Impact of urbanization on flooding in Chalakudy river

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Abstract. Extreme events like floods are a concern for any country in terms of the damages caused to life as well as property. The recent trend of unpredictable rainfall in India leads to significant changes in the flow of the river and basin characteristics, which contribute to the aggravation of floods. In the cataclysmic flood in the year 2018 in Kerala, the Chalakudy river basin was completely inundated. This region has undergone extensive environmental changes since the 1990s due to agricultural expansion, deforestation, increased urbanization etc. These indicate the need for conducting a hydrologic and land use/land cover (LULC) change analysis to identify the causes, effects and solutions to mitigate the devastating effect of floods. This goal is achieved with the help of Geographic Information System (ArcGIS) and a hydrological model (HEC-HMS). The results from the study shows that tremendous change in land use pattern has occurred over the past few decades and the notable among them is the 1003.9\% increase in built-up area. The increase in flood peak of the devastating Kerala Flood 2018, exclusively due to this land use change/urbanization is found to be about 22\% in this study area.

1. Introduction

Floods have large consequences on individuals and communities such as loss of life, damage to property and livelihood, the cost incurred in rebuilding the affected area etc. The frequency and intensity of floods are affected by urbanization and the subsequent changes in land use in many ways [1]. Paving of soil surfaces by the replacement of vegetation results in increase in runoff to rivers, reduction of infiltration and an increase in the frequency, intensity and peak discharge of flood. With less area for storage of water and a quick response to runoff, urban streams have a relatively higher peak discharge and they rise faster during rainfall events. Other anthropogenic activities also have an effect on the peak discharge by changing the rate of storage of rainwater and the runoff [2]. In areas like forests and wetlands water is stored in vegetation, their root zone and in surface depressions. Remaining water flows as subsurface flow, only when this capacity is exceeded, water flows over as runoff thus reducing the magnitude of peak discharge.

Naturally, floods occur due to many climatic factors. However, the severity and consequences of such events are determined by the way humans use the watershed. A sound understanding of the techniques required to manage the impacts of LULC changes on the hydrology of the watershed is essential for the control of floods, to reduce the flood risks, and for flood hazard mapping [4]. The anthropogenic activities should be kept in check regularly, to maintain a balance between the needs of the population and the adverse effects on the watershed.

Chalakudy River is the fifth longest river in Kerala and was hit hard by the flood in August 2018. Its basin which has undergone rapid development, was one of the worst affected areas by the unprecedented flood. Activities like urbanization, deforestation and many such forms of LULC
changes have increased largely in the area to accommodate the ever-increasing needs of burgeoning population. LULC changes can be pernicious to the smooth functioning of a watershed by influencing the flood peaks, rate of infiltration and evapotranspiration, rate of runoff and the ground water recharge [3]. Reduction in the vegetation cover may increase the resultant over land flow, thus reducing the time to attain the flood hydrograph peak. Hence the rate of travel of the peak discharge to outlet also increases, creating chances for more incidents of flooding [5]. In the floods of Aug 2018 in Kerala, the raging waters from the Chalakudy River had rendered many people homeless. If the present system of water flow is allowed to be continued without providing any preventive measures, huge loss in terms of life and property can be expected if such flood events repeats in the future. Haphazard development close to the river banks may have contributed to the increase in impermeability of the soil, which in turn augment the flood peak. Hence a study on the causes of such unprecedented flood events and its adverse effect on human life is essential to work out possible mitigation measures [6]. The objective of this study is to analyze the changes in land use pattern occurred in the Chalakudy river basin over a period of last 23 years and to determine its effect on the flood peak of Aug 2018, so that effective mitigation strategies can be implemented.

2. Description of study area
The Chalakudy River Basin lies between North latitudes 10°09”44” and 10°22”00”, East longitudes 76°15”56” and 77°07”30”. It is the fifth longest river in Kerala, India, with a length of 145.5km. The river flows through the districts of Thrissur, Palakkad and Ernakulum in Kerala. It drains a total area of 1704 km², out of which 1404 km² lies in Kerala and the rest 300 km² in Tamil Nadu. About 17% of the basin area lies below the MSL, receives an annual rainfall ranging from 1800 - 3600 mm and the average annual streamflow is around 1630 Mm³. There is a river gauging station at Arangali at the downstream, monitored by the Central Water Commission, India. Out of the total area of the river basin, approximately 54% is occupied by forest, 12% by plantations, 14% by agricultural plantations and 16% comes under homesteads with paddy fields and crops [1]. Studies indicate that the area under paddy lands decreased whereas built-up area has increased substantially over the years. Figure 1 shows the location and the basin outline of the study area.

![Figure 1. Chalakudy basin](image)

3. Materials and Methods
Remotely sensed Surface Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with 30 m spatial resolution was downloaded from United State Geological Survey (USGS) website. The study area was extracted using the shape file obtained from the kslubris website. The soil map of the entire state of Kerala was obtained from the site “European Data Centre” and the LULC map of 1995 was downloaded from Decadal LULC. The daily precipitation data for the month of August 2018 and for the month of August1995, for the Chalakudy river basin was obtained from three rain gauge
stations maintained by the Kerala State Electricity Board (KSEB). Discharge data from the Arangali gauging station for the same period was obtained from Central Water Commission (CWC).

3.1 LULC map generation and formation of land use change matrix
LULC change occurring in an area is an important factor influencing the runoff generated from a rainfall event. Hence, to analyse the effect of urbanization and the impact of the developmental activities on the runoff generation, a comparison of the change in LULC over a period of 23 years (from 1995 to 2018, based on data availability) was made. The 1995 LULC was obtained from ‘Decadal’ and as the study focuses on 2018 flood, the LULC map of the year 2018 was generated with the help of satellite images and DEM using ArcGIS by supervised classification. The 1995 LULC map was reclassified into five classes namely, forest, vegetation, water body, barren land and urban area. Then a land use change matrix was constructed to understand the temporal change in each land use category. Figure 2 shows the change detection of land uses.

![Figure 2. Change detection of LULC from 1995 – 2018](image)

3.2 HEC-HMS Modeling
After analysing the LULC change, keeping all other factors constant CN grid was developed for land uses of both the years 1995 and 2018, by using the soil map, LULC map and the DEM with the help of a CN lookup table and the standard reclassification table for NLCD classification. HEC-HMS models were developed using Arc Hydro tools and HEC Geo HMS extensions in Arc GIS [7]. Terrain preprocessing steps like filling of sinks, drainage line generation etc. were performed and then the basin file was generated using HEC Geo HMS by specifying the outlet point, sub watershed generation etc. The CN grids were also incorporated at this stage and the routing method was also specified (e.g.: Muskingum routing in this study).

In HMS once the background maps of river and sub-basins are activated the inputs can be given. For Muskingum routing the inputs are the Muskingum K and x values and the precipitation data. The Velocity (v) was determined using Manning’s equation, by extracting depth ‘y’ values of each cross section from HEC RAS and top width ‘b’ and reach length ‘L’ from Google Earth. Muskingum K was determined and x was taken as 0.25.

Both the 1995 and 2018 HMS models were initially calibrated and validated using the observed daily rainfall values from Aug 03rd 1995 to Aug 30th 1995 and Aug 03rd 2018 to Aug 30th 2018 respectively. The \( R^2 \) values were determined using MS Excel by plotting the observed and simulated discharge values and were found to be greater than 0.8 for both the models. To assess the impact of land use change on flood peak, the 1995 model is run with 2018 precipitation data and compared the results
with the observed discharge in 2018. Figure 3 and 4 shows the calibration and validation details of the 1995 model 2018 model respectively.

![Figure 3. Calibration and Validation of 1995 model](image1)

![Figure 4. Calibration and Validation of 2018 model](image2)

4. Results and Discussion

From the comparisons and analysis of the LULC maps and the hydrological models the results obtained are as follows. In the land use change matrix prepared for the period 1995 to 2018, shown in Table 1, there is obvious replacements of various categories of land use especially by urban area.
Table 1. Land use change matrix

| Land class 1995 | Barren | Built up | Forest | Vegetation | Water body | Grand Total |
|----------------|--------|----------|--------|------------|------------|-------------|
| Barren         | 22.262 | 0.259    | 0.063  | 5.245      | 0.007      | 27.837      |
| Built up       | -      | 7.026    | -      | 0.003      | -          | 7.029       |
| Forest         | 78.431 | 7.984    | 234.352| 298.7      | 2.814      | 622.281     |
| Vegetation     | 13.877 | 60.638   | 167.102| 139.227    | 4.107      | 384.951     |
| Water body     | 1.954  | 1.693    | 7.912  | 8.421      | 57.332     | 77.312      |
| Grand Total    | 116.523| 77.599   | 409.429| 451.596    | 64.261     | 1119.409    |

Area: $Km^2$

A simplified yet self-explanatory table is also derived from this, showing the rate of change assuming uniform rate through the years, which is shown in table 2. From this analysis, an increase of 70.5 sq.km in urban area, indicative of rapid urban growth in a span of 23 years of study period can be observed.

Table 2. Annual land use change rate

| Land use class | Land use 1995 | Land use 2018 | Annual rate of change (%) |
|----------------|---------------|---------------|---------------------------|
| Barren         | 27.837        | 116.523       | +9.65                     |
| Built up       | 7.029         | 77.599        | +30.42                    |
| Forest         | 622.281       | 409.429       | -1.03                     |
| Vegetation     | 384.951       | 451.596       | +0.525                    |
| Water body     | 77.312        | 64.261        | -0.512                    |

Figure 5 displays the schematic representations of hydrographs obtained from the model studies, which are compared with the actual observed discharge hydrograph. The numerical comparison is shown in Table 3. For identifying the sole impact of land use change on flood peak, the 1995 model is run with 2018 precipitation, keeping all other parameters intact. Due to the incessant rain and flooding, the observed discharge data on those flood-culminating periods were missing and hence the peak value. This may be the reason for the observed peak seems to be lower than the simulated one. From these results it is estimated that a reduction of 22.69% in peak discharge could have been made possible if the 1995 land use had been maintained as such in the following years too. Table 3 shows the numerical comparison of the different discharges.
Figure 5. Hydrograph from 1995 and 2018 model with 2018 weather data

Table 3. Comparison of discharges of 1995 and 2018 Hydrographs

| Date         | Discharge values in (m³/s) | Actual observed discharge (2108) | Difference in peak |
|--------------|----------------------------|----------------------------------|-------------------|
|              | From 1995 model            | From 2018 model                  |                   |
| 03 - 08 - 1995 | 116.1                     | 206.21                           | 236.1             |
| 04 - 08 - 1995 | 245.6                     | 427.75                           | 222.5             |
| 05 - 08 - 1995 | 192.3                     | 328.95                           | 160.3             |
| 06 - 08 - 1995 | 48.2                      | 68.58                            | 96.16             |
| 07 - 08 - 1995 | 81.3                      | 115.65                           | 115.7             |
| 08 - 08 - 1995 | 352.3                     | 435.74                           | 409.3             |
| 09 - 08 - 1995 | 866.6                     | 1071.26                          | 1046              |
| 10 - 08 - 1995 | 1218.4                    | 1618.63                          | 1038              |
| 11 - 08 - 1995 | 873.4                     | 1239.47                          | 570.7             |
| 12 - 08 - 1995 | 303.0                     | 445.73                           | 407.6             |
| 13 - 08 - 1995 | 35208                     | 459.32                           | 642               |
| 14 - 08 - 1995 | 687.7                     | 901.41                           | 777.5             |
| 15 - 08 - 1995 | 1121.1                    | 1575.17                          | 1589              |
| 16 - 08 - 1995 | 2397.6                    | 3381.06                          | 4631              |
| 17 - 08 - 1995 | 3597.9                    | 5417.78                          | 4654              | 22.69 %
| 18 - 08 - 1995 | 3351.0                    | 4322.17                          | 3047              |
| 19 - 08 - 1995 | 1635.8                    | 3253.64                          | 2564              |
| 20 - 08 - 1995 | 1392.6                    | 2103.36                          | 1821              |
| 21 - 08 - 1995 | 1797.3                    | 421.07                           | 1590.2            |
| 22 - 08 - 1995 | 1113.0                    | 844.14                           | 675.9             |
5. Conclusion
From the land use change matrix generated for the Chalakudy river basin, a drastic increase of about ten fold in the urban area is identified which has occurred over a short span of last 23 years. 2018 flood was modeled using 1995 land use and a reduction in peak by 22.69% is observed. The calamities due to the 2018 flood, which was the greatest of all occurred in last 100 years, could have reduced to a minimum, if the LULC had not been changed to this extent. Hence this study gives an insight into the adverse effect of unplanned urbanization on flood peak and thereby on the possible increase in the inundation area. More than the abnormally high rainfall, the unprecedented flood and the consequent calamities were caused due to the unscrupulous developmental but anthropogenic activities of urbanization, which could have been regulated or controlled to a great extent by the implementation of proper rules and regulations by the administrative authorities.

6. Reference
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