2018 India SWAT Conference

# Integrating urban growth predictions and climate change for hydrologic assessment in Chennai basin

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# Background

- Land use and land-cover changes strongly affect water resources. *(Wagner et al. 2011)*

- Particularly in regions that experience seasonal water scarcity, land use scenario assessments provide a **valuable basis for the evaluation of possible future water shortages**

- Changes in land use and land-cover have been identified as a major research focus for this century as they alter hydrologic processes such as **infiltration, ground water recharge, evapotranspiration and runoff, and affect water quality** (*DeFries and Eshleman, 2004)*

# Background

- Land use change has a large potential to exacerbate water scarcity *(Wagner et al. 2011)*

- This is the case in parts of India especially **Chennai basin**, where rapid socioeconomic development and urbanization have caused **major land use change in the past and further impacts** are to be **expected in the future** *(DeFries and Pandey, 2010; Döös, 2002; Lambin et al., 2003).*

## Under this background, the objective of this study is

- To assess **the Land Use and Land Cover (LULC)** change in Chennai basin using Remote sensing imageries.

- To predict **the future Land Use and Land Cover (LULC)** through Cellular Automata algorithm using **SLEUTH model.**

- To assess **the impact of climate variability under projected Land use and Land cover (LULC)** change on ***hydrological components*** *under A1B scenario.*

# Urban Growth Models

| S .NO | URBAN GROWTH MODELS | ADVANTAGES | DISADVANTAGES |
|---|---|---|---|
| 1 | Empirical Statistical Model | Study is more accurate | Useful for short term prediction only |
| 2 | Stochastic Model | It is required to know when and how much change in the future will take place | It is similar to empirical model and have higher uncertainties |
| 3 | Optimization Model | Sustainable land allocation and optimal utilization of land can be done | Optimization results may vary according to the non optimal behaviour |
| 4 | Dynamic Process Based Model | More reliable and very good to produce long term predictions | The scale issue is difficult to deal |
| 5 | Cellular Automata Model | • Able to incorporate multiple growth rules<br>• Able to produce spatio temporal effect<br>• Able to produce land use for a complex region | Time consuming process |
| 6 | Integrated Model | Able to incorporate multiple modelling approaches so the system become more efficient | Quite complicated to deal with different modelling approaches at the same time in the same system |

*(Source: LULC Cover Change Detection Models and Methods, GIAN manual )*

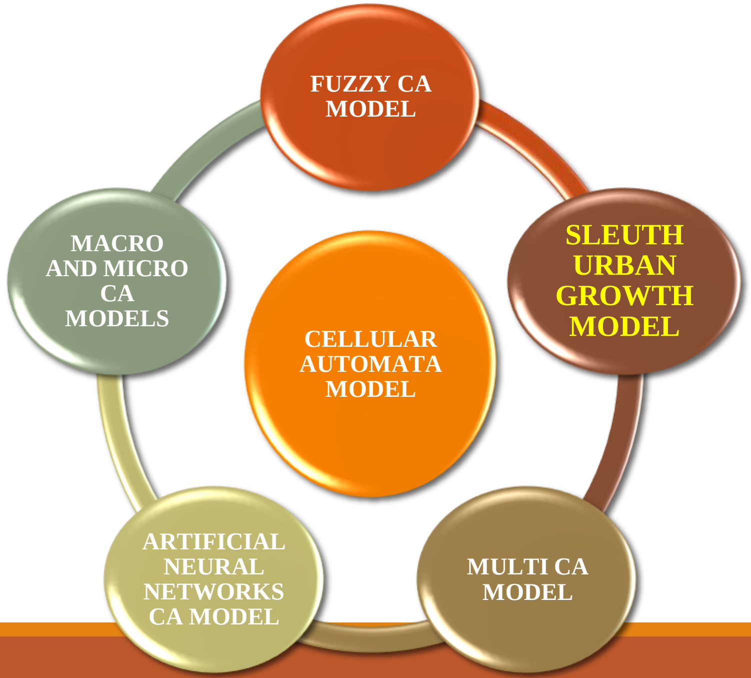
# CELLULAR AUTOMATA

- Cellular Automata (CA) models can play a significant role in simulation and modeling of real world urban processes **(Sakieh et al., 2014)**

- CA model can able to produce land use change for a complex region

- Can produce long term prediction

**TYPES OF CA MODEL**



# SLEUTH

| | |
|---|---|
| S | SLOPE |
| L | LANDUSE |
| E | EXCLUSION |
| U | URBAN EXTENT |
| T | TRANSPORTATION |
| H | HILLSHADE |

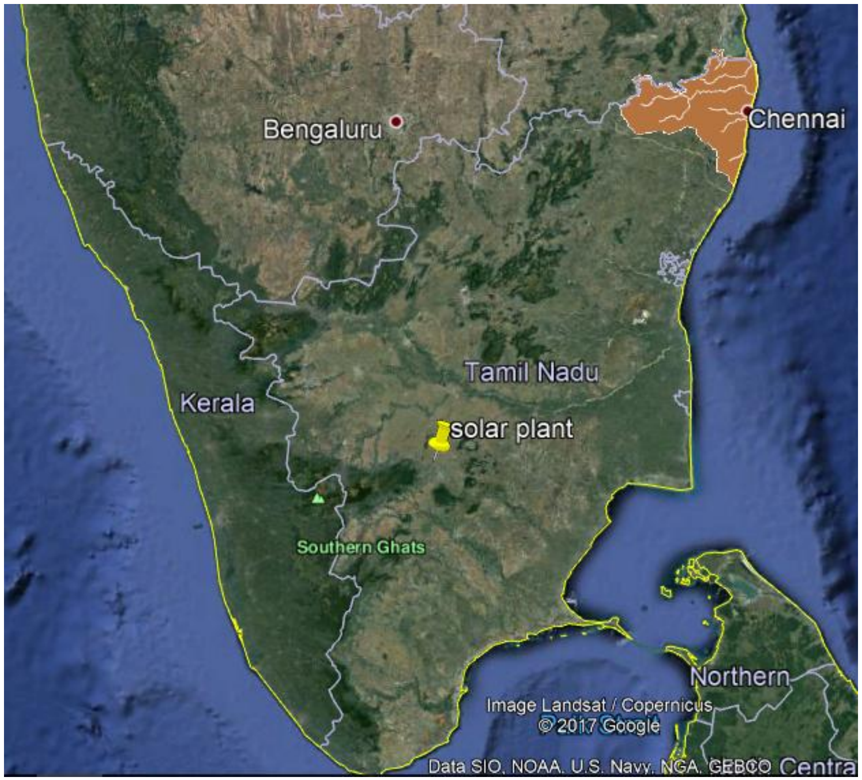
# Combined Land use and climate change

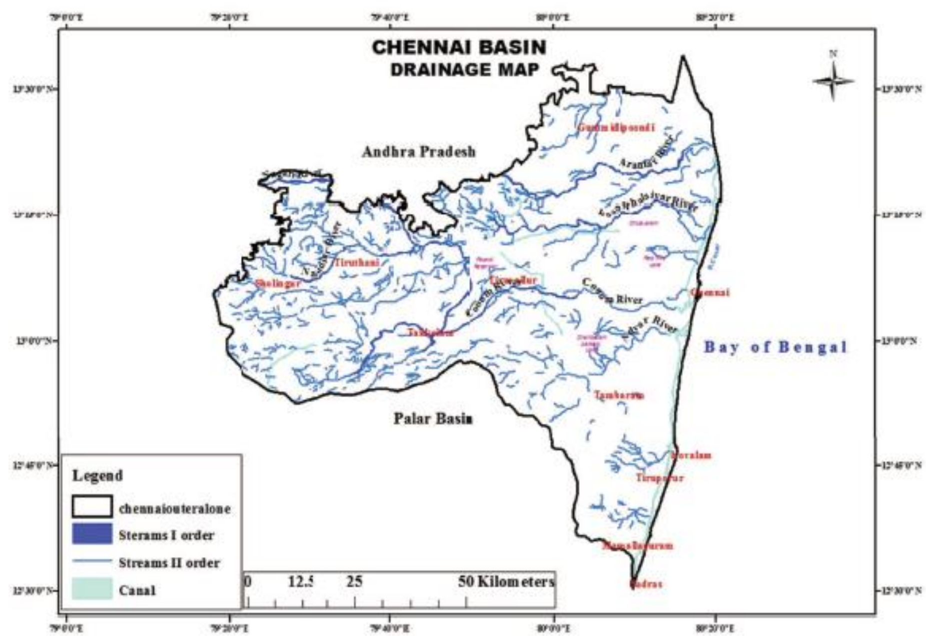
**Anushiya *et al., 2015***, *studied the changes in water balance* components of the Chennai basin under present and future climate scenarios using Soil Water Assessment Tool (SWAT).

Many studies have evaluated the effect of either urbanization (**Chang 2007; Yang *et al., 2010***) *or climate changes* (***Woldeamlak et al.*, 2007; Sanchez G *et al., 2009***) *on watershed runoff;*

*The combined* effects of these two effects using simulation models have been coming under increased scrutiny in recent years **( Cuo *et al., 2009; Srinivasan V et al.*, 2013).**

# CHENNAI BASIN




(Source: IWS, Tharamani)

# METHODOLOGY

- Identification of LANDSAT cloud free satellite imageries
  - Supervised classification using ERDAS IMAGINE
  - Landuse classified image 2000, 2008, 2010 qnd 2016
  - LULC change
- Preparation of input layers (SLEUTH)
  - **Slope** – SRTM DEM (90 x90 m)
  - **Landuse** - Classified image from LANDSAT (30 x30 m)
  - **Excluded** – Waterbodies from LULC
  - **Urban extent** – Built up area from LULC
  - **Transportations** – Open street maps
  - **Hillsahde** – DEM ( 90 x 90 m)
  - Calibration phase: Coarse , Fine and Final
  - Prediction phase
  - Projected LULC 2036
- Hydrological modelling (SWAT)
  - LULC 2016 + DEM + Soils from FAO
    - HRU
    - Weather data 2001 -2016
    - SWAT RUN
    - Hydrological components
  - LULC 2036 + DEM + Soils from FAO
    - HRU
    - MIROC 3.2 A1B scenario
    - SWAT RUN
    - Hydrological components
  - Comparison between 2016 and 2036

# FITTEST GLOBAL CLIMATE MODEL

| RMSD | CCCMA_ CGCM3.1 | CNRM_CM3 | GFDL_ CM2.0 | MIROC_3.2 | MRI_CGCM 2.3.2 | MIUB_ ECHO_G_ | MPI_ ECHAM5 | IPSL_ CM4 | LEAST OF RMSE |
|---|---|---|---|---|---|---|---|---|---|
| T-MAX | 0.948 | 0.942 | 0.953 | 0.686 | 0.833 | 0.813 | 1.061 | 1.492 | 0.686 |
| T-MIN | 1.862 | 1.817 | 1.654 | 1.633 | 1.819 | 1.852 | 1.882 | 2.136 | 1.633 |
| PPT | 496.458 | 433.654 | 493.3 | 417.181 | 437.557 | 384.783 | 505.64 | 600.3 | 384.7 |

# INFERENCES

1) Since there is an evident trend in T-Min and probable trend in T-Max, these two parameters are given priority in selecting the best GCM for the study area.

2) Also the model with highest possible resolution should be selected for greater degree of representation.

3) Hence MIROC_3.2 is chosen for climate change prediction.

# MIROC_3.2

Model sponsored from Japan.

MIROC_3.2 (Model for Interdisciplinary Research on Climate)

Atmospheric Resolution:
- T106 ( 120 km * 120 km) and **60 vertical levels**

Ocean Resolution:
- 0.28125 degree in longitude, 0.1875 degree in latitude, and 47 vertical levels

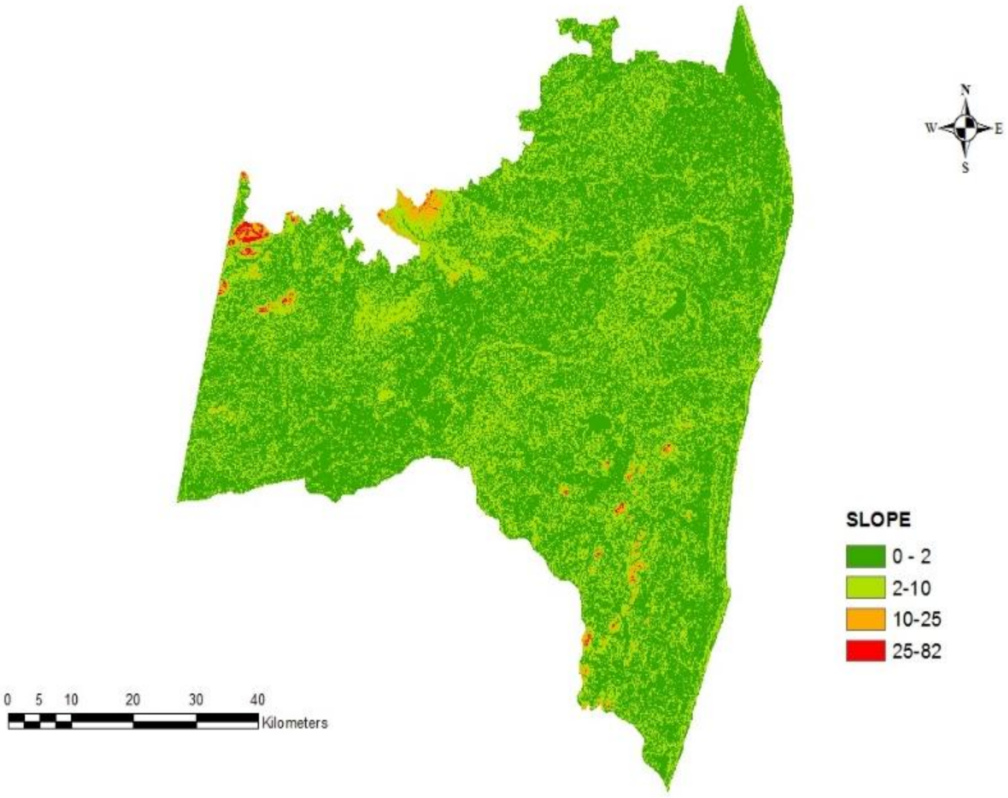
# DATA SET USED

| S.NO | DATA | SOURCE |
|---|---|---|
| 1 | Slope | DEM data<br>SRTM (90 x 90 m) |
| 2 | Land use map | LANDSAT image – (30 x 30 m )<br>OCT 2000- LANDSAT 7<br>MAY 2008- LANDSAT 5<br>OCT 2010- LANDSAT 5<br>MAY 2016- LANDSAT 8 |
| 3 | Excluded layer | Land use map - (30 x 30 m ) |
| 4 | Urban extent layer | Land use map - (30 x 30 m ) |
| 5 | Transportation layer | Open street view map |
| 6 | Hill shade layer | DEM data-<br>SRTM (90 x 90 m ) |
| 7 | Rainfall | IMD |
| 8 | Soil map | FAO |
| 9 | Climate data | MIROC 3.2 |

# INPUT LAYERS FOR SLEUTH MODEL

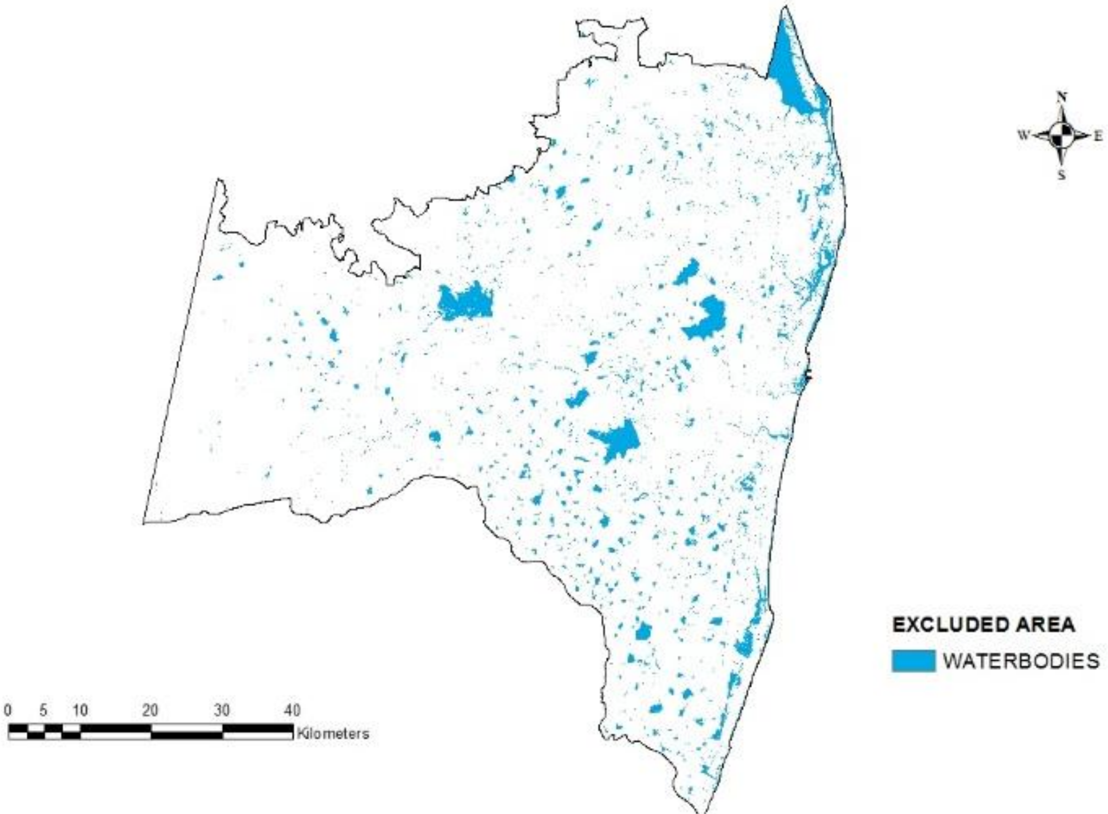
**Slope Layer**

- A slope layer of the study area was created from a Digital Elevation Model (DEM) which was developed from a SRTM-DEM ( 90 x 90 m) image.
- Slope value ranges from 2 to 80 % .
- Mostly study area comes under flat terrain category




**Slope layer**

# INPUT LAYERS FOR SLEUTH MODEL




Exclusion layer

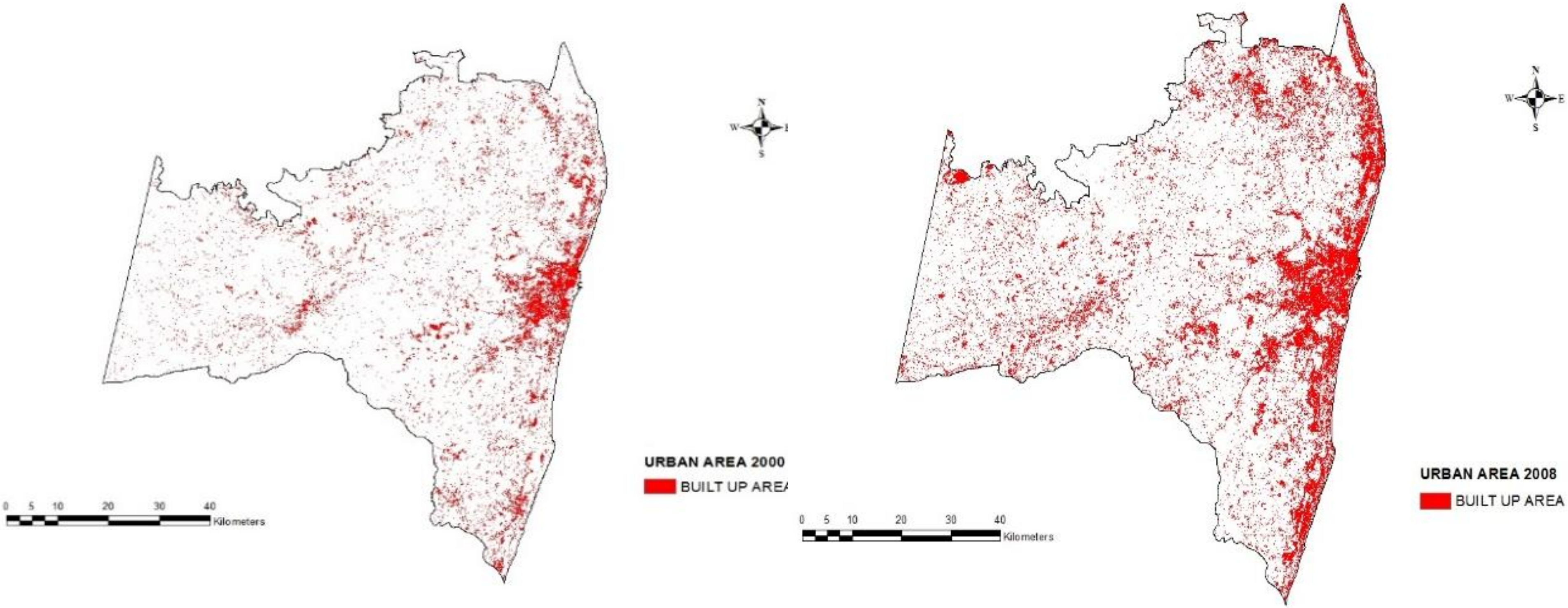
## Exclusion layer

- The exclusion map was created from the landuse layer.
- The excluded areas have a value of 1 and the areas available for urban development have a value of 0.
- In this study water bodies are considered as the excluded areas.

# INPUT LAYERS FOR SLEUTH MODEL

**Urban Extent layer**

- The urban extent for this study includes city/towns, institutional land, airport, rural residential land, and recreational land.




**2000**

**2008**

# INPUT LAYERS FOR SLEUTH MODEL

## Urban Extent layer

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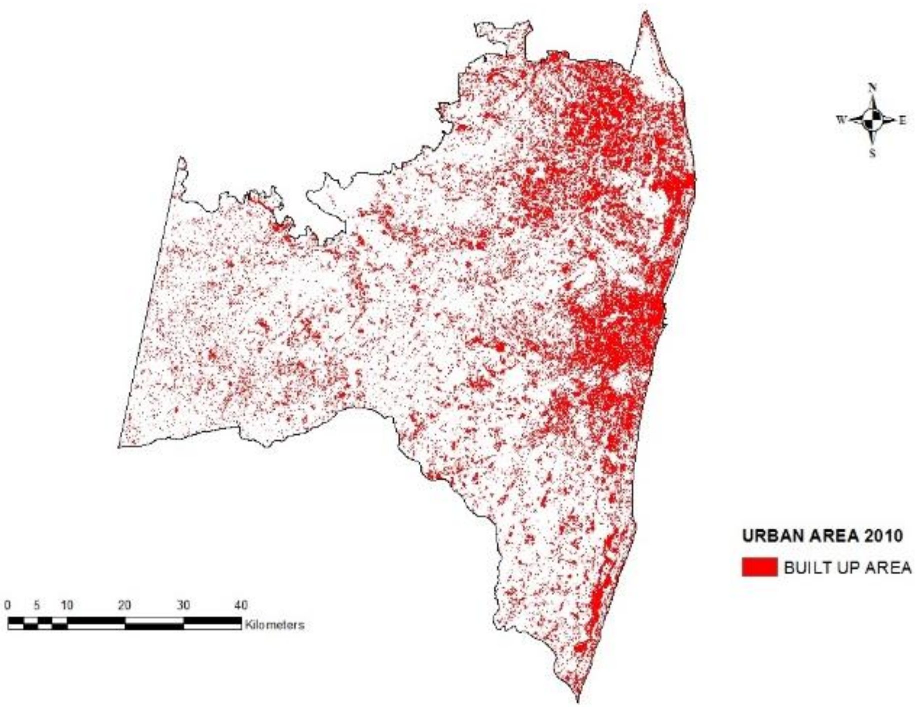
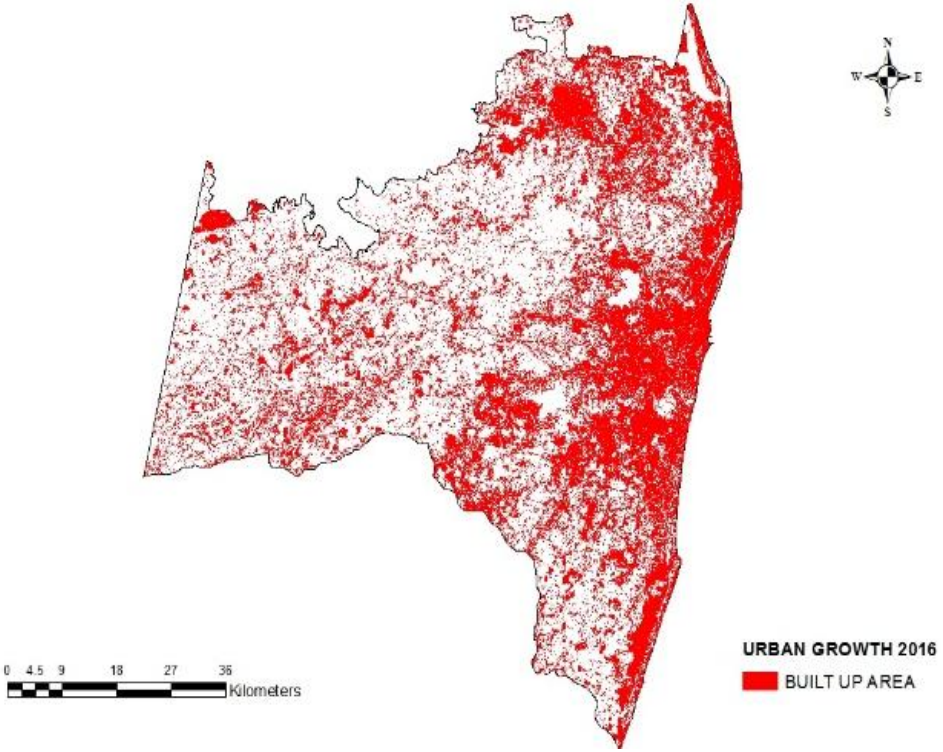


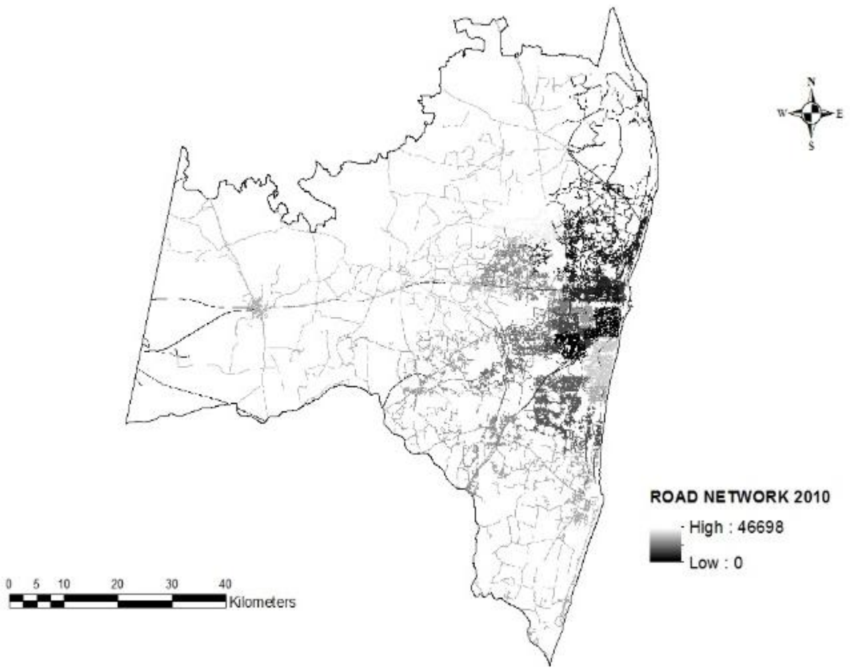

**2010**

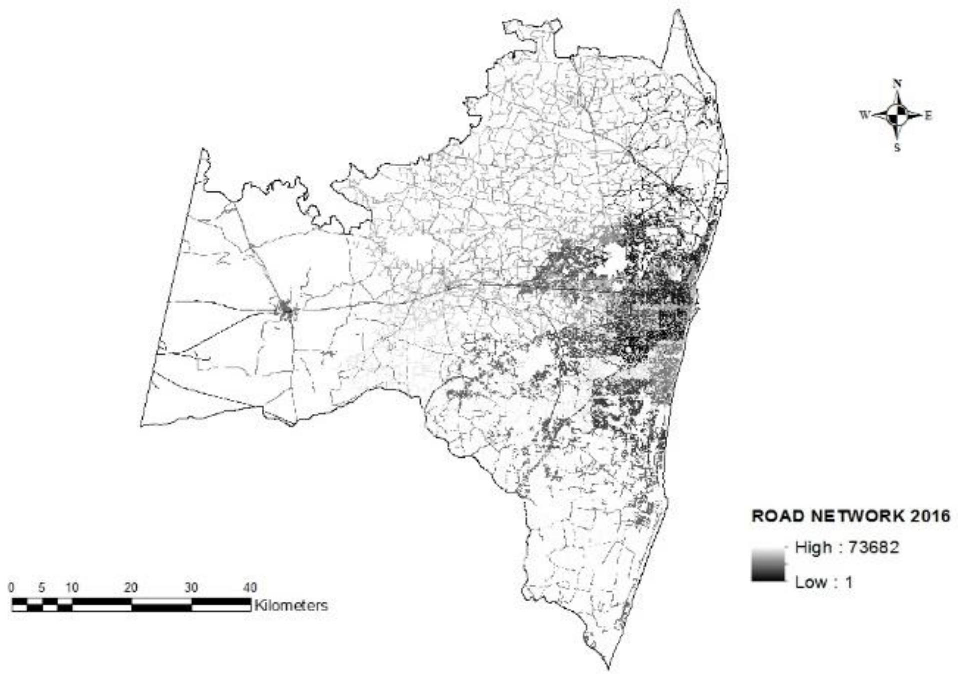
**2016**

# INPUT LAYERS FOR SLEUTH MODEL

## Transportation layer

- Open street maps has been used to create road network maps of Chennai basin



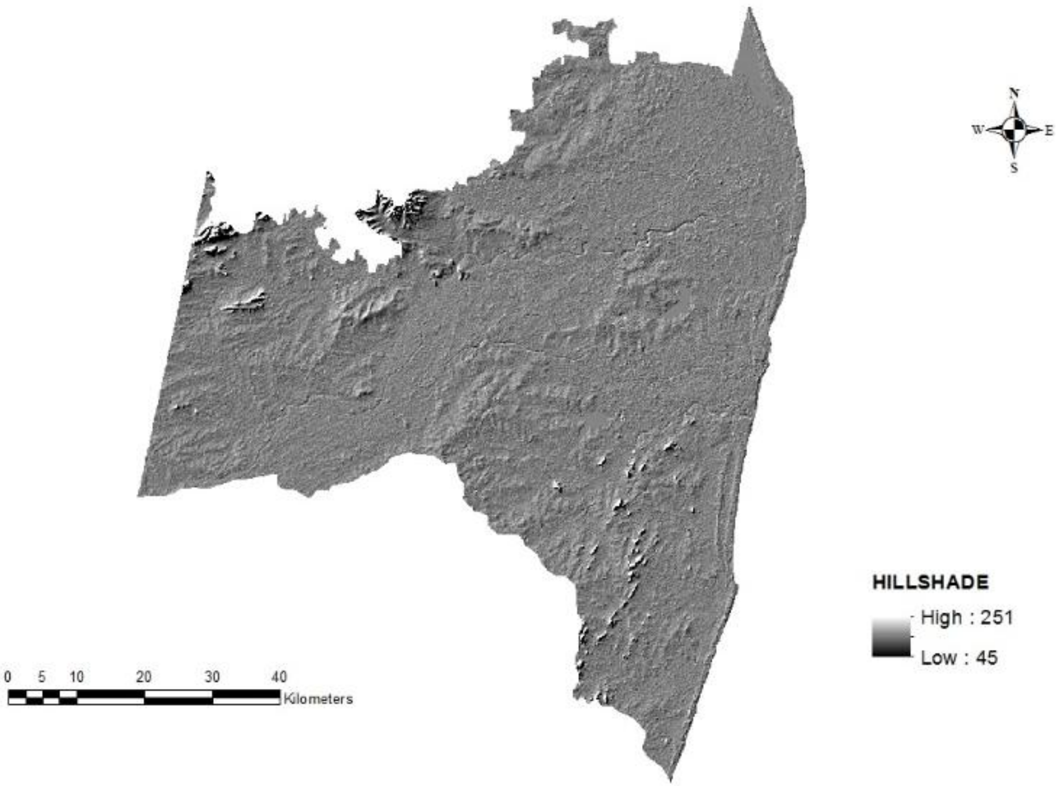




**2010**

**2016**

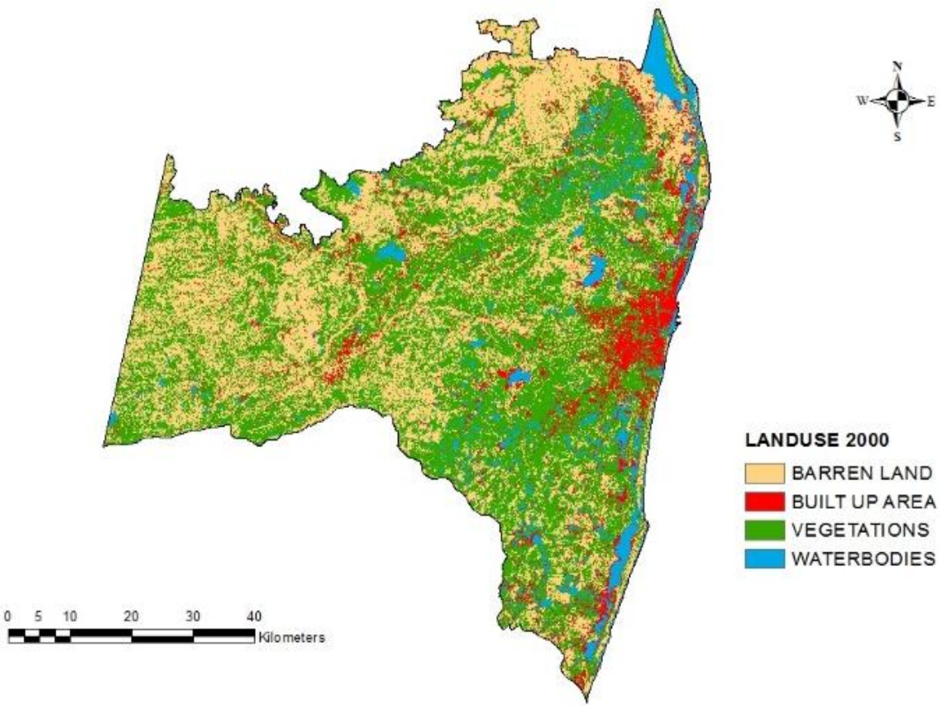
# INPUT LAYERS FOR SLEUTH MODEL

## Hillshade Layer

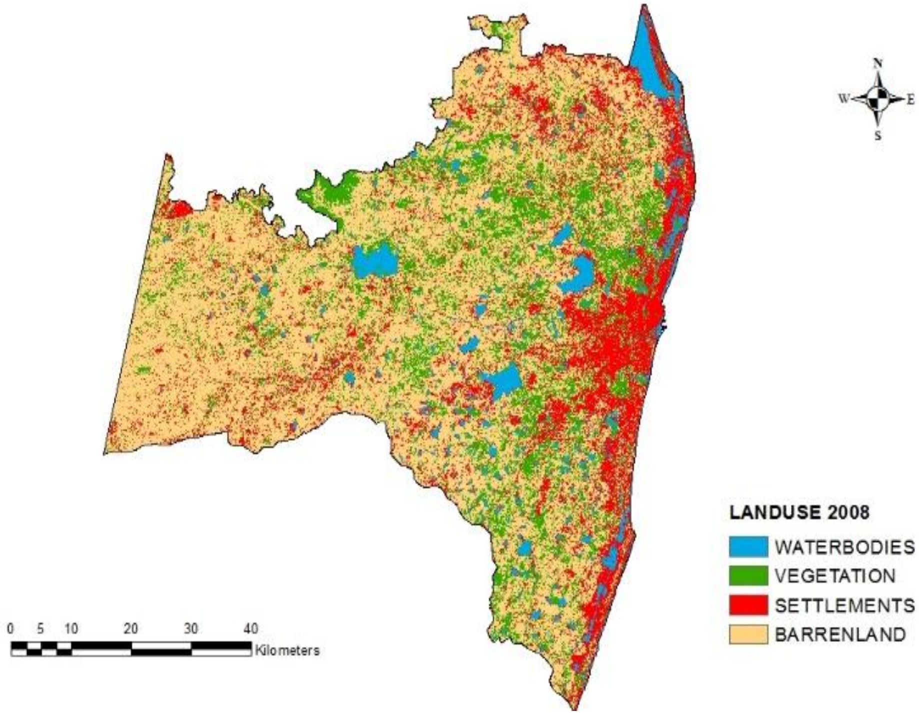



- **Hill shade** is a **shaded** relief on a map, just to indicate relative slopes, mountain ridges, not absolute height.
- Hill shade was created using SRTM – DEM ( 90 x 90 m)

# Land use Land cover maps of Chennai basin

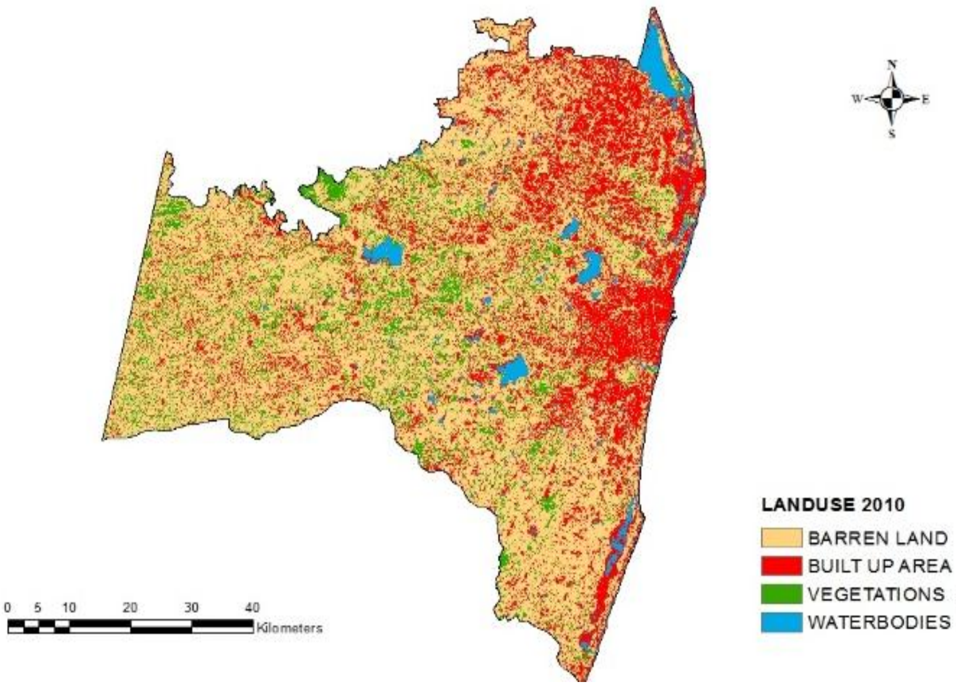



**2000**

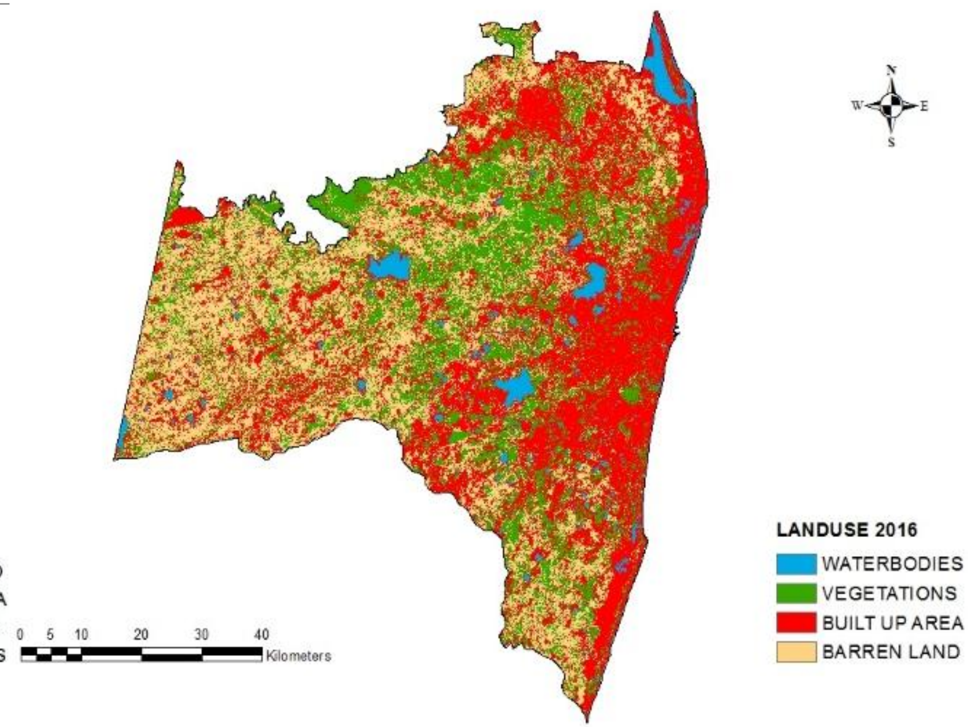



**2008**

# Land use Land cover maps of Chennai basin




2010




2016

**Land use Land cover maps of Chennai basin**

# Land use Land cover Change

LULC changes were estimated for the years **2000, 2008, 2010** and 2016 using LANDSAT series satellite imageries

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Supervised classification of the imageries were performed using maximum likelihood algorithm in ERDAS Imagine.

**Vegetation, Barren land, Built up area** and **Water bodies** are the Land use Land cover classes used for the classification

Reason for the LULC changes may be attributed to **rapid population growth, rural to urban migration, poverty and reclassification of rural to urban areas.**

It was found that some of the agricultural lands in the **North West part of the basin was rapidly changing to built-up areas due to urbanization**

# Land use Land cover Change

| CATEGORY (5474.89 km$^2$) | Land use and Land cover | | | | | | |
|---|---|---|---|---|---|---|---|
| | km$^2$ | | | | % | | |
| | 2000 (Base Year) | 2008 | 2010 | 2016 | 2008 | 2010 | 2016 |
| Barren Land | 2048.40 | 3062.40 | 2399.15 | 1668.01 | 49.51 | 17.14 | -18.54 |
| Vegetation | 2568.20 | 1077.14 | 1574.19 | 1472.06 | -58.04 | -73.72 | -42.68 |
| Built Up Area | 468.14 | 991.22 | 1310.38 | 2134.20 | 111.74 | 179.8 | 355.87 |
| Waterbodies | 390.14 | 342.12 | 189.16 | 199.61 | -12.13 | -51.4 | -48.75 |

# Land use Land cover Change

Considering the year 2000 as base year, Table 1 shows that there is rapid increase in the built up area class.

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**Vegetation and Water bodies have decreased considerably over the past decade**.

Built up area comprising human habitations developed for non-agricultural uses like building, transport and communications is largely broadened from **468.14 $km^2$ (2000) to 2134.20 $km^2$ (2016).**

This is due to urban expansion and population increase in the study area.

For instance vegetation has been greatly decreased from **2568.20 $km^2$ to 1472.06 $km^2$** between 2000 and 2016 with the net decline of 42.68 % (Table 1).

# Land use Land cover Change

Another interesting observation in the basin is that a significant amount of **agricultural land is converted into settlements** and other urban developmental activities.

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Water spread area both manmade and natural water features such as **rivers, tanks and reservoirs** were also decreased from **390.14 km$^2$ (2000) to 199.61 km$^2$ (2016)** with a decrease of 48.75 % (Table 1).

Water spread area decrease is attributed to the fact that there is a gradual conversion of water spread area into built up area by **encroachments.**

Barren land initially increased for few years from **2048.40 km$^2$ (2000) to 3062.40 km$^2$ (2008)** and then gradually decreased to **1668.8 km$^2$ in 2016** (Table 1).

## Urban Growth Model (SLEUTH) Calibration

The model runs in three modes; **test mode, calibration mode and the prediction mode.**

In test mode data is tested for **readiness of calibration and prediction.**

Calibration phase is done to determine the best fit values for the five growth control parameters including **coefficients of diffusion, breed and spread, slope resistance and road gravity with historical urban extent data**.

Lee Sallee metric helps to select the values for the next phase of calibration is used in this study.

## Urban Growth Model (SLEUTH)

Test mode has been done for the historic data (Land use Land Cover maps 2000, 2008, 2010 and 2016) by taking the best fit coefficients values given in Table 2 with **Four** Monte Carlo Iterations

Coarse calibration for predicting 2036 sprawl using the past data has been performed by taking a start value of 0, step value of 25 and stop value of 100 with four Monte Carlo iterations of 3125 simulations.

Similarly fine and final calibration has been done by taking the coefficients from pervious phase with the Monte Carlo Iteration of **Six** and **Eight** respectively

## Urban Growth Predictions

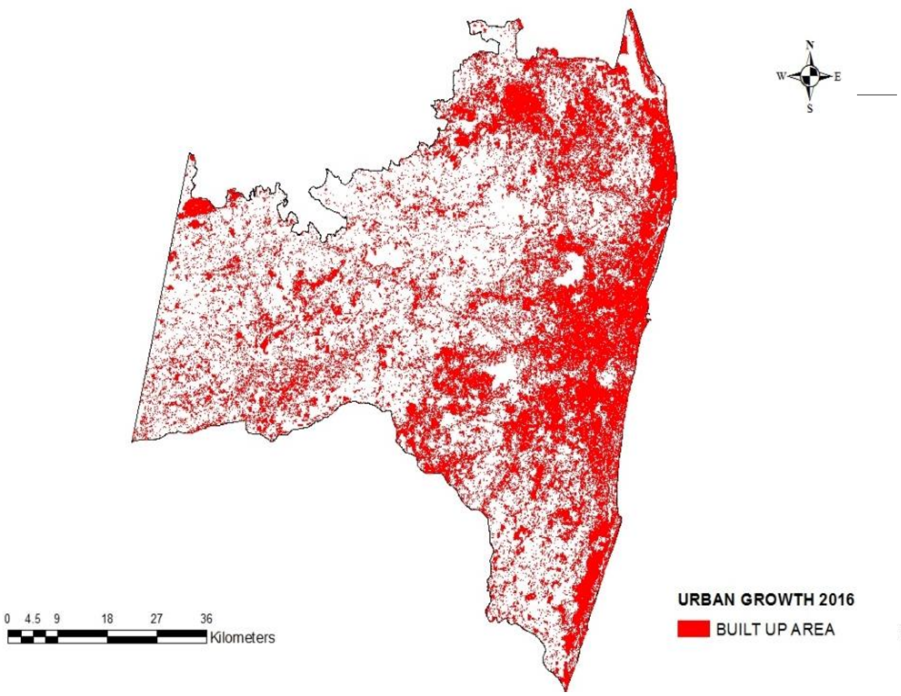
Monte Carlo Iterations are set to 100 and best fit values for prediction are given in following table.

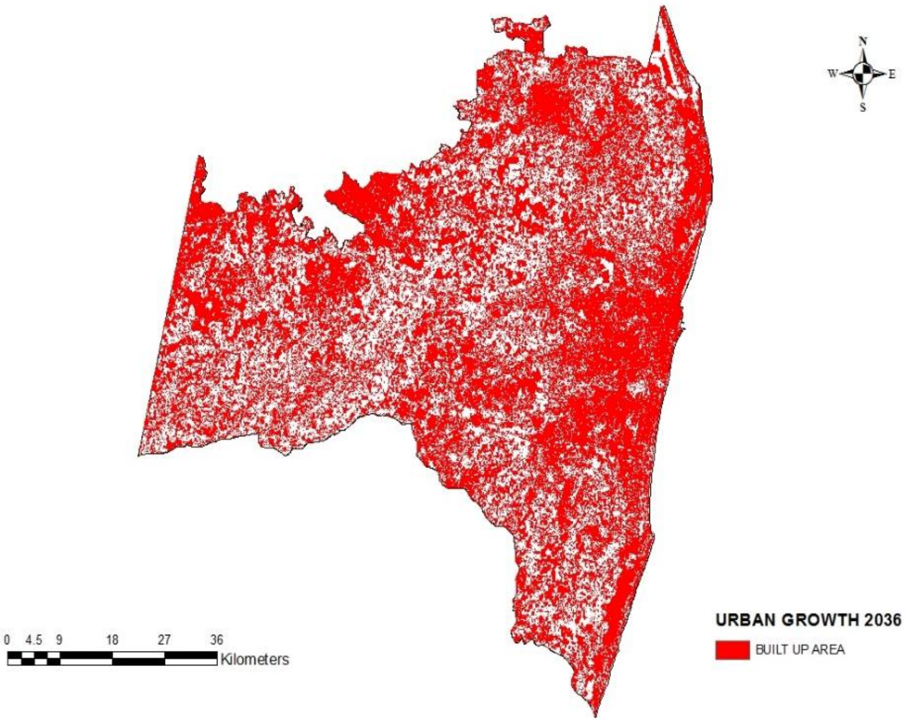
The urban expansion in Chennai basin is a **mixture of Breed, spread and road gravity expansion.**

**Breed has best fit value of 100 which shows very high scope of new settlements being generated.**

| S.No | Prediction Coefficient | Best Fit Value |
|---|---|---|
| 1 | Prediction Diffusion Best Fit | 1 |
| 2 | Prediction Breed Best Fit | 100 |
| 3 | Prediction Spread Best Fit | 12 |
| 4 | Prediction Slope Best Fit | 1 |
| 5 | Prediction Road Best Fit | 85 |
| 6 | Prediction Start Year | 2016 |
| 7 | Prediction Stop Year | 2036 |
| 8 | Mount Carlo Iterations | 100 |

# Simulated Urban growth of Chennai basin using SLEUTH 2016 and 2036



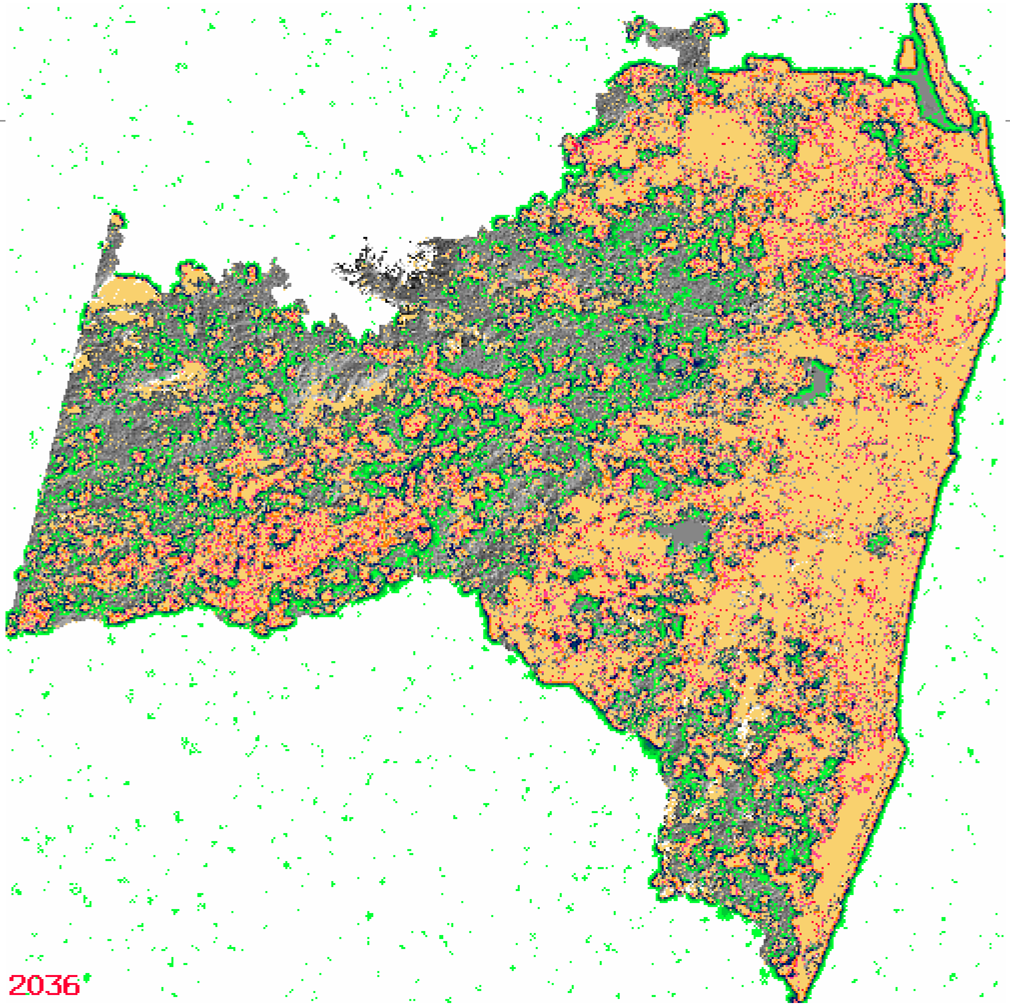




**2016**

| S.NO | Year | Urban Area km² |
|---|---|---|
| 1 | 2016 | 2134.65 |
| 2 | 2036 | 3415.99 |

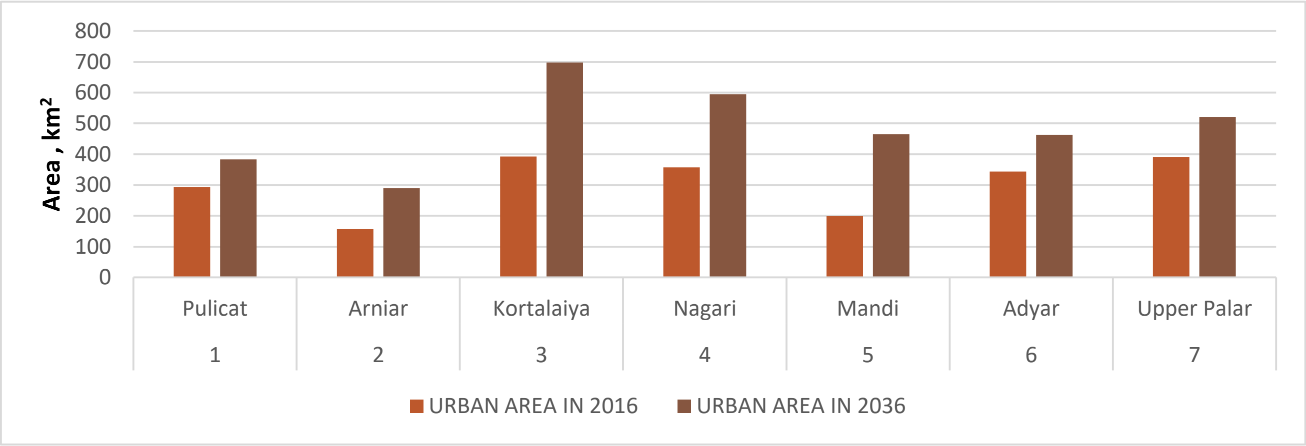
**2036**

**Urban Growth Predictions Using Sleuth Model**



# Urban Growth in Sub basin Level

| S.No | Sub Basin Name | Area km$^2$ | Urban Area in 2016 km$^2$ | Urban Area in 2036 km$^2$ | Difference in urban area | Percentage increase with respect to area | Percentage increase with respect to 2016 |
|---|---|---|---|---|---|---|---|
| 1 | Pulicat | 589.79 | 293.60 | 383.07 | 89.47 | 65 | 30 |
| 2 | Arniar | 488.42 | 157.00 | 289.49 | 132.49 | 59 | 84 |
| 3 | Kortalaiya | 1117.51 | 392.48 | 697.06 | 304.58 | 62 | 77 |
| 4 | Nagari | 954.28 | 356.70 | 595.00 | 238.30 | 62 | 67 |
| 5 | Mandi | 978.70 | 198.85 | 465.10 | 266.25 | 56 | 134 |
| 6 | **Adyar** | **702.90** | **343.50** | **463.00** | **119.50** | **66** | 34 |
| 7 | Upper Palar | 800.70 | 391.08 | 521.50 | 130.42 | 65 | 33 |



## SIMULATION RESULTS OF SLEUTH

Results of the percentage increase in the urban extent at subbasin level indicates urbanization will happen as **new spreading centre growth.**

Therefore it is necessary to understand the impact of these urban extent growth on the availability of water resources in the future for better management and planning.

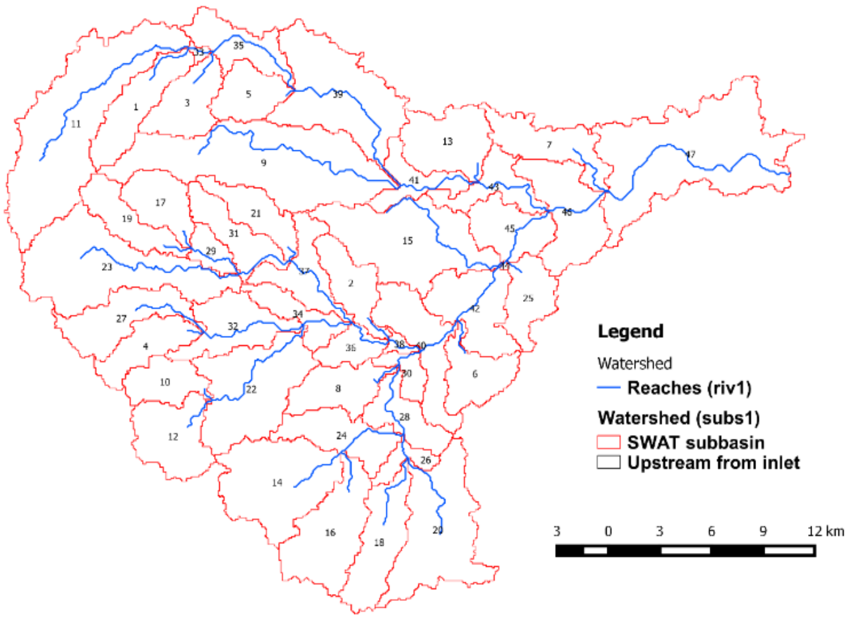
Hence for further analysis it was decided to study at a selected subbasin of the Chennai basin.

**Since Adyar subbasin has experienced floods in the year 2015, it was decided to implement the hydrological model (SWAT) at Adyar sub basin to assess the impact of predicted urban growth (2036) under AIB scenario of the IPCC using MIROC 3.2, CMIP3 model data.**

## SWAT Model

- Adyar subbasin area was subdivided into 47 sub watersheds.

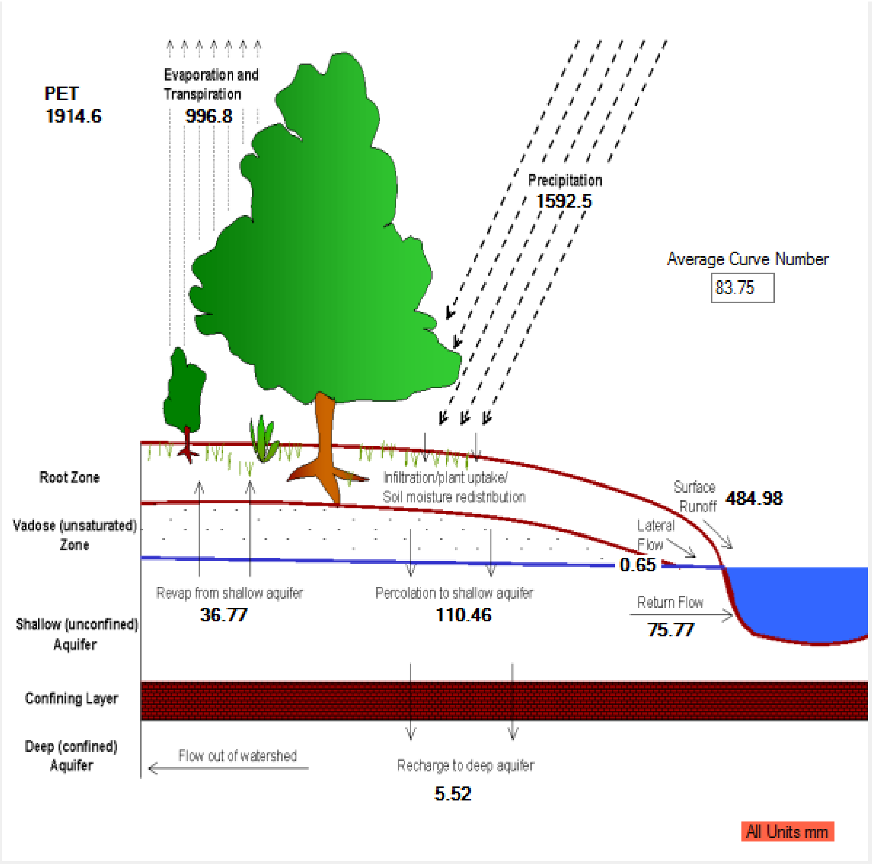
- The land use map of Adyar sub basin was classified for the year 2016 and for 2036 the projected land use maps from SLEUTH urban growth model was used.



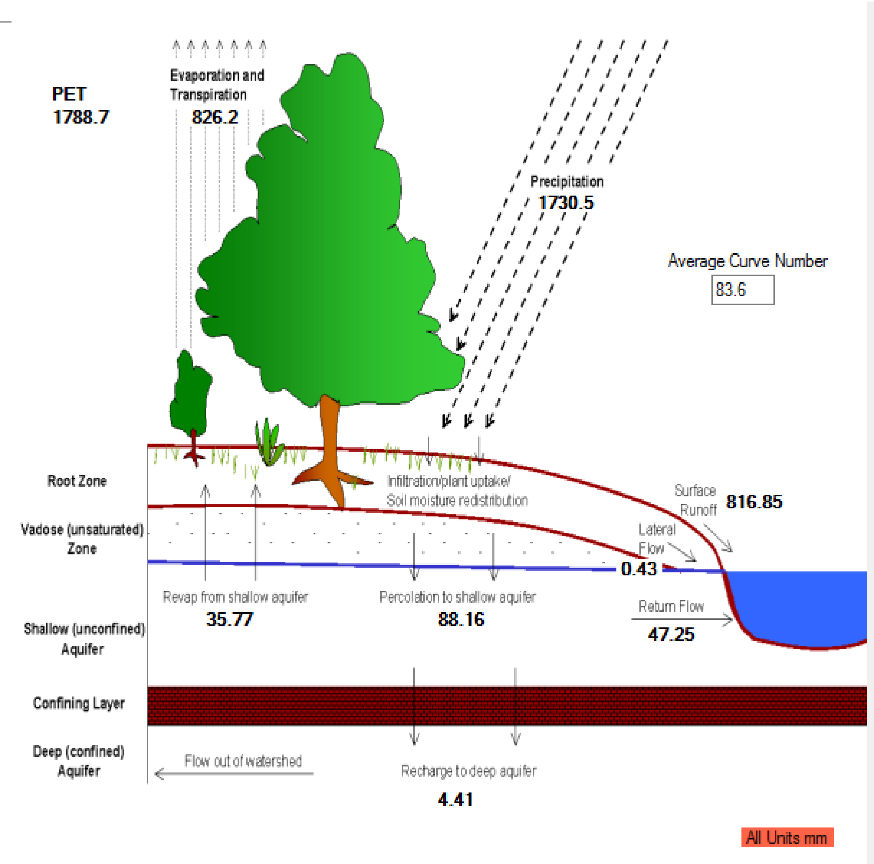

**Sub basin map**

- 3 years warm up period.
- Soil map from the Food and Agriculture Organization of the United Nations (FAO, 1995).
- 175 HRU

# Water Balance of Adyar sub basin in 2016 and 2036



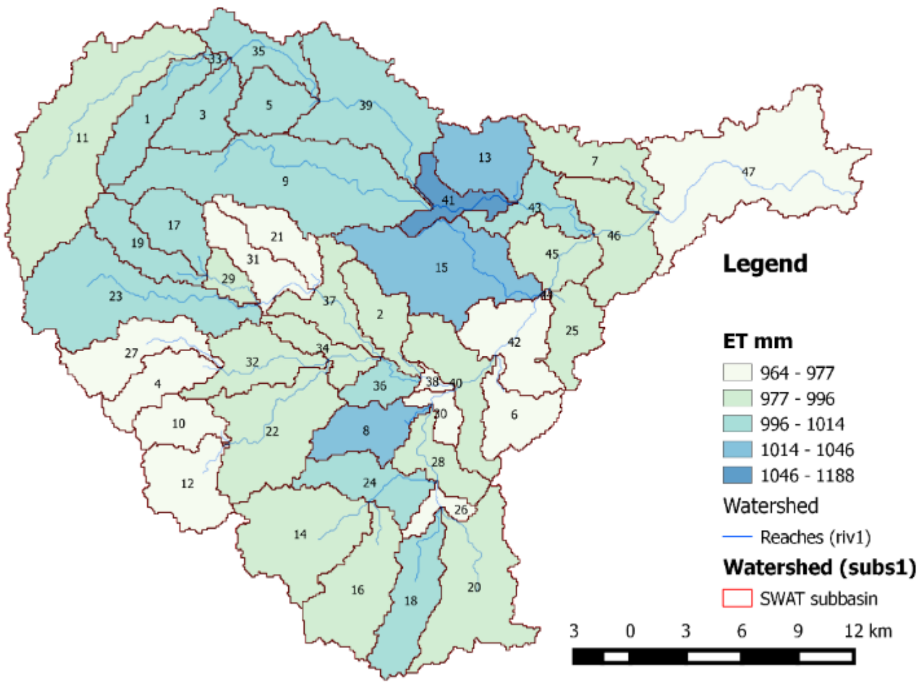

**Water balance of Adyar subbasin in 2016**



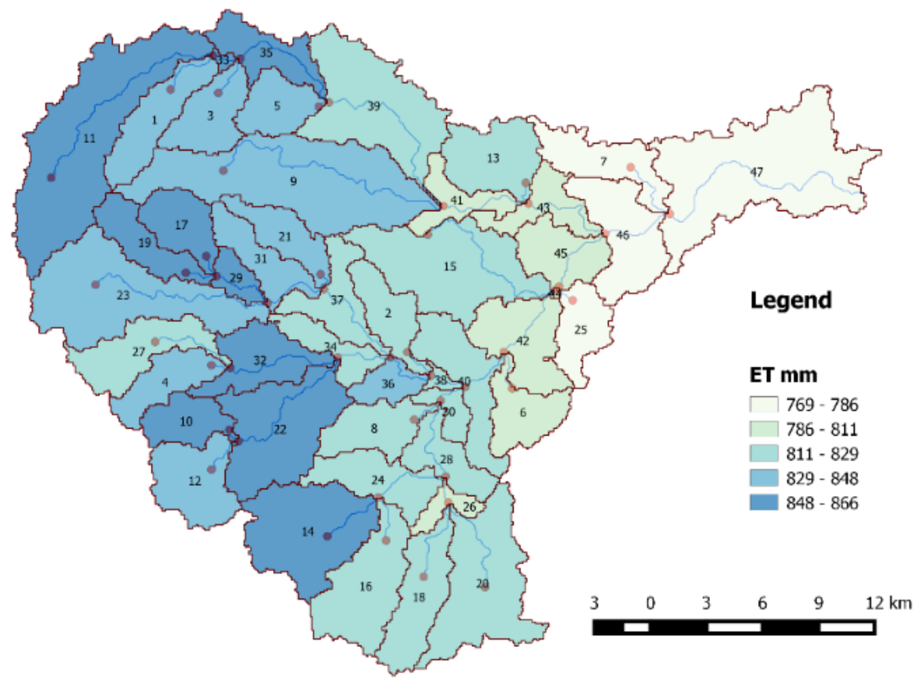

**Water balance of Adyar subbasin in 2036**

## Evapotranspiration Rate

The maximum evapotranspiration rate has a reduction from 1180 mm to 866 mm.




**2016**

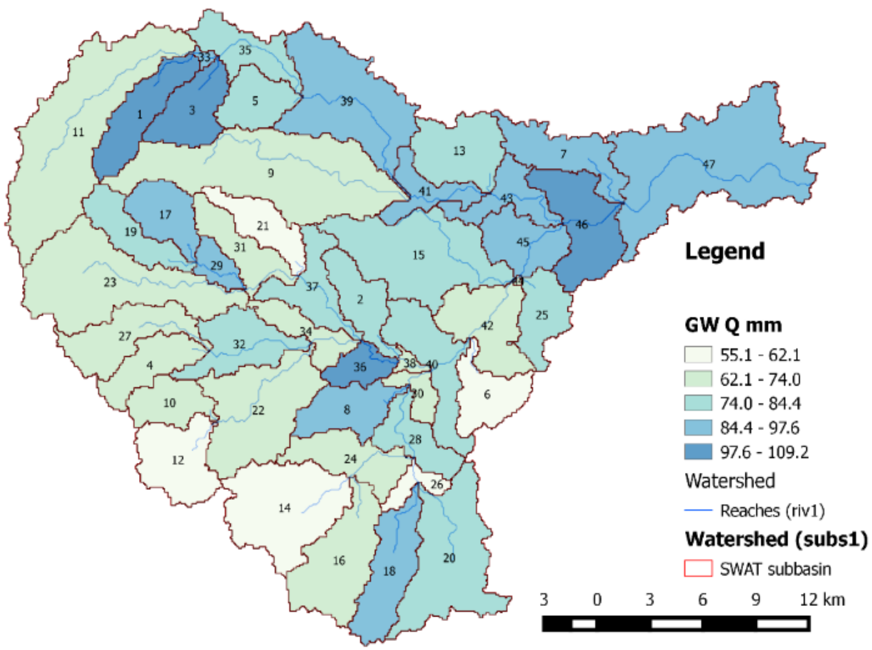


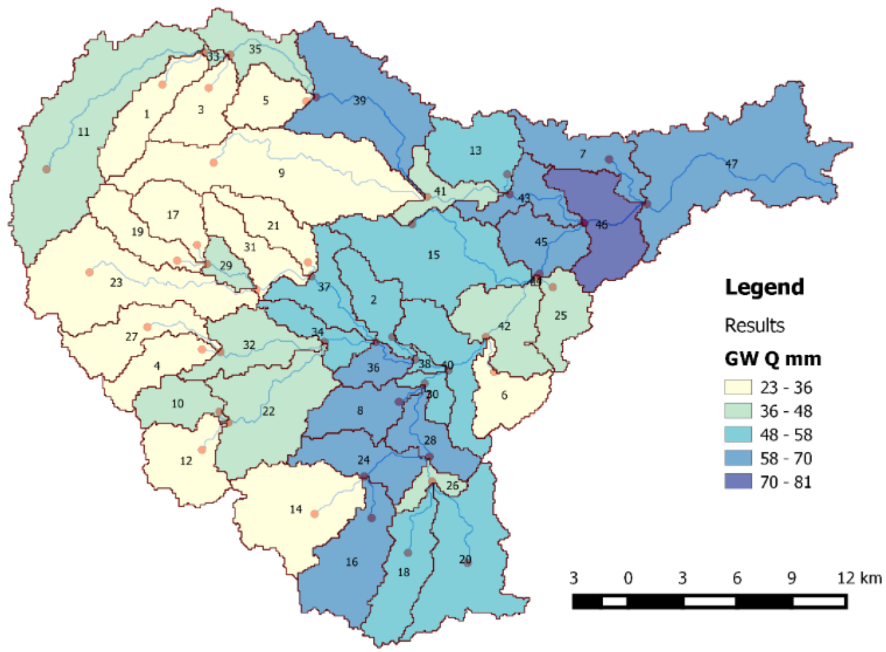

**2036**

**Annual average Evapotranspiration for 2016 and 2036**

# Groundwater Flow

The minimum range of Groundwater is 50mm in 2016 is reduced by 50% in the year 2036.




**2016**

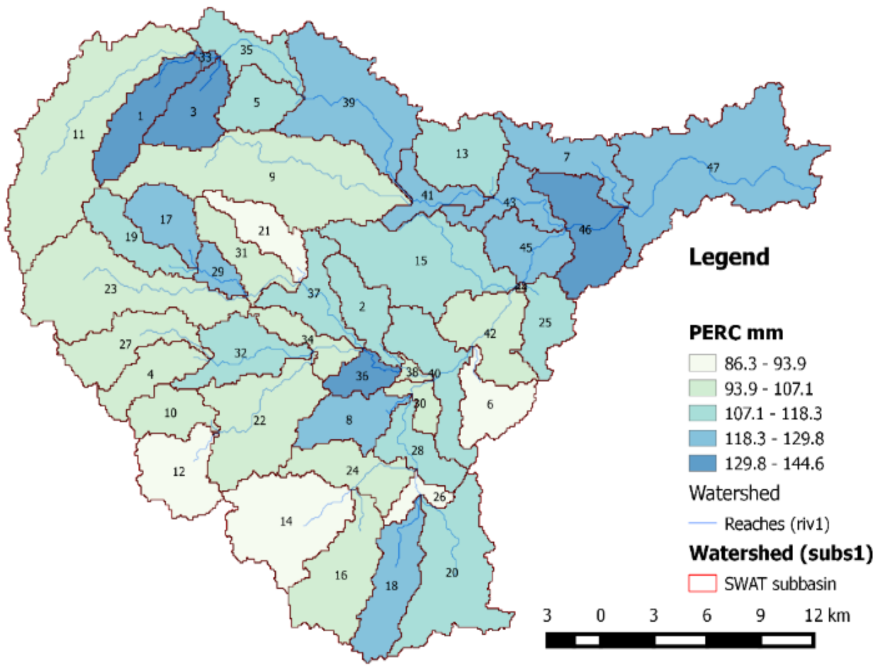
**2036**



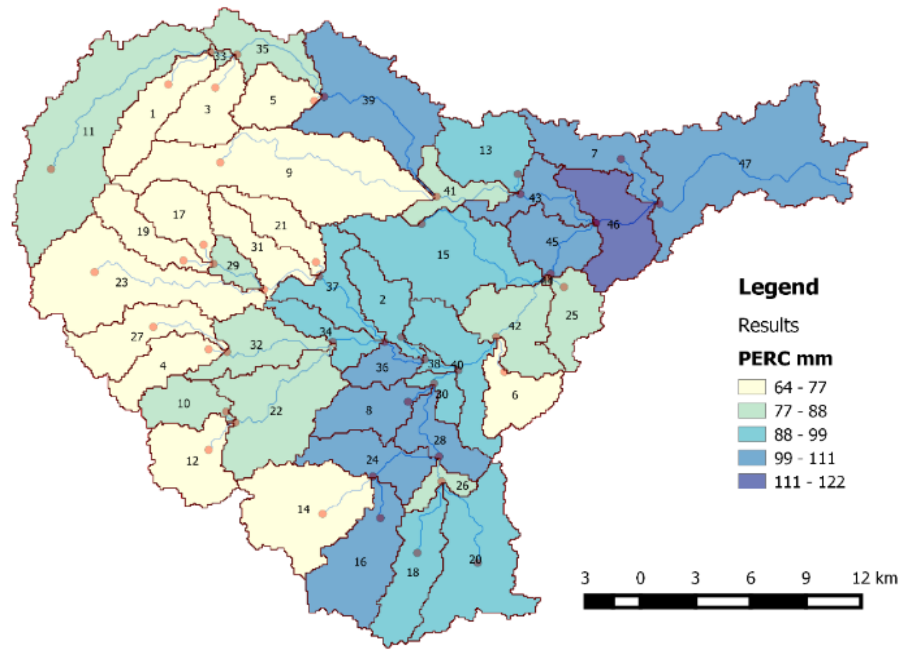
**Annual average Groundwater flow for 2016 and 2036**

## Percolation

The percolation component has reduced to 122 mm (2036) from 144 mm in 2016




**2016**

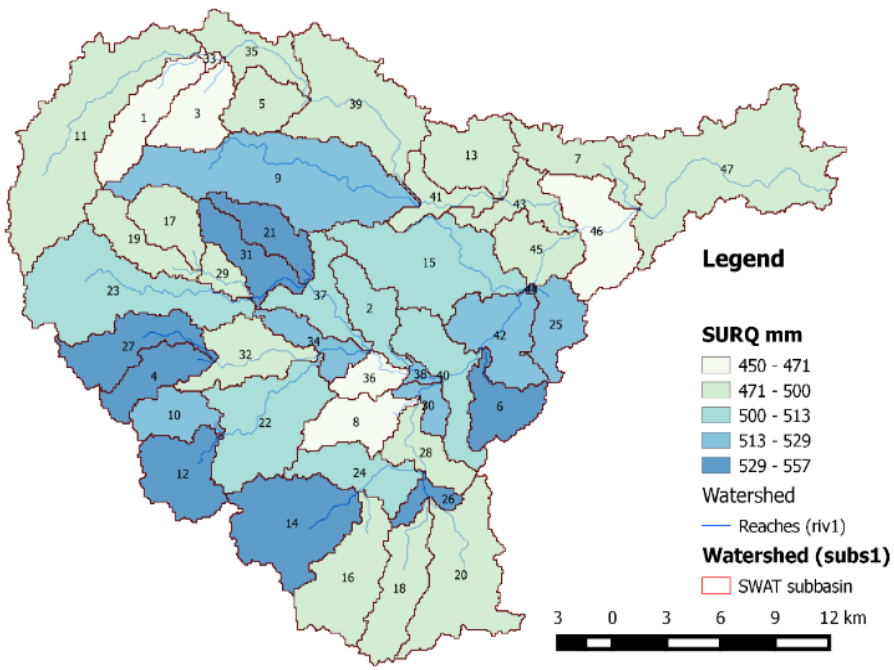



**2036**

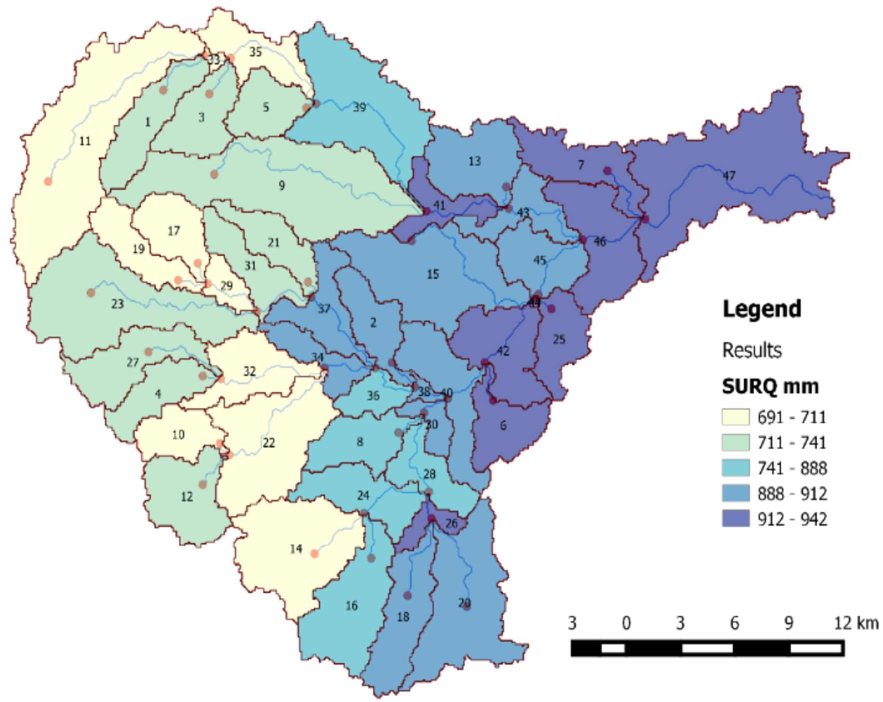
**Annual average Percolation rate for 2016 and 2036**

## Surface Runoff

The Runoff component has more impact due to the urbanization. The model predicts that the minimum runoff value has increased from 450 to 700 mm




**2016**

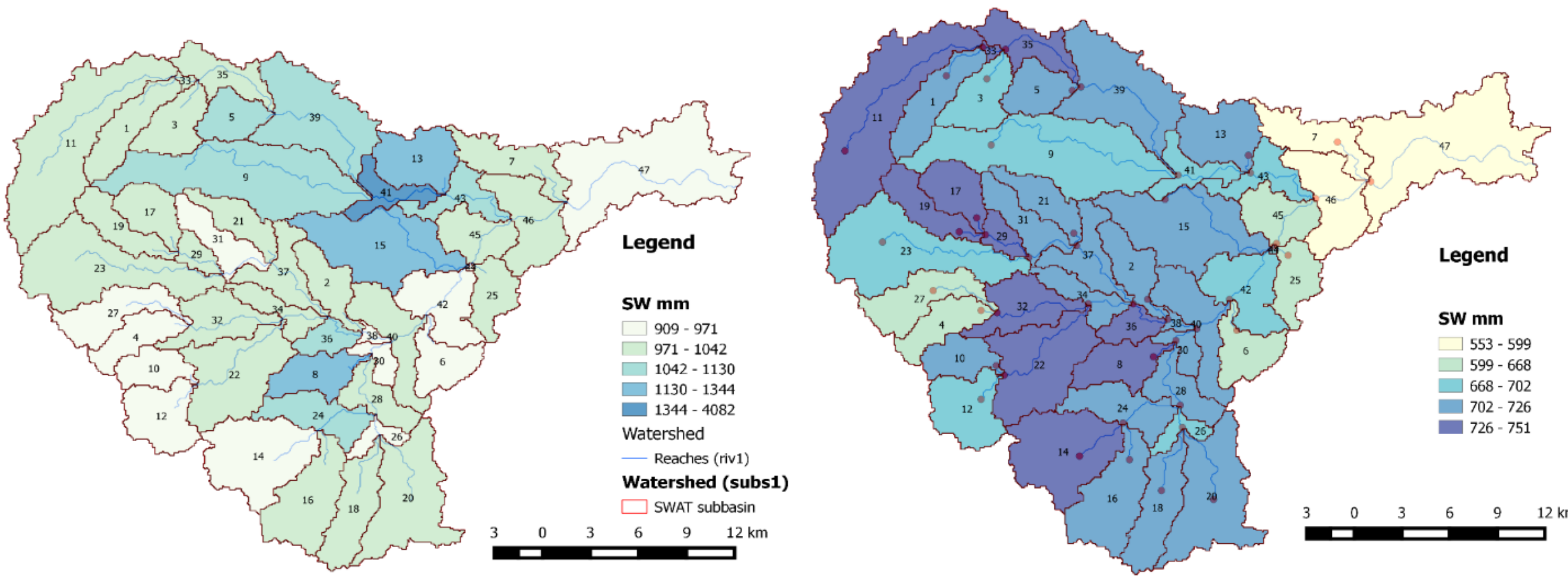



**2036**

**Annual average Surface runoff for 2016 and 2036**

## Soil Water

The soil water component has a maximum reduction from 4382 mm to 750 mm. This decrease in soil water depicts the reduction in groundwater component too



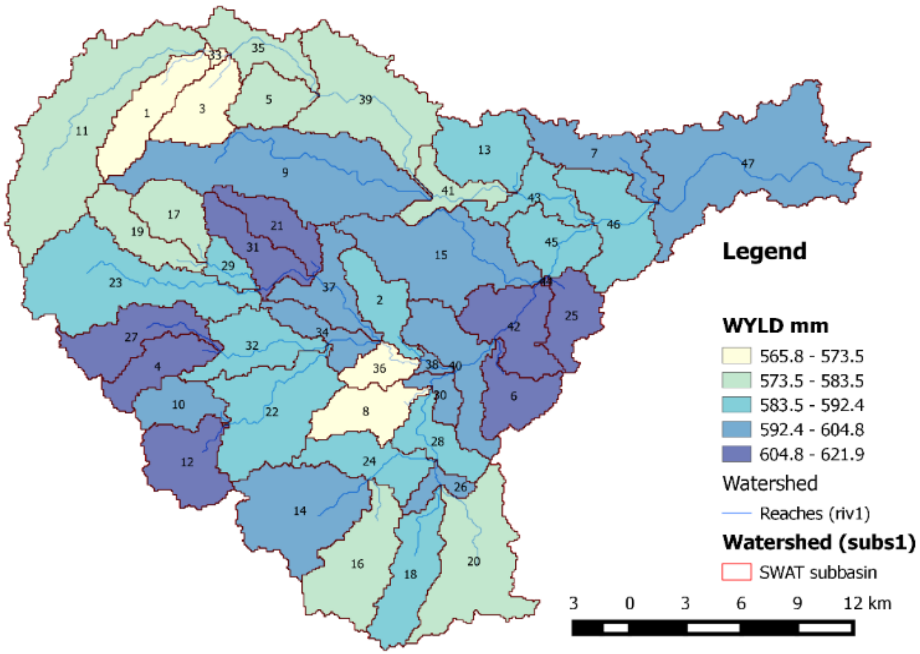

**2016**

**2036**

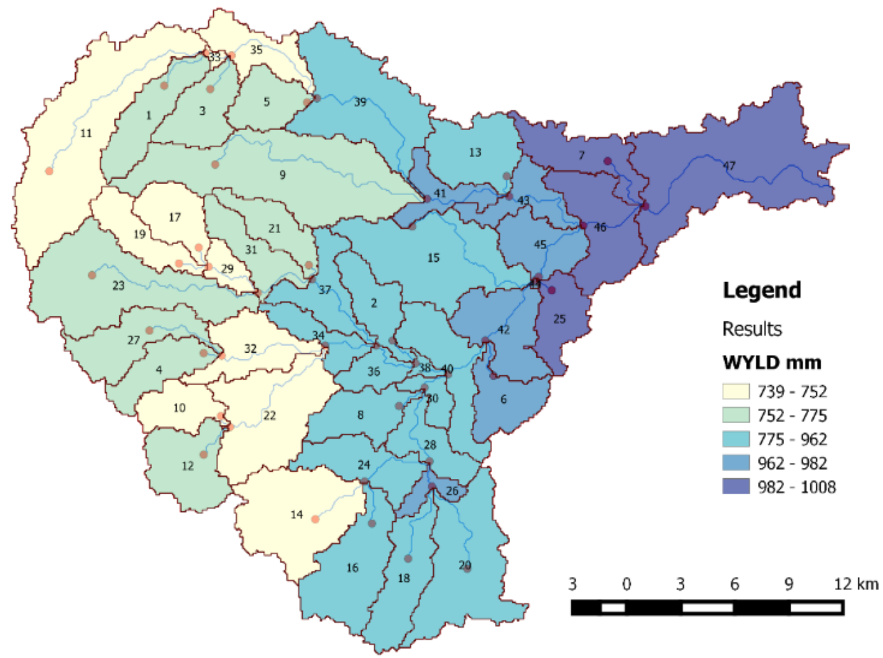
**Annual average Soil water for 2016 and 2036**

## Water Yield

The increasing surface runoff has led to the increase in water yield in the year 2036.




**2016**

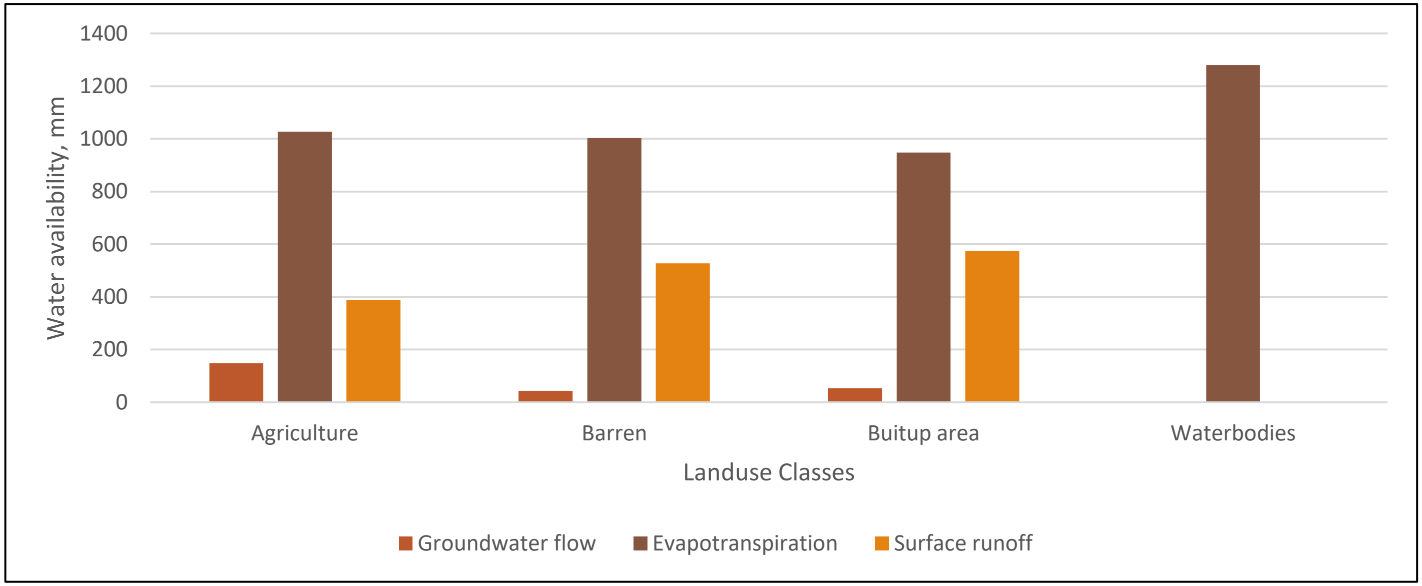



**2036**

**Annual average Water yield for the 2016 and 2036**

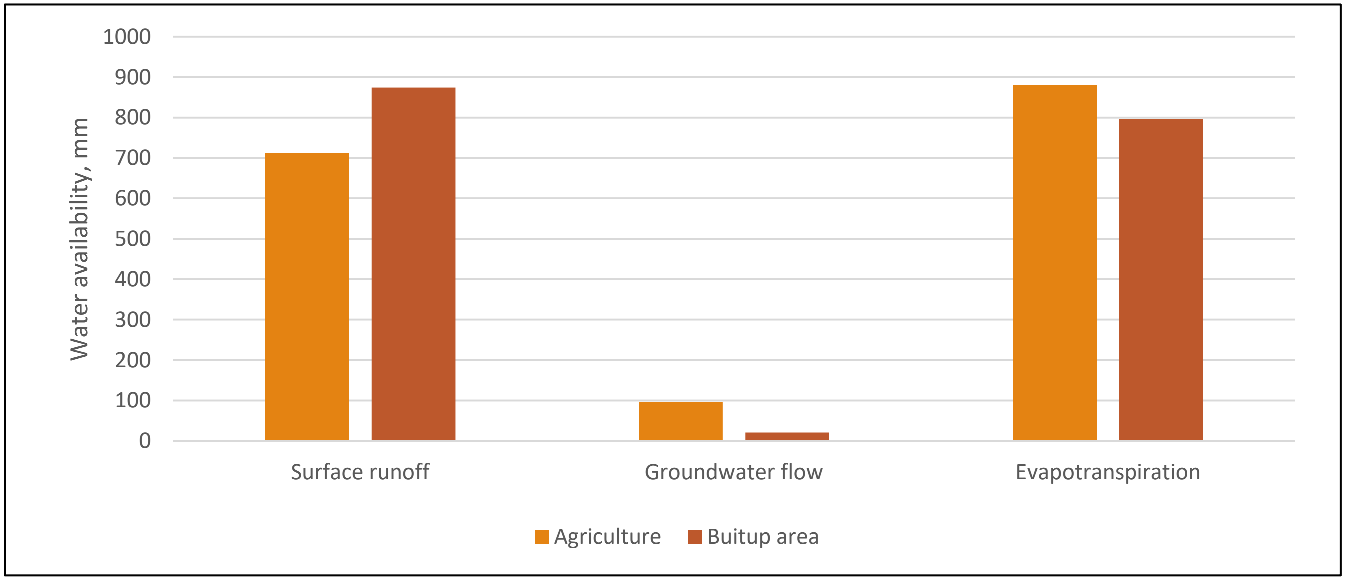
# Annual average of the hydrological components for Adyar sub basin in 2016

| LULC | Area $km^2$ | AWC mm | Surface Runoff mm | Groundwater flow mm | Evapotranspiration mm |
|---|---|---|---|---|---|
| AGRL | 240.90 | 222.63 | 387.70 | 148.08 | 1026.34 |
| BARR | 178.46 | 221.80 | 526.73 | 43.56 | 1003.13 |
| URBN | 370.50 | 223.00 | 572.84 | 52.72 | 948.31 |



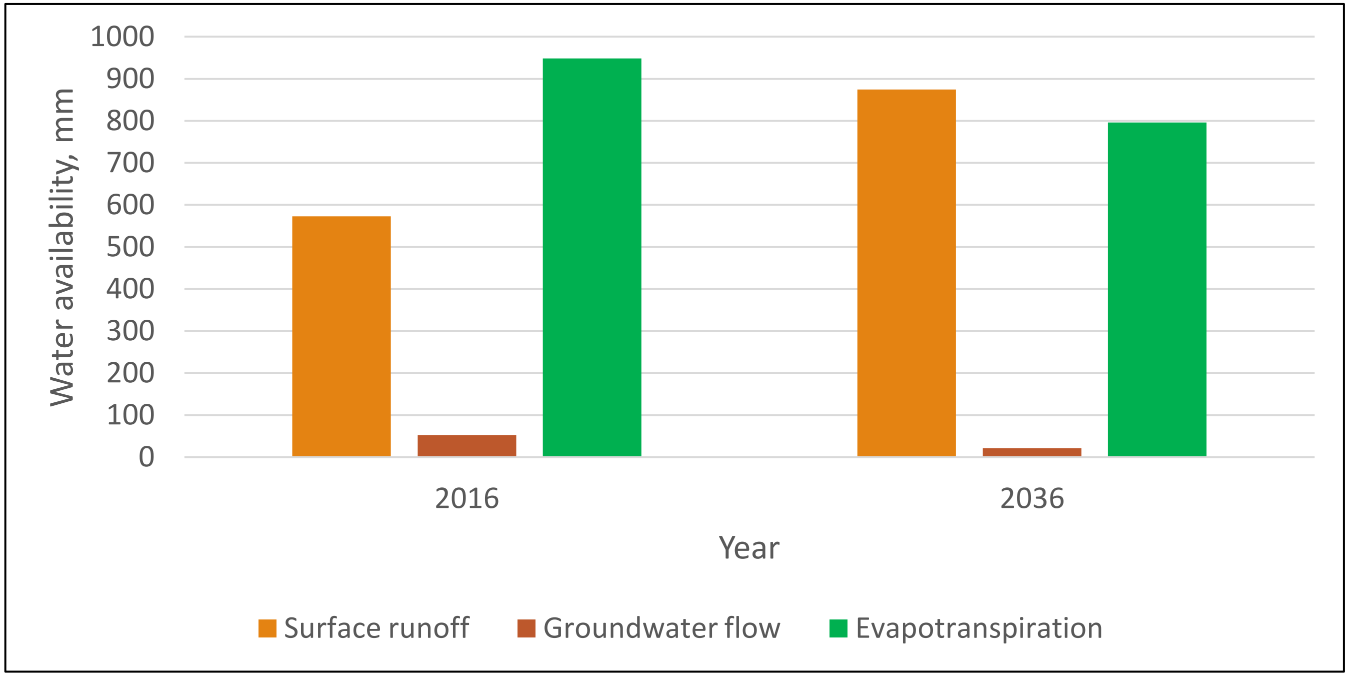
# Annual average of the hydrological components for Adyar sub basin in 2036

| LULC | Area km$^2$ | AWC mm | Surface Runoff mm | Groundwater flow mm | Evapotranspiration Mm |
|---|---|---|---|---|---|
| AGRL | 292.68 | 167.29 | 712.59 | 96.08 | 880.27 |
| URBN | 530.85 | 164.91 | 874.28 | 21.01 | 796.39 |



## Impact of urban growth on hydrological components for the year 2016 and 2036

| S. No | Urban area | Surface runoff mm | Groundwater flow mm | Evapotranspiration mm |
|---|---|---|---|---|
| 1 | 2016 | 572.84 | 52.72 | 948.31 |
| 2 | 2036 | 874.28 | 21.01 | 796.39 |



# Summary

- The urban growth model simulations have shown a significant increase in the urban extent from 2134.65 $km^2$ (2016) to 3415.99 $km^2$ (2036) for Chennai basin.

- The urban expansion is mainly by **breed coefficients with the value of 100 because of new spreading area** and is not resisted by slope.

- The study was further carried on to assess the impact of climate change on hydrological components like surface flow, potential evapotranspiration using SWAT

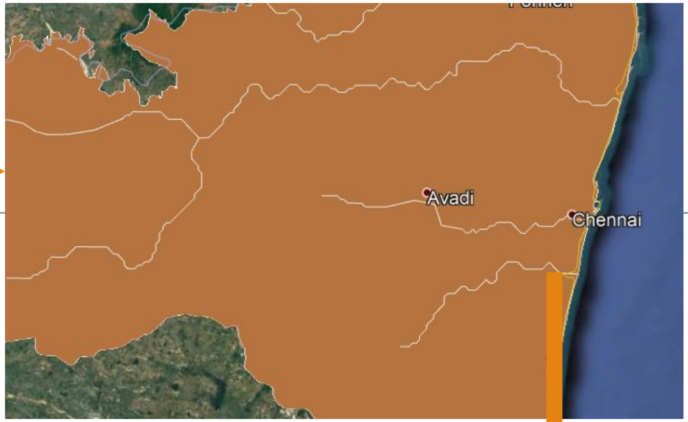
# Summary

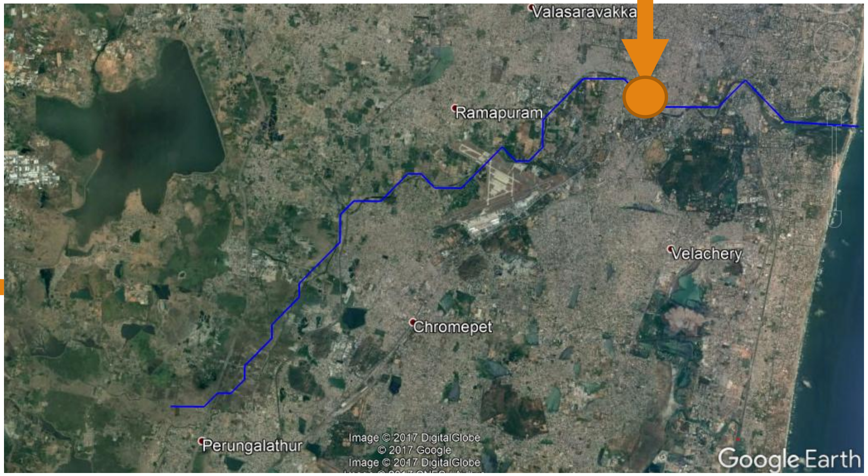
- The future climate data was obtained from the global climate model, MIROC 3.2.
- This model was selected to extract the future climate data for the A1B future scenario.
- Since Adyar subbasin has experienced floods in the year 2015, it was decided to implement the hydrological model (SWAT) at Adyar subbasin.
- The results revealed that the Runoff component has more impact due to the urbanization.
- The model predicts that the minimum runoff value has increased from 450 to 700 mm.

# Summary

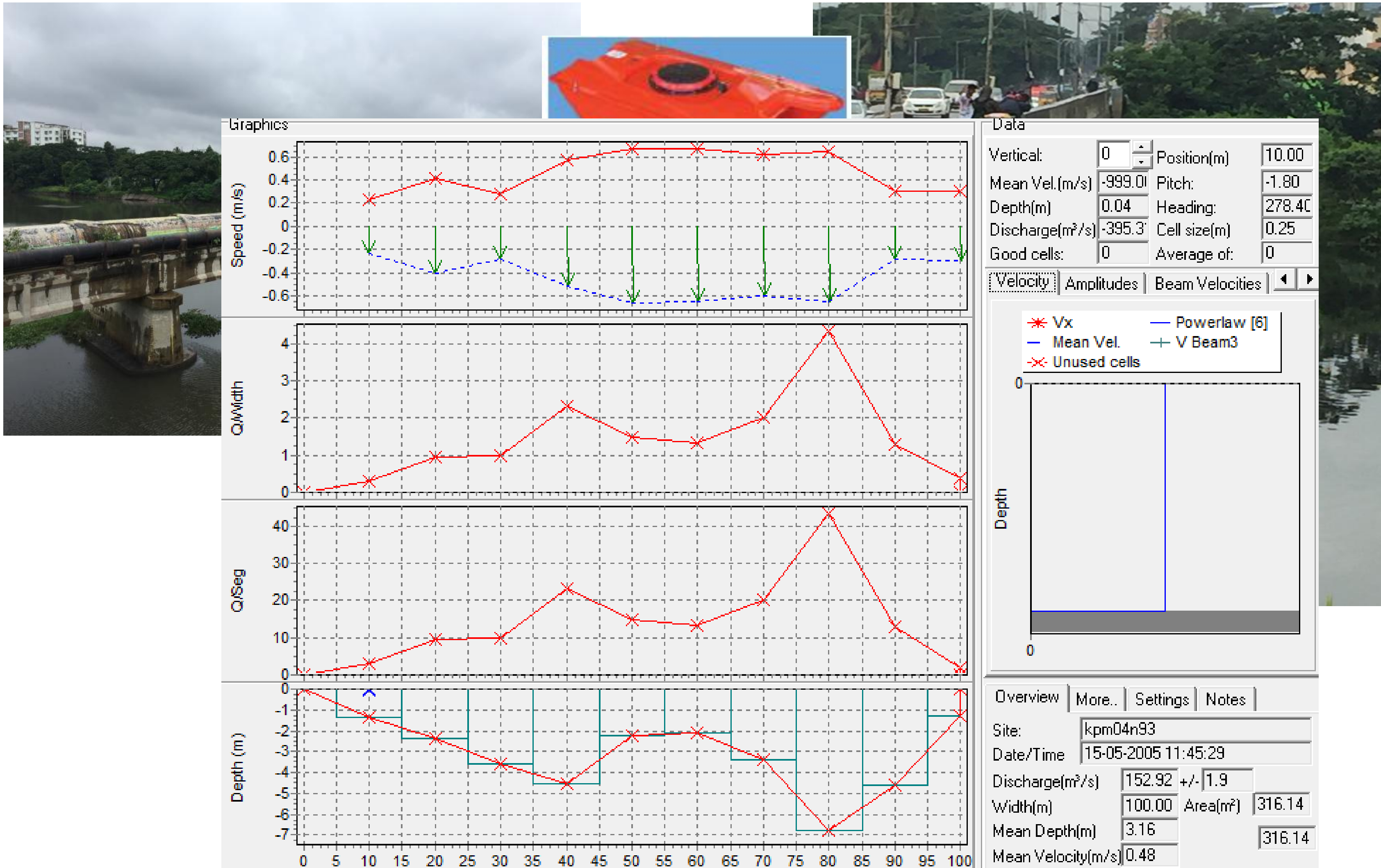
- The maximum evapotranspiration rate has a reduction from 1180 mm to 866 mm.
- The study concludes that the water resources of Chennai basin will suffer under the projected urban growth and climate change .
- The impacts are very significant in the hydrological component especially **run off.**

# River discharge measurement

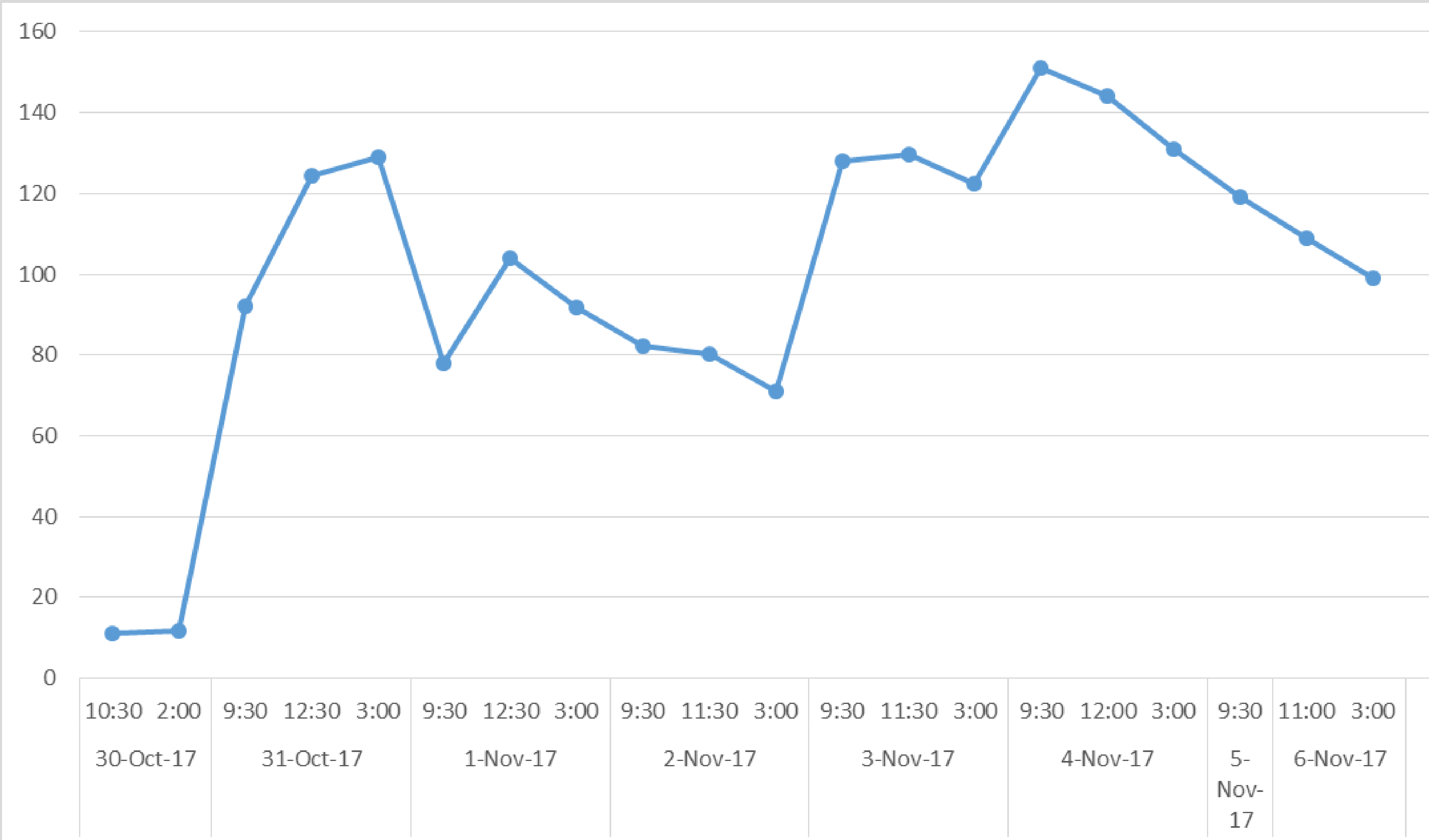




# River discharge measurement



# Hydrograph of Adyar river at Kotturpuram bridge



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THANK YOU