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Roof-Top Rainwater Harvesting-An Alternative Option to Urban Flood Mitigation and Groundwater Recharge for the City of Dhaka, Bangladesh

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Abstract: *Dhaka, the capital city of Bangladesh, is one of the quickest growing mega cities in the world. Due to large number of population and increasing trend of urbanization, recently it is facing severe crisis in supply of clean and pathogen free water. Around 87% of the present total city water supply comes from groundwater with a huge pressure on groundwater table. In addition the groundwater system is endangered due to rapid industrialization for last two decades. Some factories have installed deep tube wells privately of various capacities in the city running without any monitoring, making the situation even worse. One of the major reasons for the depleted condition of groundwater is abstracting water indiscriminately without assessing the situation. According to Bangladesh Water Development Board, the groundwater table in upper aquifer goes down by 3.5 meters every year. However in 1990 the rate was only 00.33 meter/year. Since the underground water level is regularly going down in the city, many pumps can no longer lift water. Cost of abstracting water is also increasing every year because the pumps need to go further down. In excess of exploitation of groundwater is causing high depletion rate. The water table is continuously going down in Dhaka city posing environmental threat. Moreover, in recent years Dhaka city is affected by urban flash flood caused by high intensity raindrop in small area due to the impact of climate change and global warming.Owing to rapidly developed urbanization most of surface areas are impervious so that water can infiltrate into ground. This paper focuses rainwater harvesting from roof of building by underground reservoir with pervious floor which can recharge ground aquifer. In addition the storing rain water from roof-top in underground reservoir can mitigate flash flood induced by high intensity rain in Dhaka city. During monsoon(May to September) around 315 mm monthly average rainfall occurs in Dhaka city which is situated on around 370 sq km of land with a roof area of 75 sq km as there are around 675,000 concrete houses. It is estimated that 120 million of cubic meter water can be harvested during monsoon with the current rainfall. This can reduce the dependency on groundwater at least for six months of monsoon and decrease the pressure on existing drainage system in Dhaka city. It will reduce around 20% of volume of water which induces inundation of some area for several days in Dhaka city.*

Keywords: *rainwater harvesting, urban flood mitigation, groundwater recharge, roof-top of building, global warming, climate change, Dhaka city.*

I. Introduction

Rainwater harvesting and storing is not a new technology in Bangladesh. It has also been used for domestic, agricultural, runoff control, air-conditioning etc. for a long time in different part of the world especially in arid and semi-arid regions. Around 36% of households are using the rainwater as drinking water source during the monsoon season in coastal areas having high salinity problems [3]. However, rainwater harvesting is not a common practice in Dhaka, capital city of Bangladesh.

Dhaka is one of the quickest growing mega cities in the world and facing severe crisis in supply of clean and pathogen free water. The situation is worsening further owing to the increasing population and the association expansion of urbanization and industrialization, all of which require more water and thus impose a tremendous pressure on the limited and fragile groundwater. In excess of exploitation of groundwater is causing high depletion rate. The water table is continuously going down in Dhaka city posing environmental threat.

Around 87 percent of the present total city water supply comes from groundwater with a huge pressure on groundwater table. Total demand of domestic water supply has been calculated approximately 2000 MLD by DWASA in 2008 and estimated to increase to nearly 4200 MLD in 2025 [1]. Around 87% of the present total city water supply comes from groundwater abstracting through 520 DTWs operated by DWASA; rest of 13% of water is supplied from four water treatment plants situated at Saidabad and Chandnighat in Dhaka and GodnailinNarayangonj. This is a huge pressure on groundwater table.

Moreover, the groundwater system is endangered due to rapid industrialization for last two decades. Some factories have installed deep tube wells privately of various capacities in the city running without any monitoring, making the situation even worse. One of the major reasons for the depleted condition of groundwater is abstracting water indiscriminately without assessing the situation. According to Bangladesh Water Development Board, the groundwater table in upper aquifer goes down by 3.5 meters every year. However in 1990 the rate was only 00.33 meter/year. Since the underground water level is regularly going down in the city, many pumps can no longer lift water. Cost of abstracting water is also increasing every year because the pumps need to go further down.

Another thing is urban flooding which has been a frequent event in many societies worldwide. In resent years Dhaka city is also affected by urban flash flood caused by high intensity raindrop in small area due to the impact of climate change and global warming. Owing to rapidly developed urbanization most of surface areas are impervious so that water can infiltrate into ground. Water bodies and wetlands around Dhaka are facing destruction as these are being filled up to construct multi-storied buildings and other real estate developments.

II. Climatic Patterns in Dhaka

Dhaka experiences a hot, wet and humid tropical climate which is called the Indian Ocean Monsoon climate. It has a distinct monsoonal season with a heavy rainfall due to north-easterly winds during in the rainy season. The monthly rainfall distribution of Dhaka city based on rainfall data from 1953 to 2009 is shown in Figure 1.

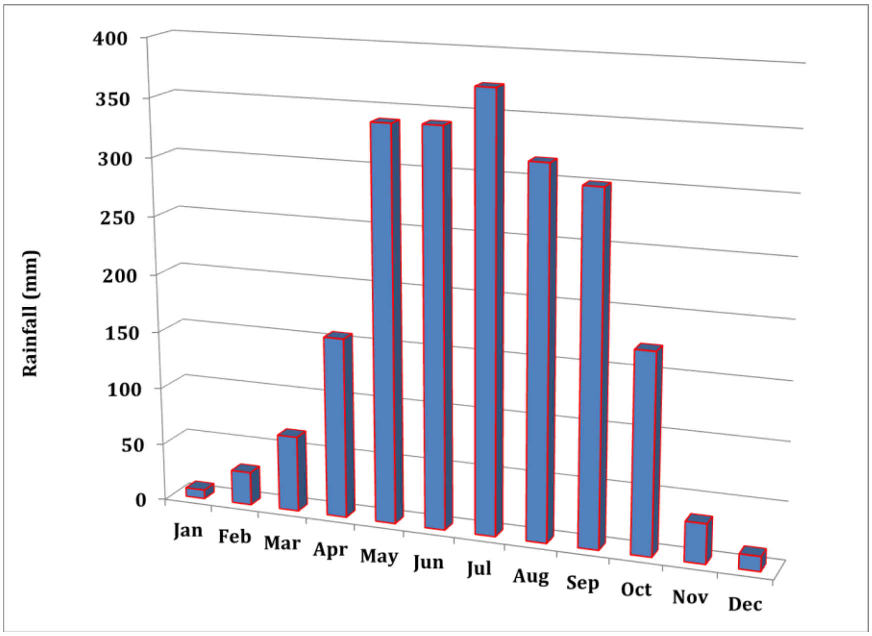

Figure 1: Average monthly rainfall distribution of Dhaka City [5]

The figure shows that nearly 80% of the annual average rainfall of 2069.5 millimeters occurs between May and September [5]. Average monthly rainfall during monsoon period varies between 300mm to 450mm. Maximum daily rainfalls during this period recorded 13 September 2004 is 341 mm[5]. On that day, approximately 40% area of Dhaka West was inundated[2]. Average temperature range is between 25^0C to 31^0C. Maximum temperature rises up to 40^0C and goes down to 6^0C.

Average relative humidity remains at 80% to 90%. Evaporation is highest in August in the study area. An average evaporation ranges from 80 to 130 mm (see table 1)

Table 1: Climatic condition of Dhaka City

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temp High ºC	34.2	36.6	40.6	42.3	40.6	38.4	35.2	35.9	35.3	38.8	33.3	31.2
Temp Low ºC	5.6	4.5	10.4	15.6	18.4	20.4	21.7	21	22	10.4	10.6	6.7
Average	18.6	21.5	26.1	28.7	28.9	28.7	28.7	28.7	28.7	27.4	23.6	19.8
Rel. Humidity	70.7	66	63	71	79	86	87	86	86	81	75	74
Evaporation	104	79	81	77	78	83	87	130	118	106	75	86
One day average (mm)	0.17	0.6	1.7	5	10.3	12.1	12.43	9.8	11	5.9	0.9	0.3

(**Source:** Bangladesh Meteorological Department)

III. Hydrogeology and Aquifer System of Dhaka

Hydrogeological setting and litho-stratigraphy of Dhaka evidenced that the area has experienced major and minor faulting at different times. Regionally the study area consist of southern half of the Madhupur Tract, which is surrounded by the floodplains of Jamuna, Ganges and Meghna rivers.Hydrogeological parameters of Dhaka are governed by the litho-stratigraphic and prevailing tectonic activities, which is part of regional hydrogeological setting and tectonic features. Moreover, Late Holocene glaciation and high energy stream flow has definite influence on the aquifer characteristics of the studyarea.

A correct understanding of hydrogeology and aquifer systems of an area has importance in successful implementation of any Artificial Recharge scheme. The aquifer systems underlying Dhaka city is the Dupitila sand formation overlain by Madhupur clay. These deposits are of Plio-Pleistocene age with its ground surface between 3m and 10m above sea level.Abstraction is the main discharge from underlying aquifer system. The upper aquifer is in direct hydraulic connection with surrounding rivers, particularly Buriganga River.

Figure 2: Generalized Tectonic Map of Bangladesh. [8]

Hydrostratigraphic cross sections have been drawn and studied to determine the lateral and vertical extent as well as depth location of the subsurface sediment formations particularly the aquifers in the study area (see figure 3).

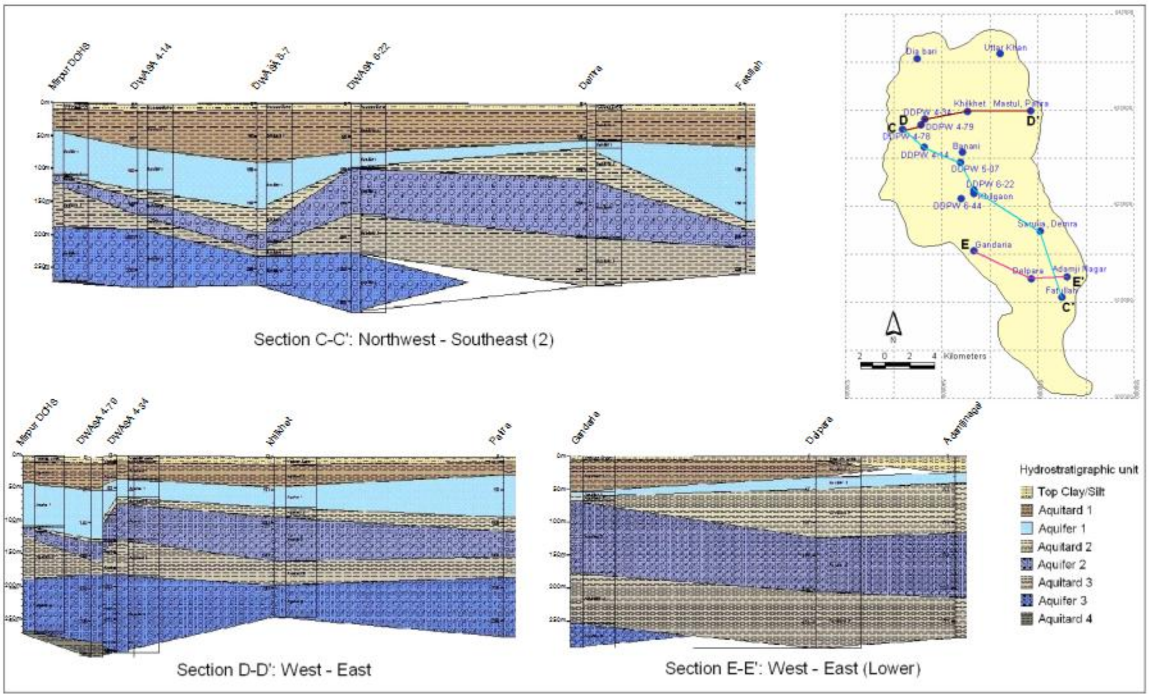

Figure 2: Hydrostratigraphic Cross section of Dhaka Aquifer

IV. Scope of Artificial Recharge in Dhaka Aquifer System

Since Dhaka city receives high intensity rainfall during the monsoon, the required parameters are favorable for artificial recharge in Dhaka aquifer from collected rainwater in monsoon. Average annual rainfall of Dhaka City is 1700-2200 mm. But most of the areas of Dhaka city are impervious, so natural vertical recharge from surface is very negligible in consideration of abstraction volume. As such rainwater collected from various rooftops (see figure 4) of the buildings may be used as a recharging source to exploiting aquifer for the water supply in Dhaka City.

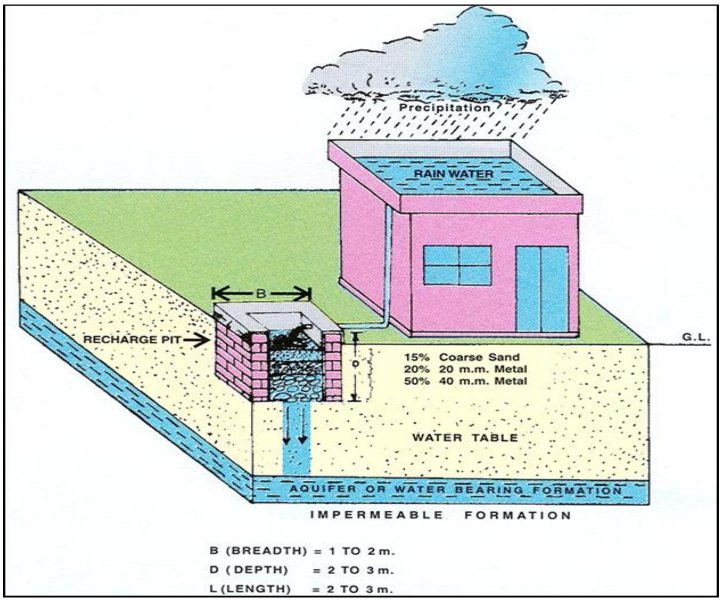

Figure 4: Schematization of roof-top rainwater harvesting through recharge pit [7]

If 60 % of rainfall can be collected, then annually about 89,496 million liters volume rain water will be available for artificial recharge to aquifer. This recharge volume can make about 245.19 mld which is more than Saidabad Treatment Plant capacity (225 mld). Moreover, it reveals from the secondary data that the measured on site parameter of rainwater suggests that the quality of rain water is good enough for artificial recharge before mixing with any kind of pollutant.

V. Data Collection and Analysis

Because of economic reason in this work we initiated the data acquisition process from secondary sources such as internet, published papers and documents, data collected by different organizations. In roof-top rainwater harvesting, rainwater is collected from roofs of buildings and stored in a subsurface aquifer layers for recharging the depleted groundwater aquifer and mitigating the flash flood. So the calculation of available roof-top rainwater, storage volume and the attenuation of flood hydrograph is very important.

Harvested Water:
Total City Area = 370 sq. km
Annual Average Rainfall = 2069.5 mm
Total Volume of Rainwater = 765.715 million cubic m.
Total number of house available for rain water collection = 678000
Average each roof Area = 110 sq. m.
Total harvested Water = 145 million cubic m.

Demand:
Total number of population = 13 million
Consumption per capita per day = 150 litters or 0.15 cubic m
Total annual demand = 712 million cubic m

Subsurface Storage Capacity:
Average roof size = 110 sq. m
Maximum one day rainfall = 200 mm
Storage volume required for a house = 22 cubic m
Considering 10000 sq. m area and maximum one day rainfall 200 mm, It is clear that the flood peak can be attenuated 20% by harvesting roof-top water (see figure 5).

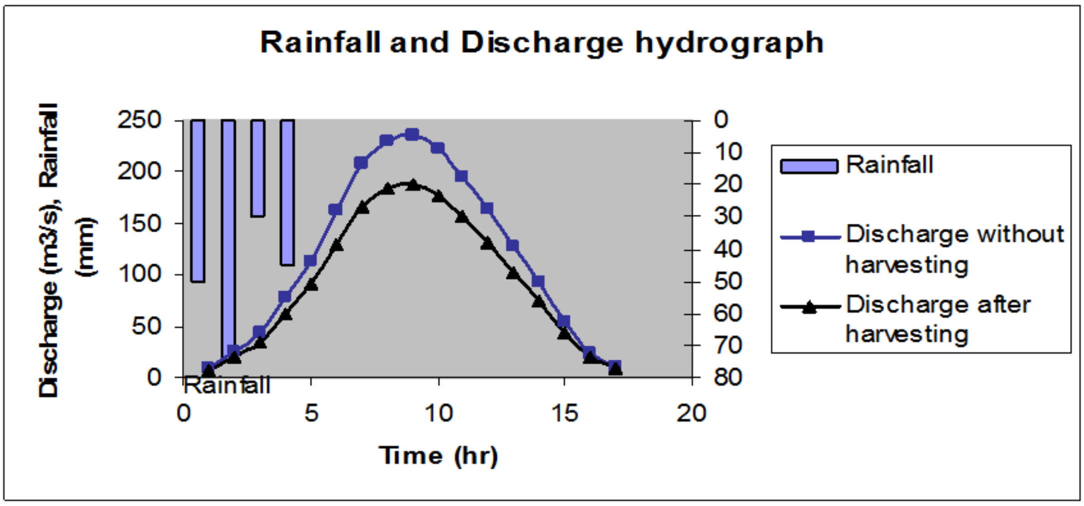

Figure 5: Rainfall chat and discharge hydrograph for 200 mm rain in one

VI. Discussion

Economic issue is important for the introduction of roof-top rainwater harvesting systems to the urban Bangladesh. Although the capital cost of building construction will increase due to construction of underground reservoir, artificial recharge is one supplemental means to restore the falling groundwater levels and mitigate the urban flash flood.

Implementation of roof-top rainwater harvesting in Dhaka city requires the external support. Government of Bangladesh or other supporting organization can provide promotion through subsidy and establish revolving funds. Government also can mandate the rules and regulation to emphasize the mandatory construction of underground reservoir. For example, Rooftop rainwater harvesting systems are now mandatory for new buildings in 18 of India's 28 states and four of its seven federally-administered union territories. As a result, artificial recharge to ground water in Lodhi Garden, New Delhi is successful to rise 0.35 m of groundwater level in about 40 ha area as well as roof-top rainwater harvesting in ShramShakitiBhavan, New Delhi estimates that 1.62 m rise of groundwater will occur in 12000 sq. m area.

The amount of recharge in Dhaka city will varies from place to place depending upon the intensity of rainfall, rainfall pattern, surface pattern and characteristics of soil. The available techniques are easy, cost-effective and sustainable in long term. Several methods of groundwater recharge like spreading, pit, induced recharge and injection well method are practiced. The area requirement of spreading method sometimes limits its use. Among them the injection wells directly feed depleted aquifers with fresh water from ground surface. The recharge through this technique is fast as well as has losses (transit or evaporation). Although the weathered soil and thick Clay layer over the aquifer system in Dhaka city exists, artificial recharge by injection wells through gravity is more practical and applicable for Dhaka city.

VII. Conclusions

Rainwater harvesting systems can be found in all the great civilization throughout the world. In industrialized countries, sophisticated rainwater harvesting systems have been developed to reduce water bill or to meet the demands of remote communities or individual households in arid regions. Roof-top rainwater harvesting in Dhaka city is found technically feasible because of rainfall pattern of Dhaka city. It can fulfill about 20% of the total yearly demand of water supply as well as attenuate the flood peak of any flood occurred in any part of this city. Further study is required to design underground reservoir, to implement this technique in sustainable way. Roof-top rainwater harvesting can be considered in combination with other systems.

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