WATER RESOURCES MANAGEMENT IN UPCOMING SMART CITY – A CASE STUDY OF AMARAVATI

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the Degree

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WATER RESOURCES DEVELOPMENT

By

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CANDIDIATE'S DECLARATION

I hereby declare that the work carried out in this report entitled "**WATER RESOURCES MANAGEMENT IN UPCOMING SMART CITY – A CASE STUDY OF AMARAVATI**" is presented on behalf of the partial fulfillment of the requirement for the award of the degree of Master of Technology with specialization in Water Resources Development, submitted to the department of Water Resources Development and Management, Indian Institute of Technology, Roorkee, India, under the supervision and guidance of Dr. Deepak Khare, Professor, WRDM, IIT Roorkee, India.

I have not submitted the matter embodied in this report for the award of any other degree of diploma.

Date: *04.05.2018* **…………………….**

Place: *Roorkee* **(Andra Sai Kumar)**

CERTIFICATION

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

……………………….

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TABLE OF CONTENTS

Page No.

CANDIDATE'S DECLARATION ii

ACKNOWLEDGEMENT iii

TABLE OF CONTENTS iv

LIST OF FIGURES vi

LIST OF TABLES viii

Abstract ix

1 INTRODUCTION 1

1.1 General 1
1.2 Impact of Land Use/Land Cover on Water Resources 1
1.3 Climate Change Impact on Water Resources 2
1.4 Urban Water Demand and Water Scarcity Problems 2
1.5 Research Gap/Rationale 3
1.6 Objectives 3

2 REVIEW OF LITERATURE 4

2.1 Land Use/Land Cover Studies 4
2.2 Climate Change Studies 4
2.3 Combined Land Use/Land Cover and Climate Change Studies 6
2.4 SWAT Studies on Water Balance 7
2.5 Water Demand Management and Low Impact Development Studies 8

3 STUDY AREA AND DATA 10

3.1 Description of Study Area 10
3.2 Data Used 12

4 METHODOLOGY 13

4.1 GIS Data Preparation 13
4.2 Past Land use/Land Cover Files Preparation 13
4.2.1 Preparation of past land use change data 14
4.3 Future Land use/Land Cover Prediction Files Preparation 14

4.3.1 Preparation of Input Files 16
4.3.1.1 DEM file 16
4.3.1.2 Slope map 16
4.3.1.3 Distance_urban map 16
4.3.1.4 Distance_road map 16
4.3.1.5 Third order polynomial spatial trend of change map 17
4.4 Comparison Studies of Amaravati with Some Indian Bifurcated State Capitals 18
4.4.1 Arithmetic increase method 18
4.4.2 Geometric increase method 18
4.5 Quantification and Estimation of Suggested Water Demand Management Options 19
5 RESULTS AND DISCUSSIONS 20
5.1 Past Land use/Land Cover Analysis 20
5.1.1 Land use/land cover overall change analysis 29
5.2 Future Land Use Prediction 30
5.3 Comparison of Amaravati with Some Indian Bifurcated State Capitals 36
5.3.1 Census data for 2001 and 2011 37
5.3.2 Population forecasting data 37
5.3.3 Existing drinking water sources status of Amaravati 40
5.3.4 Comparison study – Ranchi and Amaravati 41
5.3.4.1 Lessons from Ranchi – recommendations for Amaravati 42
5.4 Urban Water Resources Management Plan 43
5.4.1 Quantification and estimation of suggested water demand management options 48
6 CONCLUSIONS 51
6.1 General 51
6.2 Conclusions 52
6.3 Future scope of work 52
REFERENCES 54
ANNEXURE – I 57

LIST OF FIGURES

Fig. No.	Description	Page No.
Fig. 3.1	Urban sustainability framework of Amaravati	10
Fig. 3.2	Description of study area	11
Fig. 4.1	Flow chart for visualization of LCM process	15
Fig. 4.2	Flow chart of Methodology	19
Fig. 5.1	Land use/Land cover map of Amaravati in 1993	21
Fig. 5.2	Land use/Land cover map of Amaravati in 1997	22
Fig. 5.3	Land use/Land cover map of Amaravati in 2005	23
Fig. 5.4	Some Indian rivers water availability at different gauge stations (CWC Data)	23
Fig. 5.5	Land use/Land cover map of Amaravati in 2011	24
Fig. 5.6	Land use/Land cover map of Amaravati in 2017	25
Fig. 5.7	Areal contribution of all land cover classes to settlement during 1993 to 1997	27
Fig. 5.8	Areal contribution of all land cover classes to settlement during 1997 to 2005	27
Fig. 5.9	Areal contribution of all land cover classes to settlement during 2005 to 2011	28
Fig. 5.10	Areal contribution of all land cover classes to settlement during 2011 to 2017	28
Fig. 5.11	Areal contribution of all land cover classes to settlement during 1993 to 2017	29
Fig. 5.12	Change in area of five land cover types during the period of 1993-2017	30
Fig. 5.13	Determining true Euclidean distance	31

Fig. 5.14	Digital Elevation Model of the study area	32
Fig. 5.15	Slope Map of the study area	32
Fig. 5.16	Distance_Road Map of the study area	33
Fig. 5.17	Distance_Urban Map of the study area	33
Fig. 5.18	Cubic trend map of transition from All to Urban	34
Fig. 5.19	Predicted Land use/Land cover map of Amaravati in 2050	36
Fig. 5.20	Forecasted population of Dehradun	39
Fig. 5.21	Forecasted population of Raipur	39
Fig. 5.22	Forecasted population of Ranchi	40
Fig. 5.23	Forecasted population of Amaravati	40
Fig. 5.24	Harmu, a dirty waterway winds through the city centre	41
Fig. 5.25	The city's water bodies like Arghoda talab were dirty, clogged with plastic, garbage and sewage	42
Fig. 5.26	Different Low Impact Development practices	47

LIST OF TABLES

Table No.	Description	Page No.
Table 3.1	Path and Row number of satellite images	12
Table 3.2	Different sensors and date of image taken for satellite images	12
Table 5.1	Area (km^2) of each land type changed to others during the year 1993-1997	21
Table 5.2	Area (km^2) of each land type changed to others during the year 1997-2005	22
Table 5.3	Area (km^2) of each land type changed to others during the year 2005-2011	24
Table 5.4	Area (km^2) of each land type changed to others during the year 2011-2017	25
Table 5.5	Area (km^2) of each land type changed to others during the year 1993-2017	26
Table 5.6	Area (km^2) of each land type for different years	30
Table 5.7	Area (km^2) of each land type for the year 2050	35
Table 5.8	Comparison states, their capitals and bifurcation date	36
Table 5.9	Census data for 2001 and 2011 of comparison cities and % of changes	37
Table 5.10	Arithmetic Increase Method of population forecasting	38
Table 5.11	Geometric Increase Method of population forecasting	39
Table 5.12	SWITCH approach implemented in different cities of world	44
Table 5.13	Existed and Proposed sources of supply for Amaravati	48
Table 5.14	Different residential water uses and water saving calculations for Amaravati	49
Table 5.15	Water saving calculations for % of population adopted the recommended WDM options	50

Abstract

Land use change impacts surface water-balance, water quality and water demand. On the other hand, water resources degradation also posing threat to the society due to over-utilization which results insufficient water facilities for the growing demand. The present study focuses on past land use change and also predicted future land use change. For this, the land use/land cover maps of the study year for the years 1993, 1997, 2005, 2011 and 2017 have been prepared using ArcGIS and ERDAS. The results showed urban area change from 1993-2017 is 8.09 km^2, which is 3.7% for 24 years. So, urban area is growing at a rate of 0.33 km^2/year. The future land use predicted using Land Use Change Modeler in TerrSet Software in which Markov Model used. The results showed urban area change from 2017 to 2050 is 58.63 km^2, which is 26.95% for 33 years. So, urban area is increasing at a rate of 1.77 km^2/year.

Comparing capital city with other bifurcated state capitals is very useful to understand the water scarcity and management problems faced by the cities with the unexpected outgrowth of population and urbanization. An attempt made to check how population changes in bifurcated state capitals to Amaravati in which Ranchi city forecasted population matches with the estimated master plan population of Amaravati which significantly can study the changing patterns of both cities with respect of water balance and water resources management. Water scarcity, which emerges when demand exceeds supply, poses unprecedented challenges to human and ecological security.

SWITCH approach helps to make the city more sustainable in future with learning alliances, theme-city level strategic planning studying theme level city water balance, water drain and water economics. The suggested urban water resources management plan could help the city for not running towards more sources and reduce the water demands by increasing water reuse efficiencies with SATs, aquifer storage & recovery, engineered buffered technologies; implementing water demand management options like installing DMAs, systemization of water supply system, water metering, water saving devices, rain water harvesting at roof tops, green and brown buildings, constructing green infrastructure, grey water reuse; water sensitive urban design through River Krishna restoration using eco-hydrology principles, etc. The results of the study will be important input for planners for an upcoming city to understand and analyze the urban water balance for future with some proper measures taken at planning stage itself.

Chapter 1

INTRODUCTION

1.1 General

Urbanization is one of the most concern areas on present days since it is alarmingly increasing due to population growth. Urbanization impacts the availability of water upon changing land use and land cover, which it affects the watershed hydrology thereby increasing water demand (Feng Wu et al., 2015). The increased surface impervious cover due to urbanization also changes the hydrologic, or flow, river regimes thereby causes decrease in infiltration rates leading to increase in flash floods. Because of all these, the cities are not able to face these situations due to incapable sewerage facilities, insufficient drainage system, which at the time of planning and design, they do not consider these factors leading to severe urban flooding problems now-a-days.

1.2 Impact of Land Use/Land Cover on Water Resources

Land is a constrained regular asset and has an aggressive nature among its users. The change in land use absolutely gives numerous financial and social openings, however they additionally come at the expenses to sustenance creation, freshwater assets, woods assets, and atmosphere and air quality. Land use change can also alter surface water-balance; water quality and water demand (Omaid Najmuddin et al., 2017). Furthermore, land use change affects regional climate including temperature and air quality through its impact on net radiation, energy division, breaking precipitation into runoff, soil-water and evapotranspiration.

Land use change has been determined both by regular and anthropogenic variables. Changes in land cover have been occurring since the world came to exist. Nevertheless, in the current past, elements of quickly developing populace, urbanization and modern advancement, environmental change and fast mechanical improvement have expanded the pace of land use change. During the last five decades, world has experienced a significant spatial expansion of urban areas, which is mainly caused by increased population, changing economy and better living facilities (Omaid Najmuddin et al., 2017). So, land use management is of great importance because of its critical role in human development and social well-being.

On the other hand, water resources degradation also posing threat to the society due to over-utilization, insufficient water facilities for the out growing demand and non-usage of over flooded water because of lack of resources management in the urban cities which will get wasted.

1.3 Climate Change Impact on Water Resources

Climate change assumes an imperative part in each field particularly most worry for hydrology designers and water assets supervisors. Climate change has possible effect on both the long-term availability and the short-term variability of water resources (Sheila M. Olmstead, 2014). The climate change impact on urban areas and river basins is most extreme significance since these are most influenced and most vital worries for each nation. Potential provincial effects of climate change could incorporate expanded recurrence and size of dry seasons and surges, and long-haul changes in sustainable water supplies through changes in precipitation, temperature, moistness, wind power, nature and degree of vegetation, soil dampness and overflow (Sheila M. Olmstead, 2014).

Because of climate change, the access to fundamental urban administrations, particularly those connected to water supply, is relied upon to end up more troublesome, exacerbating natives' personal satisfaction (L. Bonzanigo et al., 2014). As everything is linked with the environment and climate, studying the effect of climate change on urban cities and its effect on water resources will be more useful for future. These considerations should be taken at the planning stage of future smart cities in order to overcome water problems, as the world is running towards smart cities development.

1.4 Urban Water Demand and Water Scarcity Problems

Urban water demand relies upon the working of urban setting and its monetary limit. (Collins et al., 2000). It is assessed that by 2050, half of India's populace will live in urban zones and will confront intense water issues. In India, 80% of urban populace has access to drinking water yet just 20% of the accessible drinking water meets the wellbeing and quality standards set by the WHO. (Singh, 2000).

Water shortage, which rises when demand surpasses supply, postures uncommon difficulties to human and natural security (Cheng and Zhao, 2006). Water shortage can possibly turn into a significant issue later on because of changes in atmosphere, populace and condition. The common water worry in numerous creating nations isn't just because of the constrained water sources yet different variables like poor dispersion efficiencies through city systems as a result of high water loss rate from conveyance frameworks and wastefulness of administration of water supply frameworks.

To overcome water scarcity problems, one should not go for supply management options by increasing the number of water sources but instead they should adopt demand side management options for better water management for increasing population to satisfy the water demands by using water efficiently.

1.5 Research Gap/Rationale

- All most all researchers study land use effect and water resources studies on river basin catchments, watersheds, and existing urban areas but few on future planned cities or declared smart cities
- No studies conducted on Amaravati capital city, which is declared as Andhra Pradesh capital on 2015 and also declared as smart city by union govt

1.6 Objectives

The present study was undertaken with the following objectives:

- To analyse the land use/land cover data of the study area for different years (2017, 2011, 2005, 1997, 1993)
- To predict the future land use/land cover up to 2050
- To assess the population and existing water sources of Amaravati
- To prepare urban water management plan for sustainable development of the study area

Chapter 2

REVIEW OF LITERATURE

2.1 Land Use/Land Cover Studies

The conceivable impacts of land use/land cover change and precipitation on spatio-temporal changes in extreme stream flows inside the watershed had been studied from 1992 to 2011. The outcomes demonstrate that land use and precipitation influenced stream discharge. The expanding urban advancement shows chance of about 37% of influencing outrageous stream streams inside the watershed. They presumed that inside the watershed, Land use/land cover change is the real supporter for expanded stream flow and potential flooding **(Lei et al., 2017).**

Dynamic of Land System (DLS) model can be used to simulate land use/cover and this study was simulated for the years of 2020 and 2030. For this reason, different financial and bio-physical datasets were arranged and after that incorporated into the model under three unique situations i.e. base line, monetary advancement and ecological insurance. They have utilized land use information, topographic information; soil characteristics information; climatic information and financial information. DLS model is a gathering of projects that mimics the land use flow in view of the given situation by breaking down reasons for the progression of land use examples to help land use administration choices.

To analyse the casual relationship between driving forces and the dynamics of land use change, they applied the logistic regression modelling using STATA software.

Although, DLS model has an effective framework for simulating the land system dynamics, the results should not be considered as the exact projection of future events. However, the results of this model suggest possible future patterns of land use change **(Omaid Najmuddin et al., 2017).**

2.2 Climate Change Studies

The connection between climate change and water assets, water circling reaction of climate change was reviewed in this study. They condense some investigation strategies for dissecting the effects of climate change on hydrology and water assets, for example, age innovation for climate change situation and hydrologic recreation. They expressed that the impact of climate change on water assets is a direct result of the water and water quality changes that caused by atmosphere factors (for the most part incorporates precipitation and temperature changes) and the examination of the effect of climate change on hydrology and water assets framework is principally through the basin temperature, precipitation and vanishing change caused by climate change, for example, to foresee the pattern may increment or abatement the overflow and its watershed water supply impact **(Nan, Y. et al., 2011)**.

The current writing on the reasonable monetary effects of climate change, acting through water free market activity impacts in particular waterway bowls, and the capacity of adjustment to moderate those effects was reviewed in this study. Likewise, audit what is thought about the reactions of water clients to water costs, non-value water preservation strategies, water exchanging, interest in and activities of capacity and movement framework, and trans boundary water allotment instruments. He described the potential commitments of connecting existing and new experimental research on water asset adjustment with IAMs **(Sheila M. Olmstead 2014)**.

The analysis of the effects of future climate change on water assets and extreme streams utilizing the Coupled Land surface and Hydrology Model Systems (CLHMS) was done and this model was created to foresee the 21st century climate change and water cycle change.
The CLHMS incorporate a vast scale land surface model LSX and a fine grid circulated hydrological model HMS. The coupling between the LSX and HMS depends on anticipated soil dampness and surface water depth. The land-surface models incorporate two-layer vegetation model, three-layer snow model and six-layer soil model; the hydrological models incorporate terrestrial hydrologic model (THM), groundwater hydrologic model (GHM) and channel ground-water interaction (CGI).

The outcomes exhibit that most of the GCMs have a better limit than imitate the temperature than that of precipitation. In perspective of the simulation capacity evaluation, the RCPs situations informational collection of perfect GCM was slant changed and used to drive the CLHMS. The effects of future climate changes on water assets and outrageous streams was inspected and gave diverse outcomes with utilizing RCPs on precipitation patterns and extraordinary flood occasion patterns increment or lessening on time scale **(Yongnan Zhu et al., 2016)**.

2.3 Combined Land Use/Land Cover and Climate Change Studies

The Dynamic Urban Water Simulation Model (DUWSiM) built up to join the urban water balance ideas with the land use elements model MOLAND and the climate model LARS-WG, giving a stage to long haul planning of urban water supply and water demand by breaking down the impacts of urbanization situations and climate changes on the urban water cycle.

This model gives the usefulness to surveying the liveability of brought together and decentralized water supply and water request administration alternatives in view of anticipated water request, storm water and wastewater age, entire life cost and vitality and potential for water reusing on an everyday time step. It joins urban land use change and climate change situations on a yearly basis for up to 20 years into the future.

The model offers the additional preferred standpoint of permitting examination of water administration choices in view of perceived manageability pointers, for example, entire life expenses and vitality, water request, accessible supply and wastewater generation. DUWSiM-WB runs on two-time steps; a daily time step (all water related processes) and an annual time step (Land use changes).

Results demonstrated that DUWSiM predicts storm water runoff and water request with great exactness. Future research potential outcomes incorporate extension of DUWSiM by fusing the displaying of groundwater, contaminant adjusts and a disaggregated water demand module which would catch a greater amount of the many-sided quality engaged with evaluating water request. Future research could give understanding into how urban water assets effect on urban improvement, which would enable further advancement of DUWSiM to incorporate demonstrating the impacts of water assets on urban advancement designs **(Lars Willuweit et al., 2013)**

An incorporated demonstrating system connecting urban-land development, water-assignment, and hydrological forms and inspect the joined effects of the adjustments in land use/land cover and financial movement because of urbanization and in climatic conditions on water assets was used in the Heihe River Basin over the time of 2010-2050.

The integrated framework can fill in as a valuable device to look at the effect of different advancement situations with the point of effectively allotment water assets and expanding water utilize proficiency. The hydrological impacts of changes in land use land cover and climatic conditions were displayed utilizing a basin-scale hydrological model, generally utilized as a part of the evaluations of water amount and quality.

Forecasts of urban development and urban land extension at 2050 were performed utilizing ordered weighted harmonic averaging (IOWHA) administrator mix model and dynamics of land system (DLS) model separately. Future water interest for the forecasted urbanization was resolved and water portion was enhanced and surveyed utilizing a computable general equilibrium (CGE) model. The integrated framework developed here can be used for other basins elsewhere with similar characteristics of the mentioned study area **(Feng Wu et al., 2015).**

2.4 SWAT Studies on Water Balance

The pertinence of SWAT model for the territory which experiences hydrological information shortage was assessed. The model was utilized to survey the effect of precipitation, temperature, and CO_2 focus changes on the water balance of the watershed. They expressed that there is a need exists for watershed model improvement in the windward, wet side of the islands that will be extremely delicate to climate change, as a basic assignment for a coordinated water assets administration, climate change affect appraisal, and versatile procedure to climate change.

The study addressed two things – evaluate the applicability and suitability of the SWAT model for stream flow simulations under scarcity of hydrological data; assess the impact of 3 different climate variables (rainfall, temperature and CO_2 concentration) change on the water balance components in the watershed.

The nature of existing precipitation information from the adjacent stations is imperative that is the reason they considered the little size of the watershed representing precipitation information changeability. Encourage change in modelling can be accomplished if great quality and well-represented climate information are utilized. Establishment of hydro-meteorological stations to catch fluctuation inside the study site would help any further investigations.

The water balance segments were sensitive to precipitation change when contrasted with temperature change and increment in CO_2 fixations. All the more critically, the groundwater stream part will be contrarily affected by the anticipated precipitation and temperature changes. They presumed that the anticipated situations may antagonistically influence the groundwater supportability of the watershed.

Lastly, the adapted SWAT model is a useful tool for assessing water resources availability and assessing climate change scenarios provide useful information for evaluating the future freshwater availability and designing appropriate climate change mitigation measures **(Olkeba Tolessa Leta et al., 2016).**

2.5 Water Demand Management and Low Impact Development Studies

The rainfall time series in conjunction with appraisals of residential water appliance use created by Monte-Carlo re-enactment strategy and the model demonstrates that adjustments in the traits of family unit inhabitancy, rooftop territory, apparatus write and capacity volume of a solitary store reuse framework influences the water sparing proficiency was used. With combined grey water and rainwater, the storage size of range 0-100 litres shows the greatest rate of increase of efficiency. Further analysis showed that up to 80% savings of the WC flush water can be achieved with less than storage of 50 litres. He concluded the importance of small volume domestic water reuse systems are better solutions in the urban housing environment towards a more sustainable city **(Dixon, A. et al., 1999).**

The importance of low impact development (LID) over traditional storm water design was stated in this study. Porous pavements are very much effective in infiltrating storm water runoff. He founded that the green roofs were able to retain more percentage of rainfall (an average of 63%) in the different variety of climates. The study showed that bio-retention and pervious pavements will able to infiltrate even with the presence of ground frost **(Dietz, M.E. 2007)**

The joined utilization of elective water supplies together with water effective machines can set aside to 77% or add up to consumable water utilize was demonstrated in this study. They additionally expressed that the utilization of rain water inside the home alone set aside to 40% of consumable water utilize. Aside from water savings, waste water release sparing can be accomplished using water protection methodologies and grey water reuse. They revealed that the reusing grey water is most elevated for watering gardens and flushing toilets yet it dynamically diminished with expanding individual contact with grey water **(Muthukumaran, S. et al., 2011).**

The prerequisite of high determination end utilizes water utilization information to survey water funds in family units utilizing proficient gadgets and to see how reserve funds fluctuate between various socio-statistic bunches in the group has been highlighted in this study. They expressed that the smart metering has empowered the gathering of end utilize water utilization information. They presumed that savings accomplished through water demand management programs have a stream on advantage to the whole water and waste water framework by decreasing the pinnacle hour consumable water demand, diminishes normal and peak effluent loading to the waste water framework **(Willis, R. M. et al., 2013)**

The complete literature review depicts that most urban saturated cities are facing water problems due to improper management of water resources and urban water demand. The climate change studies reveal that the effect of climate change variables will be more on water availability on rivers and precipitation. The Land use/land cover studies clearly showed the impact on water resources of urbanized areas. Various studies depicted the importance of demand side management to reduce the water demand and save the water.

In the present study, an attempt made to prepare past and present land use/land cover maps in view of all these impact factors on water resources for a future planned sustainable smart city, Amaravati, capital city of Andhra Pradesh, because impact studies of land use/land cover, climate change on water resources and importance of water demand management options are not considered at planning stage by many planners.

The study also incorporates the comparison studies of cities in view of population and drinking water scenarios to set some future goals for the planners and learn lessons from the cities facing problems on water sector and for not making the Amaravati city as water scarcer.

Finally, the study recommended some water demand management options to be implemented to cut the number of sources of water supply which are planning to construct in future by the government of Andhra Pradesh.

Chapter 3

STUDY AREA AND DATA

3.1 Description of Study Area

Government of Andhra Pradesh has set out on advancement of the new Capital City of Andhra Pradesh, which is envisioned to be the pioneer Smart City of India. It means to be world class and at standard with the guidelines put forward by nations such as Singapore.

Proposed Capital City is named after historic site of Amaravati, known for its Buddhist culture that flourished from 400 BC to 1100 AD. The site is located on the southern bank of Krishna River in Guntur District at 16.54 N latitude and 80.52 E longitude. The elevation of this area ranges from 4 to 261 m and annual rainfall varies between 965 mm and 1222 mm.

Areal extent of the Capital City is 217.50 sq.km which is carved out through voluntary Land Pooling System (LPS) of mainly green fields (agricultural land) and 29 existing village hamlets. Amaravati, capital city of Andhra Pradesh, declared as smart city on June, 2017. The urban sustainability framework set by the govt. for the capital city is presented in the Figure 3.1. The study area map is shown in the Figure 3.2.

Figure 3.1 Urban sustainability framework of Amaravati

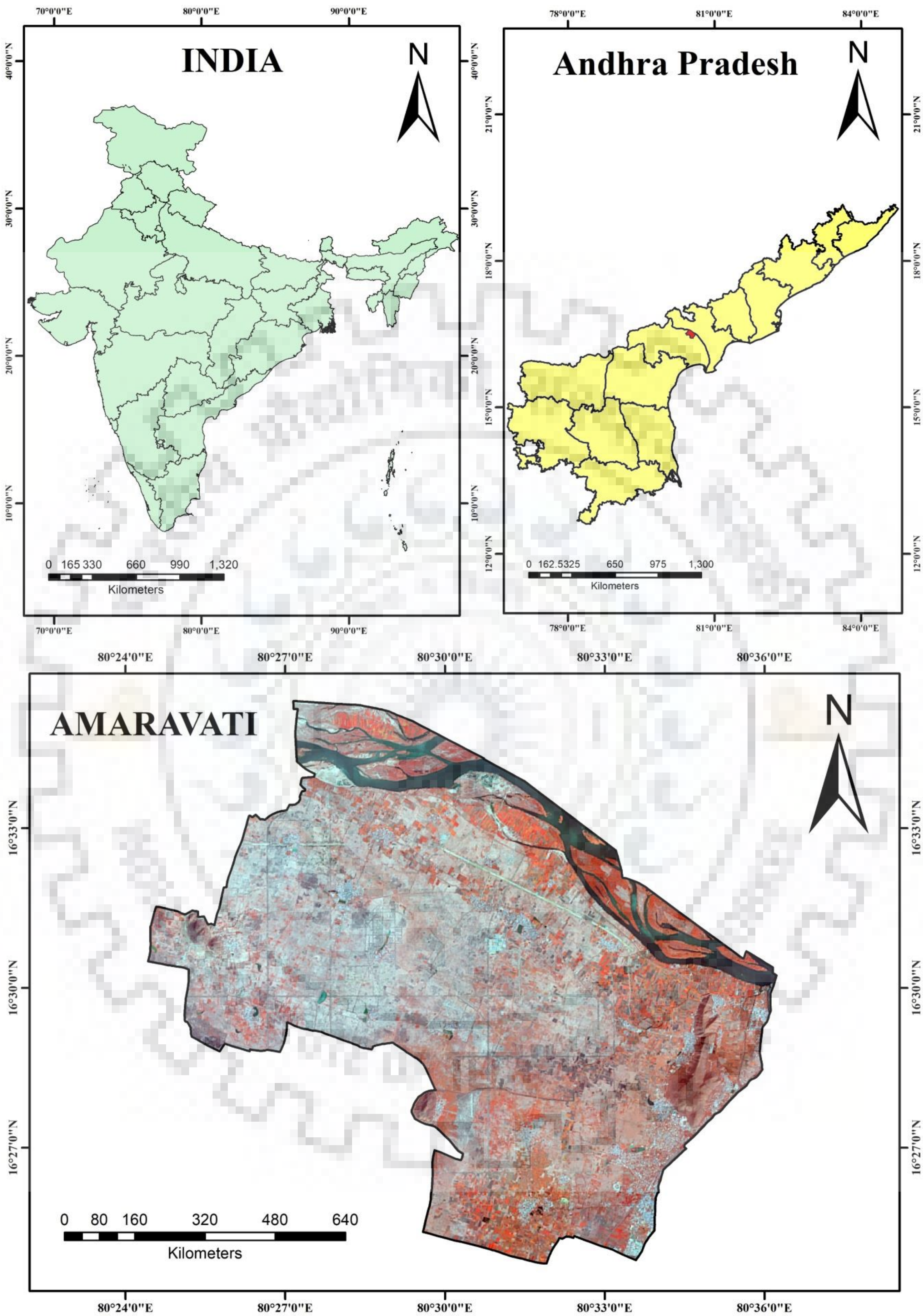

Figure 3.2 Description of study area

3.2 Data Used

Land use and land cover data for 1993, 1997, 2005, 2011 and 2017 were obtained from United Stated Geological Survey Database (www.earthexplorer.usgs.gov) with a resolution of 30m. The path and row of the satellite images for the study area are presented in Table 3.1. The details of the different satellite images sensors, date of image taken are presented in Table 3.2.

Table 3.1 Path and Row number of satellite images

Path No	Row No
142	49

Table 3.2 Different sensors and date of image taken for satellite images

S. No	Sensor	Date of Image taken
1	Landsat 8	25-03-2017
2	Landsat 7	19-10-2011
3	Landsat 7	11-05-2005
4	Landsat 4-5	14-02-1997
5	Landsat 4-5	11-06-1993

The Digital Elevation Model (DEM) was obtained from NRSC-Bhuvan open data archive (www.bhuvan.nrsc.gov.in/bhuvan_links.php) developed by Indian Space Research Organization. Shape-file layers of Amaravati were obtained by digitized the master plan developed by Andhra Pradesh government using Arc GIS. Shape-file layers of India were obtained from DIVA-GIS open data source (www.diva-gis.org) and also from www.indianremotesensing.com. Census data of Indian government were used for comparison studies. The recent road lines base map of Amaravati was obtained from open data source through QGIS software.

The software's and Models used in the study are ArcGIS, ERDAS and TerrSet.

Chapter 4

METHODOLOGY

4.1 GIS Data Preparation

Amaravati boundary shape file was prepared by digitizing the master plan using poly line editor tool in Arc GIS and it was projected in to UTM Zone 44N. The recent road lines base map of Amaravati was obtained in multiple layers as poly lines, polygons, points. The road line map should contain poly lines, the other features were deleted in QGIS software using editor tool. The Andhra Pradesh shape file was prepared from Indian shape file obtained from DIVA-GIS by selecting the all districts of Andhra Pradesh in attribute table and then made using clip tool in Arc GIS and given coordinate system as GCS 1984.

4.2 Past Land Use/Land Cover Files Preparation

The satellite images of Amaravati were downloaded from USGS Earth Explorer. The 2017, 2011 images were obtained from Landsat 8; 2005, 1997 images from Landsat 7 and 1993 image obtained from Landsat 4-5. The data from sensors was obtained in 12 single bands and single composite band of each time period image was prepared using stack tool in ERDAS. The image quality (Edge Enhancement) of five images was increased using convolution tool in ERDAS without changing the pixel size.

The land use/ land cover classification maps can be prepared in three ways, supervised classification; unsupervised classification and combined classification. The present study adopted combined classification for better accurate results. Firstly, using unsupervised classification tool (present in Raster Tab) in ERDAS, the study classified the entire satellite image into 150 classes and converted in grey scale using grey scale color scheme options. Secondly, using Google Earth Pro, synchronized and linked with the satellite image, which was opened in ERDAS, select the pixels of specific class by holding left click, drag and move and assigned specific color using attribute table. Repeat the same procedure by identifying and assigning specific color to the specific classes.

After this, the post correction procedure was followed to minimize the errors of classified one class pixels to another class by drawing a polygon around the error area and changed the class value using recode tool (present in Thematic map Tab) in ERDAS. The same procedure was followed for five different time period satellite images and finally obtained five land use/land cover maps. The present study area land use/land cover classified into five defined classes, water; urban; agriculture; forest & plantation and barren land.

4.2.1 Preparation of past land use change data

The study area land use classified images were extracted from the whole classified satellite images using extract by mask tool in Arc GIS with the Amaravati boundary shape file.

The change of pixels from one class to another class for the two different years was obtained using Matrix Union tool (present in Raster Tab-->Thematic) in ERDAS. This output file opened in Arc GIS and copied all the pixel values from one class to another class for the respective years in to excel and area was computed by multiplying the pixel count with spatial resolution (30X30) and unit multiplication factor to get in desired units (sq.kms). The percentage change of area for five classes for the respective years was also computed.

The same procedure was used for all respective images and change analysis data was prepared for 1993-1997; 1997-2005; 2005-2011; 2011-2017 and 1993-2017.

4.3 Future Land Use/Land Cover Prediction Files Preparation

The future land use/land cover classification image was prepared using Markov chain Model by TerrSet Geospatial Monitoring and Modeling system software (Land Change Modeler (LCM)).

The Land Change Modeler (LCM) was an integrated software environment within TerrSet oriented to the pressing problem of accelerated land conversion. In LCM, tools for the assessment and prediction of land cover change and its implications were organized around major task areas: change analysis; change prediction and planning interventions. The complete flow chart for visualization of LCM process is presented in Figure 4.1.

- Change Analysis: Analyzing past landcover change
- Transition Potentials: Modeling the potential for land transitions
- Change Prediction: Predicting the course of change into the future

The land cover maps used by LCM must be formatted to meet the following conditions:

- The legends in both maps should be same
- The categories in both maps should be same and sequential
- The backgrounds in both maps should be same and have a value of zero
- The spatial dimensions, including resolution and coordinates, should be same

Change Analysis, Model Training and Validation

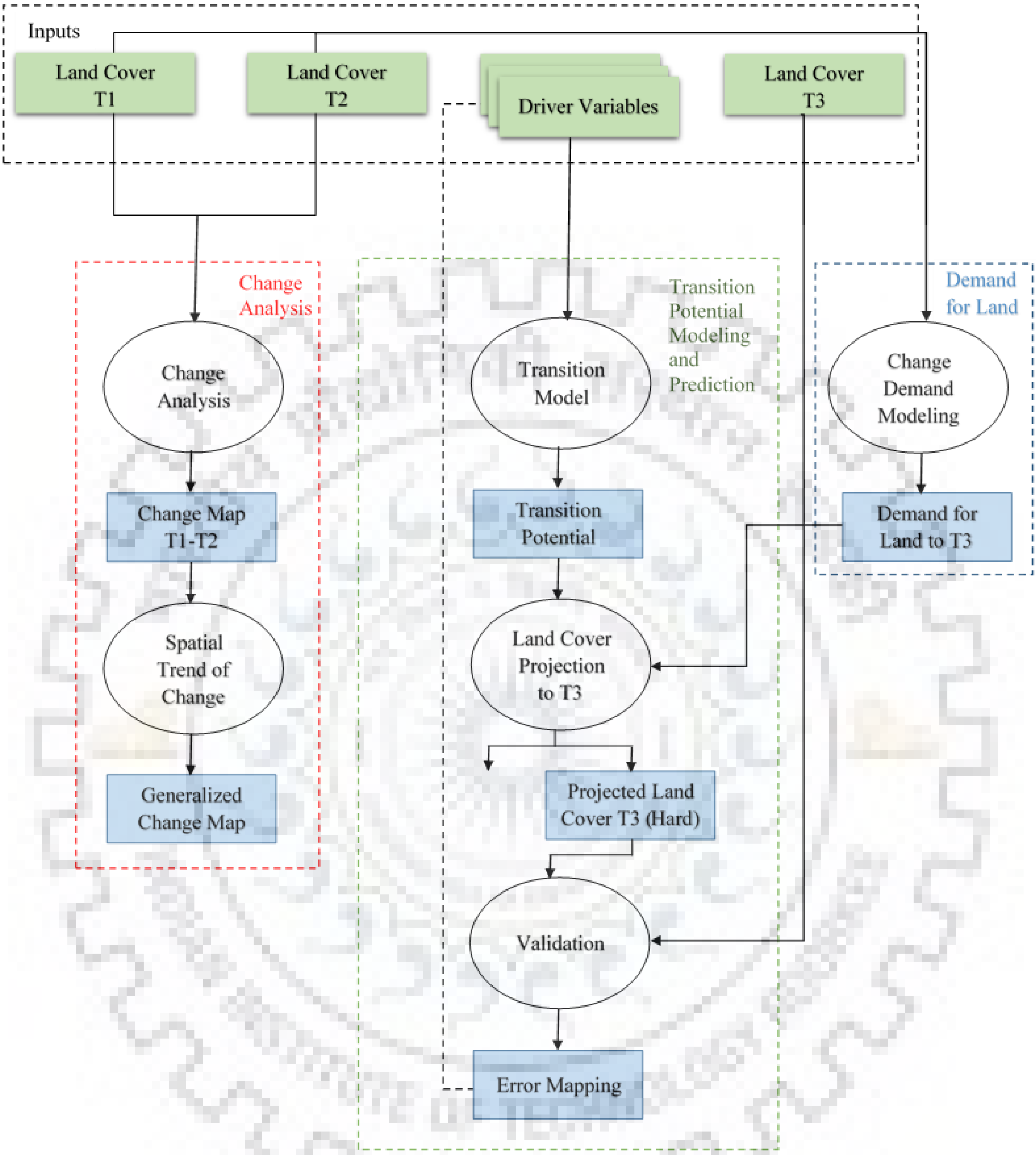

Figure 4.1 Flow chart for visualization of LCM process

The default procedure for determining the amount of change that will occur to some point in the future was by means of a Markov Chain.

Markov model was a stochastic model portraying a grouping of conceivable occasions in which the likelihood of every occasion depends just on the state achieved in the past occasion. Using the earlier and later land cover maps along with the date specified, Markov figures out exactly how much land would be expected to transition from the later date to the prediction date based on a projection of the transition potentials into the future. Note that this was not a simple linear extrapolation, since the transition potentials change over time as the various transitions in effect reach an equilibrium state.

The input files (called as variables) required for the prediction were Digital Elevation Model (DEM); Slope map; Distance_Urban map; Distance_Road map; 3rd degree polynomial spatial trend of change from all to urban map and latest land use/land cover image. All maps converted into .rst extension files using TerrSet and all were prepared as reclassified images using reclassify tool in Arc GIS.

4.3.1 Preparation of input files

4.3.1.1 DEM file

The downloaded tiles of DEM from NRSC-Bhuvan were mosaic using mosaic to new raster tool in Arc GIS (present in Data Management Tools->Raster->Raster Dataset) and extracted using extract by mask tool with Amaravati shape file and then converted into projected coordinate system UTM Zone 44N.

4.3.1.2 Slope map

From the study area DEM file, the desired slope map was obtained using slope tool (present in Spatial Analyst Tools->Surface) in Arc GIS.

4.3.1.3 Distance_urban map

The latest land use map is reclassified into single urban class by assigning all class values as No_Data leaving only urban class using reclassify tool. Then with that output file, the distance_urban map was prepared using Euclidean Distance tool (present in Spatial Analyst Tools->Distance) in Arc GIS and kept the processing extent and masking same as Amaravati boundary shape file.

4.3.1.4 Distance_road map

Using the latest road lines map of Amaravati, the distance_road map was prepared using the same Euclidean Distance tool (present in Spatial Analyst Tools->Distance) in Arc GIS and kept the processing extent and masking same as Amaravati boundary shape file.

4.3.1.5 Third order polynomial spatial trend of change map

With the two-land use/land cover images given as input in Land Change Modeler, TerrSet, the all to urban map trend was obtained in the spatial trend of change under change analysis tab with order of polynomial set as 3rd.

The present study used 1993 as earlier land cover image and 2005 as later land cover image in the Change Analysis tab of LCM. In Transition Potentials tab, four transition sub-models were evaluated; water_urban; agriculture_urban; forest & plantation_urban; barren_urban and gave six variables as driving variables for the change in urbanization. The transition sub-model ran using MLP Neural Network with 1500 sample size per class for 10000 iterations.

MLP (Multi-Layer Perception) neural network has been extensively enhanced to offer an automatic mode that requires no user intervention. In addition, it provides valuable information about the contributions of explanatory variables. With MLP, multiple transitions can be grouped into a single sub-model if it was considered that they all result from the same underlying driving forces. Only MLP can be used to model multiple transitions in one sub-model.

In this LCM, MLP was operated in automatic mode whereby it makes its own decisions about the parameters to be used and how they should be changed to better model the data. Automatic mode monitors and modifies the start and end learning rate of a dynamic learning procedure. The dynamic learning procedure starts with an initial learning rate and reduces it progressively over the iterations until the end learning rate was reached when the maximum number of iterations was reached. If significant oscillations in the RMS error were detected after the first 100 iterations, the learning rates (start and end) were reduced by half and the process has started again.

Finally, in Change Prediction tab, the year 2050 was selected as prediction date and selected Markov Chain as change demand modeling and run the model.

Post correction was done for the 2050 predicted land use image with reference to the master plan designed by the govt. of Andhra Pradesh in ERDAS by assigning high density zones, medium to high density zones, govt. zones, educational zones, industrial zones into urban class and open & recreation zones into forest and plantation class. Based on the past change only, the model will predict the future change but Amaravati is a planned city, post correction in accordance with the developed master plan should be done to see the rate of change of urbanization.

4.4 Comparison Studies of Amaravati with Some Indian Bifurcated State Capitals

Andhra Pradesh state was bifurcated on 2014 and stated their capital city as Amaravati on 2015. To see the other Indian bifurcated state capitals water problems and do not want Amaravati city to face those things, a comparative study was done by selecting 3 Indian states which were bifurcated after the year 2000.

For this, the population data of selected state capitals was obtained from govt. of India census data and population forecasting studies done using Arithmetic Increase Method and Geometric Increase Method up to 2050.

4.4.1 Arithmetic increase method:

In this method, the average increase in population per decade was calculated from the past census reports. This increase was added to the present population to find out the population of the next decade. Thus, it was assumed that the population was increasing at constant rate.

Hence, dP/dt = C i.e., rate of change of population with respect to time was constant.

Therefore, population after n^{th} decade will be $\boxed{P_n = P + n.C}$ (4.1)

Where, 'P_n' is the population after 'n' decades and 'P' was present population.

4.4.2 Geometric increase method:

In this method, the percentage increase in population from decade to decade was assumed to remain constant. The population at the end of n^{th} decade 'P_n' can be estimated as:

$$\boxed{P_n = P\,(1+I_G/100)^n} \quad (4.2)$$

Where, I_G = Geometric mean (%)

P = Present population

n = no. of decades

The existing drinking water sources data of Amaravati were obtained from govt. open data source and analyzed the data to depict which source systems were using more by local population.

The past studies on Ranchi were collected based on literature review & govt. data and analyzed how growth rate impacted the water resources on the city and suggested some recommendations to Amaravati.

4.5 Quantification and Estimation of Suggested Water Demand Management Options

With the suggested water demand management options for the sustainability of Amaravati, the amount of water can be saved were quantified based on the recommended percentages from the literature review, in view of the planned targeted amount of water supply and projected population estimated by govt. of Andhra Pradesh.

The over all methodology as discussed in the present chapter is presented in Figure 4.2.

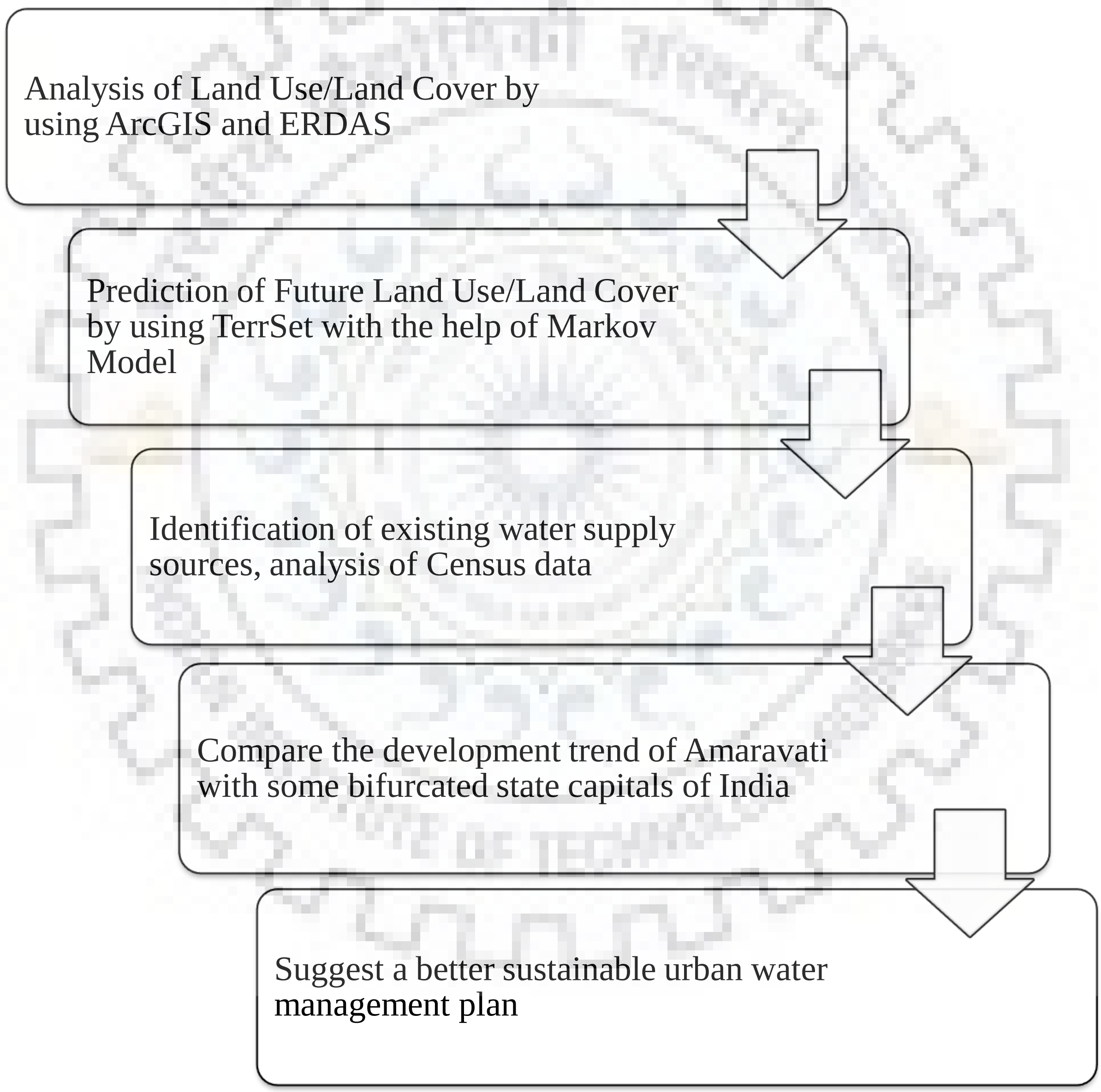

Figure 4.2 Flow chart of Methodology

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Past Land Use/Land Cover Analysis

With ArcGIS and ERDAS, the study analysed the land use/land cover data for the years from 1993 to 2017 to understand the land use conversion pattern for five land use/land cover types. The summary of land conversions has presented from Table 5.1 to 5.4.

From Table 5.1, the study observed negative percentage of change in water bodies, agriculture (very little change) and forest & plantation areas but barren and settlement shows some positive percentage of change for the period 1993-1997 (Figure 5.1 and 5.2).

Table 5.2 shows that the area of water bodies was drastically decreased and the remaining land cover areas showed positive change in which barren land showed greater percentage of change for the period 1997-2005 (Figure 5.2 and 5.3). Since river water was decreased and those areas were converted into barren, that's why the conversion change results showed the increase of barren land area. During this time period, the river faced some drought conditions and when cross checked with CWC Data (Figure 5.4), the results showed the decrease of water availability in river Krishna at the gauge station, Prakasam Barrage, Vijayawada, which was located besides the capital city.

Table 5.3 shows greater percentage of positive change in areas of water bodies and settlement but negative percentage of change in agriculture, forest & plantation and barren land areas for the period 2005-2011 (Figure 5.3 and 5.5). Greater percentage of water area change clearly reflects the high negative percentage of barren land change. There is significant increase in settlement area in this time period clearly understood that small developments had been started from this time period in the study area.

From Table 5.4, the study reveals that areas of settlement, agriculture and barren land substantially changed during the period 2011 – 2017 (Figure 5.5 and 5.6). After the capital city announced on 2015, the government started converting the agricultural land into flat and barren to start the constructional activities according to the master plan they developed. That's why; there is a drastic change from agricultural land to barren land. (The study considered 2017 was the intermediate stage of land cover change and took it as temporary change, so the flat converted agricultural land was termed as barren land cover).

Note: From Table 5.1 to 5.4, figures in the rows and columns represent area of each land type changed to others during the respective years. The bolded figures represent the area of land remained unchanged during the respective years. Figures in the last column represent the percentage of land use decrease or increase. It is calculated by dividing the difference of respective land use/cover and multiplied by 100.

Table 5.1 Area (km^2) of each land type changed to others during the year 1993-1997

Land type	Water	Settlement	Agr.	Forest & Plantation	Barren	Total (1997)	Change (%)
Water	**11.17**	0.04	0.73	0.58	0.41	12.94	-2.67
Settlement	0.02	**0.90**	3.69	0.35	0.10	5.07	2.38
Agr.	0.45	3.57	**165.54**	2.54	0.44	172.54	-0.45
Forest & Plantation	0.43	0.30	2.79	**10.54**	0.07	14.13	-1.36
Barren	1.22	0.14	0.57	0.31	**11.89**	14.13	9.45
Total (1993)	13.30	4.95	173.33	14.32	12.91	**218.81**	**---**

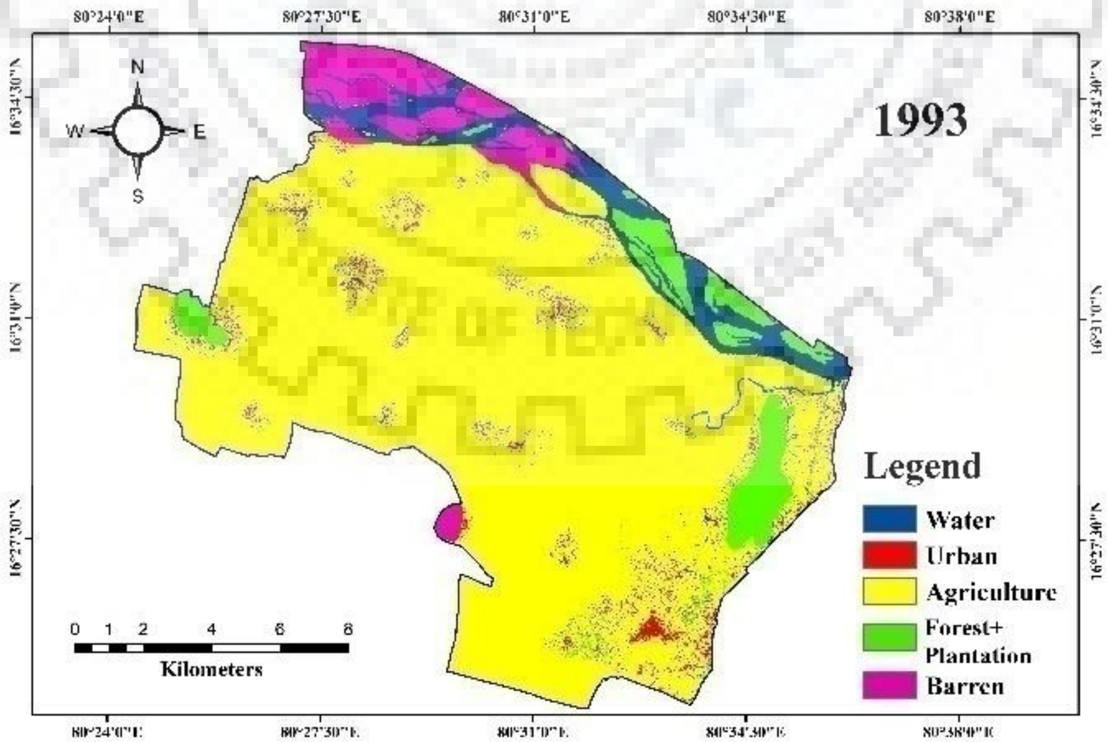

Figure 5.1 Land use/Land cover map of Amaravati in 1993

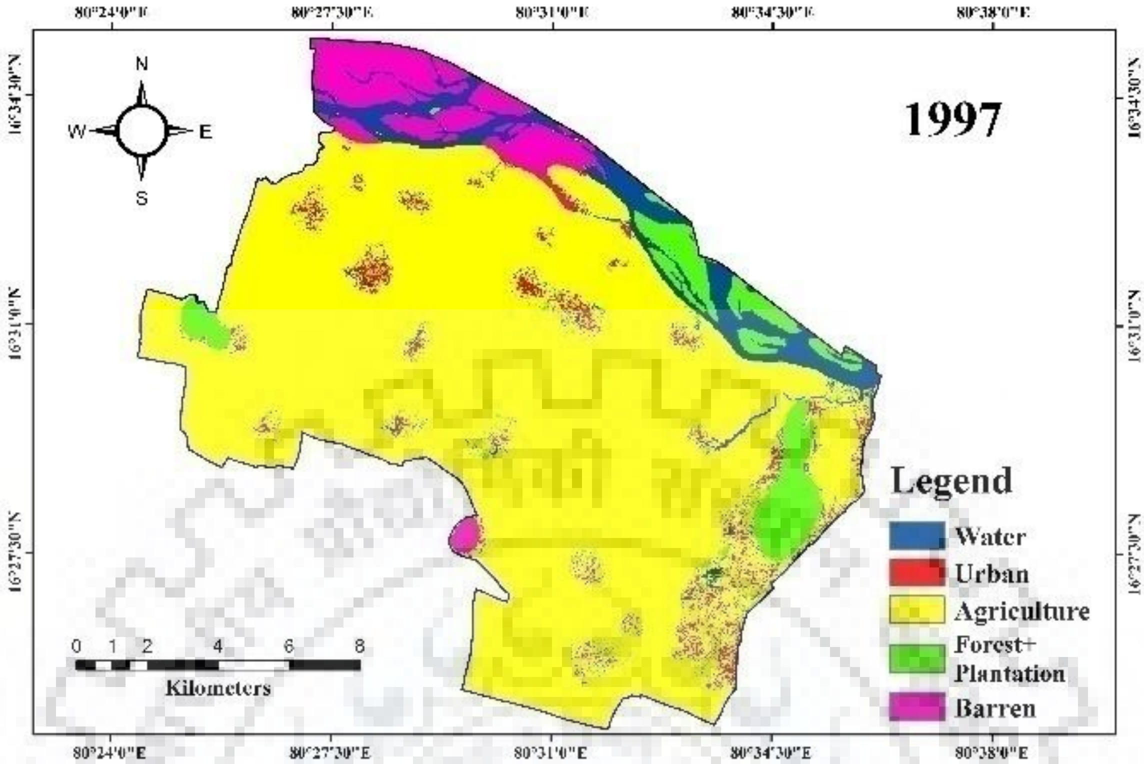

Figure 5.2 Land use/Land cover map of Amaravati in 1997

Table 5.2 Area (km^2) of each land type changed to others during the year 1997-2005

Land type	Water	Settlement	Agr.	Forest & Plantation	Barren	Total (2005)	Change (%)
Water	**6.97**	0.01	0.74	0.26	0.48	8.47	-34.59
Settlement	0.14	**1.18**	3.20	0.51	0.13	5.17	1.95
Agr.	0.82	3.65	**165.63**	3.15	1.25	174.50	1.14
Forest & Plantation	2.65	0.19	2.49	**9.50**	0.11	14.93	5.70
Barren	2.37	0.03	0.48	0.70	**12.15**	15.74	11.38
Total (1997)	12.94	5.07	172.54	14.13	14.13	**218.81**	**---**

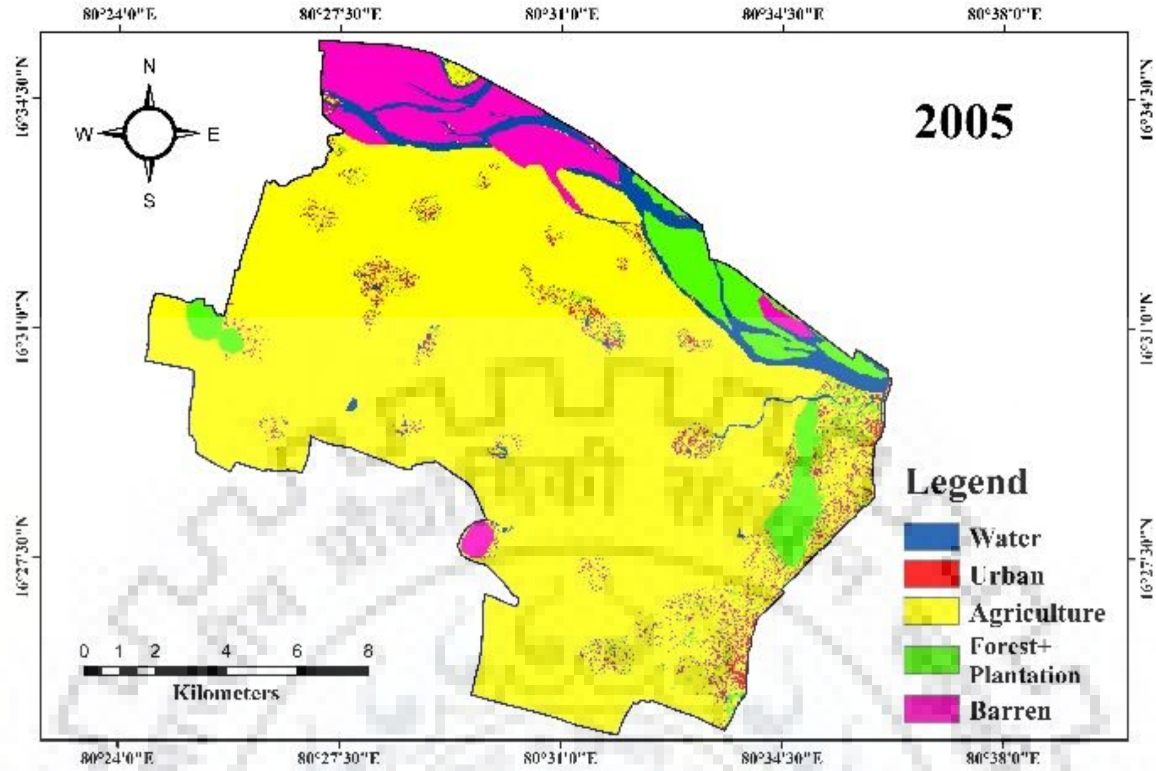

Figure 5.3 Land use/Land cover map of Amaravati in 2005

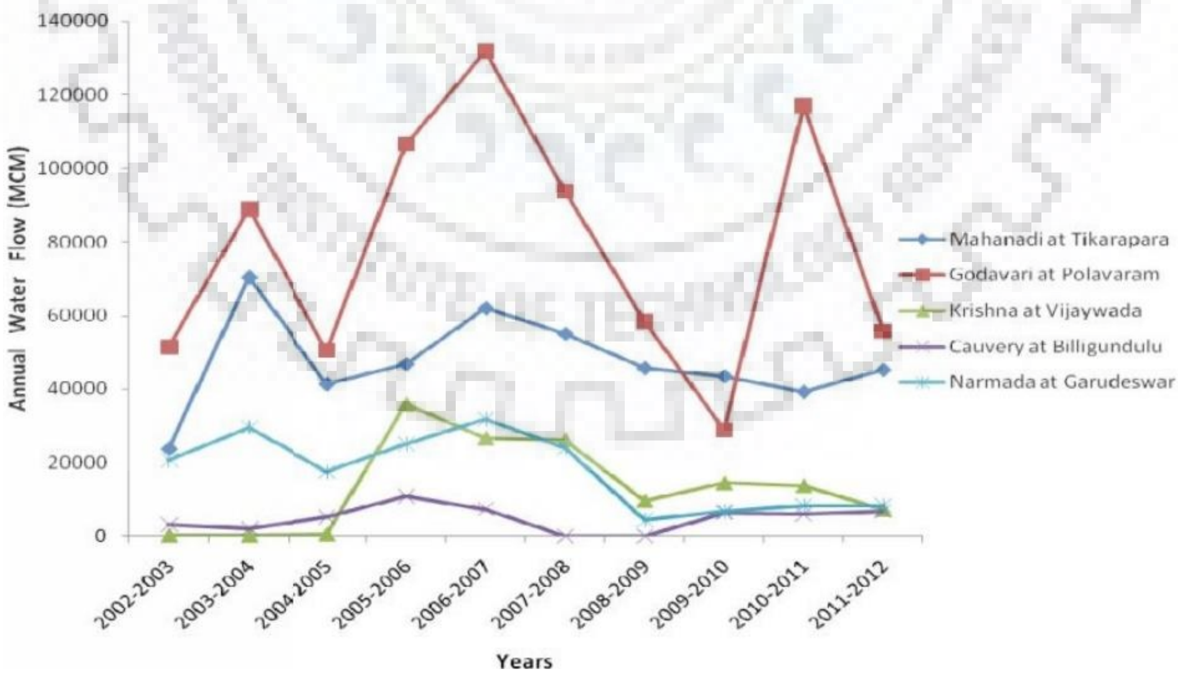

Figure 5.4 Some Indian rivers water availability at different gauge stations (CWC Data)

Table 5.3 Area (km^2) of each land type changed to others during the year 2005-2011

Land type	Water	Settlement	Agr.	Forest & Plantation	Barren	Total (2011)	Change (%)
Water	**7.34**	0.23	1.40	2.20	2.96	14.13	66.93
Settlement	0.02	**1.75**	6.11	0.42	0.21	8.51	64.65
Agr.	0.65	2.77	**163.21**	2.43	0.77	169.82	-2.68
Forest & Plantation	0.13	0.36	3.12	**9.36**	0.10	13.07	-12.50
Barren	0.32	0.06	0.67	0.53	**11.70**	13.28	-15.61
Total (2005)	8.47	5.17	174.50	14.93	15.74	**218.81**	---

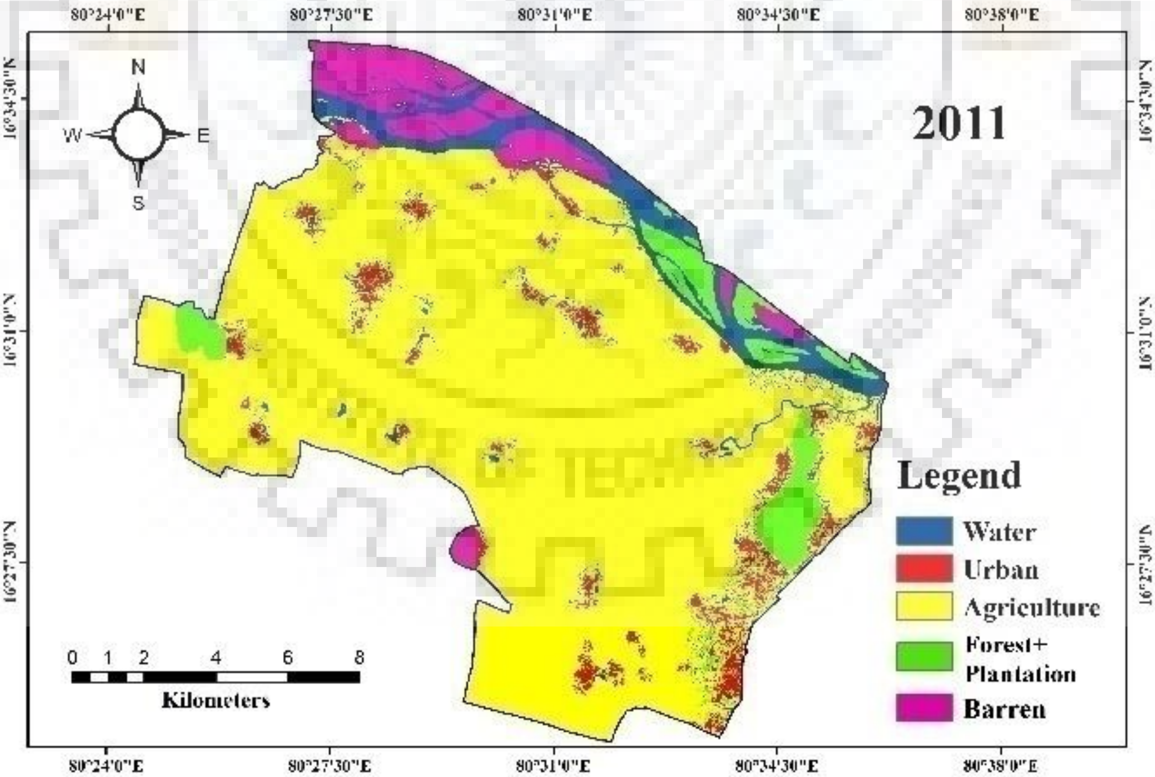

Figure 5.5 Land use/Land cover map of Amaravati in 2011

Table 5.4 Area (km^2) of each land type changed to others during the year 2011-2017

Land type	Water	Settlement	Agr.	Forest & Plantation	Barren	Total (2017)	Change (%)
Water	**11.40**	0.01	0.62	0.21	0.48	12.72	-9.99
Settlement	0.14	**3.81**	8.64	0.34	0.10	13.04	53.27
Agr.	0.44	1.83	**39.07**	1.40	0.48	43.23	-74.54
Forest & Plantation	1.07	0.30	5.41	**9.38**	1.63	17.80	36.21
Barren	1.08	2.55	116.08	1.73	**10.59**	132.02	893.96
Total (2011)	14.13	8.51	169.82	13.07	13.28	**218.81**	---

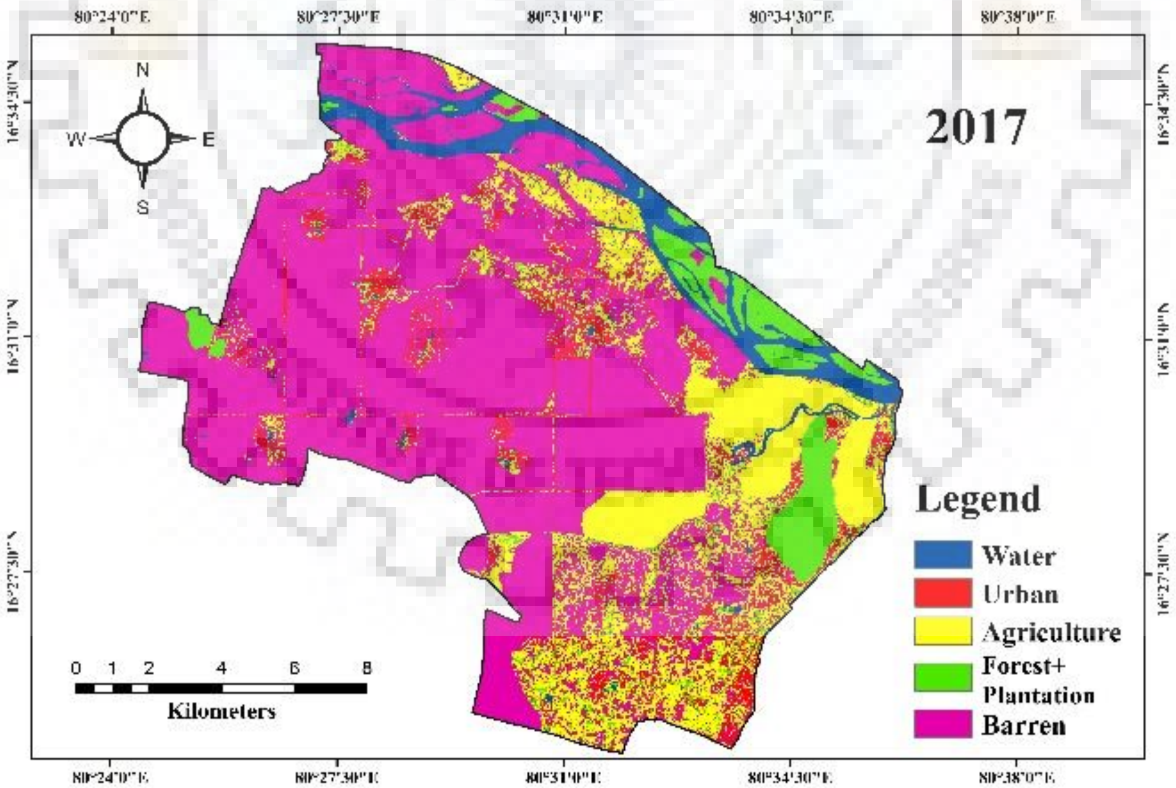

Figure 5.6 Land use/Land cover map of Amaravati in 2017

Table 5.5 shows the land conversion of Amaravati from 1993-2017. There was great percentage of settlement change and less negative percentage change of water bodies which shows that water bodies areas were stressed in the recent years. There was good percentage of forest & plantation area change shows that the people and govt. was concentrated more on greenery in the recent years. The reason for the greater percentage of areal change in agriculture and barren was explained earlier as 2017 was considered as temporary change since the flat converted agricultural land was termed as barren land cover.

Table 5.5 Area (km^2) of each land type changed to others during the year 1993-2017

Land type	**Water**	**Settlement**	**Agr.**	**Forest & Plantation**	**Barren**	**Total (2017)**	**Change (%)**
Water	**9.11**	0.03	1.05	1.26	1.26	12.72	-4.34
Settlement	0.06	**1.21**	10.77	0.73	0.27	13.04	163.41
Agr.	0.29	1.63	**39.53**	1.20	0.57	43.23	-75.06
Forest & Plantation	1.92	0.33	5.27	**9.47**	0.81	17.80	24.26
Barren	1.92	1.74	116.70	1.66	**10.00**	132.02	922.57
Total (1993)	13.30	4.95	173.33	14.32	12.91	**218.81**	**---**

The different land cover classes contributions to settlement for the different time periods have been shown in from Figure 5.7 to 5.11.

Figures 5.7 to 5.11 show that more agricultural land area was contributed to settlement with very less water bodies area contribution. Higher agricultural land contribution to settlement was observed during 2011 to 2017 and least contribution during 1997 to 2005. There was significant contribution from forest & plantation area to settlement also, higher areal conversion during 1997 to 2005 and least conversion during 2011 to 2017.

Note: The settlement area from Figures 5.7 to 5.11 were the unchanged area during the respective time period of land use change.

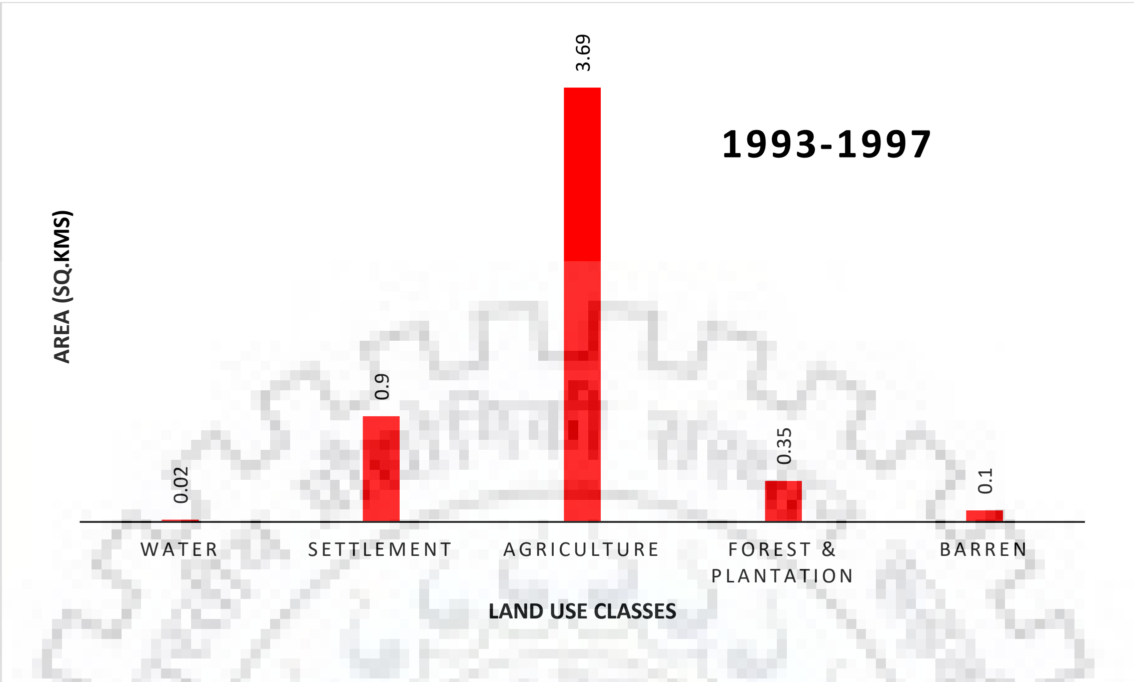

Figure 5.7 Areal contribution of all land cover classes to settlement during 1993 to 1997

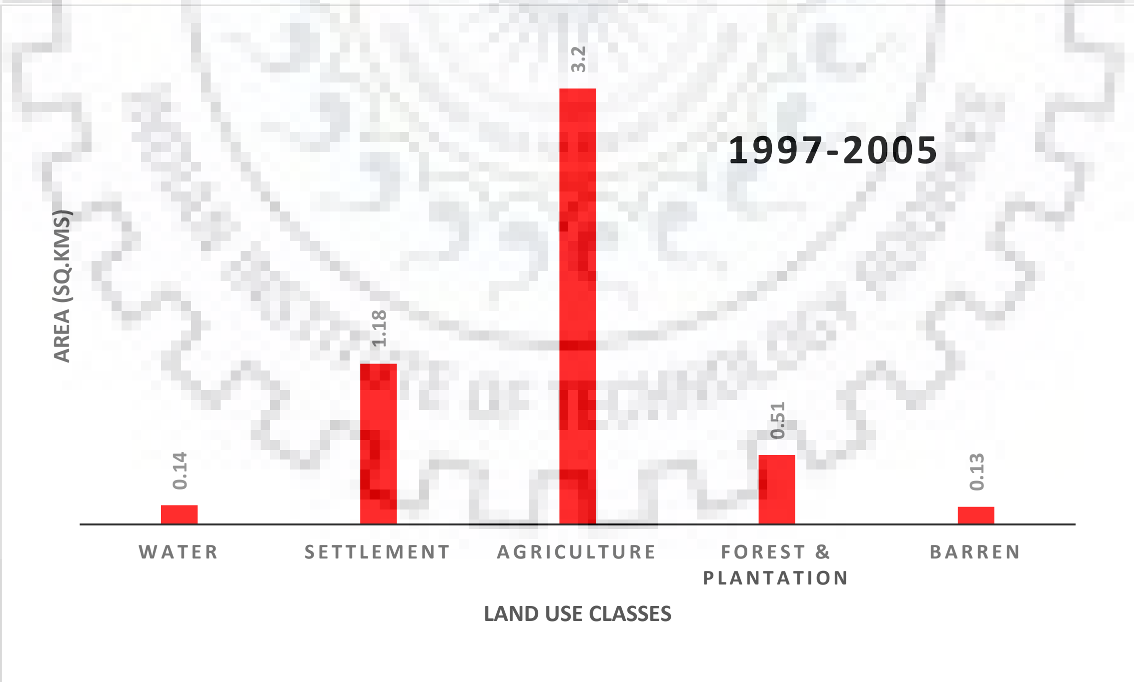

Figure 5.8 Areal contribution of all land cover classes to settlement during 1997 to 2005

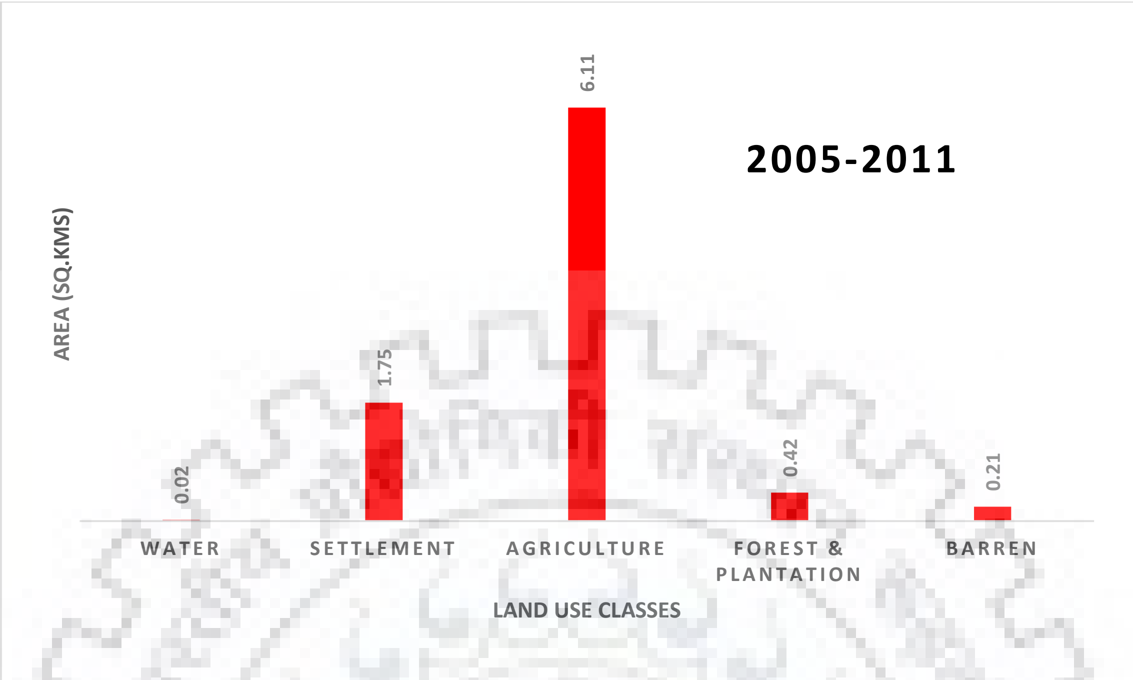

Figure 5.9 Areal contribution of all land cover classes to settlement during 2005 to 2011

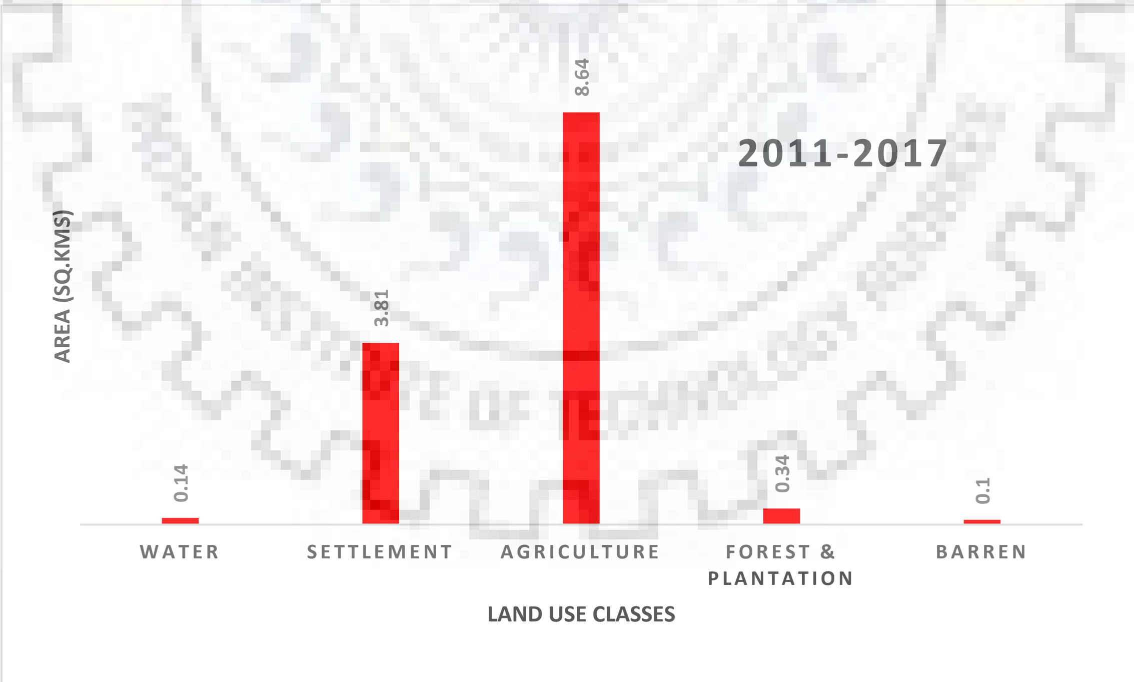

Figure 5.10 Areal contribution of all land cover classes to settlement during 2011 to 2017

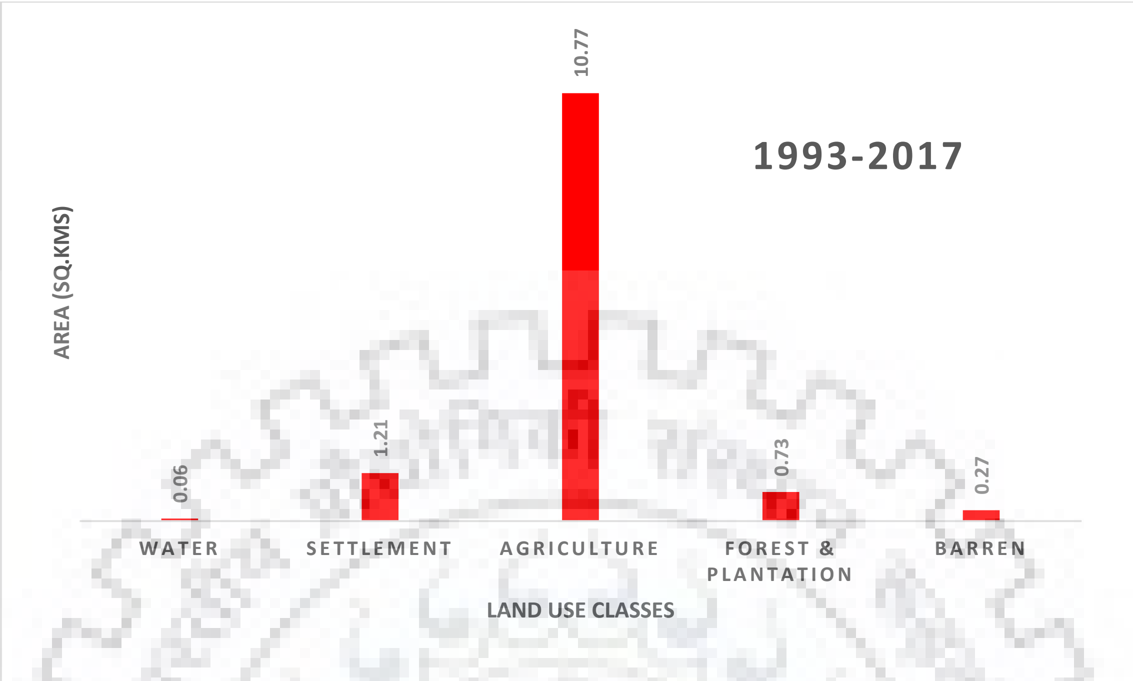

Figure 5.11 Areal contribution of all land cover classes to settlement during 1993 to 2017

5.1.1 Land use/land cover overall change analysis

The maps of land use/land cover for the study area have already been presented in the previous section (Figure 5.1 to 5.3; Figure 5.5 and 5.6).

The consolidated output of different classes of land use/land cover was presented in Table 5.6 and the variation of different classes has shown in Figure 5.12.

The results showed that settlement substantially increased from the year 2005. From 2011 to 2017, most of the agricultural land is converted to barren land due to selection of that area as capital city and started to prepare the land for construction by making flat and barren.

The land use/cover results showed the urban area change from 1993-2017 is 8.09 km^2, which is 3.7% for 24 years. So, urban area is growing at a rate of 0.33 km^2/year. Since, most of the area was covered in agricultural fields; the rate of urbanization was very low during 1993-2017.

Table 5.6 Area (km^2) of each land type for different years

Area (km^2)	1993	1997	2005	2011	2017
Water	13.30	12.94	8.47	14.13	12.72
Urban	4.95	5.07	5.17	8.51	13.04
Agriculture	173.33	172.54	174.50	169.82	43.23
Forest & Plantation	14.32	14.13	14.93	13.07	17.80
Barren	12.91	14.13	15.74	13.28	132.02

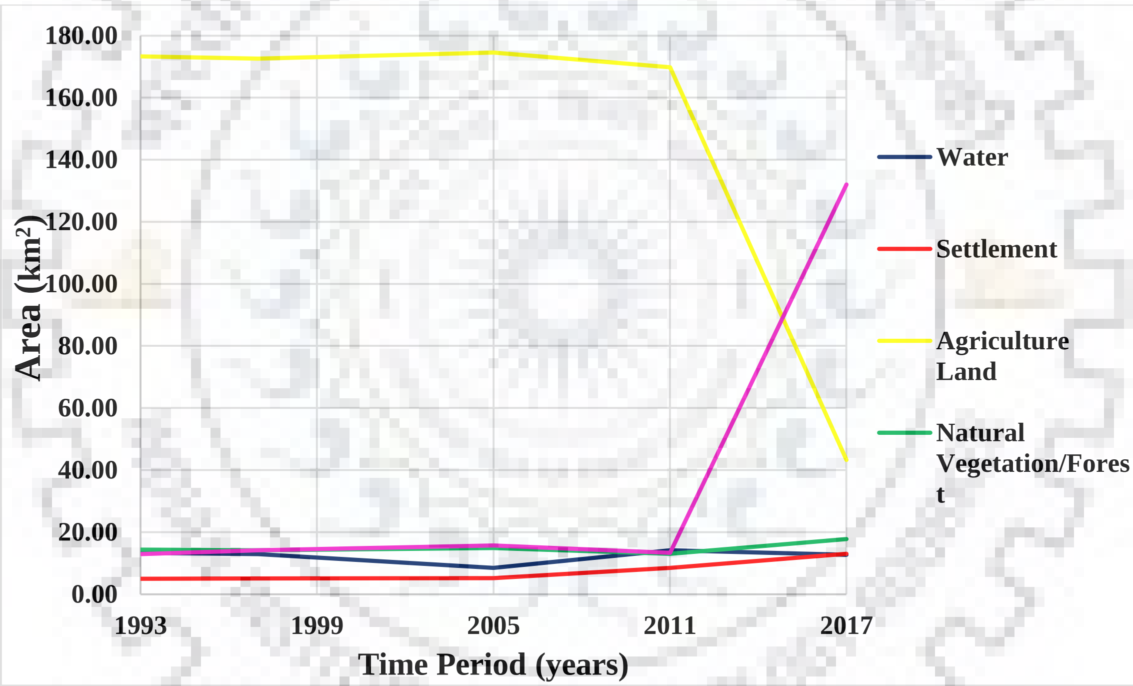

Figure 5.12 Change in area of five land cover types during the period of 1993-2017

5.2 Future Land Use Prediction

In the present study, future land use was predicted for the year 2050. For this purpose, the following are the input file maps for the TerrSet Model:

(a) DEM map

(b) Slope map

(c) Distance_road map

(d) Distance_urban map

(e) Cubic trend map of transition from all to urban

The input files prepared for the study area are presented in from Figure 5.14 to 5.17.

Figure 5.14 showed that almost all the area comes under the first category; 4-21m elevation. This depicts that the capital city area was almost flat surface, so that chances are more for urban flooding due to storm water. The values in the Figure 5.13 were represented in meters.

Figure 5.15 represents the slope map of the study area and complete area lies under the first category; 0-3.62 degrees.

Figures 5.16 and 5.17 show the distance map from roads and urban areas respectively, contains the measured distance from each cell to the nearest source, i.e. roads and urban areas.

Conceptually, the Euclidean algorithm works like that for each cell, the distance to each source cell is determined by finding the hypotenuse with *x_max* and *y_max* as the other two legs of the triangle (Figure 5.13). This calculation derives the true Euclidean distance, rather than the cell distance.

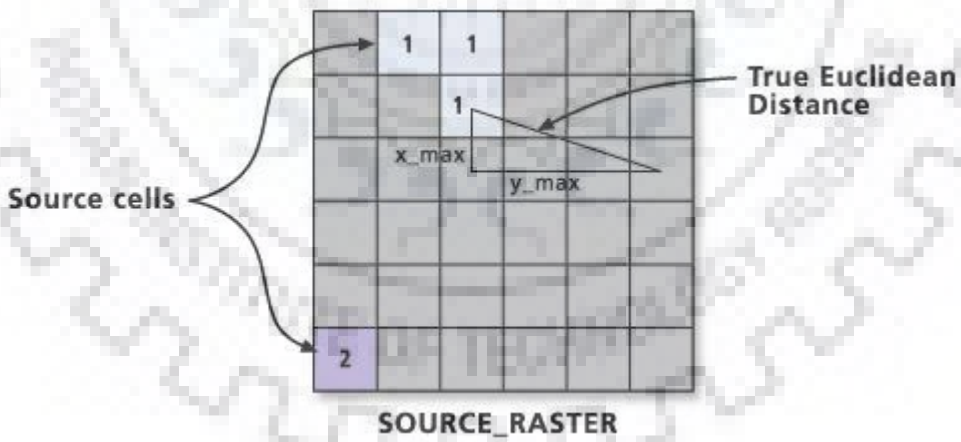

Figure 5.13 Determining true Euclidean distance

The areas having highest Euclidean distance value means that they were very far from the road network/urban areas. Figure 5.16 shows less percentage area lies in farthest from road networks. Figure 5.17 shows the significant amount of area lies in farthest from urban centres.

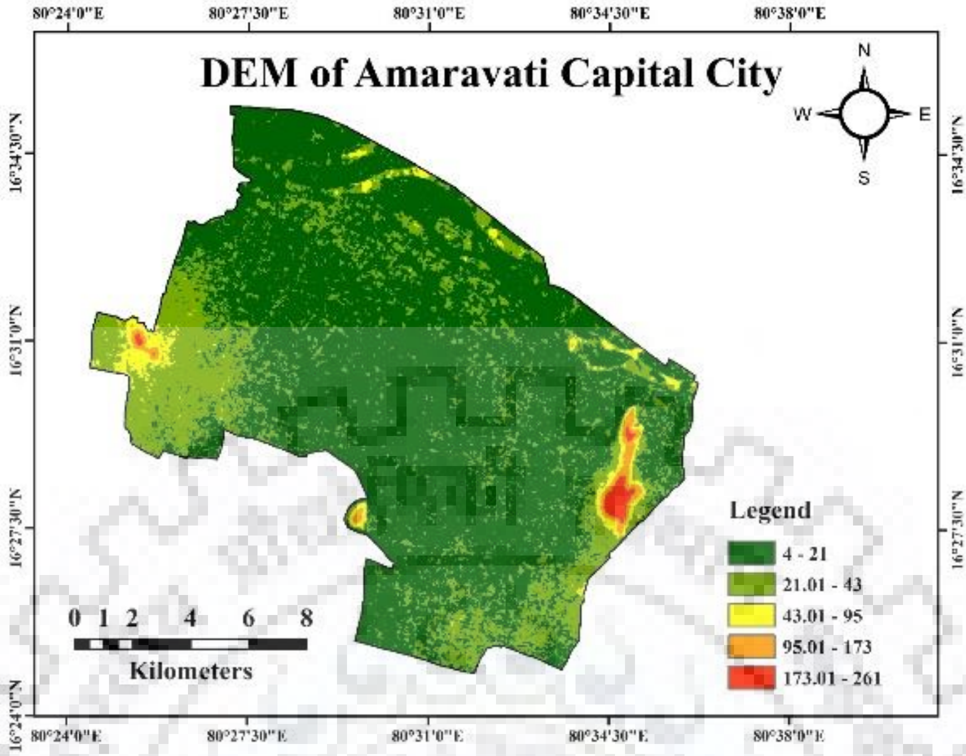

Figure 5.14 Digital Elevation Model of the study area

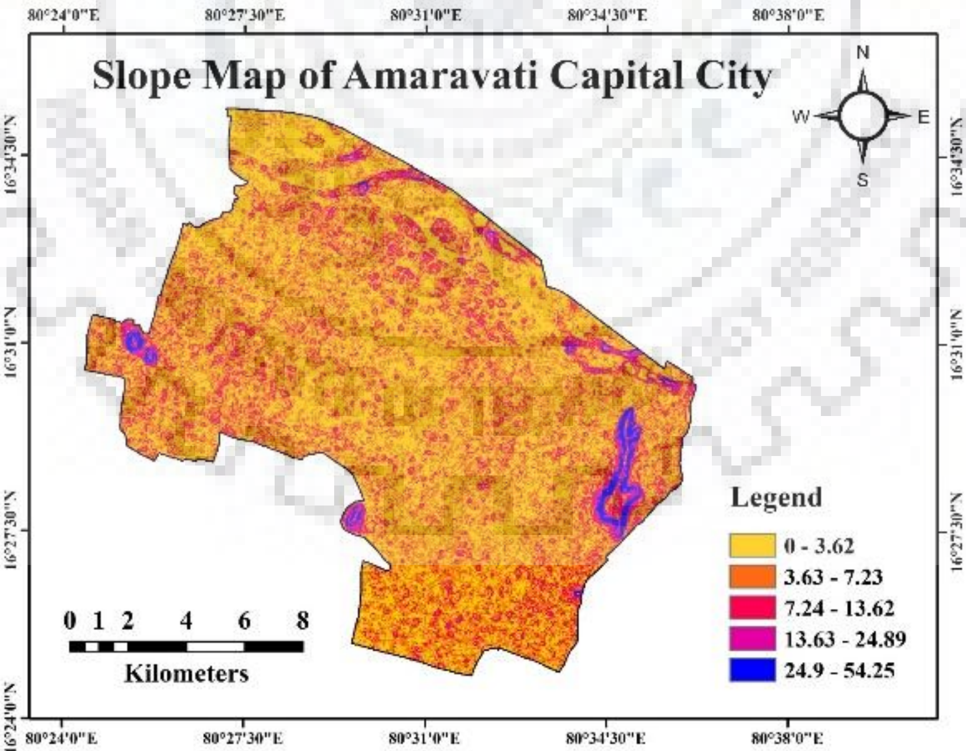

Figure 5.15 Slope Map of the study area

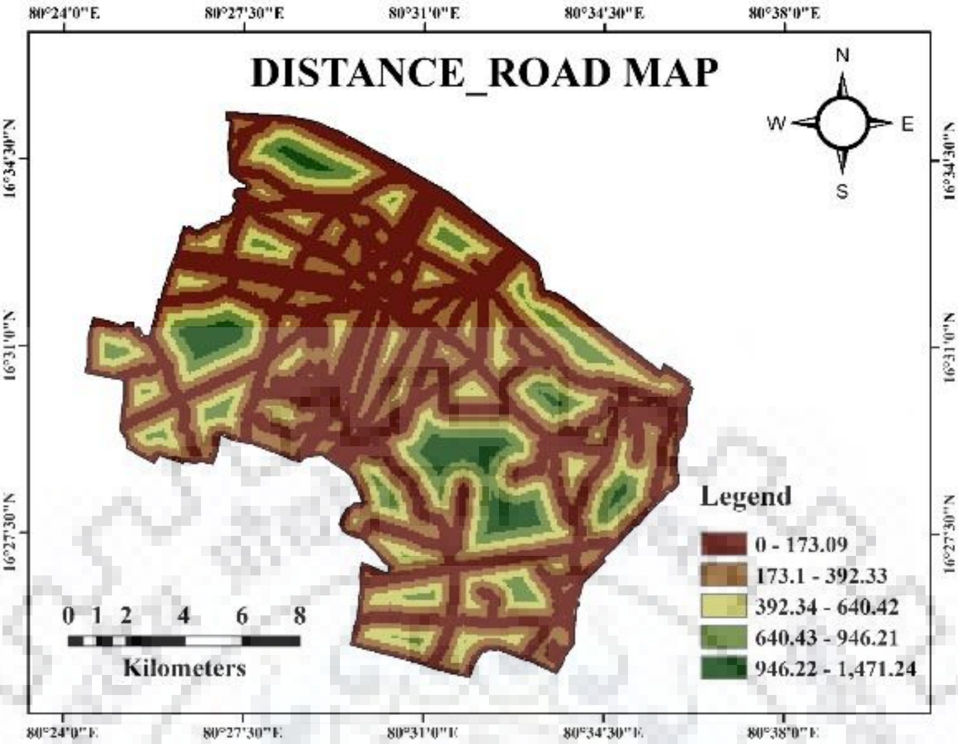

Figure 5.16 Distance_Road Map of the study area

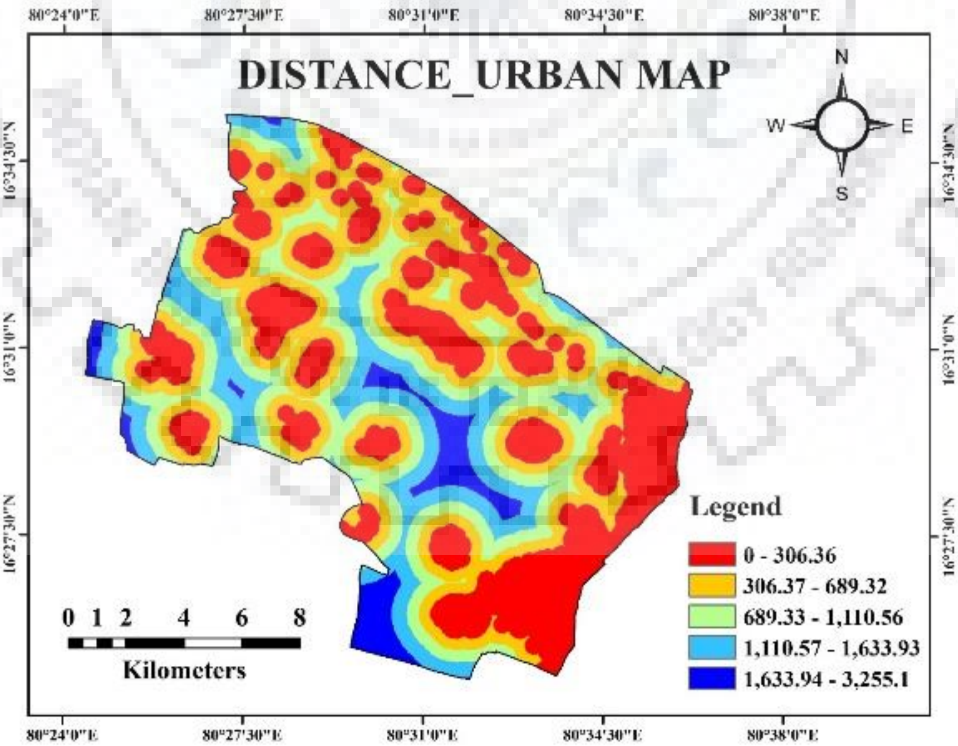

Figure 5.17 Distance_Urban Map of the study area

Figure 5.18 shows the cubic spatial trend map of transition from all land use classes to urban class. The intention of the spatial trend of change map is to provide the means of generalizing the pattern of change. The numeric values do not have any significance, rather than to provide an indication of more intense change (higher numbers, redder colours) or less intense change (lower numbers, darken green to blue colours). The output was a smooth surface which represents the gradual trends in the transition in land cover over all classes to urban class. This was the best fit polynomial trend surface to the pattern of change. The results showed that the right-side bottom and middle corner parts of the study area showed more prone to transitions.

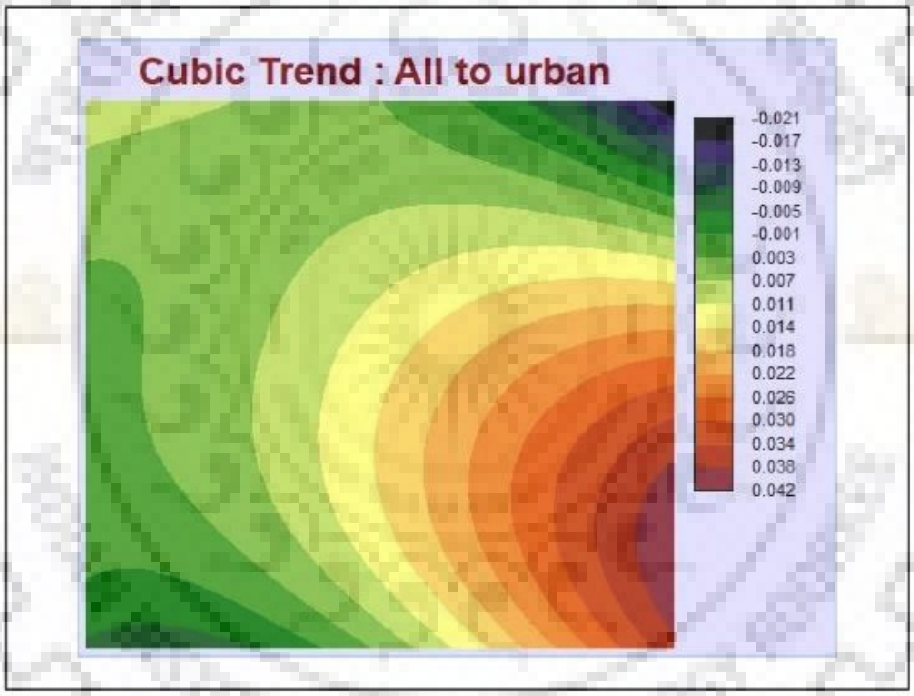

Figure 5.18 Cubic spatial trend map of transition from All to Urban

The results of predicted future land use/cover conversions are presented in Table 5.7. The results showed urban area change (land loss due to urban growth) from 2017 to 2050 is 58.63 km^2, which is 26.95% for 33 years. So, urban area is increasing at a rate of 1.77 km^2 per year. The urbanization rate is going to increase in future after developed as smart capital city and this much urbanization was not observed in past. During 1993-2050, the agriculture land was reduced by 72.59 km^2 area with the loss of 41.88%.

Urban development is the significant customer of land. In the U.S., it is evaluated that 100 m^2 of land for each sec is lost to urban use; Germany loses around 14 m^2 for every sec and Switzerland loses around 1 m^2 for each sec. By watching the inclination of land loss of Indian urban areas or real capital regions because of urban development, the information demonstrates that around 60.57 km^2 of land for each year was lost to urban use in New Delhi Region and its surroundings (National Capital Region), whereas Ahmadabad, Lucknow and Ranchi urban areas were losing 11.12 km^2 every year, 8.25 km^2 every year and 2.24 km^2 region for each year individually, which are generally high when contrasted with Amaravati capital city. The predicted land use/land cover map for the year 2050 is presented in Figure 5.19.

These past and future land use/cover studies are very useful for impact analysis on surface and ground water availability which in turn affects the water supply demand for the population. With these, the planner should develop water management plans in a sustainable manner in view of future population demand and supply analysis.

Table 5.7 Area (km^2) of each land type for the year 2050

Land use Class	**2050 Area (km^2)**
Water	7.90
Settlement	71.67
Agriculture	100.74
Forest & Plantation	23.07
Barren	15.40

Figure 5.19 clearly showed how much urbanization is going to happen in 2050. The right-side portion of the city (Mangalagiri municipality area) is going to be more urbanized. Secondly, the govt. is going to create more open and recreation places in and around the city for tourism purpose and these can be used for storm water management practices to reduce the impact of urban flooding on the city and can create more ground water recharge sites.

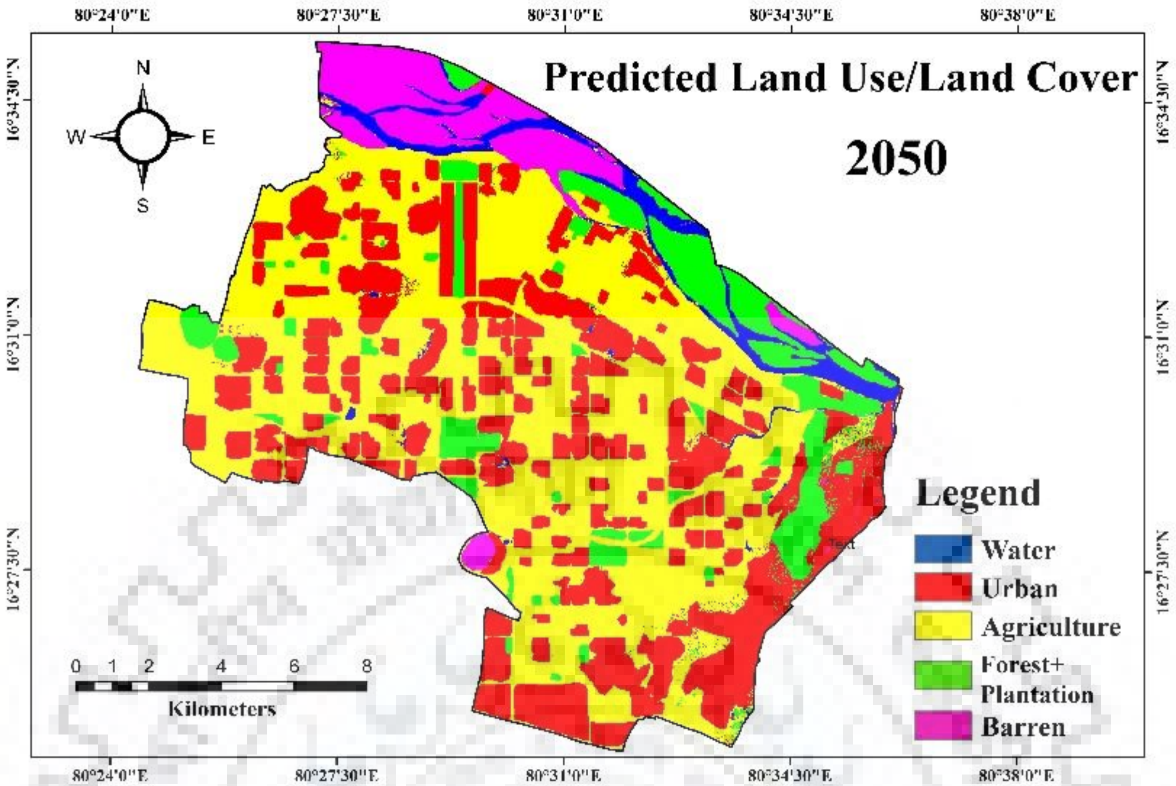

Figure 5.19 Predicted Land use/Land cover map of Amaravati in 2050

5.3 Comparison of Amaravati with Some Indian Bifurcated State Capitals

In the present study, it was considered to study the growth pattern of bifurcated state capitals. Thus, four states formed in past were considered, the details are given in Table 5.8.

Table 5.8 shows the state names, date of bifurcation along with capitals which compared with Amaravati capital city.

Table 5.8 Comparison states, their capitals and bifurcation date

State	Bifurcation Date	Capital
Uttarakhand	09-Nov-00	Dehradun
Chhattisgarh	01-Nov-00	Raipur
Jharkhand	15-Nov-00	Ranchi
Andhra Pradesh	02-Jun-14	Amaravati

5.3.1 Census data for 2001 and 2011

The census data of the four states for the years 2001 and 2011 are given in Table 5.9.

The data clearly depicts that percentage of change was more in view of Metropolitan outgrowth of cities. Raipur and Ranchi show more percentage of change compared to Dehradun which was hilly terrain city. The study reveals that Ranchi city's development as a modern urban focus started in the 1980s. According to the evaluation in 2011, its populace has developed at around 4.38% every year, higher than the national normal of 2% and this has put enormous pressure on the city's water assets.

Many studies conducted on urban growth of Ranchi and one study revealed that built-up growth of 473.7% amid 1927-2005 was basically to the detriment of agrarian land alongside the diminishment of normal water bodies reflects negative effects of developed extension.

So, the planner should also consider these aspects at the planning stage of cities, as the cities will grow faster when declared as metropolitan or smart cities.

Table 5.9 Census data for 2001 and 2011 of comparison cities and % of changes

City Name	2001	2011	Non-Metropolitan (2011)	% Change (Metropolitan Consideration)	% Change (Non-Metropolitan Consideration)
Dehradun	4,26,674	5,74,840	5,69,578	34.73	33.49
Raipur	6,05,747	11,23,558	10,27,264	85.48	69.59
Ranchi	8,47,093	11,26,720	10,73,427	33.01	26.72
Amaravati	72,642	1,14,974	---	---	58.27

5.3.2 Population forecasting data

The water supply designs were based on the projected population of the city, estimated for the design period. Any underestimated or overestimated value will create lot of problems and will not serve the purpose intended. The population was predicted using various methods which was suitable for the city with the consideration of the growth pattern followed by the city.

The present study used Arithmetical Increase Method and Geometrical Increase Method for the population prediction.

Arithmetical increase method was suitable for large and old city with considerable development and if it was used for small, average or comparatively new cities, it will give lower population estimations than actual values. The results of Arithmetic increase method of population forecasting are presented in Table 5.10.

Geometrical increase method gives higher values when compared to the previous method and can be applied for a new city at the beginning of development for only few decades. The results of Geometric increase method of population forecasting are presented in Table 5.11.

The results of both methods are represented in graphical forms and shown in Figures 5.20 to 5.23.

The master plan of Amaravati estimated 35.5 lakh population but as per Geometric increase method, it came around 7.2 lakh population. Since, it was a planned city; more settlers will come and settle in the city and expected more population in future. If we closely observe the data and the estimated population of Amaravati in 2050, Amaravati capital city estimated population was approximately matching the Ranchi city projected population.

The growth rates of Ranchi and Amaravari were not same but still the comparison was carried to look the problems associated with water sector of Ranchi and can recommend some suggestions inorder to make Amaravati, a future sustainable city and see that city should not face those kind of problems.

Table 5.10 Arithmetic Increase Method of population forecasting

City Name	2001	2011	2021	2031	2041	2051
Dehradun	4,26,674	5,74,840	7,23,006	8,71,172	10,19,338	11,67,504
Raipur	6,05,747	11,23,558	16,41,369	21,59,180	26,76,991	31,94,802
Ranchi	8,47,093	11,26,720	14,06,347	16,85,974	19,65,601	22,45,228
Amaravati	72,642	1,14,974	1,57,306	1,99,638	2,41,970	2,84,302

Table 5.11 Geometric Increase Method of population forecasting

City Name	2001	2011	2021	2031	2041	2051
Dehradun	4,26,674	5,74,840	7,74,458	10,43,395	14,05,722	18,93,870
Raipur	6,05,747	11,23,558	20,84,010	38,65,485	71,69,819	1,32,98,798
Ranchi	8,47,093	11,26,720	14,98,652	19,93,360	26,51,372	**35,26,595**
Amaravati	72,642	1,14,974	1,81,975	2,88,020	4,55,864	7,21,518

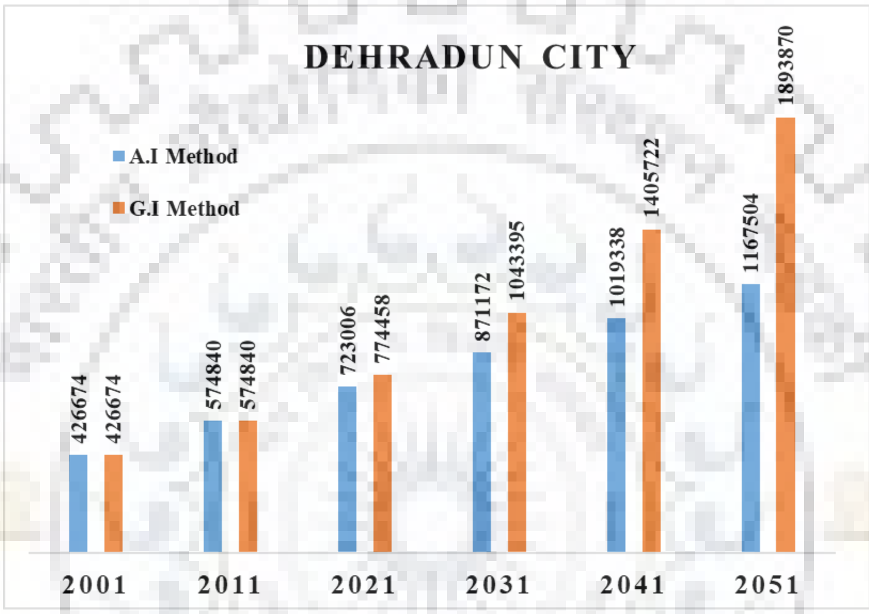

Figure 5.20 Forecasted population of Dehradun

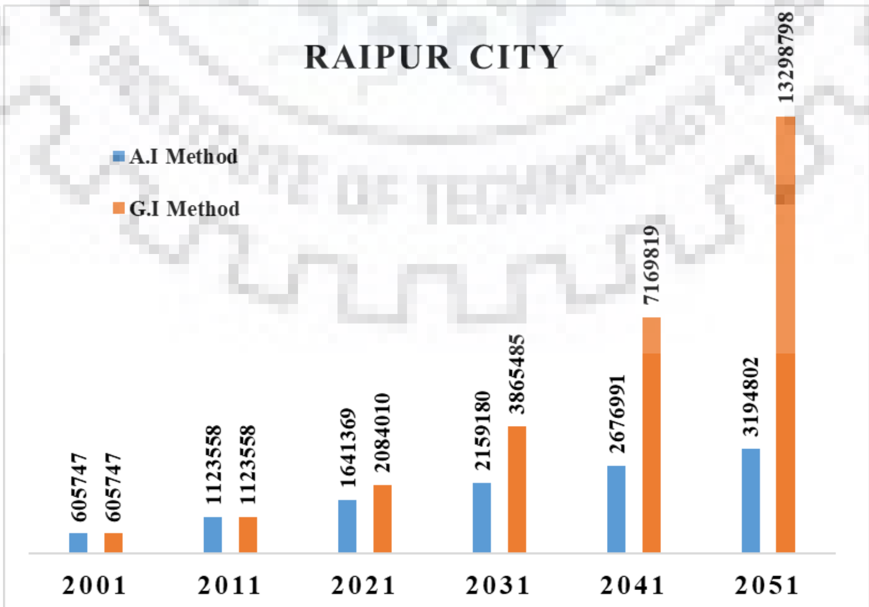

Figure 5.21 Forecasted population of Raipur

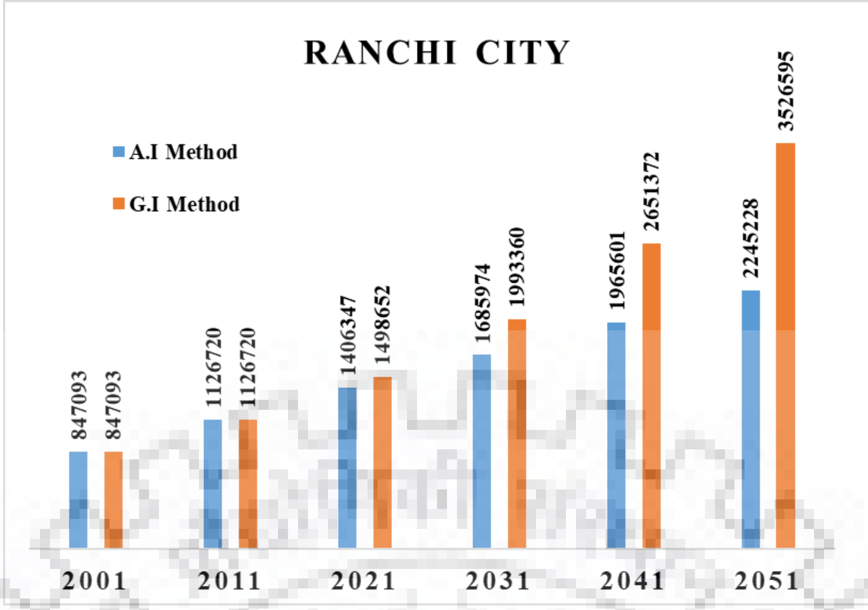

Figure 5.22 Forecasted population of Ranchi

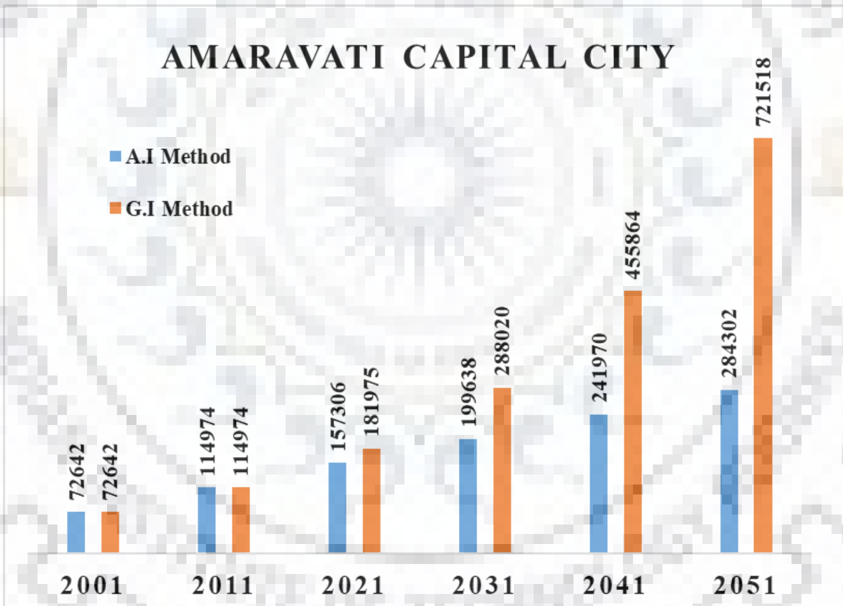

Figure 5.23 Forecasted population of Amaravati

5.3.3 Existing drinking water sources status of Amaravati

Coming to present drinking water status of Amaravati capital city villages, Annexure-I shows the main source of drinking water status (as per 2011 data) of 3 main sub-districts, namely Thullur; Tadepalle and Mangalagiri, which took a major part of area in Amaravati.

The data depicts that they are mainly depend upon river Krishna water and secondly most on ground water through hand pumps, tube wells, etc. So, river Krishna water availability is utmost importance for water sustainability of city. And also, from the collected data and interaction with govt. and local bodies, ground water is available at reasonable depths and there will be no problem of ground water availability for the study area.

5.3.4 Comparison study – Ranchi and Amaravati

Owing to unexpected out growth of Ranchi city, meeting the urban water demand has become a major problem and expecially in summer as some densely populated areas in the city were used to declared as dry zones because of acute water shortage (Figure 5.24). Ranchi has difficulty in ground water retention, has limited ground water, considering its granitic rock system, which has poor water-retention capacity. The residents were relying upon water provided by municipal corporation for drinking and also residential use yet in summers, extra water tankers were conveyed and water apportioning was done.

Figure 5.24 Harmu, a dirty waterway winds through the city centre

As per the report of the India Smart Cities Challenge, a competition for municiapal bodies in India, Ranchi meets the 135 lpcd water supply benchmark. However, the non-revenue water in the city is very high at 70%. 83% of the streets have a water distribution network and 48%

households have water connections. The drinking water and sanitation department, supplies water to 70% of its population. Improper sewerage or a storm water drainage system results in waterlogging during monsoon periods. The 4 rivers which were passing through Ranchi have been modified into drains due to high pollutant discharge (Figure 5.25). Clearly, there is lack of coordination between various agencies make city water crisis.

Figure 5.25 The city's water bodies like Arghoda talab were dirty, clogged with plastic, garbage and sewage

5.3.4.1 Lessons from Ranchi – recommendations for Amaravati

Observing Ranchi's outgrowth impact on water resources, the following suggestions recommended for Amaravati city:

- Urban development without following advancement design/master plan may prompt serious urban issue like surface and sub-surface water shortage, solid waste disposal issue, air and water contamination, urban cleanliness etc. Amaravati was developing based on the prepared master plan so the past and future land use/ land cover analysis studied in the present research will help to check the urbanization rate and impact studies can be conducted by the planners for better management.

- The monitoring of ground water usage and recharge-depletion studies should be conducted every year for better control over the sub-surface water resources.
- Systematization of the water supply system by sectorization of the system for better monitoring of the system to have control over non-revenue water.
- A separate body should be formed to look over the Industrial waste discharges into the drains to maintain the healthiness of the river.
- The suggested Theme city level strategic planning will have better coordination between various agencies to look over the drinking water issues and storm water discharges.
- Like Ranchi, the city's water connection application and water tax deposit should made online to improve the collection efficiency (Ranchi's efficiency increased up to 30%) of the water supply-related charges. With that revenue generated, more water supply coverage can made and management costs can take care off for better water supply networks.

5.4 Urban Water Resources Management Plan

In order to meet the future water demands of population, one should not go for more supply side management options by searching for more sources of supply as they degrade the environment. Instead of this, one should adopt better demand side management options for better management of water resources by increasing the efficient use of water, water reuse and utilizing the rainfall in a better and useful manner for good health of future smart cities.

One of the approach suggesting for Amaravati capital city for better water resources management is **SWITCH Approach – Sustainable Water Management Improves Tomorrow's Cities' Health.** (www.switchurbanwater.eu)

SWITCH approach was successfully implemented in many cities like Accra, Alexandria, Beijing, Birmingham, Hamburg, Lima, Zaragoza, etc. and the complete list with respective water issues solved are presented in Table 5.12.

Table 5.12 SWITCH approach implemented in different cities of world

S. No	City	Average annual rainfall (mm)	Priority water issues
1	Lima, Peru	13	Impacts of climate change on Andean water sources; Water supply for greening and productive activities in a context of extreme scarcity
2	Alexandria, Egypt	178	Managing water supply (from Nile) and demands; flooding risks; managing industrial discharges to reduce pollution
3	Zaragoza, Spain	318	Water demand management; using water to improve the urban environment
4	Tel Aviv, Israel	531	Managing water supply and demands in context of scarcity, recycling and reuse of waste water
5	Beijing, China	572	Water scarcity due to high and growing demands
6	Lodz, Poland	599	Restoration of polluted and buried rivers as part of revitalization efforts; flash flooding
7	Birmingham, UK	662	Future risks; climate change, rising groundwater levels, flooding
8	Accra, Ghana	725	Access to water and sanitation services especially in low-income neighbourhoods
9	Hamburg, Germany	773	Redevelopment of waterfront locations; flood protection
10	Bagota, Colombia	824	Industrial and waste water pollution of Rio Bagota and impacts on the environment and city water supply
11	Cali, Colombia	908	River pollution, an integrator of different problems upstream, and its impacts
12	Belo Horizonte, Brazil	1491	Preventing flooding, collection and treatment of waste water

(www.switchurbanwater.eu/cities/index.php)

The main key features of SWITCH Approach included:

a) Learning Alliances: Advancement of partner stages, called Learning Alliances, to guide and bolster the usage of research and showing exercises in the city. They spoke to some useful methods for bringing key partners (individuals and associations) into a gathering where they could talk about issues, screen and assess the procedure of change and think of solutions.

b) City-Level Strategic Planning: This procedure included visioning, situation distinguishing proof and improvement of vital headings or systems. Three essential models (CITY WATER Balance, CITY WATER Drain, and CITY WATER Economics) should create to enable the city to investigate the natural, monetary and physical ramifications of water management options.

One need to understand the problems of other cities facing on water and failed in execution of water management options. The lessons should understand like large number of organizations involved in the urban water sector leading to ambiguity in responsibilities, lack of expertise in IUWM in planning organizations, difficulty in agreeing on indicators for IUWM rather than collection of indicators and mostly the short-to medium-term focus of water management organizations which made it difficult to plan for a 30-50-year timescale.

Based on all these outcomes, the study suggested Theme City Level Strategic Planning as the master plan of Amaravati included 9 theme cities. The organizations of each theme city should look out the theme city water balance and problems and should solve at theme level itself and there should be a one central level organization to look after all these 9 organizations. If there are any inter-theme city problems, those two theme city organizations should come up with single solution and should solve it. By doing this, there will be a better water management at regional and local level.

Urban Water Management Plan recommended for Amaravati capital city:

a) Water security through RE-USE:

- Soil Aquifer Treatment (SAT)
- Engineered Environmental Buffer Technologies
- Aquifer Storage & Recovery

These three were useful for increasing water reuse efficiencies and able to increase the recharge of ground water.

b) Water demand management options:

- Management of water loss by installing District Meter Areas (DMAs) with flows and pressures monitored, linked to a GIS & Simulation Model.
- Water harvesting potential of city by rain water harvesting at roof top of buildings.
- Grey water (waste water) generated from bathing, hand and face washing and clothes washing should be recycled and reuse for flushing of toilets and gardening to reduce some water demand.
- Water metering is an important tool for reduction of water demand; in addition, metering also ensures detection of leakage in the system. The literature indicated that installation of water meters typically reduced consumption in the range of 10 to 30% and sometimes as high as 50%. For Indian group housing, the saving due to metering is considered on an average of 20% and this should be adapted to Amaravati city houses.
- Water saving devices like water saving cisterns, water saving shower or low flow shower, dual flush water system, water saving taps greatly save the water and reduce the house hold water demand.

c) Water sensitive urban design:

- River Krishna restoration using the principle of eco-hydrology to manage storm water, increase water retentiveness & improve water quality & overall improve the quality of life for residents by installation of on-line hydrological & meteorological monitoring systems, construction of sedimentation basins & specially designed reservoirs & planting of vegetation as the city is primarily depends on river Krishna water for drinking purposes.

d) Low impact development/Green infrastructure: Low impact development limits the ecological effect of advancement by overseeing storm water near its source, copying common frameworks that would permit storm water to invade into the ground, or giving transitory stockpiling so its discharge into the storm water system is moderated.

The eight Green programs recommended for Amaravati city are Green Streets, Green Schools, Green Public facilities, Green Parking, Green Parks, Green Industry, Business, Commerce and Institutions, Green alleys, driveways and walkways and Green Homes.

Green Roof Buildings and Brown Roof Buildings are likewise extremely helpful in diminishing storm water overflow intensity by postponing, holding and returning water to the air by means of ET and in this way lessen weight on the urban seepage framework, decrease the occurrences of urban flooding, there by having impressive potential for usage inside sustainable (urban) drainage systems.

The different low impact development practices which can be implemented in the city are represented in the Figure 5.26.

The importance of Low Impact Development/Green Infrastructure on storm water were stated as follows:

- By adopting Permeable Pavements, 22% of runoff leaves the system during a storm
- With Green Roofs, 60-70% of storm water volume can be reduced
- With Bioretention facilities, 26-52% of runoff retention can be achieved

Figure 5.26 Different Low Impact Development practices

5.4.1 Quantification and estimation of suggested water demand management options:

The govt. of Andhra Pradesh planned to supply 150 lpcd for the domestic water supply with 100% metering target. The estimated 2050 residential population of Amaravati is 35,52,950.

The govt. is planning to construct 2 extra sources of supply for Amaravati and one diversion canal (Pattiseema lift scheme to interlink River Godavari and River Krishna) was completed and they estimated the availability of water at source level for 2050 and the data is represented in the Table 5.13.

Table 5.13 Existed and Proposed sources of supply for Amaravati

S. No	Source Name	Existed/ Proposed	Storage (2050) TMC	Storage (2050) MLD
1	Prakasam Barrage	Existed	3.07	86.91
2	Neerukonda Reservoir	Proposed	0.41	11.61
3	Vaikuntapuram Barrage	Proposed	6.00	169.86
4	Polavaram RMC Diversion	Completed	84.70	2,397.86

The estimated residential demand at end user level was 532.94 MLD and considered unaccounted water of 10%, so total residential water demand at source level was 586.24 MLD.

The study considered all types of water uses in residential buildings (Table 5.14) and bathing, hand/face wash and cloth wash were considered for grey water generation and an average of 70% was considered for grey water reuse. This re-usable grey water was recommended to use for toilet flush and gardening purposes and places where less contact with persons.

Through water metering, an average of 20% of water (recommendation from literature review) can be saved, which means 30 lpcd (106 MLD) and it accounts 19.8% of total demand.

The study considers the average flushing of toilet was 5.7 times per day because the estimated use was 57 lpcd and average cistern capacity of 10 liters. The estimated water if dual flushing (6/3) was adopted in place of single flush was approximately 23.1 lpcd (2X6 + 3.7X3) which means a total of 33.9 lpcd (59.4% of flush demand) can be saved.

From Table 5.14, a total of 38.42% of water can be saved with the suggested demand side management options. The result shows that the sum of 57.63 lpcd (204.75 MLD) can be saved at domestic level. It means a total of 225.23 MLD can be saved at water source level (unaccounted water of 10%).

Table 5.14 Different residential water uses and water saving calculations for Amaravati

S. No	**Residential water use**	**Water use (%)**	**Estimated use (lpcd)**	**Saving with water saving measures (%)**	**Estimated water requirements (lpcd)**
1	Drinking	3	4.5	---	4.5
2	Cooking	2	3	---	3
3	Bathing	25	37.5	30	26.25
4	Utensil wash	5	7.5	50	3.75
5	Hand and face wash	3	4.5	50	2.25
6	Cloth wash	15	22.5	30	15.75
7	Floor wash	6	9	---	9
8	Toilet flush	38	57	59	23.37
9	Gardening	1	1.5	---	1.5
10	Car wash	2	3	---	3
	Total	**100**	**150**		**92.37 (38.42% saving)**

The study also estimated the percentage of population adopted the demand side management options and amount of water can be saved and it is presented in Table 5.15.

The two proposed sources storage was 181.47 MLD at source level for 2050 (Table 5.13) and Table 5.15 clearly shows that if 100% (38.42% saving) and 90% population (34.57% saving) adopted the recommended practices, they can save more than the two-proposed storage water. If 80% (30.73% saving) population adopted the demand management options, the proposed Vaikuntapuram barrage source can be avoided. At least Neerukonda reservoir can be avoided if at least 50% population (19.20% saving) can adopt the demand side management practices. The construction and maintenance costs of these two sources can be saved and utilized for the better management of these practices and govt. may also give subsidies, recommending using water saving devices, dual flush systems and installation of grey water recycle plants at colony levels for better sustainability of Amaravati.

Table 5.15 Water saving calculations for % of population adopted the recommended WDM options

S. No	% of Population adopted	Water Saved at end user (MLD)	Water Saved at source level (MLD)
1	100	204.75	225.23
2	90	184.27	202.70
3	80	163.80	180.18
4	70	143.32	157.65
5	60	122.85	135.13
6	50	102.37	112.61

Chapter 6

CONCLUSIONS

6.1 General

Studies on land use/cover are crucial for supporting land use management decisions. Past land use/cover analysis shows very low increase on urban rate whereas future land use/cover prediction suggests that rapid increase on urbanization due to declaration of capital city and its growth also depends on smart city development. With these past and future land use/cover data, impact studies can be conducted on surface and ground water resources which will useful for water balance studies of the study area.

Comparing capital city with other bifurcated state capitals is very useful to understand the water scarcity and management problems faced by the cities with the unexpected outgrowth of population and urbanization. Ranchi city forecasted population matches with the estimated master plan population of Amaravati which significantly can study the changing patterns of both cities with respect of water balance and water resources management.

SWITCH approach helps to make the city more sustainable in future with learning alliances, theme-city level strategic planning studying theme level city water balance, water drain and water economics. The suggested urban water resources management plan could help the city for not running towards more sources and can eliminate the construction of two proposed storage supplies and with the saved amount, the govt. can give subsidies to implement these saving devices at higher percentages in buildings.

The city can reduce the water demands with the proposed management options by increasing water reuse efficiencies with SATs, aquifer storage & recovery, engineered buffered technologies; implementing water demand management options like installing DMAs, systemization of water supply system, water metering, water saving devices, rain water harvesting at roof tops, green and brown buildings, constructing green infrastructure, grey water reuse; water sensitive urban design through river Krishna restoration using eco-hydrology principles, etc.

6.2 Conclusions

From the present study, the following conclusions were obtained:

i. The past land use/land cover analysis showed the urban area change from 1993 to 2017 was 8.09 km^2, at a slow growing rate of 0.33 km^2/year. This was very low urban change since most of the area were covered by agricultural lands and the population was totally depend on the agriculture as the land was very fertile due to the river fed land.

ii. The predicted future land use change showed the urban change from 2017 to 2050 was 58.63 km^2, increased at a rate of 1.77 km^2/year. This land loss due to urban growth was very less compared to some Indian cities like Delhi, Ahmadabad, Lucknow, Ranchi, etc.

iii. Monitoring of ground water usage and recharge-depletion studies; systematization of water supply system to have better control over non-revenue water; separate body to look over draining of industrial waste discharges in to the river to maintain its health and maintenance of online portal for water connection application and water tax deposit to improve the collection efficiency were the recommendations suggested for Amaravati based on the problems faced by the Ranchi water sector after bifurcation.

iv. With the suggested water demand options and quantification studies conducted, minimum of one and maximum of two water supply sources can be eliminated and with that costs of project, the study recommending to give more subsidies to the residential households for the maximum implementation of the water saving devices to save more water and make city sustainable in future.

6.3 Future Scope of Work

i. The impact studies of past and future land use/land cover on water flows using eco-hydrological model SWAT gives great scope of understanding on water flows and how the future urbanization effects the extreme flows in the planned city.

ii. The impact of future climate change on water resources gives the effect of climate on precipitation and temperature so that better management practices can be adopted for sustainable drinking water purposes.

iii. The combined impact of land use/land cover and climate change on water resources gives great idea on which parameters influences more to drive the maximum change on the water availability.

iv. From DEM analysis, the study area lies in almost flat surface. So, developing 3D DEM model and identifying critical flooded zones thereby studying storm water effects will be very useful for the govt. for selective planning of development at these zones.

v. The cost and benefit analysis of the recommended water demand management options and calculations of water savings for combined implementation of different management options will be an added advantage for better planning.

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ANNEXURE – I

Area Name	**Total/ Rural/ Urban**	**Location of source of drinking water**	**Total Number of Households**	**Main Source of Drinking Water**									
				Tap water from treated source	**Tap water from un-treated source**	**Covered well**	**Un-covered well**	**Hand pump**	**Tube well/ Borehole**	**Spring**	**River / Canal**	**Tank / Pond / Lake**	**Other sources**
Thullur	Rural	Total	15,731	9,790	1,598	44	26	3,213	168	11	1	729	151
Thullur	Rural	Within the premises	8,496	5,442	948	19	7	1,989	91	-	-	-	-
Thullur	Rural	Near the premises	4,078	2,678	327	17	12	811	39	10	-	161	23
Thullur	Rural	Away	3,157	1,670	323	8	7	413	38	1	1	568	128
Tadepalle	Total	Total	26,322	16,548	2,806	43	82	5,310	1,150	3	5	2	373
Tadepalle	Total	Within the premises	15,399	8,688	1,339	33	25	4,285	1,029	-	-	-	-
Tadepalle	Total	Near the premises	7,949	5,983	1,002	4	40	774	54	3	2	1	86
Tadepalle	Total	Away	2,974	1,877	465	6	17	251	67	-	3	1	287
Tadepalle	Rural	Total	8,032	3,735	1,107	20	68	2,881	154	1	1	1	64

Tadepalle	Rural	Within the premises	5,584	2,582	459	18	13	2,383	129	-	-	-	-
Tadepalle	Rural	Near the premises	1,727	798	456	-	38	398	20	1	1	1	14
Tadepalle	Rural	Away	721	355	192	2	17	100	5	-	-	-	50
Tadepalle	Urban	Total	18,290	12,813	1,699	23	14	2,429	996	2	4	1	309
Tadepalle	Urban	Within the premises	9,815	6,106	880	15	12	1,902	900	-	-	-	-
Tadepalle	Urban	Near the premises	6,222	5,185	546	4	2	376	34	2	1	-	72
Tadepalle	Urban	Away	2,253	1,522	273	4	-	151	62	-	3	1	237
Tadepalle (M + OG)	Urban	Total	16,794	11,924	1,172	21	13	2,381	968	2	4	1	308
Tadepalle (M + OG)	Urban	Within the premises	8,859	5,640	442	13	11	1,863	890	-	-	-	-
Tadepalle (M + OG)	Urban	Near the premises	5,739	4,803	457	4	2	367	32	2	1	-	71
Tadepalle (M + OG)	Urban	Away	2,196	1,481	273	4	-	151	46	-	3	1	237
Mangalagiri	Total	Total	41,408	28,488	2,665	121	798	8,324	655	7	12	11	327
Mangalagiri	Total	Within the	24,373	18,000	1,404	39	264	4,142	524	-	-	-	-

		premises											
Mangalagiri	Total	Near the premises	10,620	6,972	881	21	346	2,227	97	3	4	5	64
Mangalagiri	Total	Away	6,415	3,516	380	61	188	1,955	34	4	8	6	263
Mangalagiri	Rural	Total	14,137	5,964	690	34	585	6,377	186	2	11	8	280
Mangalagiri	Rural	Within the premises	7,371	2,830	293	21	206	3,872	149	-	-	-	-
Mangalagiri	Rural	Near the premises	3,574	1,717	182	9	292	1,297	30	1	4	3	39
Mangalagiri	Rural	Away	3,192	1,417	215	4	87	1,208	7	1	7	5	241
Mangalagiri	Urban	Total	27,271	22,524	1,975	87	213	1,947	469	5	1	3	47
Mangalagiri	Urban	Within the premises	17,002	15,170	1,111	18	58	270	375	-	-	-	-
Mangalagiri	Urban	Near the premises	7,046	5,255	699	12	54	930	67	2	-	2	25
Mangalagiri	Urban	Away	3,223	2,099	165	57	101	747	27	3	1	1	22
Mangalagiri (M + OG)	Urban	Total	27,271	22,524	1,975	87	213	1,947	469	5	1	3	47
Mangalagiri (M + OG)	Urban	Within the premises	17,002	15,170	1,111	18	58	270	375	-	-	-	-

Mangalagiri (M + OG)	Urban	Near the premises	7,046	5,255	699	12	54	930	67	2	-	2	25
Mangalagiri (M + OG)	Urban	Away	3,223	2,099	165	57	101	747	27	3	1	1	22