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Temporal land-use change of a reclaimed land in greater Dhaka and its impact on natural water cycle

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ABSTRACT

This study aims to explore the land-use induced impact on runoff and recharge of an impending urban growth on reclaimed land filled with sands in greater Dhaka to concede the low impact development through practicable methods. Having analyzed the temporal land-use change by Curve Number (CN), GIS-based Soil Conservation Service - Curve Number (SCS-CN) method has been used to evaluate the runoff of the study area. Initial land-use in 2010 with a higher CN 86 resulted in a lower CN 72 in 2020-2022 due to land-use change (pre-developed/existing condition) with permeable soil for urban development. However, the gradual land-use change resulted in more imperviousness and an increasing trend in CN. With ultimate CN 84, approximately 243% more runoff was predicted during complete urbanization in 2040 and beyond as opposed to CN 72 in 2020-2022. Due to the existing higher groundwater table of the area, the Water Table Fluctuation (WTF) method has been used to find the natural recharge potential. As higher CN results in more runoff and recharge loss, ultimate natural recharge potential with CN 84 declines to more than 50% of the pre-developed condition. Results from the methods suggested a comprehensive hydrological forecasting due to land-use change on reclaimed land with assorted options for natural water cycle balance.

1. INTRODUCTION

Land-use change is now an unstoppable phenomenon across the globe. The half urban world is now facing the challenges of urban water security due to rapid urbanization, population intensity, socio-economic development, diverse consumption patterns, environmental degradation and climate change (Demographia, 2021; UNESCO, 2019; IPCC, 2022; UN, 2022). Urbanization and population growth result in wide-scale changes to the water cycle with significant environmental impacts. There is a growing need for natural water cycle balance as approximately 70% of the global population will live in urban areas by 2050 and 40% will face severe water stress (UNESCO, 2020; UN-Habitat, 2020).

Dhaka, the 17th populous city in the world is projected to reach 24.6 million in 2035 with rapid urbanization (Demographia, 2021; UN, 2018, RAJUK, 2015). As per Detailed Area Plan (DAP) 2016-2035, Dhaka Metropolitan Region (DMR) with an area of 1528 sq km has been split into six regions to manage sustainable urban growth in greater Dhaka. Increasing urban population is blurring the vision of making Dhaka a liveable, functional and resilient metropolis with environmental sustainability (GOB, 2022; RAJUK, 2015). Natural drainage system in core city and peripheral Dhaka is waning due to unplanned urbanization and land-filling (Subrina et al., 2018; Bird et al., 2018, Iftekhar & Islam, 2022). Around 43% of central Dhaka's floodplain has been filled in between 2003 to 2017 and alarming levels of pollution exist in the water retention bodies in and around Dhaka (BIGD, 2019; Karim, 2014; World Bank, 2018). Continuous land-use change in Dhaka is rapidly increasing its impervious surfaces, reducing infiltration capacity and causing significant run-off, peak discharges and recharge loss. Urban water security in Dhaka is not resilient as more than 78% of the water supply is from groundwater (GW) and the aquifer depletion rate is 2 to 3 m every year (DWASA 2020). All these environmental effects are essentially linked to urbanization and urban water cycle management. There is an explicit imbalance in the natural water cycle of Dhaka Central Region (DCR).

The natural recharge potential of Dhaka aquifer and the depth of GW table (GWT) across Dhaka are falling day by day. Based on annual recharge and discharge conditions, seasonal fluctuations of GWT in Dhaka differs from less than a meter to more than 10m relying on the local hydrogeological settings, GW abstraction scenario and natural discharge phenomena of GW (JICA & DTCA, 2015). Bangladesh Water Development Board (BWDB) analyzed the rate of fall of GW table (GWT) of Dhaka from 1998 to 2008 and depicted the increasing trend of falling and GW movement towards the core city Dhaka from its periphery (BWDB, 2011). The key reasons were less recharge due to reduced pervious surfaces and increased GW extraction to meet domestic, industrial and agricultural demand. The study area named 'Jolshiri' is due to be one of the largest urban growths of Dhaka Eastern Region (DER) as per the Detailed Area Plan (DAP) of the Dhaka Metropolitan Region (DMR). It is located close to the eastern fringe of DCR as shown in Figure 1 and enclosed by two major rivers. As per the study area authority, proposed land development plans to build a modern eco city by accommodating around one million population (9,18,057) on an approximately 2133 acres (8.633 km^2) of land. This indeed depicts a high population intensity and density.

Studies on land-use change scenarios and its impact on different environmental components are available. One such study on water availability scenarios to climatic change due to temperature and precipitation has been assessed for the Tokyo Metropolitan Area (Islam et al., 2005). There is hardly any study for an impending urban growth on reclaimed land to identify the land-use induced impacts on the natural water cycle with historic rainfall data. Land-use induced runoff and recharge in the entire eastern region of Dhaka was assessed and quantified with a prediction analysis to project the future landscape of DER with time and its impact on water cycle by Huq and Rahman (2020) and Huq (2017). The study projected similar landscape and hydrological impacts within DER as evidenced in DCR if existing urban development control tools of Dhaka are not revised. At present, the selected study area is quite ready for full-scale urban growth and can plan for sustainable urban water cycle management.

Effective land-use plan for any new urbanization in greater Dhaka is a critical need to reduce the imbalance in natural water cycle management and help achieve the key objectives of urban water management as in The Bangladesh Delta Plan (BDP) 2100 (GOB, 2018) and sustainable development goals (SDG) 6 and 11. This study attempts to explore the gradual changes in water cycle i.e., runoff and natural GW recharge due to temporal land-use change of the proposed urban growth which would help provide the urban planners or developers a broad forecasting on the impacts and find feasible options to balance the natural water cycle. A prospective imperviousness caused by temporal urban growth of the reclaimed was assessed through the Curve Number (CN) analysis and linked with GIS-based Soil Conservation Service - Curve Number (SCS-CN) runoff approach. Although there are effects of climate change on rainfall and temperature, this study limits its scope to identify the impacts of historical rainfall induced runoff and natural recharge potential of the study area and finally projects the overall impacts of land-use change on water cycle.

2. MATERIALS AND METHODS

2.1 Location and Hydrogeological Settings of Study Area

The study area is situated at Rupganj in Narayanganj District and lies between latitude 23°47′5″N to 23°49′15″N and longitude 90°29′5″E to 90°31′3″E. The area is flanked by the two rivers, i.e., Balu in the west and Shitalakkhya in the east and at the center of DER (Figure 2). The area is reclaimed by infilling of dredged sands and divided into 17 sectors for residential, commercial and institutional developments. The hydrogeological setting of Dhaka is fairly an older flat floodplain and primarily linked to the Ganges-Brahmaputra-Meghna (GBM) river system interconnected by local rivers, streams, retention basins and depressions (Hoque et al., 2007; Shamsudduha et al., 2009). In general, the borehole lithology of the study area exposed three distinct geological deposits i.e., Filling materials, Alluvial deposits, deposits of Modhupur clay and Dupi Tila formation. Lithology of the area consists of clay, silty clay, organic clay with iron concentrations and organic materials (DU, 2014). The generalized geotechnical characteristics of the area is at Table 1.

2.2 Data for Analysis

Considering tropical monsoon climate of Dhaka as well as for the country, the study involved three specific datasets: (1) Topographical maps and geospatial data for quantification of land-use plan and change, (2) Long-term daily rainfall and hydrologic soil groups for runoff estimate, and (3) Annual rainfall, lithological and geological data for computing recharge potential.

2.2.1 Data for Land-use Change

As land-use change for urbanization involves the increasing imperviousness of the land, the analysis requires the computation of change in CN from the topographic maps, Landsat Image, orthophoto, Digital Elevation Model (DEM) of the area. The actual landscape of the proposed urbanization was ascertained from SRTM DEM and aerial photographs of Survey of Bangladesh (SOB). Those were used to identify the original landscape and also to specifically locate the low-lying areas that are either sand-filled or underwent some changes within the study area. The elevation, slope and basin characteristics in terms of drainage network and streams including sub-basin boundary were identified from DEM using ArcGIS. However, the detailed land-use map of the proposed urbanization was collected from Jolshiri authority to evaluate the percentage imperviousness caused by complete structural development using existing building construction rules and Bangladesh National Building Code (BNBC) 2020 (GOB, 2008; GOB, 2020).

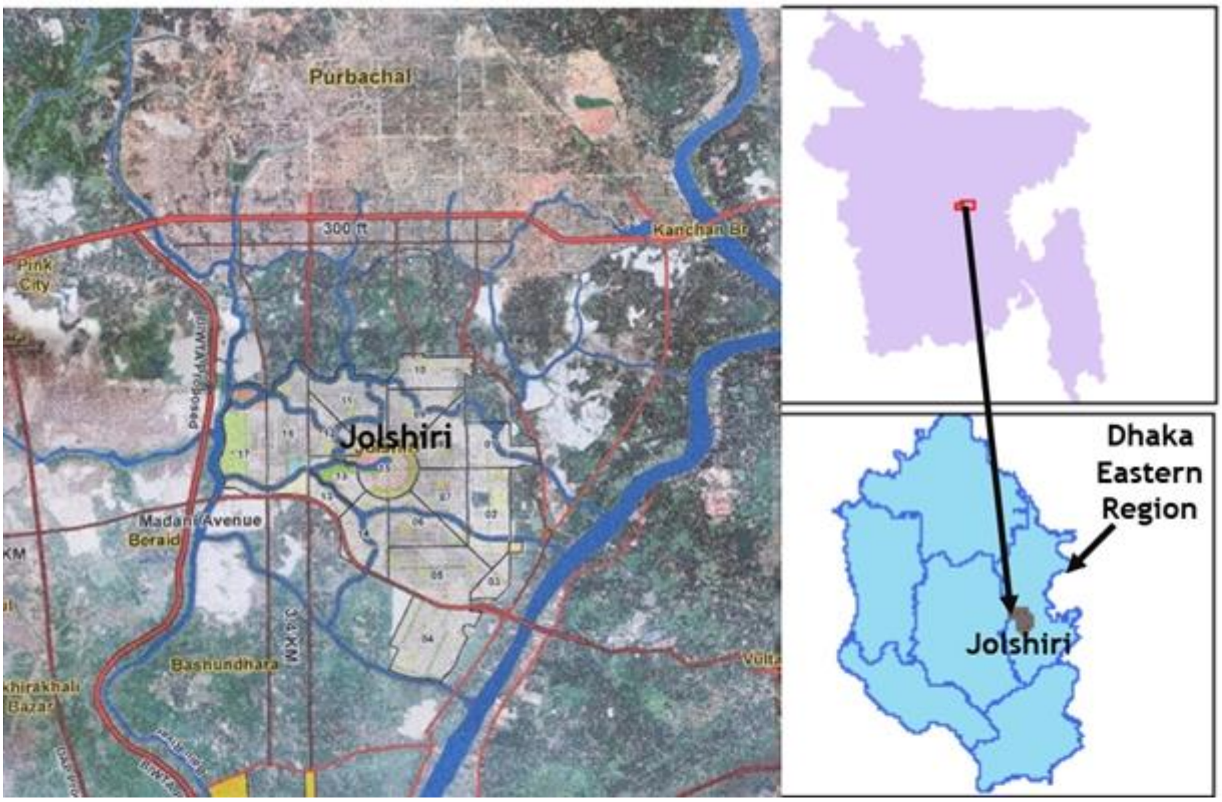

Figure 1: Regional boundary of greater Dhaka and study area Jolshiri

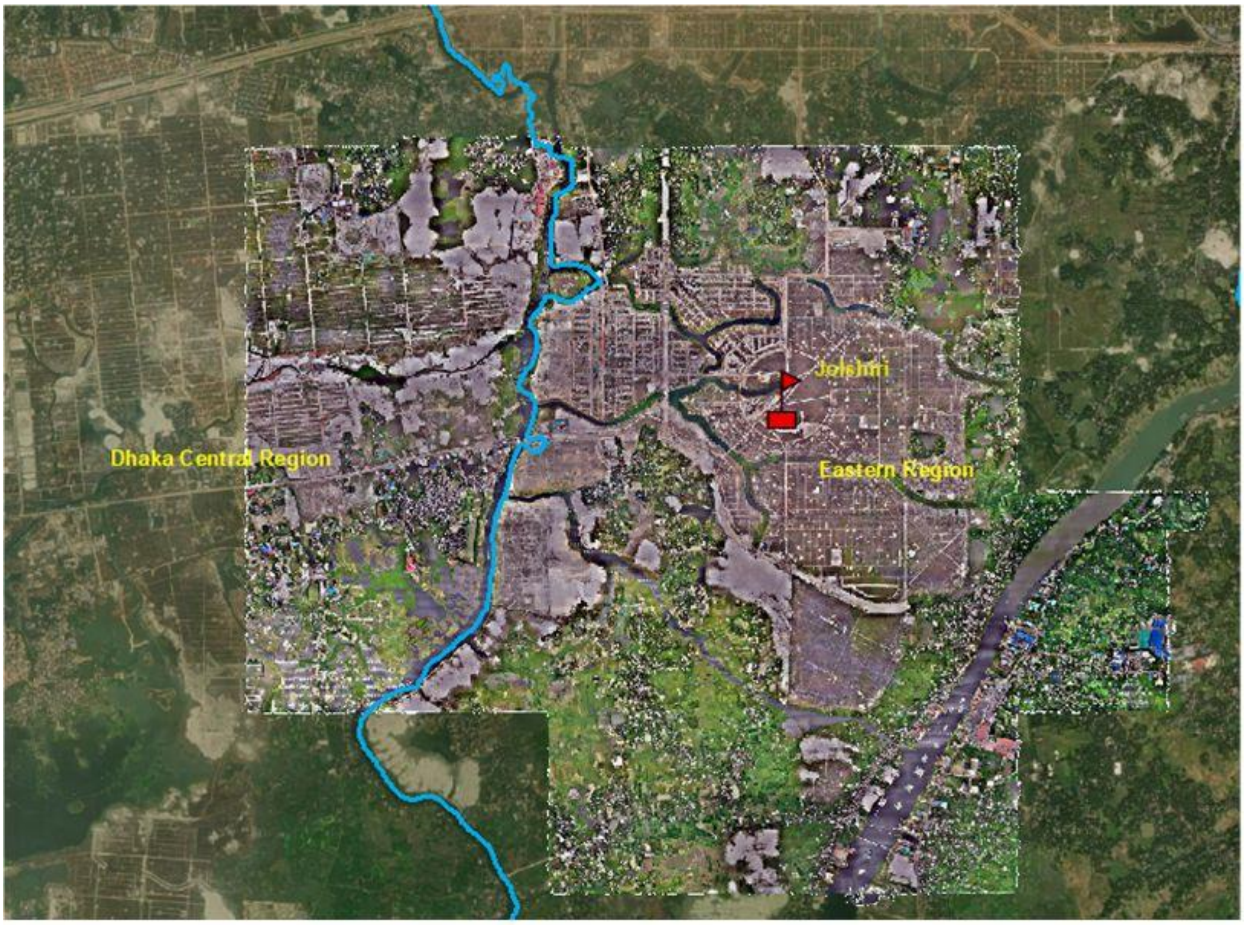

Figure 2: Orthophoto Map of Jolshiri (Source: Survey of Bangladesh (SOB), 2022)

Table 1: Generalized stratigraphic succession of study area (Source: DU, 2014)

Layer Depth (m)	Formation	Lithology
0 to 8	Filling materials	Loose to medium dense sand: Susceptible to earthquake induced liquefaction
9 to 20	Alluvium	Soft organic clay: Floodplain deposits and vulnerable to long term consolidation settlement and negative skin friction
20 to over 36	Modhupur clay and Dupi Tila	Stiff to hard clay/ dense sand: Good for foundation to rest

2.2.2 Data for Runoff Estimation

Land-use change was estimated with the infrastructure development plan of the proposed urban growth with a 5-year interval considering 2020-2022 as the pre-developed (existing condition) and 2040 and beyond as the post-developed condition indicating full-scale urbanization. The SCS-CN approach was used to quantify the direct runoff of the urban catchment with 25 years daily rainfall data (1995 to 2020) of Bangladesh Meteorological Department (BMD) for Dhaka station. Then CN was identified from the hydrologic soil groups (HSGs) of the area using SCS, TR-55 (USDA, 1986).

2.2.3 Data for Recharge Estimation

Based on the hydrogeological settings of the area, natural recharge potential was assessed using the Water Table Fluctuation (WTF) method. The water level fluctuation data (1995 up to 2015) of BWDB operated well close to the study area (Well ID GT 6768007, Rupganj, BUTM Longitude 557464.130 and Latitude 639013.940) was used for ascertaining the recharge information before the land development including the subsurface exploration data of 2014 of the study area. In addition, recent sub-surface exploration data were considered for the determination of existing GWT information of the proposed urbanization.

3. Methods

3.3.1 Trend in Land-use Change

The study area has been reclaimed with sand-filling from low-lying agricultural land to urban land. Land-use change has been observed from Landsat image data of 2010, 2012, 2016 and 2021 (Figure 3). In 2012, the land was completely filled with sands and ready for civil engineering works with further filling in 2021. DEM (Figure 4) of year 2011 signifies lower elevation of the area astride the River Shitalakkhya and Balu. Around 98% of the land was reclaimed from low-lying floodplains/ cultivable lands/ wetlands. Urban land development changed the topsoil of the area with sands and gravels with high infiltration rates as opposed to the original soils of silts and clays with low infiltration capacity. In fact, the soil profile was disturbed and altered to high infiltration soils. The onsite investigation and laboratory tests confirmed the change in soil profile from HSG ‘D’ i.e., clay loam, silty clay loam, sandy clay, silty clay, or clay to HSG ‘A’ i.e., sands which was adequately deep and well-drained with low runoff potential and rapid infiltrability greater than 7.5 mm/hour (USDA, 1986). The ultimate land development is intended with an average elevation of 8 to 8.25m SOB reference level above mean sea level. In general, surrounding areas are low-lying and flat with an average elevation of 2 to 13m SOB reference level (JICA & DTCA, 2015). With complete urbanization, the area is likely to grow as a modern township with all the urban infrastructures, amenities and facilities of urban living. According to proposed urban development by Jolshiri Authority (2015), land-use change up to 2040 and beyond has been considered with a 5-year interval as (i) Existing or Pre-Developed Land-use 2020/22, (ii) Urban Development by 2025, (iii) Urban Development by 2030, (iv) Urban Development by 2035 and (v) Full-scale Urban Development by 2040 & beyond (post-developed 100%).

3.3.2 Runoff Assessment due to Land-use Change

Runoff in general is influenced by a variety of meteorological phenomena and climatic factors. Among the important physical factors affecting runoff are the land-use, vegetation, soil type and drainage networks. The SCS model is an empirical one that requires only the Curve Number (CN) parameter which recognizes the effects of land-use change on the hydrology. Due to its minimal data input requirements, it is used for hydrological forecasting of the ungauged watersheds and the urban catchment (USDA 1986). In fact, the runoff response to rainfall is governed by two basic factors, i.e., the rainfall intensity and the soil characteristics. The infiltration losses in soils are combined with surface storage by the relation of:

$$Q = (P - I_a)^2 / P - I_a + S \tag{1}$$

where, Q = Runoff in mm, P= Rainfall depth in mm, I_a = Initial abstraction in mm; and I_a is given by the empirical relationship and S is the potential maximum retention and given by $S = (25400/CN) - 254$ mm.

The equation is rewritten as,

$$Q = (P - 0.2S)^2 / (P + 0.8S) \text{ for } P > 0.2S \tag{2}$$

$$Q = 0 \quad \text{for } P <= 0.2S$$

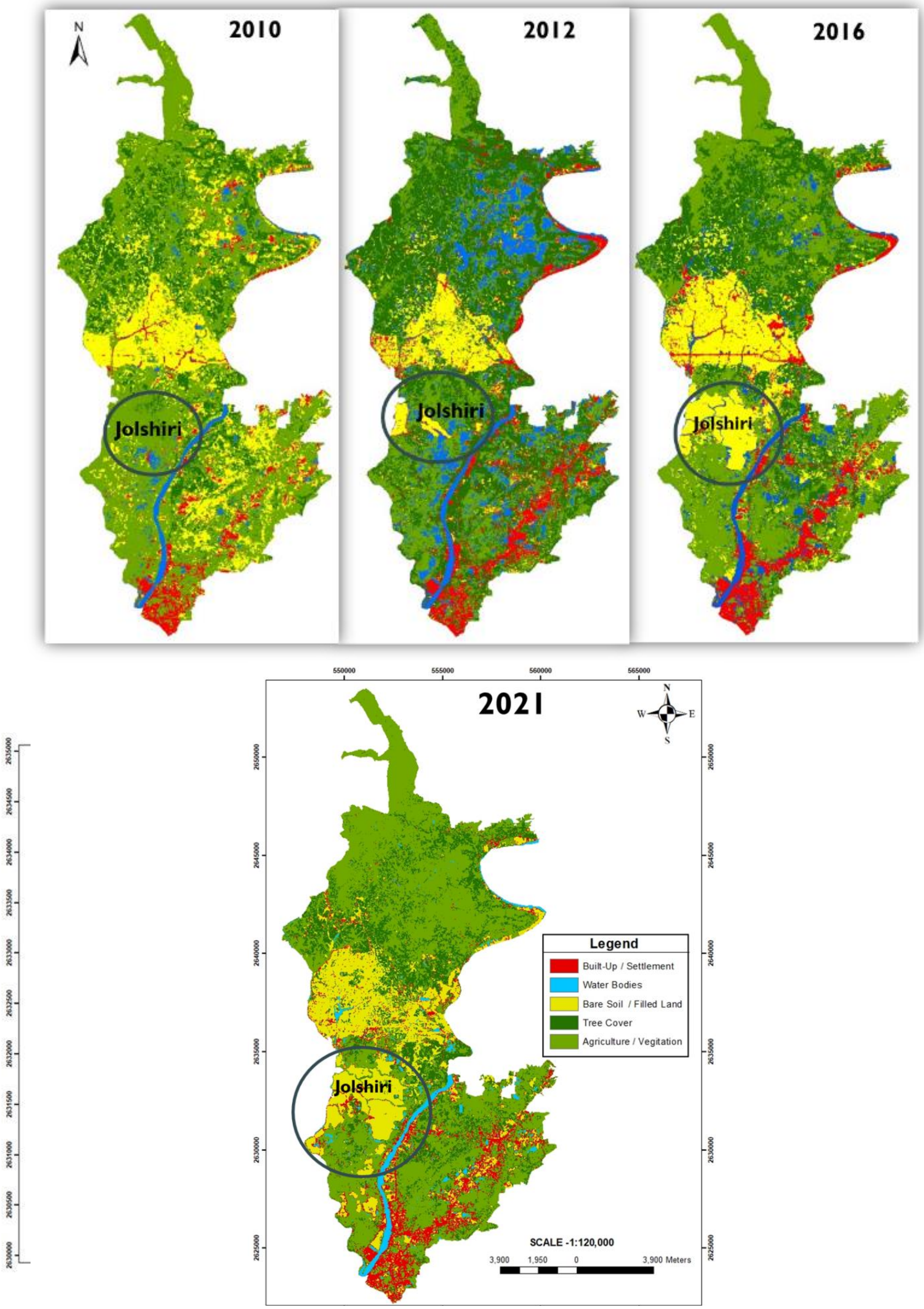

Figure 3: Land-use change of Jolshiri area

Table 2: Weighted CN for existing land-use or the pre-developed 2020-2022 condition of study area

Urban Development Existing Land-use (2020-2021) or pre-developed 2020-2021 Condition	Soil Type	Area, m^2	CN	% Area	Weighted CN (CN x %Area)
Residential Area & Community Services (65% Imperviousness)	A	0	77	0	72 (AMC II)
Impervious Areas: Paved (Roads)		1,36,417	98	2	
Impervious Areas: Paved (Utility Services)		0	98	0	
Open Space/Park/Green Space (Poor Condition)		85,822	68	1	
Open Space (Grass land)		75,84,106	68	88	
Lake (Water body)		83,0591	100	10	
Total		86,36,936		100	

Area weighted CN has been calculated for each land-use change using the following equation:

$$CN = \frac{\sum Ai * CNi}{\sum Ai} \tag{3}$$

Determination of HSGs due to land-use change is the key to assessing the area-weighted CN and runoff. With the identified CN values for each temporal land-use change, SCS-CN method was applied. Annual runoff is computed with the logical input of the SCS-CN equation in Excel spreadsheet for the daily rainfall data of each year which accounts for the average AMC, i.e., AMC II. However, all three AMC or the seasonal AMC can be integrated for precise calculation of runoff. The process is simple and illustrated by Huq and Rahman (2020) and Harbour (1994). Table 2 shows the weighted CN for existing land-use or the pre-developed 2020-2022 condition of the study area. Accordingly, weighted CN for other four land-use changes have been computed. However, the projected weighted CN due to ultimate land-use plan by 2040 and beyond (Table 3) significantly alters the existing land-use and land-cover.

3.3.3 GW Recharge Assessment due to Land-use Change

WTF method links the change in GW recharge with resulting water table fluctuations. This method is best applied to unconfined aquifers and shallow GWT that exhibits rises and declines in water level due to rainfall-fed recharge. The WTF method is expressed by Healy and Cook (2002) as:

$$R = S_y \text{ x } dh/dt \tag{4}$$

where R is the GW recharge (LT^{-1}), S_y is specific yield (dimensionless), and dh/dt is the change in height of the water table. In this study, Equation (4) is considered to estimate the natural GW recharge potential without incorporating other additional factors due to the existing high-water table in the study area that has been physically investigated and explored through sub-soil exploration in different sectors in 2021-2022.

3.3.4 State of GW Level

The key information to determine whether a pump can deliver water from the aquifer is the depth to GWT. Only one GWT observation well (GT678007 Rupganj, Narayanganj) was available close to the study area with the data of surface geology and lithological sequence of the well location. Noting the data discontinuity from 2007 to part of 2009, minimal GWT decline has been observed in between 1995 to 2015 (Figure 5).

Seasonal variations in GWT were observed due to varying rainfall intensity during pre-monsoon (April and May) and the monsoon season (June to September). With a gradual rise in GWT from June to September maximum fall around 2 m was observed during pre-monsoon between 1995 to 2015. In general, shallow GWT was identified between 1 to 6m below existing ground level (EGL). Above GWT situation was validated from the sub-surface borehole lithology of the study area that was varying in between 0.5 m to 7.5 m in 2014/2015 (DU, 2014). Sand-filled top soil of the area was ranging between 2.5 m to 8.5 m. However, inadequate observation wells and data discontinuity of the GWT information were the key limiting factors to quantify the natural recharge of the area.

3.3.5 Estimation of GW Recharge by WTF Method

Determination of annual average GWT rise with the key requirement for applying the WTF method. Considering the maximum declination of GWT from 1995 to 2015, GW level rise was identified for the year 2015. However, Specific yield values (Table 4) were considered from the Sinha and Sharma (1988) and validated from the available lithological data of the area.

The average annual natural recharge potential (around 284 mm) of the area before the commencement of urban development is given at Table 5. Difficulty in precise quantification of recharge results from the consideration of specific yield (S_y) values. This is why, a broad range of values were considered to compute the natural recharge. Alongside, other influencing factors of recharge such as GW mining, base-flow from rivers, evapotranspiration, irrigation, etc that are not considered in the study may have substantial impact on the overall recharge process.

After the completion of land filling with sands in 2016, GWT has increased significantly. Recent field data in different sectors in 2020 and 2021 reveal that GWT exists on an average below 1.87m to 2.27m below existing ground level (EGL). Table 6 shows the recently explored GWT data from different sectors of the study area.

Table 3: Weighted CN for ultimate land-use change during 2040 and beyond as per detailed land-use plan

Urban Development by 2040 & beyond or post-developed condition	Soil Type	Area, m^2	CN	% Area	Weighted CN (CN x %Area)
Residential Area & Community Services (65% Imperviousness)	A	3448734	77	40	84 (AMC II)
Impervious Areas: Paved (Roads)		2727546	98	31	
Impervious Areas: Paved (Utility Services)		227353	98	3	
Open Space/Park/Green Space (Poor Condition)		541267	89	6	
Open Space (Grass land)		858136	49	10	
Lake (Water body)		830496	100	10	
Total		86,36,936		100	

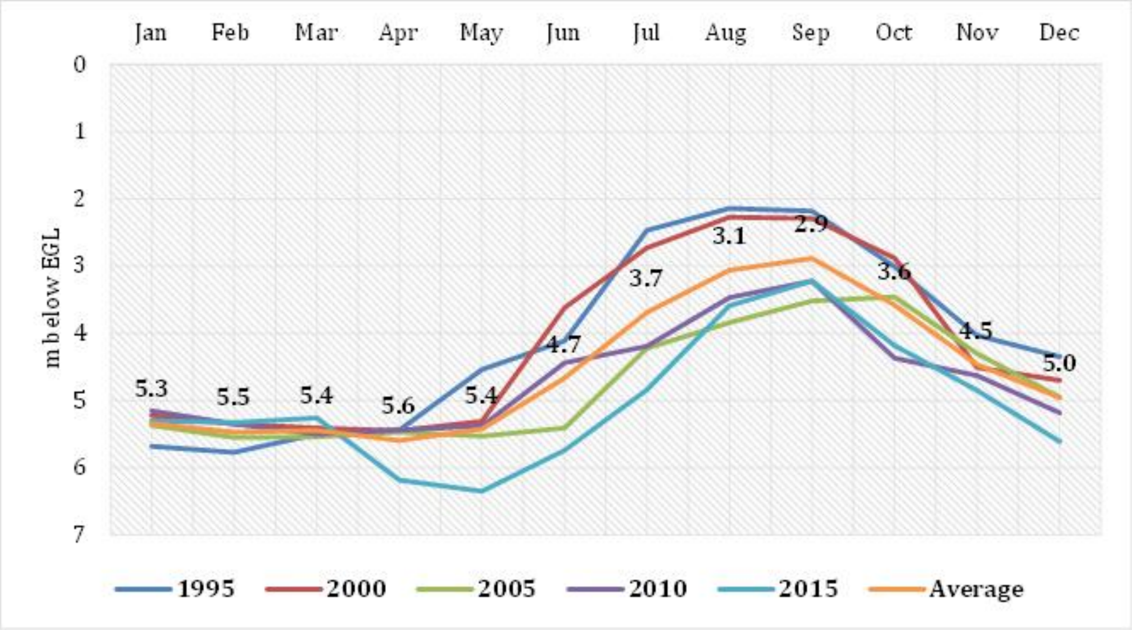

Figure 5: GW Table fluctuations at Rupganj, Well ID: GT 67668007 (Source: BWDB, 2015)

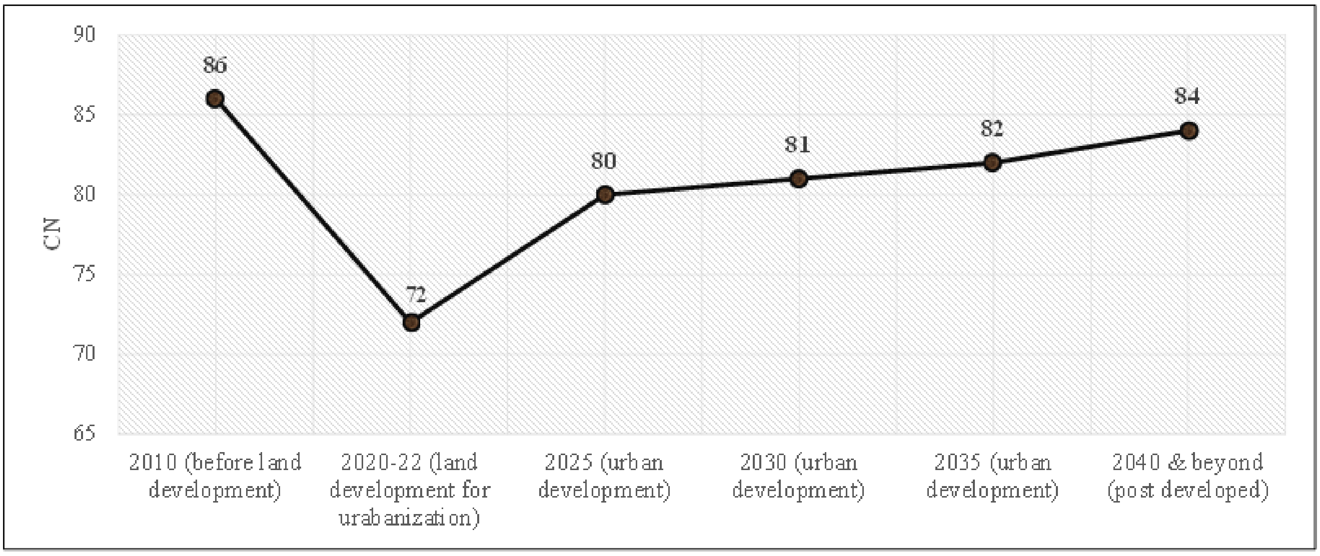

Figure 6: Impact of temporal land-use change on CN

4. Results and Discussion

Based on the temporal change in the land-use change, overall impact on natural water cycle was assessed for the growing urbanization. The obtained results and discussion are presented below:

4.1 Impact of Temporal Land-use Change on CN

The temporal change in the land-use along with the change in CN is projected in Figure 6. The higher CN 86 before land development in 2010 sharply plummeted to CN 72 due to land-development with pervious soils, i.e., sands. It is quite conclusive that the land-use change is not always detrimental when the proposed land is developed with pervious soils over the impervious soils. In fact, the existing land-use denotes a low CN 72 due to insignificant imperviousness in the area which possesses a favourable condition for increased recharge and reduced runoff. In view of the proposed infrastructure development plan, CN is estimated for each urban development caused by a 5-year time interval. A distinct leap of CN 80 is observed in 2025 due to substantial imperviousness caused by the development of urban infrastructures such as schools, road networks, stormwater and wastewater drainage facilities of the entire area (35% of total land-use) so that residential development is facilitated for the living population. Slower increase in CN is observed over the next 15 years due to gradual development of residential and other infrastructure facilities. In 2030 and 2035 condition, land-use change is mostly related to residential and commercial development which will have a slower pace with CN 81 and 82 respectively. Using the existing rules of floor area ratio (FAR), maximum ground coverage (MGC), side and rear separation distances as per Building Construction Rules (2008), BNBC (2020), DAP-2022-35; land-use change is likely with 61% imperviousness during the full-scale urban growth in 2040 and beyond which closely exposes a high-density residential development with CN 84 (USDA, 1986; Ward et al., 2004). Due to temporal change in the land-use, change in CN has an increasing tendency that would result in more imperviousness.

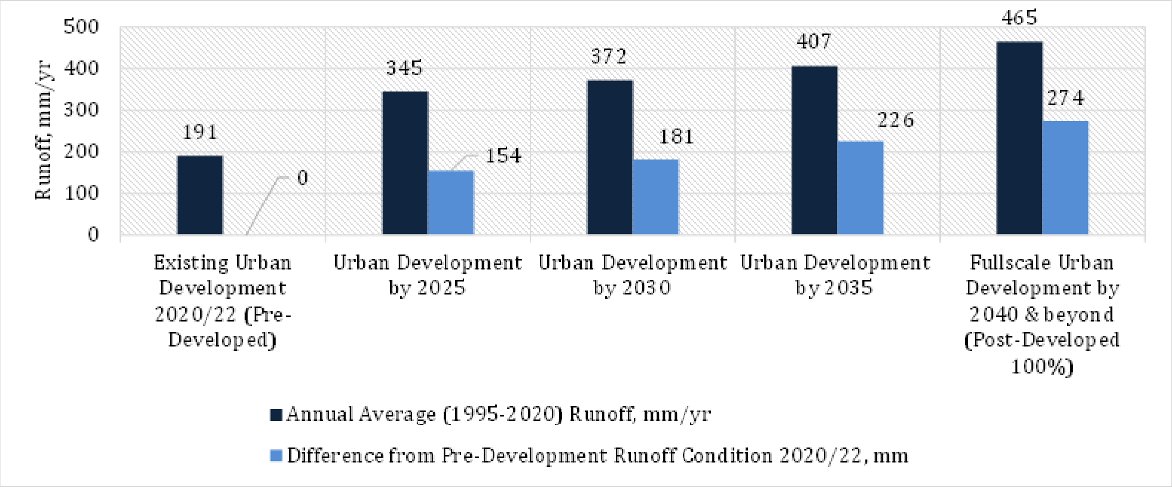

Figure 7: Impact of land-use change on runoff (Source: Author's assessment applying SCS-CN)

Table 4: Specific Yield (S_y) for recharge calculations (Source: Sinha and Sharma, 1988)

Material	Range of Specific Yield (S_y)
Sandy alluvium	0.12-0.18
Valley fills	0.10-0.14
Silt/clay rich alluvium	0.05-0.12

Table 5: GW recharge estimates by WTF method before land development (Source: BWDB, 2015)

GW Observation Well	Maximum GWT m below EGL/yr	Minimum GWT m below EGL/yr	Average GWT Rise (m)/yr	GW Level Rise (mm/yr)	Specific Yield, Sy	Natural Recharge (mm)
Rupganj (Narayanganj) GT6768007	6.48	3.13	3.35	3350	0.05-0.12 (clay rich alluvium)	167-402

4.2 Impact on Runoff

Annual runoff evaluation applying SCS-CN method involves CN assessment due to land-use change. In fact, change in CN is closely associated with the temporal changes in the original landscape, soil profile, soil permeability, and soil moisture of the area. Urbanization triggered diverse impact on runoff due to changes in CN. The resulting runoff variations are appended with the increase in CN in Table 7. Lower CN in pre-developed (2020-2022) condition resulted in lower runoff. In fact, higher the CN, higher the runoff potential of the urban catchment.

Gradual variations in runoff were determined from the representative existing or pre-developed 2020-2022 condition. The resulting annual average runoff and percentage increase in runoff from pre-developed 2020-2022 condition are graphically plotted in Figure 7. The temporal impact of land-use changes on annual runoff significantly increased from the pre-developed (2020-2022) as 191 mm to post-developed (2040 and beyond) as 465 mm. The percentage increase in post-developed condition is 243% compared to pre-developed condition (Figure 8). While computing the runoff as percentage of rainfall from pre-developed condition, it increases from 9.58% to 23.30% in post-developed condition. The volumetric assessment (Figure 9) of the runoff reveals that approximately 3996 million litres/yr or 11 million litres of water/day (MLD) will be generated as runoff when the study area will be completely urbanized as per proposed plan. If properly planned, the progressive runoff volume can be managed efficiently either to reduce stormwater drainage or integrate in the overall urban water management plan by rainwater harvesting (RWH) and artificial GW recharge. If all stormwater were harvested during full-scale urbanization and the prospective population of the study area could be served with 135 litres/day/person (lpd) as per BNBC 2020, approximately 80,000 population per day. Apart from this, options remain for distributed runoff management as well.

Table 6: GWT data of 2020 and 2021 of the study area

Sector	GWT (from) m below EGL	GWT (to) m below EGL
Sector-6	1.25	1.75
Sector-11	1.5	1.75
Sector-11	1.25	1.5
Sector-17	1.5	2
Sector-13	1	1.5
Sector-14	1	1.25
Sector-16	1.5	2.5
Sector-16	1.25	1.75
Sector-11	1.5	1.75
Sector- 5	1.37	1.52
Sector-13	3.05	3.65
Sector-13	2.45	2.6
Sector- 11	2.74	3.35
Sector- 14	2.39	2.59
Sector- 12	3.8	4
Sector- 11	2.44	3.05
Sector- 16	1.87	2.08
Average	1.87	2.27

4.3 Impact on Natural Recharge

The impact of temporal land-use change on natural recharge is primarily influenced by recharge loss. However, the actual or net recharge is likely to be dependent on both recharge loss and GW abstraction. Acute reliance on GW abstraction without surface water supply provision is likely to cause an induced recharge phenomenon in the area. Although no induced recharge is considered in this study the population change dynamics due to land-use change and requirement of GW abstraction need substantial attention to compute the impact on GW recharge.

Presence of unconfined shallow GWT with varying depth between 0.5 to 7.5 m below EGL confirmed the use of WTF method for GW recharge estimation. Annual GWT rise (before reclaiming the land) from the BWDB operated GW observation well was averaged as 3.35 m below EGL. GWT fluctuations characteristically showed recharge potentiality of the study area with seasonal monsoon rainfall. With average specific yield values for clay rich alluvium as 0.05 to 0.12, annual average GWT rise resulted in an annual average natural recharge of 284 mm. Considering the GWT rise after the land development and specific yield values for valley fills as 0.10 to 0.14, the annual average recharge potential of the area has increased to 527 mm with an increase in GWT rise to nearly 4.41m. The natural recharge potential of the study area without other influencing factors and recharge loss for the pre-developed 2020/22 condition is 527 mm and consequent changes due to land-use change are shown in Figure 10.

Having considered the runoff of pre-developed 2020/22 conditions as reference level, the average annual recharge loss is determined for other four temporal land-use changes. As CN increases due to land-use change, runoff and recharge loss also increase. With the gradual urbanization, natural recharge potential of the study area has declined compared to pre-developed 2020/22 conditions. A sharp fall from 527mm (2020/22) to 373mm in recharge is observed in 2025 due to significant increase in runoff and recharge loss. During full scale urban growth, the natural recharge potential of the study area is likely to reduce less than 50% of the existing recharge potential. Figure 11 shows zero recharge loss in the pre-developed 2020/22 condition and increasing recharge loss with the gradual urbanization process. During full-scale urbanization in 2040 and beyond, recharge loss in volume is estimated as 2354 million litres/yr or 6.48 MLD (approximately) which could potentially recharge the GW level of the study area.

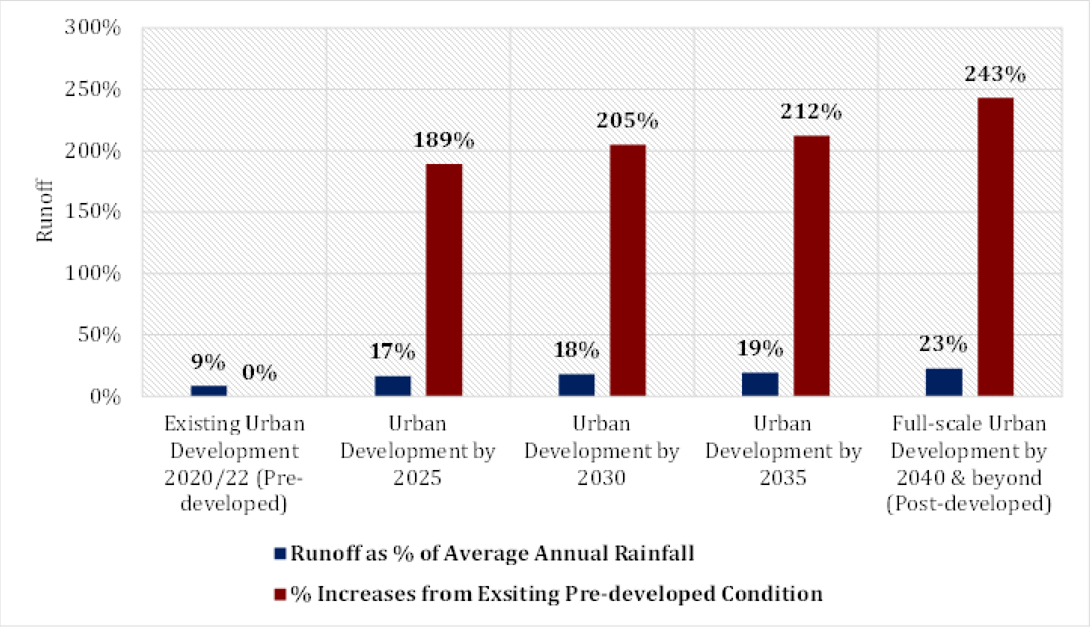

Figure 8: Percentage change in runoff due to land-use change

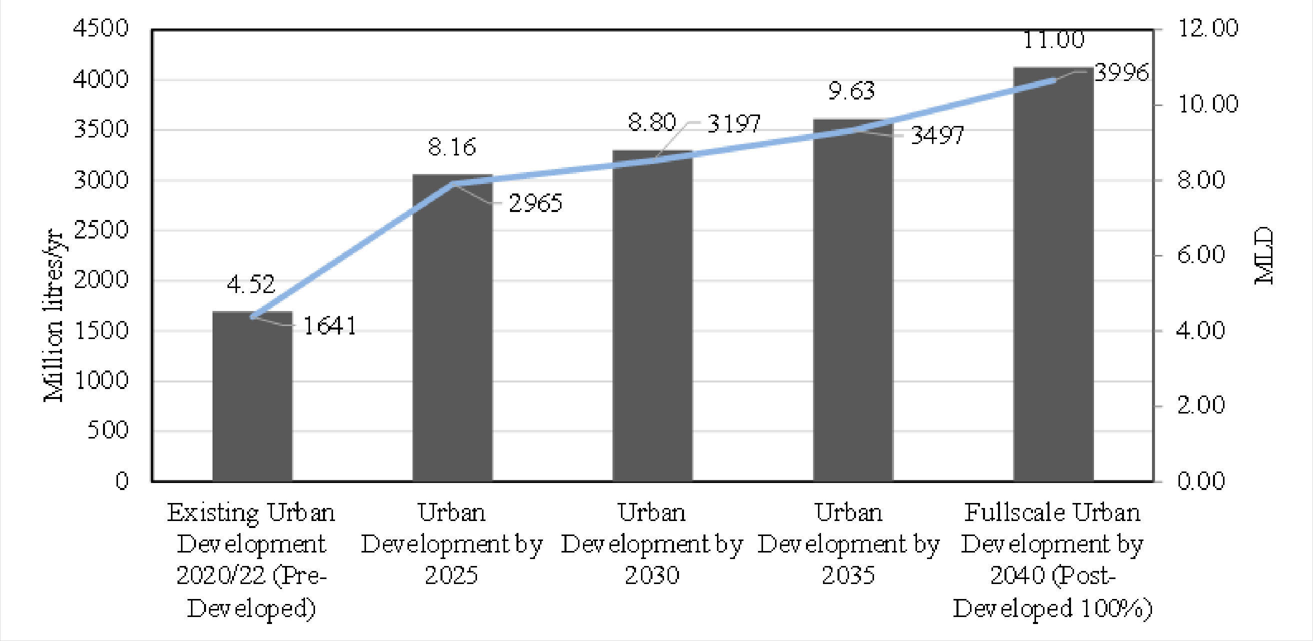

Figure 9: Stormwater runoff volume due to land-use change

4.4 Overall Assessed Impact on Water Cycle

Overall impact of land-use change on water cycle is the combined effect of runoff and natural recharge. The overall assessed impact due to land-use change is shown at Figure 11.

The identified impacts of land-use change on runoff and recharge projected a similar trend. The existing or the pre-developed (2020/22) land-use condition (CN 72) generated an annual average runoff of 191 mm and a natural recharge potentially 527 mm without recharge loss. The overall impact followed an increasing trend for runoff and recharge loss and a decreasing trend for natural recharge up to full-scale urban growth in 2040 and beyond. In fact, predicted urban development scenarios revealed the severity of impacts on runoff and recharge. In fact, higher CN resulted higher runoff and recharge loss, but lowered the natural recharge potential. The ultimate CN 84 resulted significantly higher annual average runoff as 465 mm and reduced annual average recharge as 253 mm in the proposed urbanization.

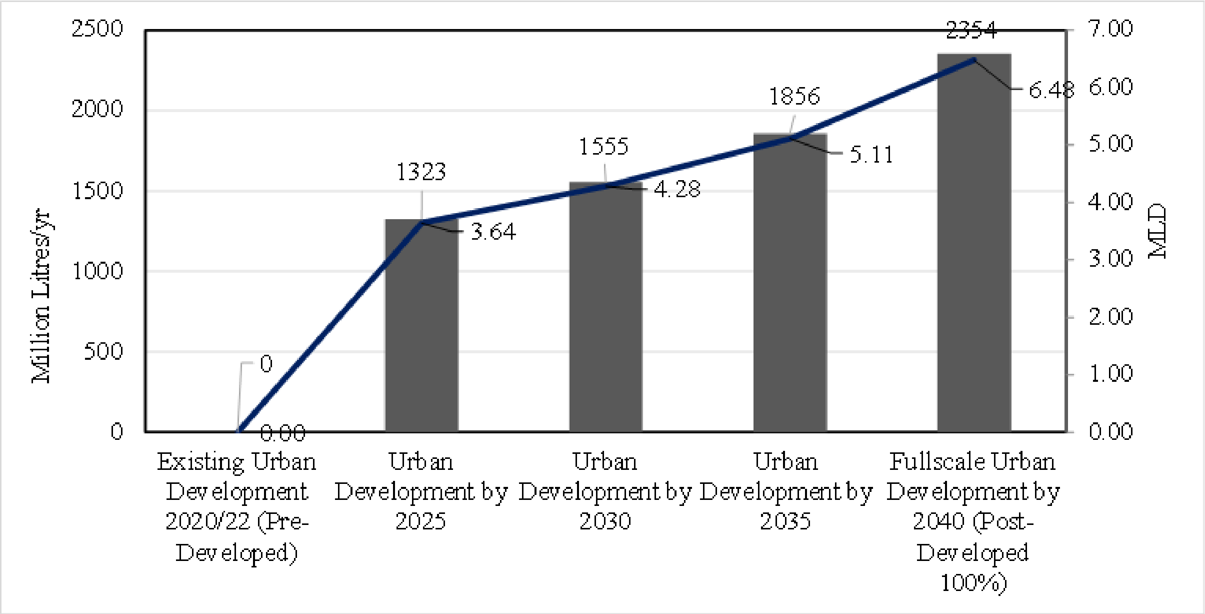

Figure 10: Annual potential loss of GW recharge (1995-2020 average)

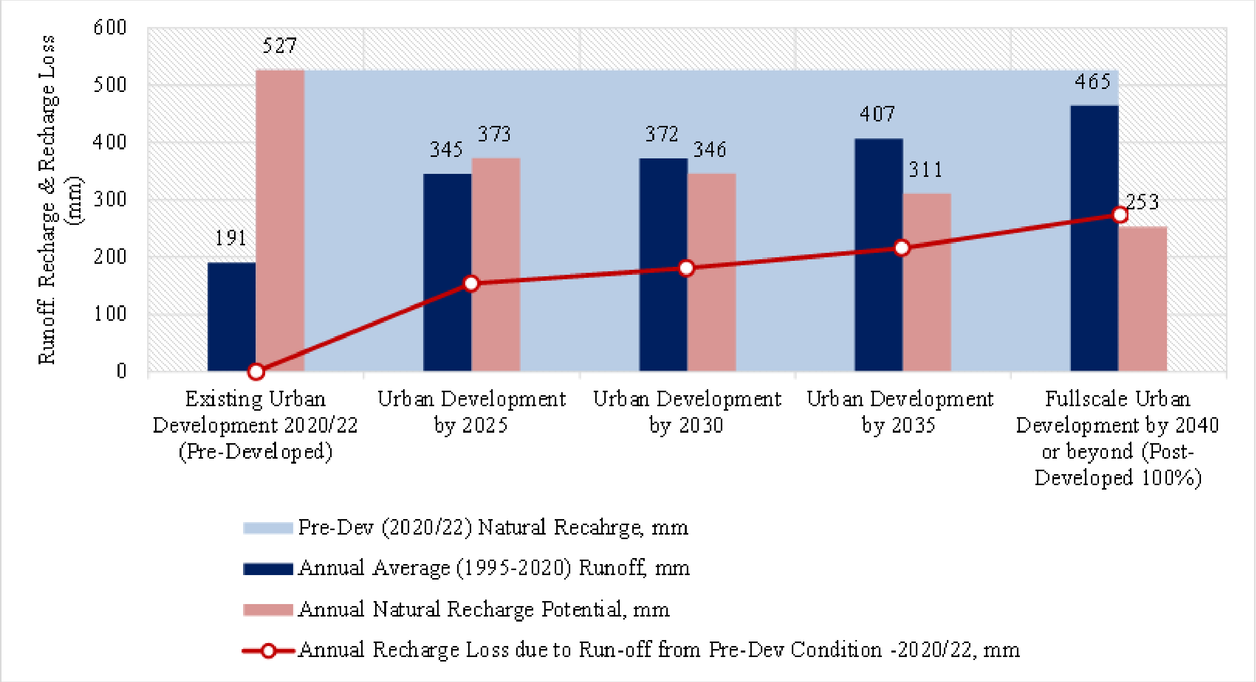

Figure 11: Overall impact of land-use changes on water cycle

4.5 Discussion

The study area is very close to DCR and located at the centre of DER. The land is reclaimed from the low-lying flood plains of two major rivers of greater Dhaka. The proposed urban growth is included in DAP and awaiting its full-scale development by 2040 and beyond. As the land-use change is inevitable for the study area, CN analysis with gradual infrastructure development projects an initial low density urban development followed by high density urban development with increased imperviousness. Identification and quantification of weighted CN is quite comprehensive for the study area as the soil profile remains unchanged during the temporal land-use change. Pre-developed 2020/2022 condition of the land-use reveals a low CN (72) for the study area because of less imperviousness and more pervious soil profile. In 2025, a sharp leap in CN 80 is observed because of the increased paved surfaces with roads and other utility services in the study area. For the next 15 years CN will increases slowly as CN 81 in 2030, CN 82 in 2035 and CN 84 in 2040 and beyond due to the slower pace of imperviousness in the land. The ultimate land-use change of the study area is likely to result in approximately 63% imperviousness during complete urbanization which closely reveals a high-density residential development. The projected population of urban growth also validates high-density urban development. In order to achieve the liveable density, urban development control tools of Dhaka city development need revision. However, if 84 is the limiting CN, more pervious surfaces need to be integrated in the overall land-use plan of the proposed urbanization so that the natural water cycle is balanced. If the urban infrastructure development follows strict monitoring and compliance of existing land-use rules, policies and BNBC 2020, greater Dhaka can ensure sustainable urban living. However, the DAP-2022-35 provides the opportunity of greater FAR leverage for the proposed urbanization that may contribute to more imperviousness and hence more runoff.

Table 7: Runoff potential due to temporal land-use change

Year	Rainfall (mm)	Runoff (mm) CN 72 (Pre-developed 2020-2022 Condition)	Runoff (mm) CN 80 (Urban Development by 2025)	Runoff (mm) CN 81(Urban Development by 2030)	Runoff (mm) CN 82 (Urban Development by 2035)	Runoff (mm) CN 84 (Full-scale Urban Development by 2040 & beyond-Post Developed 100%)
1995	1780	138	284	309	336	395
1996	2045	199	370	401	429	499
1997	2033	110	250	275	445	364
1998	2328	274	470	503	538	615
1999	2428	374	613	650	688	772
2000	1866	281	401	424	446	504
2001	1719	91	200	227	242	291
2002	1690	67	179	199	222	273
2003	1896	142	287	311	337	395
2004	2335	450	663	697	733	811
2005	2366	265	455	490	523	610
2006	2014	226	405	436	467	539
2007	2733	339	602	645	690	791
2008	2230	183	378	410	445	522
2009	2043	410	545	568	594	650
2010	1485	96	202	220	239	282
2011	1943	129	251	273	322	351
2012	1402	48	115	127	142	177
2013	1874	164	293	315	339	394
2014	1643	102	231	253	278	334
2015	2315	199	404	439	476	560
2016	1365	38	108	123	137	174
2017	2892	405	694	740	788	896
2018	1732	74	176	208	231	285
2019	1837	70	183	204	229	285
2020	1880	92	215	236	263	320

In general, SCS-CN technology involves average moisture condition (AMC II) for hydrological impact assessment. CN with AMC II provides a generalized runoff situation of the urban catchment. More precision in runoff estimate is achievable with the seasonal variation of AMC (Huq 2020). With the land-use change and increasing CN, runoff has gradually increased. The total runoff during the complete urban growth will generate more than 50% of the existing runoff. Consequently, there will be similar increase in recharge loss. The study area has good recharge potential with an annual average of 527 mm in pre-developed 2020/22 condition which will gradually reduce due to land-use change and increasing CN. Apart from increased runoff, more imperviousness or the lack of rechargeable surfaces in the land-use may significantly reduce the potential recharge scopes within the area. The proposed urbanization will be relying on GW for water demand management. However, long-term reliance on GWwould have an adverse impact on natural GW recharge capability of the area. As increased GW abstraction leads to lowering the GWT, make dewatered upper geological formation with increased effective pressure and vulnerability to land subsidence, it would result mining of water from deep aquifers to support the water demand of the population which is typical in central Dhaka. In fact, higher the density of urbanization, higher the challenges to maintain the hydrological balance of the urban area.

Assessed hydrological impacts are simply the temporal hydrological forecasting of the study area due to land-use change. This would help the city authority or the urban planners to manage the stormwater runoff in different ways as the township grows. Progressively increased runoff can be managed by a separate stormwater drainage system linked with flowing rivers and canal networks with the provisions of RWH and artificial recharge to reduce the drainage load, minimize the recharge loss and optimize the cost of the stormwater drainage system. This would otherwise help achieve the overarching goals stated in BDP 2100 and SDG 6 and 11 to have environmentally sustainable and water resilient cities. As full-scale urban development is time dependent, distributed runoff management including the use of stormwater for assorted urban demand management would help minimize the overall water demand from the landscape. If the full-scale urban growth is developed with identified CN 84, it would necessitate revised urban development control tools to have a low impact urban development or to implement sustainable water management practices for high density urban development and maintain the natural water demand from the landscape. If the full-scale urban growth is developed with identified CN 84, it would necessitate revised urban development control tools to have a low impact urban development or to implement sustainable water management practices for high density urban development and maintain the natural water cycle balance for the proposed urbanization.

5. CONCLUSIONS

Unceasing urban development is altering the original landscape of greater Dhaka very rapidly. The study area located in greater Dhaka is reclaimed from the low-lying cultivated land and expected to grow as a modern eco city by 2040 and beyond. The temporal land-use change as weighted CN is determined by increased imperviousness and linked to estimating runoff with SCS-CN method. The runoff computation by historical rainfall data by SCS-CN method is not intended to provide precise stormwater runoff estimates for exclusive use in urban planning. However, the method is inclusive to suggest the relative impacts of assorted land-use change on stormwater runoff and natural recharge.

Assessments of temporal land-use change and consequent increase in runoff volume can be a useful tool to understand the state of GW recharge for the area in study. The reduced recharge scenario would help decide whether or not to rely on GW abstraction for the urban population. To comprehend the temporal GW recharge settings, state of existing natural GW recharge of the area is essential to evaluate the changes in recharge scenario due to land-use change. Considering the localized GW condition and lithological sequence of the reclaimed land, WTF method appears as a feasible option to assess the existing state of GW recharge of the proposed urban area. By comparing the identified maximum recharge loss to natural recharge rates, it is possible to assess whether the degree of impact due to land-use change is significant or not in the local context.

The overall assessed impacts of land-use change on runoff and recharge are practically useful for temporal prediction of the hydrological balance of the urban area as well as for identifying the concerns linked with increased imperviousness on a reclaimed land. The procedures and results explained for assessing the impacts of land-use change on natural water cycle can be easily computed, assessed and used for such urban growth or local level city planning including wide-ranging options for decision making on sustainable urban water cycle management. As the study area is well connected with two major rivers and internal canal networks, increased runoff and reduced recharge phenomena of the proposed urban growth can be offset sustainably with distributed runoff management and recharge options. RWH and artificial GW recharge are two easily implementable options for the reclaimed land to lower the peak discharges due to intense rainfall as well as to reduce the drainage load and cost of stormwater drainage development and management. Alongside, unavoidable recharge loss may also be lessened with low density urban development, revised urban development control tools and more pervious landscape.

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REFERENCES

BIGD 2019 *State of Cities 2018: Water Governance in Dhaka*, Brac Institute of Governance and Development (BIGD), Brac University, Dhaka, Bangladesh. https://bigd.bracu.ac.bd/publications/state-of-cities-2018-water-governance-in-dhaka/

Bird, J., Li, Y., Rahman, H. Z., Rama, M. & Venables, A. J. 2018 *Toward Great Dhaka: A New Urban Development Paradigm Eastward Directions in Development*, Washington, DC: World Bank, 2018.

BWDB 2011 *Quantification of Gradual Fall of Ground Water Table of Dhaka City in Bangladesh*, Report by the Bangladesh Water Development Board (BWDB) in 2011.

Demographia 2021 World Urban Areas, 2021. *Built-Up Urban Areas or Urban Agglomerations*, 17th Annual Edition, 2021. Available: http://www.demographia.com/db-worldua.pdf

DU 2014 *A Report on Geological and Geotechnical Engineering Survey for Proposed Jolshiri Abashon*, Department of Disaster Science of Management, University of Dhaka.

DWASA 2020 *Annual Report 2020*, Dhaka Water Supply and Sewerage Authority (DWASA), Dhaka, Bangladesh.

GOB 2008 *Dhaka Megacity Building Construction, Improvement, Preservation and Removal Rules*, Bangladesh Gazette, 29 May 2008, Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh. https://www.dpp.gov.bd/bgpress/index.php/document/extraordinary_gazettes_month_wise/2008

GOB 2018 *Bangladesh Delta Plan 2100*, Baseline Studies on Water Resources Management, Volume 1, Part A, General Economics Division. Bangladesh Planning Commission, Ministry of Planning, Government of the People's Republic of Bangladesh. https://bdp2100kp.gov.bd/

GOB 2020 *Bangladesh National Building Code (BNBC) 2020*, Bangladesh Gazette, 11 February 2020, Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh.
https://www.dpp.gov.bd/bgpress/index.php/document/get_extraordinary/39201

GOB 2022 *Detailed Area Plan (DAP) 2022-35*, Bangladesh Gazette, 2 August 2022, Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh. https://rajuk.portal.gov.bd/sites/default/files/files/rajuk.portal.gov.bd/miscellaneous_info/2ff79c67_bbcb_4836_aae3_de29725abe44/2023-08-06-05-58-9f77d3ce0d888a01ea1d8cf440e986dd.pdf

Harbor, J.M. (1994) A Practical Method for Estimating the Impact of Land-Use Change on Surface Runoff, Groundwater Recharge and Wetland Hydrology, *Journal of the American Planning Association*, 60(1), pp. 95-108.

Healy, R. W. and Cook, P. G. (2002) Using Groundwater Levels to Estimate Recharge. *Hydrogeology Journal*, vol. 10, pp. 91-109.

Hoque, M.A., Hoque, M.M., and Ahmed, K.M. (2007) Declining Groundwater Level and Aquifer Dewatering in Dhaka Metropolitan Area, Bangladesh: Causes and Quantification, *Hydrogeology Journal*, vol. 15, pp. 1523–1534.

Huq, M. H. and Rahman, M. M. 2020 Land-Use and Land-Cover Change in Dhaka Eastern Region and its Impact on Surface Run-off. *MIST International Journal of Science and Technology*, 8(1), 35–47. DOI: https://doi.org/10.47981/j.mijst.08(01)2020.169(35-47).

Huq, H. M. 2017 *A Study on Land-Use and Land-Cover Change of Dhaka Eastern Region and Its Impact on Water Cycle*, Master's Thesis, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, (BUET Library).

Iftekhar, M.S. & Islam, M.R. (2022) How to transform Dhaka into a water sensitive city? *Urban Water Journal*, DOI: 10.1080/1573062X.2022.2026983.

Islam, M.S., Aramaki, T. & Hanaki, K. 2005 *Development and Application of an Integrated Water Balance Model to Study the Sensitivity of the Tokyo Metropolitan Area Water Availability Scenario to Climatic Changes*. Water Resour Manage 19, 423–445 (2005). https://doi.org/10.1007/s11269-005-3277-1

IPCC 2022 *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

JICA & DTCA 2015 *The Project on the Revision and Updating of the Strategic, Transport Plan for Dhaka*, Draft Final Report. https://dtca.portal.gov.bd/sites/default/files/files/dtca.portal.gov.bd/page/ff5b3474_c035_49d2_9d4e_092a74fd8a8e/DFR_UrbanTransport%20Policy%20%28Edited%29.pdf

Jolshiri Authority 2015 *Masterplan of Jolshiri Residential Development*, Dhaka, Bangladesh. https://jolshiri.army.mil.bd/

Karim, K. R. (2014) Trends of Permanent Wetland Change in Detailed Area Plan of Dhaka, *American Journal of Water Resources*, vol. 2, no. 5, pp. 106–09, 2014.

RAJUK (2015) *Dhaka Structure Plan (2016-2035)*, Regional Development Planning (RDP), Rajdhani Unnayan Kartripakkha (RAJUK), Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh. https://rajuk.portal.gov.bd/sites/default/files/files/rajuk.portal.gov.bd/page/0a05e9d0_03f7_48e4_bfd5_cad5fbcd5e23/2021-06-22-08-35-c8b98a96d0cadc8d87fa1c61f56966bb.pdf

Shamsudduha, M., Chandler, R. E., Taylor, R. G. & Ahmed, K. M. (2009) Recent Trends in Groundwater Levels in a Highly Seasonal Hydrological System: the Ganges-Brahmaputra-Meghna Delta, *Hydrol. Earth Syst. Sci*., vol. 13, pp. 2373–2385.

Sinha, B.P.C. & Sharma, S.K. (1988) Natural ground water recharge estimation methodologies in India. In Estimation of natural groundwater recharge (pp. 301-311). *Springer*, Dordrecht.

Subrina, S. & Chowdhury, F. K. (2018). Urban Dynamics: An undervalued issue for waterlogging disaster risk management in case of Dhaka city, Bangladesh, *Procedia Engineering*, vol. 212, pp. 801-808.

UN 2018 *World Urbanization Prospects: The 2018 Revision*. New York: Department of Economic and Social Affairs, Population Division, UN. https://www.un-ilibrary.org/content/books/9789210043144

UN 2022 *Sustainable Development Goals Report 2022*, New York: Department of Economic and Social Affairs, Sustainable Development, UN. https://unstats.un.org/sdgs/report/2022/

UNESCO 2019 *The United Nations World Water Development Report 2019: Leaving No One Behind*, UNESCO World Water Assessment Programme, Paris, UNESCO. https://www.unesco.org/en/wwap/wwdr/2019

UNESCO 2020 *UN-Water 2020: United Nations World Water Development Report 2020: Water and Climate Change*, Paris, UNESCO. https://www.unwater.org/publications/un-world-water-development-report-2020

UN-Habitat 2020 *World Cities Report 2020- The Value of Sustainable Urbanization*, United Nations Human Settlements Programme. https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf

USDA 1986. *Soil Conservation Service, Urban Hydrology for Small Watersheds,* Technical Relese: TR-55, Washington, DC. https://www.nrc.gov/docs/ML1421/ML14219A437.pdf

Ward, A.D., Trimble, S.W. and Wolman, M.G. 2004 *Environmental Hydrology*, 2nd Edition, Lewis Publishers, CRC Press.

World Bank 2018 *Enhancing Opportunities for Clean and Resilient Growth in Urban Bangladesh, Country Environmental Analysis 2018*, World Bank, Washington, DC. https://elibrary.worldbank.org/doi/abs/10.1596/30558