A Case Study on the Impact of Land use and Landscape Changes Corresponding to Surface Runoff and Urban Flooding

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ABSTRACT

The land use and land cover change and rainfall have a significant influence on the hydrological response of the river basins. The run-off characteristics are changing naturally due to reduction of initial abstraction that increases the run-off volume. Therefore, it is necessary to quantify the changes in the run-off characteristics of a catchment under the influence of changed land use and land cover. Urban flooding is becoming one of the common reasons for loss of human life and property. India, in the past, has experienced two such major urban flooding incidents affecting a large amount of population and resulting in substantial loss of human property. Urban flooding is specific in the fact that the cause is a lack of drainage in an urban area. As there is little open soil that can be used for water storage nearly all the precipitation needs to be transport to surface water or the sewage system. High intensity rainfall can cause flooding when the city sewage system and draining canals do not have the necessary capacity to drain away the amounts of rain that are falling. Water may even enter the sewage system in one place and then get deposited somewhere else in the city on the streets. This objective of this case study to identify the flood affected areas near Regional Meteorological Centre, Borjhar by calculating the final surface runoff for 1 day, 3 day, 5 day, 6 day rainfall interval. In this study, rainfall depth for 15 years viz. 2003 to 2017 has been collected from Regional Meteorological Centre, Guwahati. Peak discharge for return period of 5 years, 10 years, 50 years and 100 years has been calculated using Rational method. This study is useful in design of urban drainage works, for example storm sewer, culverts and other hydraulic structures.

1.1 INTRODUCTION

Impact of land use and land cover change in the runoff dynamics of a river basin has been an interesting area for hydrologists. Rainfall and land use are important parameter of runoff estimation by hydrological modeling. Different types of land surface parameters have been extracted by many researchers by remote sensing techniques using satellite imagery. Climate change related study has been done using different methods on climatic parameters by researchers. Climate change related study has been done using different methods on climatic parameters. Different methodologies have been implemented to get proper knowledge in the subject, but no general model has been established yet to predict the effect of land use and land cover changes. In the earlier days, assessment of the impact of land use and land cover changes on the run-off was mainly done through catchment experiments and different results were obtained. In the present years, the hydrological models are used with different approaches to find out the impact of land use and land cover changes. The run-off of a catchment would be affected by the land use and land cover change of that catchment which would further affect the water yield in the area. As there will be change in run-off, it would affect the hydro power potential in a hydro power project existing in the area. Therefore, for designing a hydro power project this change should be considered for getting optimum power potential in present and future. The North Eastern region of India is extremely vulnerable to natural hazards like earthquakes, floods, landslides etc.

2. STUDY AREA

The city of Guwahati is located at the banks of the river Brahmaputra and several of its tributaries pass through the city. Urban growth in the city of Guwahati has been rapid, with uncontrolled development activities. These activities have had a detrimental impact on the ecology and environment of the city. The city is surrounded by wet lands that under threat due to the encroachment and unplanned urban development of the city. The city is prone to floods and landslides and is located on the earthquake prone (zone V) belt. In addition to being vulnerable to these natural hazards, the city of Guwahati and is frequently affected by seasonal flash floods, which are not entirely caused by natural factors alone. Based on the above-mentioned situation (hazards and vulnerabilities), number of agencies (government, humanitarian and development) several experts have conducted studies on or linked with Guwahati and floods. These studies reflect useful and micro level findings that are relevant to Guwahati and the surrounding areas. There are different studies which reflect the same findings with minor changes in the recent development of new vulnerabilities. Instead of conducing new study, it is better to a conduct review of studies that focus on Guwahati and floods. This serves as the rationale behind conducting this study. The exercise is to bring all the flood study works in one place and review the same for arriving at the short term and long term measures for Guwahati for finding a solution to the problem related to risk of floods in the city.

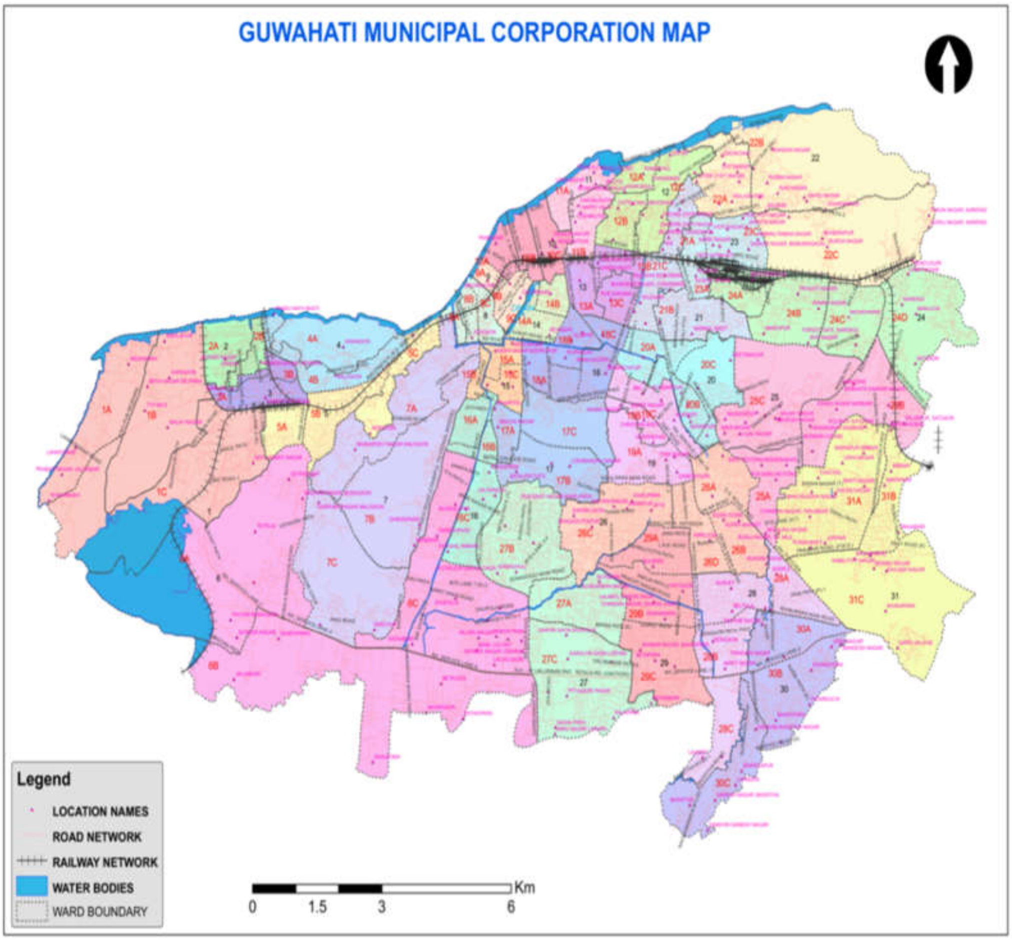

Figure 2.1: Study area map of Guwahati city, Assam (Source: Guwahati municipal corporation)

2.1 OBJECTIVE

i. Collection of last 15 years rainfall data of Guwahati from Regional Meteorological center, Borjhar.
ii. Identification of flood affected area particularly near Regional Meteorological center, Borjhar..
iii. Determination for Peak discharge for return period of 5, 10 and 100 years.
iv. Zonal identification and demarcation of areas in Borjhar considering runoff characteristics.
v. Determination of final surface runoff for 1 day, 3 day, 5 day and 6 day rainfall interval corresponding to return period 5, 10 and 100 years using Rational Method.

3. Methodology

To carry out the study both primary and secondary data was collected. To collect primary data, a detailed questionnaire was prepared with specific outcome in view and making field measurements on selected geo-hydrological parameters like ground water level in wells, volume of surface water bodies, etc. The secondary data source comprises maps, statistics, published research papers, journals, satellite imagery, etc. These secondary data were mainly collected from various organisations and departments such as Guwahati municipal corporation (GMC), Regional Meteorological Centre (RMC), water resource department (WRD), etc. The city of Guwahati is dotted with numerous surface water bodies comprising of wetlands and ponds. These water bodies play a significant role in holding rainwater for considerable period of time and serve as reservoirs. But unprecedented urbanisation and development activities have reduced these water bodies to fragmented forms. At present, the city can boast of only six wetlands, viz., the Deepor Beel, Hahsora Beel, Silsako Beel, Narengi Beel, Borsola and Sarusola Beel. Along with these natural water bodies, the city also boasts of many small ponds and tanks, which make an integral part of water supply. These surface water bodies sustain water flow dynamics between the high land and low land of the city's landscape, function as storm water reservoir and act as potential sites for natural recharge of the sub surface water. Major portion of rainfall occurs during the months of April to October from the south-west.

3.1 Calculation of Recurrence Period by Gumbel's method

The extreme value distribution was introduced by Gumbel and is commonly known as Gumbel's distribution. The estimate of rainfall intensity of given duration for different return period is obtained by this method. It is one of the most widely used probability-distribution functions for extreme values in hydrologic and meteorological studies for protection of flood peaks, maximum rainfalls, maximum wind speeds, etc. According to this theory of extreme events, the probability of occurrence of an event equal to or larger than a value of X_o is,

$$P(X \geq x_o) = 1 - e^{-e^{-y}} \qquad \ldots\ldots\ldots(3.1)$$

In which y is a dimensionless variable given by

$$y = \alpha(x - a)$$

$$a = x - 0.45005\sigma_X$$

$$\alpha = 1.2825/\sigma_X$$

Thus, $$y = \frac{1.2825(x-\overline{x})}{x} + 0.577 \qquad \ldots\ldots\ldots(3.2)$$

Where, $\overline{x}$=mean and

σ_X=standard deviation of the variable X

In practice it is the value of X for a given P that is required and as such equation 3.1 is transposed as,

$$Y_p=-\ln[-\ln(1-P)] \quad \text{.........} (3.3)$$

Noting that the return period T=1/Pand designating y_1= the value of y, commonly called the reduced variable, for a given T

$$Y_1 = -[\ln.\ln\frac{T}{T-1}] \quad \text{.........} (3.4)$$

Or $$Y_1= -[0.834 + 2.303\log \log\frac{T}{T-1} \quad \text{.........} (3.4\ a)$$

Now by rearranging equation 3.2, the variable X with a return period T is,

$$X_t=x+k\sigma$$

Where

$$K=\frac{yT-0.577}{1.2825} \quad \text{..............} (3.5)$$

Gumbel's Equation For Practical Use are as follows

Equation 3.5 gives the value of the variable X with a recurrence interval T is used as

$$X_T = \overline{x} + K\sigma_{n-1}$$

Where,

σ_{n-1} =standard deviation of the sample of size N

$$=\sqrt{\frac{\Sigma(x-\overline{x})}{N-1}}$$

K = frequency factor expressed as

$$K=\frac{yT-\overline{yn}}{Sn}$$

In which y=2 reduced variable, a function of T and is given by,

$$Y_{T} = -\left[ln.\,ln\frac{T}{T-1}\right] \quad \text{Or} \quad Y_{T} = -\left[0.834 + 2.303\log log\frac{T}{T-1}\right]$$

$\overline{Yn}$ = reduced mean,a function of sample size N

S_n = reduced standard deviation, a function of the sample size

The intensity of rainfall data that was collected from the rain gauge station was in mm/day. The intensity of rainfall in mm/day is converted to hourly rainfall intensity mm/hr, by making an assumption that the rainfall for a particular day is evenly distributed throughout the 24 hours. Hence a particular depth of rainfall for one day is assumed to be the cumulative sum of the rainfall depth for the all the 24 hours of the day. The conversion of the rainfall intensity from mm/day to mm/hr is done as follows:

The process of conversion of all the daily intensities to mm/hour is same for a period of 15 years according to the data obtained from the Borjhar Raingauge Station. Hence the conversion is shown with an example of one day i.e , the rainfall for the month of july is 280.138 mm/day.

I= 280.138 mm/day

= 11.67 mm/hr

3.2 Analysis of peak discharge:

In this project for calculating the peak runoff Rational Method was used. Based on the rainfall intensity that was collected from the recording rain gauge station at Borjhar, area of the project and run off coefficient obtained for different catch up areas, the daily peak discharge is calculated. A detail calculation of the runoff discharge is shown below.

At first the rainfall intensity in mm/day was converted to mm/hour as the entire rainfall for one day is considered to be a part of one storm that takes place per hour.

Secondly, for the different type of catchment of the project area the runoff coefficient is obtained from Iowa Strom Water Management then the wetted average runoff, C is calculated by using the following formula:

$$C=\frac{C_1A_1+C_2A_2+C_3A_3+C_4A_4+C_5A_5}{A_1+A_2+A_3+A_4+A_5}$$

According to the Iowa Storm Water Management the runoff coefficient (C) are different for different catchment area. The value is also dependent on the hydrologic land used /land covered group and ground slope of the area. Hence the entire value is obtained from the to Iowa Storm Water Management table. The value of C is obtained from the following table:

Table 3.1: Runoff Coefficient (C)

Type of area	Value of *C*
A. *Urban area* (*P* = 0.05 to 0.10)	
Lawns: Sandy-soil, flat, 2%	0.05–0.10
Sandy soil, steep, 7%	0.15–0.20
Heavy soil, average, 2.7%	0.18–0.22
Residential areas:	
Single family areas	0.30–0.50
Multi units, attached	0.60–0.75
Industrial:	
Light	0.50–0.80
Heavy	0.60–0.90
Streets	0.70–0.95
B. *Agricultural Area*	
Flat: Tight clay; cultivated	0.50
woodland	0.40
Sandy loam; cultivated	0.20
woodland	0.10
Hilly: Tight clay; cultivated	0.70
woodland	0.60
Sandy loam; cultivated	0.40
woodland	0.30

The total land cover area of the Airport Area is created by using the Google Earth software which as shown below:

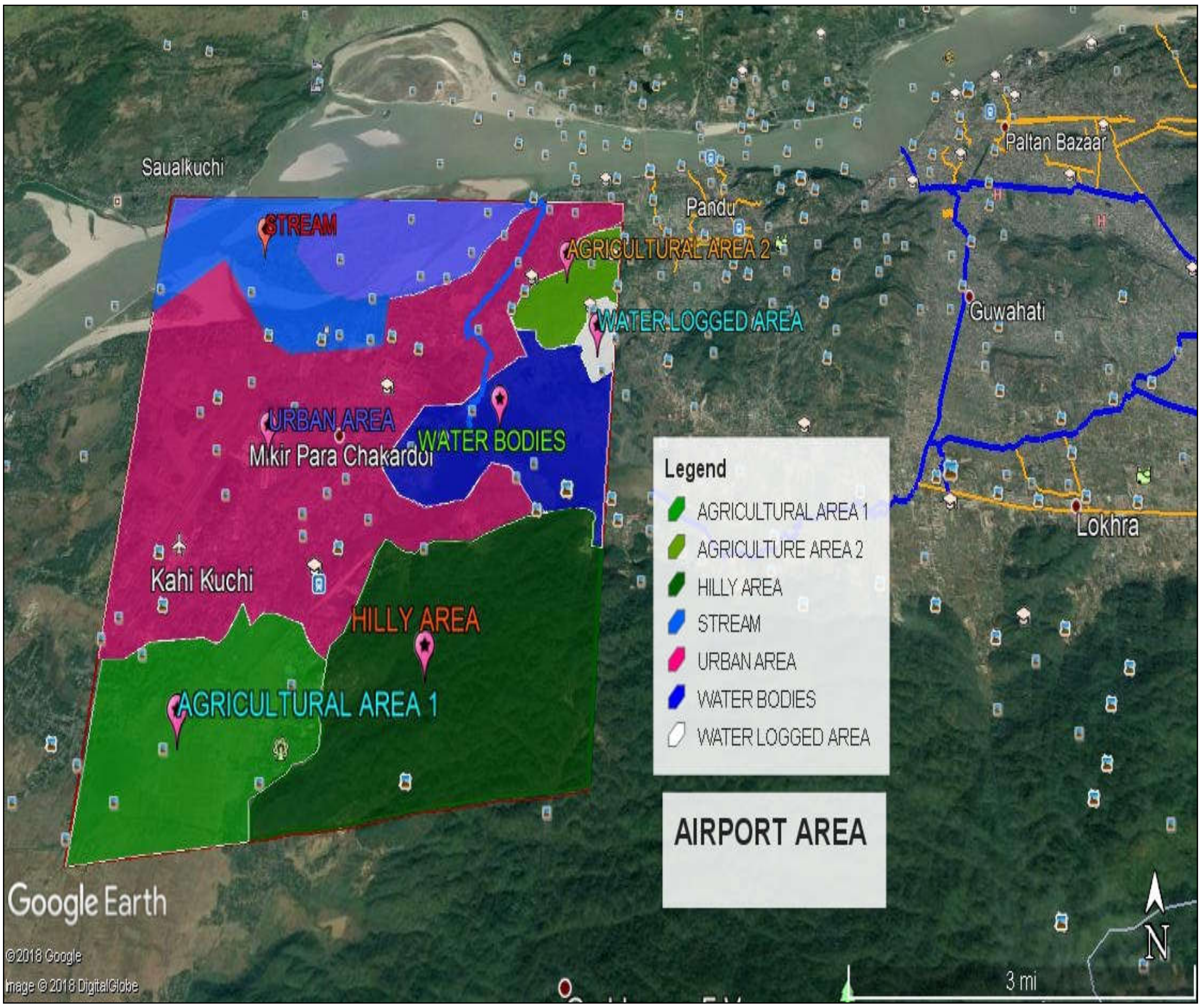

Fig3.1: Land use/ Land cover map, Borjhar Airport Area

Table 3.2: Area of land cover under different LULC types

Type	Area (Km^2)
Hilly Area	16.5
Agricultural Area 1	9.1
Agricultural Area 2	3
Urban Area	35.9
Stream Area	16
Water Bodies	8.34
Water logged Area	0.86

Where,

A_1 = Area of the hilly land (16.5 km^2)

A_2 = Area of agricultural land 1 (9.1 km^2)

A_3 = Area of agricultural land 2 (3 km^2)

A_4 = Area of urban land (35.9 km^2)

Although different types of land is covered in the project but only the Agricultural area, Hilly area, water logged area, Urban area, are taken under consideration. The stream land area and water bodies are not taken under consideration.

Calculation:

$$C = \frac{C_1A_1+C_2A_2+C_3A_3+C_4A_4+C_5A_5}{A_1+A_2+A_3+A_4+A_5}$$

$$= \frac{16.5X0.6+9.1X0.5+3X0.5+35.9X0.65+0.86X0.5}{16.5+9.1+3+35.9+0.86}$$

$$= 0.61$$

After calculation the rainfall intensity and runoff coefficient, the peak runoff is calculated by using the rational formula for a total area of 65.36 km^2.

3.3 Rational Method:

The Rational equation is the simplest method to determine peak discharge from drainage basin runoff. It is the most common method used for sizing sewer systems.

Rational Equation: **Q = CIA**

The Rational equation requires the following units:

Q = Peak discharge
C= Rational method runoff coefficient (0.61)
I = Rainfall intensity, mm/hour
A = Drainage area, (65.36 km^2)

4. RESULT AND CALCULATION

Peak discharge for return period of 5 years, 10 years, 50 years and 100 years has been calculated using rational method. Rainfall data uses for this calculation of the total time period 15 years from 2003 to 2017.

4.1 Calculation of Return Period:

Table 4.1: For 1 day return period of 5yr, 10yr, 100yr.

Order No.	INTENSITY (X) mm/day	SUM	AVERAGE	X-Xavg	(X-Xavg)2	S=∑(X-Xavg)2	S/(N-1)	Ϭn-1=√S/(n-1)
1	130.3	626.6	41.77	88.53	7837.56	15590.58	1113.61	33.37
2	99.8		41.77	58.03	3367.48			
3	56.8		41.77	15.03	225.9			
4	53.2		41.77	11.43	130.64			
5	46.2		41.77	4.43	19.62			
6	39.6		41.77	-2.17	4.7			
7	33.4		41.77	-8.37	70.05			
8	32.8		41.77	-8.97	80.46			
9	28.7		41.77	-13.07	170.82			
10	27.1		41.77	-14.67	215.2			
11	20.5		41.77	-21.27	452.41			
12	18.2		41.77	-23.57	555.54			
13	17.1		41.77	-24.67	608.6			
14	14		41.77	-27.77	771.17			
15	8.9		41.77	-32.87	1080.43			

N= 15, Sn= 1.0206, Yn=0.5128

T	T-1	T/T-1	ln(T/T-1)	ln(ln(T/T-1))	Y= -In(In(T/T-1))
5	4	1.25	0.2231	-1.5001	1.5001
10	9	1.111	0.1053	-2.2509	2.2509
100	99	1.0101	0.010049	-4.6002	4.6002

Y	Yn	Y-Yn	Sn	K=(Y-Yn)/Sn
1.5001	0.5128	0.9873	1.0206	0.9673
2.2509	0.5128	1.7381	1.0206	1.7030
4.6002	0.5128	4.0874	1.0206	4.0048

Return Period	Xavg	K	σ_{n-1}	$K*\sigma_{n-1}$	$X_t=X_{avg}+K*\sigma_{n-1}$
5	41.77	0.9673	33.37	32.27	74.04
10	41.77	1.703	33.37	56.83	98.6
100	41.77	4.0048	33.37	133.64	175.41

Table 4.2: For 3 day return period of 5yr, 10yr, 100y

Order No.	INTENSITY(X) mm/day	SUM	AVERAGE (Xavg)	X-Xavg	(X-Xavg)2	S=∑(X-Xavg)2	S/(N-1)	$\sigma_{n-1}=\sqrt{S/(n-1)}$
1	231.9	783.4	52.23	179.67	32281.31	39350.51	2810.75	53.01
2	66.7		52.23	14.47	209.38			
3	58.3		52.23	6.07	36.84			
4	58.4		52.23	6.17	38.06			
5	57.2		52.23	4.97	24.7			
6	52.6		52.23	0.37	0.13			
7	46.1		52.23	-6.13	37.57			
8	42.6		52.23	-9.63	92.74			
9	38.3		52.23	-13.93	194.04			
10	36.9		52.23	-15.33	235.01			
11	30.4		52.23	-21.83	476.54			
12	28.7		52.23	-23.53	553.66			
13	22.7		52.23	-29.53	872.02			
14	12.6		52.23	-39.63	1570.54			
15	0		52.23	-52.23	2727.97			

N= 15, Sn= 1.0206, Yn=0.5128

T	T-1	T/T-1	ln(T/T-1)	ln(ln(T/T-1))	Y= - ln(ln(T/T-1))
5	9	1.25	0.2231	-1.5001	1.5001
10	99	1.111	0.1053	-2.2509	2.2509
100	99	1.01	0.010049	-4.6002	4.6002

Y	Yn	Y-Yn	Sn	K=(Y-Yn)/Sn
1.5001	0.5128	0.987	1.0206	0.967
2.2509	0.5128	1.738	1.0206	1.703
4.6002	0.5128	4.087	1.0206	4.004

Return Period	Xavg	K	σ_{n}-1	K*σ_{n}-1	$X_t=X_{avg}+K*\sigma_{n-1}$
5	52.23	0.967	53.01	51.26	103.49
10	52.23	1.703	53.01	90.27	142.50
100	52.23	4.004	53.01	212.25	105.24

Table 4.3: For 5 day return period of 5yr, 10yr, 100y

Order No.	INTENSITY (X) mm/day	SUM	AVERAGE (Xavg)	X-Xavg	(X-Xavg)2	S=∑(X-Xavg)2	S/(N-1)	$\sigma_{n-1}=\sqrt{S}/(n-1)$
1	126.7		54.63	72.07	5194.08			
2	107		54.63	52.37	2742.61			
3	96.69		54.63	42.06	1769.04			
4	94.6		54.63	39.97	1597.6			
5	70.4		54.63	15.77	248.69			
6	70.3		54.63	15.67	245.54			
7	53.5	819.59	54.63	-1.13	1.27	20674.04	1476.71	38.4
8	48		54.63	-6.63	43.95			
9	38.6		54.63	-16.03	256.96			
10	34.4		54.63	-20.23	409.25			
11	28.8		54.63	-25.83	667.18			
12	28.7		54.63	-25.93	672.36			
13	14.5		54.63	-40.13	1610.41			

14	7.4		54.63	-47.23	2230.67			
15	0		54.63	-54.63	2984.43			

N= 15, Sn= 1.0206, Yn=0.5128

T	T-1	T/T-1	ln(T/T-1)	ln(ln(T/T-1))	Y= - ln(ln(T/T-1))
5	4	1.25	0.2231	-1.5001	1.5001
10	9	1.111	0.1053	-2.2509	2.2509
100	99	1.0101	0.010049	-4.6002	4.6002

Y	Yn	Y-Yn	Sn	K=(Y-Yn)/Sn
1.5001	0.5128	0.9873	1.0206	0.967
2.2509	0.5128	1.7381	1.0206	1.703
4.6002	0.5128	4.087	1.0206	4.004

Return Period	Xavg	K	$Ϭ_n$-1	K*Ϭn-1	Xt= Xavg+K*Ϭn-1
5	54.63	0.967	38.42	37.15	91.78
10	54.63	1.703	38.42	65.42	120.05
100	54.63	4.004	38.42	153.83	208.46

Table 4.4: For 6 day return period of 5yr, 10yr, 100y

Order No.	INTENSITY (X) mm/day	SUM	AVERAGE (Xavg)	X-Xavg	(X-Xavg)2	S=∑(X-Xavg)2	S/(N-1)	Ϭn-1=√S/(n-1)
1	178.1	1233	82.17	95.93	9202.56	55184.33	3941.7	62.78
2	174.4		82.17	92.23	8506.37			
3	164		82.17	81.83	6696.14			
4	150.6		82.17	68.43	4682.66			
5	110.5		82.17	28.33	802.58			
6	91.9		82.17	9.73	94.67			
7	88.6		82.17	6.43	41.34			
8	81.6		82.17	-0.57	0.324			
9	57.9		82.17	-24.27	589.03			
10	55.1		82.17	-27.07	732.78			
11	42.7		82.17	-39.47	1557.88			
12	37.2		82.17	-44.97	2022.3			
13	0		82.17	-82.17	6751.9			
14	0		82.17	-82.17	6751.9			
15	0		82.17	-82.17	6751.9			

N= 15, Sn= 1.0206, Yn=0.5128

T	T-1	T/T-1	ln(T/T-1)	ln(ln(T/T-1))	Y= - ln(ln(T/T-1))
5	4	1.25	0.2231	-1.5001	1.5001
10	9	1.111	0.1053	-2.2509	2.2509
100	99	1.01	0.010049	-4.6002	4.6002

Y	Yn	Y-Yn	Sn	K=(Y-Yn)/Sn
1.5001	0.5128	0.987	1.0206	0.9673
2.2509	0.5128	1.738	1.0206	1.703
4.6002	0.5128	4.087	1.0206	4.004

Return Period	Xavg	K	$б_{n}$-1	K*бn-1	Xt= Xavg+K*бn-1
5	82.17	0.967	62.78	60.72	142.89
10	82.17	1.703	62.78	106.91	189.08
100	82.17	4.004	62.78	251.37	333.54

4.2 Calculation of Peak discharge:

Table 4.5: Calculation of peak discharge for 1 day rainfall interval and return period of 5yr, 10y And 100yr

Return Period (year)	Discharge (Q) m3/sec
5	34.11
10	45.4
100	80.84

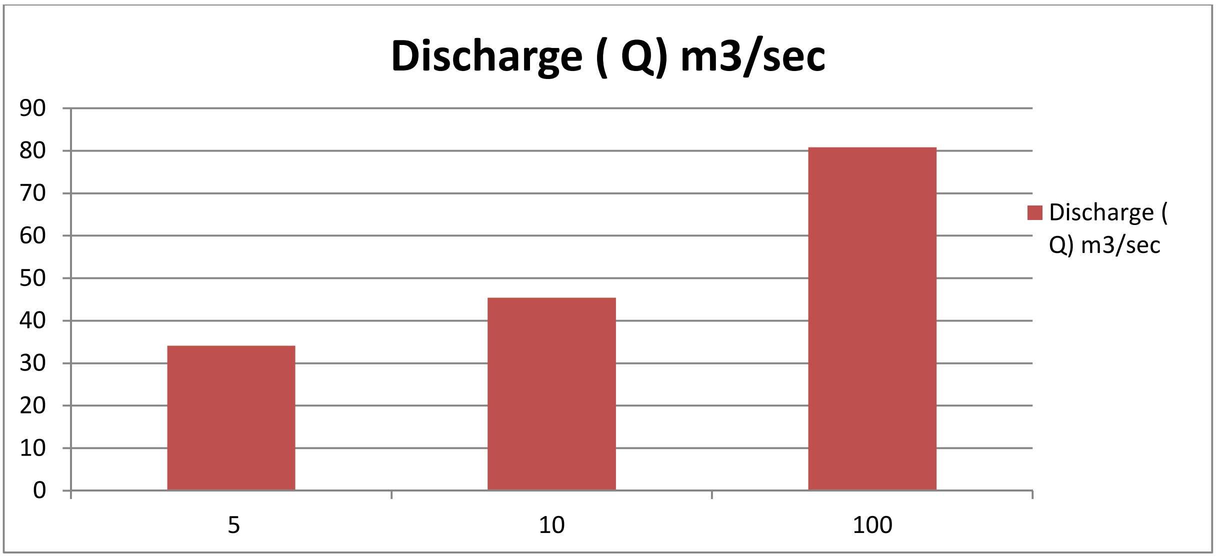

Fig.4.1 Peak Discharge Curve for 1 day return period

Table 4.6: Calculation of peak discharge for 3 day rainfall interval and return period of 5yr, 10y And 100yr

Return Period (year)	Discharge (Q) m3/sec
5	47.73
10	65.67
100	1 22.04

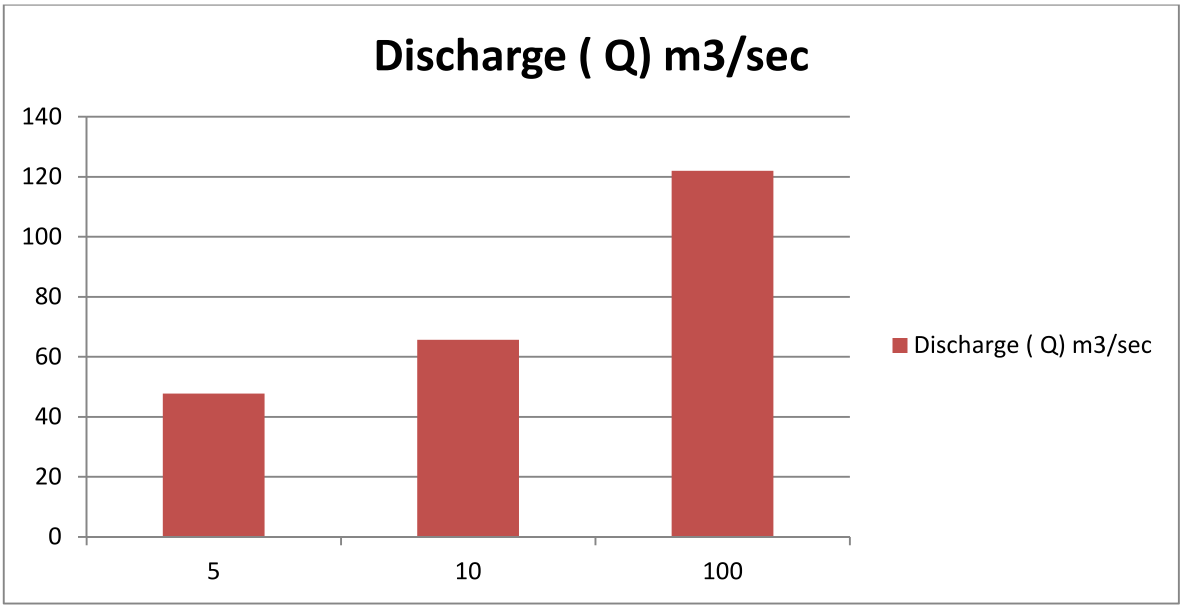

Fig.4.2 Peak Discharge Curve for 3 day return period

Table 4.7: Calculation of peak discharge for 5 day rainfall interval and return period of 5yr, 10y And 100yr

Return Period (year)	Discharge (Q) m3/sec
5	42.30
10	55.59
100	96.13

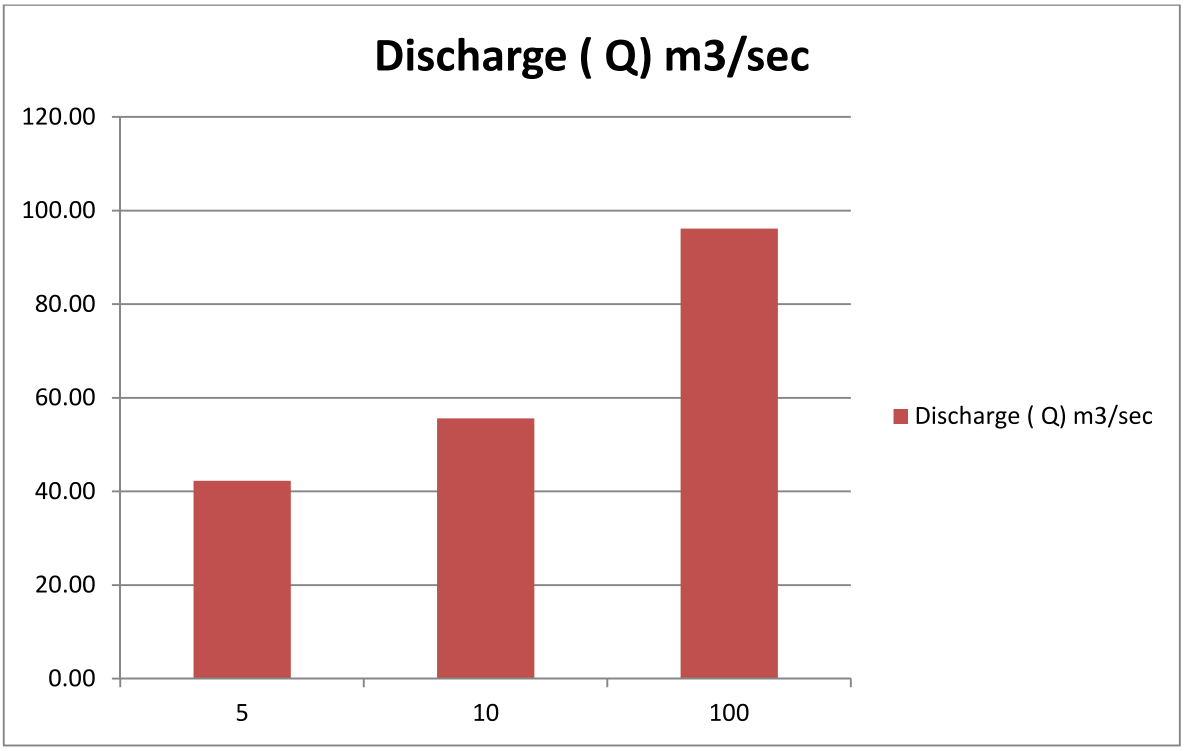

Fig.4.3 Peak Discharge Curve for 5 day return period

Table 4.8: Calculation of peak discharge for 6 day rainfall interval and return period of 5yr, 10y And 100yr

Return Period (year)	Discharge (Q) m3/sec
5	65.89
10	87.15
100	153.83

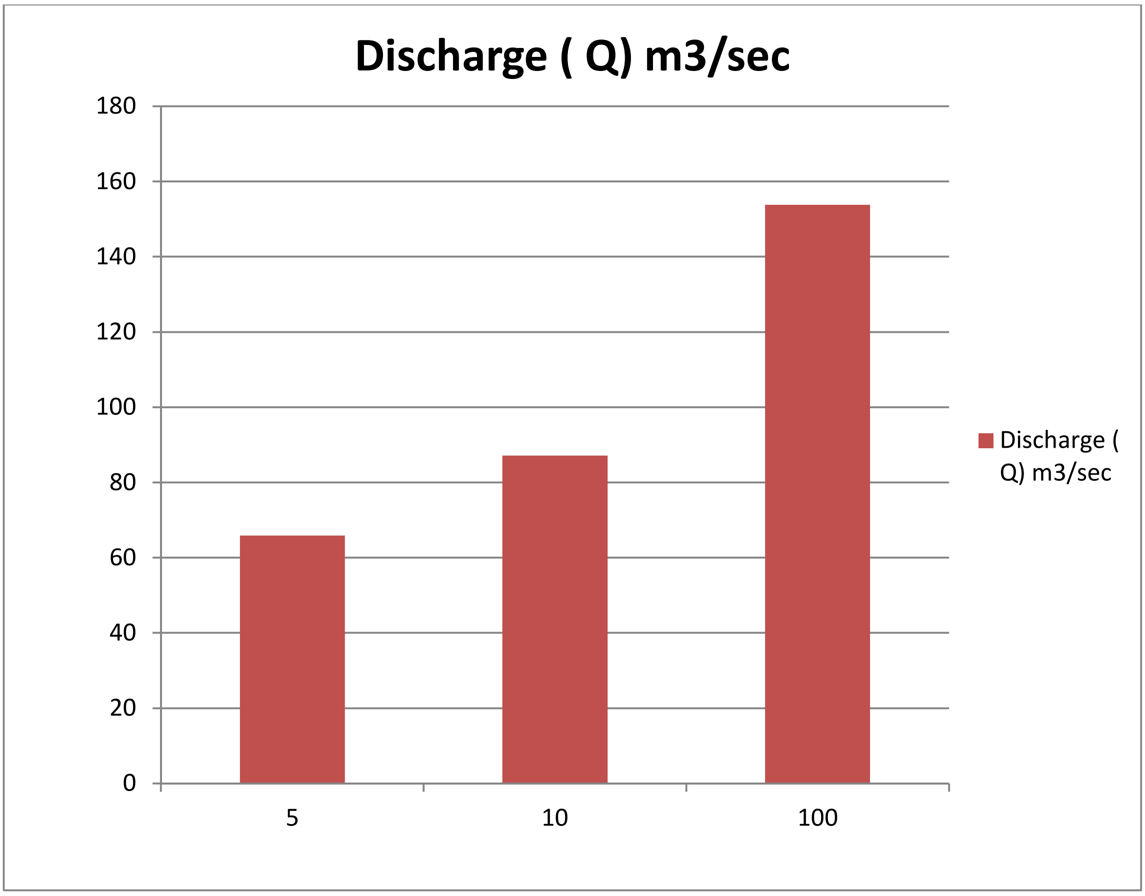

Fig.4.4 Peak Discharge Curve for 6 day return period

5. CONCLUSION

This study has been conducted for the determination of peak discharge using the rainfall data for the year of 2003 to 2017 near Regional Meteorological Centre, Borjhar, Assam. The rainfall intensity is found to be non-uniform throughout the area. The Borjhar has been divided into several zones out of which we are considering only five zones for calculation. The peak discharge is calculated in rational method for 1, 3, 5 and 10 days corresponding to 5, 10 and 100 years. The discharge shows an increasing trend in the five days rainfall interval and a decreasing trend in the six days rainfall interval. But it has to be taken into account that the peak discharge values are likely to change corresponding to the changes in land use and landscape pattern. The value of Runoff coefficient “C” is not constant as it changes from the rainfall data that we have collected. If the value of Runoff coefficient ‘C’ is likely to change in the future, then the peak value will increase. The value of discharge is considered to design the drainage section. If the value of discharge increases in future, then the runoff automatically changes due to which the drainage section fails. Government should introduce an Implement laws which will prevent drastic changes in land use pattern in the coming years.

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