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Hydrologic Performance of Drainage Network Under Different Climatic and Land-Use Conditions, A Case Study of Chattogram

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ABSTRACT

The recent alternation of urban hydrology is seen significant due to the growth of urban sprawl. In the changed urban hydrology and urban settings, the city drainage is seen underperformed and problems are manifolds. This study therefore aims to evaluate the hydrologic performance of drainage under different land use patterns demonstrating urbanization effects using the Mahesh Khal in Chattogram as a studied watershed. This study analyses land use pattern of the study area with the data collected through field investigation and also gathered from the secondary sources using ArcGIS 10.4. The change patterns are realized portraying scenarios with statistical significance. The study revealed that the trends of built-up area is significantly high figuring out over doubled in last 30 years period; 24% in 1998 to 53% in 2018 compromising the lost of open water and vegetative surfaces. In align with such changes, the peak discharges found for 2, 5, 10, 25, 50 and 100 years return period were 20, 29, 36, 44, 50 and $57\text{ m}^3\text{ s}^{-1}$, respectively, and were seen varied mostly with the curve number and imperviousness. The discharge in combination with tidal inflow into the Khal exceed the capacity of the existing capacity and is seen underperformed. The dumping of solid wastes, improper management of Khal, changes in surface slopes of connecting drains are found key factors. The study suggests that maintaining vegetation and surface slopes may increase the performances of drainage.

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1. Introduction

The recent trends of rainfall-runoff under climate change certainly put pressure on urban drainage systems in particular. The growths of urban sprawl and migration to urban from rural see the substantial changes in hydrologic cycle in many ways, such as increased impervious areas [1,2] and subsequently surface runoff while decreased vegetation cover and open space and subsequently infiltration into soils are found significant. The urban area also witness of withdrawing significant amount of water [3] in ratio with recharging volume while water quality of surface water appears to be unsuitable. The replacing indigenous vegetation with human induced development [4–8] leads to a complex challenges of managing urban watershed of a drainage system [9–11] in particular. As a result, it has been seen that the recent extreme rain events are more frequent and devastating as the rate of urban growth is so rapid than the capacity of urban drainage system [12–15]. Nevertheless, flooding is seen very linked with intense storms that are more likely to be increased with climate change [16–18] concepts, such as contribution of intense precipitation along with temperature and sea level rise may further questioned the necessity of adequacy check of urban drainage under multiplying effects of the events [19]. As evident in Bangladesh, the major urban cities like Dhaka and Chittagong undergo water from an intense rainfall events of an hour or so and causing serious disruption of city dwellers when the volume of runoff was found beyond the capacity of the existing drainage network. It is therefore necessary to understand the relation between land use pattern and hydrologic changes under climatic patterns that is economically justified, socially acceptable and environmentally sound [11,19] followed by monitoring, analysis and subsequent implementation of the preventive measures in relation to sustainable urban drainage system approach [20,21].

The rainfall-runoff is a complex hydrological phenomenon affected by various processes in urban catchment requires nonlinear and dynamic transitions of soil types, infiltration, percent impervious, evaporation, evapotranspiration, land use pattern, natural drainage conditions etc. [22–24]. The recent development of urban drainage now a days not limited to manage volume of water alone but also to address the issues of water quality and amenities named as Sustainable Urban Drainage Solutions (SUDs) or Low Impact Development (LID) have got huge attention because the concepts consider different aspects of the urban drainage system i.e. runoff quality, amenity and recreational value, social and ecological protection etc. as a whole to mimic the natural drainage system. Unlike other cities in developing countries, Chittagong is a financial capital of Bangladesh and house of the largest port in the country located in the south east belt with hilly landscapes and the major drainage canals are connected with sea. It is hugely populated and the growth of urban sprawling houses the people along coastal areas living between 0 to 5-meter elevation from mean sea level. The city faces natural hazards in frequent intervals among which water logging and flooding are prominent along with cyclone with storm surge, landslide, earthquake and flash flood are also seen to exist [25]. Due to rapid urbanization along with climate change, Chittagong city dwellers are facing water logging problem in last few years. The average rainfall of Chittagong is 3378 mm that is substantially higher than country's annual average of 2300 mm and rainfall is mostly occurs between May to October. Furthermore, it is noted that in July, the precipitation reaches its peak, with an average of 743 mm [26]. The land use patterns of an area have influences over the hydrological condition while the increasing

urbanization reduces water body and natural streams. There is an increasing trend observed for land use change due to migrating people from rural parts and this has an advance effect on the hydrological condition of city areas which sooner or later leads to water logging [27,28]. In this line, Chittagong city sees at least 12 canals off from its map in the last 48 years that is unfortunate and certainly accelerate the frequency of the water logging issues in the city. A mere 22 canals were found to be emptying into the Karnaphuli River and there was no trace of 12 canals in the premier port city where 8 of the 22 existing canals are also dying [29]. The problems of drainage system are even further exaggerate due to siltation, solid waste disposals and poor maintenance; e.g. major canals lost 42% carrying capacity due to siltation with reported 87% of the existing silt traps being dysfunctional [30]. In this line, it is also seen that over 14,000 ponds and other water bodies have disappeared in last 18 years in Chittagong. According to a survey conducted by District Fisheries Department in 1991, the number of water bodies in Chittagong city was 19,250 while the Featured Survey conducted by CDA in 2006-2007 indicated existence of 4,523 water bodies only. The indication of drainage at present condition is about 100 sq. km. drainage catchment of Chittagong city is pumped out through five canals- Chaktai Khal, Mahesh Khal, Sub area Khal, Monohar Khal and Hizra Khal, while in other parts of city left alone with natural drainage.

Scientists have given much concern about the functionality of the traditional drainage system due to its adverse effect on environment. In traditional urban drainage system, surface runoff from impervious areas may increase the occurrences of frequent flooding also may cause sudden rise in water level and may cause poor water quality in natural water bodies. As the rainfall diverted through pipe system in traditional method, the total amount of infiltrated underground reduced which causes depletion of the ground water table. There is also limited capacity and flexibility of traditional drainage system to adopt urbanization effect and climate vulnerability[31]. As discussed earlier, the concept Sustainable urban drainage (SUDs) comes to mitigate these problems. Sustainable urban drainage (SUDs) refers to management of water in small scale and facilities surface runoff in a more sustained way focusing on maintaining good health, preserving water resources and protecting biological diversity and natural resources [32–35]. Therefore SUDs is a management practices and control structures which has been designed to discharge out surface runoff in more sustained way [36] which results in increasing natural infiltration, collection of solid using sedimentation, increment of nutrient and hence reduction of pollutant etc.[37]. SUDs (known in UK) is known as Low-Impact-Development (LID) in the USA and Canada [38], Water Sensitive Urban Drainage[39] in Australia, Urban drainage in Brazil [40]. Thus, SUDs can be the effective solution in order to mitigate the problems associated with urban drainage. The SUDs concept can be divided into three major groups aiming to reduce the quantity of surface runoff, slowing down the velocity in order to allow infiltration and to allow settlement and finally providing treatment before discharge onto environment [41]. The SUDs provide a number of benefits over a traditional drainage system that is unable to facilitates. The SUDs enhance water quality of a watershed and provides protection to biodiversity in urban water bodies besides it gives protection to people and property from frequent flooding. SUDs protect the water bodies from different type of contamination from both local pollutant as well as from accidental pollution. It also provides proper utilization of natural resources which promotes sustainable use of water courses of the biosphere[42]. The components mostly highlighted in

SUDs are rainwater harvesting, detention and retention reservoirs, bio retention system, green roofing, permeable and semipermeable pavement, underground reservoir, grassed strips, attenuation storage system etc.[33,43]. The empirical formula may be established considering these effects for the development of the hydrologic models [22]. The simplest rational method considering “runoff coefficient” have already been introduced to determine the total runoff. This been done multiplying the coefficient with total rainfall [44]. Then imperviousness along with other factors such as time of concentration, soil properties, land use conditions of a catchment have been converted into a regression formulation or tabulated values to have more accurate prediction about runoff.

Despite all the attempts, city people are still facing tremendous problem related to drainage issues. Water logging are much more frequent during monsoon than that of before. Areas of vegetation have been reduced as result of urbanization. Climate pattern also changes rapidly due to geographical location of the city. Within the present contexts and future trends of urban drainage designs, a study has been undertaken with the aims of the performance of existing drainage system in Chittagong city under different changed climates and land use patterns. The specific objectives are given below.

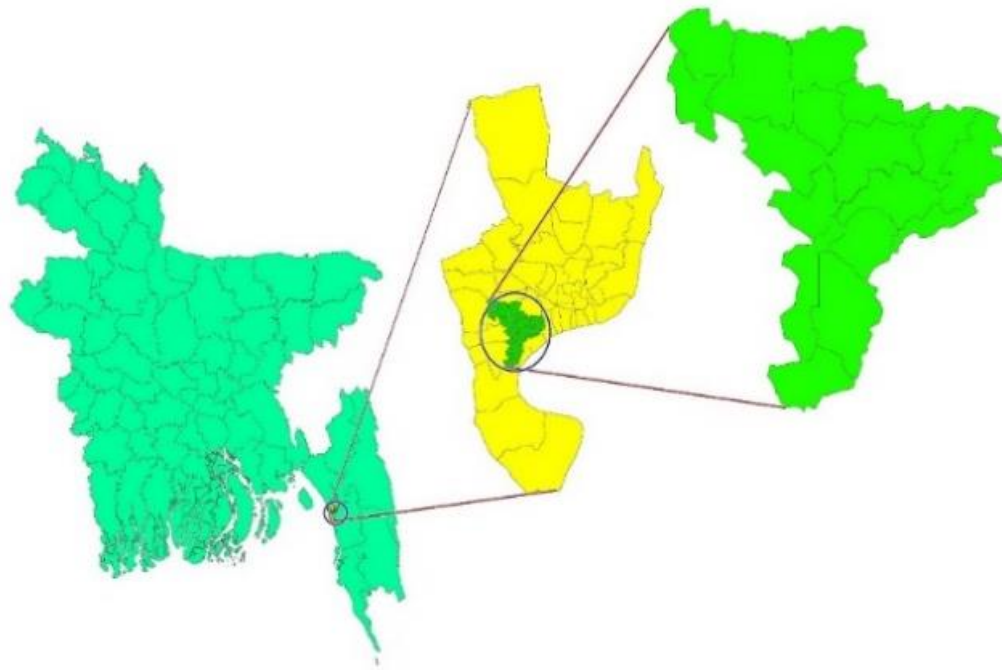
- a. To simulate the existing drainage network by using primary data to replicate the adequacy of drainage
- b. To evaluate the hydrologic performance of drainage network under different land use and climatic conditions.

This study may assist local policy makers to adopt measures ahead to manage city’s drainage network that is seen inadequate influenced by unplanned urbanization, solid waste disposal issues, lack of operation and maintenance issues.

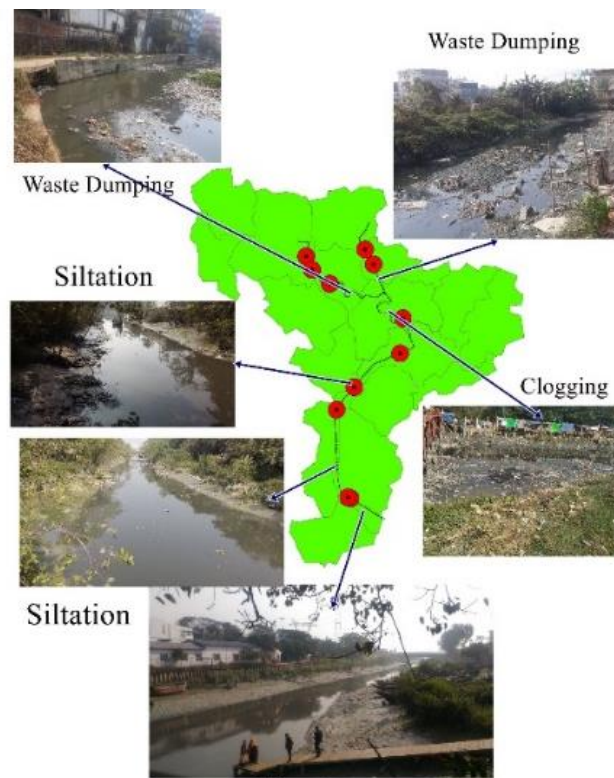
2. Methodology

2.1. Study area

Mahesh Khal, one of the major canals in Chattogram city draining a substantial amount of wastewater into the river Karnaphuli has been taken as study area as shown in Fig. 1. The catchment boundary lies between latitude ($22^{\circ}17'49.751"N - 22^{\circ}20'22.2612"N$) and ($91^{\circ}46'30.6948"E - 91^{\circ}48'45.2412"E$) and, is found to occupy the area of about 8.6 Km^2 (857.8 ha) with a slope of 16% from upstream to downstream direction. The canal is located in between Sadarghat and Khal-10 station. The study area is further classified into 17 sub-catchments or drainage sub-basin based on land use patterns. The land use patterns belong to commercial and residential mainly comprising 32% of the total area covered up by vegetation and open space, 15% is water body, while 54% is to built-up area. The length of the canal is about 6.3 Km and which is divided into 6 reaches. The canal collects the natural flow along with water draining from sub-basin areas at the upstream and finally discharges into the river Karnaphuli.



(a)



(b)

Fig. 1. The map showing (a) study area, and (b) pictures demonstrate the current situation of Mohesh Khal in Chattogram at different places.

2.2. Methods

The Fig. 2 illustrates the methodology followed in this study. The model development includes the primary data, such as cross section, side slope, bottom slope, bottom materials, tide level, discharge of the canal and also different types of land use land cover (LULC), flow path etc. are collected surveying various points along the Khal. A total of eleven points were selected for data collection as shown in Fig. 1(b). The bottom width of the canal was divided into several strips and depth of the bottom of the canal was determined using rope with a mass attached at the bottom of the rope.

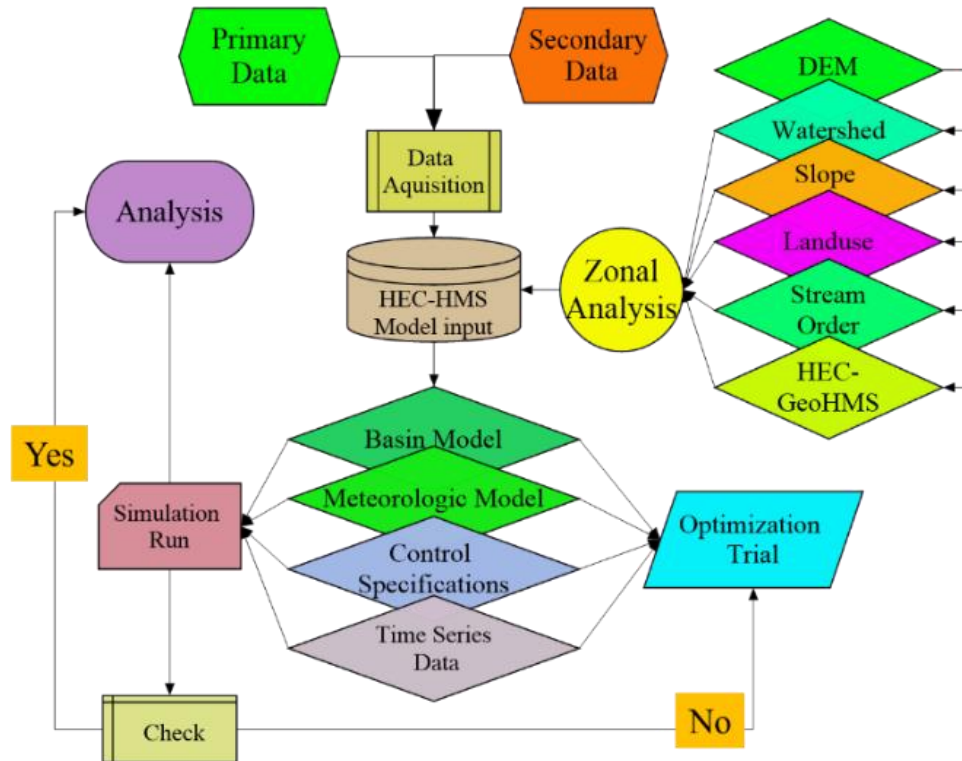


Fig. 2. Flow diagram of total working framework.

The length of the canal was determined using field calculator in ArcGIS 10.4, and the average bottom slopes were determined using 3D analyst in ArcGIS 10.4. The Khal's bed and bank materials were inspected physically and were recorded for the selection of Manning's roughness coefficient, n . Digital Elevation Model (DEM), Land use map, soil data map, precipitation, tide tables, discharge etc. were collected from the secondary sources as presented in Table 1. The land use and land cover data were recorded in different locations for actual representation of the catchment and hence, the land use map was derived using supervised classification method using ArcGIS 10.4. The classification process was repeated for different respective years (1988-2018). The generated classified land cover map was verified using ground data and Google earth, and finally accuracy check has been done using Cohen's kappa coefficient (κ). The equation used for the calculation of the time of concentration for the watershed has been taken from the published literature as defined in Eq. (1) [45].

$$\text{Time of Concentration, } t_c = \frac{FL}{A^{0.1} \times S^{0.2}} \quad (1)$$

Where,

t_c (min) = Time of Concentration

L (Km) = Length of the stream

A (Km^2) = Sub-basin area.

S (m/Km) = Overland slope

F = 58.5 When A in Km^2

SCS unit hydrograph method was adopted for flow routing along the length of the Khal studied here. The Lag time (min) for the watershed was calculated based on Eq. (2).

$$\text{Lag Time, } t_{lag}(h) = \frac{2.587 \times L^{0.8} \times \left(\frac{1000}{CN} - 9\right)^{0.7}}{1900 \times H^{0.5}} [46] \quad (2)$$

$$\text{i.e. } H = \frac{100 \times CI}{A} \quad (3)$$

Where,

L (m) = Hydraulic watershed length = $110A^{0.6}$

A (ha) = Sub-basin area.

CN = Curve number.

H (%) = Average sub-basin land slope.

= Calculated based on [47]

C = Summation of the length of the contour lines that pass through the watershed drainage area on the quad sheet and

I = Contour interval

Table 1

The secondary data used in this study.

Data	Source	Address	Resolution /Periods /Others
DEM	United States geological Survey (USGS)	https://earthexplorer.usgs.gov/	30m
Land Use Map	GlobeCover	http://due.esrin.esa.int/page_globecover.php	1 : 500000
Soil Data Map	Food and Agricultural Organization (FAO)	http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116	1000m
Precipitation	National Aeronautics and Space Administration (NASA) Bangladesh meteorological department (BMD)	https://earthdata.nasa.gov/ www.bmd.gov.bd	2018
Water tide table	Chittagong Port Authority (CPA) Bangladesh Navy Hydrographic & Oceanographic Centre (BNHOC)	http://www.cpa.gov.bd/site/view/commondoc/Tide%20Table/ http://bnhoc.navy.mil.bd/?pageid=77	2017, 2018
Discharge	Bangladesh Water Development Board (BWDB)	https://www.bwdb.gov.bd/	2018

The USDA Natural Resources Conservation Service (NRCS) method in previous known as SCS has been used for rainfall - runoff modeling addressing the factors of soil permeability, surface cover, hydrologic condition etc. The data used for CN value can be found in the “June, 1986 Technical release 55 – Urban Hydrology for small watershed (TR-55)” report [48]. In the present study, automatic calibration known as “Trial Optimization” in HEC-HMS was used to obtain the optimum parameter values that gives the more similar values among observed and simulated values instead of manual calibration that is often seen erroneous. The HEC-HMS model is basically calibrated using event based simulation where the assumed parameters undergoes an iterative adjustments under certain boundary conditions until the parameter reach to a certain accuracy level. A particular event (24 July, 2018) was selected for calibration of the HEC-HMS model parameters. The hydrograph generated from the model is compared with the observed direct runoff. Two important parameters, curve number (CN) and manning’s n were selected for calibration. The observed and simulated values were assessed using R^2 indicator. For the simplicity, all the performance evaluations were conducted considering metrological effect only. The present investigation has some limitation as it was overlooked the effects of tide, backwater and inflow from various nonpoint sources. The reasons behind this approach are due to insufficient data set, master plan of the studied catchment and limitations of the HEC-HMS model regarding uncertainties. The capacity for the canal with respect to metrological parameters of rainfall and runoff were considered to evaluate the performance of the existing Khal against various scenarios. The cross section considered for determination of the actual capacity is the average cross section of the whole canal. The discharge due to tidal effect have considered the average peak discharge available of the canal throughout the year.

2.3. Watershed delineation

Hydrological analysis for canal performance was carried out in ArcGIS 10.4 using hydrology tool in Arc toolbox. Hydrological analysis compromised the extraction of multiple components including flow direction, flow accumulation, watershed delineation and stream networks. The Fig. 3 depicts the processes of fill DEM preparation, flow direction, flow accumulation, assigning pour points, stream ordering, grid delineation, converting raster image to polygon, drainage line that were done sequentially to generate watershed delineation for the study area.

2.4. Spatial analysis

The digital elevation model (DEM) is the fundamental dataset that has been used for spatial analysis, development of basin component parameters in HEC-HMS model as well as creation of the watershed geometry. The DEM with 30 m x 30 m resolution collected using Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) radar data for the study area and is freely available in the United States Geological Survey (USGS) Web sites (<http://earthexplorer.usgs.gov>) [49].

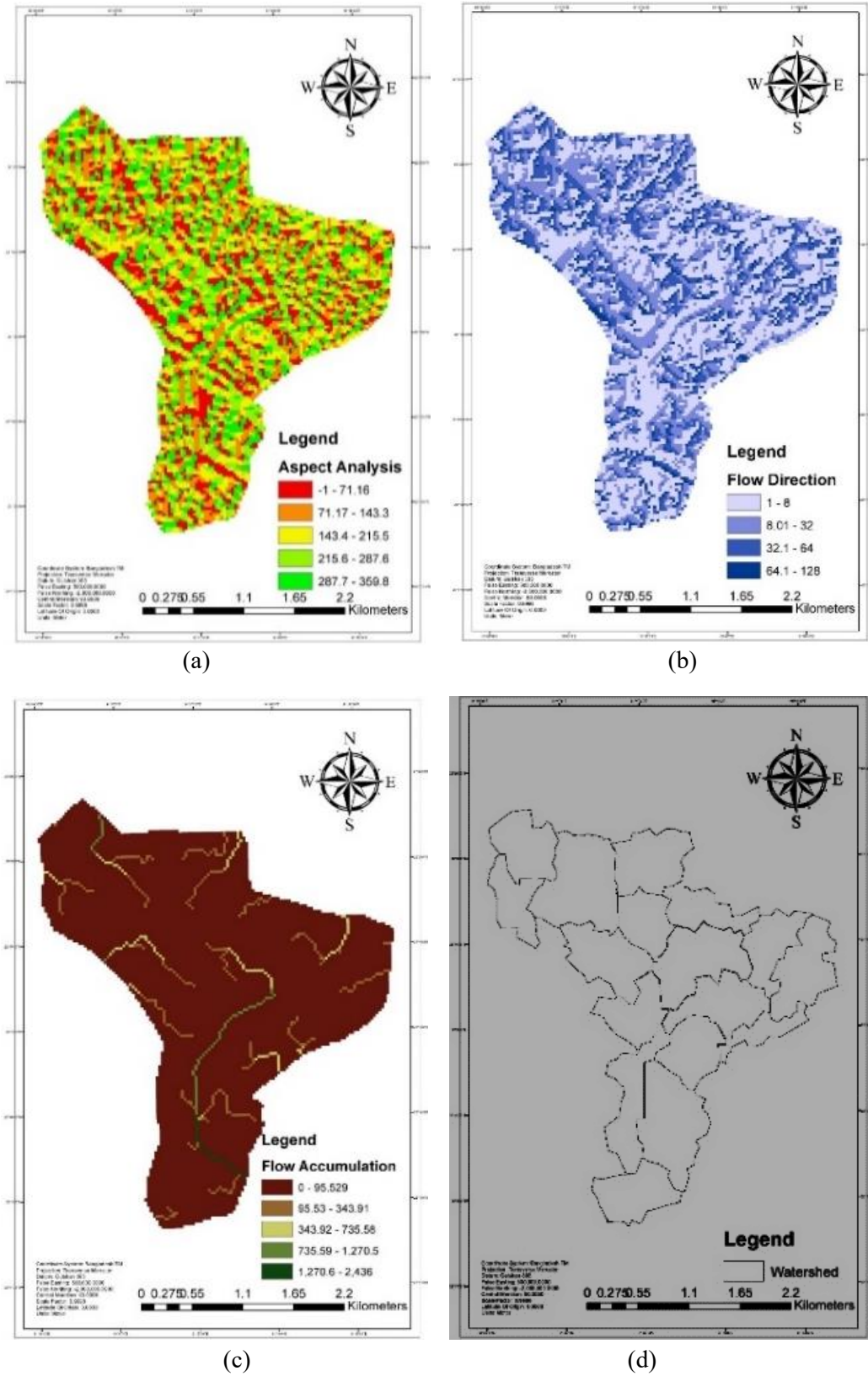
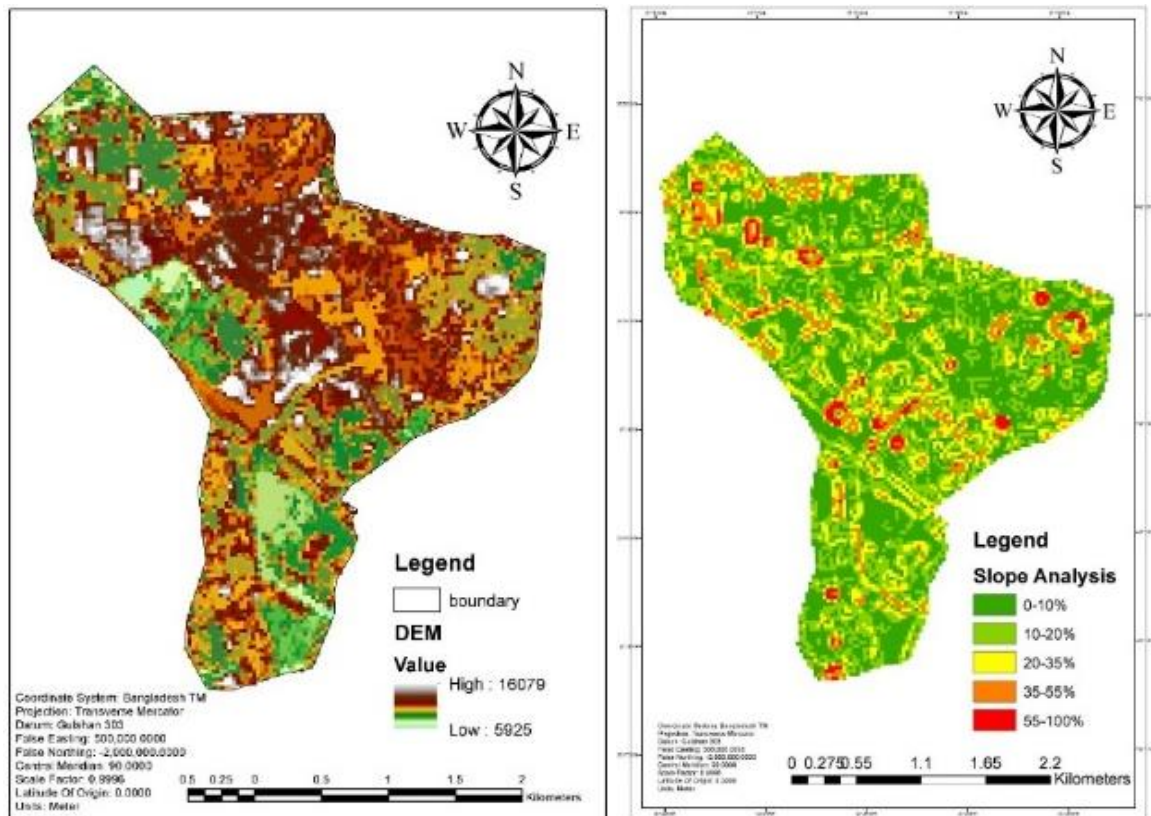


Fig. 3. Watershed delineation process showing (a) aspect analysis (b) flow direction (c) flow accumulation and (d) watershed for the studied area in Chattogram.



(a)

(b)

Fig. 4. Spatial analysis (a) Digital Elevation Model (DEM), (b) Slope Analysis

The cloud-free image was acquired in 2nd November, 2018. The fill DEM used for the further analysis shown in Fig. 4 (a). The elevation varies from 5925 m to 16079 m. The slope analysis of the study area is shown in Fig. 4 (b) indicates that the central and the north-west parts are generally steeper than that of lower portion near outfall. The slope value has been shown in percent rise and the values for each sub basins were retrieved using raster calculation and zonal analysis. Finally, the data were incorporated with each sub basin using add field command using ArcGIS 10.4. The slope values for all 17 sub-basin varies between 13% to 23%, with an average slope of the Mahesh Khal is 16%. The detailed slope analyses results are presented in Table 2.

2.5. Data preparation and model setup

The Fig. 5 illustrates the watershed with 17 sub-basins, 6 reaches, 6 junctions and 1 outlet that were imported as background layer in HEC-HMS. The basin and canal parameters were extracted from the attributes table for 17 sub-basins and 6 reaches using raster calculation and zonal statistics in ArcGIS 10.4, and summarized in Table 2 and Table 3. The hydraulic length, initial abstraction, lag time were derived using respective equations as discussed earlier. The curve number (CN) for each sub-basin was taken from TR-55 Curve Number Tables. The corrected curve number (CN*) were obtained after several optimization trials using HEC-HMS for the 17 sub-basins.

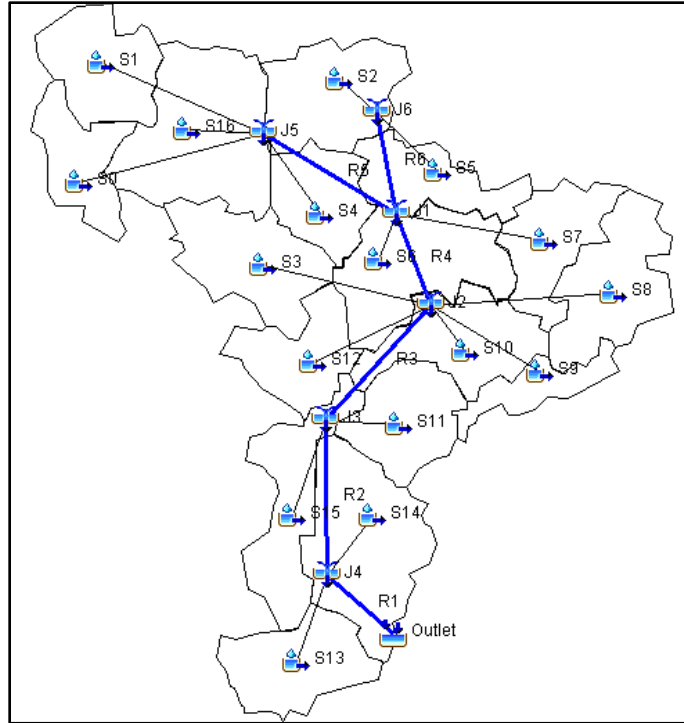


Fig. 5. Model setup in HEC-HMS for hydrologic modeling

Table 2

Physical properties of Sub- basins used in model.

Basin ID	Basin Area, A (ha) ^a	Slope, H (%) ^b	Hydraulic Length, L (m) ^c	Curve Number, CN ^d	Curve Number, CN* ^e	Initial Abstraction, Ia (mm) ^e	Percent impervious (%) ^f	Lag Time, lag (min) ^g	d/s of sub basin
S0	30.20	18.85	1523.36	84	79.06	13.45	37	16.38	R5
S1	40.01	22.53	1675.36	80	76.83	15.32	4	17.29	R5
S2	47.46	12.49	1114.83	87	83.56	10.00	63	13.57	R6
S3	48.88	16.59	1134.61	82	78.75	13.71	43	13.92	R3
S4	31.97	13.06	879.52	86	75.85	16.17	73	13.95	R5
S5	32.03	13.74	880.46	87	76.73	15.40	68	13.27	R6
S6	58.89	13.11	1268.81	86	82.59	10.71	56	15.16	R4
S7	35.65	16.99	938.91	82	78.75	13.71	44	11.82	R4
S8	48.87	16.75	1590.26	83	79.71	12.93	38	17.62	R3
S9	19.02	18.11	1044.10	86	82.59	10.71	62	11.04	R3
S10	44.53	16.51	1072.89	85	81.63	11.43	75	12.19	R3
S11	37.32	16.13	965.10	85	81.63	11.43	45	11.33	R2
S12	33.91	21.98	911.22	87	76.73	15.40	37	10.78	R3
S13	40.93	14.30	1019.99	86	82.59	10.71	56	12.19	R1
S14	68.07	13.82	1384.08	83	79.71	12.93	42	17.36	R1
S15	44.13	17.22	1067.12	87	83.56	10.00	78	11.16	R2
S16	74.71	17.78	1463.55	85	81.63	11.43	45	15.06	R5

C* Corrected CN values

^{a, b, c} DEM

^d Curve Number Chart

^e empirical equation (USACE, 2000)

^f collected from land use map

^g Schwab's equation

Table 3

Reach parameters used in the model.

Reach Name	Length (m) ^a	Top width (m) ^b	Depth (m) ^b	Bottom width (m) ^b	Bottom Slope (m/m) ^b	Side slope (1: z) ^b	Manning's n ^c
R1	557	39.01	5.63	6.67	0.001143	0.35	0.040
R2	936	34.51	4.80	11.57	0.002110	0.42	0.0450
R3	1196	39.22	3.51	10.57	0.004500	0.24	0.0450
R4	1119	33.05	3.71	19.56	0.005130	0.55	0.0775
R5	1602	17.27	3.34	8.06	0.006540	0.73	0.1000
R6	896	10.82	2.87	7.20	0.006370	1.59	0.0700

^aDEM^bField Survey^cManning's n chart**Table 4**

Others parameters used in model.

Storm depth (mm) a						
Present	2 year	5 year	10 year	25 year	50 year	100 year
74.13	91.06	122.62	143.57	169.99	189.58	209.06
Others parameters						
Properties					Value	Unit
Catchment Area, A b					8.58	Km ²
Overland Slope, S b					16.37	%
Overland Slope, S b					163.70	m/Km
Length of the stream, L b					6.30	Km
Time of Concentration, Tc c					107.24	min

^aIDF curve^bDEM^cRational method

Storm depths for different return periods have been shown in Table 3 for the present situation and for 2, 5, 10, 25, 50 and 100 years, respectively. The storm depths are adopted from the IDF curve. Others parameter includes total catchment area for the catchment, overland slope, total length of the canal and the time of concentration etc. were calculated from spatial analysis and using respective equations.

3. Results and discussion

3.1. Land use patterns

The land use patterns of the studied area using remote sensing and GIS technique were adopted as effective tools for evaluating land use and land cover analysis where the large land area can be mapped with low cost and rapidly with high accuracy. The Cohen's kappa coefficient (κ) found as 0.889 indicates high accuracy of the land-use land cover (LULC) classification obtained. The major three land use classifications have been carried out for the years of 1988, 2008, 2012 and 2018, and the results are presented in the Fig. 6 and Table 5, respectively. As seen in Fig. 6, it has been clearly illustrated that built-up areas increased sharply over the years that is alarming in

relation to urban sprawl that not only reduces the open and vegetation areas but also prone to frequent flooding putting stress on existing drainage. Table 5 present the detailed results obtained from the land cover classification of three types of land use analysis.

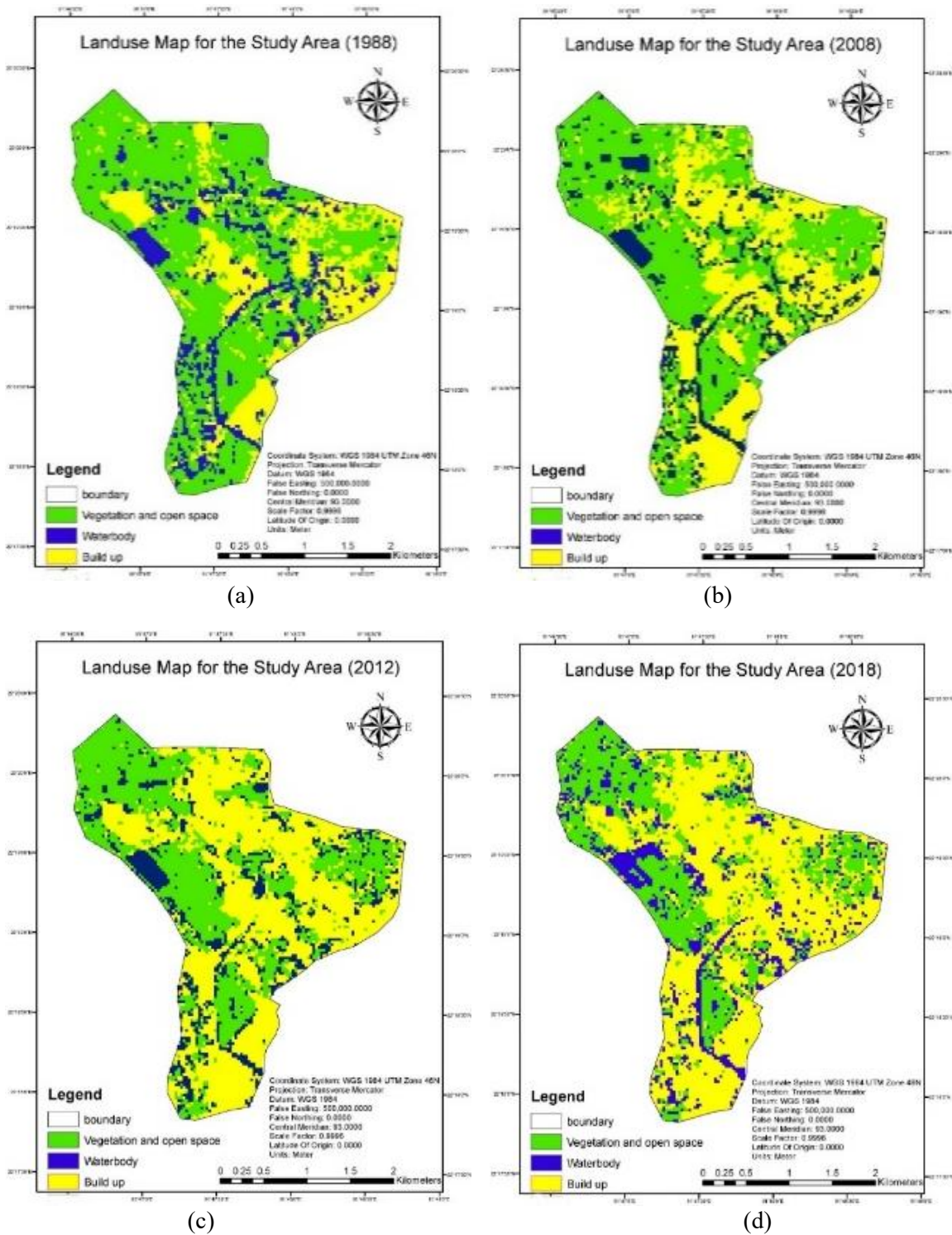


Fig. 6. Land use maps of the Mahesh Khal catchment showing the changes in the land covers during 1998 to 2018.

Table 5

Land use analysis of the study area.

Type of land use	Area in 1988 (%)	Area in 1998 (sq. km)	Area in 2008 (%)	Area in 2008 (sq. km)	Area in 2012 (%)	Area in 2012 (sq. km)	Area in 2018 (%)	Area in 2018 (sq. km)
Vegetation & open area	59.64	5.12	48.85	4.19	36.71	3.15	31.52	2.71
Water bodies	15.34	1.32	14.37	1.24	14.41	1.24	14.97	1.28
Built-up area	25.02	2.15	36.78	3.16	48.88	4.20	53.51	4.59

As seen in Table 5, the built-up area increased about 28.5% in last three decades demonstrating 25% of the total area (2.15 km² out of 8.59 km²) in the year of 1988 while that was found more than doubled (4.59 km² and in percentage about 53.51) in the year of 2020. The trend of change in built-up areas was slower up to 2008 as compared with the changes found later years. The built-up area was about 3.16, 4.20, 4.60 Km² for the year of 2008, 2012 and 2018 which is about 37%, 49% and 54% of the total area. Out of total 8.59 Km² of total land areas 5.12 Km² areas of land occupied as vegetation and open areas ranked first of three types mentioned here amounting 60% of the total area in 1988. It is well understood that within the 30 years of time span the open area and water bodies were occupied by the built-up areas that is responsible for drastic changes in surface runoff and, hence questioned the adequacy of managing runoff with existing drainage.

3.2. Validation of the model

Successful implementation of hydrological models mainly dependent on how accurately the model is calibrated and validated. Model calibration is done to match the values of runoff volume, peak discharge and time of hydrograph among observed and simulated values.

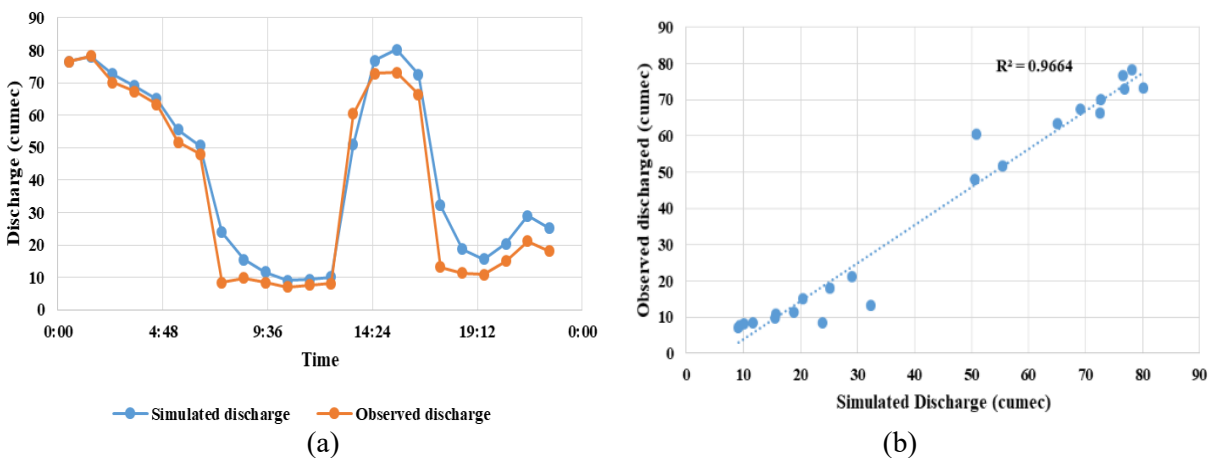


Fig. 7. Validation of the model (a) Observed and simulated discharge (b) accuracy analysis.

The calibration was done between simulated and observed discharge and the results are shown in Fig. 7(a). Initial and corrected parameter values are shown in Table 2 and Table 3. The corrected and calibrated values are considered for the further analysis and performance evaluation of the

drainage system. R^2 value obtained after implementation of all calibrated values for this particular event is 0.9664 which specifies good accuracy of the calibration as shown in Fig. 7(b).

3.3. Performance evaluation based on present situation

The actual capacity found for the canal is $103.85 \text{ m}^3\text{s}^{-1}$ whereas the average peak tidal height along with inflow has been found as 3.75 m, and the corresponding discharge due to tidal effect and inflow has been found $87.34 \text{ m}^3\text{s}^{-1}$. The capacity with respect to metrological effect is found as $16.51 \text{ m}^3/\text{sec}$ during the high tide and in combination with tide the catchment sees frequent water logging and in some cases flooding in these area even with a limited intense rainfalls demonstrating inadequacy of the existing drainage system in place.

3.4. Performance evaluation varying curve number (CN)

Curve Number (CN) value is a hydrological parameter that is frequently used to predict the direct surface runoff with eased. With the increased impervious areas, it is expected that the surface runoff will be increased further if the rate of built-up area is going in this space. Fig. 8 illustrates the change of discharge with different CN values varying from 30 to 98 in different return periods. Considering water present in canal as backwater effect from the tidal effect, the peak discharge is seen within the capacity at its present condition. However, any further changes as expected from the climate change for return period of 30, 40, 50 years, it may to exceed the carrying capacity limit of the canal. Furthermore, improper maintenances, disposal of solid wastes, reverse slope of households connections of drains are also seen to play a significant roles for reduced capacity of the existing drainage systems.

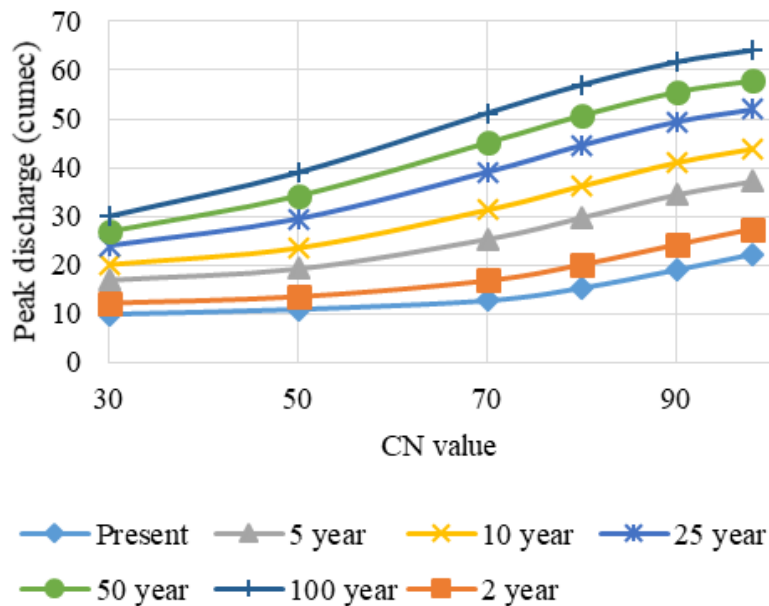


Fig. 8. Variation of discharge with CN value in different return periods.

The average peak discharge values found for 2 to 100 years return periods are $26 \text{ m}^3\text{s}^{-1}$ and $51 \text{ m}^3\text{s}^{-1}$, respectively, with respect to different CN value. The result shows that the changes are

more significant up to CN value 70, while further increase of CN value does not differ the peak discharges much. For examples, the average peak discharge values with 50 years return period with CN of 30 and 70 are found as $25 \text{ m}^3\text{s}^{-1}$ and $45 \text{ m}^3\text{s}^{-1}$, respectively, almost doubled in comparison, while that for CN of 90 is seen as $55 \text{ m}^3\text{s}^{-1}$. However, the point to be noted that the decision makers or city planners should not feel encourage to grow built-up area compromising the reduced rate of increment in peak discharge compared to CN of 70 and 90, rather it is suggested that the built-up area and open area should be planned in a harmony so that the open area can support well with any future extreme events induced by the changed climate.

3.5. Performance evaluation varying percent (%) impervious

Percent (%) impervious indicates the area which will contribute 100% surface runoff without any loss (i.e. infiltration, percolation etc.). The change of peak discharge with different percent (%) impervious varying from 30% to 98% in different return periods have been analyzed and is shown in Fig 9. As seen, the peak discharge increases linearly with the increase of the % impervious as shown in Fig. 9, as expected. The standard deviation values found almost same of 15.5 for different percent (%) impervious values. The carrying capacity of the canal exceeds almost every values of percent (%) impervious for any return periods considering back flow or tidal effects from the sea connecting river. But if tidal water not considered and only meteorological effect considered for carrying capacity of the canal, the canal will be active for all the values of percent (%) impervious up to 100 years return period. The study revealed that the variation of speak discharge with the return periods are substantially different, such as for 2 year and 100 year return periods are seen $18 \text{ m}^3\text{s}^{-1}$ and $60 \text{ m}^3\text{s}^{-1}$ peak discharges respectively, while the variation over the same return periods with different values exhibit only moderate changes.

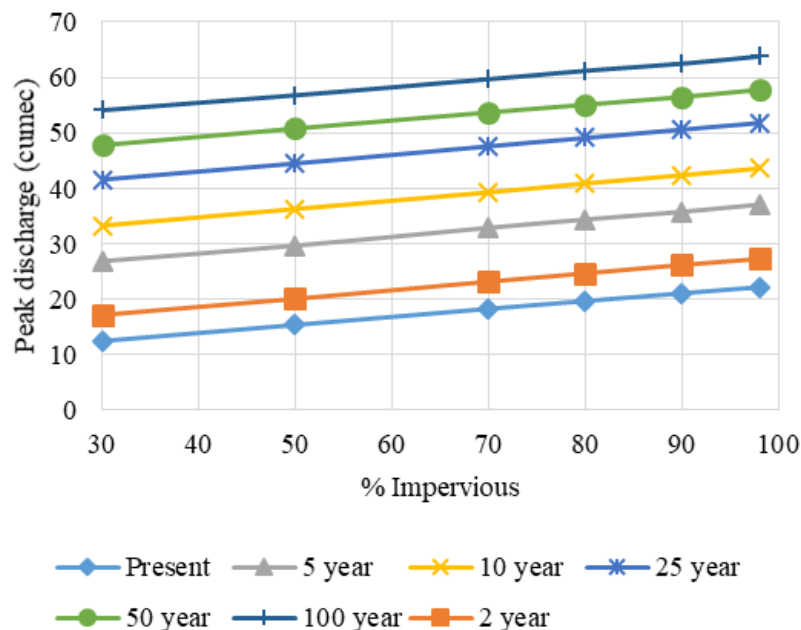


Fig. 9. Variation of discharge with % impervious in different return periods.

The result indicates that the uncertainty associated with extreme events may changes the runoff volume significantly with a drastic change in the catchment hydrology. In that case even with a small event of rainfall may generate peak discharge with quick intervals and lag time may not be adequate enough to drain the water in expected rate from the catchment.

3.6. Performance evaluation in different return periods

The change of peak discharges with the different return periods have been shown in Fig. 10. In present situation the maximum discharge value is about $15 \text{ m}^3\text{s}^{-1}$ which increase with the increase of return period and is obtained as $55 \text{ m}^3\text{s}^{-1}$ in 100 years return period. As seen in Fig.10, the peak discharge increases sharply with different return periods. The peak discharge will be almost 2.83, 3.32 and 3.75 times higher than the present discharge in 25, 50 and 100 return periods respectively.

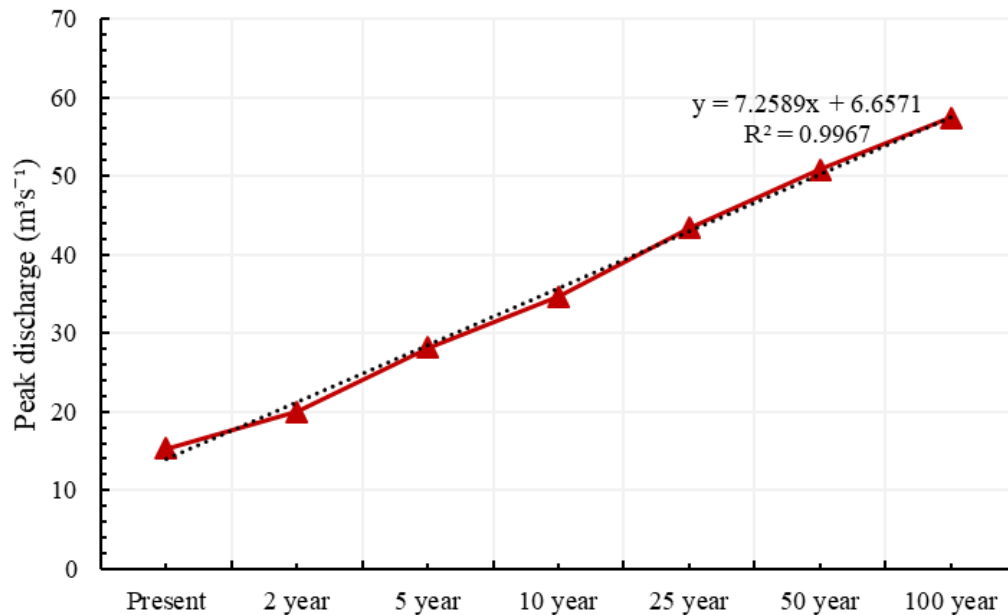


Fig. 10. Variation of peak discharge in different return periods.

3.7. Performance evaluation varying Manning's n

The Manning's n is related with the bottom materials and side materials forming natural canal, Khal, rivers etc. The lower values of the n indicate clean, uniform section having no vegetation or roughness, whereas the higher values indicate the cross section having dense brush, high stage, heavy stand of timber and underbrush or higher roughness. Fig. 11 illustrates the variation of peak discharges with respect to different n values from 0.02 to 0.15 in different return periods. It has been found that in different return periods, as expected, the peak discharges decrease with the increase of n values. The peak discharge for all n values is within the capacity of the canal if there is no tide. However, in combination with full tide, the Khal is found under capacity even for 2 year return periods.

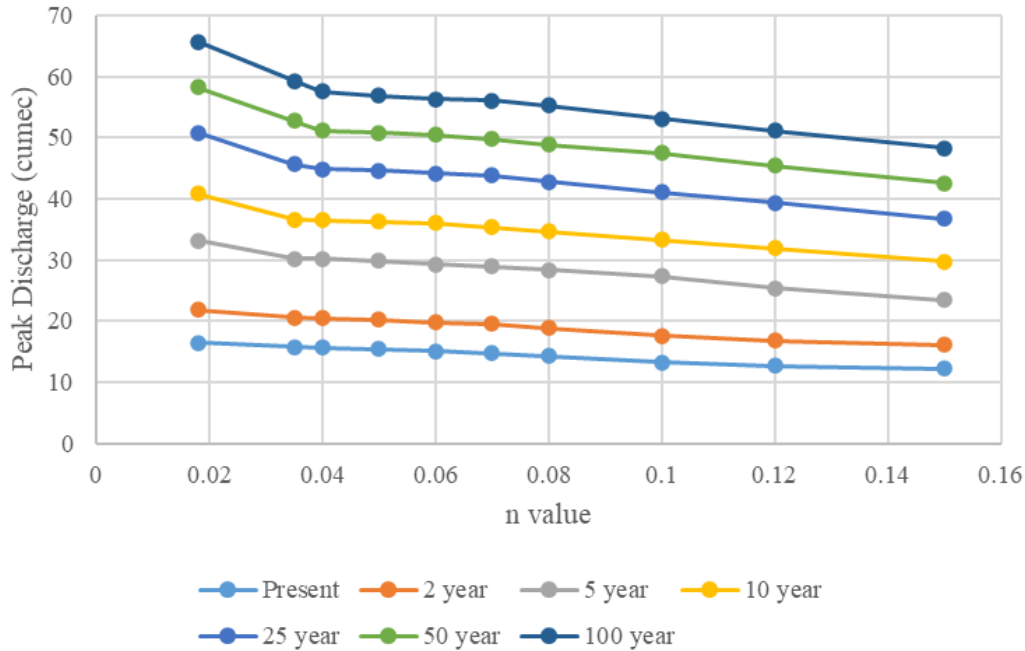


Fig. 11. Variation of discharge with n value in different return periods.

The standard deviation is found higher for a particular n value than different n values in different return periods. As for example, the standard deviation for the two different n values of 0.018 and 0.15 for different return periods are found as 18.44 and 13.48 with an average value of $41m^3s^{-1}$ and $29.84 m^3s^{-1}$, respectively. The results illustrate that the vegetated channel may help retardation of flow and reduced the flow velocity that further increased lag time. However, due to increase built-up area and encroachment of Khals, water bodies, open spaces further intensify the rapid development of surface runoff with speed putting immense pressure in the drainage systems.

3.8. Performance evaluation varying CN value with percent (%) impervious for different return periods

The Fig. 12 illustrates the change of peak discharges with respect to change in land use pattern and with different recurrence interval as a whole. The CN, represent the change in land use pattern has been considered to be varies from 30 to 98 if business go as usual towards the worst situation. For CN values 30, 50, 70, 80, 90, 98 in present situation, the total discharge capacity may exceed for percent (%) imperviousness of 90%, 80%, 70%, 60%, 40% and 30%, respectively, considering metrological effect only overlooking the tidal or backwater effects and others factors that may affect the discharges.

In this line 5 years return period the limiting percent (%) impervious values would be respectively 50%, 40%, 30%, 30%, 30% and 30% and that for 10 years return period percent (%) impervious values found 50% for CN value 30 and 30%, while for rest of the CN values the canal may underperform exceed its limit. For return period of 25 years, 50 years and 100 years, it has been found that the discharge crosses the maximum capacity even with a percent (%) imperviousness of about 30%.

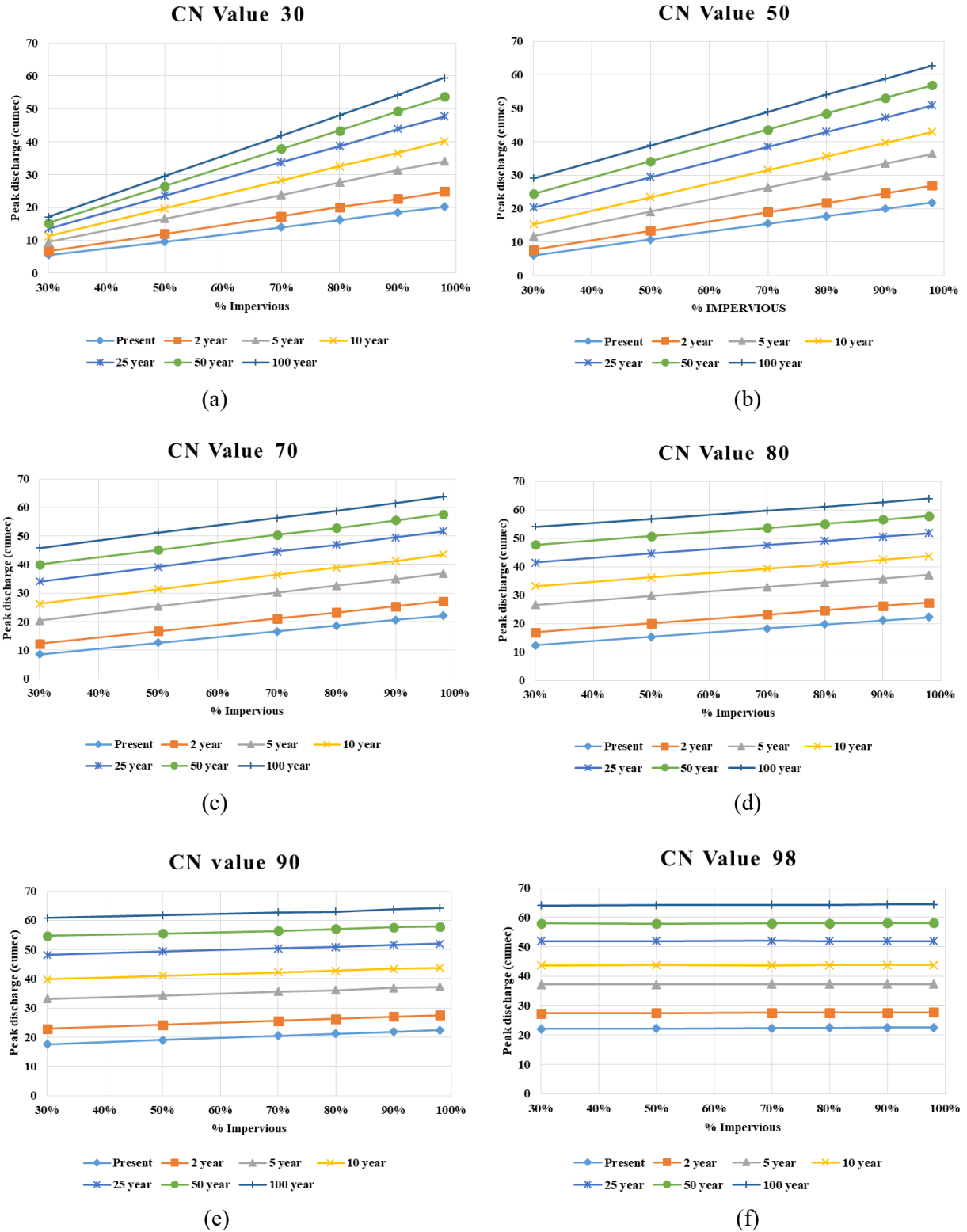


Fig. 12. Variation of peak discharge (a) CN value 30 (b) CN value 50 (c) CN value 70 (d) CN value 80 (e) CN value 90 (f) CN value 98.

4. Conclusions

Rapid growth of urbanization induced by rural urban migration has significant impact on urban hydrology and hence urban land use settings including increased percent impervious areas and surface runoff, while decreased vegetation, open space and water bodies. That in turn affects water quality and imbalance the physical, chemical and biological harmony of the watershed and its drainage systems. For the studied catchment, it is seen that the built-up area increased about 28.49% from the year 1988 to 2018. Within the 30 years of time span the built-up areas reduced about 28.12% of vegetation and open areas. The results found that the actual capacity of the Mahesh Khal is $103.85 \text{ m}^3\text{s}^{-1}$ whereas the average peak tidal height along with inflow has been found as 3.75m and its corresponding discharge due to tidal effect and inflow has been estimated as $87.34 \text{ m}^3\text{s}^{-1}$. The peak discharge would be within the capacity in present condition and also in 2 years return period for CN values up to 30, 40, 50, respectively, however, for further increased values of CN, the carrying capacity of the Khal falls short considering combined effects of rainfall induced runoff and tidal water intrusion into the Khal. The average values of discharge found for 2 and 100 years return periods are $26 \text{ m}^3\text{s}^{-1}$ and $50.5 \text{ m}^3\text{s}^{-1}$, respectively, with respect to different CN values of 90 are 20, $26 \text{ m}^3\text{s}^{-1}$ and $43.47 \text{ m}^3\text{s}^{-1}$, respectively.

The discharge increases linearly with the increase of the percent (%) impervious. The study also found that average value of discharge for 2 year and 100 years return period have been found $18.2 \text{ m}^3\text{s}^{-1}$ and $59.68 \text{ m}^3\text{s}^{-1}$ respectively. The Khal carrying capacity fall short for percent (%) imperviousness changes for return periods studied when the discharges combined with the back flows from river. However, controlling tidal discharge into the Khal may an effective solution but it is unwise and rather difficult to manage; in such case, regular cleaning, maintenance of Khal are found deemed necessary to drain out excess water from the watershed with a minimum delay.

Maximum discharge has been found from 9am to 2pm. In present situation the maximum discharge value is about $15 \text{ m}^3\text{s}^{-1}$ which increase with the increase of return period and become $55 \text{ m}^3\text{s}^{-1}$ in 100 years return period. City Planners may pay attention on implementation of SUDs in urban areas in order to address the volume of runoff in harmony with the water quality and Khals amenity values in consideration. Moreover, adoption of soft measures may further decrease the runoff discharge from urban areas, such as the potential implementation of rainwater harvesting, groundwater recharge wells, detention basins, using porous pavement, green roofing, greywater reuses and finally stop dumping solid waste into the drainage Khals or canals etc. can be an effective measures for best management practices.

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Conflicts of Interest

No potential conflict of interest was reported by the authors. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors Contribution Statement

MH Masum and J Hossen have done Conceptualization, Data collection, Formal analysis, Investigation, Methodology, Conceptualization, writing the original draft. SK Pal has done Conceptualization, Methodology, Project administration, Supervision, Validation, review & editing.

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