APPLICABILITY OF WATER SENSITIVE URBAN DESIGN (WSUD) IN DHAKA CITY

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ABSTRACT

Dhaka, the capital of Bangladesh, is undergoing rapid urbanization process. Due to the unplanned urban sprawl, the city dwellers are deprived of basic human rights among which water supply have appeared as the most censorious issue. Water supply in Dhaka city is mostly dependent on groundwater extraction and around 87% of the supplied water is extracted from groundwater sources. Such extensive pumping of groundwater and reduced infiltration due to increased urbanization have depleted groundwater storage calling into question the sustainability of the city's groundwater supply.Water Sensitive Urban design (WSUD) acknowledges and aims at overcoming these impacts by integrating water into urban development and planning to magnify the opportunities for sensitive water cycle management.The present research has been undertaken with a view to develop and design an urban area in such a way that groundwater recharge can be enhanced on a regular basis. Applicability of different measures of WSUD have been studied in this study and evaluated in terms of their costing and effectiveness in increasing groundwater recharge in Dhaka city. This study mainly focuses on two options named Infiltration Trench and Permeable Pavement considering "Purbachal New Town" as the study area. Potential infiltration of water by these processes has been assessed and based on this, design of the applied measures are provided along with the costing. Seemingly significant infiltration and potential increase of groundwater recharge has been found due to theoretical application of these approaches in the study area. Results of this study would help policy makers and the relavant authorities to develop sustanable urban areas and make the city a more livable one.

Keywords: *Groundwater recharge, Infiltration Trench, Permeable Pavement, WSUD*

1. INTRODUCTION

Dhaka, the capital of Bangladesh, is undergoing rapid urbanization process. Due to the unplanned urban sprawl, the city dwellers are deprived of basic human rights among which water supply has appeared to be the most censorious issue. Water supply in Dhaka city is mostly dependent on groundwater extraction(Paul,2009).The water demand of this city is 2470 MLD (Paul,2009) and to meet this high demand,87% of the supplied water is being extracted from groundwater sources enhancing the chance of high depletion of groundwater table (Uddin &Baten,2011).In the last 7 years, groundwater has been dropped by 20 meters and a risk of 120 meters drop down in water table is being emerged by 2050 owing to excessive withdrawal of groundwater to meet the needs of about 20 millions city residents (Uddin &Baten, 2011).Such extensive pumping of groundwater and reduced infiltration due to increased urbanization have depleted groundwater storage calling into question the sustainability of the city's groundwater supply.

Conventional storm water system use impervious surfaces to transfer water resulting in increased run off and diminution of groundwater recharge. This system cannot adapt to change conditions resulting from increased city development and climate change, leading to unmanageable water logging in the city. The existing traditional drainage system has failed to reduce water logging problem in Dhaka and the utilization of storm water has been ignored (Barua and Ast, 2011).As a result, there has been an increased need to develop and maintain a sustainable solution for integrated water resource management.

The ideas of Sustainable Storm Water Management and Water Sensitive Urban Design (WSUD) have the potential to address these issues and should be considered for future developments. Storm water harvesting, applying WSUD approaches minimise the impacts of unmitigated runoff due to urbanisation. It also reduces the peak flooding intensity and thereby city's water logging problem (Hagare et al, 2014). This study aims at assessing the applicability of different WSUD approaches to facilitate storm water management system and eventually contribute in groundwater recharge.

2. METHODOLOGY

2.1 Study Area

Purbachal New Town, the biggest planned township of Dhaka has been selected as the study area of the present study. Purbachal New Town Project is situated at the north eastern side of Dhaka city at a distance of 16 km from zero point of Dhaka (Figure 1).The total project area is nearly about 6150 acres and is divided into 30 irregular sectors of varying plot sizes (3, 5, 7.5 and 10 katha).Sector 10 of having 5 katha plots has been selected as the study location (Figure 2).

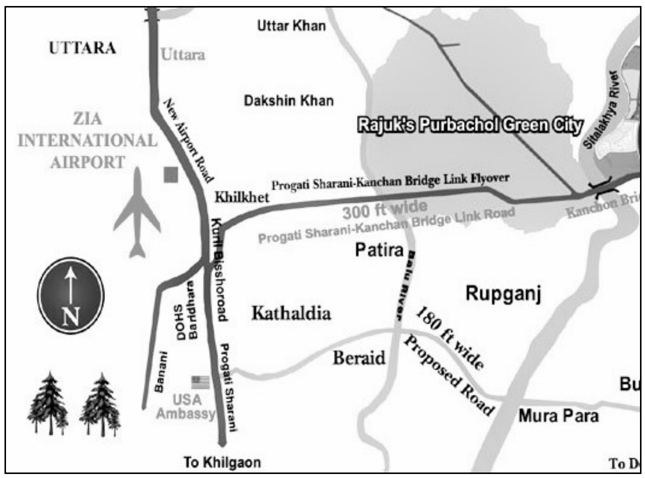

Figure 1: PurbachalNew Town Project

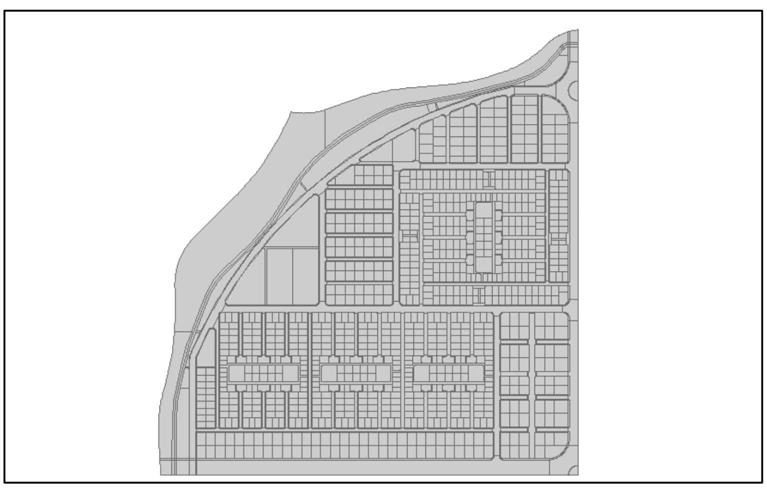

Figure 2: Sector 10, Purbachal New Town Project

2.2 Application of Water Sensitive Urban Design (WSUD) Approaches

There are a number of WSUD approaches available in harvesting storm water such as Vegetated Swales, Infiltration Trench, Infiltration Basin, Permeable Pavement, Sand Filtration etc. Among these, Infiltration Trench and Permeable Pavement have been applied in this study. Infiltration trenches are shallow excavations that are filled with an aggregate type material. They are constructed at the lowest point in a catchment area and work by creating a subsurface void where storm water runoff can be temporarily stored before infiltration into the surrounding soils occurs (Minnesota Urban Small Sites BMP Manual, 2000). Permeable pavements differ from traditional impervious pavements, as they allow runoff to percolate through hard surfaces to an underlying granular sub-base reservoir (Hagare et. al., 2014). The storm water is then stored until it infiltrates into the ground or is discharged as runoff.

This paper provides the important design consideration of WSUD measures (Infiltration Trench and Permeable Pavement) and their sustainability in terms of expected design efficiencies. Installation of infiltration trench is preferred in a small catchment area rather than infiltration basin and also suitable for residential subdivision usage (Iowa Storm water Management Manual, 2009). In this study individual plot is chosen rather than the whole catchment area because houses have not been built in these plots yet and outside the plots there are not enough spaces for applying WSUD measures. The location of the trench in individual plot is shown in Figure 3 considering a typical plan of a 5 katha plot. Construction of the major roads and main streets of the sectors of "Purbachal city" have already been completed and allocated for heavy traffic. Therefore, the roads within the boundary of each plot have been considered as permeable pavement (Figure 3) as these have not built yet and these roads will be used for low traffic.

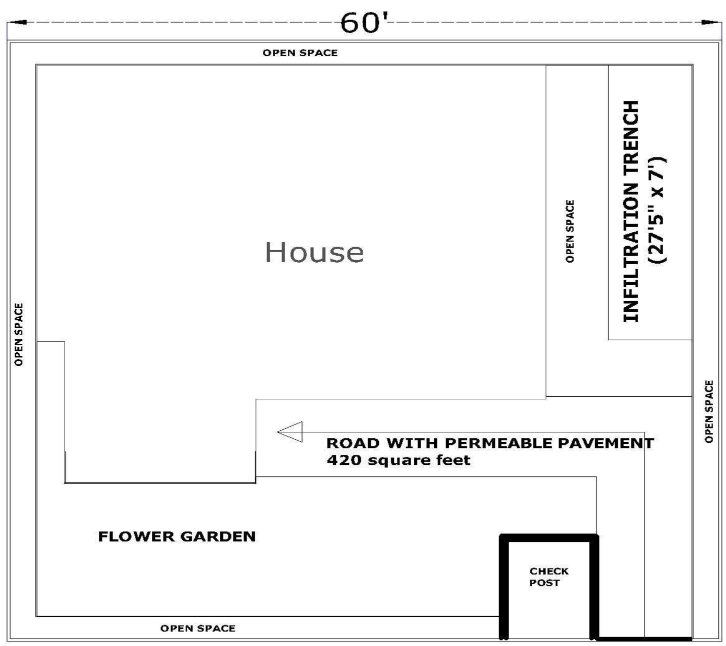

Figure 3: Position of Infiltration Trench and Permeable pavement in a 5 Katha Plot

2.2.1 Infiltration Trench

2.2.1.1 Amount of Infiltrated storm water

Volume of water to be infiltrated through Infiltration Trench has been estimated by using Rational Formula (Eqn. 1).

$$Q_p = \frac{C_s C_r I A}{360} \quad (1)$$

Where,

Q_P = Peak Runoff (m^3/sec)

A= Catchment Area (Hectare)
C_s = Storage Coefficient = 0.7 (For Residential area with detailed houses) (adopted for central drainage system by Purbachal New Town Project), (Mandal, 2008)
C_r = Runoff Coefficient= 0.4 (For Residential area with detailed houses)

According to RAJUK (Rajdhani Unnayan Kartripakkha), residential building can use maximum 62.5% of its allotted area for building construction. Therefore the maximum available catchment area of the 5 katha (3600 ft^2) plot, A= 3600*0.625 = 2250 ft^2

A= 2250ft^2= 0.021 hectares. (1 Hectare = 107639.104 ft^2)

$I\ (i_{d,T})$ = Rainfall Intensity, mm/h

Intensity of Rainfall, $i_{d,\,T}$ is determined by using Eqn. 2:

$$i_{d,T} = \frac{69.536 - 23.457\,(\ln(-\ln(1-1/T)}{d^{0.686}} \quad (2)$$ (Afrin et al, 2015)

Assuming Storm event, d = 15mins= 0.25 hour and Design period, T = 1.5 year (Mandal, 2008)

$$i_{d,T} = 174.27\, mm\,/\,hr$$

Therefore, the volume of rainwater that is expected to infiltrate by Infiltration Trench is
Q_p =2.57 m^3/day=90.4ft^3/day

2.2.1.2 Design of Infiltration Trench

Depth:

The design parameters for an infiltration trenchare trench depth, area and retention time. According to SEWRPC (1991), trench depth usually varies between 1 and 3 ft. A vertical distance of four feet is recommended between the bottom of the infiltration trench and the elevation of the seasonally high water table (Iowa Storm water Management Manual, 2009) to prevent the groundwater contamination. Considering these facts, 3 ft (0.914 m) depth has been assumed for the trench as seasonal high water table of the area is 10 ft below the ground level (Sub-soil Investigation, 2014)

Retention Time:

The relationship between depth and retention time is given in Eqn. 3

$$D = \frac{P * t}{n * 12} \quad (3)$$

Where, *D*=Depth of the Trench in meter = 0.914m
P= Percolation rate of surrounding existing soil= 30 mm/hr =1.2 in/hr (Irrigation Water Management)
t= Retention time in hr
n = Void space fraction in the storage media (0.4 for clear stone)

Putting all the values in equation (Eqn.3) Retention time, t =12 hr

Trench Area:
Likewise retentime time, soil properties are required to determine the trench area.

$$A = \frac{12 * V}{P * n * t} \quad (4)$$

Where, *A*= Bottom area of the trench (ft^2)
V=Runoff volume to be infiltrated = 90.4 ft^3/day = Q_p
P= Percolation rate of surrounding existing soil= 1.2 in/hr (Irrigation Water Management)
n =Void space fraction in the storage media (0.4 for clear stone)
t=Retention time =12 hr

Therefore Area of the trench, A= 188.33 ft^2=17.5m^2

Since the available free space in a 5 katha plot is 1350 ft^2, therefore an infiltration trench of 17.5 m^2 (188.33ft^2) can easily be accomodated within the plot.

Dimension
The area of the trench =188.33 ft^2 and
Size of the trench = 27.5ft x 7 ft x 3 ft
The details of the Infiltration Trench are shown in Figure 4.

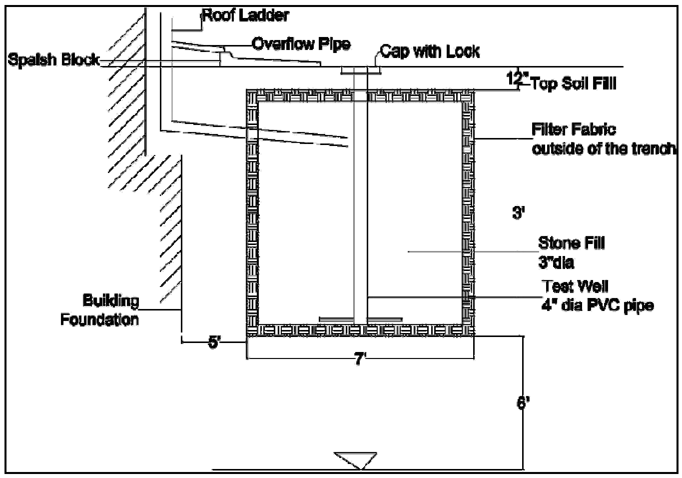

Figure 4: x-Section of Infiltration Trench (7' x 27'-5", not in scale)

2.2.1.3 Cost Estimation of Infiltration Trench

The construction of infiltration trench includes different elements such as inlet pipe, observation well, lining material etc. There are a number of specifications for the preparation of infiltration trench layer.The detail specifications of these elements along with references are shown in Table 1. Using these specifications, cost estimation of the proposed infiltration trench in this study has been performed and shown in Table 2. The Bangladesh PWD rate in civil work construction (2008) has been used in cost estimation.

Table 1 : Specification of Different Layer of Infiltration Trench

WSUD Approaches (Infiltration Trench) Layer Elements	**Specifications**	**References**
Infiltration Trench Aggregate	Clean Stone having a diameter of 1.5 to 3 inch diameters is used for this design. ASTM C33 is applied in the design	(Schueler, 1987)
Filter Fabric	The sides, top and bottom of the infiltration trench should be lined with filter fabric. The fabric should be placed around the walls and bottom of the trench, and 1 foot below the trench surface.	(Iowa Storm water Management Manual, 2009)
Inlet Pipe	Pipe should be continuously perforated, smooth interior, with a minimum inside diameter of 4-6 inch	(Pennsylvania Storm water Best Management Practices Manual,2006).
Observation Well	a 6-inch diameter PVC pipe with a lockable cap	(Iowa Storm water Management Manual, 2009)

Table 2: Cost Estimation for construction of Infiltration Trench

Work description	Quantity	Unit	Rate (BDT)*	Cost (BDT)
Aggregate	575.75	ft^3	130	74,847
Supply & installation of filter fabric	960	ft^2	3.5	3360
Supply of 4 inch perforated pipe (3 Feet) long	0.92	m	66	60
Supply of 4inch dia(10 Feet) long inch PVC pipe	18.29	m	60	1097
Excavate trench (Area=7 ft x 27ft 5 inches)	16.32	m^3/m	87	1420
Installation of filter fabric	960	ft^2	6.5	6240
Place of 4 inch perforated pipe (3 Feet) long	0.92	m	104	95
Installation of 4inch dia(10 Feet) PVC pipe	18.28	m	104	1902
Place top soil layer	5.34	m^3/m	70	371
Total				89392
Unit cost				5108/ m^2

*1 U$= 85 BDT

2.2.2 Design of Permeable Pavement

2.2.2.1 Estimation of infiltrated storm water by Permeable Pavement

Assuming the design period for the pavement, T=15 year and Storm event, d= 1 hr, rainfall intensity found by Eqn. 2 = 132mm/hr

Available area for the pavement in the plot, A_s= 39.1 m^2 (Figure 3)
=420.7 ft^2

Storage layer Volume: According to Argue (2007)

$$V = \frac{A_s * I * d}{10^3 * 360} = 0.0143 \quad m^3$$

Where, d= Duration of storm=1 hr.

Therefore, required detention volume (V_d) of a porous paving system can be computed as follows:

$$V_d = \frac{V}{n}$$

Where , n=Porosity of the retention trench(gravel = 0.35) (WSUD Technical Guideline, 2004)
V_d= 0.04086m^3/s
For 1 hr storm period,
V_d=0.04086*3600 =147 m^3/day =5187 $ft^{3/}$day.

2.2.2.2 Design of Permeable Pavement

Depth of the reservoir layer is the main design parameter of permeable pavement. This parameter is a function of surface area and volume of storm water to be stored in the reservoir layer. (Eqn. 5)
Depth of the Reservoir Layer:

$$D = \frac{V_d}{A_s * n} \qquad (5)$$

Depth, D=0.003 m
As the calculeted depth is very negligible (0.003 m), minimum depth of 1ft can be provided as the design depth.

D_{max} is a function of Infiltration rate, Porosity and Time (Eqn. 6)

$$D_{max} = \frac{p * t}{1000 * n} \tag{6}$$

Where,
p= Infiltration Rate of the subsurface soil = 30mm/hr ;(Irrigation Water Management: Irrigation methods,Annex 2)
Infiltration (drainage) time t(hr) = minimum 24 hour and maximum 48 hour; (WSUD Technical Guideline, 2004)
Assuming t = 24hr

D_{max} =2 m = 6.5 ft

Since the groundwater table is below 10ft (Sub-soil Investigation, 2014) and for prevention of groundwater contramination, design depth should be less than 6.5 ft. (WSUD Technical Guideline, 2004)

Considering this, a depth of 1 ft has been suggested as the design depth of Permeable Pavement.

The X-section of Permebale Pavement is presented in Figure 5.

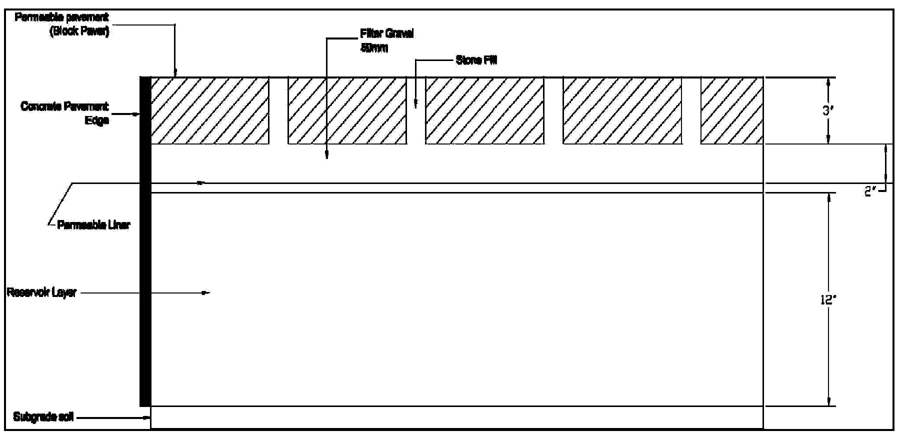

Figure 5: X-Section of Permeable Pavement

2.2.2.3 Cost Estimation of Permeable Pavement

There are various recommended filler materials applied in permeable pavement (Table 3). Following the specifications (Table 3), cost involved in construction of permeable pavement has been estimated according to Bangladesh PWD rate in civil work construction (2008) and presented in Table 4.

Table 3 : Specification of Permeable Pavement

WSUD Approach Permeable Pavement (Layer Element)	Specification	References
Porous Paving Surface	Inter locking porous pavers used assuming thickness of 3 inch	(Virginia DCR Storm water Design Specification No. 7, 2011)
Aggregate Layer	The gravel has to be stone gravel with a uniform size of between 25 - 100 mm diameter	(Adelaide, 2010.)
Geo Fabric	Must be installed along the side walls and through the base of the detention volume to prevent the migration of in-situ soils, and material from the bedding and filter layers into the system	(Adelaide, 2010.)

Table 4: Cost Estimation for construction of Permeable Pavement

Work Description	Quantity	Unit	Rate(BDT)	Cost (BDT)*
Cost of paver	800	Pcs	15	12000
Place Filter Gravel layer, (50 mm)	70	ft^3	130	9100
Installation of Filter Fabrics	420	ft^2	13.5	1472
Place gravel reservoir layer,(305)mm	420	ft^3/ft^2	130	54600
Excavate & profiling Surface	11.92	$m^{3/}m$	67	799
Install Pavement blocks	39.1	m^2	396	15483
Supply & install permeable liner liners	420	ft^2	6.5	4200
Total Cost				97,654
Unit Cost				$2497/m^2$

*1U$ = 85 BDT

3. DISCUSSION

The detail costing of Infiltration Trench and Permeable Pavement has been determined based on design and shown in Table 2 & 4. It is found that the total cost of Permeable Pavement (97654 BDT) is higher compared to Infiltration Trench (89392BDT). But the unit cost of Infiltration Trench (5105/ m^2) is higher than that of Permeable Pavement ($2497/m^{2)}$ since the area of Permeable Pavement is higher than that of Infiltration Trench. It is observed that an Infiltration Trench can allow 90.4 ft^3 of water in a day i.e. 2560 liters of water to infiltrate into the soil. Therefore, in the study site, for 894 nos of 5 katha plot have the potential to infiltrate about 835 million liters of storm water annually. Similarly Permeable Pavement can allow 4700 million liters per year (Table 5). It is understood that there are other factors such as evaporation rate; soil moisture etc. which can influence the recharging activity and the actual volume of infiltrate water through Infiltration Trench and Permeable Pavement will not be the same as the calculated value in the present study. However, the study shows an indication that there is a high potential of recharging groundwater by implementing Storm Water Harvesting approaches in the urban development.

The features of Infiltration trench and permeable Pavement are given in a tabular form:

Table 5: Features of Infiltration Trench and Permeable Pavement

Features	Infiltration Trench	Permeable Pavement
Area	17.5 m^2	39.1 m^2
Amount of Infiltrated Water per year in total 894 five katha plot(Liters)	83 million	4700 million
Cost (BDT)/ 5 Katha Plot	89,392 BDT	97,654 BDT

4. CONCLUSIONS

With the increasing demand for water in the city, the authority must look forward to find out a way out to enhance the groundwater recharge. The present study has showed that applying WSUD measures has the potential of harvesting storm water, thereby increasing the groundwater recharge and facilitate in solving the water logging problem in the city.Findings of this study would help the policy makers and the relevant authoritiesto promote sustainable development through introducing WSUD measures and make the capital city a more livable one.

However, a small area is focused in this study and only two measures (Infiltration Trench and Permeable Pavement) have been applied through theoretical process. These two measures in accordance with other measures can be applied in the practical filed as experimental basis. After a successful field experiment, the findings of the study can be implemented in the study area as well as in other areas to be developed in future with a vision to make our capital a sustainable city.

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