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Effect of LULC on Ordinates of Unit Hydrograph of Muvattupuzha Sub Basin

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Abstract

The changes in land use land cover have a strong effect on the runoff and peak discharge. It is important to analyze the flow data of any watershed to identify the peak discharge. There are several methods to analyze peak discharge. The hydrologic response of any watershed can be analyzed through the Unit Hydrograph. The main aim of the study is to analyze the effect of land use and land cover change on the ordinates of unit hydrograph of the Muvattupuzha sub-basin. The study period considered for analysis is 1998,2008, and 2018. The results from the study during the selected period show that the value of peak discharge is increasing. It is found that the increase in the population has a direct impact on the land use and land cover change which intern affects the value of peak discharge. A very strong positive correlation is obtained between the built-up area and the peak discharge.

Keywords: *Unit hydrograph, Population, Peak discharge, Hydrologic response*.

Introduction

The most significant impact due to human interventions on the hydrological ecosystem is the changes in the land use land cover. In Kerala, developmental activities take place in a rapid manner, and changes in the land use land cover take place accordingly. Most of the changes in land use happen in the built-up area. Tumaini *et al. (2003)* mentioned that the changes in the land use land cover have a strong effect on the river flow pattern, which is a major concern for hydrologists. These changes may directly or indirectly lead to floods and droughts in the present and future. Muhammad Islahuddin *et al.* (2015) reported that if rainfall and runoff data are available, then the water flow can be estimated in any watershed using the concept of the hydrograph, a curve that indicates discharge and time. Rivers play an important role in the environment for maintaining water balance. Therefore, rainfall and discharge of river are two main hydrological parameters which govern the quantity of water in a watershed.

In order to understand the response of land surface, the monitoring of discharge of the river is a very important tool for a hydrologist. Rainfall plays an important role in balancing the sustainability of water resources. The variations in the rainfall are due to climatic changes, which lead to the disintegration of the ecosystem and the environment. Uddin *et al.* (2017) conveyed that the rivers are natural geographic features that originate from mountains or lakes. Large streams are formed by the joining of narrow streams. Gradually the streams widen, and other small rivers called tributaries to join, which together discharge into sea or lake. The monitoring of river discharge is essential as it gives collective information about the land surface. The impact due to climatic change is reflected in rainfall characteristics which intern affect the imbalance of the water resources and ecosystem.

Shao-Yang Huang *et al.* (2012) described that to understand the hydrological changes due to urbanization, unit hydrograph-based models are applied. An increase in runoff volume, discharge are some problems of stormwater management faced nowadays which may lead to a flood. To prevent this flooding, unit hydrograph-related studies are essential to understand the flow rate. Correlation and regression analysis is very much applicable and can be applied to identify the effectiveness of various hydrological parameters for hydrologist. Wiroj Sangvaree and Vujica Yevjevich (1977) mentioned that the rational method and unit hydrograph method is the most applied methods by hydrologists to analyze the peak discharge since it gives a clear-cut idea in a simple way. The study area Muvattupuzha sub-basin is facing flood problems, especially during heavy monsoon. The conversion of land use into a built-up area modifies the river flow rate. The study mainly deals with the analysis of ordinates of hydrographs and their correlation with land use and population.

Literature review

Tumaini *et al.* (2003) discussed the effects of land-use change on flood peaks using a distributed rainfall-runoff model. They used DEM to analyze the land-use change and kinematic wave equation for overland flow conditions. They concluded that the main change that happened due to urbanization in land use is forest area which is converted into golf courses. They applied Manning's roughness coefficient to understand the peak changes in the hydrograph and concluded that higher peaks were formed due to lower travel time. Stathis *et al.* (2010) attempted to study the land-use change effect on the design

storm hydrograph using the SCS curve number method and GIS. The study concluded that most of the agricultural land is converted into a residential area, and 50% of forest area is converted into barren land. The study revealed that for different return periods, peak discharge and flood volume increased with a reduction in travel time. Abhinanda Roy and Reeba Thomas (2016) made a comparative study of the derivation of unit hydrograph for Bharathapuzha river basin using two-parameter Gamma distribution and three-parameter Beta distribution function. The study concluded that the unit hydrograph developed by Gamma and Beta distribution depends on the watershed characteristics than rainfall-runoff data.

Study Area

The study area selected for identifying the effect of land-use change on ordinates of the hydrograph is the Muvattupuzha sub-basin. Muvattupuzha river is the main river flowing in the Ernakulam district of Kerala State. The Muvattupuzha sub-basin has longitudes between 76º 15' and 76º 35'E and latitudes between 9º 31' and 10º 6'N. The sub-basin has a catchment area of 1630 km^2, which is in the central part of Ernakulam city. The conversion of land use into built-up areas increases the peak discharge during the rainy season, which leads to flooding in that area.

Methodology

The land-use change, runoff, and peak discharge have a direct correlation. To analyze the effect of urbanization on runoff, it is necessary to understand the changes in the peak discharge. The land-use change was found from the Landsat 8 satellite imageries of 30 m resolution. Through the ordinates of Unit Hydrograph, changes in the peak discharge can be analyzed with respect to the effect of land-use change. To identify the ordinates of unit hydrograph, the daily discharge data for four-stream gauged stations obtained from Irrigation Design Research Board, Trivandrum (IDRB) were used. One can understand the effect of urbanization if the parameters like land use, discharge, and population are correlated.

Unit Hydrograph

A hydrograph is the graphical representation of discharge in cumecs with respect to the time in an hour. Unit Hydrograph shows how the discharge of a stream is influenced by the accumulation of one unit of runoff. It is an important tool for forecasting the impact of precipitation in hydrological modeling. Unit hydrograph can be used for determining the peak discharge value. The most common and accurate way to understand the effect of peak discharge is by analyzing the ordinates of the unit hydrograph. A unit hydrograph is the storm runoff hydrograph having rainfall of unit duration occurring uniformly in a catchment producing a unit volume of runoff.

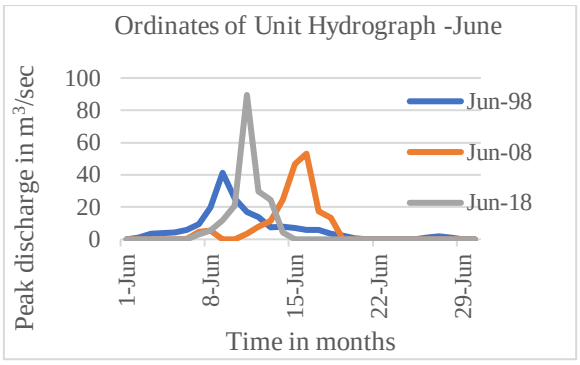
In Kerala, the major source of rainfall in South West and North-East monsoon. Kerala receives maximum rainfall during the months of June to October. Analyzing the effect of peak discharge can be better studied during the maximum rainfall period. Thus, the discharge data and rainfall data during the period June to October are considered for analysis of unit hydrograph. The yearly rainfall was calculated using the Theisen Polygon method from the daily rainfall data. Then the peak discharge graph has been drawn.

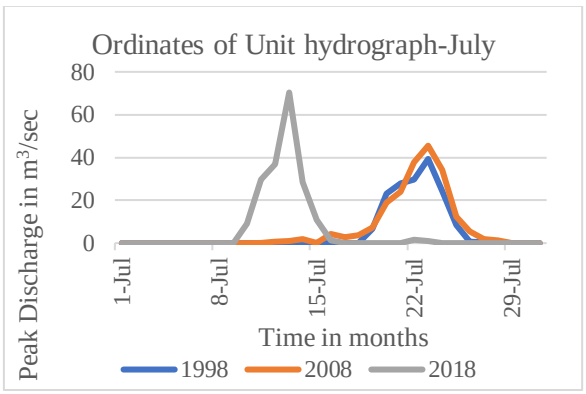
The methodology followed in drawing Unit Hydrograph

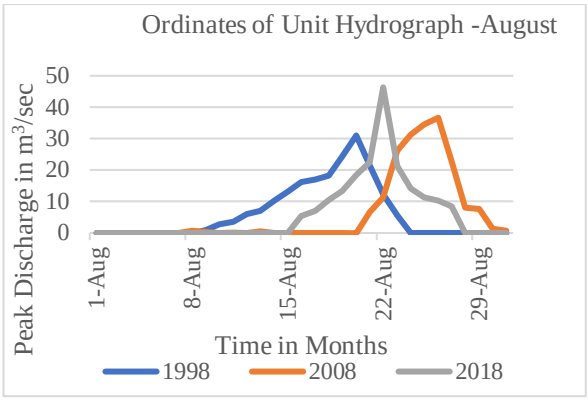
In order to find the ordinates of the unit hydrograph, baseflow was separated using the straight-line method. Then ordinate of direct runoff was found by subtracting base flow from runoff. The volume of direct runoff in cm was calculated using the equation $0.36(\sum O*t)/A$, where $\sum O$ is the sum of discharge ordinates of direct runoff in cm, t is the time interval between successive ordinates in hours, and A is the area of the basin in sq. km. The ordinate of unit hydrograph was then calculated as ordinates of direct runoff/volume of direct runoff in centimeter.

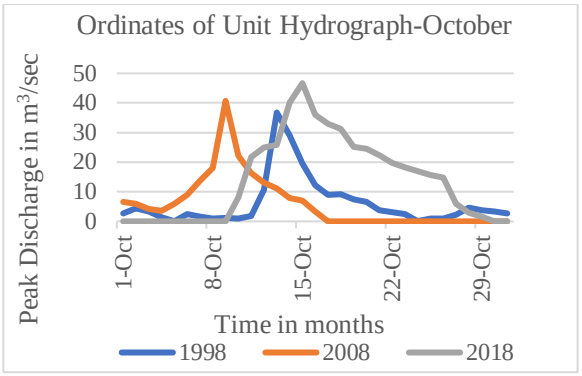
Estimation of Peak Discharge

The peak discharge is the condition in which the river attains its highest flow level during a particular storm event. When the runoff and groundwater enter the basin, the flow of the river begins to rise. To identify the peak discharge, the unit hydrograph has been drawn for the months of June to October, and the graphs are shown in Figure 1.









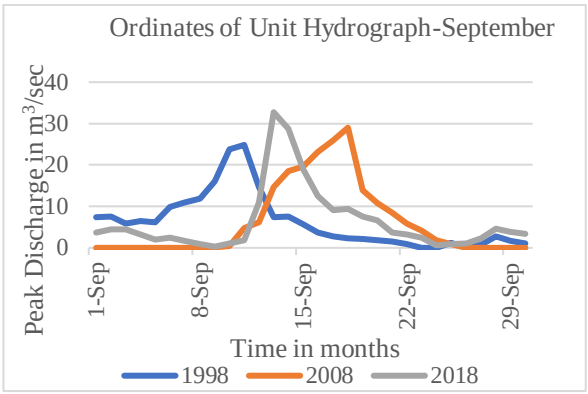


Figure1. Monthly Unit hydrographs for the years 1998,2008 and 2018

From Figure1, it can be seen that the monthly peak discharge value goes on increasing from the year 1998 to 2018. This confirms that due to overpopulation, the land use and land cover pattern of the study area increased enormously during the study period, and the main change in the land use can be seen in the built-up area. Due to the increased impervious area, runoff increases which lead to an increase in peak discharge.

The monthly and yearly peak discharge values are tabulated in Table 1.

Month	Peak Discharge in m^3/sec		
	1998	2008	2018
June	41.240	53.095	89.509
July	39.322	45.487	70.341
August	31.017	36.681	46.327
September	24.851	29.016	32.746
October	36.777	40.707	46.681

Table 1 Values of the Peak Discharge

From Table 1, it can be seen that the ordinates of the unit hydrograph increase with respect to the year. The main reason for the increase is the changes in land use land cover. The LULC changes of the Muvattupuzha sub-basin are given in Table 2.

Table 2. LULC Classification of Muvattupuzha Sub basin

Sl. No	LULC category	The area occupied in sq. km		
		1998	2008	2018
1	Built up Area	104.61	185.95	398.68
2	Forest Area	0.41	0.39	0.42
4	Mixed Crop	443.24	252.51	329.18
5	Paddy Field	130.47	50.64	39.00
6	Plantation	680.27	900.20	630.45
8	Water Body	216.43	196.04	200.08
9	Wetland	54.96	44.70	32.41

From Table1 and Table 2, it is inferred that the ordinates of unit hydrograph increase with respect to the increase in the built-up area.

From Table 2, it is noted that the main variation in the land use is in the built-up area. It may be seen that the built-up area is aggregating, and the agriculture area is diminishing during the study period. The percentage increase in a built-up area between the years 1998 and 2018 is 281.11 percent. The increase in the built-up area indicates that the study area is highly urbanized, and expansion took place in a rapid manner. Due to the rapid development and socio-economic factors, the transformation of land use took place, which led to an increase in impervious structures.

Relation with Peak discharge value and Land use

Generally, land use and discharge are directly correlated. If any variations happened in land use, especially in a built-up area, it would affect the discharge and runoff. The variations in a built-up area and the peak discharges from the unit hydrograph are shown in Table 3.

Table 3. Variations in a built-up area and peak discharge

Year	Built-up area in km^2	Peak discharge from unit hydrograph in m^3/sec				
		June	July	August	September	October
1998	104.61	41.24	39.322	31.017	24.851	36.777
2008	185.95	53.095	45.487	36.681	29.016	40.707
2018	398.68	89.509	70.341	46.327	32.746	46.681

From Table 3, it can be inferred that as the built-up area increases, the impervious area increases, and the infiltration rate decreases resulting in high peak discharge values, which can be seen from the unit hydrograph. It can be seen that the monthly peak discharge value increases from 1998 to 2018.

The variations in the built-up and peak discharges are shown in Figure 2.

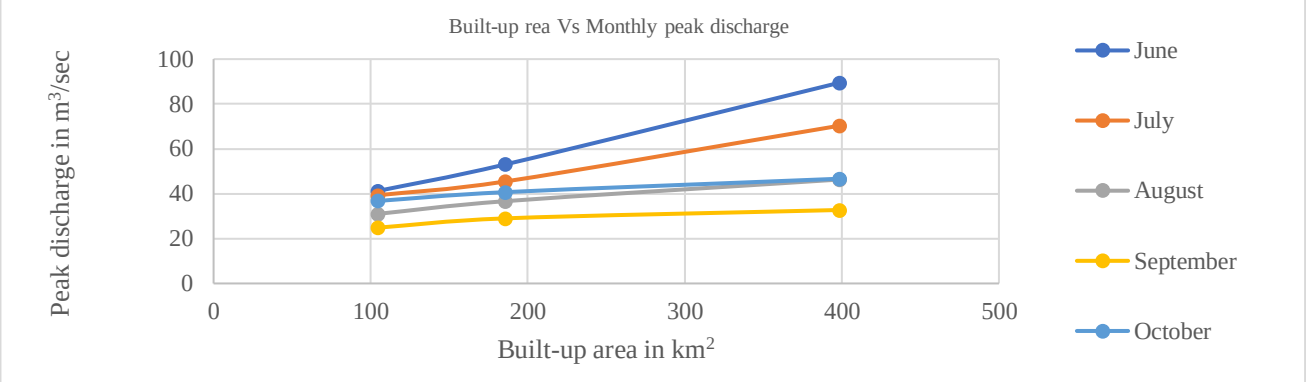


Figure 2. Variations in the peak discharge with respect to the built-up area

From Figure 2, it is inferred that the monthly peak discharge value increases accordingly with an increase in built-up area from 1998 to 2018. This is because the development of the study area is in a rapid way due to urbanization which led to an increase in a built-up area and hence increases in peak discharge value from unit hydrograph.

Percentage variation of peak discharge and built-up area

To understand the land use effect on the ordinates of unit hydrograph, it is better to identify the percentage variations in peak discharge and built-up area. The percentage variations of peak discharge in the month of June to October for the study period and built-up area from the year 1998 to 2018 are given in Table 4.

Table 4 Percentage Variations in a built-up area and the peak discharge

Year	Percentage increase in the built-up area	Percentage increase in peak discharge				
		June	July	August	September	October
Between 1998 and 2008	77.76	28.75	15.68	18.26	16.76	10.69
Between 2008 and 2018	114.4	68.58	54.64	26.30	12.85	14.68
Between 1998 and 2018	281.11	117.04	78.88	49.36	31.77	26.93

From Tables 4, it can be seen that the percentage increase in the peak discharge between the years 1998 and 2008 is maximum in the month of June and minimum in the month of October. The percentage increase in peak discharge between the years 2008 and 2018 is maximum in the month of June and minimum in the month of September. The percentage increase in peak discharge between the years 1998 and 2018 is maximum in the month of June and minimum in the month of October

Correlation Statistics

To understand the impact of urbanization on hydrological response, a correlation analysis is made. Correlation coefficients between built-up area and peak discharges were found, and the values are given in Table 5.

Table 5 Correlation values between built-up area and peak discharges

Parameter	Peak discharge in m^3/sec				
	June	July	August	September	October
Built-up area	0.999	0.996	0.994	0.959	0.991

From Table 5, it is obvious that the built-up area and the peak discharges have a strong positive correlation. It implies that built-up area and peak discharge are directly linked.

Conclusions

The study of the unit hydrograph is important in identifying the peak discharge value due to changes in land use and urbanization. The hydrological parameters like runoff, peak discharge, etc., are directly linked with land use. These parameters are positively correlated with the changes in land use and land cover.

The transformation in the land cover influences the hydrologic process in the study basin due to the increase in population. From the study, it is noted that the percentage increase in the built-up area is 281.11% during the study period of 20 years. From the land use analysis, it is seen that built-up area is increasing and the agriculture area is declining. Here the agriculture area consists of both mixed crop, paddy field, and the plantation. In the study area, most of the people were engaged in agriculture in the earlier period. But due to urban sprawl, the agricultural area has been converted into settlements. Hence the agriculture area goes on diminishing.

The percentage decrease in the agriculture area between the years 1998 and 2018 is 20.28 percent. The increase in expansion of urban sprawl and the reduction in vegetated cover resulted in the impervious area, thus increasing the runoff and peak discharge. The monthly peak discharge value increases with respect to the built-up area during the study period. The maximum peak discharge values were obtained in the months of June and July during the study period since the maximum rainfall was received during these months. If this situation persists, the infiltration will reduce, and the excess storm will flow as runoff and ultimately lead to flood in the study

area. A strong correlation can be seen between land use and peak discharge.

The study area Muvattupuzha sub-basin is a highly urbanized area. People migrated from different places in search of jobs in large- and small-scale industries. The development of Muvattupuzha city is tremendous. The encroachment of settlement happened at a devastating rate near the basin, and the development took place at a fast rate within these 20 years. The conversion of land use should be limited by the authorities to reduce the effect of urbanization.

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