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Land use Change on Storm-Water Characteristics of a Watershed in Northeast India

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Abstract*: Land use change initiates significant impact on the stormwater characteristics including hydrograph, infiltration, discharges of the catchment, etc. An extensive literature review suggests that rapid urbanization is the root cause for such alteration in stormwater features. This paper presents a field-based study to investigate the influence of land use change on the hydrological characteristics in a region situated in northeastern part of India, namely, Kakodonga Watershed, Jorhat, Assam. The hydrogeological and stormwater characteristics of the region are ascertained by means of field and laboratory tests and the data collected are rigorously analyzed to carry out the study. The evapotranspiration demand has also been investigated by incorporating various analytical models. The important and relevant conclusions are drawn from the entire work.

***Keywords*: evapotranspiration, hydrology, field work, land use, stormwater, watershed.**

I. INTRODUCTION

Land use changes in developing countries, due to more and more human's activities to explore the nature, to urbanize, industrialize, construct roads, airports, etc., usually affect forests and national reserves. This is because of the anthropogenic activities initiating settlements which then bring about agricultural expansion that encroach on forest land. The general effect of urbanisation on hydrological characteristics of a catchment is to reduce the amount of infiltration into the ground and thereby increasing the speed of runoff [1-2].

The land use change creates significant alteration in flood characteristics in catchment areas [3-5], which in turn influences the hydrological cycle of the regions [6-7].Several analytical studies were done to investigate the effects of urbanization on hydrological processes via cellular automata model [8], integrated remote sensing [9] and rainfall-runoff interrelationship model through GIS [10]. The field-based study encompassing the temporal and spatial processes of urbanization affecting flood events in catchment areas was investigated by Chen *et al.* [11].

Various evapotranspiration models and their applications in soil water modelling and analyses have been developed [12]. Different Regression models to estimate long-term evapotranspiration are available [13-14]. Comparisons of the available analytical models were reviewed by Chowdhury *et al.* [15].

Limited studies conducted on the influence of rainwater harvesting techniques on runoff and infiltration pattern suggested that itis a widely used groundwater recharge method by storing rainwater in the countries suffered with drought characteristics [16-17].

The work reported herein is aimed towards conducting a study on the influence of land use change on the hydrological characteristics of Kakodonga watershed in Jorhat, Assam, situated in the northeastern part of India. The specific objectives of the present investigation are to simulate and compare the storm hydrographs of the watershed, estimate the runoff pattern under different land-usages and apply various evapotranspiration models, based on the hydrogeological data obtained from the laboratory and field tests. The entire work has yielded a series of important conclusions.

II. STUDY AREA

The study comprises in an area of about 1113 km^2, geographically located between the latitudes of 26°15'10"*N*– 26°44'48"*N* and longitudes of 94°21'45"*E*– 93°59'10" *E* in the Survey of India Topographic sheets[18]. The Kakodonga River originates from Naga Hills near Lio Longidun village of Wokha district in the state of Nagaland, India and flows towards the north-western direction in Assam before finally discharging to the river Brahmaputra, the altitudes vary between 80 m – 760 m above the mean sea level (see Fig. 1).

The Kakodonga river basin is one of the important southern sub-tributaries of the river Brahmaputra, situated between the districts of Jorhat and Golaghat of Assam and Nagaland respectively. A small portion of the basin is covered by Naga Hills in south and the remaining belongs to Brahmaputra plain. Most of the watershed is agricultural land, comprising of tea gardens and paddy fields. Land use of the Kakodonga basin has been wet land cultivated through bore wells, tank and canal irrigations.

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A. Subsoil Characteristics

Several soil samples are collected at selected locations of the study area for hydrogeological characterization. The depths of samples varied between 1 m – 2 m below the ground surface. Both the disturbed and

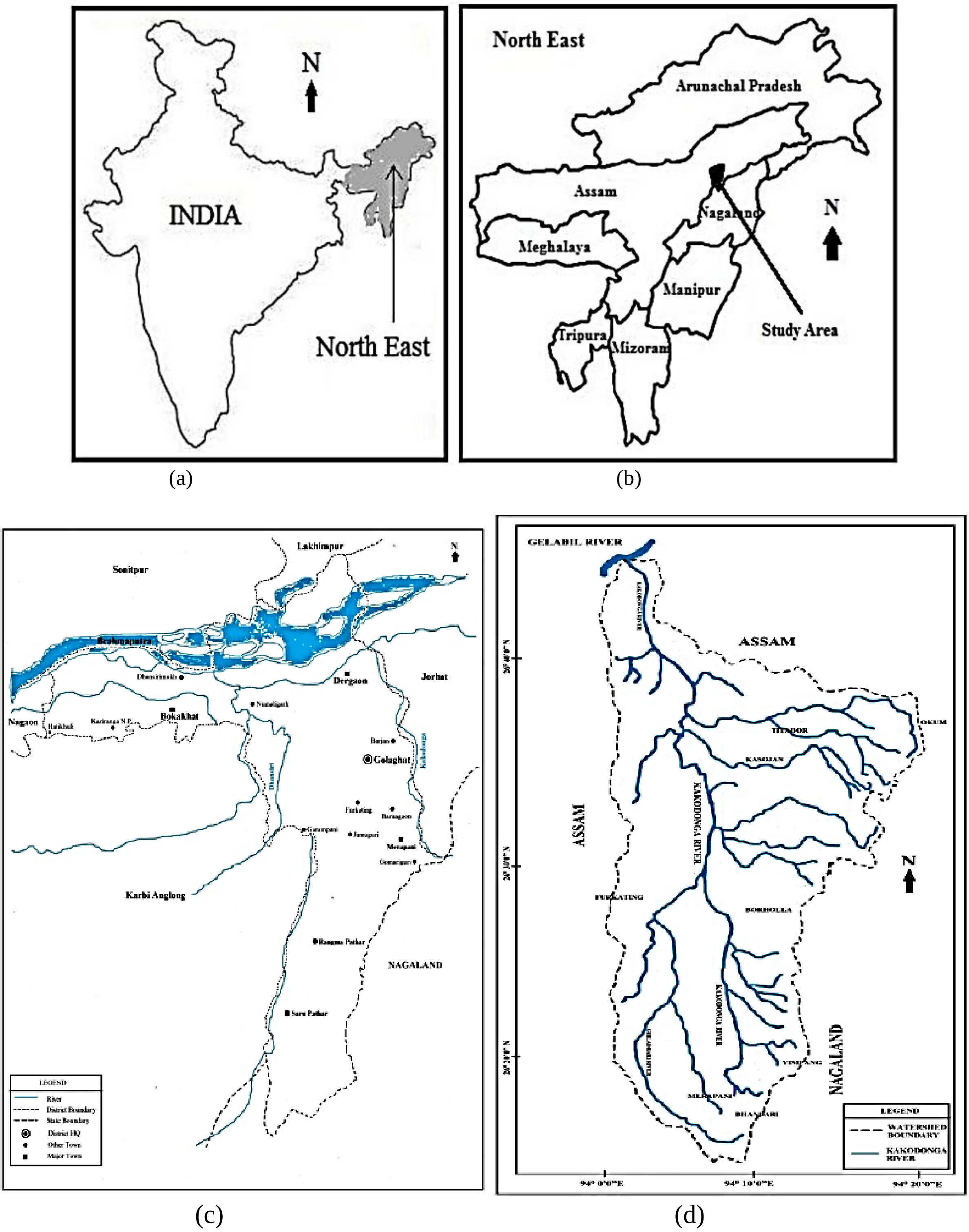

Fig.1. (a) Location of northeastern zone in India, (b) Study area location, (c) Golaghat-Jorhat district, and (d) Kakodonga watershed

undisturbed samples were collected from the site. The disturbed samples were collected by shovels, whereas the undisturbed samples were collected with the help of hand operated extractor and the mould with samples was sealed with wax (see Fig.2); the sampling mould was of 75 mm internal diameter. The disturbed samples were used to determine the following engineering properties of subsoil:

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Atterberg Limits, field moisture content, specific gravity of soil particles and Proctor compaction test parameters (i.e., optimum moisture content and maximum dry density). The undisturbed samples, on the other hand, were utilized to determine the hydraulic conductivity and unconfined compressive strength of soil. The in-situ bulk density of the subsoil

(a)

(b)

(c)

Fig.2. Collection of soil samples at site: (a) Hand operated extractor, (b) Wax sealing in mould for undisturbed sampling, and (c) disturbed and undisturbed soil samples collected from field

was determined by means of core cutter method. The hydraulic conductivity of field soil was measured by falling head permeameter (see Fig.3).

The values of different engineering properties of the soil at the field, as obtained from laboratory measurements, are presented in Table -I.

B. Hydrogeological Characteristics

The hydrological data included rainfall, runoff and evapotranspiration data, collected from the available facilities of Water Resources Department, Government of Assam, India and Assam Agricultural University, Jorhat, Assam, India. The 10 years' average river discharge data, measured by float method, are shown in Fig.4(a). The 10 years' average monthly precipitation data, obtained by non-recording rain gauge of 127 mm diameter, are shown Fig. 4(b). The peak values of both the cases were in the month of July. The rainfall-runoff characteristics of the watershed has been estimated Soil Conservation Service Curve Number (SCS-CN) method, using the following correlation [19]:

$$V = (P - 0.2\,S) / (P + 0.8\,S) \quad (1)$$

where, V and P are the runoff and rainfall volumes in mm and S is the storage capacity of the watershed in mm. The parameter S has been empirically determined as a function of the curve number (CN) using the following correlation:

$$S = 254\,(100 / CN - 1) \quad (2)$$

The parameter CN varies from 0 to 100, depending upon the type of soil, cover, hydrologic condition of the land and the antecedent wetness of the drainage basin, and can be reasonably estimated from the available literature [20].

Using the above correlations and the hydrological data, the monthly average run off through Kakodonga watershed in a year has been calculated (Fig. 4c).

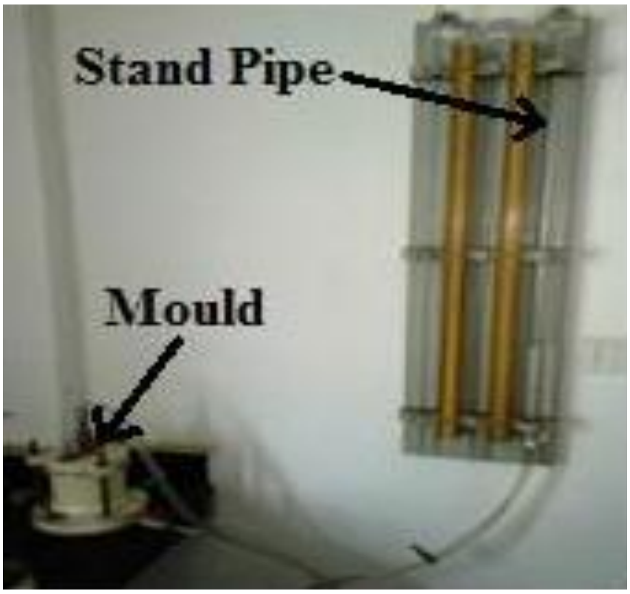
The runoff pattern of the study area is significantly influenced by the evapotranspiration potential of the watershed, which is in turn dependent on a few meteorological data. The wind speed measurements were taken by Cup Counter Anemometer, whereas the temperature and humidity were measured using the Stevenson Screen. The bright sunshine hours were recorded with a sunshine recorder, whereas the evaporation was measured by USWB class A pan. The evapotranspiration was computed by three popular analytical models, namely, Blaney-Criddle method, Thornthwaite method and Ivanov method and compared with the measured values obtained by class A pan.

The Blaney-Criddle method uses the following correlation to estimate the evapotranspiration [21]:

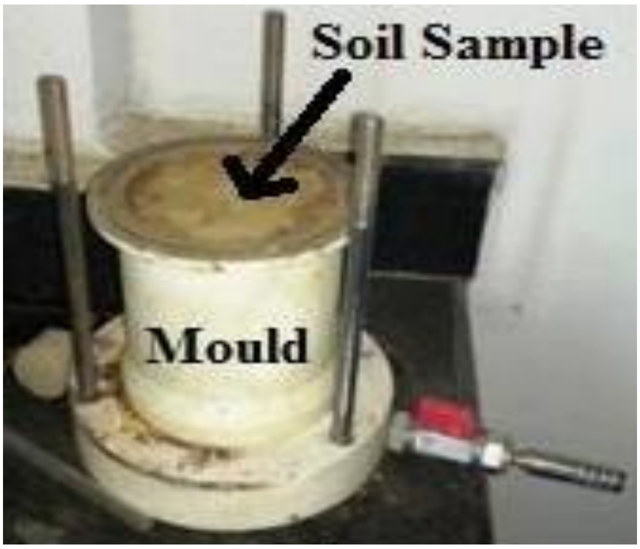
$$E_T = 0.46\,(T + 17.8) \quad (3)$$

where, E_T is the evapotranspiration in mm/m, P is the percentage of day light in hours in a year and T is the temperature in degree Celsius.

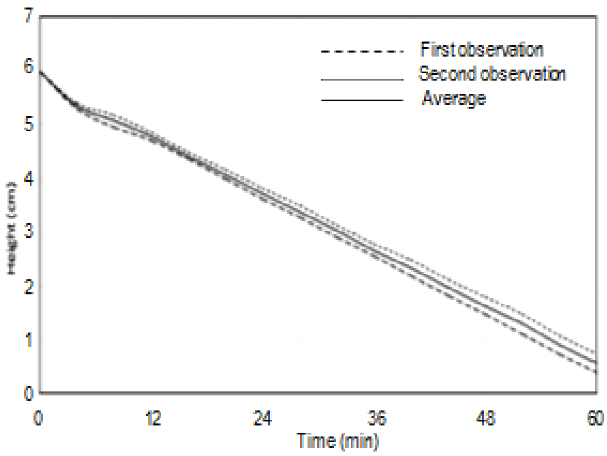
The Thornthwaite's Equation for estimation of potential evapotranspiration given by [22]:



(a)



(b)



(c)

Fig.3. Laboratory determination of hydraulic conductivity of soil: (a) Falling head permeameter, (b) mould, and (c) plot of piezometric head versus time

Table- I: Engineering properties of the soil at the field

Type of sample	Specific engineering property		Value
Disturbed	Atterberg limits	Liquid limit	14.22%
		Plastic limit	20.96%
		Shrinkage limit	37.51%
	Field moisture content		17.33%
	Specific gravity of soil particles		2.53
	Proctor compaction test	Optimum moisture content	10.86%
		Maximum dry density	17.2 kN/m^3
Undisturbed	Hydraulic conductivity		1.65 x 10^{-9} m/s
	Bulk density		12.9 kN/m^3
	Unconfined shear strength parameters		c_u = 5.7 MPa ϕ_u = 0
Type of soil at the field: clay loam			

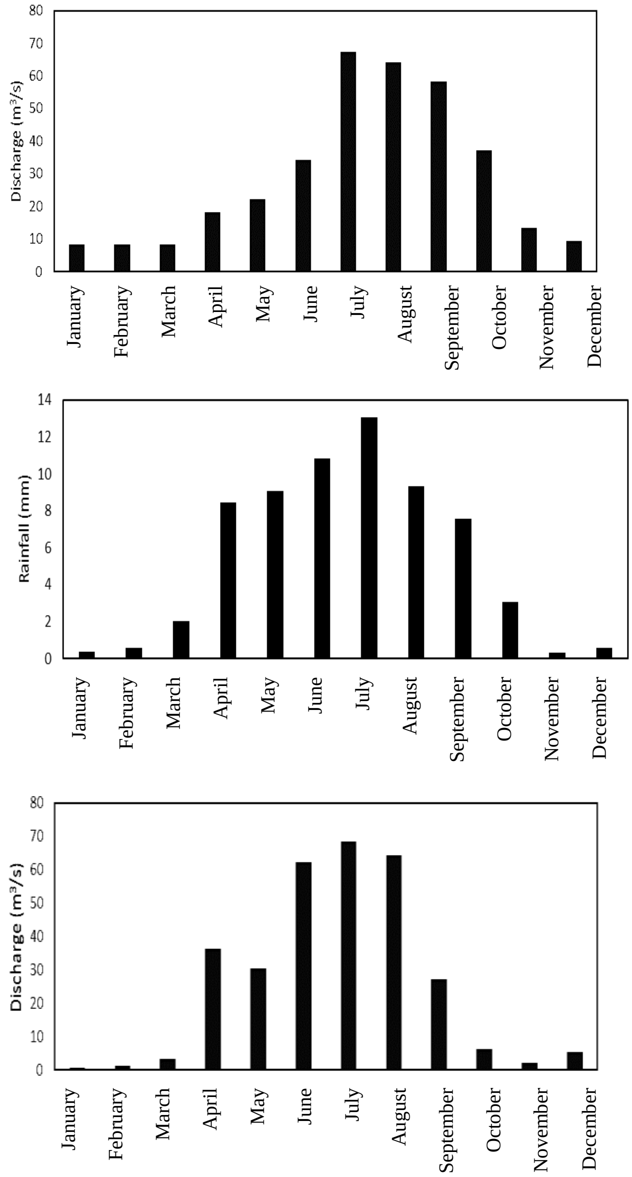


Fig.4. Bar charts for: (a) discharge in river channel, (b) rainfall, and (c) runoff

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$$E_T = 16\,(L/12)\,(N/30)\,(10\;T_i\,/\,I\,)^{\alpha} \tag{4}$$

where, E_T is the estimated potential evapotranspiration in mm/month, $L$is the average day length in hours of the month being calculated, N is the number of days in the month being calculated and T_i is the average daily temperature in degrees Celsius of the month being calculated. The parameters I and α are quantified as:

$$I = \sum_{i=1}^{12} (T_i/5)^2 \tag{5}$$

$$\alpha = (6.75 \times 10^{-7})\, I^3 - (7.71 \times 10^{-5})\, I^2 + (1.792 \times 10^{-2})\, I + 0.4932 \tag{6}$$

Ivanov's Equation is given by [23]:

$$E_T = 0.0018\,(25 + T^2)\,(100 - R) \tag{7}$$

where, E_T is the estimated potential evapotranspiration in mm/month, R is the relative humidity and T is the average monthly temperature in Celsius.

Using the above-mentioned methods, the values of potential evapotranspiration in the study area are computed and compared with the value measured in class A pan, as portrayed in Fig. 5(a), whereas the percentage variations with the class A pan measurement are depicted in Fig. 5(b). As observed, the Blaney-Criddle Equation yielded a minimum deviation of about 10-18% during the relatively dry seasons (October – March). During April-June, the Thornthwaite's Equation produced a minimum deviation of 9-15%, whereas for the period of July-September, the Ivanov's Equation yielded a minimum deviation of 5-8%.

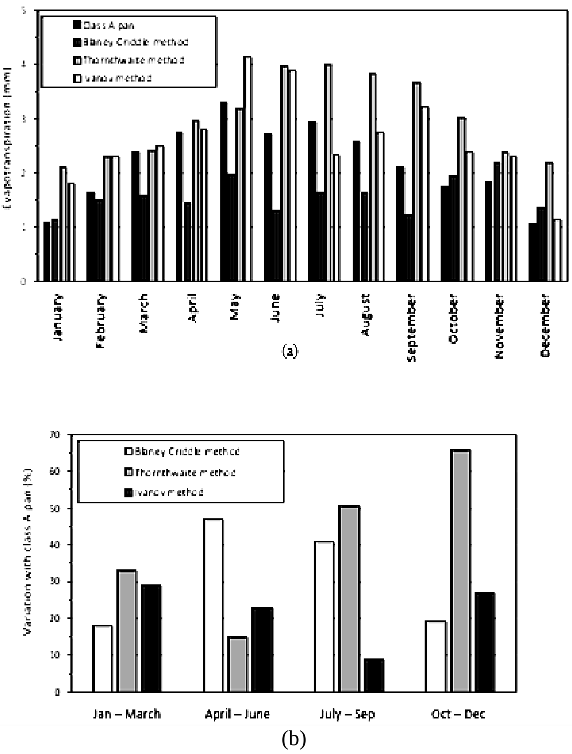
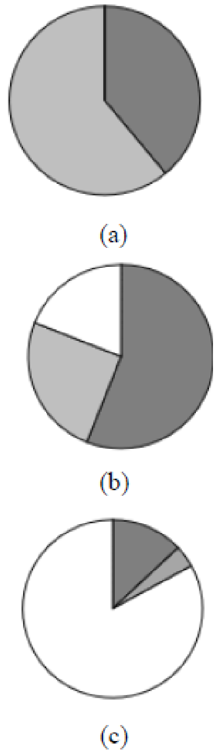


Fig.5. (a) Comparisons of different methods of estimating potential evapotranspiration, and (b) variation with class A pan data

III. LAND USAGE: ANALYSIS, INTERPRETATION

To study the land usage effect on hydrological characteristics, three distinct scenarios are considered, which are: non-urbanisation, full-urbanisation and semi-urbanisation. Here, the semi-urbanisation is the present condition. The chosen local topography of the watershed are: forest land, grass land and pavement area. The proportion of different topography in the various scenarios has been estimated through image processing done via google earth and presented by the pi-chart in Fig. 6.



Topography \ Scenario	Non-Urbanisation	Semi-Urbanisation (current)	Full-Urbanisation
Forest Land	61%	51%	4%
Grass Land	39%	26%	13%
Pavement	0	19%	83%

Fig.6. Land usage scenario for: (a) non-urbanization, (b) semi-urbanization, and (c) full-urbanization

The storm hydrographs of the three land usages are estimated and compared with each other, based on the available hydrogeological data. The infiltration rates in case of the three distinct scenarios, are computed from the available in-situ soil data, as presented in Table- II. Since the soil types varies, the infiltration rates were also found to vary in different land usages. The storm hydrographs obtained by plotting the values of field and theoretical discharges are compared (see Fig. 7). Both the curves were observed to be of similar pattern with an average variation of 16%, the peak discharge being during the monsoon (i.e., July). Considering the land usage, soil type, hydraulic gradient of the watershed and the catchment, characteristics of the draining water out of the catchment are studied. The maximum discharge is plotted against the duration of rainfall for three different land usage scenarios, as shown in Fig. 8. The curves were found to be curvilinear. As observed, the maximum discharge progressively ascended with the increasing urbanization, which is understandably due to the reduction in infiltration with decreasing forest land and

Table- II: Infiltration rates in different types of soil for various slopes of ground surface (10-6 m/s)

Slope (%) / Soil type	0 - 4	4 – 8	8 – 12	12 – 16	> 16
Coarse sand	8.82	7.06	5.29	3.53	2.19
Medium sand	7.48	6	4.52	2.96	1.91
Fine sand	6.63	5.29	3.95	2.68	1.69
Loamy sand	6.21	4.94	3.74	2.47	1.55
Sandy loam	5.29	4.23	3.18	2.12	1.34
Fine sandy loam	4.45	3.53	2.68	1.76	1.13
Very fine sandy loam	4.16	3.32	2.47	1.69	1.06
Loam	3.81	3.03	2.33	1.55	0.99
Silty loam	3.52	2.82	2.12	1.41	0.92
Silt	3.1	2.47	1.83	1.27	0.78
Sandy clay	2.19	1.76	1.34	0.85	0.56
Clay loam	1.76	1.41	1.06	0.71	0.42
Silty clay	1.34	1.06	0.78	0.56	0.35
Clay	0.92	0.71	0.56	0.35	0.21

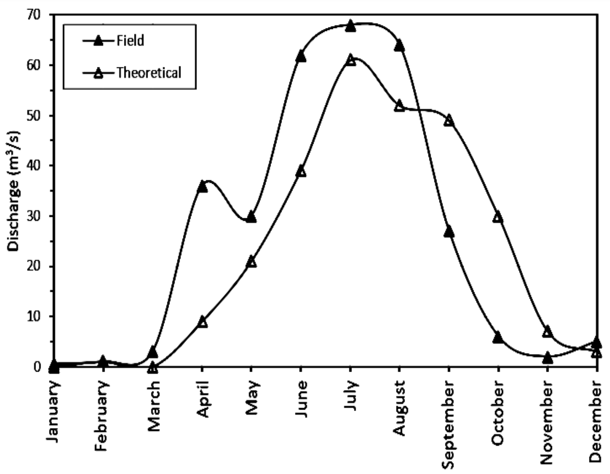


Fig.7. Comparison between theoretical and field discharge

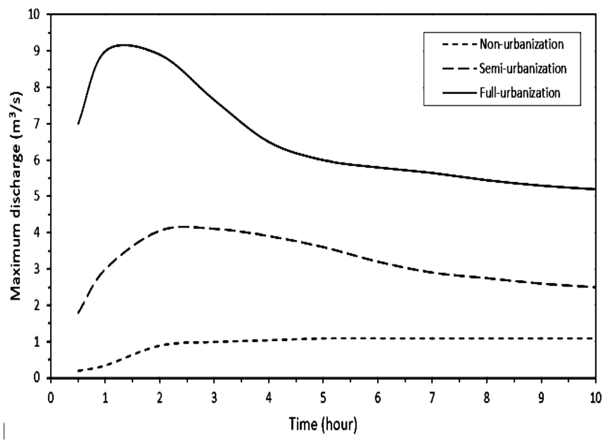


Fig.8. Time pattern of variation of maximum discharge of surface runoff for different land usage scenario

Increasing pavement area. In case of no-urbanization, the curve gradually ascended to a time of 4 hour and stabilized thereafter. For semi-urbanization and full urbanization, on the other hand, the curves attained peak values for time of 1.5 hour and 2.5 hour respectively and descended thereafter. Moreover, for semi-urbanized and fully urbanized land usages, the peak values of maximum discharge were observed to increase by 4 times and 9.1 times that of the non-urbanized land use respectively. The possible reason for such variation is the initial retardation in the infiltration in case of fully urbanized land usage initiating high runoff volume, followed by increasing infiltration with the advance of time in the grass and forest lands. The opposite phenomenon has probably taken place in case of reduced urbanization.

IV. CONCLUSIONS

The general effect of urbanization on hydrological characteristics of a catchment is to reduce the amount of infiltration into the ground and to increase the speed of runoff. The present study was aimed towards assessing the influence of urbanization on storm hydrograph of Kakodonga watershed located in the northeastern India. The SCS-CN method is used for estimating the rainfall runoff of the selected watershed and the storm hydrographs, as responses of the catchment to rainfall events of return period of 10years were estimated.

The study revealed that the runoff pattern of the study area was significantly influenced by the evapotranspiration potential of the watershed. The values of average potential evapotranspiration, as predicted from available correlations, was found to closely match with the measured values by class A pan, with an average deviation of 5-18%. As the land use pattern increased from non-urbanization to full urbanization, the surface runoff volume and maximum stormwater discharge was found to increase significantly. The peak discharge values increased by 4 and 9.1 times of that for the non-urbanized land usage relevant to semi-urbanization and full urbanization respectively. The storm hydrographs obtained by plotting the values of field and theoretical discharges were of similar pattern with an average variation of 16%, the peak discharge being during the monsoon time.

The conclusions drawn from the entire study is useful to estimate the runoff and infiltration patterns in rural and suburban regions except coastal zones where saltwater intrusion plays a significant role [24-25]. The study is helpful in solving relevant engineering problems, for example land subsidence [26].

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