estimation of water availability per capita as compared to water demand indicates that water resources of Pakistan are under stress and maintaining sufficient continuous supply of water is a growing challenge to meet the current population growth rate, industrialization and urbanization. The country is predicted to suffer from severe water scarcity during next five years. A sustainable water management system is needed immediately to cope with water related problems. Water Sensitive Urban Design (WSUD) focuses on integrated management of land and water planning. It encourages incorporation of rainwater into urban development for reuse and groundwater recharge purposes. This study has undertaken to explore the potential of implementing water sensitive urban design in the context of Lahore, Pakistan. The area selected for the study is of Main Boulevard – Gulberg, Lahore which receive hundreds of millimeters of rain during monsoon season and this rainwater goes directly into drain without any useful utilization. During the study it was realized that the soil of Main Boulevard Lahore is of very low infiltration rate. The study indicates that this low infiltration rate can be improved and sufficient amount of water can be conserved and utilized for groundwater recharge by using WSUD techniques. Different water sensitive structures are suggested in this research based on location specific requirement to demonstrate wide range of application of WSUD. Further, the proposed WSUD techniques will also help to reduce the pressure on existing drainage system making urban water management effective and sustainable.

Keywords: *Water Sensitive Urban Design, Urban Planning, Groundwater Management Techniques, Sustainable Drainage System, Integrated Water Resource Management.*

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INTRODUCTION

A huge number of world's population resides in urban areas which has affected the environment drastically. Protection of natural resources has become a major challenge. Now there is need to design such cities capable to deal with the stresses like high population and climate change. There is also need to manage the natural resources sustainably. Moreover, it is difficult to meet water demand without

compromising on its quality and to manage the waste water and floods. Sustainable development has been defined in many different ways, mostly "sustainability means balancing economic, social and environmental needs." Since resources are limited and will be possibly exhausted one day by being overused. Therefore, the goal is to achieve a balance between demand and supply of resources [1].

WSUD was used as a term in 1994 in Australia for very first time and introduced the integrated management of land and water planning which grew globally later in 1990's. The objective of this technique is to incorporate rainwater into the landscape, conserve water quality and natural system and reduce runoff and peak flows. WSUD aims to manage the water cycle by producing qualitative and quantitative impacts on land, water, aesthetic values and biodiversity as well as maintaining economic endurance. WSUD focuses on sustainability of environment and water cycle in urban development or even in redevelopment of urban structures [2].

The gradual increasing water shortage has raised the need to develop efficient water resource management. It has been estimated that many countries are going to face a severe drought in future and many researchers have recommend the necessity of water resource management to deal with this drought [3]. In Pakistan, water is the most limiting factor for agriculture due to its climate. The economy of this country mainly depends on the agriculture which further depends on the availability of water. According to the World Bank, "agriculture contributed 20% to the GDP of Pakistan in 2012 and accounted for 45% of total employment in 2008." The severe drought from 1999 to 2002 effected the country's economy very badly whereas during 2003 to 2005, the sufficient availability of water and more than average rainfall helped to recover the agriculture and improve the national economy very well. Indus Basin Irrigation System is the major adjoining irrigated area in Pakistan.

World Bank and Asian Development Bank have classified Pakistan in red zone as water stressed country. According to them, country is going to face severe water scarcity during next five years due to insufficient water availability for industrial and agricultural purposes and human consumption. If ground water table kept decreasing then the per capita availability will reach to 800 $m^3$by 2020 [4]. "The projections of crop production in Pakistan's Water Vision for 2025 show a shortfall of 11 million tons by 2010 and 16 million tons by 2020." It has also estimated that there will be shortage of 8 major food crops by approx. 28 million tons and government will be left with an only option to import edible oils and grains in sufficient quantity. Yet it would be difficult to meet the import expenses for country like Pakistan which by economy highly depends on agriculture [5].

Rationale of the Study

Along with the high increase in population, the demand and consumption of water is also increasing remarkably. In Lahore, the only source of drinking water is ground water. As a result of over exploitation of ground water and insufficient resources of recharge, water table is depleting with an alarming rate of 2ft per year[6]. WSUD is a sustainable option to manage the rainwater by designing water sensitive cities. This study has focused on the assessment of WSUD application for rainwater management in order to divert it to conserve, store and recharge groundwater by suggesting different types of planning and engineering solutions to facilitate and enhance infiltration of rainwater into the ground.

Objectives of the Study

The aims and objectives of this study were to evaluate the rainwater management under existing conditions of Main Boulevard Lahore Propose WSUD infrastructure under different local conditions of Main Boulevard Lahore in order to conserve and store water for reuse, recharge ground water and control rainwater/surface runoff

MATERIAL AND METHODS

Population/Study Area

Study area for this study was Main Boulevard Gulberg Lahore from the start till Liberty Roundabout (Length=8530.18ft, Width= 56ft each side) and a part of Noor Jahan Road from Liberty Roundabout till Liberty Market (Length=1481.7ft, Width= 36ft each side) as shown in *Figure I* below.

Figure I Satellite Imagery of Study Area

Data Collection

High Resolution Satellite Image

The satellite imagery of the study area was taken from The Urban Unit. The study area was identified and marked on this satellite imagery (*Figure I*). Another QuickBird high resolution image (acquired on May, 2010) with 0.6m resolution having RGB visible bands was attained in ".ECW" format from The Urban Unit which was further used for the digitization of the study area.

Rain Fall Data

Average monthly rainfall data for Lahore was obtained from Pakistan Meteorological Department. The graphical representation of annual rainfall for recent years (2010-2014) is shown in *Figure II*. Total annual rainfall was calculated and average rainfall was estimated that is 736.74 mm.

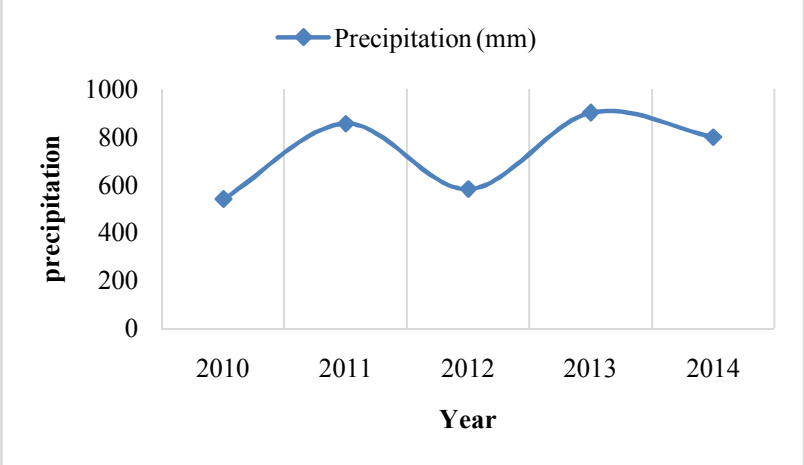

Figure II Average Precipitation Pattern in Lahore (2010-14)

Land Use Survey

Land use survey was done to collect attributes of buildings in study area. The features regarding land use survey was entered in Attributes Table (*Annex I*) that were collected during land use survey are:

a. Measurements of roads and green belts

b. Name and type of buildings
c. Stories and use of buildings

Digitization of Map

The land parcels in entire study area were digitized on ArcGIS 9.3 (*Annex II)* with the help of following steps:

a. In ArcCatalog the folder location containing desired mxdfile was browsed.
b. Folder was selected and was right clicked and then "New → Shapefile" was selected and a polygon shapefile was created and saved.
c. ArcMap was opened and that shapefile was added to data frame.

Land use Mapping

All land parcels were digitized and then parcels were classified based on their use. Land use map was prepared for this purpose. Parcels were coded with different colors according to their land use attribute while using properties of attribute table.

Soil Permeability Test

Permeability test was performed at University of Engineering and Technology, Lahore to assess the permeability of soil of study area using "Falling Head Permeameter" method.

Sampling

Random soil samples of approximately 3000 g were taken to test soil permeability from three different points labeled as Sample 'A' taken from Liberty Roundabout, Sample 'B' taken from green belt near City Tower and Sample 'C' taken from green belt near Saddique Trade Center.

Site Selection for WSUD Proposal

Study area was classified into four main groups based on land use as:

- Commercial
- Residential
- Green Area or Vacant Land
- Parking Lot
- One representing location was selected from each category to propose ideal WSUD structure for rain water harvesting and groundwater recharge for similar locations in respective category (*Annex III*).
- Mega Tower was selected as commercial Figure. It is a ten story building with a parking basement. It is used purely for the commercial purpose.
- House represents the residential class. A house of about 22 Marla was selected to show a typical WSUD house.
- A green belt portion on Main Boulevard green area category to purpose WSUD which will not only exemplify road sides WSUD measures but also applicable for the other vacant lands present in study area.
- Liberty Market Parking was chosen as parking lot as WSUD purpose a wide range of structures for parking lot. Moreover, parking area is the most suitable place for WSUD application as it has a lot of open space.

Cost Estimation

Price of all construction material used in proposed water sensitive structures was taken from market. The price of each construction material was added per cubic foot to estimate cost of a water sensitive structure.

Cost of Single Water Sensitive Structure (PKR/ft^3) = Sum Cost of all Construction Material Used (PKR/ft^3)

The estimated cost of these structures is shown in Table II.

RESULTS

Soil Permeability Results

Soil permeability test results for each sample was calculated with the help of equation:

$K_T = \{2.3 \times a \times (L/A \times t)\} \times \log (h_1/h_2)$

Following are the calculation made from those equations.

Sample A

Internal diameter of mould = D = 10.3 cm
Internal height of mould = L= 12.5 cm
Internal area of mould = A = 83.32 cm^2
Internal volume of mould = 1041.54 cm^3
Internal diameter of stand pipe = d = 0.6 cm
Area of stand pipe = a = 0.28 cm^2

Re-moulded dry density of sample = 1.75 gm/cm^3

Sample B

Internal diameter of mould = D = 10.3 cm
Internal height of mould = L= 12.5 cm
Internal area of mould = A = 83.32 cm^2
Internal volume of mould = 1041.54 cm^3
Internal diameter of stand pipe = d = 0.6 cm
Area of stand pipe = a = 0.28 cm^2
Re-moulded dry density of sample = 1.72 gm/cm^3

Sample C

Internal diameter of mould = D = 10.3 cm
Internal height of mould = L= 12.5 cm
Internal area of mould = A = 83.32 cm^2
Internal volume of mould = 1041.54 cm^3
Internal diameter of stand pipe = d = 0.6 cm
Area of stand pipe = a = 0.28 cm^2
Re-moulded dry density of sample = 1.74 gm/cm^3

The average values of hydraulic conductivity of all three samples are compared in graphical form in *figure III*. A negligible increase in the permeability of soil could be observed as we move from liberty roundabout towards Siddique Trade Center. Therefore, WSUD remains equally applicable to the entire study area.

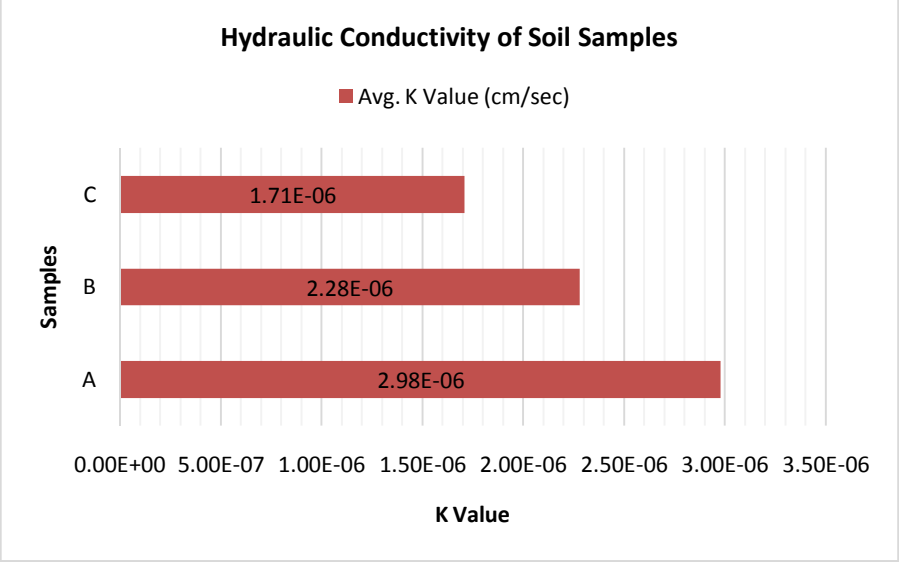

Figure III Comparative Analysis of Soil Permeability Results

Storm Water Volume Calculation

The total volume of storm water produced during monsoon seasons was calculated as;

- Volume of total storm water = Average Depth of rain fall × Total Impervious Area
  Volume of total storm water = 0.73674m × 98668.6m^2
  Volume of total storm water = 72693.104 m^3 = 72693104 L
- The total storm water capture volume (m^3) of study area was calculated through following formula.
  Capture volume (m^3) = Imperious area (m^2) x target design runoff capture depth (mm/day) x 0.001
  Capture volume (m^3) = 98669.64 x 15 x 0.001
  Capture volume (m^3) = 1480.03 m^3

Water Sensitive Structures Proposal

All water sensitive structures were designed according to the measurements used in previous studies[1]. Different water sensitive structures were selected for selected locations. The design criteria (*Table I*) was based on:

[1] Source: WSUD Engineering Procedures: Stormwater

- Type and size of catchment area
- Available space
- Feasibility of WSUD at that specific location
- Size of structure

Table I: Calculated Capture Volume of Water Sensitive Structures					
Location (Category)	Proposed WSUD Structure	Length (m)	Width (m)	Depth (m)	Total Volume (m^3)
Parking/Vacant Land	Infiltration Basin	493	0.25	0.9144	112.6998
	Porous Pavement	493	55.47	0.9144	25005.83162
	Modified Tree Pit	1.22	1.22	0.3556	0.52927504
	Total Volume Captured				25119.0607
Greenbelt	Bio-retention Basin	1.83	1.22	1.15	2.56749
	Porous Pavement	15.24	4.57	0.9144	63.68503392
	Modified Tree Pit	1.22	1.22	0.3556	0.52927504
	Total Volume Captured				66.78179896
Commercial Plaza	Porous Pavement	14.33	24	0.9144	314.480448
	Infiltration Basin	14.33	0.25	0.9144	3.275838
	RRWH	4	3	3	36
	Total Volume Captured				353.756286
House	Porous Pavement	9	3.05	0.9144	25.10028
	Rain Garden	1.83	1.22	0.9144	2.04148944
	RRWH	3	2	3	18
	Total Volume Captured				45.14176944

Cost Estimation

Net cost of this proposal for selected locations only (based on market price Jan-Mar 2015) is approx. 4, 65, 547 PKR per cu. ft. Cost estimation of each proposed structure on respective location are given below in Table II.

Table II Cost Estimation of Proposed Water Sensitive Structures		
Landuse Categories	**Proposed WSUD Structure**	**Cost**
Parking/Vacant Land	Infiltration Basin	1675 PKR/ft^3
	Porous Pavement	406 PKR/ft^3
	Modified Tree Pit	497 PKR/ft^3
	Total Cost for Parking	2578 PKR
Greenbelt	Bio-retention Basin	227 PKR/ft^3
	Modified Tree Pit	497 PKR/ft^3
	Porous Pavement	406 PKR/ft^3
	Total Cost for Greenbelt	1130 PKR
Commercial Plaza	Porous Pavement	406 PKR/ft^3
	Infiltration Basin	1675 PKR/ft^3
	RRWH	1754934.467 PKR/ft^2
	Total Cost for Plaza	1757016 PKR*
House	Porous Pavement	406 PKR/ft^3
	Rain Garden	128 PKR/ft^3
	RRWH	2894289 PKR**
	Total Cost for House	2894823 PKR

*Forthe plaza of 1615m^2.

** For the house of 343m^2.

DISCUSSION

Pakistan is facing a water shortage which tends to become severe in near future. The increasing population and urbanization has created a high pressure on natural water resources. Water, being basic and compulsory element for life needs to be conserved for a sustainable future. To avoid serious water scarceness in near future, the country has to shift to the nontraditional methods to conserve and manage water resources because traditional methods have failed to do so. A report publish by South Asia Regional

Water Vision (2000), according this report the projections of crop production in Pakistan's Water Vision for 2025 show a shortfall of 11 million tons by 2010 and 16 million tons by 2020." It has also estimated that there will be shortage of 8 major food crops by approx. 28 million tons and government will be left with an only option to import edible oils and grains in sufficient quantity. Yet it would be difficult to meet the import expenses for country like Pakistan which by economy highly depends on agriculture [5].

This study was done to propose an innovative measure in order to deal with such issue. During primary study of selected area, it was found that hydraulic conductivity of the soil is very low. The larger part of area is paved and there very less permeable area with the compacted top surface of the soil. The soil permeability test results showed that soil is of clay nature with very low infiltration rate. Moreover, groundwater level is constantly decreasing.

For effective recharge of groundwater, soil permeability needs to be increased by using filter media with the high infiltration property. Therefore, research has suggested WSUD elements with filter media that will increase infiltration capacity of soil. Various types and sizes of filter media combinations are suggested to increase infiltration of soil so that runoff could easily penetrate into groundwater. Moreover, Pakistan faces heavy rainfall during monsoon season every year and past few years have shown increased precipitation. In addition, major floods have been recorded each year in the history of Pakistan in different areas. Flood prevention is one of the primary objectives for social, cultural and economic safety of country. It should be integrated into the water management plan without making any compromise.

On the other hand, Rainwater is considered as precious source of water and rainwater harvesting is an evolving trend around the globe. Rainwater harvesting may help to reduce impact of urbanization on urban water cycle by minimizing the demand for potable water and generation of wastewater and surface runoff and by integrating vegetated structures and other water treatments to make water reusable. Likewise rainwater harvesting, water sensitive urban design conserves, stores and helps to recharge groundwater resource. The research has shown that Pakistan has wide potential for WSUD in both existing infrastructure with presences of open and vacant land as well as making it a permanent part in all future developments and urban plans. Thus WSUD suites Pakistan geographically and geologically.

Khalid M, *et al* in 2013 conducted a study on Groundwater Levels Susceptibility to Degradation in Lahore as a result of over exploitation of ground water and insufficient resources of recharge, water table is depleting with an alarming rate of 2ft per year [6].This WSUD application will benefit country in following purposes: It will manage runoff by reducing onsite flow volume and flood occurrences. It will also reduce pressure on conventional drainage system by providing an alternative system. It will manage the rainwater sustainably making it reusable. It will help to restore groundwater level by escalating soil infiltration that will ultimately fulfill water demand to some extent. It will provide wide opportunities for labor.

WSUD structure enhances the aesthetic and recreational worth of the area. In this research, the fact that came to know is that Pakistan needs to overcome conventional management of urban water cycle for sustainable future. By adopting novel techniques like WSUD, most of surface runoff and rainwater can be used for beneficial purposes of the country instead of wasting this runoff by letting it into the existing drains and sewage system.

From this study, where different kinds of land use categories i.e. vacant land, greenbelts, commercial and residential buildings were selected, it can be said that the since water sensitive structures are flexible in shape and size, the proposed design may be replicated with slight modifications at other vicinities country wide as per local conditions. The proposal is one time investment for several years however, the maintenance cost of these water sensitive structures cost very much low than construction. There is scope for the life cycle assessment of these water sensitive structures so that WSUD proposal worth could be analyzed properly. In this research, the fact that came to know is that Pakistan needs to overcome conventional management of urban water cycle for sustainable future.

CONCLUSION

By adopting novel techniques like WSUD, most of surface runoff and rainwater can be used for beneficial purposes of the country instead of wasting this runoff by letting it into the existing drains and sewage system.

RECOMMENDATIONS

Keeping in view, the water paucity, land availability and climate conditions this study has recognized that WSUD is quite feasible option for conserving water through rain water harvesting and ground water recharging in the context of Lahore Pakistan. RWH and WSUD techniques should be included in the

curriculum of educational institutes. Impervious surfaces and urban obstacles/ structures are the main hurdles in groundwater recharge and WSUD are the techniques to minimize their ill effects.

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