# URBAN FLOOD MODELING USING ARCSWAT: MANGALURU

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**Abstract -** *Detailed descriptions and models of the affected metropolitan areas are used to calculate and anticipate the impacts of urbanization on the hydrological procedure as well as water resources. The Water & Soil Analysis (ArcSWAT) model was chosen to test its applicability in the water-scarce city of Mangaluru, India. The primary aim of this project is to find out the rainfall simulation in Mangaluru city and find the flood zone for the study. The catchment area of Mangaluru city is immeasurable. Therefore, a regionalization approach was adopted to estimate the basin outlet flow. Validation and calibration of the SUFI-2 algorithm for the flow process using SWATCUP2012 was performed monthly. The model has been evaluated along validated by comparing observed and simulated water fluxes from the outlet from 1991 to 2015 and 2015 to 2022, respectively. SWATCUP results show a good match among simulated along with observed flow. In summary, urban development can affect runoff, in the research area. Research shows that greater attention should be paid to flood prevention and management of water when planning future urban growth in the region.*

***Key Words***: **Urbanization, ArcSWAT, SWAT CUP, Calibration, Validation**

## 1.INTRODUCTION

Urban watershed hydrology or hydrological procedures in the urbanized watersheds is one of the various sub-branches of hydrological science that has become clearly important in recent years. As per the WMO (World Meteorological Organization), floods are the third largest catastrophic event in history. According to the Federal Emergency Management Agency (FEMA), flooding is defined as dry land being covered by water.

Urban flooding occurs when surface runoff exceeds the capacity of municipal water systems (Nie, 2014). As the impermeable surface increases due to urban development and climate change, floods also increase. The risk of floods is rising because of the effects of urbanization as well as changes in climate. Urban climate increases resulting from changes in land use in urban areas have a negative impact on urban residents and infrastructure. Impacts include destruction of habitats and variations in the quality & quantity of precipitation, leading to alterations in water quality (Jacobson, 2011).

According to statistics, since 2009, over half of all people on Earth have made the transition to city living, marking a milestone in human history. Furthermore, population forecasts indicate that by 2030, growth and migration, particularly in large cities and wealthy nations, would push the urban population to over 80% of the overall population. Population growth and urbanization cause environmental impacts and often affect the sustainability of water resources (Ermias Sisay, 2017).

Urban flood research has been conducted worldwide for many years and results in a wide range of mathematical tools, both free and proprietary. Graphical user interfaces (GUIs) have made it possible for programs like SWAT, SWMM, HEC-RAS, HEC-HMS, MIKE FLOOD, etc. Urban flood modelling software such as has also become widespread. The outputs that can be produced by software have become increasingly easier to understand. GIS software such as QGIS and ArcGIS makes it easy to capture and enter data directly into the model. (Vinay Ashok Rangari, 2020).

This study's main objective is to determine the rainfall-runoff simulation in Mangaluru city using ArcSWAT. SWAT, is a computer-friendly hydrological model utilized to simulate the flow of water in rivers. An interface among ArcGIS and the SWAT framework has been employed recently: ArcSWAT, a third-party software extension for ArcGIS.

## 2. MATERIAL AND METHOD

### 2.1 Description of Study Area

Mangaluru is the capital of Dakshina Kannada district and the main port city of Karnataka, known as the gateway to Karnataka. It is the fourth largest city in the state. It is located at 12°52' latitude and 74°53' longitude. The city is situated on the country's west coast. It borders the state of Kerala to the south, Udupi district to the north, Bantwal taluk to the east and the Arabian Sea to the west. The Western Ghats spread to the city of Mangalore on the eastern side. It is found in the backwaters formed by the Gurupura River and Netravati River. The total area of Mangalore district is 30,600 hectares. The city's jurisdiction covers an area of 12,877 hectares.

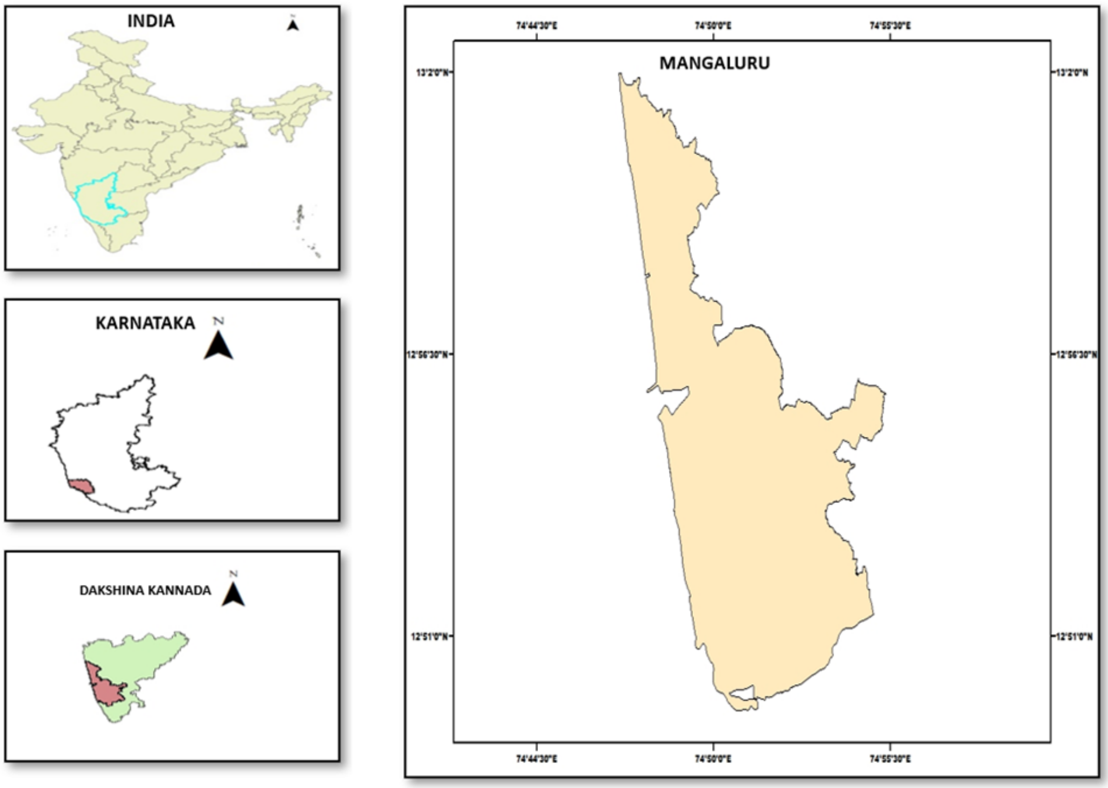


**Fig-1:** Study Area

## 2.2 Data collection

a. Rainfall data: For 30 years (1991–2022) is gathered from Karnataka State Natural Disaster Monitoring Center, Karnataka.

b. Image data: DEM is a raster file containing units or arrays of pixels with height. Topography has been explained by a DEM, which explains the location elevation in an area at spatial resolution. For this project, DEM with 30m x 30m resolution has been downloaded from ISRO Bhuvan, cartosat-1. It was prepared for coordination purposes (WGS 1984 UTM Zone 43 N) and was made using water resources in a GIS environment. The fig-2 shows the DEM of the Mangaluru.

c. Land "use/cover (LULC): The map of land use is obtained by the processing of satellite Landsat 8 image of 2022 which has a spatial resolution of" 30m.

d. Soil data: The soil has been attained in land as well as soil use survey of India. Which was to the scale of 1:50,000.

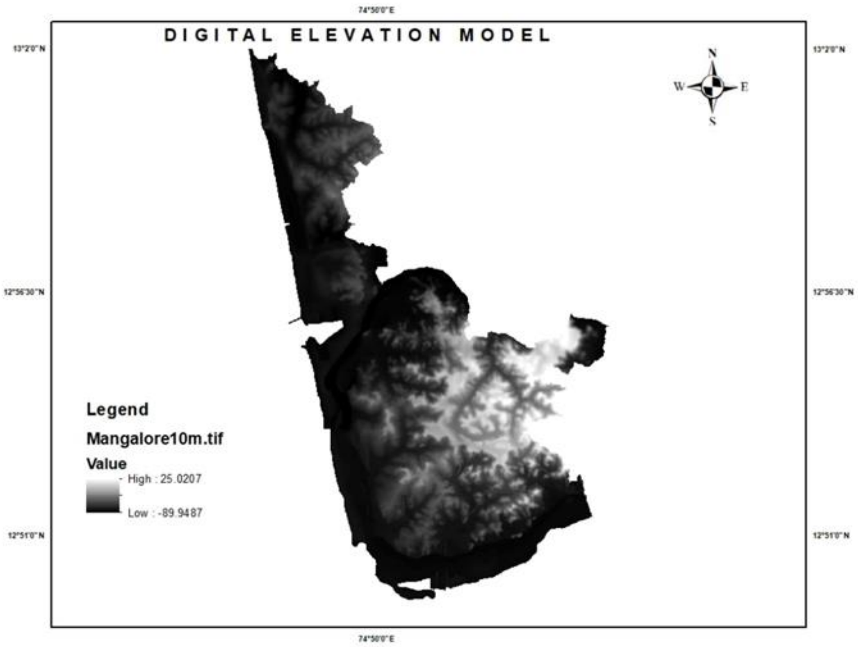


**Fig-2:** Digital Elevation Model of Mangaluru

### 2.3 Model description

According to "Arnold et al. (1998), the SWAT model is also termed the the soil and water assessment tool, which has been a semi-distributed watershed model with" an interface of GIS which utilizes the meteorological, land, and soil use data to calculate daily water balance as well as delineate stream networks as well as sub-basins using a DEM ("Digital Elevation Model"). The SWAT model used information from weather, land, and soil use maps, among other sources, to simulate runoff volume along with sediment production (Neitsch et "al. 2005; Haverkamp et al. 2005). The hydrological cycle is simulated by the SWAT model by utilizing the subsequent water balance" eqn 1.

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{Swep} - W_{gw}) \ldots \ldots 1$$

where,

| | |
|---|---|
| "$SW_t$ | final water content in (mm) |
| $Q_{surf}$ | runoff amount on specific days in (mm) |
| $R_{day}$ | precipitation amount on specific days in (mm) |
| $E_a$ | evapotranspiration amount on day in (mm) |
| $W_{gw}$ | return the amount of flow on a day in (mm) |
| $W_{sweep}$ | amount of water percolated into the vadose zones on a day in (mm)" |

Two techniques for forecasting extreme (excessive) precipitation are suggested by the SWAT model. The SCS curve number approach is the first of these, and the Green as well as Ampt penetration equation is the second (Arnold et al., 2012). In 1972, the US Soil Conservation Service (SCS) created the count curve. Equation 2 uses the SCS approach to calculate the overall daily runoff depth or daily excess rainfall (mm).

$Q_{surf}$ has been predicted by eqns

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)^2} \dots\dots\dots\dots\dots\dots.2$$

where,

| | |
|---|---|
| $Q_{surf}$ | "accumulated runoff or rainfall excess (mm) |
| $R_{day}$ | rainfall depth for the day (mm) |
| S | retention parameter (mm)" |

The retention parameter fluctuates both temporally because of the variations in soil water content and spatially because of variations in land use, management, slope, and soil types. Equation 3 defines the retention parameter.
This will be calculated by:

$$S = 25.4\left(\frac{100}{CN} - 10\right) \dots\dots\dots\dots\dots\dots..3$$

### 2.4 Calibration and validation

The statistical model's prediction accuracy is measured by the coefficient of determination ($R^2$). The SD is used to illustrate the results. $R^2$ has a max. value of 1 and a minimum value of 0. It is the percentage of variance that the model can account for. Finding out whether the $R^2$ is high or low can typically be determined by plotting a linear regression profile. $R^2$ indicates how much "of the variance in the calculated data the model can account for. As per Santhi et al. (2001) and Van Liew et al. (2003)", values higher in comparison to 0.5 are typically regarded as acceptable. R2 values range from 0 - 1, with the greater values depicting the smaller changes.

The size of the variance of the residual, or "noise," related to the variance of the measured data, or "data," is determined utilizing the NSE ("Nash-Sutcliffe efficiency") statistic (Nash and Sutcliffe, 1970). The observed plot as well as the simulated data's fit to the 1:1 line has been depicted by the NSE. Equation 4 illustrates how NSE is "calculated.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i-1}^{n}(Y_i^{obs} - Y^{mean})^2}\right] \dots\dots.4$$

In this case, n represents the total number of observations, $Y_{mean}$ represents" the observed data mean, and, $Y_i^{Obs}$ represents the $i^{th}$ observation for the constituent subject to evaluation.

According to several studies (Singh et al., 2004; Chu and Shirmhammadi, 2004; Vasquez-Amábile and Engel, 2005), RMSE has been among the most widely used statistical error measures. Guidelines for qualifying for a lower RMSE have only been published as an evaluation of various models, despite the widespread agreement that the better the model, the lower the RMSE (Singh et al., 2004). A measurement model named RMSE-based standard deviation (RSR) has been performed in accordance with the suggestions made by Singh et al. (2004). Using the observational standard deviation, RSR normalizes RMSE and accounts for measurement error. Equation 5 illustrates how to compute RSR, which is the product of the measured data's standard deviation and RMSE.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}\right]} \dots\dots.5$$

As per Gupta et al. (1999), percentage bias (PBIAS) quantifies the average propensity of simulated data to differ from observed data by a certain amount. Smaller values of PBIAS depicted more accurate simulation models; 0.0 is the ideal value. Positive outcomes suggest that the model is biased toward underestimation, whereas negative outcomes suggest that the model is biased toward overestimation (Gupta et al., 1999). The equation is used to calculate PBIAS. where PBIAS, given as a percentage, is the deviation of the data under evaluation.

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * 100}{\sum_{i-1}^{n}(Y_i^{obs})}\right] \ldots\ldots\ldots.6$$

Where, n -number of observations at the time of the period of simulation, $Y_i^{sim}$ - simulated flow value with the respected time, $Y_i^{obs}$ - Observed flow data.

## 3. RESULT AND DISCUSSION

### 3.1 Watershed delineation

Automatic watershed identification using ArcSWAT, which uses DEMs to perform digital terrain analysis, calculate slopes, and stream lengths, and identify watershed boundaries and water networks in Mangaluru city. The basin of Mangaluru city is divided into 96 sub-basins with 49 outlets. As can be seen from the table above, sub-basin No. 1, sub-basin No. 64 is the largest sub-basin with an area of 377.36 hectares. 72 is the smallest with an area of 5.10 hectares. Fig 3 depicts the watershed of the Mangaluru city.

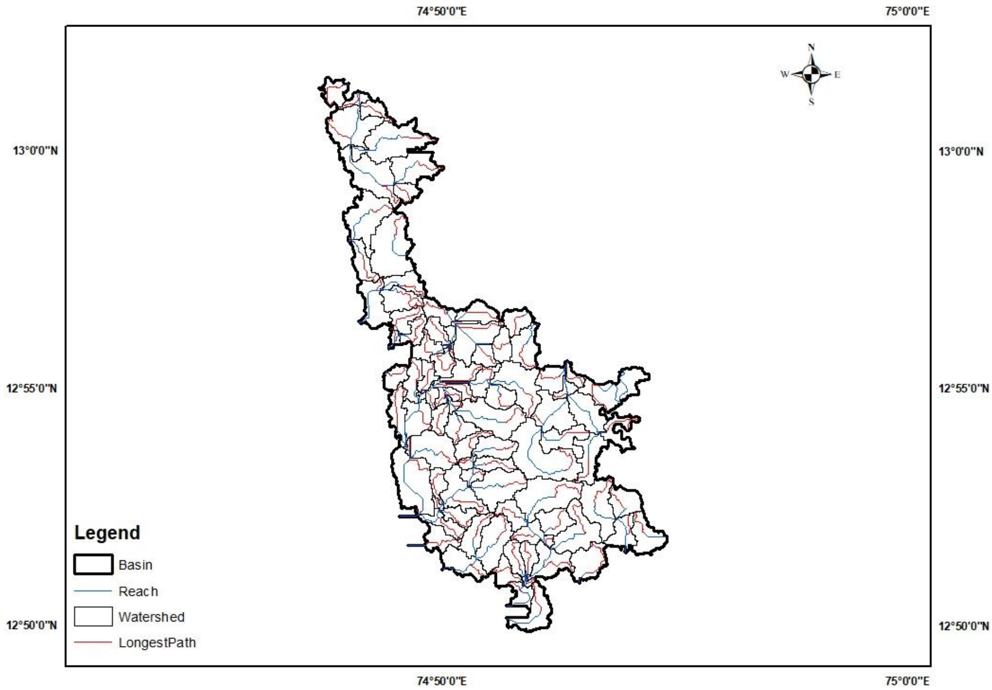


**Fig-3**: Watershed Deliniation of Mangaluru

### 3.2 Land use and landcover

In the HRU analysis step, data on land use is utilized as a separate GIS layer (either vector or raster) that has been reclassified by utilizing ArcSWAT. Where the land use consists of built-up areas, agricultural land, mud flats, water bodies, tree clade areas, wastelands, and wetlands. The area of each land and the percentage of area covered is mentioned in Table 1. Figure 4 represents the LULC of the city. Has the city is developing day by day, the rate of urbanization is also getting increased, and the percentage of the imperviousness of each subbasin can be noticed. More than 50 percent of the area are having a percentage of imperviousness greater than 55%. We know that an increase in the percentage of imperviousness is equal to a rise in runoff. This demonstrates clearly that there is a high probability of rainfall converting to runoff with greater peaks and larger volumes of flood. The LULC map for 2022 is displayed in Figure 4.

**Table no: 1 Percentage of different areas covered in Mangalore city.**

| Particular | Percentage of area covered (%) |
|---|---|
| Built-Up | 62.96 |
| Agricultural Land | 13.18 |
| Tree Clade | 6.86 |
| Water Bodies | 12.72 |
| Waste Land | 3.46 |
| Wetland | 0.77 |
| Others | 0.011 |

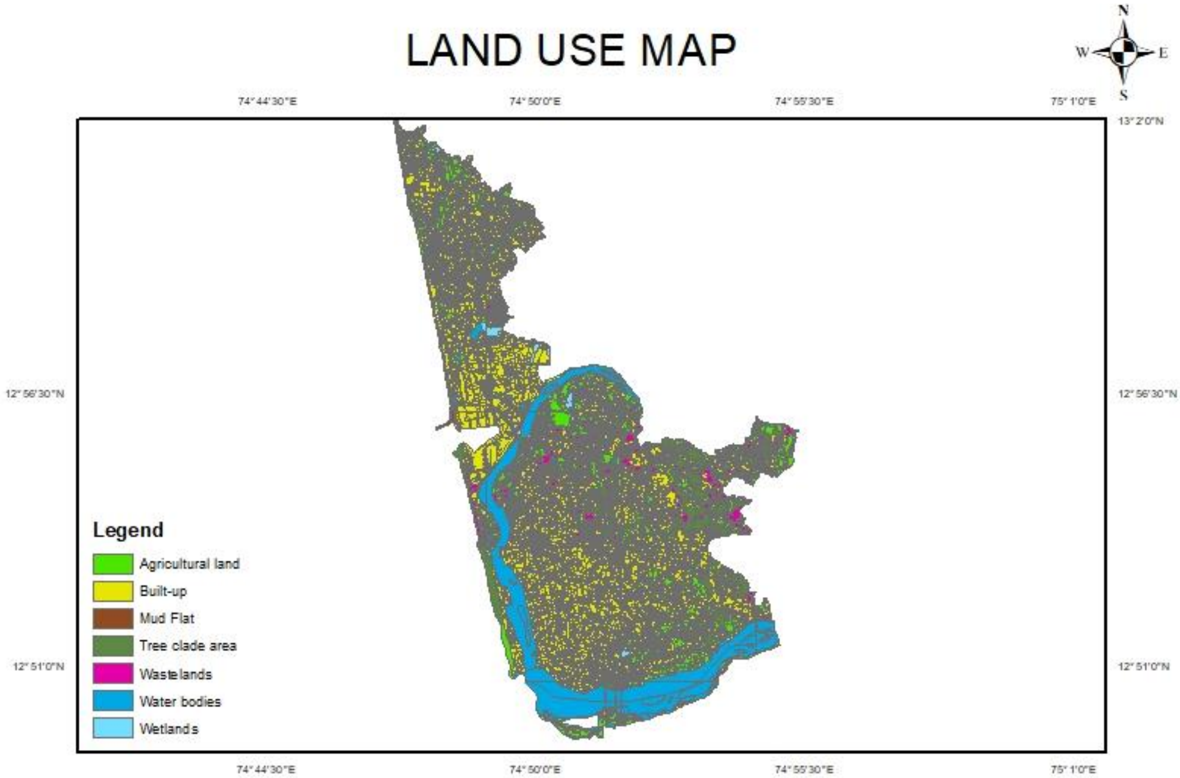


**Fig-4:** Land use Land Cover of Mangaluru city

Has the city is developing day by day, the rate of urbanization is also increasing, from Table 1. The percentage of the imperviousness of each subbasin can be noticed. More than 50 percent of subbasins have a percentage of imperviousness greater than 55%. We know that an increase in the percentage of imperviousness is equal to a rise in runoff. This depicts clearly that there has been a greater probability of conversion from rainfall to runoff with greater peaks as well as higher flood volumes. Fig 4 shows the LULC map of the year 2020.

**Soil texture:**

From the ArcSWAT model, after reclassifying the soil map the types of soil that are available in Mangaluru city are determined. The 3 main soil types have been identified on the soil map as sandy clay loam, sandy loam, and clay loam. The percentage of area that each soil type covers and soil texture are described below. Fig 5 depicts the soil types of the Managluru city

**Table:2 Soil group classification of Mangaluru city**

| Sl no | Soil Group | Hydrological soil group | Percentage of area covered |
|---|---|---|---|
| 1 | Sandy loam | A | 72.34 |
| 2 | Sandy clay loam | C | 18.99 |
| 3 | Clay loam | D | 8.67 |

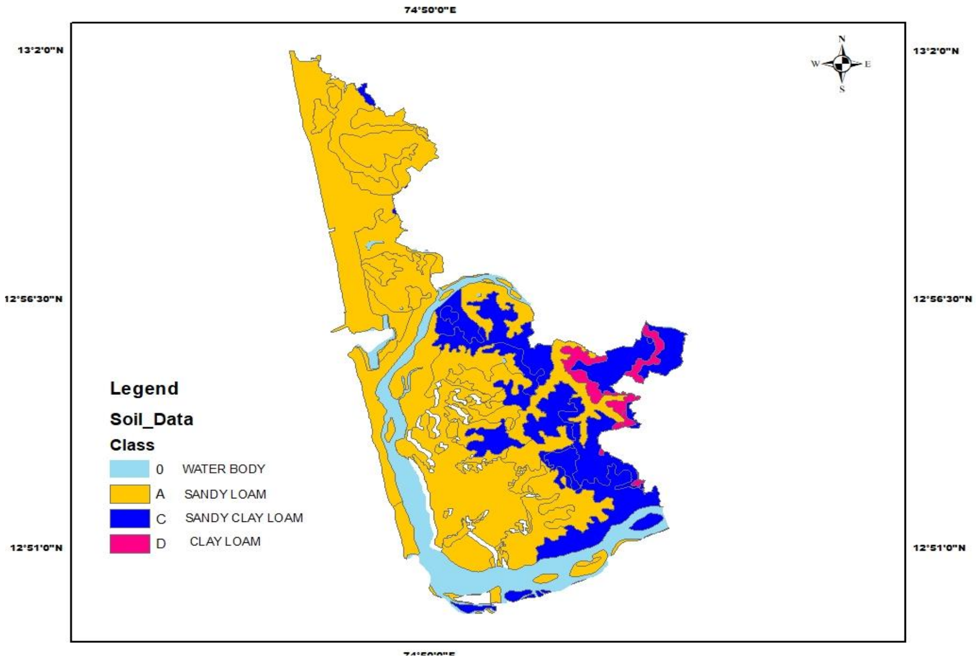


**Fig-5:** Soil Classification of Mangaluru city

### 3.4 Model calibration and validation

The accuracy of the measurement model had been evaluated and can be used by sending flow data from the basin to the area of interest for the period 1990-2015 and 2016-2022, respectively, for measurement. The evaluation was performed using multiple regression analysis using Sequential Uncertainty Adaptation-2 (SUFI-2). While the R2 value was 0.75 in the calibration period (1993 - 2015), NSE was 0.53 in the monthly flow calibration in the same period. As shown in Table 3, the RSR value is 0.70 and the percentage difference (PBIAAS) is 4.0%.

Conversely, the R2 (coefficient of determination) value of the verification process results for the 2016-2022 period is 0.74. However, in the same period, the monthly output NSE value of the basin was 0.57, RSR (Reason for Standardization Analysis) was 0.69, and PBIAS (Percent Deviation) was 6.2% as shown in Table 3.

**Table:3 Summary of model performance for calibration and validation period**

| Year | "Period | Evaluation of Statics of Parameters | | | | | |
|---|---|---|---|---|---|---|---|
| | | NSE | $R^2$ | PBIAS | *p*-factor | *r*-factor | RSR |
| 1990-2015 | Calibration | 0.53 | 0.75 | 4.0 | 0.69 | 0.52 | 0.70 |
| 2016-2022 | Validation | 0.57 | 0.74 | 6.2 | 0.63 | 0.67 | 0.69" |

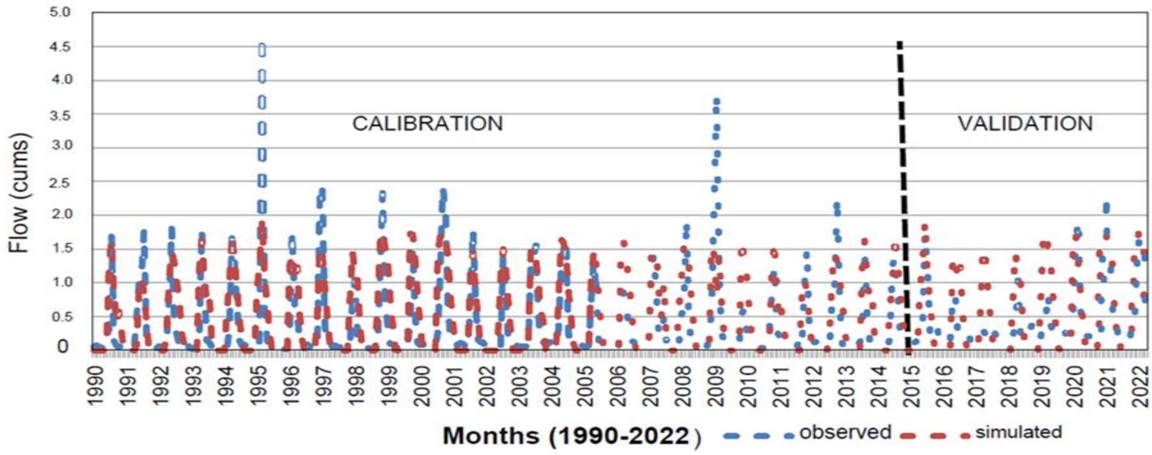


**Fig-6**: Graph showing the observed and simulated flow of Mangaluru city

### 3.5 Flood index map

Different features of the water balance of the Deme basin have been found by utilizing a calibrated as well as validated SWAT model. A flood map was created using ArcMap by analyzing overlap using average curve counts, runoff, and precipitation. The results showed that the area was divided into 3 areas: high flood area, medium flood area, and lower flood area. Analyzing the overlap between peak discharges for each completed basin in ArcMap shows that many subbasins have one final flow. The map shows that Kottara Chowki, Kodialguthu, PVS, Attavar, Ekkur, Kadri Kambala Adyar, Panjimogeru, Alake, Bykpady industrial area, and Thokkottu are flood-prone areas, and are at risk of major floods. Fig 7 below shows the flood zone in Mangaluru city. Major floods include commercial areas, residential areas, and some major cities.

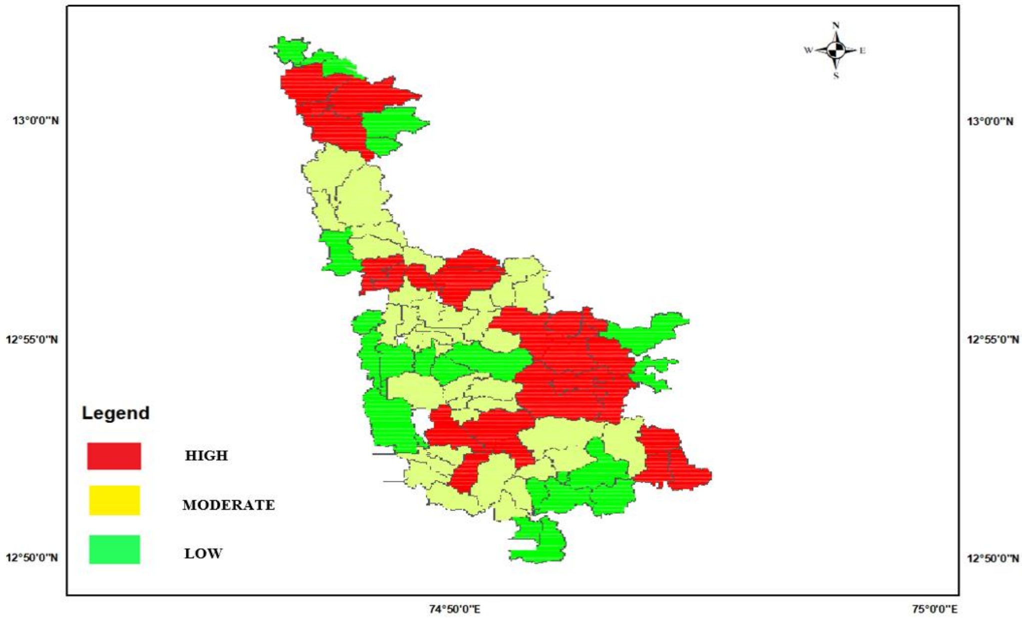


**Fig-7:** Flood index map of Mangaluru city

## 4. CONCLUSIONS

**The current study allows for the drawing of the following conclusions:**

- A supervised classification algorithm was used to generate a map of land use for the area from the image of the satellite. Since 62.96% of the region's land is used for land use, there is a corresponding increase in the percentage of impervious surface.

- The normal discharge pattern has been shown to be similar to the observed discharge. The correlation coefficient (R2) is 0.74, depicting a good relationship among observed as well as simulated flows.
- Some key areas at moderate to high flood risk can be easily identified from the flood risk map and Google Earth projections. Therefore, these areas require immediate attention at the time of the floods and should be given the highest priority. The security as well as risk map thus created could be utilized for future development planning.
- It has been shown that SWAT is an effective tool for simulating flood hydrographs at specific locations. This study provides further information on flood forecasting and analysis for hydrological modeling, hydrodynamic modeling, and flood control strategies.

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