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Land-Use and Land-Cover Change in Dhaka Eastern Region and Its Impact on Surface Run-off

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ABSTRACT

The aim of this study is to identify the impending urbanization-led land-use and land-cover (LULC) change of Dhaka Eastern Region (DER) and assessing its impact on surface runoff. Remotely sensed image data and proposed land-use plans for DER is analyzed and mapped in this study to detect the changes of LULC. A faster pace of land transformation was observed during 2016-17 from unpaved to the paved surface. Four post-developed LULC scenarios were predicted from the classified Landsat imagery of 2016-17 with increasing imperviousness. Runoff was estimated by SCS-CN method integrating RS and GIS tools. LULC changes according to land cover classes were assimilated with the hydrologic soil groups and then runoff depths were estimated for annual rainfall events in DER. Like the slower trend of urbanization, area-weighted CN also increased slowly during 2016-17 but followed a moderate leap in RDP and scenario-1. However, CN dropped in scenario-2 mainly due to the change in land-cover by infilling of highly permeable hydrologic soils. Predicted scenario-3 and 4 resulted in higher CN respectively because of increasing imperviousness in LULC. Higher CN resulted in higher runoff and more drainage requirements. RDP scenario or the predicted scenario-1 with CN 84 is potentially a viable LULC option for DER by 2035 and beyond that may cause more than 30% to 50% runoff comparing to the representative 2010 LULC condition.

1. INTRODUCTION

Urbanization, a continuous development phenomenon across the globe is physically causing a change in the land-use and land-cover (LULC) of countries and cities with more impervious or paved surfaces. Land use planning is the broad allocation of land as per city functions in an urban area and land cover is the result of that land-use planning. Residential areas constitute a major part of urban land use in any city. Urbanization turns out to be paradoxical when urban development goals attempt to ignore environmental sustainability. Unplanned urban spatial growth with poor to no concerns about the environment is increasingly marked in the lower-middle-income countries where the pace of urbanization is the fastest. The impact of unplanned urbanization on the city environment upsets the ecological factors and leads to a gradual degradation of life-support systems including air, water, and land (Mashreque, 2009).

Since independence, Dhaka city is growing both horizontally and vertically in an unplanned manner without any systematic and effective land-use planning (Nahrin, 2008; Kalam, 2009). Dhaka-centric development has made the capital a fast-growing megacity and a hub of urban agglomeration. Increased economic activity in Dhaka is continuing rural-urban migration and putting pressure on the city's limited land, degrading environment, and collapsing urban services (Zaman *et al.*, 2010). As land is getting scarce in central Dhaka, peripheral land inclusion as per DAP (Detailed Area Plan) by Rajdhani Unnoyon Kartipakkha (RAJUK) makes a new provision for greater Dhaka, named as Dhaka Metropolitan Region (DMR) (RAJUK, 2015).

The primate city Dhaka with an area of 368 square km has the population density around 45,700 people per square kilometer, making Dhaka the most densely populated city in the world (Demographia, 2017). Recent Dhaka Structure Plan (DSP) 2016-35 provides a long-term strategic direction for an environmentally sustainable and livable greater Dhaka city with the key focus on the urban development of DMR for 20 years (RAJUK, 2015). DMR is geographically extended to Dhaka City and comprised of six regions, presented in Figure 1.

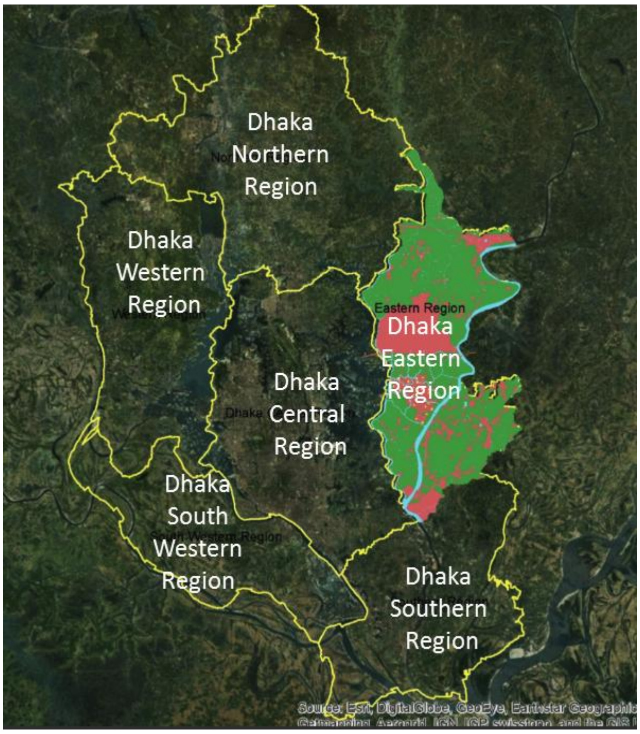

Figure 1: Dhaka Metropolitan Region (DMR) and Study Area: Dhaka Eastern Region (DER) (RAJUK, 2015)

LULC change of DMR is particularly noticeable in the case of change of Dhaka Central Region or core city Dhaka due to its unplanned spatial growth and increased imperviousness over the years without much consideration to urban development control tools relating to development intensity and density. Limited unpaved surface in central Dhaka is making the city waterlogged during monsoon because of intense rainfall and water-stressed during pre-monsoon due to over-extraction of groundwater (Shamsudduha *et al.*, 2011; Akhter *et al.*, 2009). Urgent focus is needed in the ongoing urban development initiatives and activities of DER which is very close to core city Dhaka and awaiting significant urban growth in the near future.

Remote Sensing (RS) and Geographical Information Systems (GIS) are now widely used to study LULC change due to urbanization. Integration of RS and GIS provides valuable information on the multi-temporal data on the processes and patterns of LULC change including mapping, analyzing and monitoring the trend of land-cover change dynamics (Shalaby & Tateishi, 2007; Ram & Kolarkar, 1993). While considering the case of the capital city Dhaka, the LULC change study is limited to core city Dhaka and the fringe area. One of the studies assessed the LULC changes and urban expansion dynamics of the entire central region of Dhaka using RS data in conjunction with socio-economic variables (Dewan *et al.*, 2009).

There is no study so far on Dhaka Eastern Region (DER) that identifies and predicts LULC change and its impact on surface runoff using Soil Conservation Service (SCS) - Curve Number (CN) method. The integration of GIS and RS technology in the SCS-CN model is increasingly used by many researchers nowadays (Rajbanshi, 2016). The SCS-CN method developed by Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA) is an empirical approach to quantify runoff of a watershed, agricultural fields or area from rainfall events (Ahmad *et al.*, 2015; USDA, 1972). This is a widely used hydrological model for estimating direct runoff from the relationships between rainfall, land-uses and hydrologic soil groups (Harbor *et al.*, 2006; Gitika & Ranjan, 2014). The CN is a dimensionless index and a design tool that represents the runoff potential of watershed/drainage area/basin/ agricultural fields relying principally on hydrologic soil group (HSG), LULC, land treatment, hydrologic conditions and antecedent moisture condition (AMC) (USDA, 1986; USDA, 1989). An example of the LULC change study by integrating RS, GIS and CN technology was in the Jobaru River basin of Japan. The study identified the land-use changes during 1948, 1975, and 2005 with an increase in urban area and forestry, a decrease in agricultural and barren lands, while water and others remained relatively unchanged. The average CN decreased for the whole Jobaru River basin which implied a decrease in overall runoff potential (Sumarauw & Ohgushi, 2012).

Effective land-use planning with due concerns to hydrogeological aspects can reduce runoff, ensure better drainage and enhance groundwater recharge potentiality (Harbor, 1994). This study attempts to evaluate the LULC changes of DER from pre-developed (2010) to post-developed context (2035 and beyond) to broadly classify the LULC changes in terms of paved and unpaved surface including water bodies. Alongside, the study also intends to provide a general hydrological forecasting due to LULC-induced impacts on the potential surface run-off of DER considering the seasonality of soil moisture. Finally, the most likely LULC change along with CN is ascertained for DER that may sustain hydrological balance.

2. LOCATION AND HYDROGEOLOGICAL SETTING OF STUDY AREA

The location and important details of the hydrogeological setting of the study area are appended below.

A. *Location of Study Area*

The study area (Figure 2) involves the eastern region of greater Dhaka as per RDP. It is just on the eastern side of core city Dhaka and beside the eastern fringe area. It is selected because of its impending urban development activities and likely to have a major change of existing LULC from agricultural to urbanized areas by 2035. As per DSP 2016-35, DER is planned to accommodate partly the population pressure of central Dhaka (RAJUK, 2015). Significant urban growth by RAJUK and others are waiting for implementation. It is situated between 23° 42´ to 24° 0´ North latitude and 90° 26´ to 90° 37´ East longitude on the eastern side of core city Dhaka. Given the area allocation of DMR, DER occupies 14.1% of the total DMR area with approximately 215.28 sq km. (RAJUK, 2015). It is bounded by a part of Kaliganj Upazila of Gazipur district on the northern side and Rupganj Upazila of Narayanganj district on the southern side including a part of Tarabo and Rupshi area of Narayanganj Sadar Upazila (JICA & DTCA, 2016).

B. *Existing LULC and Topography*

The study area, DER is closely a riverine basin of the river Shitalakkhya and Balu except for the raised middle portion of the area. It is predominantly an agricultural area and occupying more than 80% of the entire region. The existing built-up area (mainly residential) occupies less than 10% of the total area. Water bodies comprised of less than 10% of the total area is also used for agriculture during the dry season (JICA & DTCA, 2016). The LULC of the study area is a mix of agriculture, vegetation, tree-covered land, bare land, sand-filled land, and built-up area. The land adjacent to the river Shitalakkhya dominantly comprises of agricultural land. The land enclosed within the two rivers on the southern part is comparatively low lying than the northern part with bunded agriculture, bare and sand-filled land. Few low-lying areas have been observed with seasonal water within the agricultural land. From the field investigation together with recent satellite imagery i.e., Google earth and Landsat (2016) infers that the mid-portion of DER is transformed from agricultural land to residential land with urban development activities such as grading of existing lands and sand-filling of the low lying areas. Purbachal New Town (PNT), the largest urban growth by RAJUK is also located in this region. Areas planned for residential development are expected to have an average elevation of PWD (Public Works Department) reference level of 7.5 to 8 m. Other areas are generally low, flat, fertile, and flood-prone and the elevation varies from 2 to 13 meters above sea level (JICA & DTCA, 2016). Figure 3 shows the Digital Elevation Model (DEM) from SRTM data before urban development which signifies higher elevation in PNT areas and lower in Jolshiri and areas beside the rivers.

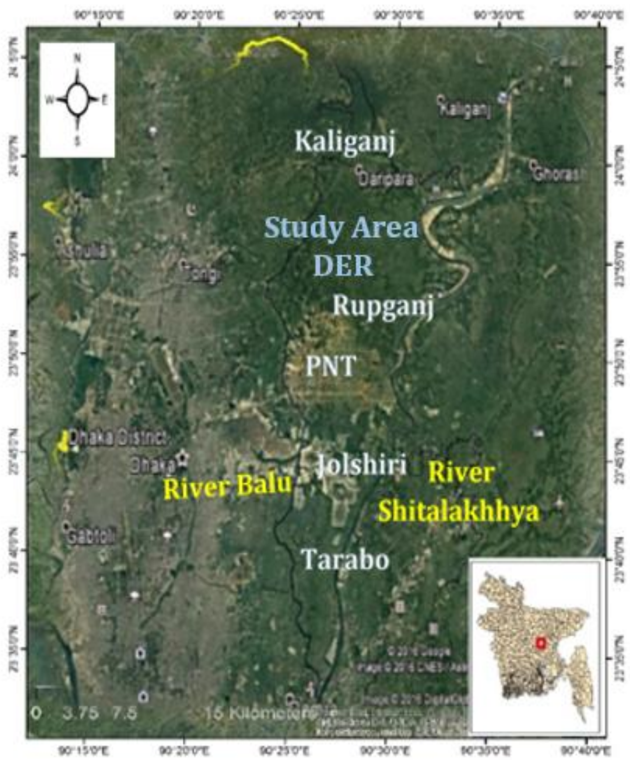

Figure 2: Location of Study Area: Dhaka Eastern Region (DER) (RAJUK, 2015)

Elevation beside the river Shitalakkhya and Balu is generally low. Few abandon channels also characterize the area being modified by human interaction as well as agricultural practice. Most of the water bodies are being used for fisheries or seasonal cultivation. As the road network is not fully developed, the industrial development covers less than 3% of the total area and mostly concentrates by the riverside of Balu and the Shitalakkhya, and Bhulta area (JICA & DTCA, 2016). The slope of the study area varies within 0 to 3% that may have a trivial influence on runoff.

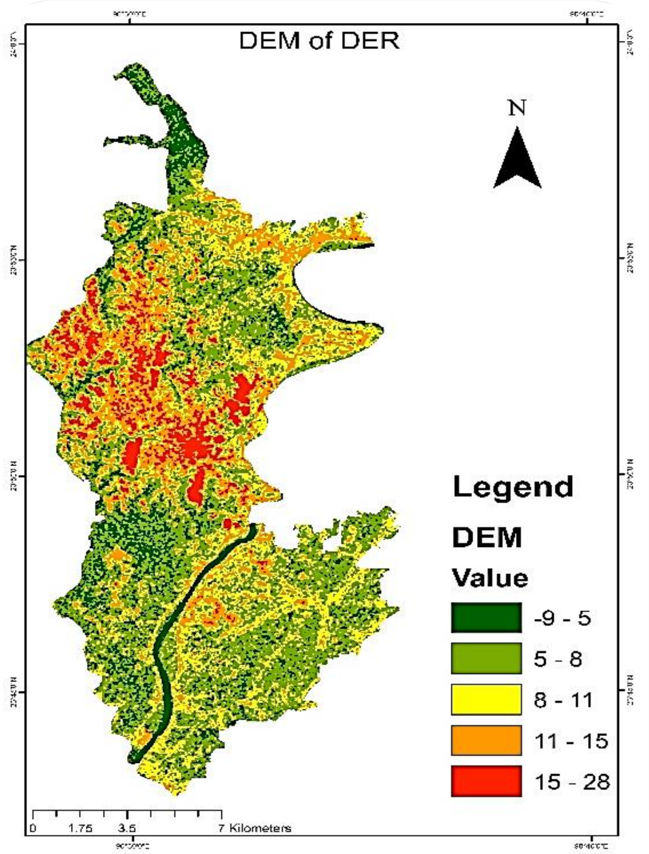

Figure 3: Digital Elevation Model (DEM) of DER (*SRTM DEM Landsat Image Data of 2010*)

C. Climate

Like the other parts of the country, Dhaka has a tropical monsoon climate (Hoque *et al.*, 2007) and can be broadly classified into three seasons: Pre-Monsoon, Monsoon and Post Monsoon or Dry Season (Sultana, 2009). Monsoon is considered to begin from June till September and non-monsoon from October to May with some variations (JICA & DTCA, 2015). The humid climatic condition is characterized by short cool winters and long hot summers with high relative humidity and low active wind speed (Sultana, 2009). Dhaka has an annual precipitation of 1,400 to 2,400 mm, and about 80% of which is concentrated during the monsoon season from June to September (JICA & DTCA, 2015). The temperature varies from $18°C$ in January and $29°C$ in August with an annual average temperature of $25°C$.

D. Geology of DER

The natural geological settings of DMR is linked with the Ganges-Brahmaputra-Meghna (GBM) river system (locally known as Padma-Jamuna-Meghna river system) by the interconnecting streams and retention basins (Hoque *et al.*, 2007, Shamsudduha *et al.*, 2011). It is situated in the central part of Bangladesh comprises of an older flood plain having relatively flat terrain conditions with few depressions. Four rivers—the Buriganga, Turag, Balu and Tongi Khal (canal)—form the area borders of Dhaka Central Region; whereas river Balu forms the western boundary and the river Shitalakkhya forms part of the eastern boundary of DER. In general, these local rivers feed the flood plains and marshy lands in and around Dhaka city (Hoque *et al.*, 2007). The generalized surface geology of the study area is formed by the Holocene deposits of alluvial sand, marsh clay and peat, alluvial silt including Modhupur clay residuum (JICA & DTCA, 2015) and the Pleistocene deposits of alluvial silt and Modhupur clay (Hoque *et al.*, 2007; Shamsudduha *et al.*, 2011).

Some western part of the study area bordered by river Balu has three distinct surface deposits: Floodplain and High Floodplains of Holocene age and the Madhupur clay of Pleistocene age (Hoque *et al.*, 2007). A comprehensive geological and geotechnical investigation in the Jolshiri Housing Project area within DER to determine subsurface geology using by Standard Penetration Test (SPT) in 2014 confirmed that the project area is shielded with mostly fluvial deposits. i.e., flood plains of Holocene age and the surface deposits are the input of sediments from the river Shitalakkhya. The remnant portion is the gully of Modhupur terrace that might have been originated due to the dissection of the uplifted Modhupur terrace. The adjacent low land of the area contains recent flood plain deposits.

The lithology of the area consists of clay, silty clay, organic clay with iron concentrations and organic materials. Reddish-brown, yellowish-brown, grey colours with mottling are prominent in the clays (DU, 2014). The topsoil texture of the study area mainly consists of clay and varying as mixed clay, clay loam, silty clay and silty clay loam. The classified soil depth mostly varies between 0.60 to $1.22\,m$. However, topsoil depth extends below more than $1.22\,m$ in the mid-portion and north of the study area. The permeability is classified as mixed rapid($> 7.5\,mm/hr$), moderate ($3.8 - 7.5\,mm/hr$) and slow ($1.3 - 3.8\,mm/hr$) (BARC, 1988). However, urban development activities are continually changing the soil profile at the study area.

3. METHODOLOGY

The study involved five different sets of data: Thematic maps, Geospatial data, Satellite data, Hydrological data, and Geological data. LULC change analysis required the data of thematic maps, DEM, elevation, Landsat Image. Runoff analysis involved slope of the area, drainage/stream network, topsoil texture, soil depth, soil permeability, and daily rainfall data and lithological sequence of the study area. Table 1 illustrates the details of data requirements including the sources of data.

Table 1

Data Requirement of the Study

Data Types	Details of Data	Source of Data
Thematic Maps	DAP (2010) of DMDP and RDP Survey 2013	Rajdhani Unnayan Kartripakkha (RAJUK), Dhaka Structure Plan 2016-35, Japan International Cooperation Agency (JICA)
	Land-use Planning of Purbachol New Town (PNT) Project Land-use Planning of Jolshiri Housing Project	RAJUK Jolshiri Abashon Authority
	Surface Geology	Geological Survey of Bangladesh (GSB)
	Soil Classification	Soil Resource Development Institute (SRDI)
Geospatial Data	Top Soil Texture, Soil Depth, Soil Permeability	Bangladesh Agricultural Research Council (BARC)
Satellite Data	SRTM DEM Landsat Image of 2010, 2012, and 2016 (30 m resolution) Sentinel 2A Image of 2017 (10 m resolution)	USGS (SRTM Global DEM) USGS, NASA European Space Agency (ESA)
Hydrological Data	Daily, Monthly and Annual Rainfall (1995-2015)	Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD)
Geological Data	Lithological Sequence (Bore-log)	BWDB, Department of Public Health Engineering (DPHE) and Geological Investigation Report of Jolshiri Housing Project, 2014

A. Categorization of LULC for the Study

To simplify the different details of the LULC plan of DER and mark the changes easily from mapping, three broad categories of LULC have been taken into consideration. These are:

- **Paved:** Means imperviousness caused by structural (built-up) development which includes all residential, industrial, commercial, settlements, services, roads, or any other mixed urban, and other urban development and structure on the surface.
- **Unpaved:** Means pervious surface that includes all agricultural land, crop fields, fallow lands, low height vegetation, tree cover, bare soil or filled land, and open space.
- **Waterbody:** Means any surface water body which includes rivers, lake, canals, pond and/or any surface water body within the geographic boundary.

B. Application of RS and GIS in LULC Change Detection

RS and GIS were used to study LULC change due to urbanization. DEM was 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. ArcGIS with its several built-in functions was used to turn the DEM into a derivative map of slope and drainage network. Landsat 5 (TM) of 2010, Landsat 7 (ETM+) of 2012, and Landsat 8 (OLI/TIRS) of 2016 and Sentinel-2A (MSI) of 2017 were selected as the remotely sensed image data for the study. Collected Landsat images and DEM were geo-referenced according to the geographic coordinate system (GCS_WGS_1984). Geographic coordinate systems indicate location using longitude and latitude based on a sphere (or spheroid) while projected coordinate systems use X and Y based on a plane. The projected coordinate system used for this study is WGS_1984_UTM_Zone_45N which is applicable to Bangladesh. Table 2 shows the data acquisition date including polygon path and row.

Table 2
Landsat and Sentinel-2A Image Acquisition Date and Polygon Path/Row

Satellite	Sensor	Acquisition Date	Polygon Path / Row	Resolution
Sentinel-2A	MSI (Multi-spectral Imager)	01 Feb, 2017	-	10 m
Landsat-8	Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	16 Feb, 2016	137/44	30 m
Landsat-7	Enhanced Thematic Mapper + (ETM+)	13 Feb, 2012	137/ 43 and 137/44	30 m
Landsat-5	Thematic Mapper (TM)	30 Jan, 2010	137/ 43 and 137/44	30 m

For this particular study, a supervised classification method has been used. Focal analysis has been performed for the Landsat 7 ETM+ (2012) to remove the black stripes around the image. The geometric correction was performed on all the images using a Landsat TM image of the same area from 2010 as reference. The atmospheric effect of the imageries was corrected following López-Serrano *et al.* (2016). Training polygons were drawn covering the pixels having the same land-use. To train a single land-use class, 30 polygons were drawn. This process was performed for all the 5 (five) classes and saved as a signature file (.sig extension) using the classification toolbar of ArcGIS 10.2. This signature file was finally used during the supervised classification step. For the rest of the three imageries (2012, 2016, and 2017), separate three signature files were developed through training the datasets based on the above-mentioned processes. All the images were verified using Google Imagery of those dates.

Pre-Developed (2010) LULC represented in Landsat imagery of 2010 has been classified using 'Maximum Likelihood Classification' (MLC) with five land-cover types: Paved (Existing Built-up/ Settlement), Unpaved (Bare Land / Filled Land), Unpaved (Agriculture / Vegetation - Low Height 3 to 4 ft Plantation), Unpaved (Tree Cover), and Waterbodies. Accordingly, the other three images were also classified in the same land-cover category. Non-urban land uses remained dominant in DER such as agricultural land, bare land, and tree-covered land. From the potential information content of band combination, the combination $(5, 4, 3)$ was used which provided the most agricultural information and it was also useful for vegetation studies. As 2016 and 2017 imageries were mostly identical in terms of land-cover classification, the image of 2016 was used to represent the LULC information of the existing 2016-2017 condition. Percentage imperviousness is an important factor for any urban growth. Higher imperviousness is likely to cause a higher population and structural density. Following four predicted scenarios were developed through the conversion of identified land-cover of existing 2016-2017 condition:

- **Predicted Scenario-1:** Conversion of Identified Tree-covered Land for Urban Development with 65% Imperviousness.
- **Predicted Scenario-2:** Conversion of Identified Agricultural Lands for Urban Development with 65% Imperviousness.
- **Predicted Scenario-3:** Conversion of Identified both Tree-covered and Agricultural Land for Urban Development with 65% Imperviousness.
- **Predicted Scenario-4:** Conversion of Identified both Tree-covered and Agricultural Land for Urban Development with 85% Imperviousness.

C. SCS-CN Method for Runoff Estimation

Runoff is one of the important hydrologic variables used in water resources applications and management planning (Amutha & Porchelvan, 2009). Human-induced LULC change is very common that causes a significant impact on the hydrologic system (Bhaduri *et al.*, 2000). The SCS-CN method is now used as the method for computing peak runoff rates and volumes for Urban Hydrology (USDA, 1986) and also for the analysis of land use changes, i.e., urbanization or low impact development of urban areas (Banasik *et al.*, 2014).

i. Application of Soil Conservation Service (SCS) - Curve Number (CN) Method for Runoff Computation

The CN parameter can represent LULC changes and their impact on surface runoff (Sumarauw & Ohgushi, 2012; Melesse & Shih, 2002; Harbor, 1994). Runoff estimation by CN method with several years of daily rainfall data provides an initial or general estimate of the impact of LULC change on long-term annual or seasonal average runoff depths (Harbor, 1994). Although the method is the time-consuming and error-prone the impact of LULC changes on runoff due to proposed and predicted development scenarios can be ascertained quite reasonably for local planning uses (Harbor, 1994). The spatial distribution of CN due to LULC change (urbanization in particular) and corresponding runoff response is likely to show a shift in the overall water cycle of the study area (Bhaduri *et al.*, 2000; Melesse & Shih, 2002).) A study on urban watersheds notes that the SCS-CN method appears to be sufficiently sensitive to determine the effect of urbanization on the volume of runoff (Samuel *et al.*, 1973).

ii. SCS-CN Runoff Equation

In the SCS-CN method (USDA, 1986), runoff equation is based on infiltration losses that are combined with surface storage by the following relation:

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

Where, Q = runoff (in), P = rainfall (in), S = potential maximum retention after runoff begins (in), and I_a = initial abstraction (in).

Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and land cover parameters. Through studies of many small agricultural watersheds, I_a was found to be approximated by the empirical equation, $I_a = 0.2S$ (USDA, 1986).

Simplifying Equation (1), runoff can be estimated in inch as follows:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad (2)$$

Here, $Q = 0$ for $P < 0.2S$

For Indian conditions (Ministry of Agriculture, India, 1972), $I_a = 0.3S$ and the empirical relationship is,

$$S = (25400/CN) - 254\ mm \quad (3)$$

The equation can be rewritten as,

$$Q = (P - 0.3S)^2/(P + 0.7S) \quad (4)$$

Knowing the value of CN, runoff from the watershed can be computed from Equations (3) and (4). The CN is ranging from 0 when S is ∞, up to 100 when $S = 0$. Both conditions represent the extremes between total infiltration ($runoff = 0$) and totally impervious watersheds ($rainfall = runoff$). However, many of the computations use 30 as the lowest value, even when lower values could be detected (USDA, 1986).

iii. Antecedent Moisture Condition (AMC)

The SCS introduced the AMC concept to determine soil moisture before a storm event, the condition of which could affect the calculation of runoff (USDA, 2004). There are three conditions for dry (AMC I), normal (AMC II) and saturated soils (AMC III) that are assigned as a function of the five-day antecedent rainfall (Table 3) (USDA 2004). The moisture condition could affect runoff estimates because it modifies the CN whose standard values are set to the AMC II by default. For modelling purposes, watersheds are often considered as average moisture conditions, i.e., AMC II. After selecting the AMC, the standard CN values, if necessary, can be converted to AMC I or AMC III using the following functions (USDA, 2004).

$$CNI = (4.2 * CNII) / (10 - 0.058 * CNII) \quad (5)$$

$$CNIII = (23 * CNII) / (10 - 0.13 * CNII) \quad (6)$$

Table 3

AMC Group and Related Soil Characteristics with 5-day Antecedent Rainfall (USDA, 2007)

AMC Group	Soil Characteristics	Total 5-day Antecedent Rainfall, mm	
		Dormant Season	**Growing Season**
I	Soil is dry but not to the wilting point; satisfactory cultivation has taken place	< 13	< 36
II	Average condition	13 *to* 28	36 *to* 53
III	Heavy or light rainfall and low temperature have occurred within the last 5 days; saturated soil	> 28	> 53

iv. Hydrologic Soil Groups (HSGs)

Soils are classified into four HSGs (Table 4) according to the premise that soils found within a climatic region that are similar in depth to a restrictive layer or water table, transmission rate of water, texture, structure, and degree of swelling when saturated, will have similar runoff responses. Soils in group A have the lowest runoff potential, soils in group B have moderately low runoff potential, soils in group C have moderately high runoff potential and group D soils have the highest runoff potential. With urbanization, native soil profiles may be mixed or removed or fill material from other areas may be introduced (USDA, 1986). As a result of construction and other disturbances, the soil profile can be altered from its natural state and the listed group assignments generally no longer apply, nor can any supposition based on the natural soil be made that will accurately describe the hydrologic properties of the disturbed soil. In these circumstances, an onsite investigation should be made to determine the hydrologic soil group (USDA, 1986).

Table 4

Classification of HSGs (USDA, 1986)

HSG	Soil Type	Soil Texture	Runoff Potential	Infiltration Rate & Water Transmission Capacity
A	Deep, well-drained sand and gravels	Sand, loamy sand, or sandy loam	Low	Rapid ($> 7.5\ mm/hr$) High
B	Moderately deep, well-drained with moderately fine to coarse textures	Silt loam or loam	Moderate	Moderate ($3.8 - 7.5\ mm/hr$) Moderate
C	Clay loams, shallow sandy loam, soil with moderately fine to fine textures	Sandy clay loam	Moderately high	Slow to Moderate ($1.3 - 3.8\ mm/hr$) Low to Moderate
D	Clay soil that swells significantly when wet	Clay loam, silty/ sandy clay, or clay	High	Very Slow ($< 1.3\ mm/hr$) Low

v. Runoff Estimation

LULC change detection maps provided the area-based hydrologic soil groups. CN was determined to identify the hydrologic soil groups of the study area. Then area-weighted CN was computed for each LULC map. The data and method applied to compute runoff by SCS-CN method are appended below.

- LULC maps of the study area were prepared considering the pre-developed and post-developed LULC characteristics including identification of permeable and impermeable areas by applying GIS.
- Hydrologic soil groups (A, B, C, and D) were identified as per area coverage of each soil group.
- Then CN was assigned according to the delineated area. The CN relied on the area's hydrologic soil group, LULC, and hydrological condition. In this study, CN was assigned following SCS Tables in USDA, 1986; USDA2007; and Subramanya, 2008.
- Area-weighted composite CN for different land-use and hydrological soil conditions was computed using the following equation.

$$CN = \sum(Ai * CNi) / \sum Ai \quad (7)$$

Area-weighted CN represents the average moisture condition of the soil or AMC II. While considering the seasonality of rainfall, the soil was considered to have all three antecedent moisture conditions. However, the AMC III condition was considered for wet season (monsoon) and AMC I condition during the dry season. Both seasonal AMC and average AMC were considered in this study to ascertain the variation of runoff depths between the conditions. The seasonality for this study was considered as AMC I for Dec, Jan, Feb, Mar (winter or dry period); AMC II for Apr, May, Oct, Nov (just immediate pre-monsoon - Apr and May and immediate post-monsoon – Oct. and Nov.); and AMC III for Jun., Jul., Aug., Sep. (monsoon and wet Period).

Obtaining the CN value for each LULC change scenario, the SCS-CN method was applied. Runoff computation involved the hydrological data, mainly the long-term daily rainfall data of 21 years from 1995 to 2015. As there was no rainfall station within the study area, daily rainfall data of Dhaka, Gazipur and Narayanganj for 21 years (1995 to 2015) were collected from BWDB and used for this study. As the runoff estimation was data-intensive, one rainfall station closer to Eastern Region CL42 (BWDB) was selected for computing daily runoff estimation. The rainfall data of each year was then transferred to an Excel spreadsheet so that the daily values were a single column of rainfall depths (in inches). However, days with zero precipitation may be deleted from the file to reduce the size of the spreadsheet. For each LULC and area-weighted CN, a column was prepared for runoff depth where each cell was determined by logical input: If $P > [(300/CN) - 3]$, then $Q = (P - (300/CN) + 3)^2 \,/\, [P + (700/CN) - 7]$, else $Q = O$. Where, P was the rainfall depth in inches and Q was the depth of runoff in inches. It is to be mentioned that initial abstraction I_a from rainfall was considered $0.3S$ for the study area considering the Indian condition. The above logical input and spreadsheet analysis techniques were suggested by Harbor (1994) to compute storm-water runoff depths for different LULC conditions. Runoff depths for weighted CN with AMC I and AMC III were also determined in a similar way. With 21 years of rainfall data and eight study LULC conditions, a total of 336 Excel spreadsheets were prepared $[\{21 \times 8(for\ average\ AMC) + 21 \times 8(for\ seasonal\ AMC)\} = 336]$ to compute annual runoff depth of 21 years.

4. ANALYSIS OF LULC CHANGE AND ITS IMPACT ON RUNOFF

The following paragraphs briefly state the analysis of LULC change and its impact on surface runoff for DER.

A. Analysis of Remotely Sensed Image Data and Proposed RDP Scenario by RAJUK

Figure 4 includes the generated LULC maps of study area respectively for the pre-developed 2010 and 2012, existing 2016-17 and the proposed LULC of DER as per RDP for 2016-35. The chronological evaluation of LULC change from 2010 to the RDP scenario (2016-35) simply reflected the conversion of all unpaved bare soil or bare land into the paved surface by structural development, and consequent increase in overall built-up areas including a significant decrease in agricultural lands. However, due to the unavailability of GIS-based land-use data of RDP, specific broad details of the land-use plan and the given strategic zoning map for DER were used to identify the changes in LULC. The comparison of the existing 2016-17 condition to the RDP scenario identified a remarkable shift in the overall LULC pattern of DER. In the RDP scenario, the overall percentage increase in the paved surface was almost $\mathbf{40\%}$ of the existing 2016-17 condition, and the overall decrease in unpaved agricultural land was around $\mathbf{20\%}$. However, the RDP scenario accounted for around a $\mathbf{1.5\%}$ decline in water bodies than the existing condition. Though there were some marked differences in the water bodies on the image of 2012 compared to 2010 and 2016, it was assumed temporary waterlogged areas. So, the percentage area of water bodies was considered the same for all the three Landsat images.

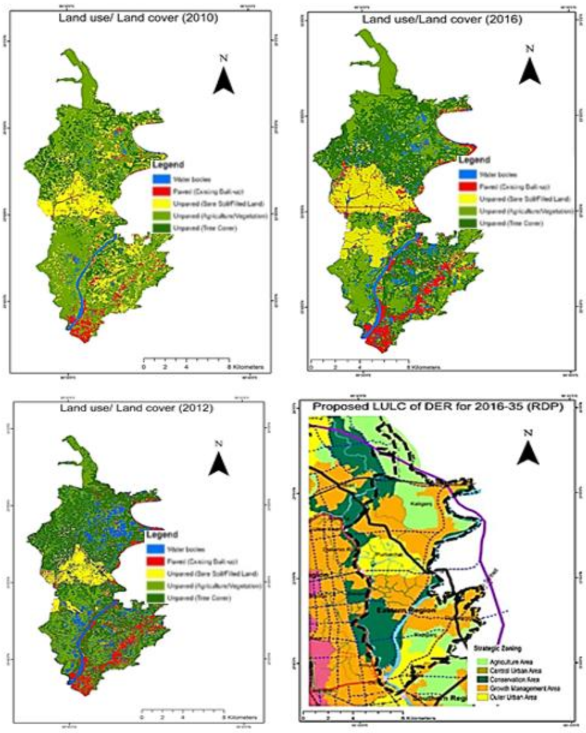

Figure 4: LULC Maps of DER from Landsat Image Data and RDP 2016-2035 (*Author's Interpretation of Landsat Image Data*; RAJUK, 2015)

Table 5 shows the quantified change of LULC of DER from the classified image of 2016-17 to the RDP scenario of 2016-35 proposed by RAJUK.

Table 5
Quantified Change of LULC of DER from 2016-17 to RDP Scenario (2016-35)

LULC Category	2016-17 (Existing Condition)		2016-35 (RDP Scenario – Proposed Post Dev by RAJUK)	
	Area (km^2)	% of Land	Area (km^2)	% of Land
Paved (Built-up/ Settlement)	16.25	7.55	104.42	48.50
Unpaved (Bare Land / Filled Land)	42.00	19.51	0.00	0.00
Unpaved (Agriculture / Vegetation/ Tree Cover)	140.60	65.31	98.13	45.58
Water bodies	16.43	7.63	12.73	5.91
Total	215.28	100.00	215.28	100.00

B. Analysis of Imperviousness of Proposed Land-use Plan of PNT and Jolshiri Housing in DER

To ascertain the basis of considering 65% imperviousness due to residential development, likely imperviousness of Purbachol (PNT) and Jolshiri Housing Projects (two major urban growths of DER) were investigated from the proposed land-use plan approved by RAJUK. Following the existing Floor Area Ratio (FAR) and Maximum Ground Coverage (MGC) rules of 2008 (GOB, 2008), the likely percentage imperviousness of the proposed land-use plans of both impending urban growth of study area were approximately 65% for PNT and 63% for Jolshiri Housing Area which revealed a likely high-density residential development.

C. Analysis of Predicted LULC Scenarios of DER

Post-developed predicted scenarios of LULC change followed a trend of increased urbanization and reduced unpaved surfaces (Figure 5).

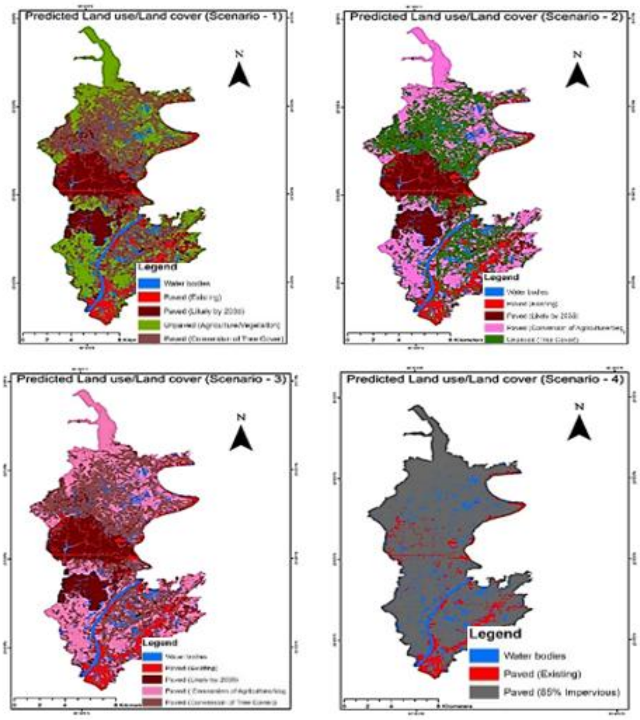

Figure 5: Predicted LULC Maps of DER from Classified Map of Existing 2016-2017 Condition
(*Author's Interpretation of Landsat Image Data*)

Conversion of all bare and filled land including identified agricultural or/and tree-covered land from the remotely sensed image of 2016-17 into paved built-up areas with a certain percentage of imperviousness was the key consideration of the predictions for post-developed scenarios. However, all the predictions include urban development of PNT and Jolshiri area by 2035 from the identified bare soil and filled land of existing 2016-17 LULC map. the study included general imperviousness of 65% in case of residential urban development except for scenario-4 which was predicted with 85% imperviousness and where the residential development would lead to commercial/industrial development.

D. Analysis of Surface Runoff due to LULC Change

The impact of LULC change on surface runoff is assessed in this study based on a total of eight LULC scenarios. Considering the soil classification map, topsoil texture, soil depth, lithology, and the detailed geological investigation of PNT and Jolshiri area; HSG 'D' was the main soil group of the study area with low permeability and infiltration capacity. The existing built-up area, mostly developed by sand-filling is verified by field visit and Google earth images and categorized as HSG 'A'. The trace of PNT development identified in the 2010 LULC map as bare soil or filled land was transformed with more permeable HSG 'B' soil. LULC of 2012 detected new land development activities which in fact, was infilling low-lying areas in the southern part of PNT in the Jolshiri area. Finally, LULC of 2016-17 exposed the entire area of PNT and Jolshiri area with changed soil profile. Table 6 shows the quantified area-weighted CN values derived from the existing LULC map of 2016-2017. Similar area-weighed CN values were deduced from maps of pre-developed 2010 and 2012, post-developed RDP and for four other predicted scenarios of 2018-35.

Table 6
Computation of Area-Weighted CN for Existing 2016-2017 LULC Condition (2016 RS Image Data)

Existing LULC 2016-17	HSG	Area (km^2)	CN	$\%Area * CN$	Weighted CN
Paved (Existing Built-up)	A	16.25	79	596.32	
Unpaved (Bare / Filled Land)	A	18.08	77	646.67	AMC (I) 64
Unpaved (Bare / Filled Land)	B	23.92	86	955.56	AMC (II) 81
Unpaved (Agriculture / Veg)	D	69.54	83	2681.08	AMC (III) 92
Unpaved (Tree Cover)	D	71.06	73	2409.60	
Water Bodies	–	16.43	100	763.19	
Total		**215.28**		**8052.41**	

5. RESULTS AND DISCUSSION

Important deductions have been drawn so that the results of the study are useful for practical applications and decision making for planned urban development within DER.

A. Resulting Trend and Predicted Change of LULC of DER

LULC trend from 2010 to 2016-17 revealed the significant conversion of the unpaved agricultural area of DER to the paved area due to urbanization in the near future. The classified LULC image of 2016-17 detected the direction of likely post-structural urban development as projected in RDP for DER by RAJUK for 2016-35. LULC change predicted in scenario-1 followed the RDP scenario but included more lands for urban development. Predicted scenario-2 was almost identical to scenario-1 in terms of land-cover categories, but differed in land conversion. However, predicted scenario-3 and 4 depicted complete conversion of all unpaved land of DER except water bodies. Figure 6 broadly mirrored the overall studied trend of LULC change of DER combining the pre-developed (2010) condition to RAJUK proposed post-developed (2016-35) and predicted post-developed scenarios for 2018-35 and beyond.

The LULC changes in terms of classified land-cover of Landsat imageries except the given RDP scenario proposed by RAJUK quite clearly provided the direction of urban development proposed in the RDP scenario. However, extensive land-filling and changing activities including various housing development plans by real-estates that were observed may upset the proposed plan of RDP. While comparing the existing 2016-17 LULC with the RDP scenario, a remarkable shift was observed in terms of paved built-up areas which occupying 49% of the total land and causing a further decline in agricultural lands to approximately 46%. Analysis of proposed land-use plans of PNT and Jolshiri Housing (RAJUK approved) resulted in an urban development intensity with approximately 65% imperviousness. However, the existing FAR unless reviewed would lead to more densification within DER.

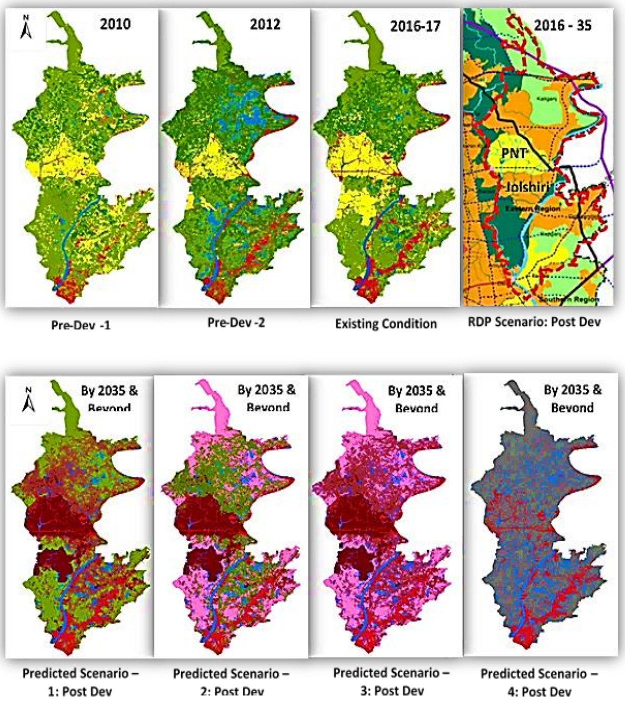

Figure 6: Trend of LULC Change of DER from 2010 and by 2035 and beyond

Figure 7 quantified the overall approximate % change in LULC in terms of the intended study LULC category from the pre-developed 2010 condition to predicted post-developed scenarios for 2018-35 and beyond. In sum, the quantified paved surface increased from 4% to 94% and the unpaved surface decreased from 88% to 0.0% from 2010 to predicted scenario-4, while the water bodies reduced from nearly 8% to 6%. Paved surface coverage increased as 4% in 2010, 6% in 2012, 8% in 2016-17, and 49% by 2035 as proposed in RDP of DER. In predicted scenarios the increase in the paved surface is likely to be approximately 60% by 2035 and beyond for both prediction-1 and 2 and 94% for predictions 3 and 4. Besides, the consequent decrease in the paved surface can be noted as 88% in 2010, 86% in 2012, 84% in 2016-17 and 45% by 2035 as proposed in RDP. However, predicted scenario-1 and 2 recorded approximately 33% of the total land as the unpaved surface which was about 12% less than RDP. However, predicted scenario-3 and 4 are likely to be without any unpaved surface.

B. *Impact on Runoff due to LULC Change*

The assessed LULC changes in DER would have a significant impact on surface runoff. The findings on surface runoff due to LULC changes are mentioned below.

i. *Area-weighted CN due to LULC Change*

Annual runoff estimation by the SCS-CN method involved the evaluation of CN due to LULC change. Area-weighted CN provided an average moisture condition or the AMC II for the HSGs. Though surface prediction and assignment of CN on the predicted land-cover may not be precisely accurate, it may involve an increase or decrease in the overall area-weighted CN. The resulting weighted CN due to LULC change was graphically plotted in Figure 8. Before any urban development, HSG for the study area could be assigned as a whole as category 'D' soil with the lowest permeability and infiltration capacity. However, urban development traced in this study since 2010 identified a gradual change in the soil profile. The existing 2016-17 LULC provided a combination of 'A', 'B' and 'D' category soil as classified following TR-55 (USDA, 1986) and validated by geological investigation report of Jolshiri area and also by laboratory tests of certain soil samples.

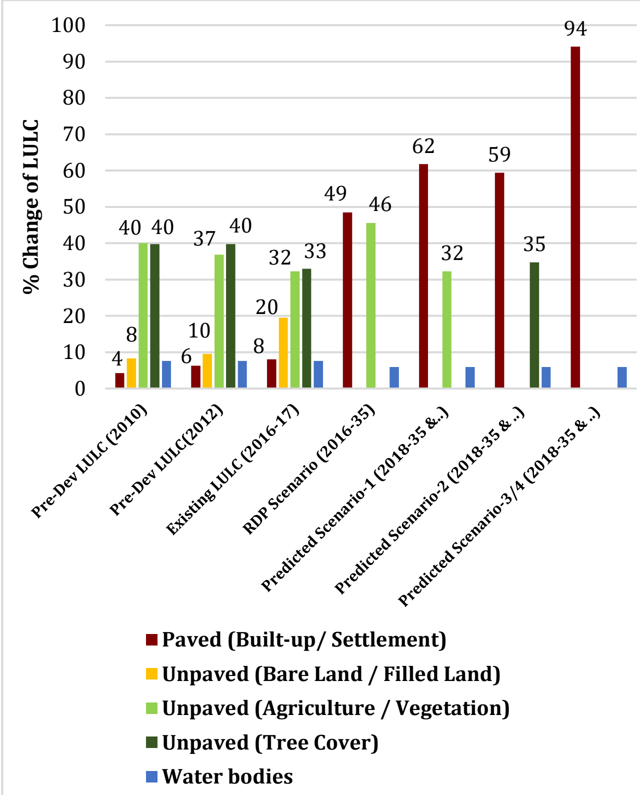

Figure 7: %LULC Change as per Classified Land-cover of DER from 2010 and by 2035 and beyond

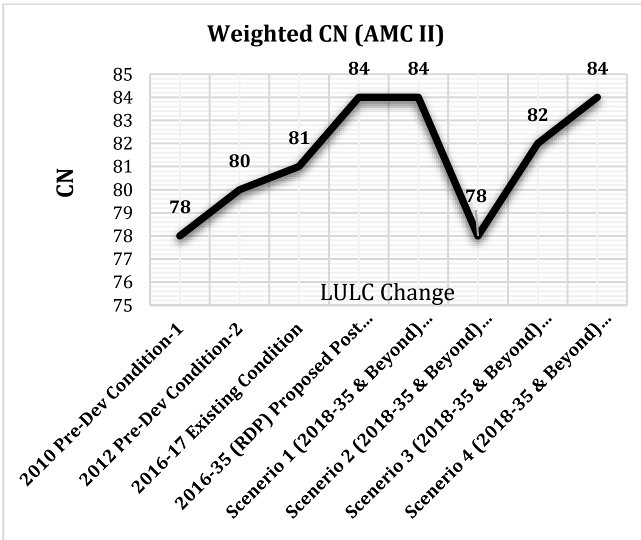

Figure 8: Variation of CN due to LULC Change of DER

The pre-developed (2010) CN of the study area was 78 and 84 for the RDP scenario which is quite high to generate significant runoff. The CN of the study area then remained constant up to scenario 1 and plummeted to 78 for scenario 2. Then, it again increased to 82 for scenario-3 and 90 for scenario 4. Predicted scenario-1 depicts a CN similar to the RDP scenario, i.e., CN 84 . In fact, LULC predicted in scenario-1 was identified as a potential variant of the RDP scenario with more land inclusive to urbanization compared to RDP.

Predicted scenario-2 was the result of the conversion of agricultural land for urban development and it followed a sharp decline in the CN compared to the RDP scenario or scenario-1. Scenario-2 has an area-weighted CN value 78 which was identical to pre-developed 2010 LULC. The low-lying and low-permeable HSG 'D' soil of agricultural lands required land development by HSG 'A' category soil (mainly sand-filling) to attain reference PWD RL of 7.5 to 8 m prior to any structural development. Residential land development in the Jolshiri area by reclaiming low-lying agricultural land with the help of sand-filling bore the evidence of the consideration for the study area. The soil test of the Jolshiri area also confirmed that the area was filled up with highly permeable medium to fine sands. This particular change in the soil profile lowered the area-weighted CN and essentially described an important inference on the LULC change of the study area. Conversion of low-lying agricultural land to attain certain elevation with more permeable soil or sand for residential development with assumed 65% imperviousness is likely to reduce the area-weighted CN, thereby likely to reduce runoff until it is paved.

Scenario-3 entailed LULC changes by a complete paved surface with approximately 65% imperviousness, yet the area-weighted CN (82) remained below the RDP scenario or scenario-1. Overall CN was decreased because of the conversion of all unpaved land of HSG 'D' into more permeable soil (HSG 'A' and 'B'). This conversion increased the CN compared to scenario-2. Scenario-4, depicted scenario-3 with 85% imperviousness which increased the CN to 90 . More paved surface and imperviousness of LULC would otherwise exhibit more runoff and inhibit recharge due to lesser scopes for infiltration and percolation.

ii. Runoff Variation due to LULC Change and Seasonality of AMC

Figure 9 shows the percentage of rainfall that may turn into the runoff for varying LULC scenarios including the difference in runoff due to LULC change for average (AMC II) and seasonal AMC.

Progressive runoff variations were ascertained from the representative pre-developed 2010 LULC condition. Though runoff estimation by the SCS-CN method with long term daily rainfall was increasingly data-intensive the inclusion of seasonality in soil moisture condition added further complexity in estimation. A significant runoff variation resulted between the estimates with average and seasonal AMC. Results with seasonal AMC provided approximately 14% to 17% higher runoff than average AMC. In essence, annual runoff estimation may involve seasonal AMC where there is a distinct seasonal variation of rainfall.

Figure 10 shows the percentage increases in the runoff against the representative 2010 LULC condition for both average and seasonal AMC. RDP or predicted scenario-1 resulted in 30% more runoff in the case of seasonal AMC of soil and more than 50% higher runoff from the pre-developed 2010 condition in the case of average AMC (AMC II).

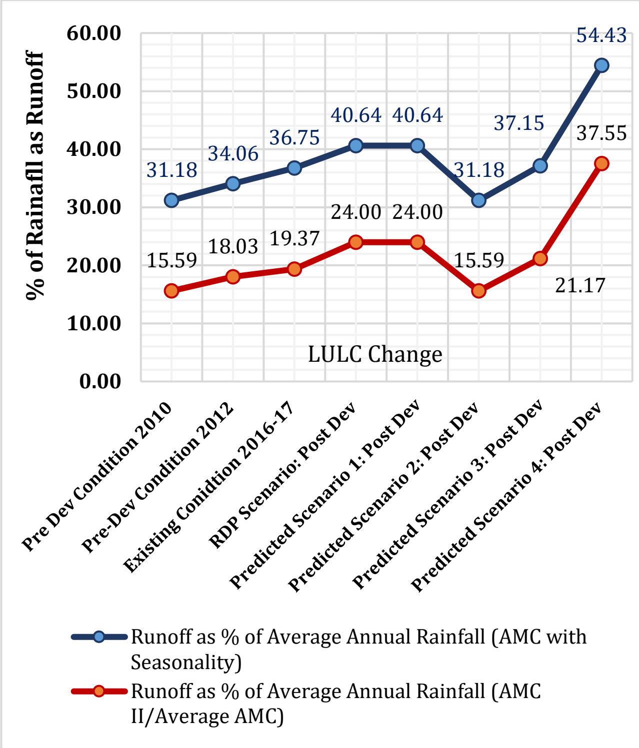

Figure 9: Percentage Runoff from Rainfall due to LULC Change of DER

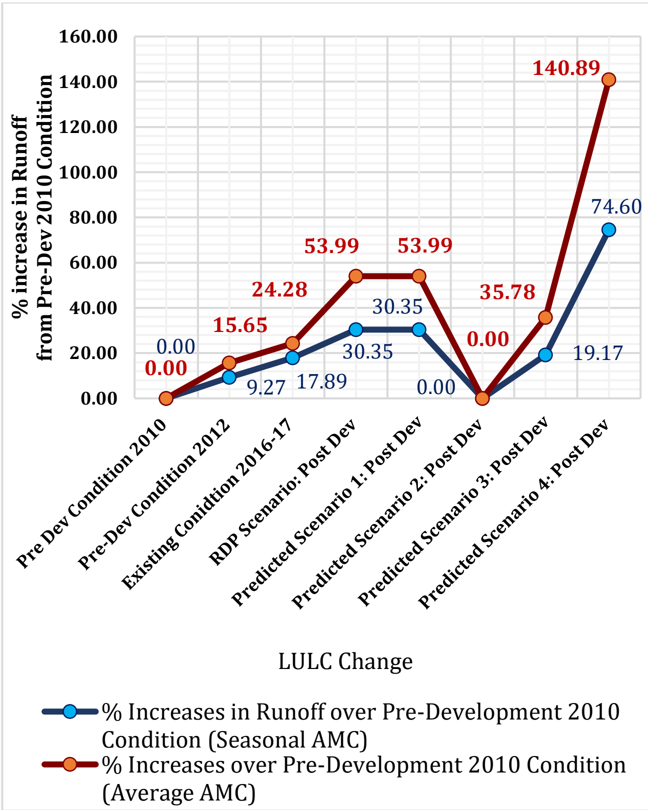

Figure 10: Percentage Increases in Runoff against the Representative 2010 LULC

C. Overall Assessed Impact on Runoff due to LULC Change in DER

Figure 11 quantifies the overall impact on runoff due to LULC change which indeed is a recharge loss. Pre-developed 2010 LULC with CN 78 resulted in an average 31% runoff from rainfall with a runoff depth of 626 mm/yr in the case of seasonal AMC. With CN 80, the runoff was nearly 34% with a runoff depth of 684 mm/yr in 2012. Existing LULC (2016-17) with CN 81 generated about 37% runoff with a runoff depth of 738 mm/yr . However, approximately 40% annual runoff was identified in both RDP and predicted scenario-1 with CN 84 which had an annual average runoff depth of 816 mm.

An exception to the increase in runoff was scenario-2 which showed that all LULC change was not detrimental, rather beneficial as this change would revert the land with pre-developed runoff potential. Predicted scenario-3 with CN 82 again increased more than 37% runoff with a runoff depth of 746 mm/yr when compared with scenario-2, but the impact was lesser when compared to RDP or predicted scenario. Finally, the maximum runoff nearly 55% with a runoff depth of 1093 mm was generated by CN 90 of predicted scenario-4. The overall impact followed an increasing trend up to RDP/predicted scenario-1 and had a fall in predicted scenario-2. In fact, predicted scenario-2 revealed the LULC of DER with similar CN of pre-developed 2010 condition and resulted in no impact on runoff. The hydrological impact again followed an increasing trend and resulted in a severe impact in the case of LULC with CN 90. This scenario resulted in more than 50% runoff and significant recharge loss.

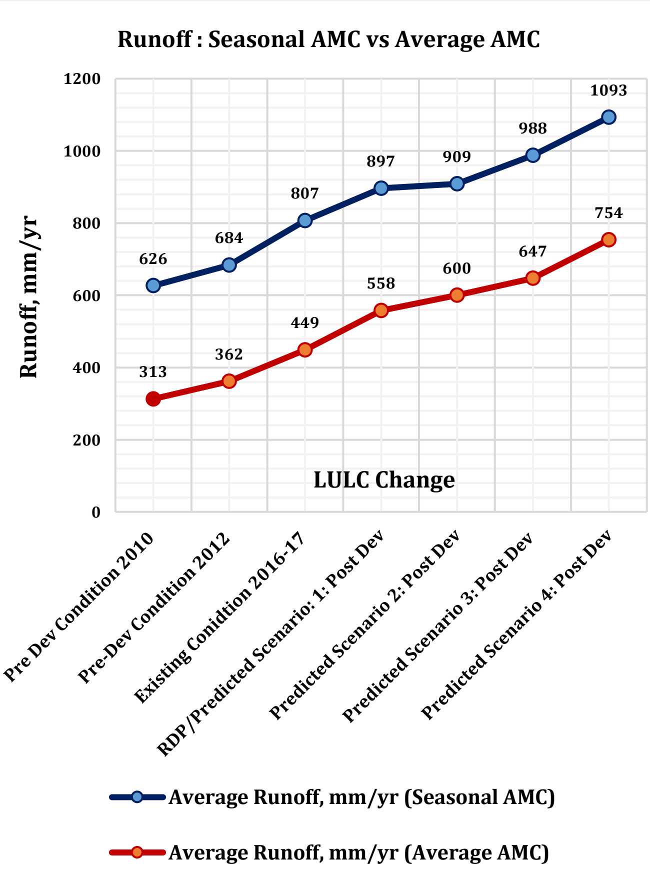

Figure 11: Impact on Runoff due to LULC Change

6. CONCLUSIONS

This study focused primarily on identifying the impending LULC change of DER due to urbanization and its impact on surface runoff using RS, GIS and CN Technology.

Existing LULC changes of DER were mapped from Landsat 5 (TM), 7 (ETM+) and 8 (OLI-TIRS) imageries, respectively for 2010, 2012, and 2016 using supervised classification. LULC changes mapped in this study provided a total of eight scenarios of which the pre-developed condition is described by 2010 and 2012 and existing conditions by 2016-17. Out of the five post-development scenarios, one is proposed by RAJUK as per RDP and most likely to shape the future LULC of the Eastern Region of Dhaka. The other four predicted post-development scenarios derived from the Landsat imagery of existing 2016-17 LULC, in effect, represented the direction of future urban growth and mostly covered the entire urban development proposed in RDP for DER. The classified Landsat imagery of 2016-17 detected the direction of likely post-structural urban development as envisaged in RDP for DER.

A slower pace of urbanization was traced in terms of paved built-up coverage with 4.0% in 2010, 6.0% in 2012 and 8.0% in 2016-17 from the total 215.28 km^2 land of DER. Conversely, a faster pace from 8.0% in 2010 to 20.0% in 2016-17 was observed in case of unpaved bare soil or filled land transformed mainly from agricultural and tree-covered areas which might be a built-up paved surface with a likely 65.0% post-developed imperviousness by 2035 or beyond as projected in RDP scenario. RDP proposed LULC had a significant increase in paved built-up areas from existing 8.0% to 49.0% by 2035. Besides, four post-developed LULC changes were predicted from the classified Landsat 8 imagery where predicted scenario-1 followed the RDP scenario with nearly 62.0% paved surface mainly due to conversion of the identified unpaved tree-covered area as opposed to the conversion of agricultural areas in case of scenario-2. However, predicted scenario-3 and 4 with maximum urbanization resulted in nearly 94.0% paved surface with respectively 65.0% and 85.0% imperviousness.

This study estimated runoff by the SCS-CN method of integrating RS and GIS tools. Like the slower trend of urbanization, area-weighted CN also increased slowly till 2016-17 but increased substantially in RDP as well as scenario-1. Hydrological impact on runoff was assessed from the pre-developed 2010 LULC as a reference year. Two different sets of impact on runoff were observed due to average and seasonal variation of antecedent moisture condition (AMC) of soil. Distinctively, seasonal AMC generated around 14.0% to 17.0% higher runoff than average AMC.

Given the assessed impacts of LULC change on runoff, scenario-2 is hydrologically more suitable than others. But, the direction of LULC change indicates RDP or predicted scenario-1 is an impending LULC of DER. In effect, RDP/scenario-1 (CN 84) was considered as the limiting LULC for DER which would approximately result in 40.0% of total rainfall as runoff annually with seasonal AMC. However, predicted scenario-4 with maximum CN 90 would result in more than 50.0% runoff which indeed, would depict the typical landscape of core city Dhaka within DER.

Finally, the method and results illustrated in this study on the impacts of land-use change on runoff can be used in local-level city planning and likely to be useful for a general hydrologic forecasting as well as for understanding consequences associated with the land-use changes. Before structural development, an adequate natural drainage system should be planned to avoid excess runoff and the usual waterlogged situation observed in core city Dhaka due to intense rainfall. This would in turn lower the post-structural drainage development cost. Besides, inevitable recharge loss may be addressed.

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