WATER RESOURCES MANAGEMENT PLAN IN SMART CITY: A CASE STUDY OF DEHRADUN CITY

A DISSERTATION

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by:

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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this thesis titled **"Water resources management plan in Smart city: A case study of Dehradun city"** is presented for the partial fulfillment of the requirement for the award of the Master of Technology, submitted to the Department of **Water Resources Development and Management, Indian Institute of Technology Roorkee, India,** under the supervision of Dr. Deepak Khare, Professor, WRD&M, IIT Roorkee, India and Dr. Santosh Murlidhar Pingale, Scientist-C, Hydrological Investigations Division, National Institute of Hydrology, Roorkee, India.

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

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CERTIFICATE

This is to certify that the thesis entitled "**Water resources management plan in smart cities – A case study of Dehradun city**" is a bonafide record of the thesis prepared by Ruchi Tripathi, Enrollment No: 17548029 under our supervision and guidance, in partial fulfillment of the requirements for the award of Degree of Master of Technology in Water Resources Development and Management from Indian Institute of Technology Roorkee, for the year 2017-19.

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LIST OF ABBREVIATIONS

ADB	:	Asian Development Bank
ArcGIS	:	Aeronautical Reconnaissance Coverage Geographic Information System
DEM	:	Digital Elevation Model
DSCL	:	Dehradun Smart City Limited
E	:	East
EPA SWMM	:	United States Environmental Protection Agency Stormwater Management Model
ERDAS	:	Earth Resource Development Assessment System
FRI	:	Forest Research Institute
ICT	:	Information & Communication Technology
IDF	:	Intensity Duration Frequency
IMA	:	Indian Military Academy
Km	:	Kilometres
LCM	:	Lanad Change Modeller
LULC	:	Land Use/Land Cover
M	:	Metres
MLD	:	Million Litres per Day
MS-EXCEL	:	Microsoft Experiential Curriculum for the Enhancement of Learning
MSL	:	Mean Sea Level
N	:	North
ONGC	:	Oil and Natural Gas Commission Limited
PMC	:	Project Management Consultancy
Q-GIS	:	Quantum Geographical Information System
SWM	:	Smart Water Management
SWMM	:	Storm Water Management Model
UNICEF	:	United Nations Children's Fund
WHO	:	World health organization
WTP	:	Water Treatment Plant
IMD	:	Indian Meteorological Department
CDM	:	Change Detection Matrix

ABSTRACT

Rapid urbanization and quest for development at individual and State level necessitate the urge for exploring the consequences of it on the natural resources available. In the present study, an attempt has been made to assess the land use/land cover (LULC) change and urban water demand for the Dehradun city from the Indian Himalayan region over the period of time. The urban water demand has been calculated by using census data and water supply data has been analyzed and further extrapolated to 2030 by using polynomial trend line. The LULC changes were analyzed for the years 2001 to 2018 using geospatial techniques. The six different LULC classes have been identified in the study area which includes agriculture, barren land, forest, shrubs, urban settlement, and water. The significant variations have been observed in areas of urban settlement class (increase by 73.53%) and agriculture class (decrease by 49.67%) from 2001 to 2018. This has been well depicted through change detection matrix. The results also indicated that the urbanization and population growth will increase urban water demand and it may exhibit more pressure on surface water and groundwater resource in the future. Also, this trend in LULC has been analyzed and predicted for 2030 keeping various factors in mind like road distance, urban area distance, past LULC, DEM, etc. and quantified the future expansion in an urban area in Dehradun city. Since, storm water management is a challenging in the upcoming or growing cities like Dehradun. Therefore, impact of LULC change on storm water in Dehradun city has also been studied using Storm Water Management Model (SWMM). Further, the smart city concept of managing water resources with the application of Information and Communication Technology (ICT) has been discussed and analyzed to get satisfactory outcomes by handling real-time data with electronic tools. Further, the critical reviews have been made and discussed on smart water management techniques and suggested adaptive and intervention measures for Dehradun city with the help of ICT. Ultimately, this study seeks to draw attention towards the trend followed in urbanization and indigence for a sustainable water management plan to be adopted at this stage.

Keywords: Smart city, Stormwater management and techniques, LULC changes, water demand, the Indian Himalayan region, Water resources management

Chapter 1
INTRODUCTION

1.1 Background

Since the old ages, it is seen that water is a vital resource for the survival of all forms of life on Earth. Its importance is often ignored because of its availability today. Also, urbanization is the most needed change in today's world. Urbanization is one of the key parameters through which the development of any country can be analyzed (Annez and Buckley, 2009). But, urbanization too has its limitations, which is reflected in the form of availability of resources, pollution to the environment, destruction of many habitats, lethargic living habits etc. Lack of scientific understanding, overexploitation, contamination, improper management plans, and climate change is making water resources further vulnerable to extinction (Praveena and Aris, 2009; Kumar and Nigam, 2016).

Due to development, the urban area is increasing over the expense of agriculture and forest. It has been observed that use of land keeps on changing as per the needs of human beings. During the last five decades, the world has experienced a significant spatial expansion of urban areas, which is mainly caused by increased population, changing the economy and better living facilities (Najmuddin and Siqi, 2017). Many researchers have worked in the past to analyze the urban sprawl (Hurd and Wilson, 2001; Weng, 2001; Sudhira and Jagadish, 2003; Yang and Liu, 2005; Baxter and Glass, 2008; Bhatta, 2009; Liu and Yang, 2011). With the change in land use change, the direct effect on water availability and demand can be seen. Land use change can alter surface water-balance, water quality and water demand (Najmuddin et al., 2017). The trend in land use change help to extrapolate the future urbanization going to take place and to make a strategic plan to continue the growth in a sustainable way.

The population is another big issue for water management researchers today and needs serious attention from all communities, institutions as well as administration. Water supply is restricted in an area but demand is increasing day by day. Urban water demand relies upon the working of an urban setting and its monetary limit (Collins et al., 2000). A study was conducted by UNICEF and WHO which showed that the population of people living in urban areas who don't have access to potable water supply increased from 113 million in 1990 (5% of total urban population) to 173 million in 2000 (6% of total urban population) (Humanitarian and Urban, 2002). Forecast of the population and water demand estimation gives an opportunity to the water research developers to seek for its management at an early stage before the resources end up.

1.2 Statement of the problem

Studies have been done on water resources assessment and management (Drissia and Anitha, 2019; Sadeghfam and Nadiri, 2019; Xie and Zhang, 2019), however, the increase in urbanization and population growth have not been taken into consideration in the fastest growing city like Dehradun in Indian Himalayan Region. Only a few studies focused on upcoming planned cities or declared smart cities (Kumura et al., 2015; Patawala and Zadbuke, 2017) which is the need of the hour. Dehradun has been declared as a smart city on 23rd June 2017 which emphasize that proper water management should be done at early age itself. The study urges to draw the attention of the mass towards the growing need of a strategy to cope up with the rapid urban sprawl taking place over a concise area. Being the hub for all administrative, social and institutional activities, migration towards this city has followed exponentially increasing trend. With the increase in population, water demand for the city has followed the same trend line. Quality of water in Dehradun is often objected in media and research but the decrease in quantity is hidden because groundwater is the primary source of water supply and its decline can't be seen without a proper survey. A city has only restricted sources of water supply and new sources can't be explored due to topographical constraints, so the shift should be towards the demand management plans and suitable adaptive measures in urban areas like Dehradun.

Smart Water Management (SWM) is just the combination of Information and Communication Technology (ICT) and real-time data which is expected to bring tremendous results in generating a solution for water resources management hurdles. SWM is becoming a burning topic of today as governments, researchers, water resource developers, and many hydrologists are applying smart principles into management plans at their respective levels. The prospective usage of smart applications in water management is broad and includes solutions for water quality, water quantity, efficient irrigation, leaks, pressure and flow, floods, droughts and much more.

Therefore, in the present study, the impact of the land use/land cover (LULC) change has been made using geospatial techniques for the period of 18 years (2001-2018) and the trend in LULC has been analyzed and then further simulated and quantified LULC changes for 2030 and analysed present and future urban water demand to understand the clear stress on water resources in the Dehradun city. Finally, the use of SWM has been critically reviewed and discussed to manage urban water in a sustainable manner and suggested management interventions and adaptive measures to manage storm water and water demand in the city.

1.3 Research gap/Rationale

- River basin, catchments, watersheds, and existing urban areas are common fields to study for researchers because of the availability of data but only a few focus on upcoming planned cities or declared smart cities.
- Dehradun has been declared as a smart city on 23rd June 2017 which emphasize that proper water management should be done at early age itself.
- Studies have been done on water in terms of its quality degradation but reduction in water availability is not much explored till date in the case of Dehradun city.

1.4 Objectives

This study seeks to develop the most suitable water management plan for sustainable growth in Dehradun, through the following specific objectives:

- To assess water supply sources and long term water demand and analyze the trend in water availability and demand.
- To study the impact of LULC changes on water resources over a period of time
- To study the storm water management in urban areas using SWMM.
- To explore suitable options for sustainable and smart water management.

1.5 Significance of the study

This study signifies not only the importance of stress on water resources but also suggests ways to manage it. This study has incorporated major issues causing water crisis such as urbanization, population rise, urban water flooding, mismanagement in distribution of water and wastage of water. These problems are analyzed not only for today but also have been predicted for future. This way, a trend for future situations is made and accordingly plans are made to sustain the water for future generations as well. Moreover, new ways of management have also been suggested with connections of smart techniques to adapt well with the concept of smart city. Use of ICT has been used well in this study to match the digital world.

1.6 Organization of the Thesis

The thesis is organized in six chapters. In chapter one is introduction which includes background of the study, statement of the problem, research gaps, objectives, and significance of the study. Chapter two provides a review of existing literature. Description of study area and sources from where data is collected is discussed in chapter three. In chapter four, the methodologies which include a flow of conduction of study, the materials, methods and techniques of data collection are described. In chapter five, the results and discussion of the study are presented. It includes LULC change, water demand analysis, storm water modeling and management using SWMM and results of the same have been presented. Lastly, the critical review on smart water management through ICT techniques have been discussed and suggested adaptive/intervention measures to urban water management for Dehradun city. In chapter six, the conclusions drawn from the study and recommendations are discussed.

Chapter 2

LITERATURE REVIEW

Humans are the basic factor in the spoiling of ecology and environment. "Urban ecology" is the term popped up in this study to explain the impact of urbanization on natural ecology. It focuses on how much humans have and are degrading the ecological vector. Effects of human activities on climate in an adverse manner are also highlighted here. This is going to impact all living species in the long run (Borer et al., 2000; Collins et al., 2000).

Jat & Khare, 2008 focuses on the sprawling of an urban area in a city of India, Ajmer. It has been studied for a span of 25 years from 1977 to 2002 using advanced geospatial techniques. The characteristics of urban sprawl have been studied and noticed that the urban area in the city has increased more than three times the population growth.

Since the study area chosen in this study is Dehradun, a study of urban sprawl in the city is important. Deep & Saklani, 2014 has been used CA Markov Model to encounter increment in urban settlement area. The modeling is triggered by cellular automata. The focus of this was to find green and sustainable tools for proper planning and management of the upcoming smart city, Dehradun. Since, it has capabilities to attract lots of tourism too apart from being the capital city of the state.

Urbanization is considered to be a key for the measurement of growth and development in any country. Modernization brings with it, a higher class of living which is an important parameter for the growth of the country. Also, urbanization brings with itself, an increase in salary of employees, higher prices of commodities, new technological advancements and a lot more change (Annez and Buckley, 2009).

LULC not only analyzes the urban growth but is equally important in the analysis of change in the hydrological cycle. Important parameters such as evapotranspiration, infiltration capacity and also leaf area index, in terms of impact on agriculture. This work studies the changes in these hydrological vectors due to change in LULC over a span of time (Das et al., 2018).

Smart city idea is no doubt full of many challenges, mentioning some would be sustaining social bonding, practicing green technology, proper management, and planning by skilled people, etc. Also, intervention and hindrance of government is another major problem involved in adopting any new concept. Unemployment and poverty still stay at the top of the list containing challenges to a smart city (Blauw and de Bruin, 2016).

Intermittent supply, though considered to be providing water saving results, in actual, may cause irony if parameters such as supply timings, rate of flow and locations where the connections are made are not designed properly. New guidelines are presented in which focus has been made on water scarcity problems in the upcoming cities because of many environmental and man-made changes. Need is to shift the management from the supply side to demand side (Vairavamoorthy and Pathirana, 2008).

Water problems are found to be maximum in developing areas. Bangalore is one such example where water demand has drastically increased because of it being an Information & Technology hub. People migrate to this city for jobs and better living standards. But due to lack of proper water distribution and maintenance, the city is facing a problem in supplying drinking water to its residents. Bangalore Water Supply and Sewage Board (BWSSB) have reported its huge losses due to these issues (Raj, 2013).

Studies done on Dehradun suggest that there has been a decrease of 3.75% in forestry and also a decrease of 9.5% in the water area from 2000-2009. This change is expected to have come because of human involvement with nature in a manner which is not ecologically acceptable. With the help of satellite images, LULC maps are generated and the show considerable urban sprawl in Dehradun city. This is probably due to migration towards the capital of the state due to its importance (Kuldeep and Kamlesh, 2011).

Leaks are bound to occur in any distribution system, but its detection at the right time is what needed for the effective water networking system. Leakages are conventionally detected by many methods such as manually, or using high resolution satellite imageries, etc. Smart leak detection ball is a new concept in this field of leak detection and it can detect very minute cracks discharging 0.1 gallons/min. It has proved to be effective in many countries and has saved a huge amount of water from being wasted from the leaks. It is very handy and completely scans the pipeline from inside with the help of acoustic wave’s transmission. Important parameters such as pressure, discharge, velocity, etc can be well identified with the help of this instrument (Fletcher, 2008). Also, placing of leakage sensors in the water distribution pipeline is used to bring the error due to leakage into the acceptable range. This works on the principle of whole to part. The huge network is divided into small networks to analyze the system in a better way and also to detect the leakage in real time basis (Xie et al., 2019).

Urban flood is nowadays considered to be a disaster to many researchers. Waiker and Undegaonkar (2015) have very well notified the difference between urban and rural floods. This is because, in the urban area, outlets are very few due to settlements all over. The peak is increased in the case of urban floods and simultaneously, the time of concentration is tremendously reduced. EPA SWMM is one of the effective tools to analyze the real-time urban water flooding in the sub-catchment. Its inputs cover all the possible characteristics needed for analyzing flash floods such as DEM, percentage of imperiousness, possible conduit path for stormwater drain, rainfall time series, etc. (Waikar and Undegaonkar, 2015).

The smart city is a concept emerging from the combination of Information & communication technology and the physical world. Its main objective is to offer the advanced and interactive potential for its residents. It helps in achieving the objectives of sustainability with the inputs from GIS and RS. It is found to be much more secure and efficient. A smart city is an important approach in the developing cities and must be considered as a step towards an innovative success in planning and management in India (Tiwari and Jain, 2014; Beaulieu, 2009).

A report of Dehradun's development suggested the areas of flooding due to stormwater. This bought the idea to study for the stormwater management model for the city to search for more areas ponded by stormwater. Being the capital city and tourism hub, Dehradun has a lot of chance to get flooded during flash storms. If advanced detection of the same is made and proper drainage network is plotted, this situation can be very well escaped. SWMM is a model to give real-time data of how the water will flow on any storm event, into junctions, conduits, sub-catchment and finally into the outfalls. It gives the results at manually selected intervals and is much validated with the actual results (EPA, 2010).

Another concept of managing urban water supply is through Smart Water Grids (SWGs). SWG is a full network of inflow and outflow of water in the system. Freshwater, as well as reclaimed water coming from Waste Water Treatment Plant (WWTP), is stored and the further supplied to meso-grids, which ultimately connect to the households. The water from WWTP can also be fed into Industrial and agricultural use. The connections from the central reservoir to the meso-grids are made in dual ways so that any calamity occurring in one meso-grid can be compensated by supplying water from other meso-grid (Lee and Kim, 2015).

Chapter 3
STUDY AREA AND DATA USED

3.1 Description of the study area

Dehradun, as declared on 23rd June 2017, as one of the 100 smart cities by Government of India is situated at 30°19’N latitude and 78°20’E longitude (Fig. 3.1). Besides being the most developed city of Uttarakhand, Dehradun is also a hub for many administrative, cultural, strategic and educational institutions such as Indian Institute of Petroleum, Forest Research Institute (FRI), Oil and Natural Gas Corporation (ONGC), Indian Military Academy (IMA), Survey of India and other famous boarding schools like Doon School. In general, the average slope of the Dehradun city is varying from North to South direction about 1024m above mean sea level (MSL) in North and 596m MSL in the south (Annexure I). The two major drains of the city are Bindal and Rispana Rao.

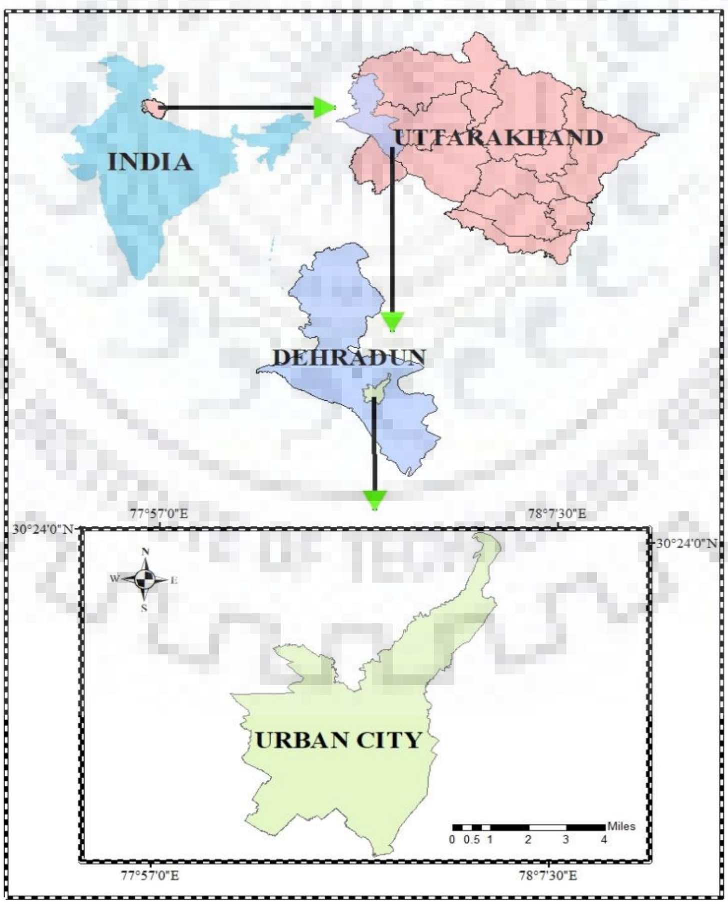


Fig. 3.1 Description of study area

3.2 Data used

- Data used for the preparation of LULC maps and the DEM (Annexure I) have been obtained from the United Stated Geological Survey Database (www.earthexplorer.usgs.gov). The satellite imageries have been downloaded from path number 146 and row number 39 for the four time periods (20th Jan, 2001 and 23rd Jan, 2008 by Landsat 4-5, and 24th Nov 2014 and 2nd Oct 2018 by Landsat 8 sensors, respectively).
- Road network, waterways and electric cable network of the city has been obtained from the https://www.openstreetmap.org/. (Annexure IX)
- Population data has been obtained from Census data of Government of India for the years 1991, 2001 and 2011.
- Shape-file layers of India, Uttarakhand, and Dehradun have been obtained from DIVA-GIS open data source (www.diva-gis.org) and also from www.indianremotesensing.com.
- Water supply data in the city has been collected fromthe PMC, DSCL and ADB assisted Uttrakhand Urban Sector Development Investment Plan. The installments of tube wells are primly divided into 4 zones (North, South, Raipur, and Pithuwala) and the tube well data for them is shown in the Table 3.1:

Table 3.1 Number of tube wells in all 4 zones

TUBEWELLS	**NORTH**		**SOUTH**	**RAIPUR**	**PITHUWALA**	**Total**
Major tube wells	39		61	14	25	139
Minor tube wells	23		24	4	6	57
Total	62		85	18	31	**196**

Surface water supply data (Table 3.2), though very limited is fed mainly through five water sources and majorly divided into three systems of water supply as:

- ✓ 1st system: Bandal river (discharge of 20-22MLD) and Bijapur canal (discharge of 5.5-6MLD)
- ✓ 2nd system: Kyarkuli gadhera (discharge of 15MLD)
- ✓ 3rd system: Masifall gadhera (discharge of 8MLD) and Salani Gadd gadhera (discharge of 12-13MLD)

From the 1st system, assured water supply of 25-27MLD is available which is the fed to Dilaram waterworks water treatment plant, having the capacity of 27.5MLD. Water from 2nd system is fed to Galogi Powerhouse and Purkoli waterworks water treatment plant, having a capacity of 15MLD. But, water from this source has high calcification problem due to which only 5MLD effective water reaches the treatment plant. A new gravity main is proposed in this system. From 3rd system, water is fed to Sheshan Shahi Waterworks water treatment plant which has the capacity of 14MLD. In this system, full water of Masifall Gadhera is drawn while the remaining water is supplied by Salani Gadd Gadhera as hardness is a big problem in the later source.

Table 3.2 Surface water supply data

S.No	Water sources	Normal flow (MLD)	Assured supply (MLD)	WTP	WTP capacity (MLD)
1	Bandal river	20 to 22	25-27	Dilaram Water works	27.5
2	Bijapur canal	5.5 to 6			
3	Kyarkuli gadhera	15	5	Purkoli water works	15 (eff. 5MLD)
4	Masifall gadhera	8		Shehan Shahi water works	
5	Salani gadd gadhera	12 to 13	14		14

- Conduit data and drainage network (Table 3.3) in the city has been obtained from City Development Plan (Jawaharlal Nehru National Urban Renewal Mission, 2007). Only data for the catchment area of Bindal river has been taken into consideration for better and specific simulation. The Conduit data used for Dehradun city is as follows:

Table 3.3 Conduit data

S.No.	Name of the Drains	Length (km) /width (m)	Connected areas
1.	From Brijlok to New Cant Road Nala	4.5 km, width 6m	Salawala, Chandralok colony, Dilaram Bazar, New cant. Road, Rajpur Road

2.	Mannu Ganj Nala	4.8 km, 3m to 5m	Ghantaghar to Moti Bazar, Neshvilla Road, Mannu ganj, Moti Bazar, Anand chowk, Dandipur, Khadri, Jilak Road
3.	Govind Garh Nala	2.5km., 2.5 to 4.0m	Shanti vihar, Teacher colony, Rajendra nagar, Saiyyed Mohalla, Yamuna Colony
4.	Chorkhala Nala	1.0 km, 2m to width	Mitralok, Deeplok, Aakash deep, Rajendra bag BBlock
5.	Bhandari Bagh Nala	3.5km, 4 to 6m	Lakhi Bagh, Vishwakarma colony, Bhandari bagh, Pathari Bagh, THDC colony
6.	Chandra Nagar to Race course drain	5.5 km, 2 to 5m width	Haridwar Road, Race course, Chander Nagar, Police line, Race cource A, B, C Block, Saraswati Vihar
7.	Subhash Road-Police head office	4km, 1.5m	Subhash Road, Cross Road, New Survey Road, New Road, Kachahri Road, Chander Nagar
8.	Asian School Nala	2.2 km, 3m	Ganga Vihar, Kalindi Enclave, Kanwali village, Engineer Enclave, Om vihar, Shastri Nagar

- Rainfall data for 18 years (2001-2018) was downloaded from power project datasets https://power.larc.nasa.gov/

3.3 Software used

Different software's have been used for different purposes in this study, which includes:

- ARC-GIS 10.4
- Erdas IMAGINE 2018
- Terrset Geospatial Monitoring and Modelling System
- Q-GIS 3.6
- EPA SWMM 5.1
- Geo-SWMM
- MS-Excel 2016

Chapter 4

METHODOLOGY

The general conceptual framework of the methodology adopted in the present study is presented in Fig. 4.1 and subsequently discussed in the following sections:

4.1 LULC Maps preparation

For the preparation of LULC maps, satellite imagery of Dehradun has been downloaded from USGS Earth Explorer. Imageries were cloud free and have been downloaded taking care of crop periods, when full vegetation is observed, generally from October to March. The images have been layer stacked in ERDAS software to combine different bands especially 7 bands (ERDAS IMAGINE>Raster>Spectral>Layer stack). The image then masked for the shape-file of core urban city using ARC-GIS (ARC-GIS>Arc toolbox> Spatial analyst tools> Extraction> Extract by mass). The black pixels have been removed for making it error free. LULC classification can be done in three ways namely, supervised, unsupervised and combined. Combined classification is preferred for small areas and therefore used in this study. For this, unsupervised classification has been done for 150 classes in grayscale color mode (ERDAS IMAGINE>Raster> Classification> Unsupervised> Unsupervised classification). The image thus obtained has been synchronized with Google EarthPro and each of the 150 class has been recognized and further merged into 6 classes using recode tool (ERDAS IMAGINE>Raster>Thematic>Recode). Further, correction of pixels has been done again by making signature files (ERDAS IMAGINE>Select image>Drawing>Draw polygon) in the region where error occurs and then correcting the pixel color of that region only by using thematic recode tool (ERDAS IMAGINE>Select image>Thematic>Recode). The image then opened in ARC-GIS and the calculation for the area of each class has been done using calculate geometry tool. Pictorial representation of the steps followed for LULC map preparation is shown in Fig. 4.2.

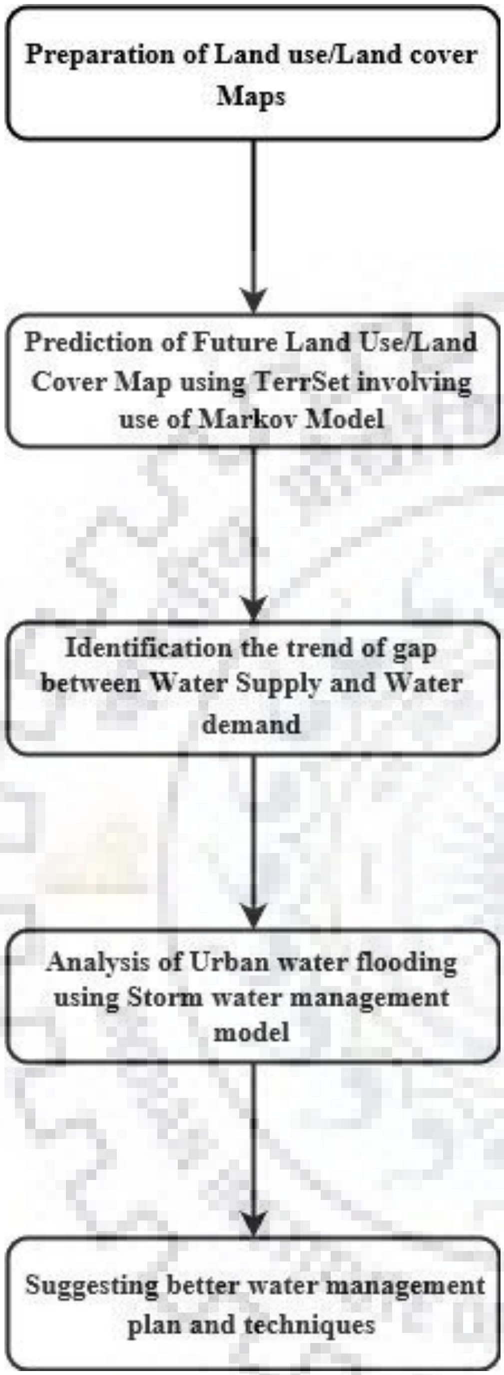


Fig. 4.1 Overall conceptual framework

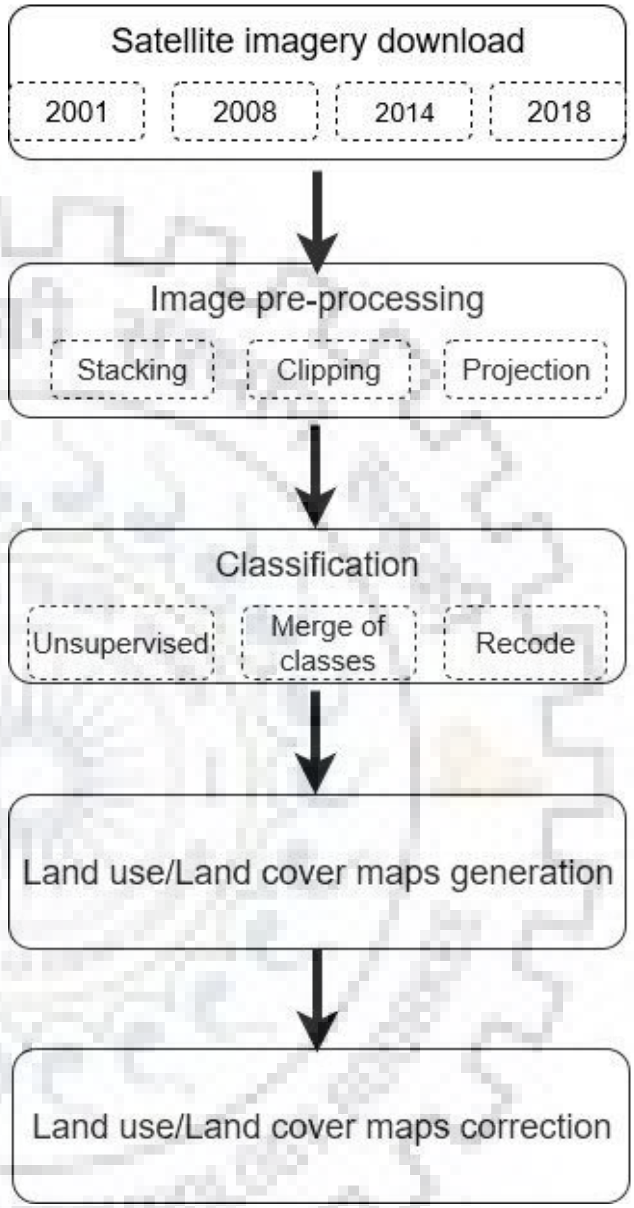


Fig. 4.2 LULC maps preparation

4.2 Change detection matrix preparation

Change detection matrix has been prepared to analyze the shift from one land use class to another. It gives how much area of an individual class has been transformed into the other class, and thus detects the change. For its preparation, two already classified images of 2001 and 2018 have been taken. The imageries considered for this analysis should not have any no data value, if there is any other class else than the classified six classes then set them to zero. Change detection analysis have been performed in ERDAS (ERDAS IMAGINE>Add LULC of 2001 and 2018>Raster>Thematic>Matrix reunion) and analyzed in ARC-GIS (Open recently generated an image in ARC-GIS>Open Attribute table>Export to excel). The attribute table of ARC-GIS shows the number of pixels of which class has been converted to the other class.

4.3 Future LULC map preparation using Terrset

Since the expansion of urban area is influenced by the urban area boundary (disturbance zones) near it and also we need to generate disturbance map/distance map which will be required as an input in Terrset software. To get the distance from the urban area, the only urban area has been extracted from the LULC map using "con" tool (ARC-GIS> add 2018 land-use>Spatial analyst tools>Conditional>Con). The expression has been made in Con tool to generate Distance map as ("Value" =5); since 5 is the value corresponding to Urban class and if this condition is true then give constant value as 1. This will give only the urban area of the image. This has been fed as an input to calculate distance map using Euclidean distance tool (ARC-GIS> Arc toolbar> Spatial analyst tools>Distance>Euclidean distance).

Since, urban sprawl is also influenced by the road near it, therefore road data have been downloaded from (https://www.openstreetmap.org) and masked for a study area in ARC-GIS. This road data has been further processed in Q-GIS software (Q-GIS> Open data> Vector> Browse for road data file> add> layer names as "line"). All lines (roads, river, cable lines, etc.) have been added in the map, then it has been exported as shape-file to ARC-GIS (right click on map lines> Export). Only road data is then extracted from the all line map (ARC-GIS> Open line map> Right click>Edit feature>Start editing>Open attribute table>Select by attribute> give expression: "highway" = " ">delete selected>open editor toolbar>save edits>stop edit). Now, we have to calculate the distance map for the roads using the same steps as done for urban distance map. Now DEM file is downloaded from USGS Earth Explorer and masked for the study area. Fill tool has been used to correct the error in the DEM file (ARC-GIS>Add DEM file>Arc toolbox>Spatial analyst tools>Hydrology>Fill). Since, Terrset does not work with 4-bit data (which is generally prevailing in present systems), so the files have been converted in 8-bit data using ERDAS software (ERDAS>Open LULC Maps>Raster>Subset and chip>Create subset image>Data Type>Output-Thematic-unsigned 8-bit>OK). If any error occurs in the thematic layer generated, then correct it (Right click on thematic layer>correct alert problem>OK). Same steps have been followed for all the LULC Maps. Slope calculation is also important to be done before the prediction of Future land-use. Therefore, the slope map has been generated in ARC-GIS using DEM file (ARC-GIS>Spatial Analyst tools> Hydrology>Slope) (Annexure I).

The future predicted LULC map has been made using Markov chain Model by Terrset Geospatial Monitoring and Modeling system software (Land Change Modeller (LCM)). All the input files have been kept in a separate folder and given as input to Terrset. The following three major tasks have been performed in LCM to predict the trend and hence generate probable future LULC image (Fig. 4.3):

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

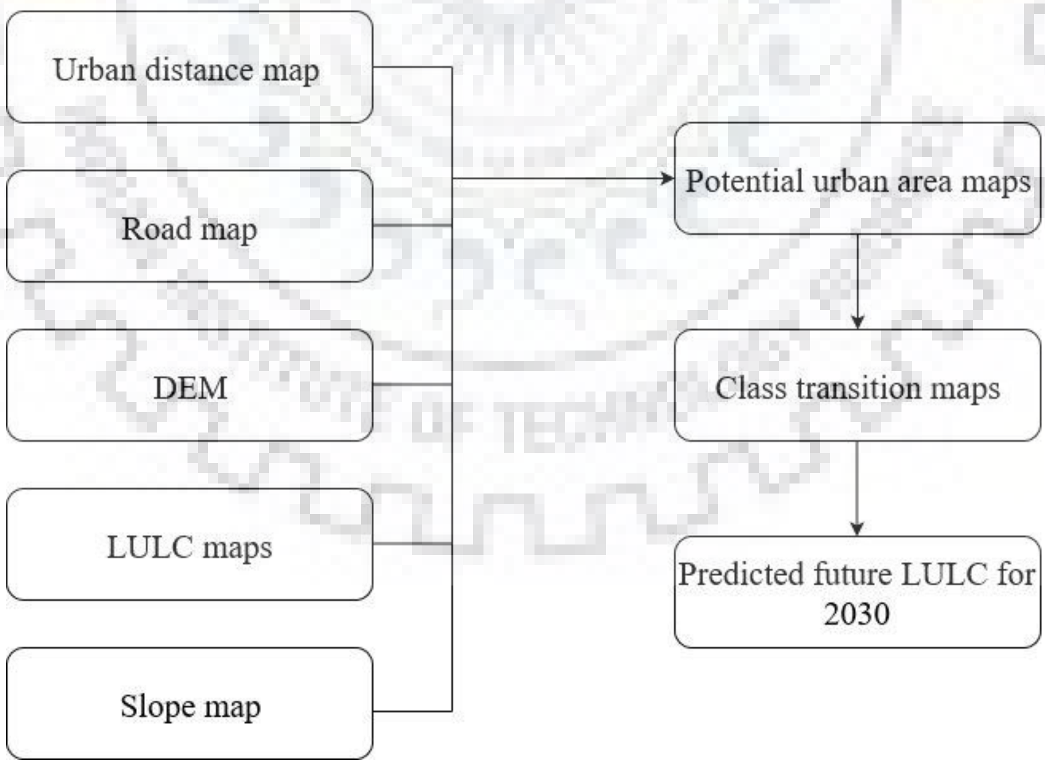


Fig. 4.3 Preparation of future LULC map

4.4 Water demand and supply analysis

Being at the foothills of Himalaya, Dehradun city is abundant in groundwater resources, which in turn makes overexploitation of the groundwater. Nearly 80% of the city's water demand is fed by the groundwater. Since, it has already been analyzed in the city that the urban sprawl is increasing at an alarming rate, consequently, water quantity is to be at stake of this urbanization. Urban area not only decreases the groundwater recharge sources because of paved roads and settlement but also increases the water demand of the city due to the increasing population. To study this trend and find the gap in water demand and supply, further analyses have been carried out in this study (Fig. 4.4). Since, the demand is directly linked with the population, so the population was first forecasted with the help of census data published by the Government of India, available for the years 1991, 2001 and 2011. This demand graph is extrapolated to 2030. Supply data for the city has also been obtained from authorities and combined with the demand trend line on the same graph.

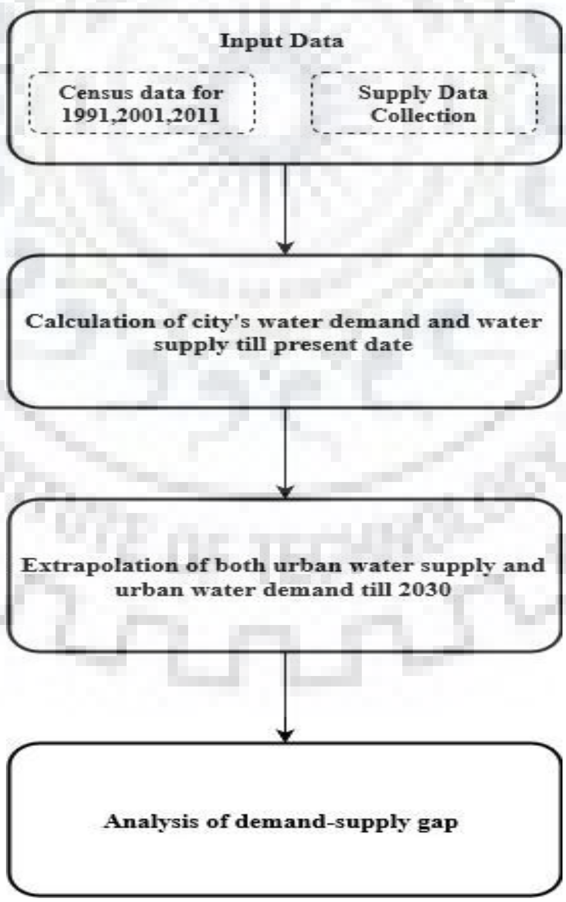


Fig. 4.4 Methodology for supply-demand analysis

4.5 Analysis of stormwater management through SWMM

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff part of SWMM works on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub-catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (EPA, 2010).

The detailed methodology adopted in this study to estimate the urban runoff has been depicted in Fig. 4.5 and described through the following steps as described in SWMM 5.1 and GeoSWMM 5.1 model manual: :

- A geodatabase was created and all default files were loaded
- Components such as junctions, conduits, outfalls, sub-catchments and a rain gauge have been marked with the help of previously available data
- Specifications to these components have been provided such as inert elevation of conduits, outfalls, and junctions. Profile and geometry of sub-catchments have been provided in the model.
- Time series data have been prepared using daily rainfall data and the analysis have been carried out for a rainfall corresponding to 10 years return period.
- Analysis options have been chosen as per requirement like Kinematic wave routing method, Curve number infiltration model, reporting time of 15 minutes, etc.
- The project was exported as .nip file to EPA SWMM 5.1
- A primary simulation has been carried out to identify the errors and then finally simulation was successfully run by removing errors. Results of the simulation run has been analyzed and graphs were created

The roughness of the conduit has been kept 0.012 for all conduits. The analysis was done with rainfall series of the 1hr interval which have been obtained by the Intensity-Duration-Frequency

(IDF) curve generated from daily precipitation. This has been performed by using IMD formula for calculating short duration rainfalls. The formula is as follows:

$$P_t = P_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}} \tag{4.1}$$

where, P_t is the required rainfall depth in mm at t-hour duration, P_{24} is the daily rainfall in mm and t is the duration of rainfall for which the rainfall depth is required in an hour.

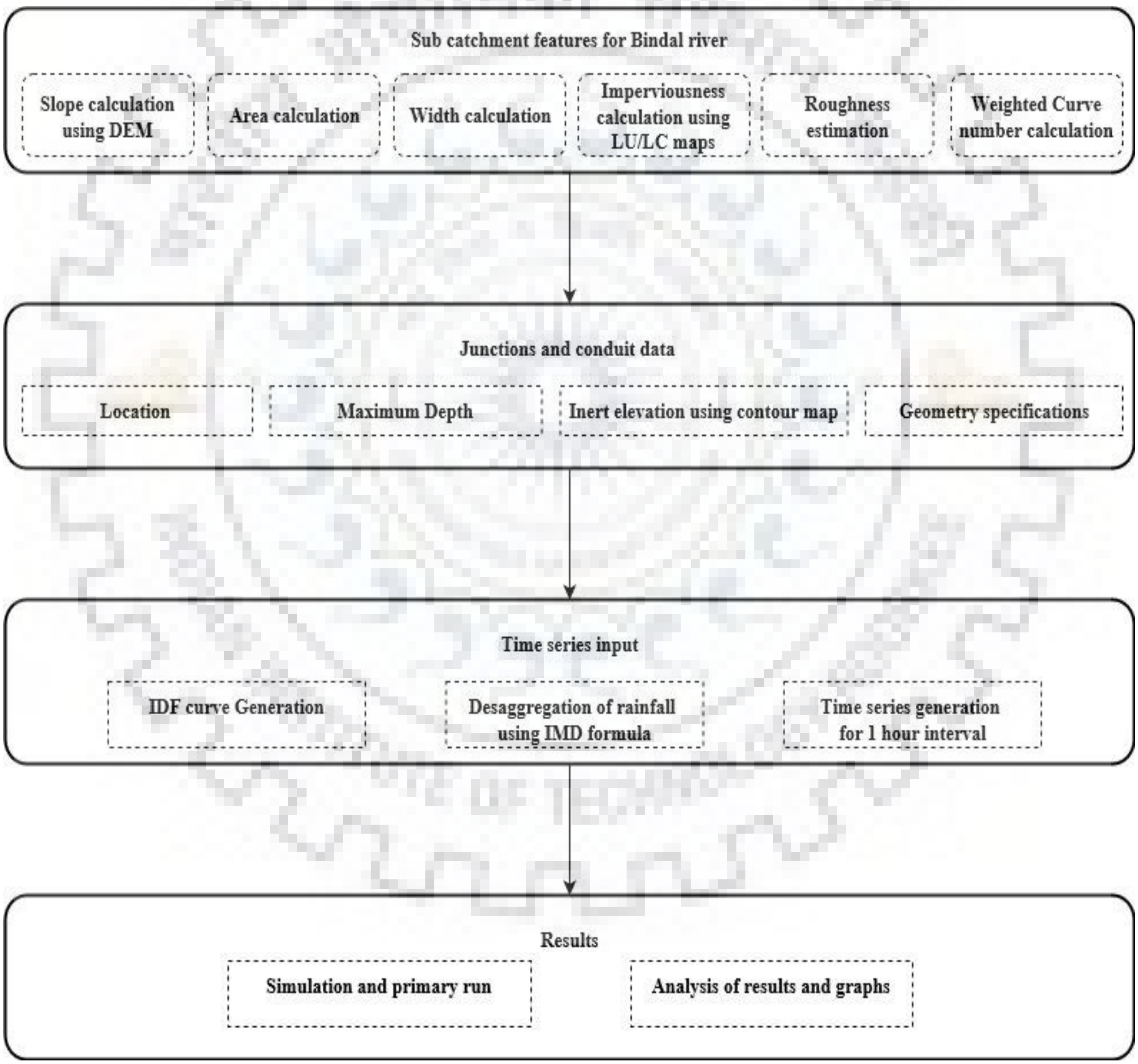


Fig. 4.5 Urban rainfall-runoff simulations using SWMM model

By this short duration rainfall of 24 hours, 12 hours, 6 hours, 2 hours and 1 hour values have been obtained. The mean and the standard deviations have been calculated for each short duration rainfall intensity. Further, return period has been calculated for the above data using the plotting-position formula:

$$P = \frac{m}{N+1} \tag{4.2}$$

Where, m=event's order number and N is the total number of rainfall events in the data. Further, k_t values are calculated using Gumbel's distribution formula as:

$$k_T = -\sqrt{6}/\pi[0.5772 + \log(\log\frac{T}{T-1})] \tag{4.3}$$

Where T is the return period.

Rainfall intensities have been calculated using the following Gumbel's equation:

$$x_T = \overline{X} + k_T * S \tag{4.4}$$

Where x_T is the required intensity and, $\overline{X}$ and S is the mean of the data calculated above respectively.

Finally, the IDF curve have been generated with the values of intensity, duration and return period. This IDF curves have been further split into 24 hours, with 1-hour interval for the 10 year return period rainfall. This served as the input to time series.

Sub-catchment characteristics such as width and slope have been calculated in GeoSWMM pre-processing tool and geometrical specifications have been taken from the data available. Curve number has been calculated from the SWMM Manual (Annexure-V).

Chapter 5
RESULTS AND DISCUSSION

5.1 Analysis of LULC change

With ArcGIS and ERDAS, the LULC data for the years from 2001 to 2018 have been analyzed to understand the land use conversion trend for six LULC classes namely, water, forest, agriculture, shrubs, urban settlement and barren land (Fig. 5.1 (a) & (c), 5.2 (a) & (c)). Better presentation of area (in Km^2) of each class is shown in the shown pie chart (Fig. 5.1 (b)). This graph of area distribution in 2001 shows that agricultural land has more contribution than any other class in the study area. Agricultural land is about 50% of the total area (33.26 Km^2), while urban area is about 30% of the total area (19.76 Km^2).

The LULC map of the year 2008 (Fig. 5.1 (c)) shows that area of agricultural land has decreased and urban settlements have increased. Arithmetically, about 48%of the total area (31.26 Km^2) has been covered by agricultural land while, 37.69% area included urban area (24.49 Km^2) as represented in area distribution graph of 2008 (Fig. 5.1 (d)).

Similarly, LULC of the year 2014 and 2018 clearly shows rapid growth of urban areas (Fig. 5.2 (a) & (b)). About 31% of the total area has been covered by agricultural land (20.91 Km^2) whereas, about 46% is covered by urban area (30 Km^2) as shown in area distribution map of 2014 (Fig. 5.2 (b)) and it can be analyzed from the same graph for 2018 (Fig. 5.2 (d)) that the situation has almost reversed from 2001 to 2018 with 52.77% of urban area and 25.75% of agricultural land.

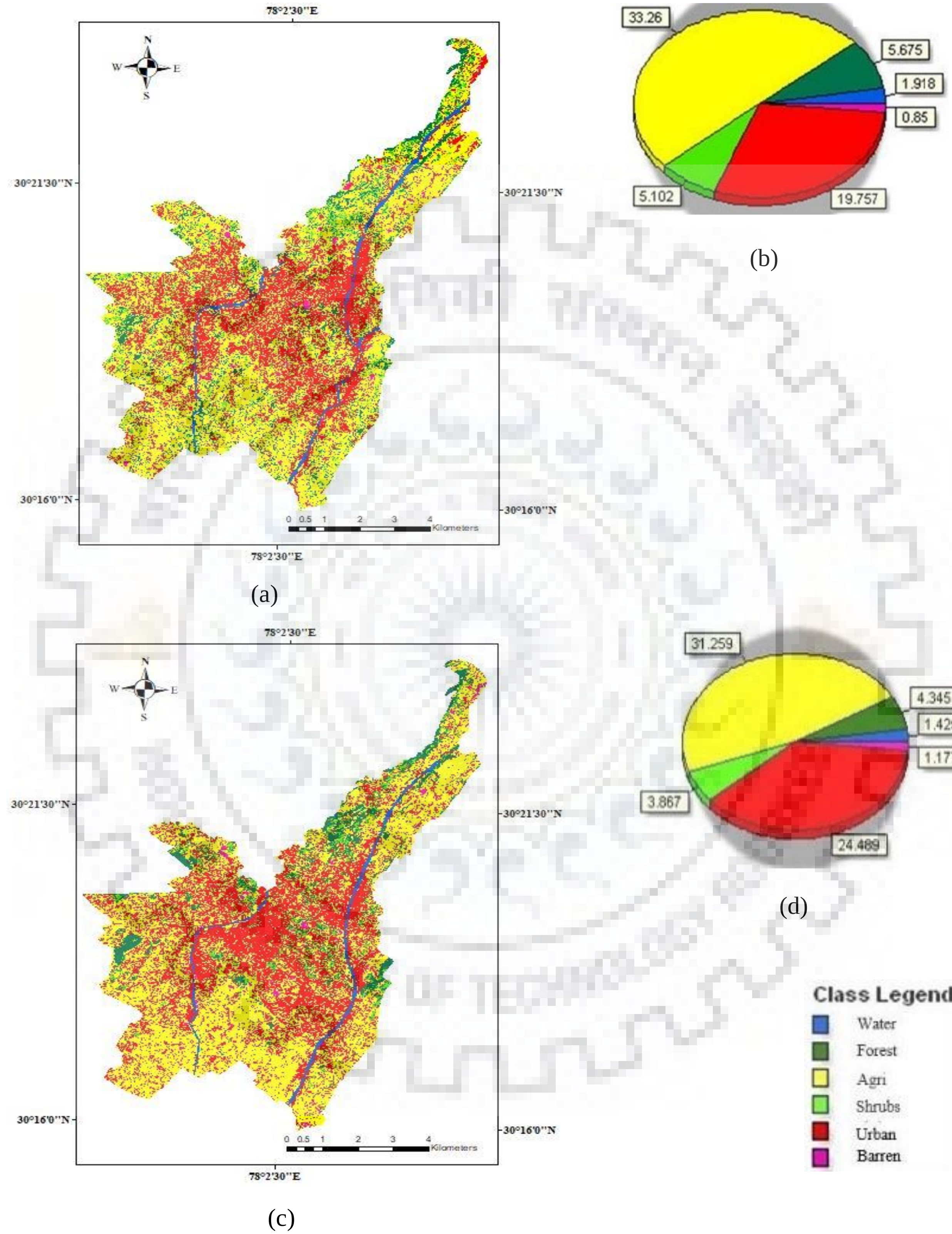


Fig. 5.1 LULC maps (a, c) and area distribution graphs (b, d) for 2001 and 2008 respectively

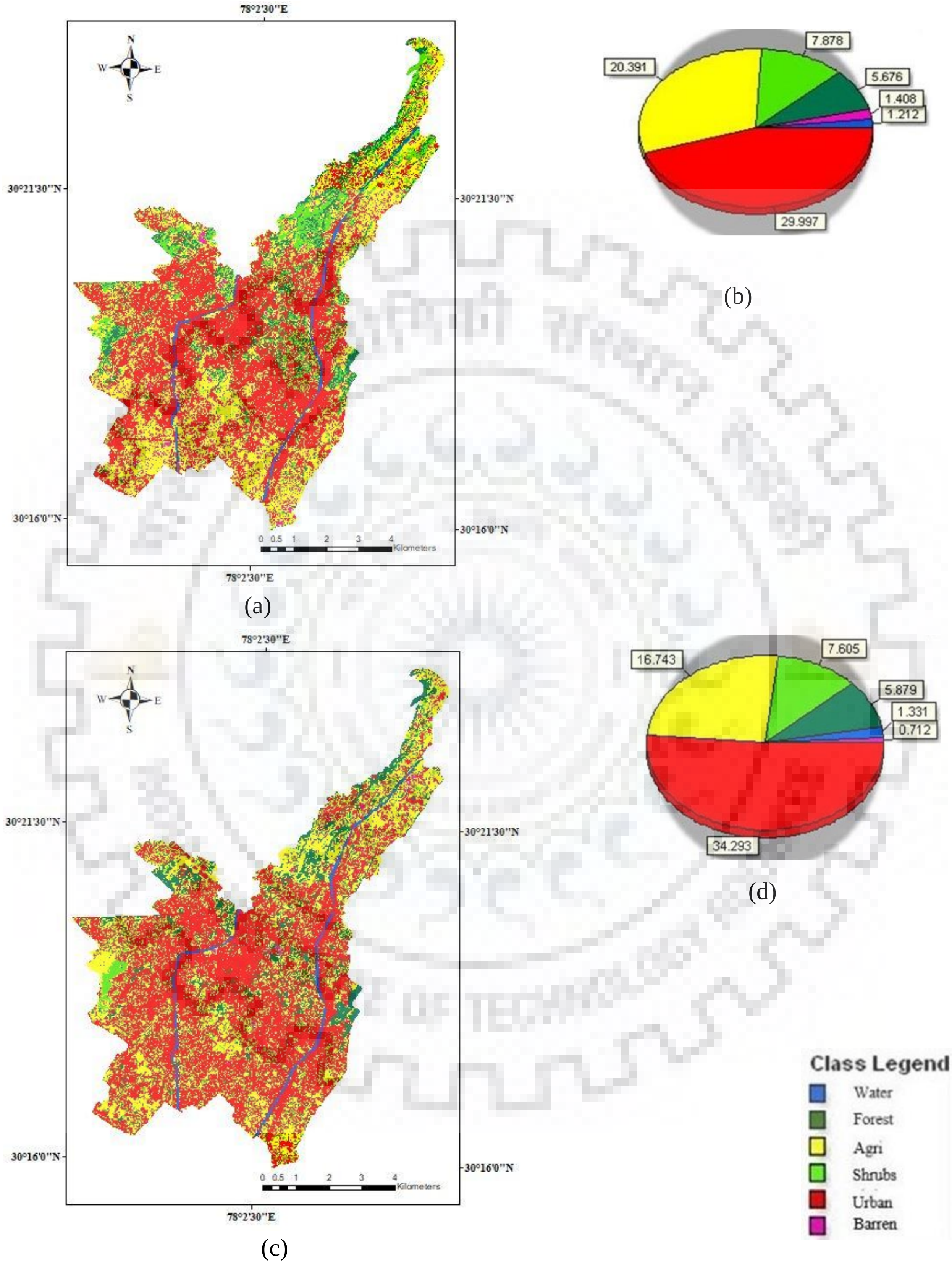


Fig. 5.2 LULC maps (a, c) and area distribution graphs (b, d) for 2014 and 2018 respectively

Table 5.1 Accuracy assessment of LULC maps

Category	**2001**	**2008**	**2014**	**2018**
Overall accuracy	95.24	92.46	96.88	97.62
Kappa coefficient	0.943	0.924	0.963	0.971
Class wise user accuracy (in %)				
Water	100	85.71	93.75	100
Forest	85.71	85.71	100	100
Agriculture	100	100	93.75	100
Shrubs	100	85.71	93.75	85.71
Urban	100	100	100	100
Barren	85.71	100	100	100

A better comparison of LULC maps of 2001 and 2018 is shown in the following Change detection matrix (CDM). The blue colored figures show the persistent area of the class from 2001 to 2018 (Table 5.4). CDM clearly indicates the conversion of the area from one class into another. Explanation of this can be given by explaining the first row of the area. It shows that 0.36 km^2 of water is persistent from 2001-2018, 0.13 km^2 of the forest, 0.33 km^2 of agricultural land, 0.05 km^2 of shrubs area, 0.46 km^2 or urban area and 0.01 km^2 of barren land in 2001 has now converted into the water in 2018. Agricultural area is decreased by about 50% and the urban area has increased by about 74%. This is going to decrease the perviousness of the ground and thus groundwater recharge has to be compromised for this change in the area.

Table 5.2 Change detection matrix for year 2001-2018

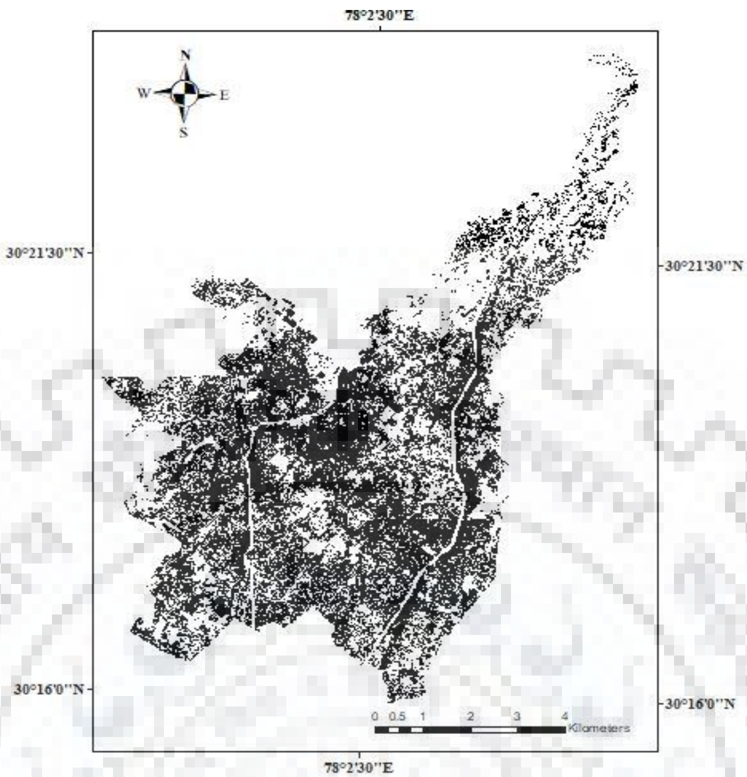
	CHANGE DETECTION MATRIX			**AREA(km2)**					**%AGE**
S.No.		**WATER**	**FOREST**	**AGRI**	**SHRUBS**	**URBAN**	**BARREN**	**Total individual class area2018**	**CHANGE**
1	**WATER**	0.36	0.13	0.33	0.05	0.46	0.01	1.34	-30.21
2	**FOREST**	0.13	1.67	2.68	0.97	0.41	0.01	5.87	3.34
3	**AGRICULTURE**	0.30	1.68	9.90	1.50	3.09	0.27	16.74	-49.67
4	**SHRUBS**	0.14	0.74	4.26	0.60	1.78	0.08	7.60	49.02
5	**URBAN**	0.97	1.44	15.71	1.94	13.85	0.39	34.30	73.58
6	**BARREN**	0.02	0.02	0.37	0.04	0.17	0.09	0.71	16.47
	Total individual class area 2001	1.92	5.68	33.25	5.10	19.76	0.85	66.55	

5.2 Prediction of LULC for the year 2030

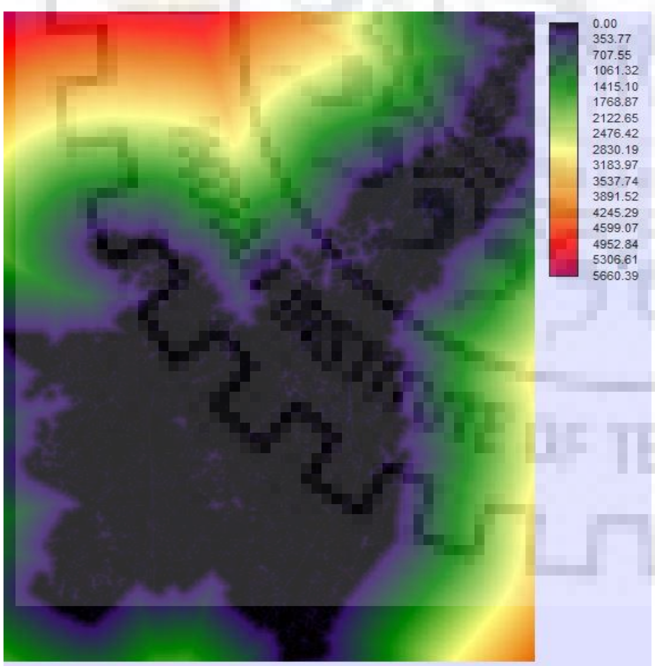
With the help of Terrset software which works on geospatial modeling, future prediction of LULC map has been prepared for the year 2030. Since the focus is to analyze the urban sprawl, only urban map has been provided as an important input to the Terrset modeling (Fig. 5.3 (a)). Also, the urban settlement is expected to increase by the influence of the surrounding urban areas. Therefore, distances from an urban area and the future probability of the expansion of urban are required the input of urban distance map (Fig. 5.3 (b)). The Fig.5.10 shows the probable distance from the urban settlement. Similarly, the distance from the road also plays a crucial role in urban sprawl. The diagram (Fig. 5.3 (c)) shows the distance from the road map. Analysis and model training in Terrset requires many transition maps which show how the transformation is taking place over the years. Fig. 5.4 shows the transition maps which help the model to build a trend of change in LULC.

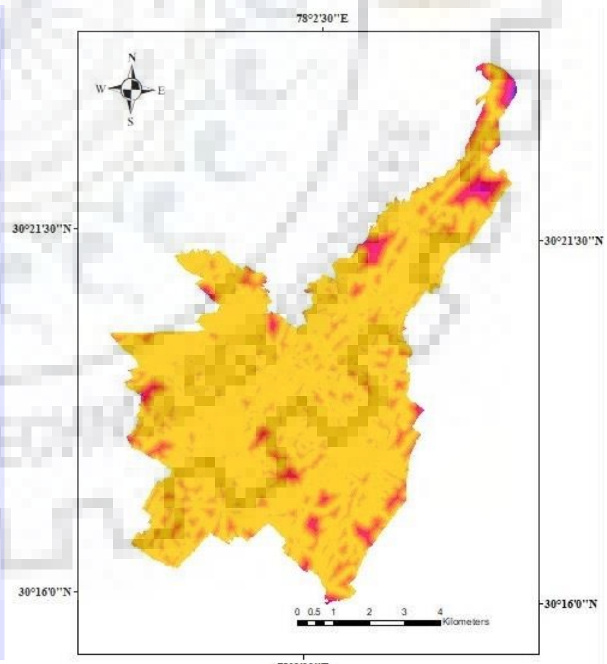
By analyzing the trend, Terrset generates the potential for further change in LULC from the historical LULC maps. For each class, maps have been generated and the class having the best potential is replaced by the other class. This way, the old trend is used to build the model and hence predict the future LULC. The potential for transition maps are also represented, that have been generated for few classes such as agriculture to urban (Fig. 5.5 (a)), forest to urban (Fig. 5.5 (b)), shrubs to urban (Fig. 5.5 (c)) and barren land to urban (Fig. 5.5 (d)).

With the maps available, Terrset geospatial model trains itself by analysis all the changes taking place and how they can further take place. Fig. 5.6 (a) is a training file map which shows how the agricultural land is changing and how much is persistent. This has been made with the input of three-time period LULC maps and change in their trend has been carried forward for future LULC predictions. Similarly, two classes can also be analyzed in one map for better understanding. The change of forest and agricultural land into urban and also which areas are persistent in their classes has been presented in Fig. 5.6 (b). Also, Fig. 5.7 (a) & 5.7 (b) clearly shows the variation in classes, this is similar to change detection matrix. Change in LULC class map has been generated showing the change from all classes to urban class from 2001-2008 (Fig. 5.7 (a)) and 2008 to 2014 (Fig. 5.7 (b)).



(a) Only urban map





(b) Urban distance map (c) Road map

Fig. 5.3 ((a), (b) & (c)) Input files prepared for Terrset

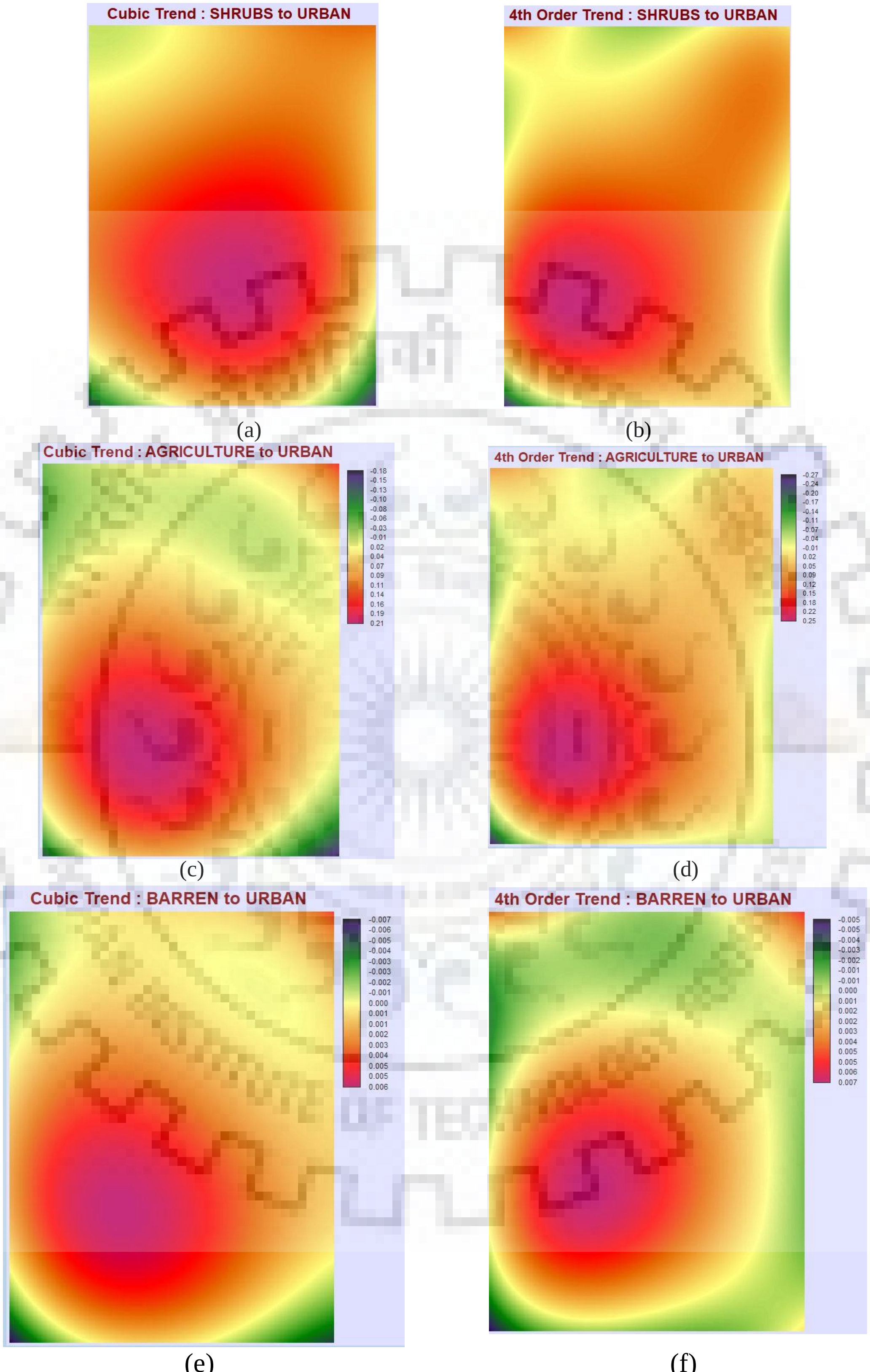
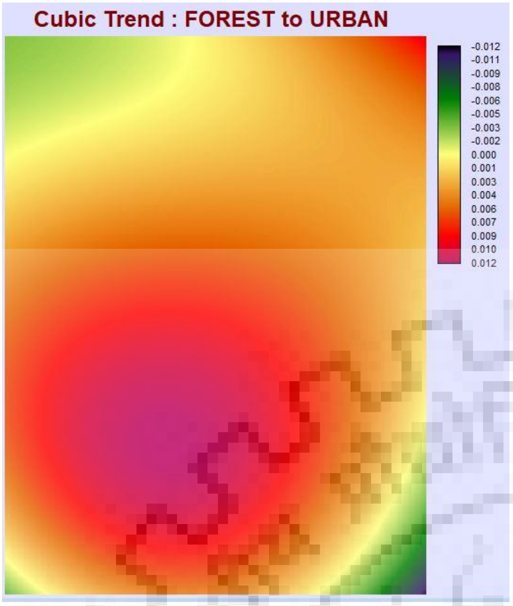
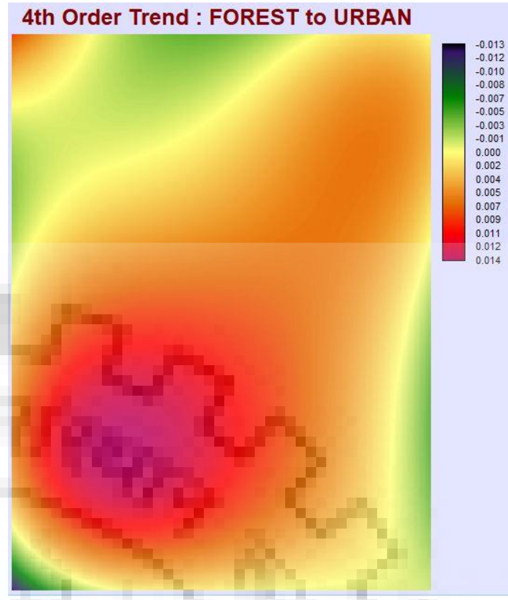


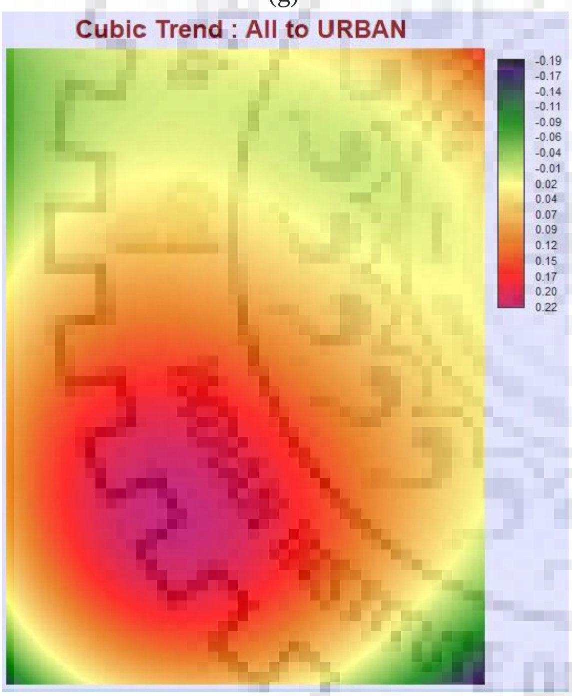
Fig. 5.4 Trend maps for cubic and 4th order trend for (a, b) shrubs to urban, (c, d) agriculture to urban, (e, f) barren to urban (g, h) forest to urban & all to urban (i, j) respectively



(g)



(h)



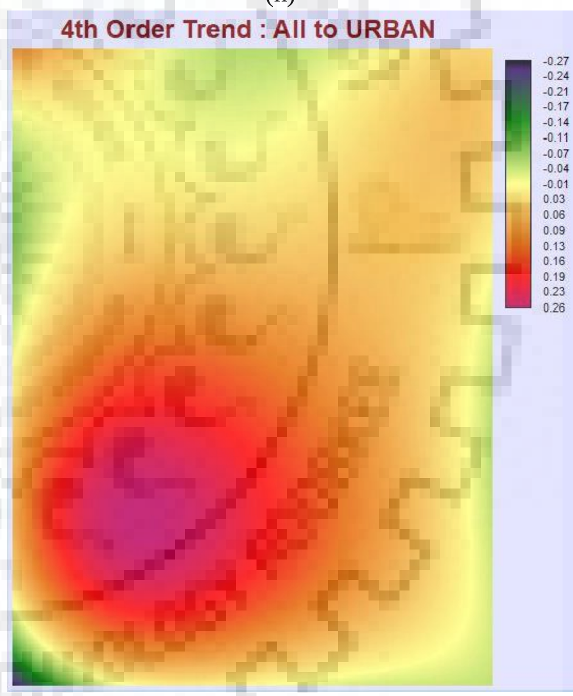


Fig. 5.4 Trend maps for cubic and 4^{th} order trend for (a, b) shrubs to urban, (c, d) agriculture to urban, (e, f) barren to urban (g, h) forest to urban respectively & all to urban (i, j) respectively continued

Finally, after analyzing all the data, a final transition from all classes to urban area, called as cross-classification map, has been made from the year 2001 to 2008 (Fig. 5.8 (a)). This is just like the digitized form of the change detection matrix, which shows how the pixels have changed. The legend of Fig. 5.8 (a) & (b), attached with the map reflects the class transformation, and each transformation has been given a unique code. These cross-classification maps have been made to depict the change in class from 2001 to 2008 (Fig. 5.8 (a)) and 2008-2014 (Fig. 5.8 (b)).

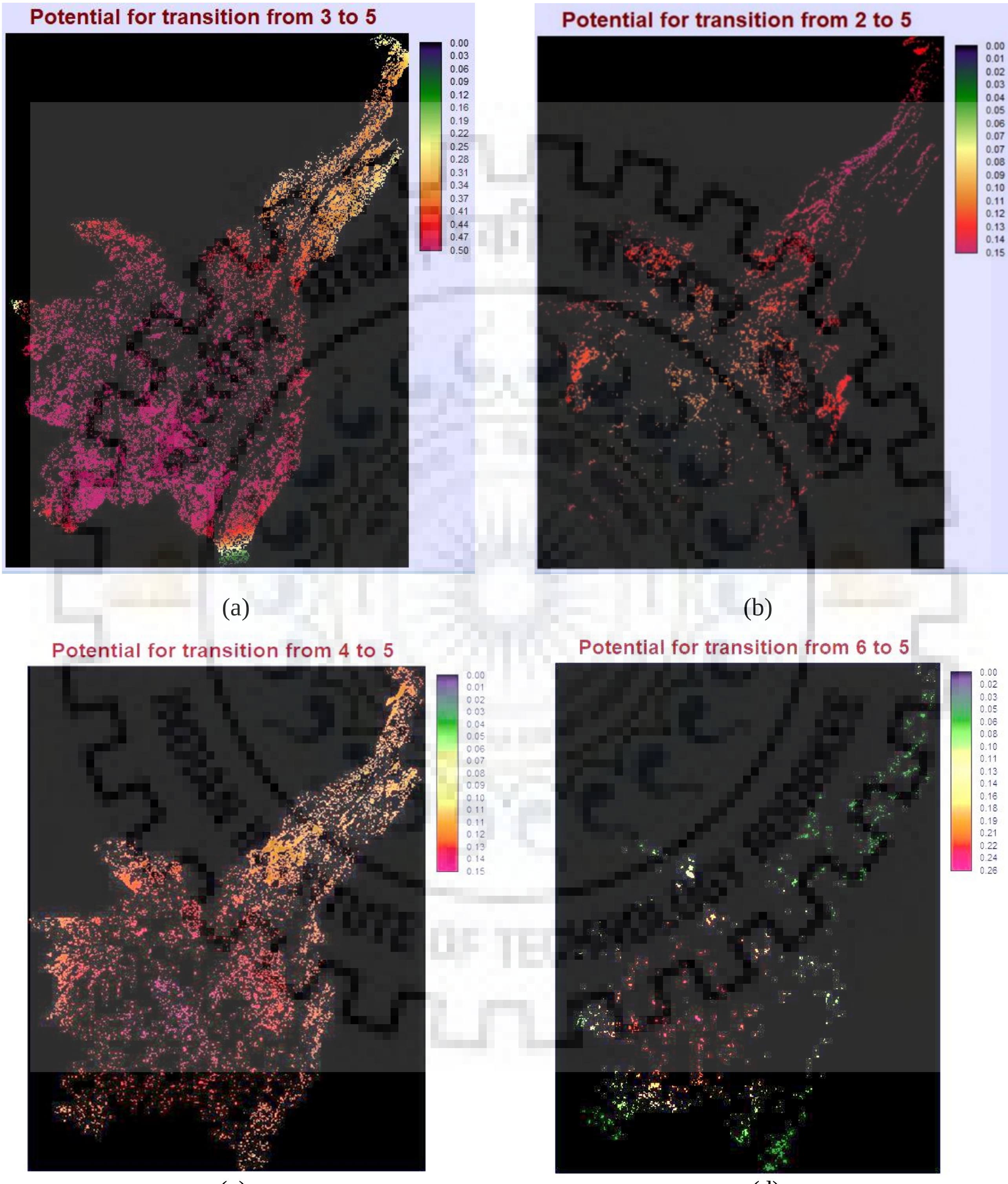
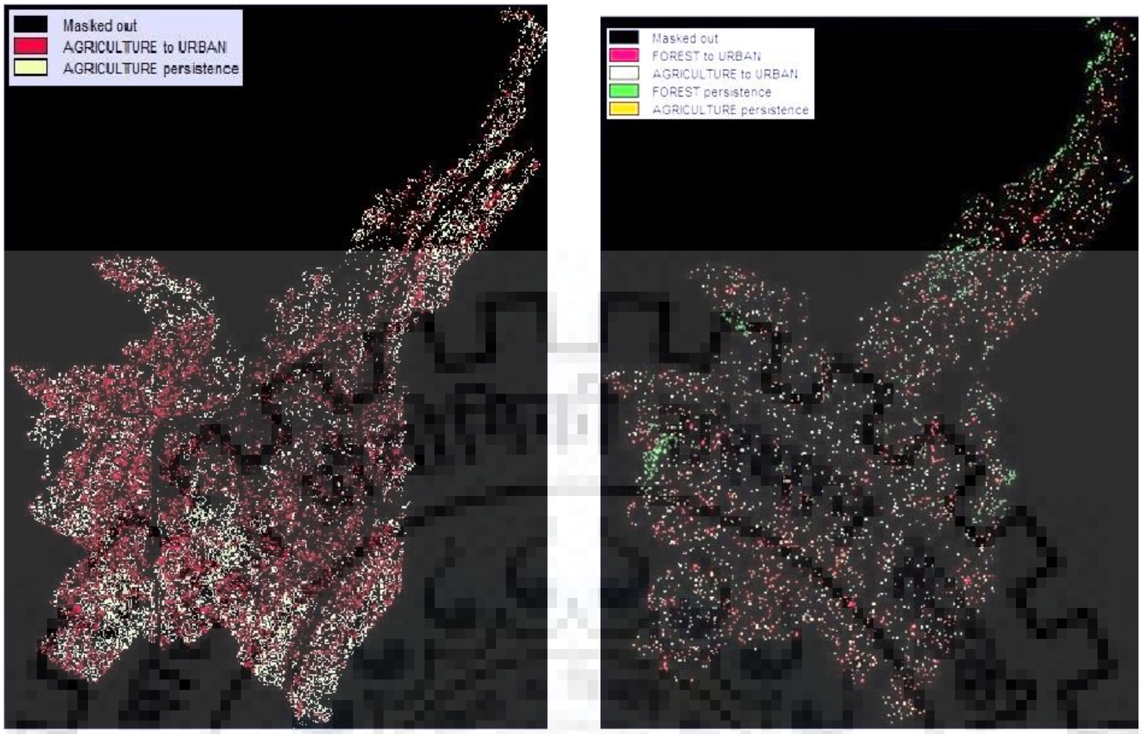
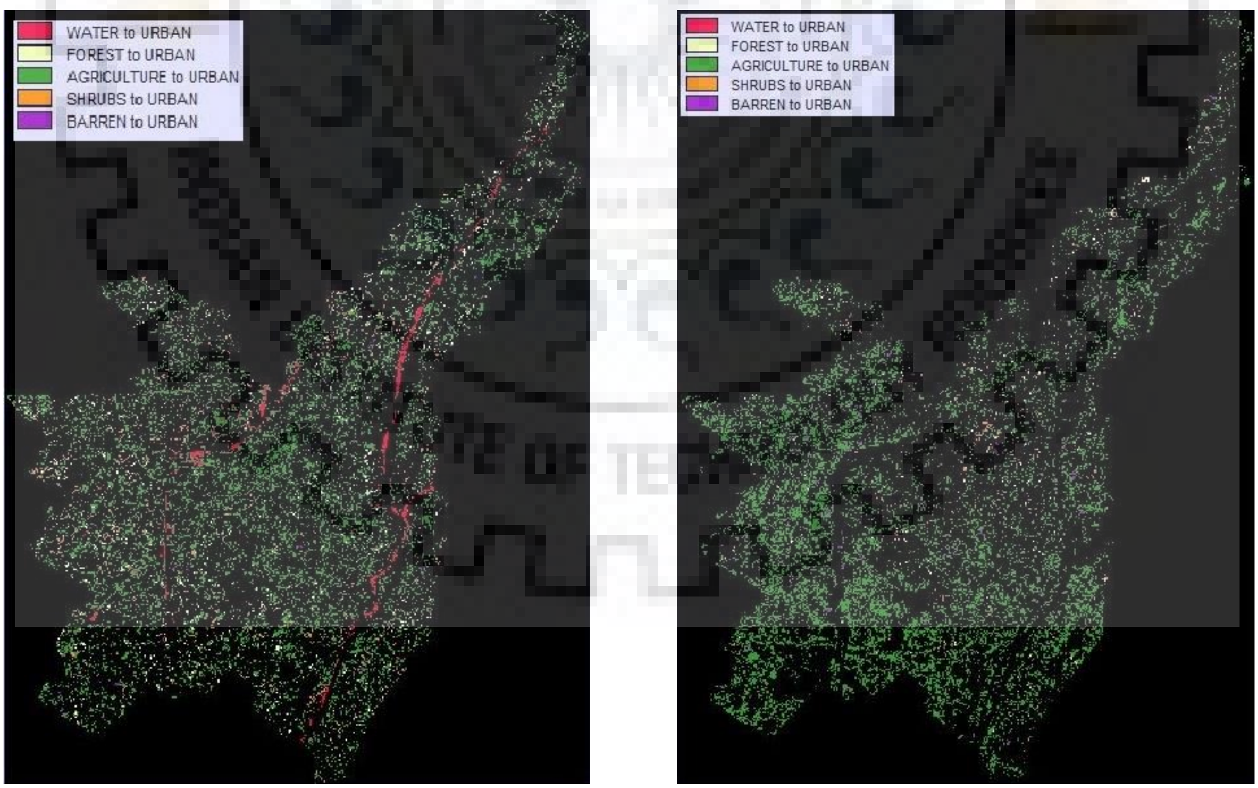


Fig. 5.5 Transition potential maps for (a) agriculture to urban, (b) forest to urban, (c) shrubs to urban and (d) barren to urban



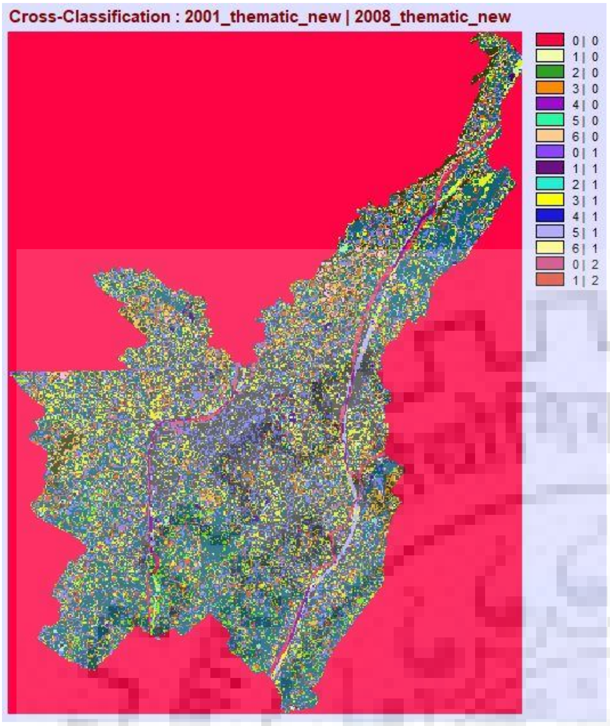
(a) (b)

Fig. 5.6 Training file maps for (a) agriculture to urban area (b) Training file map from agriculture to urban area and forest to urban combined

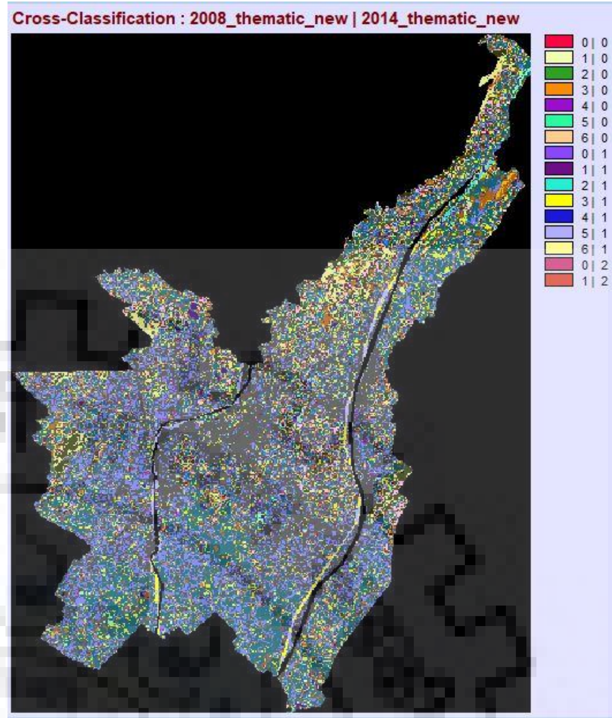


(a) (b)

Fig. 5.7 Change map from all class to urban class for (a) 2001-2008 & (b) 2008-2014



(a)

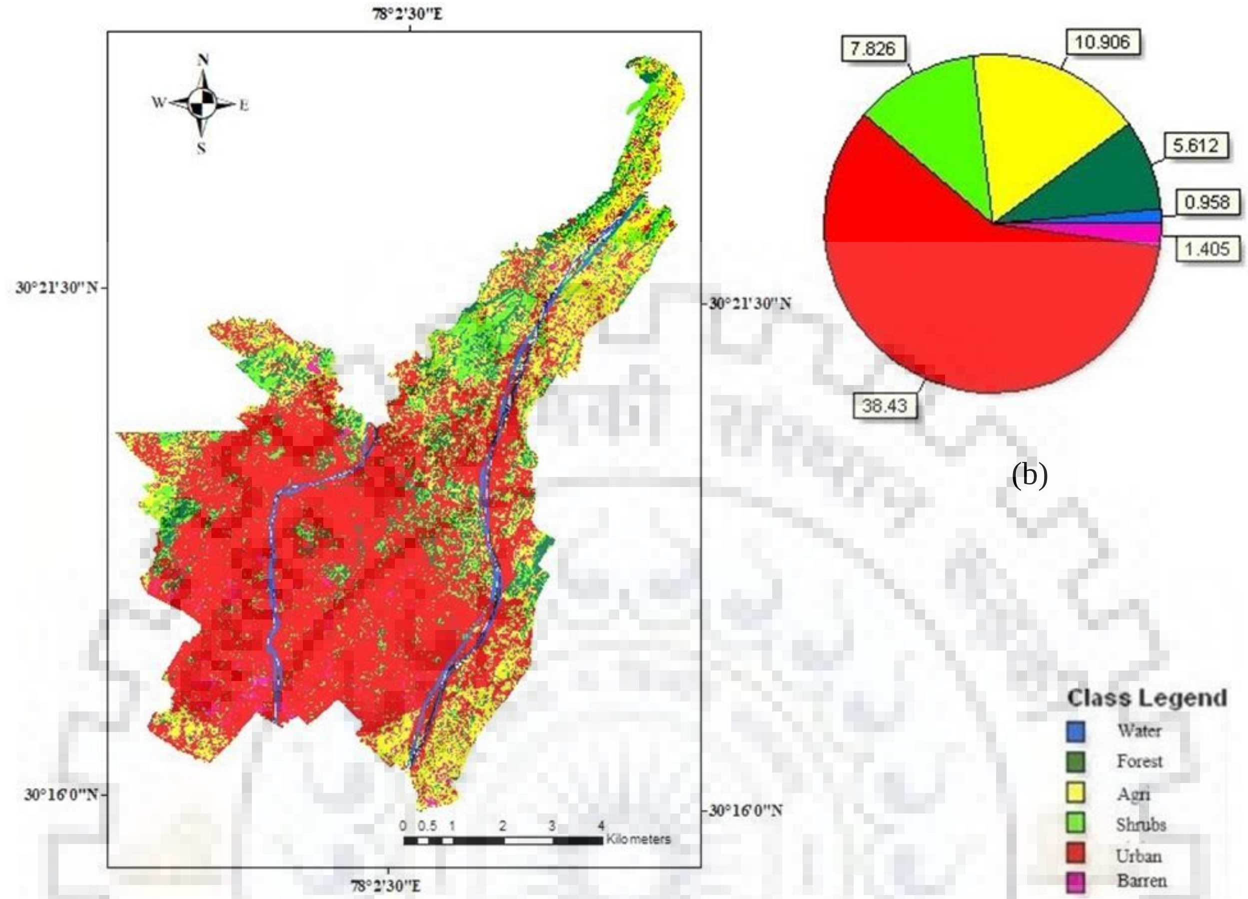


(b)

Fig. 5.8 Cross-classification map from (a) 2001-2008 and from (b) 2008-2014

The results of Terrset software have been provided in the Annexure III to see how the back end analysis have been performed for the preparation of future LULC for the year 2030 (Fig.5.9 (a)). The overall accuracy of 31.54% has been achieved and accuracy above 30% is generally considered good for this model (Terrset manual). The predicted results for the year 2030 shows the same trend of urbanization as already prevailing in the past years.

For better understanding, area distribution of LULC map for the year 2030, shows how the urban settlement has increased over the expense of other classes (Fig.5.9 (b)). Fig.5.31 shows the 60% of the total area in urban (38.43 km^2) whereas agricultural land cover is 10.91 km^2 (approx. 16.8%).



(b)

(a)

Fig. 5.9 LULC maps (a) and area distribution graphs (b) for 2030

5.3 Results of stormwater modelling using SWMM

Stormwater is a major burning problem in the urban area. As it is already seen that the urban area in Dehradun city has increased by about 73% from 2001-2018, the scope for stormwater drainage plan plays an important role. Stormwater management model has been used in this study to analyze the water spread area during the flood events. For the same, IDF curves for different return periods have been generated by Gumbel's method to serve as input to the SWMM model (Fig. 5.10 and Table 5.3).

Table 5.3 Maximum intensity, duration and return period relationship

DURATION	**RETURN PERIOD(T)**				
(HOURS)	*2yrs*	*5yrs*	*10yrs*	*50yrs*	*100yrs*
1Hr	24.16	34.56	41.46	56.62	63.04
2Hrs	15.22	21.77	26.12	35.67	39.72
6Hrs	7.32	10.47	12.56	17.16	19.10
12Hrs	4.58	6.56	7.87	10.76	11.98
24Hrs	2.91	4.16	4.99	6.82	7.59

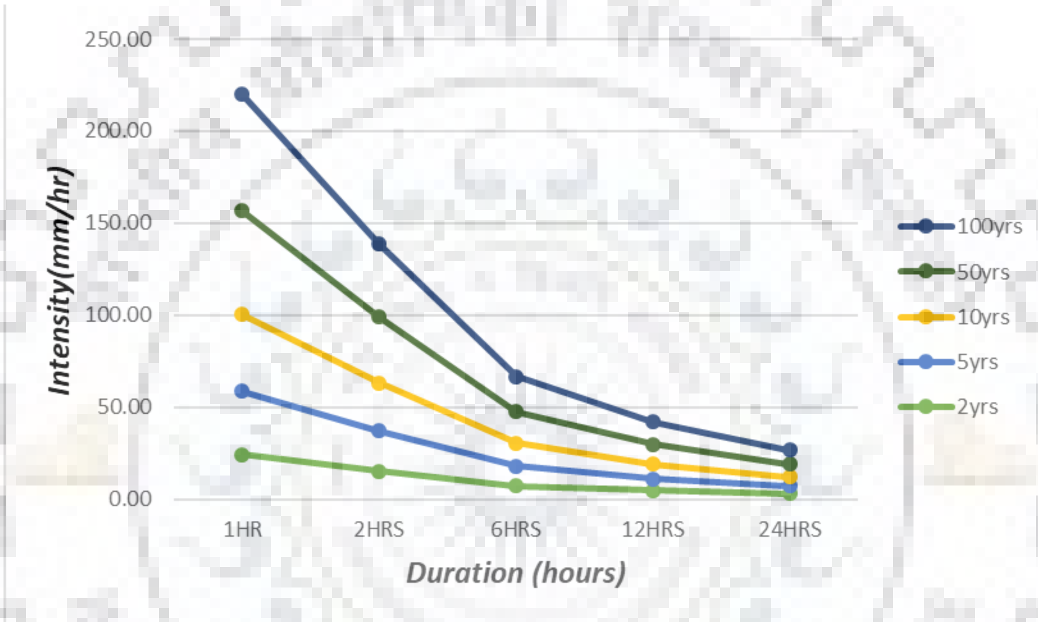


Fig. 5.10 IDF curves for different return periods

Now with this IDF curve (Fig. 5.10), the return period of 10 years is chosen for the study and maximum rainfall of 119.76 mm has been considered as the storm event for the study. Fig. 5.11 shows the distribution of maximum rainfall into 24 hours and time interval of 1 hour has been considered for this study. (Annexure IV) Time series (Fig. 5.11) has been provided as an input in terms of volume in “mm” to the SWMM.

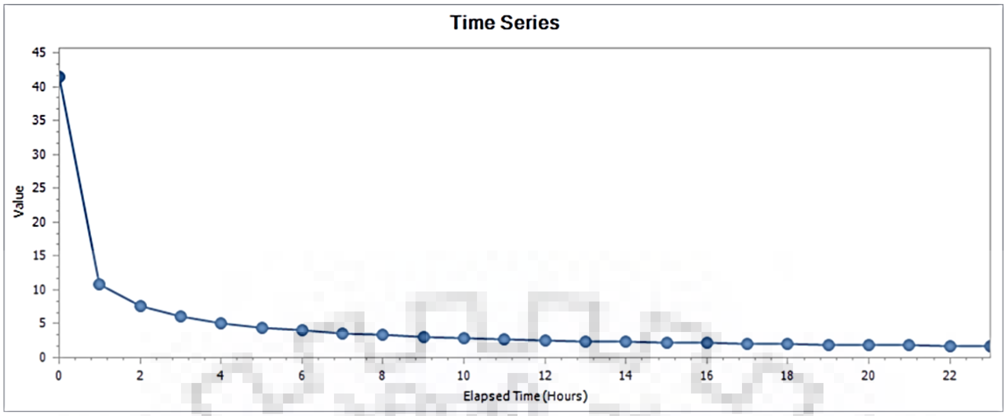


Fig. 5.11 Time series input viewer for SWMM

Also, the location of elements (Fig. 5.12) of SWMM has been identified, using City development report 2007. The simulations run in SWMM which gives the output of the nodal surcharge, conduit surcharge, node flooding, sub-catchment runoff, and outfall loading (Annexure -VII). Also, the water and elevation profiles of two conduits on a drain are shown in Fig. 5.13 (a) & (b) shows how the water is flowing in the conduits.

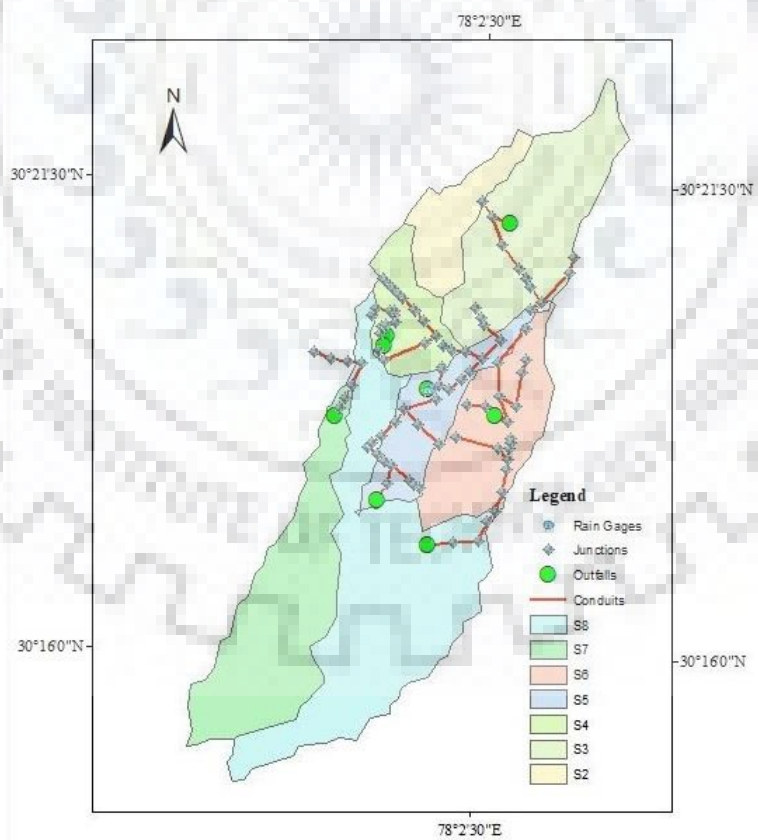
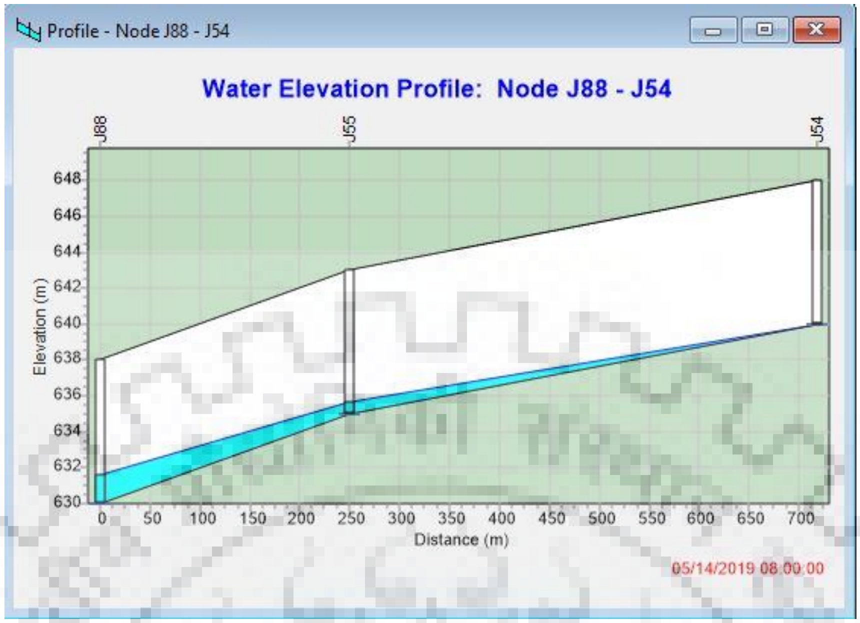
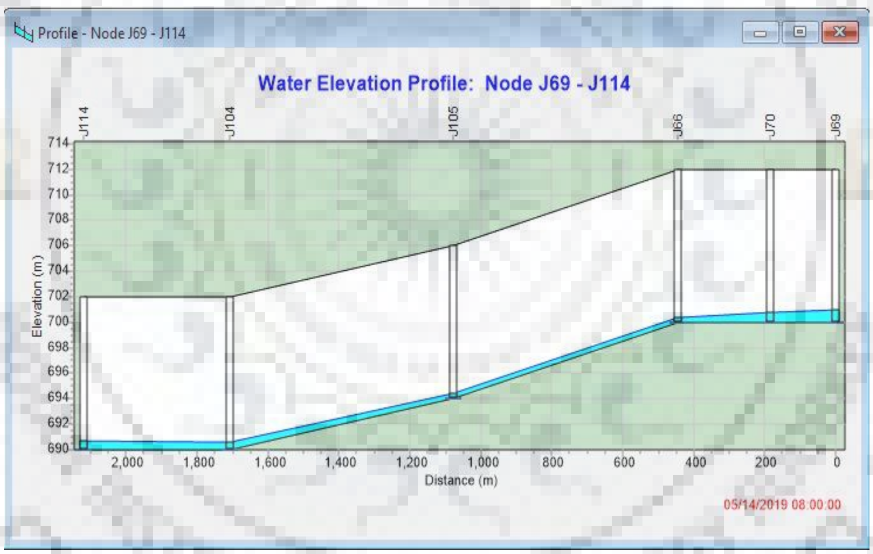


Fig. 5.12 Location of elements of SWMM input



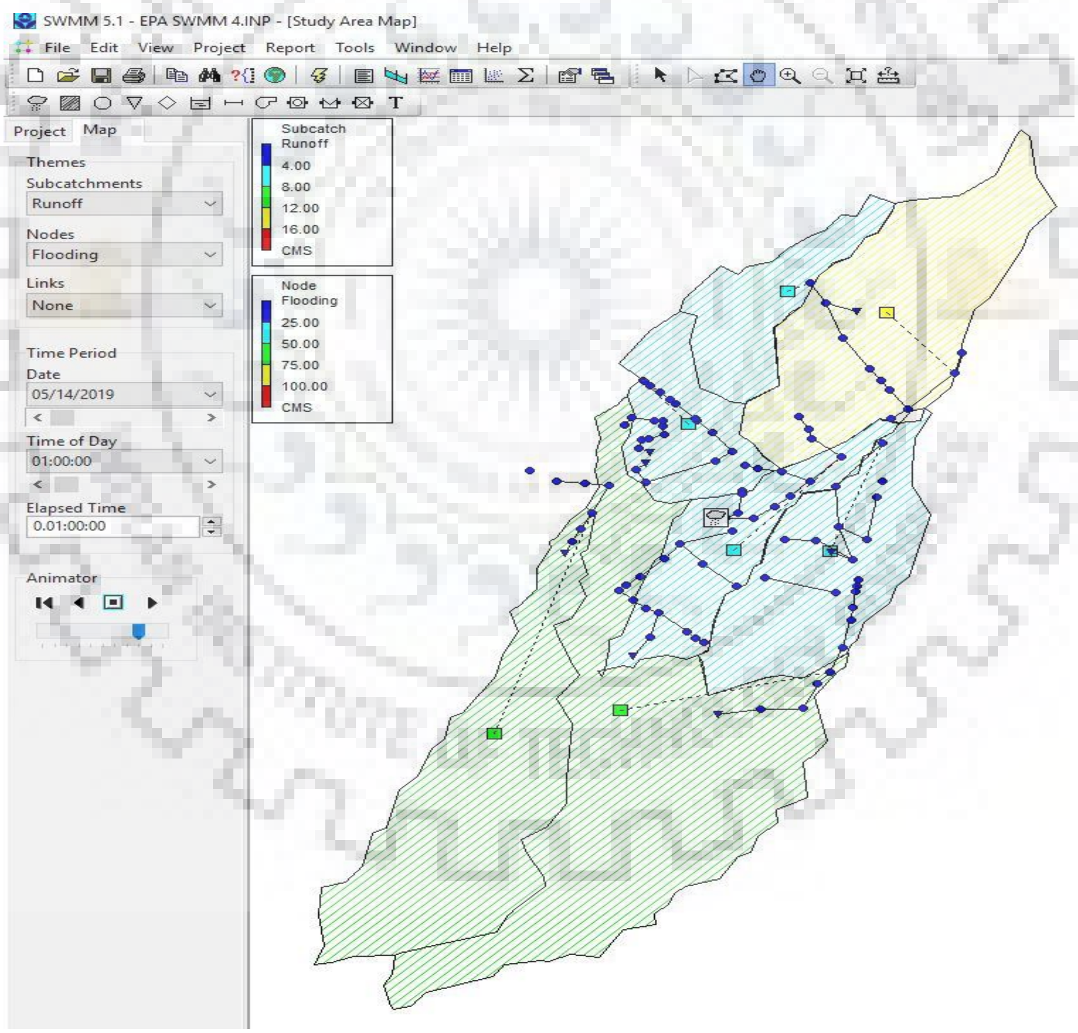
(a)



(b)

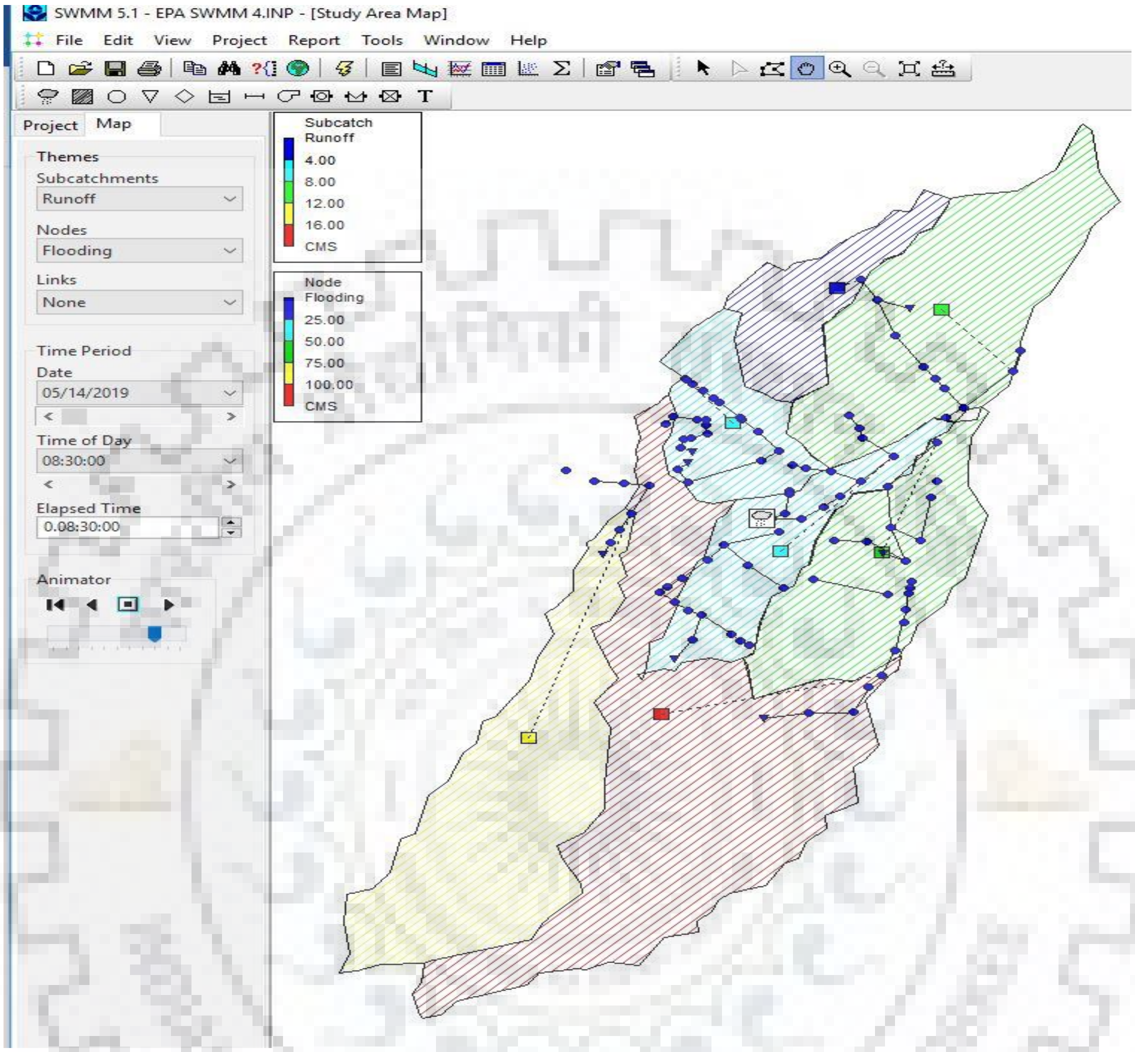
Fig. 5.13 Water elevation profile from Node J88 to J54 & Node J69 to J114

Basically, SWMM is used to zanalyze the real-time flooding in the area due to any storm event. Storm year been considered here is the rainfall of 10 years return period. Its effect on the sub-catchments and further on the drainage map of the city has been calculated in this study. The input of 24 hours, 1-hour interval rainfall has been fed into the model and reporting for every 15 minutes of the water drainage have shown. Live flooding of the water is also displayed in the model for various permutations between elements (conduit, sub-catchment, junctions, outfalls, etc.) and the variable parameters such (runoff, depth, surcharge, roughness, depth, elevation, slope, etc.). All the variables and elements can be analyzed as per requirement. Full report of the simulation run in SWMM is attached in Annexure VI. A combination of sub-catchment runoff and flooding in nodes have been shown in Fig. 5.14 (a) at 01:00:00 (1 hour from the beginning of analysis) and Fig. 5.14 (b) shows the same combination situation at 08:30:00. The variation in the two can be seen in color difference and legends attached show the values corresponding to the color. Another combination is the slope of sub-catchment, volume in nodes and velocity in links. Fig. 5.15 (a) shows the situation in the initial 15 minutes, at 00:15:00. Also, the situation for the same combination is shown in Fig. 5.15 (b) at 14:00:00.



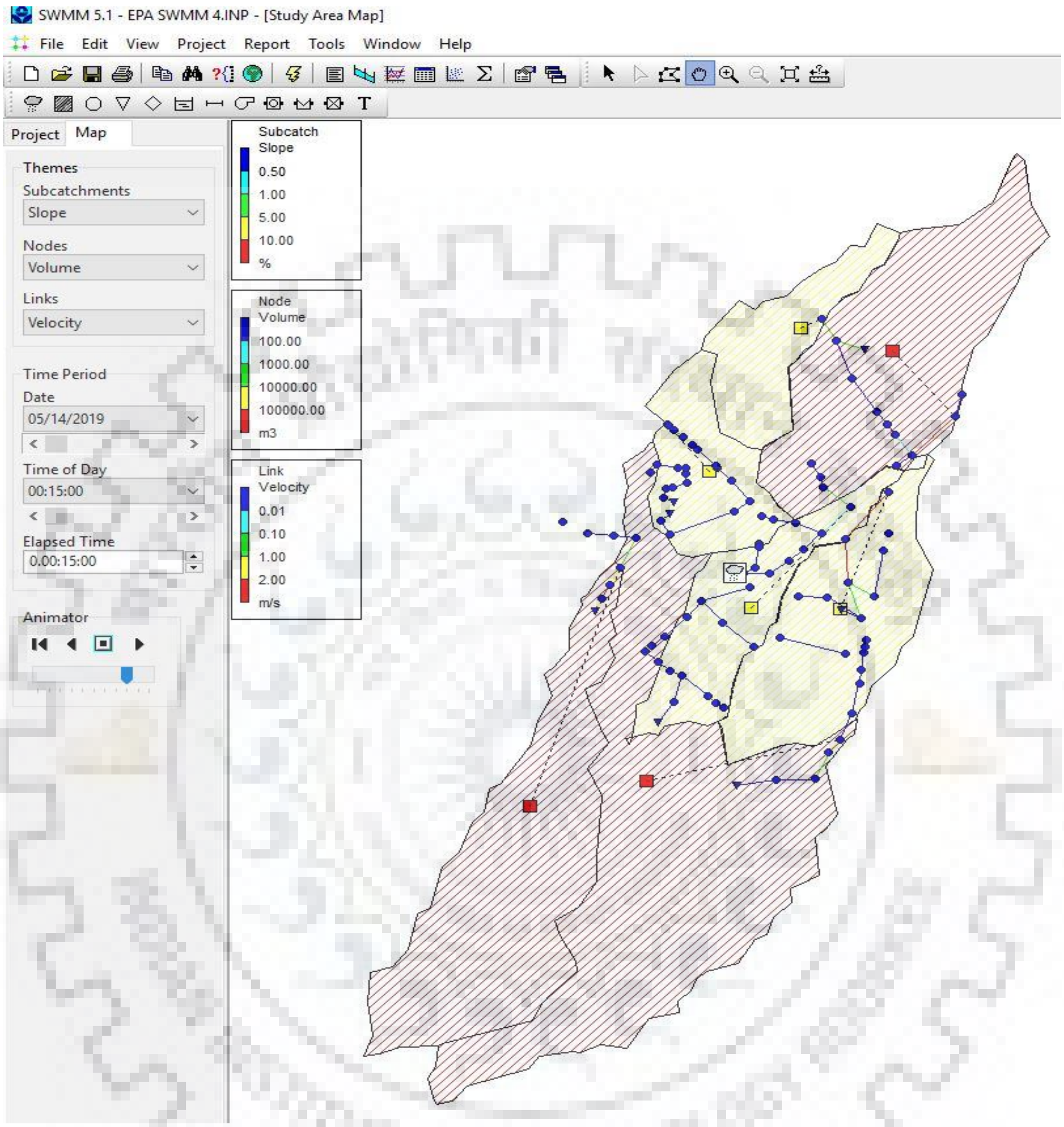
(a)

Fig. 5.14 Subcatchment: runoff and Nodes: flooding at (a) 01:00:00 and (b) 08:30:00



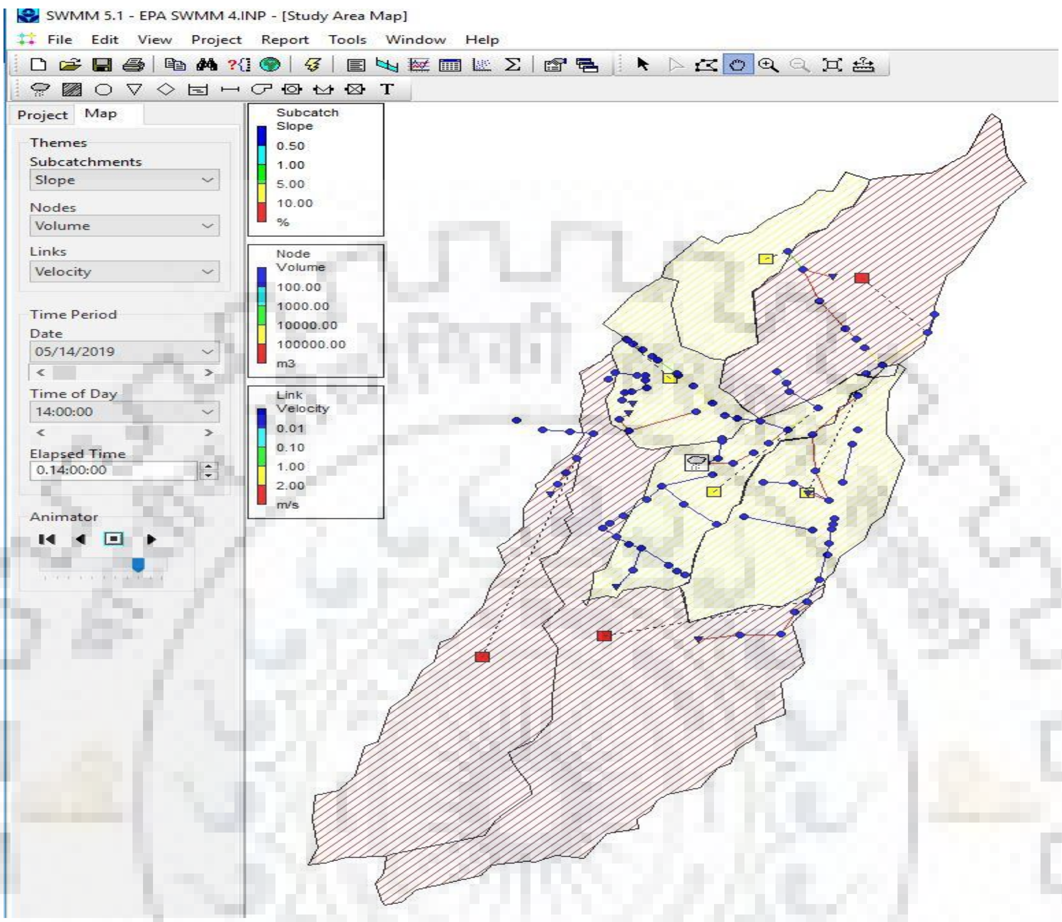
(b)

Fig. 5.14 Subcatchment: runoff and Nodes: flooding at (a) 01:00:00 and (b) 08:30:00 continued



(a)

Fig. 5.15 Subcatchment: slope, nodes: volume and links: velocity at (a) 00:15:00 and (b) 14:00:00



(b)

Fig. 5.15 Subcatchment: slope, nodes: volume and links: velocity at (a) 00:15:00 and (b) 14:00:00 continued

Validation of SWMM results:

Subcatchment characteristics have been shown in Table 5.4. Using these characteristics and the output of the model run have been used for the validation of SWMM results. The validation has been done by calculating the runoff coefficient and finding that lies in the prescribed values (Table 5.5). The output of the model gives runoff for each subcatchment (Annexure VII) and area was calculated by the model itself. The following equation for calculating runoff coefficient.

$$k = \frac{Q}{iA} \tag{4.5}$$

Where, k is runoff coefficient, Q runoff discharge, i is the rainfall intensity and A is the subcatchment area.

Also, validation has been done by observing that the runoff depth. Rainfall depth taken for analysis is 119.76mm whereas the runoff depth calculated by dividing the runoff volume by subcatchment area is 74.55mm.Since runoff depth calculated is less than rainfall depth, it shows that some storm water has infiltrated while the rest goes as stormwater runoff. (ANNEXURE VIII)

Table 5.4 Subcatchments characterstics

Characterstics	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
Rain gauge	R1	R1	R1	R1	R1	R1	R1
Outlet	J114	J82	J22	J8	J64	J80	J55
Width(m)	8768.16	25336.3	9431.02	11322.8	17448.2	27814.4	44030.2
Area(hect)	350.73	1031.45	377.24	452.91	697.93	1112.58	1761.21
% slope	9.45	14.87	9.95	6.93	7.54	13.16	16.21
% Impervious	22.65	36.5	59.46	56.71	54.53	46.67	50.42
N-Imperv	0.8	3.7	2.24	2.57	3.8	5.19	8.88
N-Perv	2.71	6.44	1.53	1.96	3.17	5.93	8.74
CN	75.6	77.14	82.55	82.41	81.82	81.08	82.44

Table 5.5 Calculation of runoff coefficient and runoff depth

	Runoff(10^3m^3)	Intensity(mm/day)	Area(hect)	Runoff coefficient	Runoff depth
S2	229.23	119.76	350.73	0.55	65.36
S3	690.69	119.76	1031.45	0.56	66.96
S4	341.92	119.76	377.24	0.76	90.64
S5	391.7	119.76	452.91	0.72	86.49
S6	564.21	119.76	697.93	0.68	80.84
S7	835.47	119.76	1112.58	0.63	75.09
S8	1258.56	119.76	1761.21	0.60	71.46
SUM	4311.78	119.76	5784.05	**0.62**	**74.55**

5.4 Water Demand and supply analysis

Since the population is a major factor affecting water resources in any city, analysis of population and thus urban water demand has been estimated for Dehradun city((Table 5.6 and Fig. 5.16). Water supply data obtained from DSCL office has also tabulated for this analysis (Table 5.7). Finally, both water supply and demand has been analyzed and presented in Fig. 5.16.

Table 5.6 Calculation of water demand from census data

Year	Total Population	Urban population %	Urban Population	Dehradun city population	Per capita water demand	Water Demand(MLD)
1991	1,025,679	49.82	510,993	286,157	135	38.63
2001	1,282,143	52.9	678,253	393,387	135	53.11
2011	1,696,694	55.52	942,004	578,400	135	78.08

Table 5.7 Analysis of water supply and water demand data

Year	Water demand(MLD)	Ground water supply(MLD)	Surface water supply(MLD)
1966		3.6	5
1970		9.94	
1973		14.11	
1975		20.88	
1980		26.64	
1985		42.91	
1990		72.58	27.5
1991	38.63		
1995		94.61	
2000		116.06	
2001	56.11		
2005		155.95	
2010		248.56	
2011	78.08		
2015		279.52	
2019		351.95	14

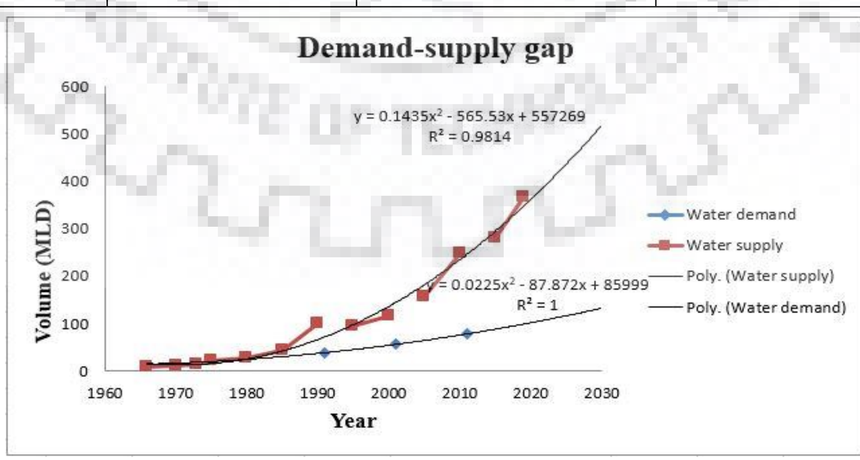


Fig. 5.16 Demand-supply gap trend line

5.5 Discussion on smart water management techniques

With the above results, it has been cleared that the water crisis in Uttarakhand is about to be faced in the near future. The proper management plan needs to be adopted at this stage to secure the water supply for the future. Smart approach has to be adapted to meet the real-time water demand of the upcoming smart city. Literature review suggests numerous ways and management plans that are already or can be applied to the city for effective water management in a less tedious and highly efficient way (Kumar and Kumara, 2011; Washington, 2014; van Hattum et al., 2016; Patawala et al., 2017). But being a Himalayan region city, it has topographic and climatic challenges. The study needs to be done before adopting any method as they require huge inputs and must not be taken casually. Some of the methods have been reviewed and discussed below:

(c) SEQ water grid, Australia: In the year 2007 and 2008, Australia has also faced water crisis in which the water capacity of three major dams (Wivenhoe, Somerset, and North Pine) decreased to less than 17%. To overcome this, they introduced two-way movement of water which also includes treatment facilities (example desalination and purification of recycled water). SEQ water grid consists of 12 connected dams, 10 connected drinking water treatment plants, 3 advanced water treatment plants, 1 desalination plant, 28 water reservoirs, and 22 bulk water pumping stations. They also invented new sources like harvesting rainfall water (Newbold, 2009).

(d) Smart Water Grids (SWGs): It has been already adopted in countries like Korea. In this system, a central grid is divided into several grids which look after the water supply in a particular area. Water coming from these grids is then purified and recycled to the central grid or to a separate reserved grid. This extra water is used at times of high water demand or the unavailability of fresh water supply. The flow in the pipes is bi-directional which is controlled by ICT. When there is no disturbance, all grids will work independently but with any need in any grid, water will be diverted there through means of ICT (Lee et al., 2015).

(e) Leaks in the pipeline is obviously a matter of concern for all as it not only accounts for monetary loss due to wastage of useable water but also decreases the reliability of common people over the supply given by the government. One solution to the detection of leaks can be the application of SmartBall (Fletcher, 2008). SmartBall not only detect leaks but also give the report of the existing condition of the pipes, which in actual requires huge time and money to be detected. The situation becomes more severe when the case is of large diameter pipes as in them the amount of water lost is large which affects the Revenue collection amount as well. SmartBall is a free-swimming device, spherical in shape and smaller than the pipe bore allowing it to roll smoothly through the pipeline and give the highest responsiveness to even small leaks.

5.6 Interventions/Adaptive measures

- *Dual distribution and management system of water*:

  Due to the upcoming shortage of water in the world, recycling of wastewater seems to be a necessary step for proper management of the water resources. But in a country like India with several society constraints for the adoption of using reclaimed water, it's difficult to go for prevailing methods of supplying treated wastewater. The following dual water distribution (water grid) plan for the Dehradun city has been recommended for water resources management (Fig. 5.17).

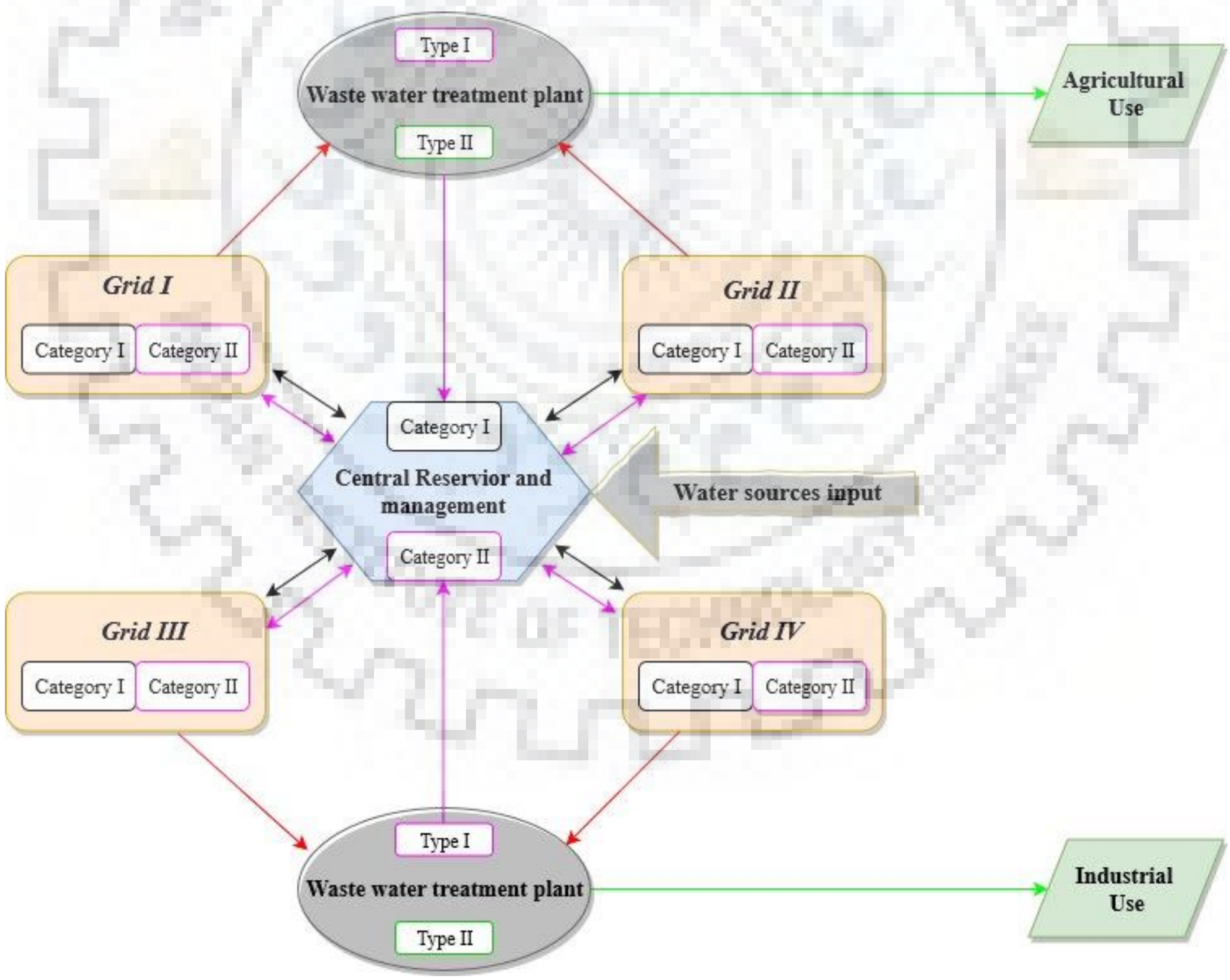


Fig. 5.17 Dual water grid system: fresh and reused water

Notations:

→	Conduit carrying reclaimed water coming from waste water treatment plant
↔	Dual path conduit containing reclaimed water from a central reservoir and management unit to grid
↔	Dual path conduit containing fresh water from a central reservoir and management unit to grid
→	Conduit carrying fresh water from water sources such as groundwater, surface water, and stormwater
→	Conduit carrying wastewater from grids to wastewater treatment plans
→	Conduit carrying water treated for agriculture and industrial use
Category I	Input from water sources such as ground water, surface water and storm water
Category II	Reclaimed water coming from wastewater treatment plant
Type I	Higher quality water treatment for domestic use (washing, bathing, etc.)
Type II	Lower quality water treatment to meet agricultural and industrial standards

This is a complete installation of the new system containing recycled water. In this system, fresh water from natural sources such as groundwater, surface water, and stormwater can be primarily treated and fed into the central reservoir unit. From here water can be fed to several grids from where it is further been distributed to households. A separate pipeline or the existing pipeline and overhead tanks can be used for this purpose. The wastewater coming from the households can be carried to the wastewater treatment plant where the treatment is bifurcated into two types. Type I is the better quality treated water which can be fed as input to central reservoir and management unit from where it can be sent to grids in category II storage units and the further to households for purposes other than drinking and cooking. This reclaimed water can be used for washing, flushing, gardening, etc. The type II treated water can be treated keeping in mind the quality standards required for agriculture and industrial requirements. This way the whole system can be well sustained and green, which are the two basic requirements of the smart city. Also, the pipelines coming out of grids are bi-directional so that if any contingency happens at any place near to 1 grid, water can be supplied from other grids if needed. To make this system smarter, the whole routing can be controlled by ICT tools from a control room. This way input and flows in and out all the pipelines can be operated by smarter means with ICT tools.

- *Installment of pressure sensors along the pipelines:*

  Leakage is a big problem prevailing in any water distribution system, and due to it a lot of valuable water is lost before the detection of the leakage. A method has already been followed in few places such as is smartball, as discussed previously in this chapter. But still, it is a onetime process and can't be done very frequently. This study proposes installment of interactive pressure sensors all along the pipelines which continuously provide updates to the municipalities with the leakages in the form of sudden pressure drops so that actions can be taken before the considerable loss of the water occurs. These pressure sensors can be installed at some distance from each other but in enough proximity to catch each other's signal and ensure that no point is left unscreened by the sensors.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Dehradun's urban area is expanding at an unmatchable pace but the resources available are limited and if not used wisely, will end up soon in future. Results show that agricultural land has reduced from 33.26 km^2 in 2001 to 16.84 km^2 in 2018. Also, the sudden rise in an urban area is observed since the urban settlement area in 2001 was 19.76 km^2 but in 2018 has increased to 34.93 km^2. This change is healthy in terms of development but can turn into a curse if the development is not sustainable, as in the present case of Dehradun. Also, the trend in population growth is alarming and it results in increased urban water demand. Water demand in 1991 was 38.63 MLD and has reached to 78.08 MLD in 2011 and it is going to cross 100 MLD. This trend needs to be studied well with supply trend and the gap has to be minimized. A proper analysis needs to be done for the estimation of the cost, feasibility, and outcomes of all the plans. The future LULC of the year 2030 suggest about 60% conversion of land into an urban settlement and is alarming. Results of stormwater management model suggest the probable path for stormwater and the places urban flooding. It needs to be studied that which option is more suitable for escaping the city from the water crisis. The smart approach helps in performing difficult tasks with an effective and less complicated way. It helps users to identify the real-time demand of any action to be taken and accordingly respond immediately from the system without going actually to the field. Proper analysis of the available and wasted water with the crux of ICT is very well applied in suggested methods. Smart management, if properly analyzed can give a solution for the need of the hour, that is, good quality access of water to everyone at all times.

6.2 Conclusions

With the use of modern softwares available which gives real time analysis even prior to the happening of event, management plans can be used to fullest. In this study, various problems have been acknowledged in Dehradun city using many tools and the results came out suggesting various keynotes. Thus, the study has concluded to the following points:

- LULC maps for historical data suggest that urban area has increased by 73.58% whereas agricultural area has decreased by almost 50%. This directly impacts the ground water recharge, increases urban water demand and also increases urban flooding due to more impervious land.
- LULC for 2030 shows to follow the same trend of urbanization and thus gives an idea of how the problems are going to increase in the near future
- Results of SWMM suggest that Node J44 is flooded for 22 hours and 7 minutes. Maximum flooding was observed as 04:02 a.m. with the total flood volume of $307.7*10^6$ litres. Also nodes J43, J84 and J116 were also observed to be surcharged for 23 hours each. For these places, proper drainage path and ponded area with pervious base should be provided to avoid flooding
- The suggested plan of Dual distribution water grid with the use of ICT suits well in solving all the problems like urban water demand by recycling water, storm water management by using it as a source of water through proper routing. Also, involvement of ICT upgrades the system and helps in smooth functioning without any delay.

6.3 Recommendations

A proper sustainable management plan has to be adopted considering all economic, financial, climatic and topographic restrictions and the best-suited needs to be adopted for making urbanization a success for the city instead of a dome. Several limitations were faced during the processing of study and thus some recommendations are made for the scope of further study. These would be as follows:

- Since SWMM was run considering the return period analysis, therefore the storm event generated was hypothetical and hence, calibration and validation of the same was not possible due to unavailability of data.
- Demand-supply gap analysis was done and supply has come out to be greater than demand but only basic demand of the residents was considered. But the major demand of agriculture and industries wasn't considered due to lack of data. Also, capacities of tubewells taken are installed capacity, not the running capacity.

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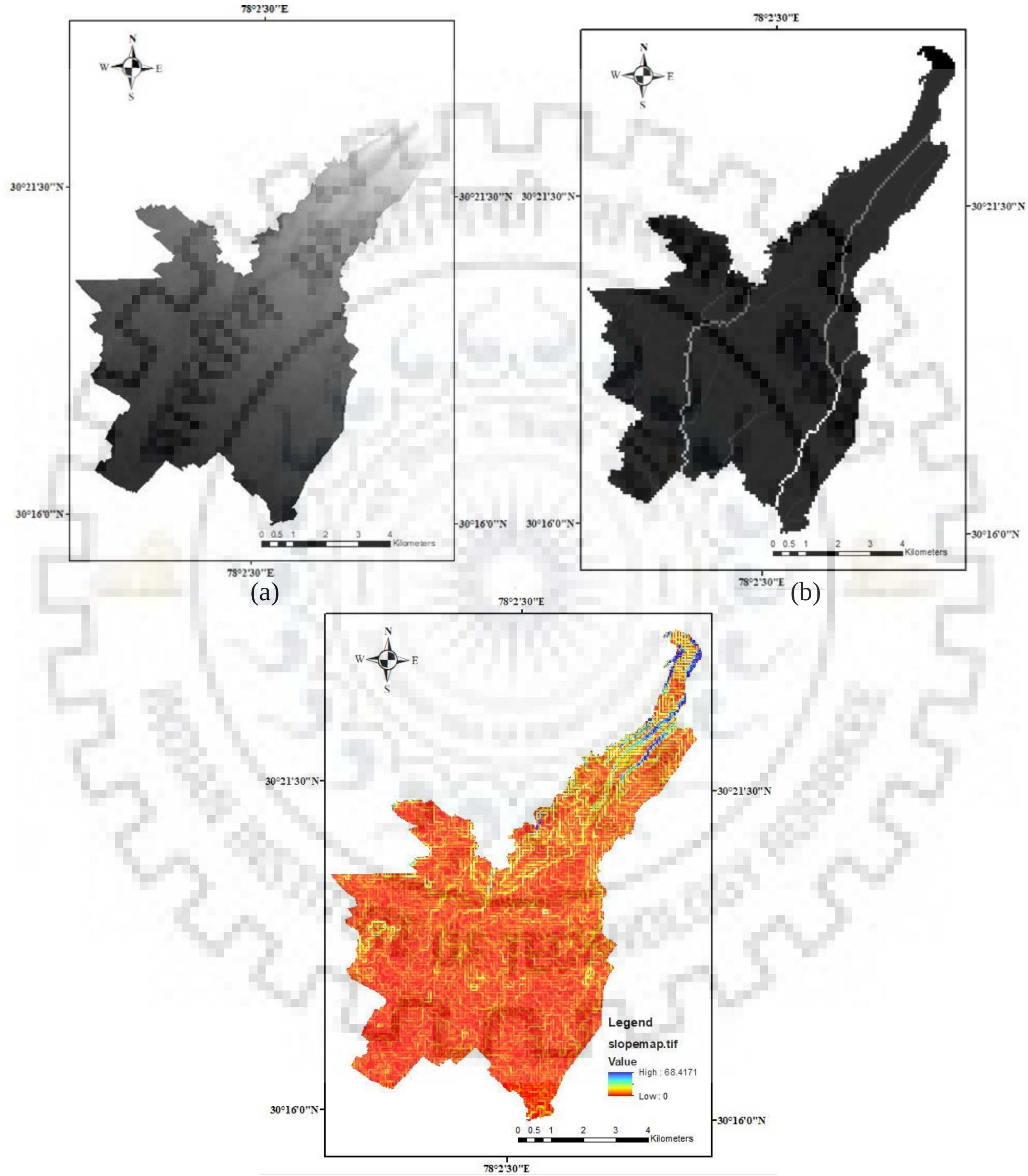
ANNEXURES

Annexures-I



(c)

Fig. 1 DEM processed files: (a) DEM (b) Flow accumulation map (c) slope map

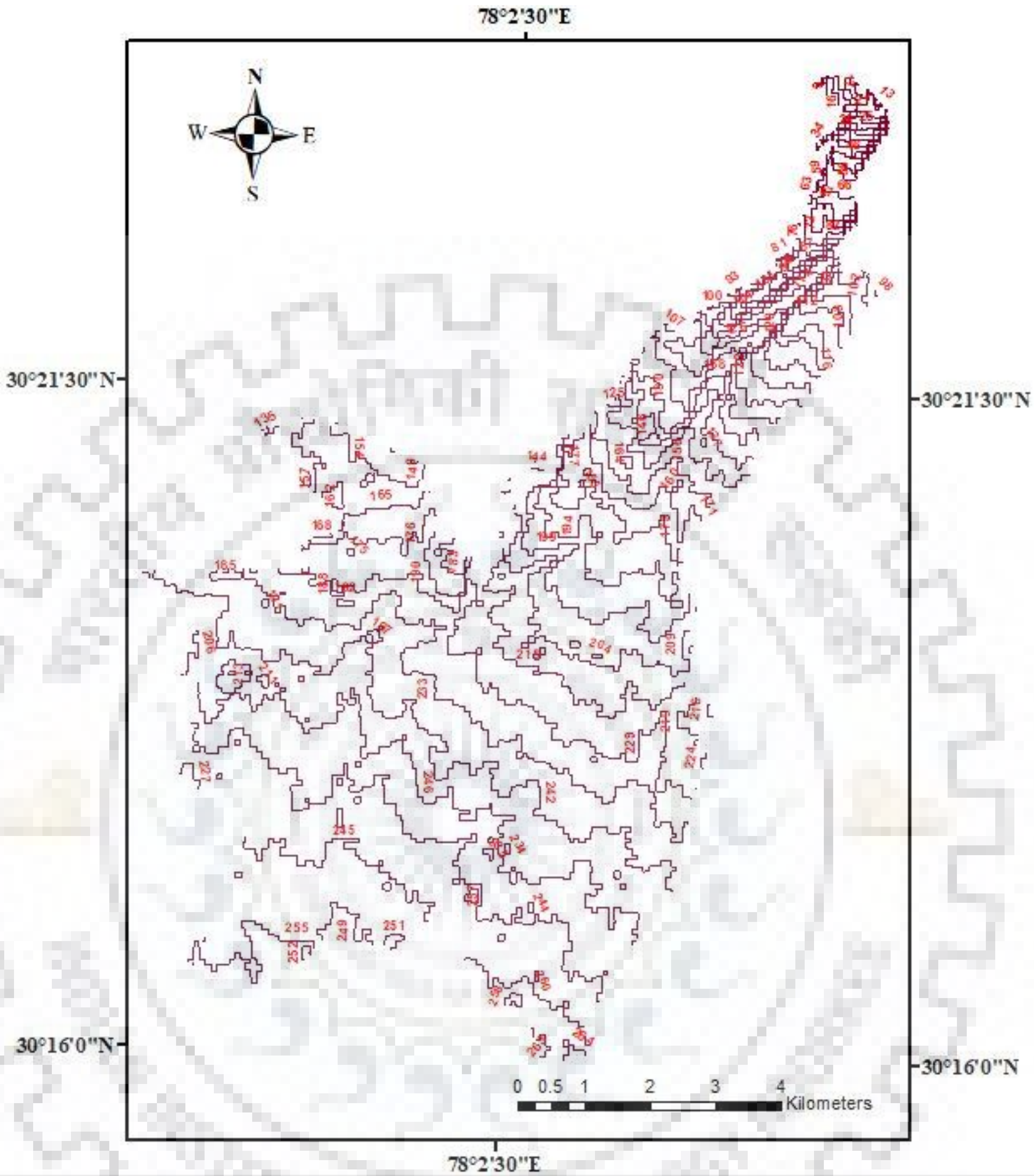


Fig. 2 Contour map

Annexure-II

Accuracy assessment report of LULC maps:

CLASSIFICATION ACCURACY ASSESSMENT REPORT (LULC 2001)

Image File : g:/2001.img
User Name : User1
Date : Wed Nov 21 01:18:29 2018

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Class 0	0	0	0	---	---
Class 1	7	7	7	100.00%	100.00%
Class 2	6	7	6	100.00%	85.71%
Class 3	8	7	7	87.50%	100.00%
Class 4	7	7	7	100.00%	100.00%
Class 5	8	7	7	87.50%	100.00%
Class 6	6	7	6	100.00%	85.71%
Totals	42	42	40		

Overall Classification Accuracy = 95.24%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.9429

Conditional Kappa for each Category.

Class Name	Kappa
Class 0	0.0000
Class 1	1.0000
Class 2	0.8333
Class 3	1.0000
Class 4	1.0000
Class 5	1.0000
Class 6	0.8333

----- End of Kappa Statistics -----

CLASSIFICATION ACCURACY ASSESSMENT REPORT (LULC 2008)

Image File : g:/2008.img
User Name : User1
Date : Wed Nov 21 02:25:51 2018

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy

Class 0	0	0	0	---	---
Class 1	6	7	6	100.00%	85.71%
Class 2	7	7	6	85.71%	85.71%
Class 3	9	7	7	77.78%	100.00%
Class 4	6	7	6	100.00%	85.71%
Class 5	7	7	7	100.00%	100.00%
Class 6	7	7	7	100.00%	100.00%
Totals	42	42	39		

Overall Classification Accuracy = 92.46%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.9243

Conditional Kappa for each Category.

Class Name	Kappa
Class 0	0.0000
Class 1	0.8333
Class 2	0.8286
Class 3	1.0000
Class 4	0.8333
Class 5	1.0000
Class 6	1.0000

----- End of Kappa Statistics -----

CLASSIFICATION ACCURACY ASSESSMENT REPORT (LULC 2014)

Image File : g:/2014.img

User Name : User1

Date : Wed Nov 21 03:56:50 2018

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Class 0	0	0	0	---	---
Class 1	15	16	15	100.00%	93.75%
Class 2	18	16	16	88.89%	100.00%
Class 3	15	16	15	100.00%	93.75%
Class 4	15	16	15	100.00%	93.75%

Class 5	16	16	16	100.00%	100.00%
Class 6	17	16	16	94.12%	100.00%
Totals	96	96	93		

Overall Classification Accuracy = 96.88%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.9625

Conditional Kappa for each Category.

Class Name	Kappa
Class 0	0.0000
Class 1	0.9259
Class 2	1.0000
Class 3	0.9259
Class 4	0.9259
Class 5	1.0000
Class 6	1.0000

----- End of Kappa Statistics -----

CLASSIFICATION ACCURACY ASSESSMENT REPORT (LULC 2018)

Image File : g:/2018.img
User Name : User1
Date : Wed Nov 21 04:53:04 2018

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Class 0	0	0	0	---	---
Class 1	7	7	7	100.00%	100.00%
Class 2	7	7	7	100.00%	100.00%
Class 3	7	7	7	100.00%	100.00%
Class 4	6	7	6	100.00%	85.71%
Class 5	7	7	7	100.00%	100.00%
Class 6	8	7	7	87.50%	100.00%
Totals	42	42	41		

Overall Classification Accuracy = 97.62%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.9714

Conditional Kappa for each Category.

Class Name	Kappa
Class 0	0.0000
Class 1	1.0000
Class 2	1.0000
Class 3	1.0000
Class 4	0.8333
Class 5	1.0000
Class 6	1.0000

----- End of Kappa Statistics -----

Annexure-III

Summary report of Terrset GeoSpatial Modelling:

Land Change Modeller MLP Model Results

(Created: 27-03-2019 12:49:42)

1. General Model Information

1) Input Files

Independent variable 1	DEMfinal
Independent variable 2	road_distance
Independent variable 3	2018_urb_distance
Independent variable 4	slope
Independent variable 5	All_to_urban_trend3rd
Independent variable 6	All_to_urban_trend4th
Independent variable 7	Forest_to_urban_trend4th
Independent variable 8	Agri_to_urban_trend3rd
Training site file	Future_Train_URBAN

2) Parameters and Performance

Input layer neurons	8

Hidden layer neurons	6
Output layer neurons	4
Requested samples per class	902
Final learning rate	0.0001
Momentum factor	0.5
Sigmoid constant	1
Acceptable RMS	0.01
Iterations	10000
Training RMS	0.4266
Testing RMS	0.4258
Accuracy rate	31.54%
Skill measure	0.0872

3) Model Skill Breakdown by Transition & Persistence

Class	Skill measure
Transition : FOREST to URBAN	-0.2772
Transition : AGRICULTURE to URBAN	0.3912
Persistence : FOREST	0.5189
Persistence : AGRICULTURE	-0.2504

2. Weights Information of Neurons across Layers

1) Weights between Input Layer Neurons and *Hidden Layer Neurons*

Neuron	h-Neuron 1	h-Neuron 2	h-Neuron 3	h-Neuron 4	h-Neuron 5	h-Neuron 6
i-Neuron 1	0.8827	0.1315	0.5483	-0.5273	0.1045	-0.2329
i-Neuron 2	0.9236	-0.1765	0.6435	-0.6110	0.2652	-0.2903
i-Neuron 3	0.8281	-0.3747	0.4569	-0.7466	0.3639	-0.4393
i-Neuron 4	1.0340	-0.2280	0.8490	-0.8621	0.3048	-0.0252
i-Neuron 5	-0.7420	0.3586	-0.8033	0.7992	-0.1767	0.2336
i-Neuron 6	-0.6598	0.6438	-0.9360	0.9471	-0.0114	0.2787
i-Neuron 7	-1.1331	0.0338	-0.5731	0.5417	-0.3528	0.8471
i-Neuron 8	-1.0450	0.3055	-0.6235	0.5759	-0.4284	0.2016

2) Weights between Hidden Layer Neurons and Output Layer Neurons

Neuron	o-Neuron 1	o-Neuron 2	o-Neuron 3	o-Neuron 4
h-Neuron 1	-0.8080	-1.7968	1.8747	-0.8063
h-Neuron 2	-0.3279	0.3608	-0.9623	-0.3799

h-Neuron 3	-0.6887	-1.6418	1.3351	-0.1805
h-Neuron 4	0.1476	0.8310	-2.1408	-0.3751
h-Neuron 5	-0.5494	-0.5454	0.1285	-0.5332
h-Neuron 6	0.0444	0.0002	-1.3805	0.1987

3. Sensitivity of Model to Forcing Independent Variables to be Constant

1) Forcing a Single Independent Variable to be Constant

Model	Accuracy (%)	Skill measure	Influence order
With all variables	31.54	0.0872	N/A
Var. 1 constant	31.65	0.0887	6
Var. 2 constant	31.54	0.0872	5
Var. 3 constant	31.42	0.0856	2
Var. 4 constant	31.54	0.0872	4
Var. 5 constant	32.22	0.0962	7
Var. 6 constant	31.48	0.0864	3
Var. 7 constant	31.14	0.0819	1 (most influential)
Var. 8 constant	32.27	0.0970	8 (least influential)

2) Forcing All Independent Variables Except One to be Constant

Model	Accuracy (%)	Skill measure
With all variables	31.54	0.0872
All constant but var. 1	25.52	0.0070
All constant but var. 2	25.52	0.0070
All constant but var. 3	25.52	0.0070
All constant but var. 4	25.52	0.0070
All constant but var. 5	32.50	0.1000
All constant but var. 6	31.48	0.0864
All constant but var. 7	26.89	0.0251
All constant but var. 8	33.13	0.1083

3) Backwards Stepwise Constant Forcing

Model	Variables included	Accuracy (%)	Skill measure
With all variables	All variables	31.54	0.0872
Step 1: var.[8] constant	[1,2,3,4,5,6,7]	32.27	0.0970
Step 2: var.[8,5] constant	[1,2,3,4,6,7]	33.41	0.1121
Step 3: var.[8,5,3] constant	[1,2,4,6,7]	33.47	0.1129

Step 4: var.[8,5,3,2] constant	[1,4,6,7]	33.47	0.1129
Step 5: var.[8,5,3,2,4] constant	[1,6,7]	33.47	0.1129
Step 6: var.[8,5,3,2,4,1] constant	[6,7]	33.30	0.1106
Step 7: var.[8,5,3,2,4,1,7] constant	[6]	31.48	0.0864

Annexures-IV

Short duration rainfall from the daily rainfall data table made is as follows:

Table 1. Short duration rainfalls

YEAR	Daily Max	24hr inten	12HRS	12hr inten	6HRS	6hr intens	2HRS	2hr intens	1HR	1hr intensity
2001	81.71	3.4	64.55	5.38	51.48	8.58	35.71	17.85	28.33	28.33
2002	36.15	1.51	28.56	2.38	22.77	3.8	15.8	7.9	12.53	12.53
2003	39.93	1.66	31.54	2.63	25.16	4.19	17.45	8.72	13.84	13.84
2004	70.86	2.95	55.98	4.66	44.64	7.44	30.97	15.48	24.57	24.57
2005	58.68	2.45	46.36	3.86	36.97	6.16	25.64	12.82	20.34	20.34
2006	63.01	2.63	49.78	4.15	39.7	6.62	27.54	13.77	21.85	21.85
2007	54.86	2.29	43.34	3.61	34.56	5.76	23.97	11.99	19.02	19.02
2008	62.17	2.59	49.11	4.09	39.17	6.53	27.17	13.58	21.55	21.55
2009	53.34	2.22	42.14	3.51	33.6	5.6	23.31	11.65	18.49	18.49
2010	149.51	6.23	118.11	9.84	94.19	15.7	65.34	32.67	51.84	51.84
2011	86.83	3.62	68.6	5.72	54.7	9.12	37.94	18.97	30.1	30.1
2012	83.28	3.47	65.79	5.48	52.47	8.74	36.39	18.2	28.87	28.87
2013	164.29	6.85	129.79	10.82	103.5	17.25	71.79	35.9	56.96	56.96
2014	82.36	3.43	65.06	5.42	51.89	8.65	35.99	18	28.55	28.55
2015	58.65	2.44	46.33	3.86	36.95	6.16	25.63	12.82	20.33	20.33
2016	53.3	2.22	42.11	3.51	33.58	5.6	23.29	11.65	18.48	18.48
2017	57.44	2.39	45.38	3.78	36.19	6.03	25.1	12.55	19.91	19.91
2018	98.06	4.09	77.47	6.46	61.78	10.3	42.85	21.43	34	34
MEAN	75.24611	3.14	59.44	4.95	47.41	7.9	32.88	16.44	26.09	26.09
SD	33.96818	1.42	26.08	2.24	20.8	3.57	14.43	7.42	11.44	11.78

Also, the final generated time series table fed to EPA SWMM 5.1 is as follows:

Time	Cu.Intensity		Intensity	Cum. Vol.	Vol.
0:00	1.73	1	1.73	41.52	41.52
1:00	2.18	2	0.45	52.31	10.79
2:00	2.5	3	0.315	59.88	7.57
3:00	2.75	4	0.251	65.91	6.03
4:00	2.96	5	0.212	71	5.09
5:00	3.14	6	0.185	75.44	4.45
6:00	3.31	7	0.166	79.42	3.98
7:00	3.46	8	0.151	83.04	3.61
8:00	3.6	9	0.139	86.36	3.32
9:00	3.73	10	0.129	89.45	3.09
10:00	3.85	11	0.12	92.34	2.89
11:00	3.96	12	0.113	95.05	2.72

12:00	4.07	13	0.107	97.62	2.57
13:00	4.17	14	0.102	100.07	2.44
14:00	4.27	15	0.097	102.39	2.33
15:00	4.36	16	0.093	104.62	2.23
16:00	4.45	17	0.089	106.76	2.14
17:00	4.53	18	0.086	108.81	2.05
18:00	4.62	19	0.082	110.79	1.98
19:00	4.7	20	0.08	112.7	1.91
20:00	4.77	21	0.077	114.55	1.85
21:00	4.85	22	0.075	116.34	1.79
22:00	4.92	23	0.072	118.07	1.74
23:00	4.99	24	0.07	119.76	1.69

Annexures-V

Land Use Description	Hydrologic Soil Group			
	A	B	C	D
Cultivated land				
Without conservation treatment	72	81	88	91
With conservation treatment	62	71	78	81
Pasture or range land				
Poor condition	68	79	86	89
Good condition	39	61	74	90
Meadow				
Good condition	30	58	71	78
Wood or forest land				
Thin stand, poor cover, no mulch	45	66	70	83
Good cover	25	55	77	77
Open spaces, lawns, parks, golf courses, cemeteries, etc.				
Good condition: grass cover on 75% or more of the area	39	61	74	80
Fair condition: grass cover on 50-75% of the area	49	69	79	84
Commercial and business areas (85% impervious)	89	92	94	95
Industrial districts (72% impervious)	81	88	91	93
Residential				
Average lot size (% Impervious)				
1/8 ac or less (65)	77	85	90	92
1/4 ac (38)	61	75	83	87
1/3 ac (30)	57	72	81	86
1/2 ac (25)	54	70	80	85
1 ac (20)	51	68	79	84
Paved parking lots, roofs, driveways, etc.	98	98	98	98
Streets and roads				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89

Fig. 3 Curve number calculation data for sub-catchments in SWMM

Calculation of curve number for each subcatchment by using the LULC maps prepared for the subcatchments

Table 2 Curve number calculation

S2	AREA(km^2)	% AREA	CN
Water	0.74	0.21	66
Agriculture	0.85	0.24	81
Shrubs	0.81	0.23	61
Urban	0.79	0.23	92
Barren	0.31	0.09	79
SUM	3.5		
Weighted CN			75.6

S6	AREA(km^2)	% AREA	CN
Forest	0.63	0.09	66
Agriculture	0.94	0.13	81
Shrubs	1.32	0.19	61
Urban	3.80	0.55	92
Barren	0.29	0.04	79
SUM	6.97		
Weighted CN			81.82

S3	AREA(km^2)	% AREA	CN
Forest	2.12	0.21	66
Water	0.01	0.00	98
Agriculture	2.01	0.20	81
Shrubs	1.95	0.19	61
Urban	3.70	0.36	92
Barren	0.35	0.03	79
SUM	10.14		
Weighted CN			77.14

S7	AREA(km^2)	% AREA	CN
Forest	3.12	0.28	66
Agriculture	1.39	0.13	81
Shrubs	0.88	0.08	61
Urban	5.19	0.47	92
Barren	0.54	0.05	79
SUM	11.12		
Weighted CN			81.08

S4	AREA(km^2)	% AREA	CN
Forest	0.34	0.09	66
Water	0.07	0.02	98
Agriculture	0.32	0.08	81
Shrubs	0.56	0.15	61
Urban	2.24	0.59	92
Barren	0.23	0.06	79
SUM	3.77		
Weighted CN			82.55

S8	AREA(km^2)	% AREA	CN
Forest	1.99	0.11	66
Water	0.42	0.02	98
Agriculture	3.59	0.20	81
Shrubs	1.51	0.09	61
Urban	8.88	0.50	92
Barren	1.22	0.07	79
SUM	17.62		
Weighted CN			82.44

S5	AREA(km^2)	% AREA	CN
Forest	0.35	0.08	66
Water	0.02	0.00	98
Agriculture	0.61	0.14	81
Shrubs	0.82	0.18	61
Urban	2.57	0.57	92
Barren	0.15	0.03	79
SUM	4.53		
Weighted CN			82.41

Annexure VI

Status report of EPA SWMM 5.1 is as follows:

NOTE: The summary statistics displayed in this report are based on results found at every computational time step, not just on results from each reporting time step.

****

****
Analysis Options
****
Flow Units .... …CMS
Process Models:
Rainfall/Runoff .... …....YES
RDII .... NO
Snowmelt .... NO
Groundwater .... NO
Flow Routing .... YES
Ponding Allowed .... NO
Water Quality .... NO
Infiltration Method .... CURVE_NUMBER
Flow Routing Method ...... DYNWAVE
Starting Date APRIL-14-2019 00:00:00
Ending Date APRIL-14-2019 23:00:00
Antecedent Dry Days 0.0
Report Time Step 00:15:00
Wet Time Step 00:05:00
Dry Time Step 01:00:00
Routing Time Step .... 30.00 sec
Variable Time Step .... YES
Maximum Trials 8
Head Tolerance .... .0.016404 m

****
Element Count
****
Number of rain gages ...... …1
Number of subcatchments ... 7
Number of nodes 99
Number of links 87
Number of pollutants ...... …0
Number of land uses 0

****
Raingage Summary

****

Name	Data Source	Data Type	Recording Interval
R1	T1	VOLUME	60 min.

****

Subcatchment Summary

****

Name	Area	Width	%Imperv	%Slope	Rain Gage	Outlet
S2	350.73	8768.16	22.65	9.4500	R1	J114
S3	1013.45	25336.30	36.50	14.8700	R1	J82
S4	377.24	9431.02	59.46	9.9500	R1	J22
S5	452.91	11322.80	56.71	6.9300	R1	J8
S6	697.93	17448.20	54.53	7.5400	R1	J64
S7	1112.58	27814.40	46.67	13.1600	R1	J80
S8	1761.21	44030.20	50.42	16.2100	R1	J55

****

Node Summary

****

Name	Type	Invert Elev.	Max. Depth	Ponded Area	External Inflow
J2	JUNCTION	668.00	8.00	0.0	
J3	JUNCTION	665.00	8.00	0.0	
J5	JUNCTION	665.00	8.00	0.0	
J6	JUNCTION	670.00	10.00	0.0	
J8	JUNCTION	670.00	10.00	0.0	
J10	JUNCTION	670.00	10.00	0.0	
J12	JUNCTION	650.00	8.00	0.0	
J13	JUNCTION	670.00	6.00	0.0	
J16	JUNCTION	670.00	6.00	0.0	
J17	JUNCTION	660.00	6.00	0.0	
J18	JUNCTION	660.00	6.00	0.0	
J19	JUNCTION	660.00	6.00	0.0	
J20	JUNCTION	660.00	8.00	0.0	
J21	JUNCTION	660.00	6.00	0.0	
J22	JUNCTION	670.00	6.00	0.0	
J23	JUNCTION	670.00	6.00	0.0	
J24	JUNCTION	660.00	4.00	0.0	
J25	JUNCTION	660.00	8.00	0.0	
J27	JUNCTION	660.00	8.00	0.0	
J28	JUNCTION	640.00	8.00	0.0	
J29	JUNCTION	660.00	4.00	0.0	

J30	JUNCTION	660.00	4.00	0.0
J31	JUNCTION	650.00	4.00	0.0
J32	JUNCTION	650.00	4.00	0.0
J34	JUNCTION	650.00	10.00	0.0
J35	JUNCTION	650.00	10.00	0.0
J36	JUNCTION	640.00	10.00	0.0
J37	JUNCTION	655.00	10.00	0.0
J38	JUNCTION	625.00	10.00	0.0
J39	JUNCTION	625.00	10.00	0.0
J40	JUNCTION	628.00	10.00	0.0
J41	JUNCTION	620.00	10.00	0.0
J42	JUNCTION	625.00	10.00	0.0
J43	JUNCTION	690.00	1.30	0.0
J44	JUNCTION	660.00	3.00	0.0
J47	JUNCTION	655.00	8.00	0.0
J48	JUNCTION	650.00	8.00	0.0
J49	JUNCTION	640.00	8.00	0.0
J50	JUNCTION	640.00	8.00	0.0
J51	JUNCTION	645.00	8.00	0.0
J54	JUNCTION	640.00	8.00	0.0
J55	JUNCTION	635.00	8.00	0.0
J56	JUNCTION	640.00	6.00	0.0
J57	JUNCTION	645.00	6.00	0.0
J58	JUNCTION	638.00	6.00	0.0
J61	JUNCTION	633.00	6.00	0.0
J62	JUNCTION	670.00	3.00	0.0
J64	JUNCTION	690.00	3.00	0.0
J65	JUNCTION	680.00	3.00	0.0
J66	JUNCTION	700.00	12.00	0.0
J67	JUNCTION	700.00	12.00	0.0
J68	JUNCTION	701.00	12.00	0.0
J69	JUNCTION	700.00	12.00	0.0
J70	JUNCTION	700.00	12.00	0.0
J73	JUNCTION	660.00	4.00	0.0
J74	JUNCTION	660.00	4.00	0.0
J76	JUNCTION	620.00	10.00	0.0
J78	JUNCTION	660.00	3.00	0.0
J80	JUNCTION	640.00	6.00	0.0
J81	JUNCTION	730.00	12.00	0.0
J82	JUNCTION	720.00	12.00	0.0
J83	JUNCTION	660.00	4.00	0.0
J84	JUNCTION	650.00	1.30	0.0
J85	JUNCTION	650.00	6.00	0.0
J86	JUNCTION	660.00	3.00	0.0
J87	JUNCTION	630.00	8.00	0.0
J88	JUNCTION	630.00	8.00	0.0

J89	JUNCTION	650.00	8.00	0.0
J90	JUNCTION	655.00	8.00	0.0
J91	JUNCTION	620.00	8.00	0.0
J92	JUNCTION	660.00	6.00	0.0
J93	JUNCTION	650.00	10.00	0.0
J94	JUNCTION	650.00	8.00	0.0
J95	JUNCTION	660.00	10.00	0.0
J97	JUNCTION	670.00	10.00	0.0
J98	JUNCTION	670.00	10.00	0.0
J99	JUNCTION	670.00	10.00	0.0
J100	JUNCTION	670.00	10.00	0.0
J104	JUNCTION	690.00	12.00	0.0
J105	JUNCTION	694.00	12.00	0.0
J106	JUNCTION	655.00	4.00	0.0
J107	JUNCTION	640.00	8.00	0.0
J109	JUNCTION	630.00	10.00	0.0
J110	JUNCTION	630.00	10.00	0.0
J111	JUNCTION	620.00	10.00	0.0
J113	JUNCTION	625.00	10.00	0.0
J114	JUNCTION	690.00	12.00	0.0
J9	JUNCTION	670.00	10.00	0.0
J52	JUNCTION	680.00	3.00	0.0
J115	JUNCTION	660.00	3.00	0.0
J116	JUNCTION	680.00	1.30	0.0
O1	OUTFALL	630.00	6.00	0.0
O2	OUTFALL	612.00	10.00	0.0
O3	OUTFALL	650.00	6.00	0.0
O4	OUTFALL	650.00	4.00	0.0
O5	OUTFALL	638.00	6.00	0.0
O6	OUTFALL	610.00	8.00	0.0
O7	OUTFALL	650.00	3.00	0.0
O8	OUTFALL	688.00	12.00	0.0

****
Link Summary
****

Name	From Node	To Node	Type	Length	%Slope	Roughness
A1	J68	J67	CONDUIT	277.8	0.3600	0.0120
A2	J114	J104	CONDUIT	411.8	0.0001	0.0120
F1	J29	J30	CONDUIT	160.6	0.0002	0.0120
F2	J30	J83	CONDUIT	312.8	0.0001	0.0120
F3	J83	J73	CONDUIT	104.5	0.0003	0.0120
F4	J73	J24	CONDUIT	86.3	0.0004	0.0120
F5	J24	J74	CONDUIT	150.9	0.0002	0.0120
F6	J74	J106	CONDUIT	212.9	2.3495	0.0120

F7	J106	J32	CONDUIT	87.2	5.7440	0.0120
F8	J32	J31	CONDUIT	143.2	0.0002	0.0120
F9	J31	O4	CONDUIT	153.8	0.0002	0.0120
E1	J22	J23	CONDUIT	24.8	0.0012	0.0120
E2	J23	J13	CONDUIT	84.0	0.0004	0.0120
E3	J13	J16	CONDUIT	179.2	0.0002	0.0120
E4	J16	J18	CONDUIT	184.9	5.4169	0.0120
E5	J18	J17	CONDUIT	101.1	0.0003	0.0120
E6	J17	J21	CONDUIT	355.7	0.0001	0.0120
E7	J21	J19	CONDUIT	43.0	0.0007	0.0120
E8	J19	J20	CONDUIT	281.3	0.0001	0.0120
E9	J20	J25	CONDUIT	412.9	0.0001	0.0120
E10	J25	J27	CONDUIT	276.7	0.0001	0.0120
E11	J27	J12	CONDUIT	952.1	1.0504	0.0120
E12	J12	J28	CONDUIT	252.0	3.9722	0.0120
E13	J28	O5	CONDUIT	170.9	1.1701	0.0120
H2	J85	J57	CONDUIT	365.0	1.3701	0.0120
H3	J57	J56	CONDUIT	304.0	1.6448	0.0120
H4	J56	J80	CONDUIT	520.3	0.0001	0.0120
H5	J80	J58	CONDUIT	311.5	0.6420	0.0120
H6	J58	J61	CONDUIT	249.6	2.0036	0.0120
H7	J61	O1	CONDUIT	210.7	1.4243	0.0120
D1	J37	J36	CONDUIT	726.1	2.0662	0.0120
D2	J36	J107	CONDUIT	319.5	0.0001	0.0120
D3	J107	J109	CONDUIT	432.9	2.3107	0.0120
D4	J109	J110	CONDUIT	246.6	0.0001	0.0120
D5	J110	J40	CONDUIT	124.8	1.6023	0.0120
D6	J40	J42	CONDUIT	255.4	1.1746	0.0120
D7	J42	J41	CONDUIT	216.2	2.3133	0.0120
D8	J41	J111	CONDUIT	178.4	0.0002	0.0120
D9	J111	J76	CONDUIT	431.0	0.0001	0.0120
D13	J38	J113	CONDUIT	132.4	0.0002	0.0120
D12	J113	J39	CONDUIT	143.0	0.0002	0.0120
D11	J39	J111	CONDUIT	497.7	1.0047	0.0120
D14	J35	J34	CONDUIT	586.5	0.0001	0.0120
D15	J34	J36	CONDUIT	460.3	2.1729	0.0120
C1	J6	J9	CONDUIT	246.7	0.0001	0.0120
C2	J9	J10	CONDUIT	169.3	0.0002	0.0120
C3	J10	J8	CONDUIT	478.3	0.0001	0.0120
C4	J8	J99	CONDUIT	565.1	0.0001	0.0120
C5	J99	J2	CONDUIT	376.2	0.5316	0.0120
C6	J2	J3	CONDUIT	275.1	1.0905	0.0120
C7	J3	J5	CONDUIT	338.7	0.0001	0.0120
C8	J5	J94	CONDUIT	375.4	3.9987	0.0120
C15	J94	O3	CONDUIT	70.8	0.0004	0.0120
C9	J92	J95	CONDUIT	56.6	0.0005	0.0120

C10	J95	J93	CONDUIT	321.7	3.1101	0.0120
C11	J93	J94	CONDUIT	200.1	0.0002	0.0120
B1	J64	J65	CONDUIT	947.4	1.0556	0.0120
B2	J65	J62	CONDUIT	707.4	1.4138	0.0120
B3	J62	J115	CONDUIT	592.3	1.6886	0.0120
B4	J115	O7	CONDUIT	308.6	3.2421	0.0120
B8	J86	J78	CONDUIT	405.3	0.0001	0.0120
B9	J78	J115	CONDUIT	581.8	0.0001	0.0120
B6	J52	J44	CONDUIT	732.9	2.7299	0.0120
B7	J44	J62	CONDUIT	432.5	-2.3130	0.0120
A10	J81	J82	CONDUIT	360.4	2.7757	0.0120
A9	J82	J67	CONDUIT	861.3	2.3226	0.0120
A8	J67	J69	CONDUIT	417.6	0.0001	0.0120
A7	J69	J70	CONDUIT	185.6	0.0002	0.0120
A6	J70	J66	CONDUIT	258.3	0.0001	0.0120
A5	J66	J105	CONDUIT	632.5	0.9487	0.0120
A4	J105	J104	CONDUIT	631.0	0.6339	0.0120
A3	J104	O8	CONDUIT	413.3	0.4839	0.0120
G1	J47	J90	CONDUIT	110.1	0.0003	0.0120
G2	J90	J48	CONDUIT	103.0	4.8589	0.0120
G3	J48	J50	CONDUIT	268.8	3.7226	0.0120
G4	J50	J49	CONDUIT	214.6	0.0001	0.0120
G5	J49	J54	CONDUIT	482.1	0.0001	0.0120
G6	J54	J55	CONDUIT	467.9	1.0687	0.0120
G7	J55	J88	CONDUIT	250.1	1.9998	0.0120
G8	J88	J87	CONDUIT	470.5	0.0001	0.0120
G9	J87	J91	CONDUIT	533.2	1.8757	0.0120
G10	J91	O6	CONDUIT	560.8	1.7833	0.0120
G11	J89	J51	CONDUIT	949.2	0.5268	0.0120
C12	J100	J97	CONDUIT	181.8	0.0002	0.0120
C13	J97	J98	CONDUIT	305.8	0.0001	0.0120
C14	J98	J99	CONDUIT	409.7	0.0001	0.0120
D10	J76	O2	CONDUIT	395.1	2.0254	0.0120

**************************	Volume	Depth
Runoff Quantity Continuity	hectare-m	mm
**************************	---------	-------
Total Precipitation	681.725	118.231
Evaporation Loss	0.000	0.000
Infiltration Loss	123.625	21.440
Surface Runoff	431.176	74.778
Final Surface Storage	127.437	22.101
Continuity Error (%)	-0.075	

**************************	Volume	Volume
Flow Routing Continuity	hectare-m	10^6 ltr

```
**************************     ---------     ---------
Dry Weather Inflow .......          0.000        0.000
Wet Weather Inflow .......        429.712     4297.166
Groundwater Inflow .......          0.000        0.000
RDII Inflow ..............          0.000        0.000
External Inflow ..........          0.000        0.000
External Outflow .........        395.358     3953.620
Internal Outflow .........         30.769      307.695
Evaporation Loss .........          0.000        0.000
Exfiltration Loss ........          0.000        0.000
Initial Stored Volume ....          0.000        0.004
Final Stored Volume ......          3.722       37.223
Continuity Error (%) .....         -0.032

*************************
Highest Continuity Errors
*************************
Node J56 (56.37%)
Node J93 (50.37%)
Node J78 (29.29%)
Node J98 (18.20%)
Node J97 (17.11%)

***************************
Time-Step Critical Elements
***************************
Link E1 (99.90%)

********************************
Highest Flow Instability Indexes
********************************
Link C1 (5)
Link C2 (5)
Link C12 (3)
Link C3 (2)

*************************
Routing Time Step Summary
*************************
Minimum Time Step           :     3.20 sec
Average Time Step           :     4.25 sec
Maximum Time Step           :    30.00 sec
Percent in Steady State     :     0.00
Average Iterations per Step :     2.00
Percent Not Converging      :     0.00
***************************
```

Analysis begun on: Sat April 20 02:20:13 2019
Analysis ended on: Sat April 20 02:20:14 2019
Total elapsed time: 00:00:01

Annexure VII

Result summary of SWMM:

Summary Results

Node Surcharge — Click a column header to sort the column.

Node	Type	Hours Surcharged	Max Height Above Crown Meters	Min Depth Below Rim Meters
J43	JUNCTION	23.00	0.000	1.300
J44	JUNCTION	22.12	0.000	0.000
J84	JUNCTION	23.00	0.000	1.300
J116	JUNCTION	23.00	0.000	1.300

(a)

Summary Results

Conduit Surcharge — Click a column header to sort the column.

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Dnstream Full	Hours Above Normal Flow	Hours Capacity Limited
A6	0.01	0.01	0.01	3.40	0.01
A8	0.01	0.01	0.01	7.78	0.01
B9	0.01	0.01	0.01	0.14	0.01
C15	0.01	0.01	0.01	14.32	0.01
C4	0.01	0.01	0.01	9.18	0.01
C7	0.01	0.01	0.01	22.12	0.01
E1	0.01	0.01	0.01	4.96	0.01
E10	0.01	0.01	0.01	9.67	0.01
E2	0.01	0.01	0.01	12.17	0.01
E3	0.01	0.01	0.01	19.79	0.01
E5	0.01	0.01	0.01	13.70	0.01
E6	0.01	0.01	0.01	22.49	0.01
E7	0.01	0.01	0.01	7.73	0.01
E8	0.01	0.01	0.01	22.40	0.01
E9	0.01	0.01	0.01	12.60	0.01
G8	0.01	0.01	0.01	22.49	0.01

(b)

Summary Results

Node Flooding — Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
J44	22.12	5.740	0	04:02	307.696	0.000

(c)

Summary Results

Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
S2	118.23	0.00	0.00	37.45	65.36	229.23	7.96	0.553
S3	118.23	0.00	0.00	29.20	68.15	690.69	13.32	0.576
S4	118.23	0.00	0.00	14.97	90.64	341.92	8.63	0.767
S5	118.23	0.00	0.00	16.09	86.48	391.70	8.37	0.731
S6	118.23	0.00	0.00	17.37	80.84	564.21	10.37	0.684
S7	118.23	0.00	0.00	21.05	75.09	835.47	14.54	0.635
S8	118.23	0.00	0.00	18.40	71.46	1258.56	19.78	0.604

(d)

Summary Results

Outfall Loading — Click a column header to sort the column.

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS	Total Volume 10^6 ltr
O1	99.95	10.534	14.539	830.500
O2	0.00	0.000	0.000	0.000
O3	98.02	5.038	8.350	382.237
O4	0.00	0.000	0.000	0.000
O5	97.86	4.516	8.604	336.212
O6	99.66	15.636	19.784	1249.426
O7	99.73	3.196	4.635	249.861
O8	99.93	11.559	18.247	905.366

(e)

Fig. 4 Summary results of SWMM: (a) node surcharge, (b) conduit surcharge, (c) Summary results of node flooding (d) subcatchment runoff & (e) outfall loading

Annexure VIII

Validation reference for SWMM

Land Use	C	Land Use	C
		Lawns:	
		Sandy soil, flat, 2%	0.05 - 0.10
Business:		Sandy soil, avg., 2-7%	0.10 - 0.15
Downtown areas	0.70 - 0.95	Sandy soil, steep, 7%	0.15 - 0.20
Neighborhood areas	0.50 - 0.70	Heavy soil, flat, 2%	0.13 - 0.17
		Heavy soil, avg., 2-7%	0.18 - 0.22
		Heavy soil, steep, 7%	0.25 - 0.35
		Agricultural land:	
		Bare packed soil	
		*Smooth	0.30 - 0.60
		*Rough	0.20 - 0.50
Residential:		*Cultivated rows*	
Single-family areas	0.30 - 0.50	*Heavy soil, no crop	0.30 - 0.60
Multi units, detached	0.40 - 0.60	*Heavy soil, with crop	0.20 - 0.50
Munti units, attached	0.60 - 0.75	*Sandy soil, no crop	0.20 - 0.40
Suburban	0.25 - 0.40	*Sandy soil, with crop	0.10 - 0.25
		Pasture	
		*Heavy soil	0.15 - 0.45
		*Sandy soil	0.05 - 0.25
		Woodlands	0.05 - 0.25
Industrial:		*Streets:*	
Light areas	0.50 - 0.80	Asphaltic	0.70 - 0.95
Heavy areas	0.60 - 0.90	Concrete	0.80 - 0.95
		Brick	0.70 - 0.85
Parks, cemeteries	0.10 - 0.25	Unimproved areas	0.10 - 0.30
Playgrounds	0.20 - 0.35	Drives and walks	0.75 - 0.85
Railroad yard areas	0.20 - 0.40	Roofs	0.75 - 0.95

Fig. 5 Runoff coefficients for different land covers

The above data is given by "The clean water team guidance compendium for watershed monitoring and assessment" by State Water Resources Control Board 5.1.3 FS-(RC) 2011

Annexure IX

Road map and drainage map of the study area are shown below. These have been used in running of Terrset ann SWMM

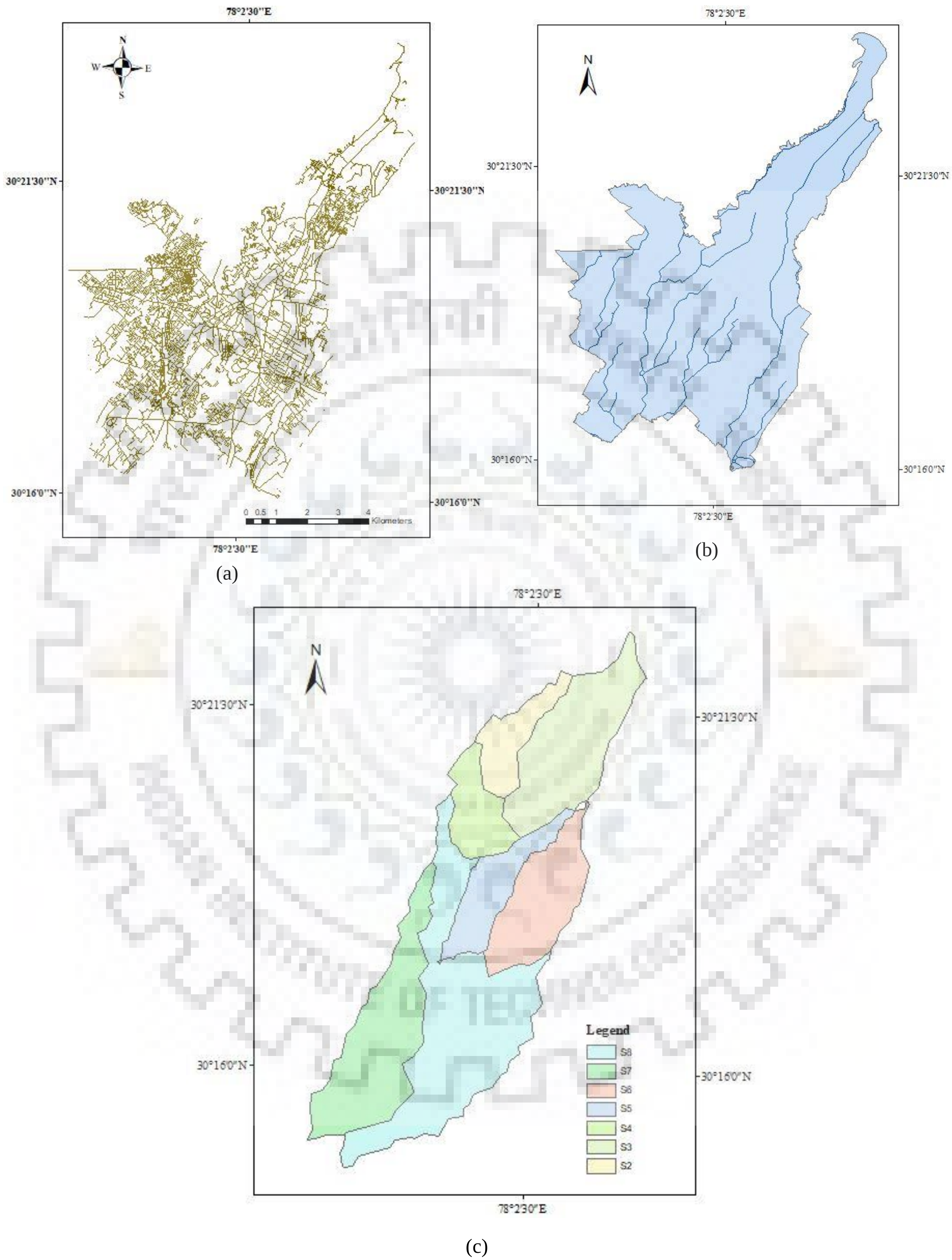


Fig. 6 (a) Street map, (b) Drainage map & (c) Subwatersheds of Bindal river