Effect of Population Growth on Land Use and Runoff of Muvattupuzha Sub-basin

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Received: 14 April 2020 Revised and Accepted: 8 August 2020

Abstract

The impact of exorbitant increase in the population results in the change ofland use pattern, runoff pattern and hydrological imbalance. The impervious areas increase which results in thereduction ofinfiltration rate and increased peak runoff. Flood is the main impact due to excess runoff which is very difficult to control. Land use pattern, population and runoff are closely linked with each other. Asthe population increases the land use land cover changes which intern increase the impervious surface and leads to peak runoff value. In the present study an attempt has been made to correlate the growth of population with land use changes during the study period and with the runoff values. The study area selected is Muvattupuzha sub-basin in Kerala, India. The landuse land cover changes were evaluated over a period of 20 years (1998-2018). Satellite imageries were used for evaluating the landuse and land cover changes.Thiessen polygon method was used for the estimation of the runoff. GIS was used in the analysis. It is found that the population has increased by 55 % and the built-up area increased by 281 %during the study period. The runoff per unit rainfall increased by 106 %.

Key words: Population, Runoff correlation, Thiessen Polygon, Flood, Impervious

Introduction

Jora Ligtenberg reported that the population living in urban areas increased globally during the last century. This is higher in developed countries than in undeveloped countries, since there exists a positive relationship between urbanization and income level. Zonguxue Xu and Gang Zhao described that the development level of a country is reflected in urbanization which encompass the relationship between environment and human society.Rapid urbanization has an adverse effect on landuse and runoff pattern. Suman Patra et.al discussed that the unplanned, unsystematic increase in rapid urbanization cause severe effects on environmental components which mainly reflect on land in the form of landuse and land change cover changes.Statistics of India shows that urbanization degree increased from 27.7 percent to 31.1 percent having a growth rate of 3.3 percent during the year 2001- 2011.Gulden Gorani represented that due to urbanization,people began to live together on a closer area resulting in an increase in waste water which is being discharged into local bodies and drainage resulting in pollution. Mayaetal enunciated that for proper planning and development, adequate studies related to resource extraction and mining are required. The onsite and off-site impacts on environment due to mining activities will affect the land use pattern and runoff.

Venkatesh K and Ramesh H conveyed that for a sustainable watershed, the influence of land use land cover changes is very important and has a direct influence on hydrological yield. Due to the changes in land use and land cover, the water quality which reaches the downstream part gets degraded.Alemayehu Kasaye Tilahun emphasized thattheland use pattern is an important aspect in runoff analysis. Due to rapid increase in urbanization, the land cover is subjected to changes which causedimperviousness, leading to decrement in infiltration rate and increase in runoff rate.Samie etalevaluated the land use change on runoff on Chenar Rahdar watershed using Landsat and SWAT model and concluded that SWAT model gives a better runoff result in landuse change.Letha J etalanalyzed a river basin and checked whether the flow pattern is changing due to change in landusepattern. Ashantha Goonetilleke and Jane-Louise Lampard reported that as per UN statistics, the population in urban areas will reach 66 percent by 2050.The increase in urbanization results in conversion of vegetative areas into impervious surfaces. Deposits of pollutants on these impervious surfaces took place due to anthropogenic and natural activity.Studies are necessary to assess these changes quantitatively and qualitatively.

Literature review

Sajikumar N and Remya Raveendran (2015) studied the impact of land cover and landuse changes on runoff characteristics using SWAT model. They concluded that peak runoff value increased by an amount of 15%. Venkatesh K and Ramesh H (2018) studied the impacts of landuse land cover changes on stream flow for Tungabhadra river basin to analyze the economic and environmental changes. To assess the efficiency of SWAT, they used coefficient of determination and Nash -Sutcliffe.The result obtained in the study can be applied for the conservation of water and soil management.Jora Ligtenberg (2017) studied the water balance changes due to urbanization. Runoff increased as the area is more urbanized and the peak flow also increased.It was also reported that as impervious area increases,runoff also increases and storing excess water in cities isthe better solution to overcome this effect.Sumanetal (2018)made an attempt to study the spatio temporal characteristics in Havrah Municipal Corporation,West Bengal using GIS technique.In the study, the inverse distance weighting interpolation method was applied to analyze the rainfall distribution and ground water level. Gulden Gorani (2017)studied the urbanization impact on peak runoff in Bogota.He applied curve number and triangular unit hydrograph methods to identify the pre-flow pattern and peak discharge formula for post-flow condition.He concluded that urbanization results in increase of impermeable surface which inturn affects the basin drainage efficiency and leads to increase in peak runoff. Manish et al (2019)analyzed the available data of rainfall and landuse change pattern and reported that it is hard to correlate the runoff with landuse pattern. They applied curve number method along with GIS and RS for establishing a relationship between the rainfall,landuse and runoff. They observed in their study that runoff is increasing with increase in imperviousness due to the change in urban sprawl.

Study Area

Metropolitan cities are mainly affected due to urbanization.This effect will have an impact on hydrological parameters. Ernakulam which is considered as the second central business district in Kerala is a fast-growing city. The river flowing through Ernakulam district is Muvattupuzha and the basin is Muvattupuzha River Basin. The basin consists of four sub-basins namely Kothayar or KothamangalamSub-basin,Kaliyar or Kaliyar sub-basin, Thodupuzhar or Thodupuzha sub-basin,Moovar or Muvattupuzha sub-basin.Muvattupuzha sub-basin is selected as the study area.

The Muvattupuzha sub-basinlies betweenlongitudes 76º 15’ and 76º 35’E and latitudes 9º 31’ and 10º 6’N. The sub-basin has a catchment area of 1630 km^2, which is in the central part of the city.Muvattupuzha River, is an important river in Ernakulam district, which is the confluence of three rivers namely Kothayar,Kaliyar and Thodupuzha ar.Thodupuzhar is the major source of water supply in the city which flows towards Vaikkom lake and then joinsthe Arabian Sea.During rainy season the low-lying areas of the basin gets flooded due to excess runoff.

Methodology

Landuse change and runoff are normallycorrelatedto each other.To analyze the impact of urbanization, it is necessary to study and consider the changes in landuse pattern, runoff characteristics and population.To study the land use changes,Landsat 8 satellite imageries of 30 m resolution were downloaded for the years 1998,2008 and 2018 from USGS earth explorer website. Using Arc GIS 10.1 softwaretool,the imageries were classified. Analysis of the landuse land cover changes werecarried out for the whole basin and then applied to four sub-basins.The populationdetails are taken from the district census handbook of the years 1991,2001 and 2011.Shape files of census block and river sub-basin were overlaid. Using the join operation in the GIS,the attribute tables of both these were merged and sub-basin wise population were found out for the various sub-basins in the study area.The runoffwas calculated using Thiessen Polygon. Then runoff per unit rainfall was estimated for the sub-basin. Runoff per unit rainfall is defined as the runoff value divided by the rainfall value. The runoff per unit rainfall values were correlated with the population and LULC changes.

The LULC maps of Muvattupuzha Sub-basin for the years 1998, 2008, 2018 are shown in Fig 1, Fig 2, and Fig 3 respectively.

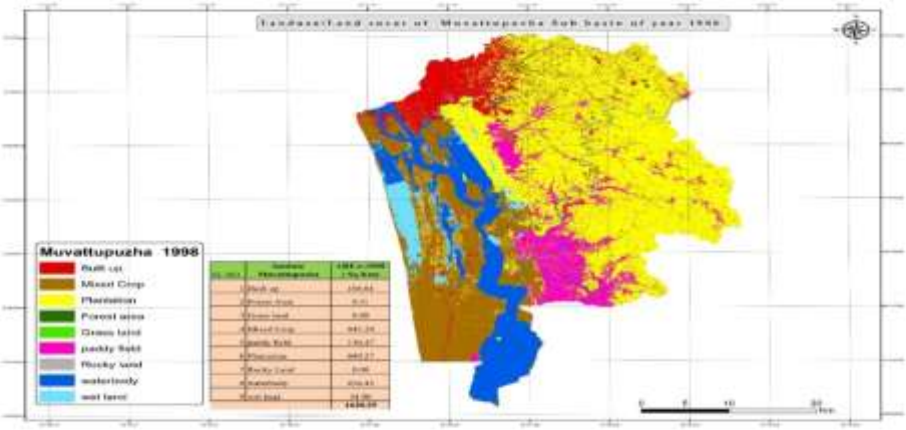

Fig1LULC of Muvattupuzha Sub-basin corresponding to the year 1998

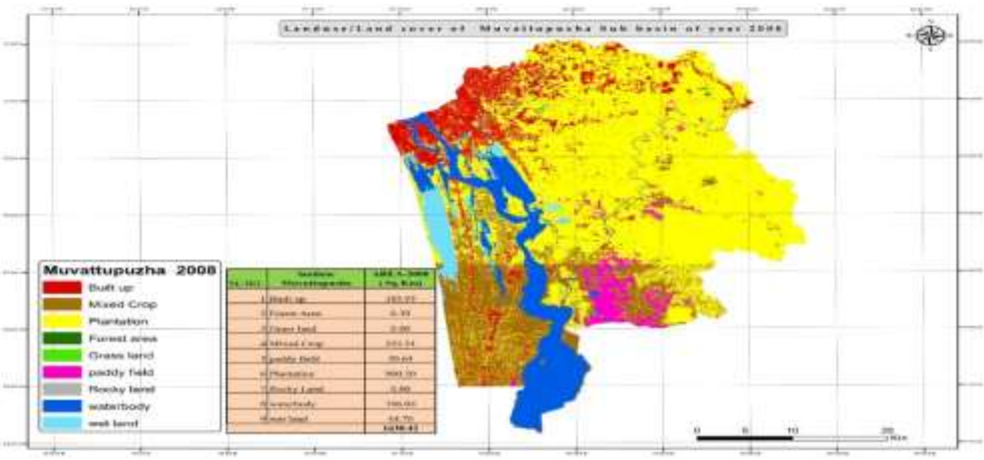

Fig 2 LULC of Muvattupuzha Sub-basin corresponding to the year 2008

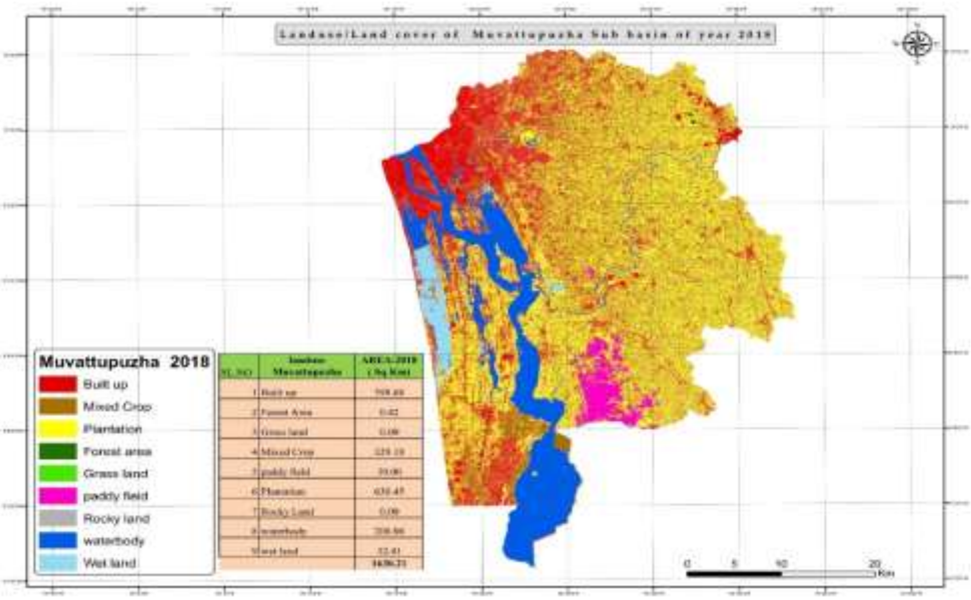

Fig 3 LULC of Muvattupuzha Sub-basin corresponding to the year 2018

Analysis of landuse land cover changes

Landuse land cover changesare very important to predict the runoff characteristics due to urbanization.The landuse land cover changes werefound out for the entire Muvattupuzha River Basin(MRB). From that the landuse land cover has been found out for each sub-basinof MRB namely Kothamangalamsub-basin,Kaliyar sub-basin,Thodupuzha sub-basin and Muvattupuzha (Moovar)sub-basin. The Muvattupuzha river is the main source of water for the Muvattupuzha area and it is the one of the main rivers flowing centrally along the city. In the present study, the landuse classification of Muvattupuzha sub-basin is considered since this sub-basin is the confluence of other three sub-basins. The LULC changes of MuvattupuzhaSub-basinis given in Table 1.

Table 1 LULCClassification of Muvattupuzha Sub-basin

LULC Category	Area occupied in sq.km		
	1998	2008	2018
Built up area	104.61	185.95	398.68
Forest area	0.41	0.39	0.42
Mixed crop	443.24	252.51	329.18
Paddy field	130.47	50.64	39
Plantation	680.27	900.2	630.45
Water body	216.43	196.04	200.08
Wetland	54.96	44.7	32.41
Total	1630	1630	1630

Built up area

The most change happened among all categories is the built-up or residential area. The analysis implies that built up area is increasing from 1998 to 2018. The increase in built up area between the years 1998 and 2008 is found to be 77.75%. The increase in built up area between the years 1998 and 2018 is found to be 281.11%. This percentage increase in built up area is very high. This increase indicates that as the population increases, people try to change the landuse and the more changes happened in the built-up area. People have a tendency to occupy in the central core of acityand it gets congested. From the figure1,2 and 3,it is clear that the population is not only concentrated in the core area but also spreads to the outskirts too.

Forest

The forest area in the study area remains constant throughout the study period.This indicates that developmental activities have not taken place in this category of landuse. To maintain a hydrological balance, it is better to retain the forest as it is. Itis seen that forest occupies an average area of 0.4 km^2

Mixed crop

Muvattupuzha is the area known for mixed crop cultivation. Crops like pineapple, banana, arecanut, coca, ginger, turmeric, cardamom, coffee and rice are cultivated in this area. The total area of the mixed crop in the year 1998 is 443.24 km^2 which decreased to252.51 km^2 in the year 2008. The area increased to 329.18 km^2 in the year 2018. The percentage decrease in mixed crop area between the years 1998 and 2008 is 43.03 %and the percentage decrease in mixed crop area between the years 1998 and 2018 is 25.73 %.

In the study area, crops are cultivated according tothe season.The decrease in the mixed crop area during the study period implies that due to low market value, reduction in government subsidy, the benefits from the government not coming on time andnon-availability of laborers, the farmers or cultivators are not in a position to cultivate the crops. They are not ready to cultivate all the mixed cropson a regular basis.The latter increase in mixed crop vividly pictures the cultivation of paddy named Pokkali, which grows more in acid saline soil, in addition to the other crops. From the analysis it is found that the overall mixed crop area has decreased during the study period. Low market value of the cultivated items, reduction in subsidies from government, climatic factors, transformation of areas into commercial or residential areas, non-availability of laborers and cultivation of selected crops are the reasons for the reduction.

Paddy field

The soil of Moovar sub-basin isacid saline, alluvial and laterite. Paddy is the most suitable crop for cultivation in this area.A paddy named Pokkali was cultivated because that crop is good in acid saline soil .It is seen that the paddy field areahas decreased from 130.47km^{2}during the year 1998 to 39 km^{2}duringthe year 2018.The decrease in percentage of paddy field from the year 1998 to 2008 is 61.18% and that between the years1998 to 2018 is 70.10 %. This revealed from the satellite imageries that this area is converted into residential and commercial areas.Conversion of paddy field into built up is a source of high income for the farmers and this is one of the reasons for the reduction in paddy area.

Wetland

Wetland is marshy or swamp area which are covered with water. Wet land plays an important role in the ecosystem. Wetland prevents flooding just like a sponge holds water.In the Muvattupuzha River basin, only this Moovar sub-basin has enough wet land.In the study area, the area of wet land in the year 1998 was 54.96 km^2 which then decreased to 32.41 km^{2}in the year 2018.The percentage decrease in wetland between the years 1998 and 2008 is found to be 22.95%.Also, the percentage decrease in wetland between the years 1998 and 2018 is found to be 41.02%. This percentage decrease is high. The intervention of human activities causes alterations and hence there is a decrease in wetland. In the early period of study, Moovar sub-basin had enough wetland so no flood issues were reported. From the study it is seen that wetland area is decreasing which revealed that encroachment of human activitieshas taken place by converting them into settlements. Flood issues are reported in the recent years. The overall decrement indicates rapid encroachment due to urbanization.

Plantations

Plantations in the study area mainly include rubber, coffee, coconut and areca nut. Rubber plantation predominates the most.The plantations in the study area has increased from 680.27 km^{2}during the year 1998 to 900.2 km^{2}during the year 2008 and later decreased to 630.45 km^{2}in the year 2018.The percentage increase in the plantation between the years 1998 and 2008 is found to be 32.32% and decrease in percentage in the plantation between the years 1998 and 2018 is 7.32%.Due to the increase in the population, the demand for the built-up area increased and the area is converted into residential areas. Due to the reduction in market value of rubber, coconut, areca nut and non-availability of workers, the land is converted into built-up area and production centers.

Analysis of Population Statistics

Population,landuseand runoff areclosely linked with each other. As population increases, landuse pattern changes and runoff characteristics vary drastically. The population data are taken from the district census handbook for the periods 1991 ,2001 and 2011.Since the population varied linearly between the years 1991 to 2011,arithmetic increase method was adopted to estimate the population for the years 1998,2008 and 2018 with a R^2 value of 0.9902 and estimated values are given in Table 2.

Table 2 gives the estimated runoff volume and population during the years 1998,2008 and 2018 in the Muvattupuzha Sub basin.

Year	Population	Runoff in Mm^3
1998	2187409	2807.66
2008	2685099	2929.75
2018	3182789	6063.29

Table 2 Estimated runoff volume and population in the Muvattupuzha Sub basin

From the projected population data,it can be seen that the population in the study area has increased from 2187409 during the year 1998 to 3182789during the year 2018.The percentage increase in population between the years 2008 and 2018 is found to be 18.53 %.The percentage increase in population between the years 1998 and 2018 is 45.50%. This percentage increase is very high which indicates that urbanization is taking place at a devastating rate.Uncontrolled urbanization may create environment and hydrological imbalance and climatic changes. It can be analyzed that as population increased the built-up area also increasing. The built-up area increased from104.61 km^2 to 398.68 km^2 between the study period from 1998 to 2018.The percentage increase in built-up area for the period 1998 and 2018 is found to be 281.11%. Fig4 shows the variations in the built-up area with respect to the population.

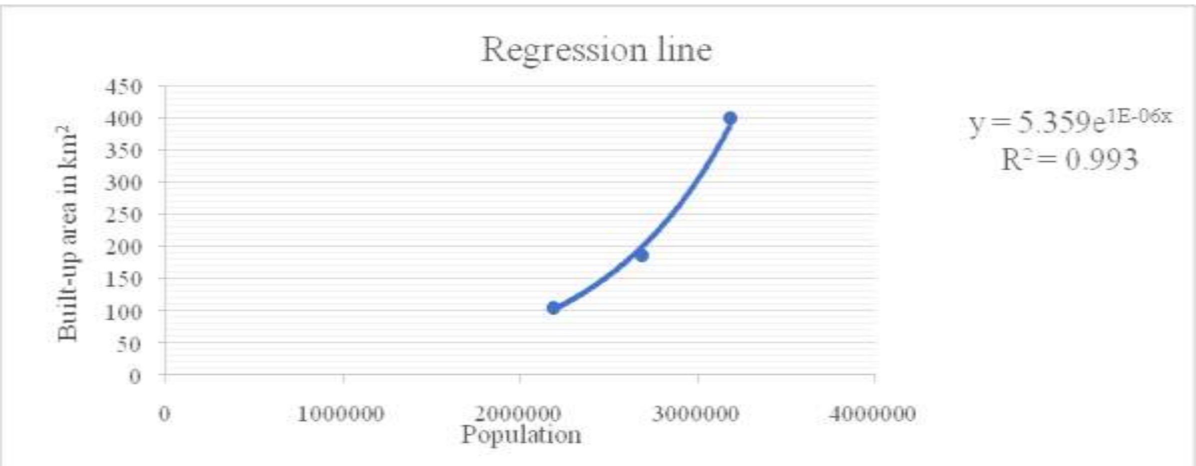

Fig4 Variation of built-up area with respect to the population

A regression analysis has been carried out and a relationship between the population and built-up has been found and the equation is given below.

$Y=5.3593e^{IE-06x}$ and the equation has a R^2 value of 0.9935

Analysis of Runoff

Runoff is the main after effect of urbanization in any metropolitancities. When runoff happens in excess,flooding of low-lying areas occurs.In the study area, the runoff analysis has been carried out using Thiessen Polygon method.In the study area seven rain gauge stations were considered for constructing the ThiessenPolygon. Runoff has been calculated for the whole year based on daily discharge data obtained from the data center of Irrigation Design and Research Board(IDRB), Trivandrum.Fig 5Shows the Thiessenpolygon map of the entire river basin.

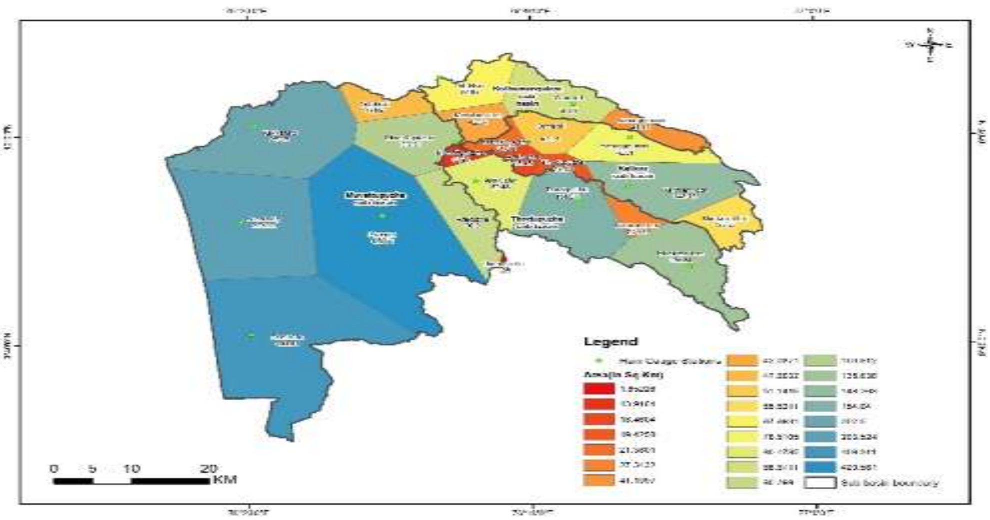

Fig 5Thiessen Polygon map of Muvattupuzha River basin with sub basin wise.

The variations in runoff with respect to populationis shown in Fig 6.

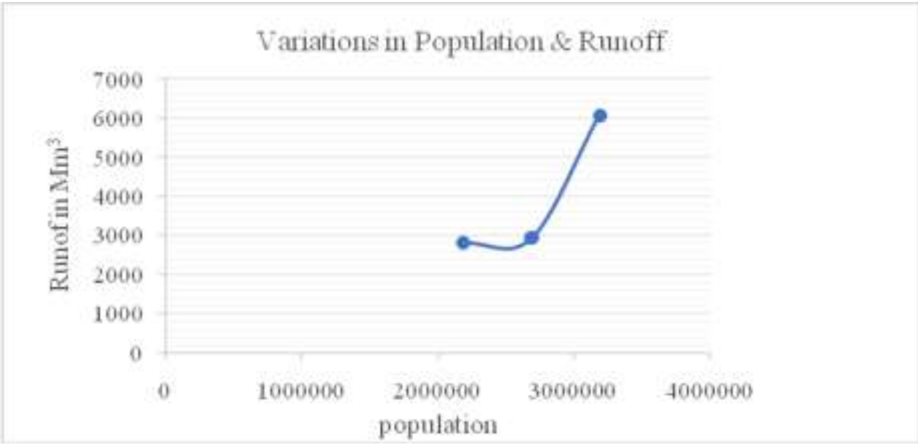

Fig 6 Variations in Population and Runoff

It can be observed from Fig6that as thepopulation in the study area increases the runoff increases. Thechanges in the built -up area, agriculture and wetland specifically depict the change in the landuse pattern of the study area. This indicates that development activities are carried out in the city limits in an uncontrolled manner. Due to these changes, the runoff increases.

Estimation of Runoff for unit rainfall depth

Runoff mainlydependsonrainfall and when the amount of rainfall is high, the runoff is also high. In order to understand the effect of urbanization on the runoff, the concept of runoff per unit rainfall is introduced. It is the runoff per unit rainfall for a particular period. The mean Thiessen rainfall valueswere found and the runoff per unit rainfall were calculated for the three years and the values are given in Table 3.

Table 3Values of Runoff per unit rainfall

Study area	Year	Runoff in m^3	Mean rainfall from Thiessen Polygon in m	Runoff per unit rainfall in year, m^3 per meter	% increase in rainfall /runoff between the years 1998 and 2008	% increase in rainfall /runoff between the years 1998 and 2018

Muvattupuzha sub basin	1998	2807665039	2.799	1002944835	0.978	105.6
	2008	2929752273	2.892	1012757808		
	2018	6063291086	2.940	2061867661		

Table 4 gives the details of the population and the corresponding values of rainfall per unit runoff and the built-up area.

Table 4Population and Runoff per unit rainfall

Year	Population	Built-up Area, sq.km	Runoff per unit rainfall, m^3 per m
1998	2187409	104.61	1002944835
2008	2685099	185.95	1012757808
2018	3182789	398.68	206186766

The variation in runoff per unit rainfall with respect to the population is shown in Fig. 7.

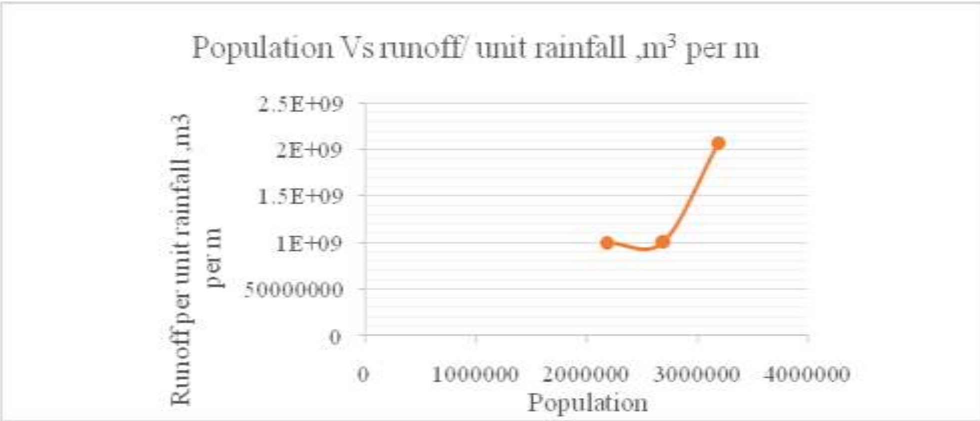

Fig7Variations in runoff /unit rainfall with respect to the population

From Fig7,it is seen that the runoff per unit rainfall increases with respect to the population.This clearly pictures that the population in the study area during the study period increased at an enormous rate and the runoff increased drastically by 105.6% during the year 2018 when compared with the year 1998.

Fig8shows the variations in the runoff per unit rainfall values with respect to the built-up area.

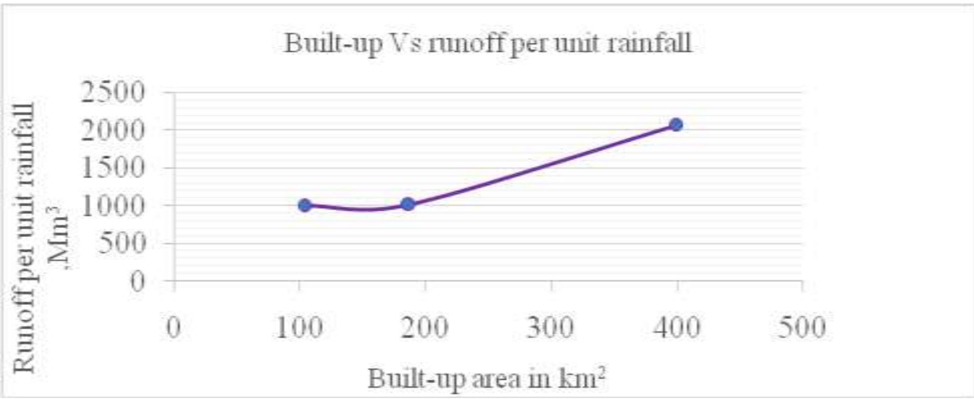

Fig. 8. Variations in runoff per unit rainfall depth with respect to built-up area

From Fig8, it can be observed that the runoff per unit rainfall value increased as built-up area increased during the study period. The percentage increase of built up area between the years 1998 and 2018 was 281.11% and the percentage increase in runoff per rainfall between the years 1998 and 2018 was 105.6%. The percentage increase in population between the years 1998 and 2018 was 35.47%. This clearly pictures that urbanization pattern affects the land use characteristics especially in the form of runoff. More runoff per rainfall value emphasize that the study area will be flooded especially during the season of heavy rainfall. Due to excess runoff, the hydrological characteristics change and leads to imbalance inenvironment.

Correlation Statistics

In order to understand the interdependency between various parameters, coefficient of correlation values were found betweenthe various parameters and the values are given in Table5

Table 5Correlationcoefficient values between the various parameters for Muvattupuzha Sub-basin

Parameters	Agriculture	Population	Runoff for unit depth of rainfall
Built-up area	-0.996	0.968	0.965
Population	-0.944	1	0.870
Agriculture	1	-0.944	-0.983

It can be seen fromTable 5 that agricultural area has a strong negative correlation with built-up area, population and runoff per unit value. Agriculture area is taken as the sum of paddy, mixed crop and plantation areas.As the population increases, built-up area increases, agriculture area decreases and hence the runoff per unit depth of rainfall also increases. Fromthe Table 5, it can also be seen that built-up area and population have a strong positive correlation with the runoff volume for unit depth of rainfall.The study area,Muvattupuzha sub-basin is geographically located within the urban limits and has more human interventions. This correlation analysis shows that with increase in urbanization, built-up area increases, agricultural area decreases resulting in increased runoff.

Conclusions

The landuse change and the correlation of runoff with land use changes and population were studied in the study area. In the landuse change analysis, it was observed that the major impacts were related to built-up area, agriculture and wet land. The increase in built-up area decreases the agricultural area and wetland areathus decreases the pervious area and is the reason for the increase in runoff.During the study period of 20 years, the percentage increase in the built-up area is 281.11%, the decrease in agriculture area is 70.10% and the decrease in wetland area is found to be 41.02 %. Itis observed in the study that the increase in the population during 1998 to 2018 is as45.50%.A relationship between the population and the built-up area has been established with a R^2 value of 0.9935.

The Muvattupuzha sub-basin is situated in a low-lyingarea in which settlement has been observed as per the study. With the increase in urbanization during 1998 to 2018, there is a possibility fornatural disasters like flood, soil erosion or landslides.Due to the increase in settlement, the study area experiences flood problems nowadays.Suitable measures can be taken to minimize the conversion of agricultural land and wetland area into other categories of land use. These measures will reduce flooding that may occur in the Muvattupuzha sub-basin due to land use changes.

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