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Application of Water Sensitive Urban Design Technique in Bangladesh

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Abstract

This study explores the adaptation of water sensitive urban design (WSUD) as a sustainable design approach into the urban setting of Ashulia within the Dhaka district of Bangladesh which is facing several environmental challenges such as flooding, water logging and pollution of water bodies due to unmanaged and unsustainable urbanization. WSUD offers a holistic approach to management of stormwater runoff quality and quantity with the aim of mimicking the natural hydrological cycle as of pre-development phase using various design elements such as Gross Pollutant Traps (GPT), swales, bioretention basin, constructed wetlands, sedimentation basins, infiltration trenches and rainwater harvesting. Methodology consists of development of Intensity Frequency Duration (IFD) curve, soil data collection and pre-liminary design of infiltration trench system in a medium scale catchment within the study area. Initial findings suggest that incorporation of WSUD elements measures such as infiltration trenches can be instrumental in attenuation of peak discharge. However, low infiltration soil capacity of the study area suggests the requirement of other WSUD elements to be constructed upstream of the trenches signifying the complexity of adoption of infiltration trenches solely in the local condition. Future work will involve more research to ger more detailed information of the local conditions and suitability of more conducive WSUD measures that can provide more fruitful results to alleviate growing stormwater management issues in Ashulia, Bangladesh.

Keywords: WSUD, Dhaka, Stormwater, IFD, infiltration trench

1 INTRODUCTION

Ashulia, a rapidly growing cities within the Dhaka district of Bangladesh has been facing lots of environmental challenges such as marine pollution, water logging, flooding, etc. due to unmanaged urbanization and drainage system. Traditional drainage systems are dwindling and unable to cope with the increasing runoff due to the increasing impermeable surfaces. Also, the stormwater quality is degrading as the runoff from agricultural, residential and industrial areas carries lots of pollutants which are detrimental to the local water bodies and bio species within them. These issues are exacerbated by climate change posing serious threats to the urban and marine environment. There has been a substantial shift of landscape as the built up area has escalated by 77.36% by 2020 mainly for industrial and residential purposes, which underscores a critical shift from agrarian to urban land use increasing ecological imbalance and disaster vulnerability (Hosen et al., 2021). Despite of receiving adequate amount of rainfall during monsoon season, the surface runoff that goes to water bodies carries lot of pollutants along with it , which upon consumption by local people has led to spread of various diseases such as diarrhea, cholera, etc. (Khan & Siddique, 2000). With all these issues encircling major cities like Dhaka and developing cities like Ashulia in Bangladesh, it demands for conducive measures such as WSUD to be adopted into the Urban settings to reduce the aftermath of development and achieve sustainability.

WSUD is a comprehensive approach which integrates urban planning with sustainable water management techniques to achieve the objectives of protection of natural systems, enhancement of water quality, restoration of urban water balance, reduction in demand for potable water, and integration of stormwater treatment within landscape (Donofrio et al., 2009). WSUD is a vague realm constituting various engineered elements incorporating entire urban water cycle into urban development and planning and are classified on the basis on the function they perform such as retention, detention, conveyance, infiltration, evapotranspiration , treatment and harvesting of stormwater (Kuller et al., 2017). Table 1 shows various functions offered by different WSUD measures (Kuller et al., 2017).

Table 1. WSUD measures and functions

WSUD Measures	Functions
Bioretention and raingarden	evapotranspiration, infiltration, treatment, harvesting
Infiltration system	Infiltration, treatment
Screen/GPTS	treatment
Sediment basins	Retention/detention, treatment
Swales	Conveyance, infiltration, evapotranspiration, treatment
Tanks	Retention/detention, treatment, harvesting
wetlands	Retention/detention, Conveyance, evapotranspiration, treatment, harvesting
Permeable pavements	Retention/detention, infiltration
Ponds and lakes	Retention/detention, evapotranspiration, treatment, harvesting
Green roof and walls	Retention/detention, treatment, harvesting, evapotranspiration

The principle of WSUD approach is encapsulated by cohesion of Best Management Practice (BMP) and Best Planning Practice (BPP), where BMP refers to the best practical method or techniques adopted to achieve specific objectives related to WSUD and BPP refers to the process of analyzing the site conditions and developing a land use plan to integrate BMP's structural and non-structural measures either solely or in combination as per the requirement of the site (Wong & Eadie, 2000). Table 2 represents application of WSUD measures in various scales in urban catchment (Lloyd et al., 2002).

Table 2. Application of WSUD measures in various scales

Scale	WSUD Measures
Allotment	Rainwater harvesting, infiltration system, sediment trap, bio-filtration system, porous pavement
Streetscape/precinct	Bio-retention system, infiltration system, swales, buffer strip, constructed wetland, pond, sedimentation trap, porous pavement
Regional/ open space	Infiltration system, bio-retention system, porous pavement, constructed wetland , buffer strip, pond, swale, lake, urban forest,

	rehabilitated waterway

In this research, we tend to identify pre-requisites and data required for applying WSUD measures in site specific condition of Ashulia located in Dhaka, Bangladesh and demonstrate the application of those data in design of an infiltration trench in a medium scale catchment of the site.

2 METHODOLOGY

Methodology includes site selection for conducting WSUD study, collection of hydrological data such as rainfall data and development of Intensity Frequency Duration (IFD) curve, soil data collection and design of infiltration trench for the selected catchment.

2.1 Site Selection

The site selected for the research is Ashulia, which lies in Dhaka district with longitude and latitude as 23° 53' 59.1936" N and 90° 19' 23.0952" E. Ashulia is a developing area with burgeoning markets, infrastructures such as universities, commercial places and residential settlements. Unmanaged and unplanned urbanization has led to severe issues such as water pollution, water logging, flooding, water scarcity, etc. News covering the agony of Ashulia where people were forced to live in waterlogged conditions for 4 months during monsoon season because of failed drainage system due to clogging from industrial wastewater highlights the dire situation that needs to the addressed (Akash A.R, 2017). Also, the incident of garment workers falling sick due to consumption of polluted water in 2013 highlights the seriousness of the situation and advocates for the necessity of shift in water management system to more robust and sustainable ways (news.com.au, 2013). Figure 1 shows the location of Ashulia within Dhaka district of Bangladesh.

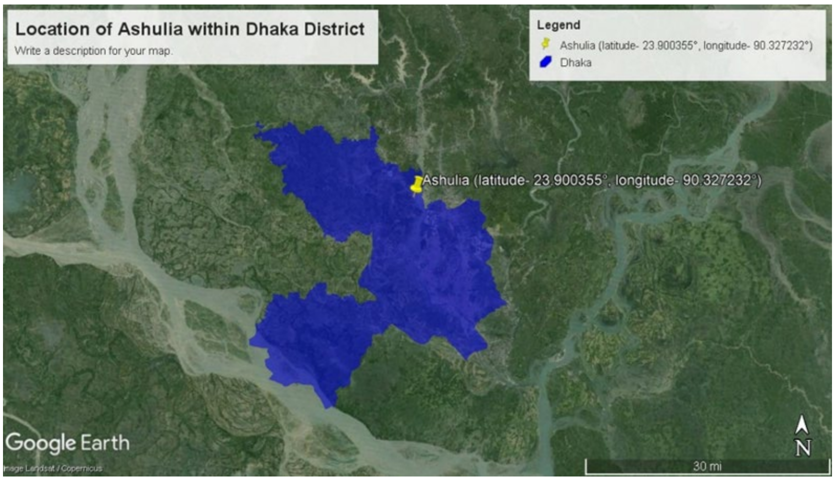

Figure 1. Location of Ashulia within Dhaka district

2.2 Data Collection

2.2.1 Rainfall Data

Most of the WSUD elements are designed for rainfall events ranging from 1- year Annual Recurrence Interval (ARI) to 5-year ARI depending upon the scale of the project, while 5- year to 100-year ARI rainfall event is used to design big structures to prevent big floods (Melbourne Water, 2005). Since only 24-hour rainfall data was available for Bangladesh, data from 1970-2016 was extracted from the Bureau of Meteorology of Bangladesh. Short duration of rainfall data is not measured and not available for Bangladesh as developed countries like Australia.

Short duration rainfall data is required to get the IFD curve so empirical relation developed by Indian Meteorological Department (IMD) was used for estimation of short duration rainfall, which was used in Sylhet city and found that the formula gave the best estimation of short-duration rainfall (Rasel & Hossain, 2015). Equation 1 gives the best estimation of short duration rainfall.

$$P_t = P_{24} \times \sqrt[3]{\frac{t}{24}} \quad (1)$$

Where, Pt=Required rainfall depth in mm in t-hour duration
P24= Daily rainfall in
t = duration of rainfall in hour

Rainfall for 10 minutes, 15 minutes, 30 minutes, 1-hour, 6-hour, 12-hour and 24- hour was calculated based on the empirical relationship given in equation 1.

2.2.2 Soil Data

Soil properties are imperative for design of WSUD elements, so soil map was developed for Dhaka using ArcGIS by extracting digital soil map of Dhaka from the website of Food and Agriculture organization (FAO) of the United Nations (Food and Agriculture Organization of the United Nations, 2024). Figure 2 shows soil map of Dhaka developed using ArcGIS.

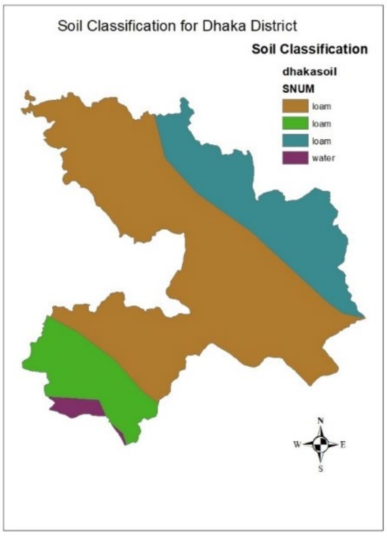

Figure 2. Soil Map of Dhaka

Based on the information of the world soil map, soil data was obtained from Soil and Water Assessment Tool (SWAT) and analyzed. Table 3 shows the properties of soil for Ashulia ,Dhaka.

Table 3. Soil Properties of Ashulia, Dhaka

SNAM (HRU)	Hydrologic group	Texture	Sat. hydraulic conductivity	Clay (%)	Silt (%)	Sand (%)
Nd46-2ab-3815	C	Loam	15.15 mm/hr	24	29	47

2.3 Development of IFD curve for Dhaka Region

IFD is a three-parameter curve consisting of intensity, frequency and duration of rainfall which is widely used in planning, designing and risk assessment of any water project (Hajani & Rahman, 2018). As Bangladesh doesn't have proper database for extracting IFD curve, IFD curve was developed by using the estimated rainfall data. The annual maximum series as extracted from the estimated rainfall data from 1970 to 2016 and the annual series was fitted into probability distribution called as Generalized extreme value (GEV) distribution for estimating rainfall quantiles for different return period such as 2,5,10,12,25,50 and 100 years. GEV distribution has been used to estimate design rainfall (IFD) in the current Australian Rainfall and Runoff 2019 (Hajani & Rahman, 2018). R software which provides an environment for statistical computing and graphics was used for fitting the annual maximum series into GEV distribution. Table 4 represents the developed IFD table for rainfall intensity in mm/hr for different return periods and duration.

Table 4. IFD Design Rainfall Intensity (mm/hr)

Rainfall Intensity (mm/hr)						
Return Period (years)						
Duration	**2`**	**5**	**10**	**25**	**50**	**100**
10 min	135.36	189.48	233.64	301.08	361.14	430.92
15 min	103.6	140.72	178.12	229	274.24	326.6
30 min	65.38	91.26	112.18	143.84	171.82	204.06
1 hour	41.19	57.51	70.61	90.35	107.69	127.58
6 hours	12.44	17.44	21.43	27.55	32.98	39.26
12 hours	7.85	10.97	13.49	17.31	20.69	24.58
24 hours	4.94	6.91	8.50	10.92	13.06	15.53

Figure 3 shows the IFD chart for Design Rainfall Intensity.

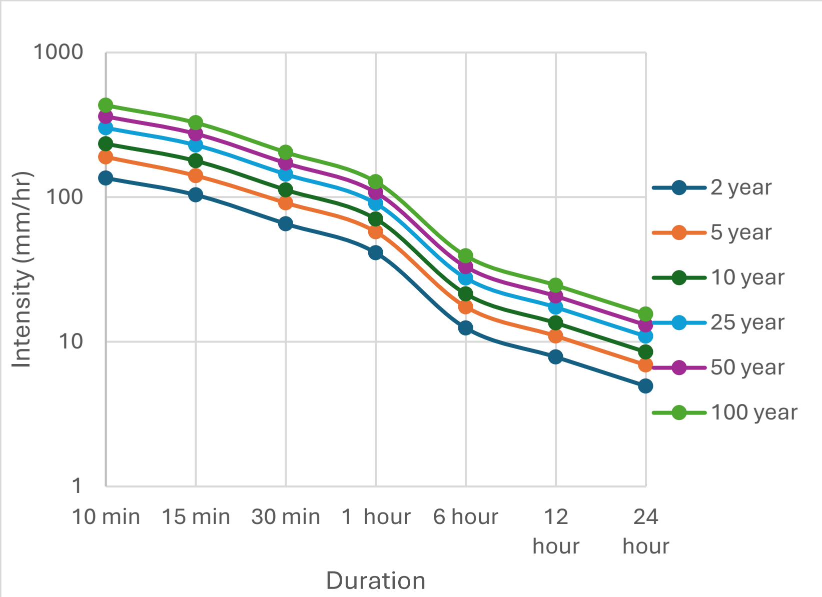

Figure 3. IFD for design rainfall intensity

2.4 WSUD Tools and Technologies Assessment

Among various WSUD technologies such as bioretention swales, infiltration trenches, rainwater harvesting, swales, buffers, constructed wetlands, etc., applicability of infiltration trenches for the precinct scale development area has been studied and analyzed. Infiltration trenches are linear trenches consisting of stone filled or any other porous media as a filtration layer allowing temporary detention of stormwater during peak periods before allowing them to infiltrate into the surrounding soils (Rodríguez et al., 2014). The primary objective of infiltration trenches is quantity control, which is control of flow during peak periods, but it also provides additional benefit of pollution control (Argue J.R, 2002).

2.4.1 Design of Infiltration Trench

2.4.1.1 Design Considerations

Design standards which are adopted for design are based on WSUD technical guidelines adopted by various councils across Australia. Table 5 shows the feasibility conditions for application of infiltration system (Melbourne Water, 2005).

Table 5. Minimum sites requirements for infiltration trenches

Site Parameters	Requirements
Soil hydraulic conductivity	3.6 mm/hr to 360 mm/hr
Soil Salinity	Not favorable
Groundwater (GW) table	Base of trench at least 1m above seasonal highest GW
Site Terrain	Not greater than 10%

Table 6 shows the guidelines for proper selection of type of trench according to the application scale (Melbourne Water, 2005).

Table 6. Infiltration type and application scale

Infiltration System	Allotment Scale (< 0.1 ha)	Medium Scale (0.1 ha- 10 ha)	Large Scale (>10 ha)
Leaky wells	applicable	Non-applicable	Non-applicable
Infiltration Trenches	applicable	applicable	Non-applicable
Infiltration soak-aways	Non-applicable	applicable	Non-applicable
Infiltration Basin	Non-applicable	applicable	applicable

2.4.1.2 Catchment Area Details

The area selected for the design of the infiltration trench is area of the Daffodil International University in Ashulia, Dhaka spanning around 6.37 hectares consisting of buildings, pavements, vegetations and barren land. Figure 5 shows the catchment area selected for design of infiltration trench.

Figure 4. Catchment Area

Table 7 shows the catchment area distribution in detail.

Table 7. Catchment Area Details

Area Type	Area (in hectares)	Area(%)
Roof Area + Pavement	0.79	12.40
Vegetation Area	1.96	30.77
Barren land	3.62	56.83

2.4.1.3 Design Calculation

Calculation of coefficient of runoff (C):

Depending upon the land use, the runoff coefficient for the catchment can be calculated as

Runoff coefficient= ((roof area%+pavement%) * 0.9 + vegetation area% * 0.55 + barren land%* 0.3)/100 (Kibria & Biswas, 2019)

= (12.40*0.9 + 30.77 * 0.55 + 56.83* 0.3)/100

= 0.45

The runoff coefficient of the catchment is obtained as 0.45

Discharge Calculation:

Volume of stormwater to be infiltrated by the stormwater has been estimated using the rational formula

$$Q_P = \frac{C*I*A}{360} \qquad (2)$$

Where Q_p= Peak discharge (m^3/s)
I= Intensity of Rainfall (mm/hr) is taken as 103.6 mm/hr for 15 min duration of 2-year return period from the developed IFD curve table number 4 (Wahab et al., 2016).
A= Area of catchment (in hectare)=6.37 hectare
C= Coefficient of Runoff=0.45

Q_p (Peak discharge) = 0.83 m^3/s

For 15 minutes rainfall duration, volume of stormwater expected per day= 0.83*60*15 m^3/day

= 747 m^3/day

Calculation of retention time of trench

Retention time refers to the time stormwater is held within the trench before completely draining it off to the surrounding soil. The relation between depth and Retention time is given by equation 3 (Wahab et al., 2016).

$$D = \frac{P*T}{n*12} \qquad (3)$$

Where, D= Depth of trench = 8 feet (assumed)
P= percolation rate (in inches) = 15.5 mm/hr= 0.59 inch/hr (saturated hydraulic conductivity from table 3)
n= void fraction in the storage media= 0.4 for clear stone used as filter media (Wahab et al., 2016)

Retention Time (T)= 65 hours

Calculation of Trench Area

The required surface area of the trench is given by equation 4 (Wahab et al., 2016).

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

Where, A= Area of infiltration trench in ft^2
V= Volume of water to be infiltrated given by equation 2 = 26214.97 ft^3/day
P= percolation rate (in inches)=0.59 inch/hr
T= Retention time given by equation 4 in hours= 65 hours

Surface area of infiltration trench= 20480.45 ft^2 = 1884.20 m^2

Design Summary

Table 8 shows the design summary of WSUD element for selected catchment.

Table 8. WSUD design summary

WSUD Type	Surface Area	Depth	Retention volume (per day)	Retention Time
Infiltration Trench	1884.20 m^2	2.44 m	747 m^3	65 hours

3 RESULT AND DISSCUSSION

Larger surface area of the infiltration trench suggests the requirement of other WSUD technologies such as Gross Pollutant Traps (GPT), bio-retention swales, rainwater harvesting and buffer to be incorporated upstream to reduce the load coming into the trench highlighting the fact that WSUD elements can perform better if constructed in a planned manner with series of treatment train (IOWA Department of Natural Resources, 2009). Also, addition of vegetation on the top layer of trench can increase evapotranspiration and help reduce water load and reduce volume required for the trench (Van Roon, 2005). Low percolation rate of soil media beneath the trench signifies that trench is more susceptible to the horizontal flow, thus length of the trench is more critical to the depth so necessary reinforcements to the length can increase the efficiency of the trench (Guerra et al., 2021).

Pre-treatment measures such as grit chambers, sediment traps, swales, etc. can remove large portions of Total Suspended Solids (TSS) and overall sediment load, hence increase the efficiency of infiltration trench. Infiltration trenches can be expected to remove sediment content by 90%, total phosphorous by 60%, total nitrogen by 60%, metals by 90%, bacteria by 90%, and organics by 90% (Schueler et al., 1992). Incorporation of perforated pipes beneath the filtration layer allows for re-use of water for domestic uses which in turn reduces the emptying time of the infiltration trench and make it ready for another wave of rainfall event (Melbourne Water, 2005). This also signifies how WSUD technologies assist in recycling water to meet the increasing demand of water to the growing population and lessen the stress on the water resources.

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