EFFECTS OF RAPID URBANIZATION ON THE POTABLE WATER RESOURCES USING GIS TECHNIQUES AND WEAP MODEL – A CASE STUDY OF VARANASI, INDIA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

SHIKHAR KUMAR

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DEPARTMENT OF GEOLOGY

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BY

SHIKHAR KUMAR

DEPARTMENT OF GEOLOGY

DR. J. MALSAWMA (Supervisor)

PROF. RAMAKAR JHA (Jt. Supervisor)

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IN GEOLOGY OF MIZORAM UNIVERSITY, AIZAWL

SUPERVISOR CERTIFICATE

I DR. J MALSAWMA, hereby declare that the subject matter of this thesis is the record of bonafide research work done by MR. SHIKHAR KUMAR under my guidance and that the contents of this thesis did not form basis of the any previous work in any other University/Institute to the best of my knowledge. This work is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Geology.

DR. J. MALSAWMA
(Supervisor)
DEPARTMENT OF GEOLOGY
MIZORAM UNIVERSITY, AIZAWL

SUPERVISOR CERTIFICATE

I PROF. RAMAKAR JHA, hereby declare that the subject matter of this thesis is the record of bonafide research work done by MR. SHIKHAR KUMAR under my guidance and that the contents of this thesis did not form basis of the any previous work in any other University/Institute to the best of my knowledge. This work is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Geology.

PROF. RAMAKAR JHA
(Jt. Supervisor)
DEPARTMENT OF CIVIL ENGINEERING
NIT PATNA

Prof. (Dr.) Ramakar Jha
Chair Professor
Department of Civil Engineering
National Institute of Technology Patna, INDIA

DECLARATION

I SHIKHAR KUMAR, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Geology.

SHIKHAR KUMAR

HEAD

DR. J. MALSAWMA (Supervisor)

PROF. RAMAKAR JHA (Jt. Supervisor)

Prof. (Dr.) Ramakar Jha
Chair Professor
Department of Civil Engineering
National Institute of Technology Patna, INDIA

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SHIKHAR KUMAR
Department of Geology
Mizoram University
Aizawl, Mizoram

CONTENTS

CHAPTER 1

INTRODUCTION

The rural population in all developing and developed nations is moving towards urban areas. By 2050 it is predicted that 67% of the world population is expected to be living in urban areas (UN 2011), with the most rapid levels of urbanization taking place in developing countries (Zhang 2016). The world is witnessing the largest and most drastic urban population and urban density growth in the history of mankind.

The word 'Urbanization' can mean two things in different contexts. One is that increasing number of population is moving from the rural to urban areas in an area or a country. It can also refer to the effect of such transfer of population to the change of land use from agriculture, vegetation or barren land to built-up human settlements, industrial areas or commercial buildings. Both these meanings are obviously interrelated and have been ongoing in various parts of the world with ever increasing rate. It is also likely, that despite our best efforts, the majority of future urban growth will be in informal areas as governments struggle to keep up with the increasing demand for basic services including water supply, sanitation and formal housing. Urbanization is directly linked to the degradation of environmental quality, including quality of water, air and noise (Cullis et al. 2005, 2018; Liang 2011; Bobylev et al. 2016; Zhang 2016).

The increase in urban population and change of land use puts intense pressure on the environmental resources of an area and poses risks to not only quantity but also quality of valuable natural resources and habitat which are present there (OECD, 1990). When the population of a city grows, it consequently changes the land use of the surrounding areas from natural, agricultural, other vegetative areas or water bodies etc. to black-topped, concrete structures, which in turn not only change the natural water flow of the area but also hinder the groundwater recharge in these places (Strahler, 1975). Another important thing to understand is that urban areas don't always grow evenly in all directions and the preferred growth direction could be dependent on various factors which include availability of natural resources and also availability of manmade facilities. As a result, some parts of a city could be found to be more dynamic than other parts (Deng and Haung, 2004). During the growth of a megacity, when the urbanization rate is high due to influx of population, the city has to undergo haphazard and swift growth which results in a patchy and very densely packed urban area. This also causes the urban areas to encroach over water bodies and/or stream flow regions. This reduces the recharge of natural water bodies like lakes and rivers and also has adverse affects on the replenishing of aquifers. Many megacities in India have been culprit to this kind of growth and as a result in time they lose the local natural resource of water and are forced to transport water from further away. This is very much a preventable issue if the growth of a city can be regulated and planned before hand while keeping the local resources intact (Vinoth Kumar et al., 2007).

In India, due to urban development along the rivers, the rivers are now under severe threat. Even though non-existence of life without fresh water is a recognizable and acceptable fact everywhere on the planet, the pure rivers and freshwater sources are being abused. Rivers which are lifeline to any city or society are being treated as sewage drains and are used to throw away all kinds of wastes so that the river can take it away downstream.

Moreover, the ability to develop the land in an urban area located in the vicinity of a river system in India heavily influences economic activity and the quality of life in cities (Turkstra, 1996). One direct implication of such an urban sprawl is the change in land use and land cover. Due to increasing population and high economic growth in selected landscapes, rapid urban development and land use changes have occurred in India during recent years. Further, urban development has both direct and indirect impacts on water resources and urban water management. Some impacts result from the direct modification or destruction of streams, lakes and wetlands. Other impacts occur primarily offsite due to changes in the quality and quantity of runoff from urban development and construction activities, climate change (mainly rainfall and temperature), and development of heat island like situations (Dreher and Price, 1992). Their collective diminution portends not only worsening water shortages and potential conflicts over scarce supplies, but mounting the ecological damage. As a result, increasing number of water-borne diseases is spreading among the people who live along the banks of polluted rivers. As per WHO, 1.1 billion people lack access to an improved drinking water supply; many more drink water that is grossly contaminated (Marale et al., 2012).

1.1 Need for urban development

The urban environment includes areas with very high density of buildings and presence of consistent and intense human activity (McIntyre et al., 2001). There are not many studies regarding the environmental consequences of past and current urban development processes. Planned cities were quite common earlier in America, but it was replaced by the idea of Urban Agglomeration. Due to urban agglomeration planned cities became an unpopular and impractical process (Henderson-Smith 2002). In the twentieth century, the New Town idea was revived like the British Garden cities in Radburn, New Jersey (1929), which was then followed by the government sponsored "greenbelt" towns in Ohio, Greendale, Wisconsin and Maryland among other states (Henderson-Smith 2002). In India, most of the cities are having urban agglomerations and the green belt towns are rarely noticeable. However, there have been constructions of Extensions building of metropolitan cities in India in planned way similar to the Greater Noida near New Delhi (Kumar et al. 2010).

The rate of increase of urban sprawl and mapping of the same is very essential for city planning as it gives the city planners the way to understand the development trend. This information will help the city planners to make adequate adjustments to the urbanization plans and also regulate it so that it can be sustainable (Lv et al., 2012). The difficulty in proper assessment of urban growth in rapidly growing urban areas is the lack of proper tools for proper collection of data and irregular monitoring of the urban growth. The data collection has to be good and comprehensive including historical data so that city planners can make adequate changes.

The process of studying spatial urban growth involves land use / land cover change, urban development pattern, population density, floating population, pollution due to existing and floating population, water quality of river system, climate change impact and urban water management and modeling. Land use is an important study because the state of land resources and sustainable development of land resources is very important in developing a sustainable development of economy for a city or a country as a whole (Ma and Cui 1987; Jaiswal and Verma 2013). The study would provide the trends and estimate the change in above variables and its impact on urban water management for coming years. (Himiyama, 1999; Kim 2007; Wang and Zhou, 1999; Kim 2009).Evaluation of the periodic changes in spatial extent and patternof urban development in different years is essential for planning (i) urbanization promotion areas, and (ii) urbanization control areas.

Geographic Information System (GIS) and Remote Sensing are powerful tools which are used for urban growth analysis (Feng, 2009). As the term Remote Sensing implies, large inaccessible areas of the planet can be easily studied and a synoptic view of the region can be created without ever going to the area physically. Using historical Remote Sensing data, the change of the land use and the growth of urban or any other land use can be studied using the temporal data (Lu et al., 2009; Wakode et al., 2011). Deterioration of quality of environment can also be studied using the analysis of such data in specific regions of the city. Different types of remote sensing techniques have been used in various studies around the world to study and map the land use changes and the study of spatial extent of urban development in different parts of the world (Howarth, 1986; Fung and LeDerw, 1987; Eastman and Fulk, 1993; Jensenet al., 1993, 1995; Li and Yeh, 1988). These techniques include image differencing (Toll, 1980), image rationing (Nelson, 1983), post-classification comparison (Howarth and Wickware, 1981), masking method (Pilon et al., 1988), nearest neighborhood and principal component analysis (Fung and LeDrew, 1987; Li and Yeh, 1988). Most of the techniques have limited capability in capturing the characteristics of urban sprawl as these have been developed in the context of image analysis or fractal theory (Webster, 1995; Batty and Longley, 1994). In addition to remote sensing approach, it was found that entropy approach can provide information on the pattern of periodic changes in urban development (systematic/random). Entropy, which is a measure of disorder or randomness (Miller,1969) has been applied to a variety of practical problems indifferent fields, including physical, biological, and social sciences (Fast, 1970; Wyatt, 1967; Morowitz, 1970; Kullback, 1959; Quilstler, 1953 and 1955; Buckley, 1968; Theil, 1967 and 1972; Chapman, 1977; Medyedkov, 1967; and Thakur, 1972 and 1979).

1.2 Urban water management under different climatic and anthropogenic activities

In contemporary times the surface water resources are increasingly facing a number of challenges. There has been increasing demand of water for different purposes due to exponential population rise and developmental needs in urban areas. From the estimations of several UN organizations one billion people on the earth do not have adequate facilities of safe drinking water and virtually two billion people do nothave adequate access to sanitation facilities. During the meeting of UNGASS held in New York, June 1997, Vice President of World Bank said that "By 2050 two out of every three people in the world might not have access to fresh water and sanitation".(United Nations, 2010). In the developed and developing countries water demands are more in three key areas: (1) Human needs, drinking water and adequate sanitation; (2) Agricultural needs for the growing population; and (3) Industrial needs, to provide the required goods and services to the growing population.

The other major problem confronting world's water resources is their declining quality. Over three billion people are losing their lives every year because of water related diseases resulting from consumption of water of poor quality. From the past several decades the water quality in the Indian rivers is declining drastically. There are several hundreds of rivers that are receiving million liters of raw sewage, agricultural and industrial wastes daily without prior treatment.

From there on, the examination of the groundwater quality at different areas during the investigation time span and it's correlation with global just as Indian principles will give the data about its appropriateness of the water for everyday use. From that point, a connection between the urban development and its effect on the earth can likewise be built up. It will be valuable to know how the urbanization procedure has influenced the surface just as groundwater assets quantitatively and subjectively. A total urban water equalization of the area will be useful to distinguish the commitment and effect of urbanization forms on the water assets of the district. Such examination will be useful to draw consideration of specialists, specialists and average folks to execute the manageable practices to spare the earth from the ramifications of urban development in not so distant future.

The urban living condition quality decays consistently as the megacities arrive at their maximum saturation point and can't adapt to the ever increasing pressure on their infrastructure. Enormous stress on water assets can be seen in numerous megacities and in recently industrialized Asian nations, which endure potable water shortage. Other factors which cause water scarcities in quick urbanization conditions include rapid population increase, growth of unplanned dense urban settlements in the sub-urban areas, changes in lifestyle and thus a rise in per capita water consumption (Mohr et al, 2011; Uitto and Biswas, 2000). So the positive parts of urbanization have frequently been dominated in Asian megacities by weakening in the physical condition and personal satisfaction brought about by the enlarging holes among flexibly and interest for basic administrations and foundation (Rahman, 2007).

Concurrently, it is now widely accepted that globally temperatures will increase and rainfall will become more variable, thereby affecting local climates across the world and that this can be largely attributed to human impacts (IPCC 2014a). Within urban areas, it is generally predicted that the increase in global temperatures associated with climate change will be exacerbated as a result of the urban heat island effect due to the modification of natural surfaces, where vegetation would have reduced heat (IPCC 2014b). Climate change is likely to also impact on water quantity and quality through a combination of higher temperatures and reduced freshwater flows (Cullis et al. 2015). Increasing demand for water from upstream users also results in reduced fresh water flow, which is further increasing the concentration of key pollutants and deteriorating water quality in rivers and associated economic risks for downstream users.

Both climate change and increasing urbanization, particularly informal development, are likely to negatively impact on water quality of rivers which, in turn, could have significant economic impacts for the communities dependent on these rivers both for direct use, but also indirectly in terms of the water-dependent economic activities such as agriculture. Better understanding of the link between increasing water quality risks due to urban development and climate change and the associated economic impact that this has, is therefore, critical in terms of identifying the need for interventions, improved management and investments in ecological infrastructure to ensure sustainable development and to mitigate against the increasing risks associated with rapid urbanization and climate change.

The difference between developed countries and developing nations is that developed countries always have managerial capacity, financial resources and experience to monitor and plan the urban growth whereas developing nations can have difficulty in having such tolls or facilities. In countries like India and more specifically in cities like Varanasi, the rapid urban growth due to rapid increase in population which inadvertently cause climate change are the main challenges for the urban planners and managers (Putra and Baier, 2008). Growth dynamics understanding is absolutely essential for economically and ecologically feasible planning of development of urban areas. Nearly one third of India’s population is now living in urban areas. Needless to say that it is essential that information on growth patterns of cities, climate change and the impact of these factors on living conditions is procured and studied (Farooq and Ahmad, 2008). The following research work is done on Varanasi urban agglomeration and Varanasi district as a whole. This city was selected because (a) it is a rapidly growing urban area with a large tourist population as well due to its religious and spiritual importance, (b) the city has major deficiency in its planning of potable water supply and waste water management, and (c) the pollution due to this urban area has adverse effects on the environement of the entire region including the major surface and sub-surface water resources.

The present work is done with the aim of presenting the rapidly going down quality of water of the Ganga River, the cause of which is dumping of raw sewage, solid wastes, dead animal carcasses etc. from the city directly into the river without second thoughts. Rapidly growing population and growth of the city with the lack of sanitation system to deal with the growth of the city has brought the situation of the city and Ganga River to such a bad point.

1.3 Objectives

The main objectives of this study are:

1. To analyze urban population density, floating population, water demand and urban sprawl at Varanasi with remote sensing and GIS support.
2. To delineate Land use/ Land cover change detection using various methods including Entropy approach.
3. To study the hydro-meteorological variables rainfall and temperature for possible climate change scenario.
4. To assess water quality of River Ganga at Varanasi using filed data and satellite data
5. To provide scenarios for urban water management based on urban development, water pollution, and available water resources for possible climate change in future.
6. To analyze the rapid growth of the urban sprawl and its trend using various remote sensing and GIS techniques during different time periods using historical as well as recent data
7. Study the land use land cover changes in Varanasi and the impact of urban growth in deteriorated in water quality of River Ganga

8. Determination of the impact of climate change in urban land use, groundwater table and the water pollution.

1.4 Structure of the Thesis

The structure of the thesis is very classical used for this kind of studies. The thesis has been divided into 9 chapters. Chapter 1, the introduction provided a short description about research background, the rationale behind the research and the objectives of the research. Chapter 2 consists of detailed review of literature of past work done in the same study area as well as the same theme of research. It contains the basic aspects of the theme of this research and then it also focuses on study area selected for the work. Results of previous studies done by various researchers for different urban agglomerations around the world and as well as Indian conditions were studied from which the methodology for this study has been derived. Chapter 3 provides various information about the Varanasi district including it growth rate, hydrogeological characteristics among others. All this information is necessary to follow the rest of the methodology of the work. In Chapter 4, the various thematic maps developed for the study area discussed which are then used for interpretation of urban water status of the district. In Chapter 5, data about population, population density, urban sprawl and entropy based analysis of Varanasi is discussed. Chapter 6 discusses climate change which includes analysis of rainfall, temperature and solar radiation data of Varanasi. Surface and sub-surface water quality as well quantity data is discussed and analyzed in Chapter 7. The various results are put together and discussed in Chapter 8 as a combined model of all data is used to predict future status of water management in Varanasi. Lastly, conclusion of the study is put in Chapter 9. It also includes the suggestions for the water management plans for sustainable development of the city.

CHAPTER 2

LITERATURE REVIEW

A variety of studies have been performed worldwide about the effect of economic growth of countries on the climate for different urban centers. In today's developed regions, the transforming force of urbanization was felt earlier and reached high levels of urbanization. In 2011 approximately 78 percent of the people of the developed region lived in urban areas, while 47 percent lived in urban areas of the less developed regions (United Nations, 2012). Urbanization refers to a trend in the cities and suburbs where a growing proportion of the population lives. In addition, the transition to settlements, trade sectors and industries of land use from agriculture or barren land or vegetation is observed. Such an urbanization trend has been ongoing for several decades because of population increases and the reclassification of rural localities into urban centers (United Nations, 2010). Cities are driving economic growth and providing the increasingly increasing population with a wide variety of jobs. It attracts increasing numbers of people (United Nations Human Settlements Programme (UN-HABITAT), 2010). The three pillars of sustainable development are integrated into urbanization: economic development, social development and protection of the environment.

An urban expansion can also be called as 'horizontal expansion' or 'dissipated urbanization'. Uncontrolled and disproportionate development of an urban area into the surrounding landscape, creating low-density, poorly designed development patterns. Common in both high- and low-income countries, urban sprawl is characterized by a dispersed population in separate residential areas, with long blocks and poor access often over motorized transportation and lack of well-defined business hubs (Unicef, 2012).

The rapid growth of metropolitan areas was called "urban sprawl" over recent years, referring to a complex pattern of land use, transportation, and economic and social development. As cities grow into rural areas, large areas are developed in the low density pattern of "leapfrog" (Frumkin, 2002).

Urban expansion frequently happens quickly, rather than slowly. The low-density use of land, where per capita land consumption is much higher than in the more populous city areas, is another key feature (Hill, 2014). The research has contributed to the identification and analysis of the urban distribution of Hyderabad through remote sensing and GIS technology.

A fragmented urban spread can facilitate high traffic, high industrial output concentrations, environmental degradation, informality and non-regulated land growth and housing markets A fragmented and unregulated urban spread can encourage a high degree (Kraas et al., 2014).

In many megacities of developing and new developed Asian nations, stress on the distribution and management of limited water supplies can be observed. In light of a rapid urbanization, the motive forces of water shortages include population growth, unplanned (informal) settlement growth in the (sub) urban areas, changes in lifestyle and the resulting increase in consumption of per capita water (Mohr et al., 2011; Uitto and Biswas, 2000).

There are also significant environmental threats in mega-cities, such as noise, water and soil pollution (Hardoy et al., 2001). A large number of threats from water resources include drought, floods and urban environment, inadequate infrastructure for fresh water and sanitation, and river pollution and groundwater exploitation. A case study on the effect of urbanization on the Guangzhou water supply, China has shown that urban isation has both a qualitative and quantitative influence on water supplies (Baier et al., 2009; Strohschön et al., 2013; Wiethoff et al., 2011).

Urban expansion in its various forms is a common and contemporary issue in India and a challenge for urban planning institutions, as infrastructure development costs are constantly rising (HPEC, 2011).

In addition, these changes in the urban development structure and rapid urbanization have adverse environmental and water resource effects (Wehrhahn et al., 2008).

The standard of the urban environment worsens every day as major cities hit saturation points and are unable to cope with the rising stresses put upon their infrastructure. The destruction of habitats has contributed to rising water and air pollution. These are further destroyed by a relentless invasion and transition into urban concrete jungles of habitats, from forests, grasslands, coastal areas, wetlands and waterways (Nagendra et al., 2012).

Water scarcity problems due to erratic precipitation would escalate with accelerated climate change, especially in semi-arid cities like Bangalore (Nagendra et al., 2013).

Industrialization and economic growth boosts population growth and peri-urban development which leads to massive city suburban expansion. Even for the same time period, urban areas are not growing uniformly throughout the city. It is dynamically active in some parts of the city and features fewer development or expansion activities in certain areas (Deng and Huang, 2004).

The total urban population in Asia grows by an average of over 45 million a year, which means that more than 10 km^2 (mainly productive) of agricultural land is converted to urban uses every day (United Nations Human Settlements Programme (UN-HABITAT), 2010).

As the urban expansion increases, land use changes from different types into urban buildings. Due to the urban decline of the center, the mapping and monitoring of urban spread is extremely important for urban planners to understand and then regulate urban development trends in the periphery (Lv et al., 2012).

In previous land use trends, spatial growth of cities results in changes. Such an urban expansion phenomenon is distinguished by haphazard development patchwork leading to unsafe development in any city. Satellite time series data provide a high potential for urban expansion, urban extension, and for monitoring changes in land utilization and soil consumption (Nole et al., 2012).

Satellite remote sensing was widely utilized and recognized as a potent and efficient tool for the detection of land use and land coverage changes in connection with geographic information systems (GIS) (Harris and Ventura, 1995; Weng, 2002; Yeh and Li, 1999). The remote satellite sensing provides economical, multi-spectral and multi-temporal data, transforming it into valuable information to understand and monitor patterns and processes of land development and to build land and land coverage data. It offers the ability to monitor urban agglomerations dynamically by studying multi-time data and has proved to be an effective tool for mapping land use and change over time in this particular region. In comparison, GIS technology offers a versatile environment in which data required for changing detection and database creation to be processed, analyzed and displayed.

The integration of remote-sensing data and GIS techniques was shown to be a useful means by means of Landsat images in Chinese Zhujiang Delta, to analyze the direction, rate and spatial pattern for land use change (Weng, 2002).

Many past urban mapping studies using global remote sensing data have used the Landsat data for analysis in medium spatial resolution. In the area of Jing-Jin-Tang, China, for example, Lu et al. (2014) used multi-temporal Landsat images to monitor urban agglomerate development in two decades. From 1990 to 2006, Griffiths et al (2010) developed a multi-sensor mapping approach to urban development in the Bangladesh area of Dhaka. The automatic procedure for the extraction of build-up areas in Ikonos and QuickBird has been tested by Pesaresi et al.(2011). Taubenbock et al. (2012) monitored 27 megacities' urbanization with a time series of 10 year Landsat scenes over the past 40 years. Remote sensing has also been used for site risk/suitability assessment for urban development and the avoidance of areas sensitive to the environment or hazards (Youssef et al., 2011). In order to predict urban scales of Sana (Metropolitan Yemen), the SLEUTH model was used to predict the gap between Al-Shalabi et al. (2013), while Jha et al. (2008) considered entropy approaches to research the spatial degree of urbanization and frequent shifts in urban growth patterns (systematic/random). Remote sensing and GIS techniques have led to the evaluation of new agricultural opportunities for government and private sector through increasingly increasing urban areas of agricultural land (Abdel Kawy and Abou El-Magd, 2013). The spread of impermeable surfaces is also considered an indicator of the level of urbanization as an expansion of the urban area. A wide range of environmental sciences issues and issues central to global environmental changes and human/environmental interactions include knowledge of impervious areas, particularly the size, location, geometry, spatial pattern of impervious areas and the perviousness–imperviousness ratio. Remote sensing techniques can also play an important role in estimating impermeable surfaces in this case (Weng, 2012). In one watershed, the magnitude, position, geometrical pattern, and spatial pattern of imperceptible surfaces have hydrological consequences. The impermeability can also change the quantity and quality of urban land water in the area. It is also noted that an increase in the impermeable cover would result in increased volume, duration and intensity of the urban rush with the help of remote sensing and GIS techniques. The integrated remote sensing and GIS techniques have therefore been used worldwide and are therefore available for various studies of urban growth (Weng, 2001)

Urban development is also attracted in India, as newly urbanized land typically is seen across the old parts of the city in a tight band. In highly developed cities such as Bangalore and Pune, because there is little ground the center maintains a rather stable population, while outlying cities are increasing and fragmentation on the outskirts is ongoing (Taubenböck et al., 2009).

Kit et al. (2012) have employed a high-resolution satellite imagery approach to classify informal settlements such as the urban slums of Hyderabad, India using the principle of lacunarity. This slum position map is an efficient tool to identify particularly overcrowded areas of the city and to be a credible source for later assessment of vulnerability and resilience.

In the context of the analysis of decadal urban growth rates and their related properties for Kolkata megacity of India, Bhatta (2009) used multi-temporal and multispectral remote sensing images; in the case of Seto (2011) he analyzed the urban growth of Bengaluru, India and noted that Bengaluru urban development was at the expense of farmland.

Satellite remote sensing data from the Landsat series provide a major advantage for the study of urban development. Despite their low spatial resolution, Landsat data may provide useful information for a variety of urban applications including analyzes of history of urban development; modeling and projection of future urban growth; infrastructure requirements prediction and planification; impermeable surface assessments and rushing in watersheds; agricultural land , forests and other vulnerable sites (Seto, 2011).

Several decades of explosion in population and increasing urban growth in both developed and developed countries have had profound environmental and socio-economic impacts (Leao et al., 2004; Longley, 2002).

Comprehension of urban development growth and change is crucial for students of urban dynamics and for those who need to manage resources and provide services in these fast changing environments (Sanchez, 2004; Yang, 2002; Chen, 2002; Aysan et al., 1997; Wright, 1996; Clark and Jantz, 1995).

Land is a valuable asset. More than 21% of the world's population lives on agricultural land, covering just 7% of the world's total area. Sustainable economic development can have a significant impact on a country's land resources and environment (Ma and Cui, 1987; Chen and Peter, 2000; Lin, 2002; Ho and Lin, 2004). When the land use situation has a negative impact on sustainable development, the Government should adopt new regulations and legislation or adapt it to enhance effective land resource management. Many scientists have sought to analyze qualitatively the effects of land policies (Cai, 2003; Ding, 2003; Ho and Lin, 2004; Lin and Ho, 2005; Lichtenberg and Ding, 2008), but some of the analyses were based on accurate and reliable data (Wang, Jing et.al, 2012). Accurate and timely information is crucial to long-term economic development plan and short-term land management on land use and land use adjustments at national level (Zhang and Zhang, 2007). Better understanding of land resources and timely regulation and land use control are essential for sustainable development. The present states of various forms of land use and changes in land use that have taken place in the past have to be clearly seen. Such changes must be explained and the driving forces of land policy analyzed and changes in land utilization predicted in the future (Wang, Jing et.al, 2012).

Land use mapping has always been a expensive and time-consuming operation. In the recent years, space technology has become a powerful tool, particularly for detecting changes, for land use/land cover studies. Due to the synoptic view, map format and repetition coverage remote sensing technology represents a viable source for the collection of quality land cover information at local, local, and global levels, contrary to traditional methods of field surveys in which preparations and final mapping have taken several years for land use / land coverage of a zone (Csaplovics, 1998; Foody, 2002). Land use is a matter of ongoing growth and pattern change. Planners need up-to - date information only easily, economically and reliably obtainable via remote sensing techniques for regional economic growth (Gautam N. C. and Narayan L.R.A., 1983).

In India and other developing countries, rapid urbanization and growing changes in land use as a result of population and economic growth in selected landscapes are late. The towns expand in every way leading to extensive urban expansion and changes in urban land use. In city or peripheral rural areas, the spatial patterns of these changes are clearly noticed than they are in the center of the city. It is clearly illustrated by shifting patterns of urban land use (Kumar et al., 2008). Varanasi population increased from 2,508,110 to 3,147,927 in the last decade and the density changed from 1,618/km2 to 1,995/km2 (from 1991 to 2001). These unplanned urban expansions and urban spreads in the central areas of Varanasi have resulted in dense settlements. These areas are subject with little green space to dense and aggravated settlement patterns. Patterns of the use of land such as tree cover, developed area, agricultural land, etc. were estimated by Kumar et al. (2008) through remote sensing and study of the effect on this urban environment of changes in land use patterns.

In the case of land use transition, numerous studies, using Geographical Information (GIS) and remote sensing techniques, in both developing and developed countries, have been conducted to explore connections between spatial and temporal trends, the driving forces and environmental factors etc. Examples include Ryznar and Wagner (2001), who used remote sensing images to detect the shifting net vegetation in Detroit. Li et al (2003), who combined the urbanization index with GIS methods, examined the scale, intensity and spatial heterogeneity of urban growth in the Shanghai region. Leao et al (2004) have been evaluating the outcomes of various development plans and have used a cellular automatic (CA) model to simulate urban growth in Porto Alegre in Brazil. Wilson and Lindsey (2005) investigated the dynamics of land use in the central Indiana region with an analysis of Landsat's satellite imagery classification and change detection. Their link between land use change and socioeconomic processes including population change and financial investment in the built environment has been important. Xiao et al (2006), using GIS and remote sensing, analyzed urban development in Shijiazhuang City and discussed the correlation between urban land growth and multiple socioeconomic factors independently through linear unitary regressions. Al Rawashdeh and Saleh (2006), who followed the urban spatial development of Jordan's Amman region, adopted Remote Sensing and GIS techniques to address possible environmental impacts from the ongoing fertile land loss. Shi and Li (2007) talked about the influences on land-use urban development policies, such as a rise in housing prices, suburbanism and the multicenter urban development mode, etc. In order to analyze spatial and temporal dynamics of the urban spread along the urban rural transect of Guangzhou City, Xi and Cho (2007) combined temporal remote sensing data with a gradient analysis. These researches offer useful tools and insights to improve our understanding of the problem of land-use change. In the process of urban land use transition, however, most works either rely on theoretical abstraction and qualitative discussion (for example, Shi and Li, 2007), or simply use a unitary linear regression to analyze the association between urban earth growth and each motive factor separately (e.g., Wilson and Lindsey, 2005; Xiao et al., 2006). Comprehensive and quantitative studies of the socio-economic factors driving urban development and the physical elements affecting the spatial distribution of urban areas are generally rarely reported.

Tasks relating to urban planning are subject to cooperation by experts from various policy areas. People are familiar with various urban planning aspects. It is also a barrier to further growth of urban planning. It is now easy, in computer science in particular, to use urban GIS. Computers for urban planning have been widely used. The history of computer planned contribution has been tracked by Klosterman and Landis (Klosterman,1994; Klosterman and Landis, 1988). Its ability to store and process large amounts of information is the significance of computers used in urban planning (Han and Kim, 1988; Harris, 1987). Harris pointed out that planning activities use current information to improve our understanding of our world (Harris, 1987). The result is a great capacity to achieve the future of society. In contrast, Hopkins and Schaeffer (1985) considered the planning of information activities. Knowledge is generated to justify the actions made. Knowledge is then evaluated. Furthermore, there is a distinction between formal and informal information which helps to understand the role of information in planning. Formal information is socially identified and formalized information (Burch et al., 1989). Information on official information answers questions like the use of information, the need for information and the intended information. Han and Kim (1988) pointed out that formal data may include legal mandates, planning procedures and situations of problems. Informal information, for example rules of thumb, intuition, personal decisions and experiences, is something that has not been formalized. In view of the importance of informal information, planning computer systems historically concentrated on formalized information. It may be worth emphasizing that information and expertise are definitely not the same when addressing data technology for the purposes of urban planning, even though some of the publications tend to support the notion that information technology enhances knowledge and methods somehow automatically (Kammeier, 1998). Progress in planning methodology can only be attributable to knowledge and knowledge, not information gaining or IT. The best techniques and the new use of the machine can only be used as a DSS, but never replace good decisions and management.

It will switch terminology from information to knowledge as the discussion shifts from information systems to management of knowledge. Awareness is a knowledge that has been compiled and translated into a solution to problems and decision taking that is accessible and relevant (Beckman, 1997)

There are two types of classifications of knowledge. The codified and formally expressed knowledge is explicit knowledge (Nonaka, 1994). It can be displayed, stored, shared and applied effectively (Beckman, 1997). If the rate of refuse generation is formal, then an example of explicit knowledge is to understand what actions to take to reduce the level of refuse generations when the rates rise above reasonable levels. If shortcuts are made to speed up the implementation of reduction policies that are not documented and only acquire experience, this is an example of tacit understanding. Tacit knowledge includes information difficult to express, to represent and to communicate, which is the extension of informal information. UPDSS was specifically designed to facilitate knowledge sharing and integration. However, the management of knowledge is close to that of technical infrastructure (Alavi and Liedner, 1999).

Many solid waste management (SWM) problems in the world are complex because the characteristics of the solid waste and the objective of management are not completely defined. Such problems require a flexible approach. Managing the collection, transportation, and disposal of municipal solid waste (MSW) is mostly unscientific in India (Gupta et al. 1998) and thus demands immediate attention. Although managing waste is an essential service, it is not receiving the proper priority it deserves and hence the services are inadequate. The selection of appropriate technologies and the design of sustainable SWM systems is not only a technical issue but involve multi-thematic criteria (van de Klundert, Urban Waste Expertise Program Policy Meeting II report, 2000). The problems of waste management in developing countries have been taken seriously only recently. Waste generation reduction is now being considered an educational and awareness task that has to be promoted at the societal level (Agamuthu and Hansen, 2007).

Municipal bodies in India render SWM services (Katpatal and Gupta, 2005). In general, there is insufficient planning for waste management because of the lack in information and systems which supports the decision making process. A system analysis approach is necessary and a model is desirable because of interactions between many factors within a waste management system (Wang et al., 1997). Decision makers play a key role in the entire SWM process but can be misguided by the complex nature of solid waste. Existing SWM planning tools provide limited assistance to decision makers struggling to find strategies that address their multiple concerns (Harrison et al., 2001). The tools used in combination to address waste parameters, management options, and multiple objectives of the SWM strategy severely constrain the effectiveness of a manual search process using these tools. The decision-making process is hampered sometimes because of the lack of information and the absence of an information system. Decision support systems (DSSs) are designed to help decision makers solve complex spatial problems. DSSs are computer-based information systems that use data and models to interactively support semistructured or unstructured decisions. Spatial analysis has been attempted to solve complex environmental problems through DSSs and proximity analysis (Zeiss and Lefsrud, 1995; Lin and Kao, 1999; McIntyre and Parfitt, 1998). Making (good) decisions requires knowledge, intelligence, and expertise to solve the conflicts associated with specific objectives. Expert knowledge is of utmost importance for designing a DSS, especially in environments involving uncertainty. Chang et al. (1997) developed a DSS incorporating a geographical information system (GIS) for managing chemical emergency events in an urban environment. Chang and Wang (1997) developed an innovative DSS as a graphical, interactive, problem structuring tool for managing and planning of waste collection, recycling and incineration. Chang et al. (1997) studied the ability of GIS, used with a multiobjective programming model for vehicle routing and scheduling, to analyze the optimal path between a given origin and destination in a waste collection network. MacDonald (1997) developed a spatial decision support system (SDSS), which includes an expert system database management capability to supply organized and analyzed relevant data, to help the planner understand the spatial nature of the problem. Characterization based cost-effective methodologies (Gay et al., 1993) have also been suggested. Tanskanen (2000) developed a computer model for analyzing on-site collection systems of waste materials separated at the source for recovery. Chang et al. (2001) showed that the complexity involved in managing these systems owing to the public and private sectors' involvement can be managed by using state-of-the-art information technology based on the Internet. Such electronic communication becomes an indispensable tool for sharing of information between all users and agencies, thus improving the overall managerial efficiency.

Lukasheh et al. (2001) reviewed GIS and environmental decision support system technologies and their applications for solving complex environmental problems. Chang and Chang (2002) illustrated the application of web-based DSS for rehabilitation of the estuarine ecosystem and satisfying the goals for sustainable management. A multiple-objective model has been attempted by Chambal et al. (2003) that capture a site's MSW management goals, objectives, and concerns to facilitate the evaluation of competing strategies. The model ranks competing MSW alternatives based on how well they meet the decision maker's strategic objective. Fiorucci et al. (2003) developed a DSS to assist the planner in decisions concerning the overall management of solid waste at the municipal scale. This DSS determines the optimal number of landfills and treatment plants, as well as the quantities and characteristics of the refuse generated. Dyson and Chang (2005) presented a systems dynamic approach for predicting waste generation in fast growing urban areas based on a set of limited samples from a case study in San Antonio. This analysis presents various trends of solid waste generation associated with five solid waste generation models using a system dynamics simulation tool called Stella. Chen and Chang

(2006) used gray fuzzy multi objective programming to aid in the decision- making process for allocating waste load in a river system under various uncertainties and risks. This study considers a multi criteria objective function combined with gray and fuzzy messages within a cost-benefit analysis framework integrating the prior information of quality models, quality standards, and potential benefits. Malczewski (2006) presented a literature review of GIS-based multi criteria decision analysis. Zimin (2008) designed an open urban emergency DSS. Sumathi et al. (2008) addressed the site location of a new landfill using a multi criteria decision analysis and overlay analysis using GIS. Rogers and Louis (2009) designed a DSS based on robust performance assessment and evaluation among consolidating community water systems. The need of a SDSS for SWM was realized in India, which helps remove gaps in sectoral management of MSW. Katpatal et al. (2008) and Barlaz et al. (2003) suggested the research community can work together with the solid waste industry to increase and improve alternatives for integrated SWM programs that meet economic and environmental criteria. SWM also involves conflicts, especially in Indian urban areas with high population densities and irregular urban growth. Participative approaches that use IT-based methods, based on combined GIS and multicriteria evaluation techniques, and involve the public in the decision making process have the potential to build consensus and reduce conflicts, such as those arising from the setting up of different types of waste facilities (Higgs 2006).

The land use and cover are clearly connected, however, with the Earth's surface characteristics. The use of soils could be pasture, farming, urban development, logging, mining, etc. Categories of land may be cropland, forests, wetlands, farmland, highways and urban areas (Meyer, 1995). Many shifting patterns of land use, driven by diverse social causes, lead to changes in land cover that influence biodiversity, water and radiation, trace emissions and other combined climatic and biosphere processes (Riebsame, Meyer and Turner 1994). Shift detection is the method of looking at changes in an object's state at different times (Singh, 1989). The basis for the use of remote sensing data to detect change is that land cover changes result in radiance values that can be remotely sensed. The growing flexibility in manipulating digital data and increased computer power has resulted in various techniques to perform satellite imagery changes detection. Many experiments were carried out with remote sensing and GIS detection of shifts.

Jusoof and Hassan (1998) reveal that distant sensing information provides important land use information. This also implies that the identification of shift depends on the spatial, temporal, and spectral and radiometry of the sensor used in data collection. Zeng Shan (1999) has used remote sensing and GIS apps in urban surveys in China at the moment to give more weight to knowledge on the acquisition of urban land use, and to a comparison between urban areas over the most recent decades, thus providing an overview of the nature of processes of deforestation that are explored through remote sensing and Mertens and Lambin (2000) Chen et al (2000) review and summarize its achievements for China in early remote sensing applications for environmental surveillance and research in energy. Apan et al (2001) studied the nature and size of riparian landscape structural changes within a catchment using two different pictures at a Lockyer Valley Catchment in Queensland, Australia, to develop appropriate mapping and evaluation technologies, and to use the thematic mapper digital image to studying these changes within a catchment. Shannon entropy was defined by Yeh and Li (2001) to measure and differentiate types of spread which represents the concentration of spatial variability distribution in a given region. Sudhira et al (2003) suggested that urbanization should be carried out radially or linearly along roads in a well-established town. Methods of scattering, study of spatial and temporal shifts, alongside collateral information (such as Survey of maps of India, etc.), could be achieved effectively and cost-effective with the aid of spatial and temporal technologies such as the geographical information system (GIS). GIS and remote sensing are land-based technologies and therefore very useful in formulating and implementing the land portion of the strategy for sustainable development.

In the newly established wetland of the yellow river delta, Yue et al (2003) developed models for the conservation of the recently-built delta for landscape change. In the identification of the newly formed wetland, four models were used for landscape transition. The models included patch connectivity, ecological diversity, the strength of human influence and the medium area centre. Alados et al. (1957-1994) studies were carried out in order to research key processes for the creation of a model for the dynamics of land-based coverage that would assess landscape changes and vegetation cover for the years 1957–94. Air photos taken in 1957, 1985, and 1994 were used to determine the land cover and landscape trends. They scanned toposheets and aerial photographs of the year and analyzed the overlay using GIS software. They also performed the soil inspection to verify the analysis results. The research by Ye qui et al (2004), which based the Hierarchical Regional Space (HRS) model, has described and analyzed the dynamics of Beijing City's fast-growing urban scenery. With the help of available spatio-temporal data of different periods, Kayhko and Skanes (2005) carried out retrospective landscape change trajectory analyzes and verified all collected landscape information from the GIS environment using field data to identify the path of trajectory analysis change. Ayad (2005) described the use of remote sensing and GIS in the urban planning process as an important factor in decision making. Their goal was to evaluate, using remotely sensed data (satellite and air photography) and raster GIS modeling the visual shift in a fast changing coastal region of Egypt. The landscape trends and landscape form of reaction studied as a case study by Abdullah and Nakagoshi (2006) in relation to land use changes in Seldor, Malaysia. Kong et al (2007) studied arid conditions in which water acquires satellite pictures and uses ERDAS for study in the limiting factor most of the time. Ansi et al. (2010), for further analysis used patch analysis and patch area matrices, defined change detection as a time process to identify land cover changes with remote sensing images of two different periods after mining has been stopped. Its aim was to identify how geographic and remotely sensed data can predict patterns of habitat diversity and land cover changes; and to identify the relation among post mining spatial, temporal, fragmented, and diverse fluctuations in the landscape. By using GIS and remote sensing, Bhatta (2008) studied Kolkata's urban growth trend. He used satellite data in different spectral resolution and tested it with the time's toposheets. He also found urbanization to be responsible for economic development. Junge et al. (2009) found that the population density growth of Nigeria and Benin has contributed to land use change and to soil erosion, forest destruction, declines in plants and animal species. Verma et al. (2009) indicated that remote sensing and GIS was a great tool for monitoring and managing urban growth and management, providing quick and reliable data, while also saving time and money spent in the traditional processes. In the mountainous town of Baguio in northern Philippines, Verzoa and Gonzalez (2010) studied land use change. Their survey demonstrates the possibility of detecting and quantifying up-to - date concentrations from time series aerial photos and satellite images, along with remote sensing network, geographic information systems and photogrammetric techniques, and this facility will help track the growth of developed areas as well as draft initiatives and policies to resolve the inevitable urban impacts. They investigated the attractive methodology used by Shannon's Entropy in urban sprawl studies and management, since entropy shows dispersion and compactness. The urban sprawl assessment has been studied by remote sensing by Bhatta et al. (2010). The conceptual ambiguity of spread and the lack of consensus amongst researchers , particularly from distance sensing data, has made measuring urban sprawl very difficult. Many scales and parameters are used to quantify the sprawl, but many are suffering from several constraints. Pocas et al. (2011) used three different temporal satellites images of the same area to determine the various vegetation type, barren/complementary land, land and used land matrices and land matrices to characterize spatial heterogeneity, fragmentation, and landscape complexity.

It is known that urban areas have unique climatic features, on which anthropogenic activities have reshaping effects (De Laat and Maurellis, 2006; Mills, 2007). Among urban climatic features, perhaps temperature differences between urban and rural areas have been studied the most since Howard (1820) until recent years (Figuerola and Mazzeo, 1998; Sakakibara and Owa, 2005; Stone, 2007; Yılmaz et al., 2007a; Bulut et al., 2008). From the results of the case and review studies, a general conclusion can be withdrawn as that urban temperatures are dramatically higher than rural depending on complex factors (e.g., urban surface roughness and urban canyon; Arnfield, 2003). According to Mochida et al., (2005), total heat balance in an urban area would be composed of incoming and outgoing heat fluxes through its surfaces and heat generation and heat storage in it if this space was taken as a volume under control. From a general perspective, in urban environments, two sources of heat cause increased temperature compared to its surroundings (Rizwan et al., 2008). One of them is the generation of large amount of heat from urban surface structures human has modified because they can absorb and reflect solar radiation more than the surfaces they originally had due to albedo differences. In this respect, temperatures of paved and natural surfaces were measured and they were found to have favorable and unfavorable effects on air temperature and human comfort, respectively (Yılmaz et al., 2007b, 2008; Gui et al., 2007). The other heat source in urban area is the anthropogenic heat sources (Rizwan et al., 2008), which can directly emit heat or contribute to the storage of produced heat in urban areas by reducing the quality of urban air. Various writers in different parts of the world have studied in detail these two heat generation mechanisms. For instance, Arnfield (2003) and Zak et al., (2007) studied the role of modified features of urban surface by considering surface topography; Oke (1973), Landsberg (1981), Karl et al. (1988), Zhou et al. (2004), Jauregui (2005), and Hughes (2006) emphasized the size and population of cities; Landsberg (1981), Roth et al. (1989), and Hejazi and Markus (2009) investigated the effects of urban density; Oke et al. (1991), Eliasson (1996), and Bonacquisti et al. (2006) considered the orientation of streets; Park (1986), Wu and Haith (1993), Cotton and Pielke (1995), Taha (1999), Eliasson and Svensson (2003), Gómez et al. (2004), Wong and Yu (2005), Kottmeier et al. (2007), Yılmaz et al. (2008), Jusuf et al. (2007), Liang and Weng (2008), and Katpatal et al. (2008) studied land use or rate of green and impervious areas and type, form, and heat capacity of buildings, while writers such as Brunner and Schnelle (1974), Ackerman (1977), Oke (1987), and Kottmeier et al. (2007) investigated the effects of human activities emitting excessive heat (presence of heavy industrial areas and motor vehicle traffics and air pollutants).

In Turkey, urbanization, together with the changes in general global circulations, is taken responsible for the changes in longterm temperature trends (Türkeş et al. 2002; Türkeş and Sümer 2004). Urban developments have accelerated in Turkey since 1950s (Kongar 1976; Işık 2005). Urbanization process quite low before 1950 gained momentum due to migrations from rural to urban regions following that year (Işık 2005). Between 1950s and 1980s, population increase in urban areas was due to industrialization, and by early 1980s, urban population exceeded the rural population of Turkey for the first time. From 1985 onward, as Turkish cities have been growing, most of the meteorological stations may have been affected by the land-use changes (e.g., devegetation or revegetation, non-agricultural uses of the lands) within and outside the cities, rapid urbanization, and likely thus both the urban heat island effect and the urban cooling effect (Türkeş et al., 2002; Türkeş and Sümer, 2004).

Today, this population movement from rural to urban continues due to two significant developments, namely, tourism and terror phenomenon in addition to industrialization especially in the eastern part of Turkey (Işık, 2005). For instance, in a study related to climatic change trend in Turkey, Türkeş and Sümer (2004) classified Turkish cities, where the 70 stations used in the study are located in order to show the general urbanization characteristics of these cities by considering only the population size and generated six classes and reported that total percentage of the medium urban stations is about 40, whereas total number of the stations that lay within the true urban classes (i.e., urban, large urban, and mega city) accounts for about 59%. This extraordinary population growth in developed and newly developing Turkish cities has been increasing the number and effectiveness of heat sources in urban areas mainly by causing the transformation of natural areas into deforested and impervious surfaces in an unplanned manner and by emitting large amount of substances into urban atmosphere from fuel combustion for domestic heating, transportation, and industry. In Turkey, studies related to climate change and urban climatic effects began to be conducted in mid-1990s by considering either whole Turkey (Türkeş et al., 1995, 1996; Kadıoğlu, 1997) or city— specific regions (Karaca et al., 1995a,b; Tayanç and Toros, 1997). Since that time both quality and quantity of these studies have been increasing (e.g., Karaca and Tayanç, 1998; Türkeş et al., 2002; Türkeş and Sümer, 2004; Çiçek, 2005; Tatli et al., 2005; Kutiel and Türkeş, 2005; Tatli, 2007; Yılmaz et al., 2008; Bulut et al., 2008). In these studies, common conclusion is that the climate of Turkey has entered a warming trend which extents variation depending on the studied areas, seasons, time of the day, and employed methods. For instance, Türkeş et al. (1996) revealed significantly decreased diurnal temperature ranges at most stations of Turkey in all seasons, except partly in autumn. Tayanç and Toros (1997) in their study over four urban stations and their neighboring rural sites for the 1951–1990 period revealed that there is a shift toward the warmer side in the frequency distributions of daily minimum and 21.00-h temperature difference series. Karaca and Tayanç (1998) stated in their study over 54 stations of Turkey that there is a statistically significant temperature increase in urban temperatures. Türkeş et al. (2002) analyzed the updated temperature series of the 70 stations in Turkey for the period 1929–1999 and found increasing trends for the annual, winter, and spring mean temperatures particularly over the southern regions of Turkey and decreasing trends for summer and, particularly, autumn mean temperatures over the continental inner and northern regions. Türkeş and Sümer (2004) concluded that significant trends in the daytime and particularly in the nighttime temperatures and the ranges of the maximum and minimum temperatures are a clear indication of ongoing changes over the long-term climatic variability of Turkey. In a city-specific study (Ankara), Çiçek (2005) found a mean temperature difference of 2.01°C between the urban and rural parts of the city while Yılmaz et al. (2008) found a 1.7°C temperature difference between urban and rural in another Turkish city Erzurum.

During urban development, the land surface is changed from undisturbed soils with natural vegetative cover to disturbed soils, managed landscapes, and built materials. The altered landscape, without adequate storm water controls, modifies the hydrologic cycle by reducing infiltration rates and increasing runoff peak discharges and volumes (Leopold, 1968). Observed urbanization impacts on hydrologic response include increased rates of water, sediment, and associated pollutant delivery (Booth, 1990; Booth and Jackson, 1997) and heating of receiving waters (Galli, 1991). From a broader urban hydrology perspective, increased imperviousness in urban areas is known to influence spatial and temporal distribution of land-atmosphere fluxes of water and heat, the partition of heat fluxes between latent and sensible, and carbon cycling (Milesi et al., 2003; Dow and DeWalle, 2000; Grimmond and Oke, 1999). These observed effects are expected to spread and intensify as the amount of impervious surface in the conterminous United States rapidly expands beyond the 2004 estimate of 112,610 km^2 (Elvidge et al., 2004).

TIA is used as an indicator of environmental quality (Arnold and Gibbons, 1996) and is also referenced in the literature as a surrogate measure of urbanization to correlate with receiving water quality and ecological health (Snyder et al., 2005; Schueler, 1994; Klein, 1979). Using TIA in urban hydrologic modeling applications, however, may result in overestimation of runoff volumes and rates (Alley and Veenhuis, 1983). Runoff originating from EIA and NEIA is exposed to different hydrologic processes along their respective flow paths. Therefore, their contribution to the hydrograph at the watershed outlet may be different. Recently, because of its direct effect on storm water runoff, reducing EIA has been identified as a key best management practice to control storm water runoff (Wright and Heaney, 2001). Although EIA is known to have a higher correlation with runoff than TIA, most methods estimating the impervious area for watershed modeling determine TIA because direct measurement of EIA is difficult (Booth and Jackson, 1997). Common methods to estimate TIA for small urban watershed modeling applications include direct measurement by field survey and visual inspection of aerial photos. For large watersheds, common TIA estimation methods include: analysis of rainfall-runoff data, rainfall-runoff simulations, assigning TIA values to land use type (Kauffman et al., 2006), and using equations correlating TIA to population (Heaney et al., 1977; Stankowski, 1972) or other watershed characteristics (e.g., curb length density). These methods have been extensively applied to storm water modeling projects, but field surveys and inspection of aerial photos are time consuming and the other methods provide a coarse estimate of bulk imperviousness in a catchment (locations of impervious surface are not defined). One solution to provide fine-scale coverage for large areas is to perform image processing operations on digitized high-resolution aerial photographs (Fankhauser, 1999). Access to satellite data in the 1970s promoted the use of satellite imagery to classify impervious surfaces for urban hydrologic modeling (Ragan and Jackson, 1975). Numerous methods have since been introduced to process satellite imagery to estimate percent impervious surfaces for hydrologic modeling, resources management, ecosystem assessment, and urban planning (Deguchi and Sugio, 1994; Ridd, 1995). The earliest methods used relatively coarse resolution, yet widely available, satellite data (for example, 30m resolution Landsat). Imperviousness was estimated using a variety of approaches, but in general they relied on relationships between impervious surfaces and spectral derivatives (for example, tasseled cap greenness) (Bauer et al., 2002). Using these relationships, methods to estimate impervious surfaces were introduced, including multiple regression (Forster, 1980), artificial neural networks (Flanagan and Civco, 2001), and regression tree models (Yang et al., 2003).

The drawbacks of using coarse resolution imagery not only include classification confusion caused by pixels with mixtures of surface types, but also the lack of precise location of impervious surfaces. Accuracy has been improved by incorporating ancillary spatial data (for example, road centerlines, parcel polygons, socioeconomic) (Harris and Ventura, 1995; Ji and Jensen, 1999; Yang et al., 2003), but even sub pixel estimation approaches do not define precise impervious surface locations needed for urban hydrologic modeling. Fine-scale imagery is one solution to provide accurate detection and location of impervious surfaces (Goetz et al., 2003; Sawaya et al., 2003; Correa and Adhityawarma, 2004). Moreover, for direct detection techniques, spatial resolution has been shown to provide a better operator for impervious surface detection than spectral resolution (Cablk and Minor, 2003). EIA estimation requires more effort than TIA estimation; consequently, fewer EIA estimation techniques have been introduced. In fact, a literature search uncovered no automated methods that define spatially explicit coverages of EIA, although use of the percent impervious surface along a flow path has been related to stream health (Snyder et al., 2005). Sutherland (1995) described four EIA estimation approaches that require substantial manual effort or simplifying assumptions: (1) field surveys coupled with analysis of aerial photos, topographic data, and collection system maps (Miller, 1978); (2) arbitrarily assigning a value by land use type, population, or other surrogate parameter;(3) derivation based on analysis of rainfall-runoff data (Boyd et al., 1993; 1994); and (4) application of derived empirical equations (Alley and Veenhuis, 1983). The first method is limited to small watersheds because it requires substantial time and effort. The other three methods may be applied rapidly, but are usually inaccurate when applied outside of the derivation areas and they do not provide the spatial distribution of the impervious surfaces necessary to accurately predict stormwater runoff and precisely identify locations of stormwater controls. These drawbacks limit the methods to small urban catchments or coarse planning level assessment in large urban catchments.

Lee and Heaney (2003) presented a systematic process to estimate EIA within a tiered framework. The first level of the framework applied literature data. The next several levels included incrementally more complex (and/or time consuming) methods culminating with the use of field surveys. This tiered framework can provide important details for modeling and analysis applications, but is limited to small areas because of the time and effort required.

In physical sciences entropy relates macroscopic and microscopic aspects of nature and determines the behavior of macroscopic systems in equilibrium (or close to equilibrium). Entropy is not an observable; that means there does not exist an operator with the property that its expectation value in some state would be its entropy (Wehri, 1978). It is, rather, a function of a state. For example, if the state is described by the density matrix, its entropy is given by the van Neumann formula. Entropy is viewed in three different but related contexts and is hence typified by three forms as discussed in what follows.

There is, however, a lack of consensus as to the meaningfulness of entropy. The implication that entropy is a measure of the meaningfulness of a particular decomposition of a set of values is erroneous. Shannon and Weaver (1949) assumed that all communication errors carried an equal penalty. Marschak (1971) argues that this assumption may be the cause of misunderstandings about the meaning of the entropy measure. Given the equal penalty assumption, entropy does measure the information value of a system. However, a measure based on the probability distribution cannot determine the information value of a system when unequal penalties are assigned to the various possible errors. According to Marschak, the value of an information system, or informativeness, can decrease even with an increase in information transmitted. Entropy does not measure all of the relevant aspects of information even in the sense of uncertainty as to the message transmitted. This weakens the argument for using entropy as a measure of information loss resulting from aggregation of records.

Fama (1965) and Theil and Leehders (1965), amongst others, used entropy to evaluate the predictive ability of forecasters, using information inaccuracy defined as S qi log.qi=pi ., where qi is the fraction of values for which outcome i occurs and pi is the fraction for which outcome i is forecast. Information inaccuracy equals the reduction in uncertainty from knowing the outcome as opposed to the forecast. In this case, all forecast errors may not carry an equal penalty as in the case of security prices. Then, the measure fails to distinguish between inaccuracy resulting from an overly optimistic forecast and that from an overly pessimistic forecast.

A similar criticism applies to the use of entropy as a measure of decentralization in an organization (Murphy and Hasenjaeger, 1973). However, interpretation of entropy in the distribution of tasks and decisions within an organization as a measure of disorder or decentralization in the decision making process is of great value. The decomposition property of the entropy measure permits insights into the nature of entropy decentralization in a hierarchical system. This decision making ability may be attributed to entropy within the informal decision units, entropy within a supremal unit or entropy between and at the various decision making levels themselves.

CHAPTER 3

THE STUDY AREA AND DATA COLLECTION

River Ganga plays an important spiritual and religious role for many people in India. Since ancient times Ganga River has played a significant role in the Indian civilization (Priyadarshi, 2009). Around 2,000,000 people take holy bath in Ganga River on a daily basis. Currently half a billion people are living beside the banks of the river and an estimation of over one billion people by year 2030 (Jaiswal, 2011). Uttar Pradesh state alone contributes upto 50 % of the pollution load to the river (Jaiswal, 2011). Though water quality and quantity in the river changes depending on the season. The river is severely polluted in cities like Varanasi, Rishikesh, Kanpur, Allahabad, Patna and Calcutta and the pollution in these cities is different from each other (Gosselin, 2012).

Varanasi is situated in Uttar Pradesh, north part of India (Figure 3.1). The city is located on the bank of the River Ganga. Varanasi city is also called as the city of temples. Most renowned temples are Kashi Vishwanath Temple, Annapurna Temple, Sankatha Temple, Sankatmochan Temple etc. Varanasi is also called as the "Cultural Capital of India". The city is connected with spiritualism, Sanskrit, yoga and many kinds of dance and music. Sri Tulsi Das, famous poet who wrote the Rama Charit Manas and Internationally famous Sitar maestro Mr. Ustad Bismillah Khan heils from Varanasi (National Informatic Center, 2011(a)). Throughout the year many kinds of festivals are celebrated in Varanasi, almost every month atleast one festival is celebrated. Also there are many kinds of religious fairs (Mela`s) going in Varanasi throughout year and the pollution load during that that will higher (Ruback, 2008).

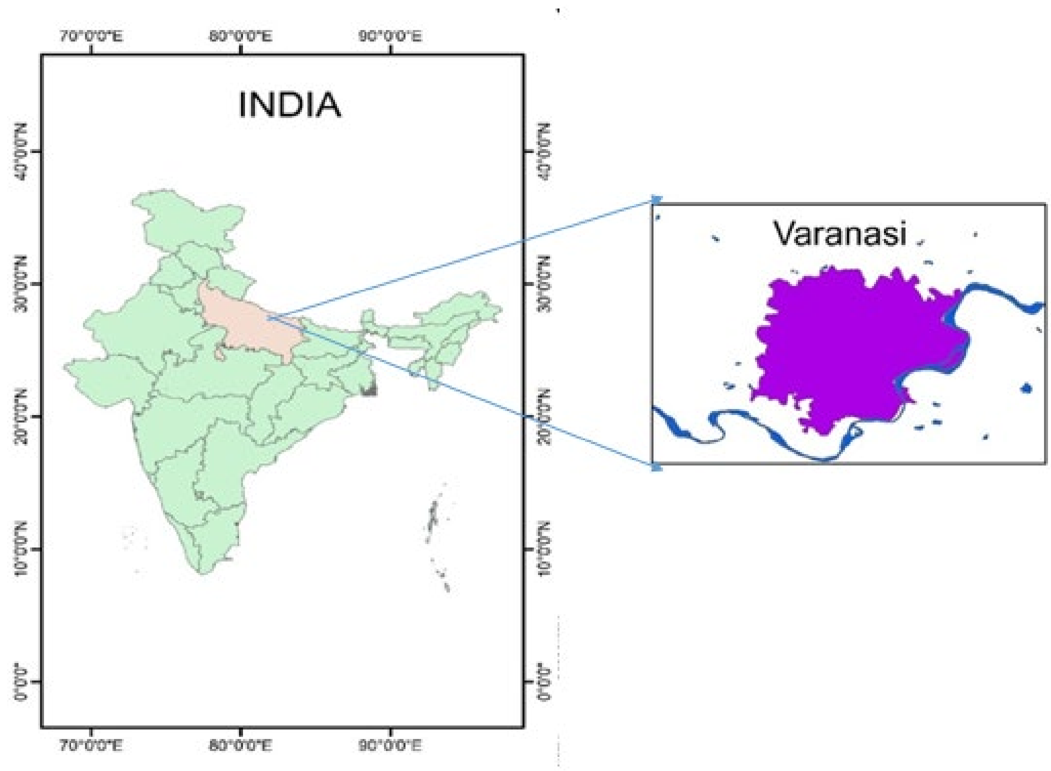


Figure 3.1: The study area

The city is still in a process of development. In Varanasi the water quality is very poor and it is no longer suitable for holy dips. The city lies between the two tributaries of Ganga namely Varuna and Assi which are vast sources of sewage (Tripathi, 1991). According to the World Health Organization the Coli-form bacteria level is 3000 times higher than the standard permissible limit on the ghats in Varanasi. The presence of Mercury in Ganga River at Varanasi as 0.00023 ppm is observed which is barely below the alarming level (Priyadarshi, 2009).

Government of India started a project to control the pollution load to the Ganga River in 1986 called "Ganga Action Plan" (GAP). The aim of the project was to divert and treat the sewage that goes into Ganga River and protect the river from pollution sources. The project was carried out in two phases, GAP-1 from 1986 till 1991 and GAP-II from 1991 and continues till now. According to the government statistics, 35 % of river pollution has been tackled in GAP-I and 30 % in GAP-II (Comptroller and Auditor General of India, 2011). Several thousand millions of rupees has been spent in this project but the result is still reported as failure, leading to increasing concern over pollution in the river Looking into the gravity of the situation, but without adequate consideration of the factors leading to the failures, on 2nd June 2010 Indian Prime Minister Manmohan Singh announced "Mission Clean Ganga 2020" project aims to stop raw municipal sewage and industrial wastes enter Ganga (The Hindu, 2011).

3.1 Geography

Varanasi is located on the banks of the river Ganges in the Indo-Gangetic Plain, a densely populated alluvial plain. The urban agglomeration of Varanasi stretches between 82°56'E - 83°03'E and 25°14'N - 25°23'5'N and covers an area of approximately 150 km² (Kumar et al. 2010) (Table 3.1). It is surrounded by River Assi (Assi Nala) at the upstream of Varanasi and River Varuna at the downstream. (Figure 3.2).

Table 3.1: Varanasi Municipal Corporation and urban agglomeration area

Spatial Unit	Area (Sq. Km)
Varanasi Municipal Corporation (VMC)	82.1
Varanasi Urban Agglomeration (VUA)	112.26

Source: Master Plan for Varanasi 2031, Varanasi Development Authority

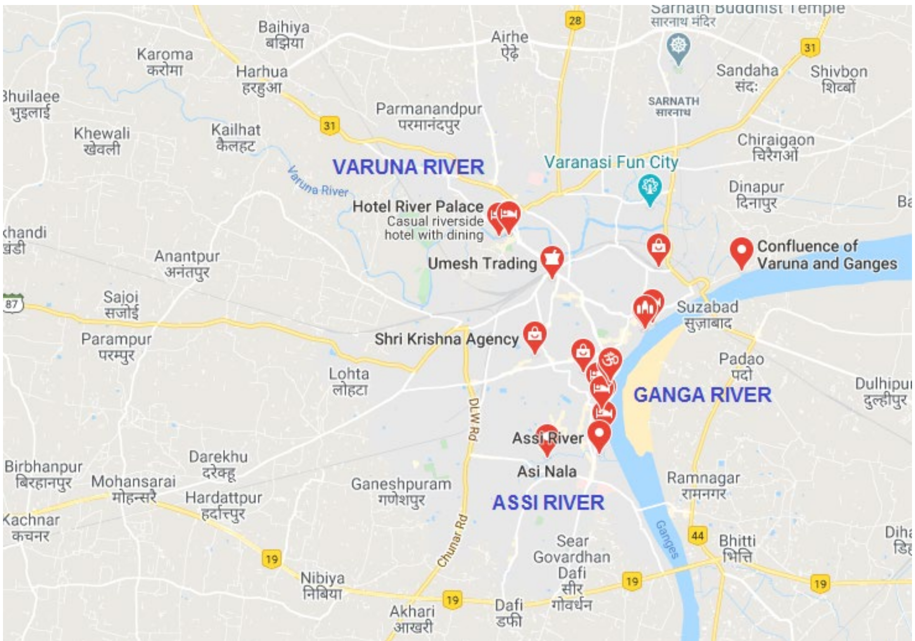


Figure 3.2: River Ganga, River Varuna and River Assi at Varanasi

District of Varanasi is situated in south-west section of Uttar Pradesh and it extends from longitude 82°15 to 83°30' East and latitude 24°35' to 25°30' North. On the north side Varanasi is bordered by Jaunpur and Ghazipur districts, Mirzapur district on south side and Bhadohi district on the western border. The total area of the district is 1535 Sq. Km. Varanasi district in further sub divided into two tehsils viz. Varanasi Sadar and Pindra. The district is also divided in to eight developmental blocks viz. Kashi Vidyapeeth, Badagoan, Pindra, Chiraigoan, Chlolapur, Harahua, Prajiline and Sevapuri. The district consists of 1327 villages and 11 towns. (District statistical Magazine , 2007)

The district of Varanasi forms part of the central plain of Ganga physiographically the district can be divided into two physical regions, namely the northern alluvial plain and the southern plateau area. The northern alluvial plain, including the rivers Gomti and Varuna, is drained by the ganga and its tributaries. The southern plateau is deeply dissected by the Karamnasa river and its effluents, consisting of extensive hills and mesas of Vindhyan sandstone and shales.

3.2 Demographics

In 2011 the metropolitan area of Varanasi counted 1,599,260 inhabitants whilst the urban agglomeration Varanasi counted 3,682,194 inhabitants (Census of India 2011).The total population of Varanasi district is 31.3867 lakhs having urban population 12.6057 lakhs and rural population about 18.7810 lakhs as per the census 2001. The district has population density of 1995 person per sq. km. Total villages in Varanasi district is 1327. **(**District Statistical Magazine, 2007**).** Today, Varanasi has grown very fast reaching a population of over 3.68 million, which accounts 0.3 % of the total Indian population and 1% of the population of Uttar Pradesh (Census of India, 2011). The demographic profile of the city shows a decadal growth of 25.51% from 1991 to 2001 and 17.32 % from 2001 to 2011 (Table 3,2). Due to urbanization, Varanasi is experiencing a fast growing population with ca. 1.6 million people living in urban agglomeration (Table 3.2; Census of India, 2011). Average population density increases from 2045 persons/km^2 in 2001 to 2399 persons/km^2 in 2011 (Table 3.2; Census India, 2011). Furthermore, International Traceability System Ltd.

(2011) publishes the district's profile, revealing total geographical area of Varanasi is ca. 1526 km^2 with about 1139 km^2 (75%) agriculture area located in the rural.

Table 3.2: Demographic development of Varanasi (Census of India, 2011)

Item	2001	2011
Total Population	3 138 671	3 682 194
Decadal Growth	25.21 %	17.32 %
Rural	1 878 100 (59.84%)	2 083 017 (56.57%)
Urban	1 260 571 (40.16%)	1 599 177 (43.43%)
Average density	2.045 / km^2	2.399 / km^2

The city has three main natural drainages: Assi in the south, Varuna in the north and Ganga in the east. Agricultural activities were widespread along these rivers in former times. Today, most agricultural areas remain in the outskirts of the city, only smallholder farming are scattered in urban area. However, cultivation areas are expected to decrease, due to continuous increase of build-up areas in order to fulfil the growing demand for living space and administrative facilities. In 1991, according to the City Development Plan (CDP; JNNURM, 2006), about 20% of the urban area is under cultivation located in fringe area. However, it is supposed to decrease to about 9.4% by 2011, whereas the urban area is supposed to expand by 23.7% (JNNURM, 2006). For this reason, agricultural area within the city boundary will probably soon be replaced.

3.3 Climate

Varanasi is located in the Cancer Tropic. The district of Varanasi falls into the subtropical region and its climate is classified as tropical to subtropical, with hot summer and severe winter. The minimum temperature reported during winter is 7 ºC (Ministry of Earth Science, 2011). During the summer the maximum temperature is recorded at 45 ºC and the minimum is reported at 22.6 ºC over rainy season. The mean relative humidity is 55.75 percent per month.

Between July and September, the district receives most of the annual rainfall by south-west monsoon season. The average normal town rainfall is 1113.4 mm. (District Statistical Magazine, 2007). The city has a tropical climate with a pronounced monsoon season effect. In the months of June to September, 67 % of annual precipitation occurs. The research area appears as a flat alluvial plain with an average height of 76 m above sea level, and a low relief.

3.4 Geology

Geology of northern India is subjected to the Himalayan orogeny. Due to continental collision between the Eurasian and the Indian plate, the Himalaya arise and a basin filled with alluvial sediments was formed (Figure3.3). Here, the largest alluvial basin system, the Indo-Gangetic Plains (IGP), occupies the northern part of India marking the merge of Indian subcontinent with the continent. The IGP is divided into four areas: Gangetic Plains, Punjab-Rajasthan Alluvial Plains, Bramhaputra Plain and Bengal Plain (Shukla and Raju, 2008). The study area is located in the eastern part of the Gangetic Plain located in the center of the Indo-Gangetic Plain (Sharma et al, 2007). Geomorphologically, being situated in a plain, Varanasi terrain is mostly even with average altitude of 76 m NN (Raju et al., 2011). The study area underground consists of thick quaternary sediments which have been classified into Older Alluvium and Newer Alluvium. Older Alluvium represented by Varanasi Alluvium from Middle to Upper Pleistocene contains polycyclic sequences of oxidized micaceous sand, silt and clay with nodular calcareous concretion, also known as Kankar, the formation of which is due to precipitation of calcium carbonate from groundwater (Raju et al., 2009; Raju et al., 2011). Newer Alluvium of Holocene (terrace alluvium) occurs adjacent to the river Ganga representing the channel and terrace sediments. The sediment comprises fine grey sand and alternate bands of grey sand, silt and clay, respectively (Geological Survey of India, 2002; Shukla and Raju, 2008; Raju et al., 2011). Characteristics of both Older and Newer Alluvium are its loose and unconsolidated nature. Shukla and Raju (2008) revealed stratigraphic information from three borehole, which shows that lithology of the study area consists of three different sediment packages: (i) medium to coarse sand derived from the subcontinent, (ii) fine to medium sand originating from Himalaya and(iii) interlayered clay, silt and sand. Generally, these sediments show a coarsening trend in upward direction.

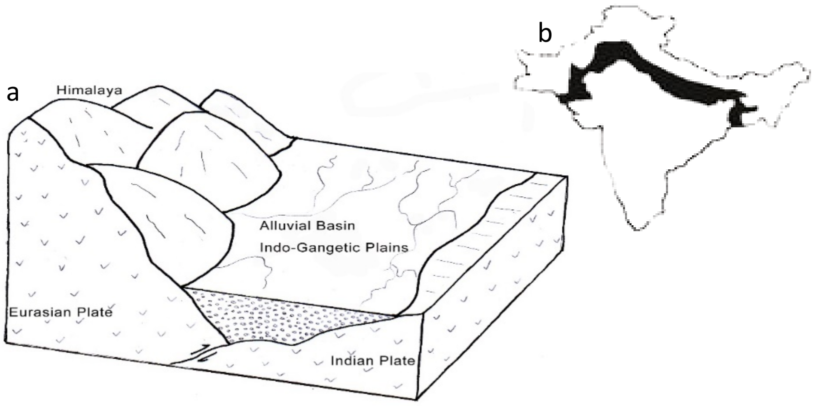


Figure 3.3: Alluvial basin formed by continental collision (a; adapted from Aller et al., 1987) and the position of the Indo-Gangetic Plains (b; adapted from Rice-Wheat Consortium, 2011)

The Geological profile extrapolated from borehole data are shown in in Figures 3.4 and 3.5. A vertical cross section of the underground was derived from drilling information of a borehole at Banaras Hindu University campus. The layers 1, 2 and 3 are fine sands with various clay and silt fractions. They comprise the shallow unconfined aquifers which can be characterized as individual groundwater lenses with lateral dimensions of 10 – 150 m capped by thin impermeable clay layers. Confined deeper aquifers can be found in layer 4 made up of moderately well sorted coarse to medium grained sands. Grain size is decreasing in the following layer 5 which creates the lower aquifer limit. Finally with layer 6 a clayey fine sand layer was found at the bottom of the drilling.

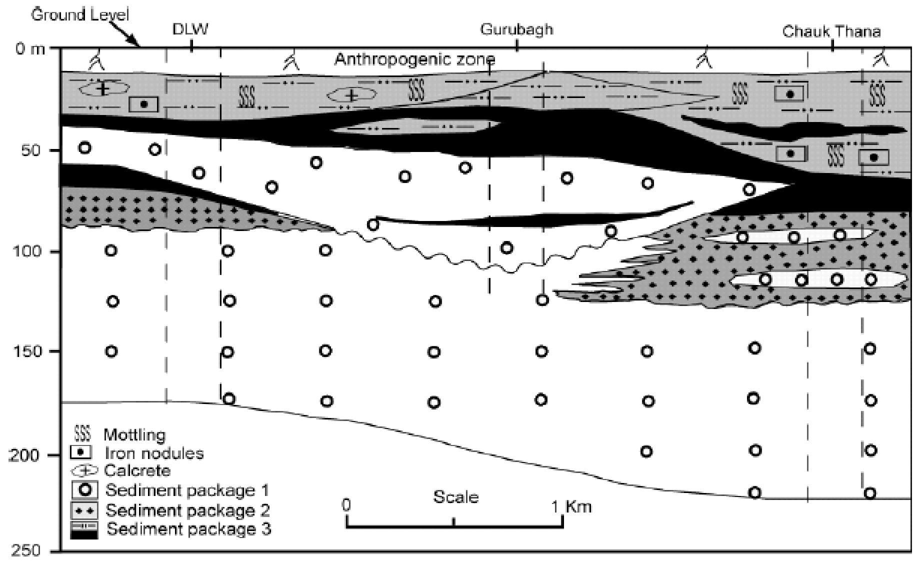


Figure 3.4: Geological profile extrapolated from borehole data (Shukla and Raju, 2008)

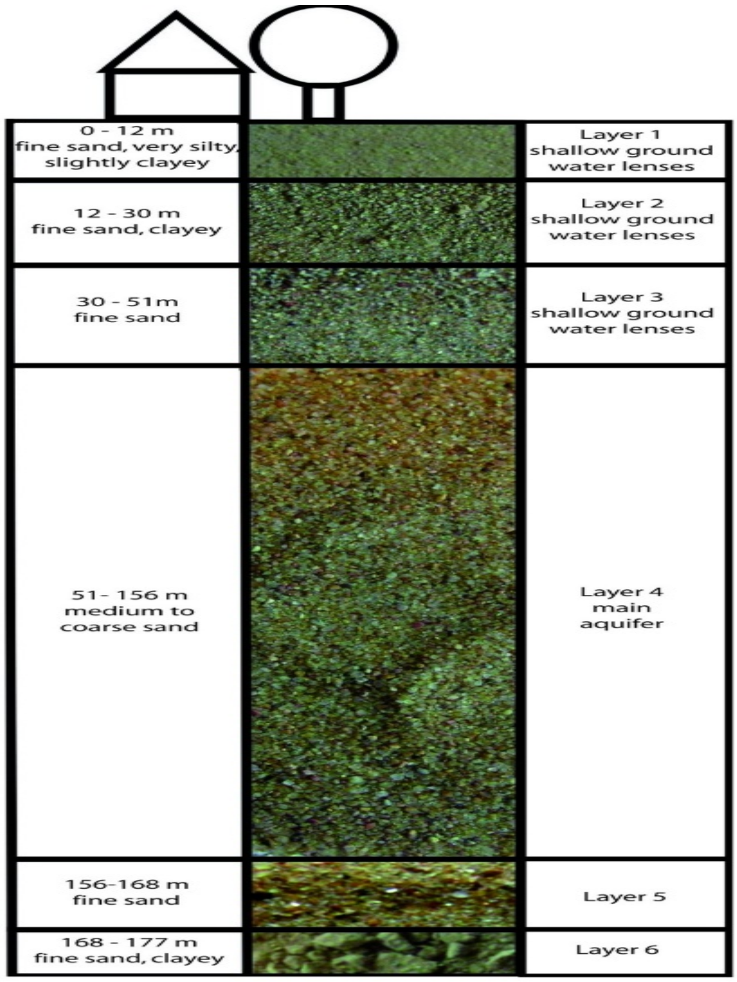


Figure 3.5: Lithological section derived from ground samples (Blomair, 2011)

3.5 Hydrogeology and Groundwater Resources

With regard to the hydrogeology of Uttar Predesh, five hydrogeological zones can be divided as follows: Bhabar, Tarai, central Ganga Plain, marginal alluvial plains and southern peninsula zone (Central Groundwater Board, 2011). The study area has access to one of the richest aquifer in the world (Vrindhanath, 2011) due to its location in the central Ganga Plain. Figure 3.6 depicts a hydrological map of Varanasi and its environs. Varanasi with the Ganga River as its principle drainage on the east side of the city (Keshari, 1999), has two tributaries: Varuna in the north and Assi inthe south. Both tributaries discharge into Ganga River from the west. Due to near surface alluvial deposits, potential aquifers in various depths are available throughout the plain. Extensive exploratory studies identified four aquifer groups within 700 m below ground level (bgl). Their thickness varies from few meters up to 300 m (Karanth, 1987, quoted in Vrindhanath, 2011) and are laterally continuous (Shukla and Raju, 2009). Alternated layers of sand, silt and clay develop silty sand lensoid, which is capped by thin permeable muddy kankar in the near surface result ina multi-tiered aquifer system (Raju et al., 2011; Raju et al., 2009; Shukla and Raju, 2008; Vrindhanath, 2001 and Keshari, 1999). However, aquifer potentiality increases with its degree of assortment (Raju et al., 2001; Shukla and Raju, 2008). Various publications suggest the depth of shallow aquifers to be between 20-60 m and are under unconfined conditions yielding up to 40 L/s (Vrindhanath, 2011; Keshari, 1999). The depths to water level were suggested to vary between 5-20 m bgl (Keshari, 1999). The deeper aquifers with depth more than 60 m bgl show confined to semi-confined condition (Shukla and Raju, 2008; Keshari, 1999) and have great groundwater potential, which can yield up to 60 L/s. The groundwater of the study area has its source of recharge 80% from the annual rainfall from southwest monsoon during July and August (Raju et al., 2009). Shukla and Raju (2008) state that groundwater slope with an average hydraulic gradient of 0.00035 from north to south, whereas deeper water levels are found in the western part of town as compared to the eastern part.

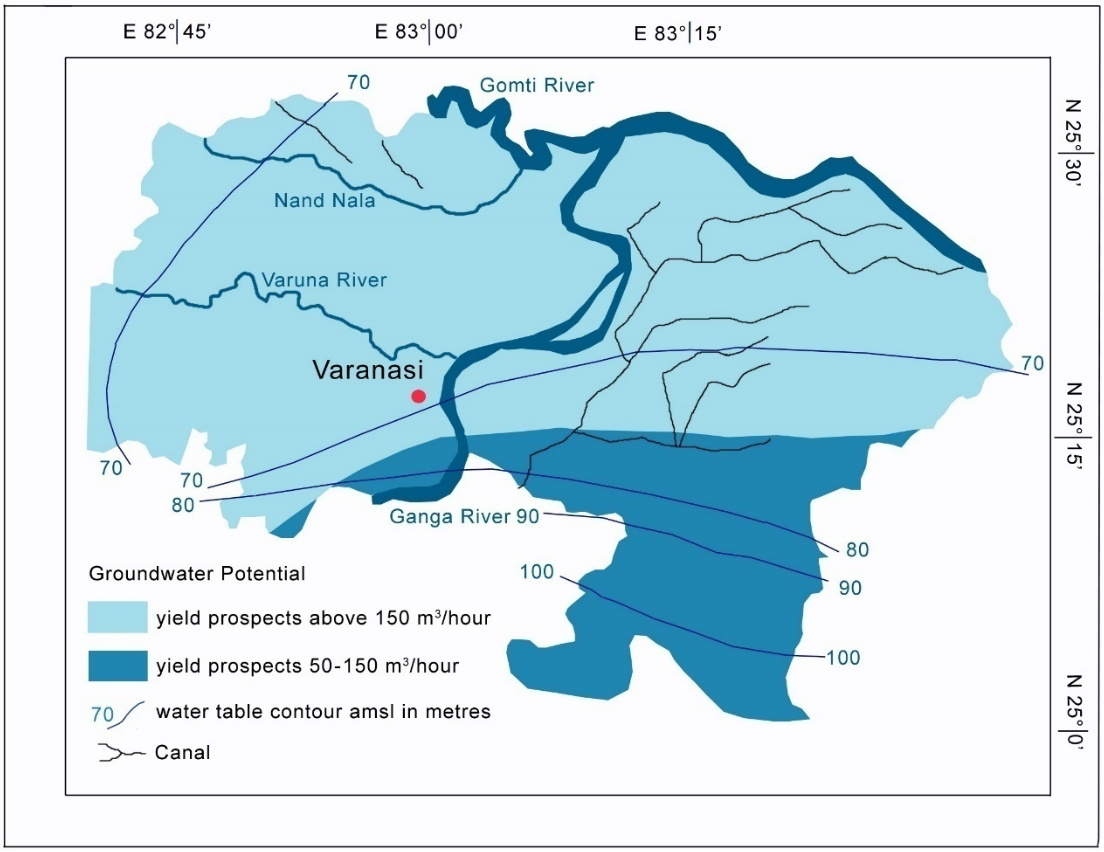


Figure 3.6: Hydrological map of Varanasi (Source: Geological Survey of India, 2009)

3.6 Satellite Data

To measure the Geo-spatial satellite geotiff file of Level 1 and 2 data from USGS website { https://earthexplorer.usgs.gov} were collected. To collect Data, the latitude and longitude of the study area is defined and corresponding path and row of a satellite is obtained. The United3States2Geological & Survey(USGS) provides on-demand generation of Landsat@8 Thermal Infrared Sensor (OLI/TIRS) Surface Reflectance data through Earth Explorer Surface Reflectance items give a check of the surface spectral reflectance as it would be measurable at ground level without barometric scattering. The Surface 3Reflectance data are created at the Earth & Resources Observation and Scienc2Center at a 30-meter&spatial resolution. The EROS Science Processing Architecture on-request interface changes satellite images for climatic impacts to make Level-2 data items. Landsat&8 Surface Reflectance data are created from the Landsat Surface Reflectance Code (LaSRC). The utilization of coastal aerosol band to perform aerosol reversal tests is used by LaSRC, it additionally uses auxiliary climate data from MODIS and uses an exceptional radiative transfer model.

Once a satellite data is identified, it can be downloaded with through proper login account. Processed scenes are requested and downloaded as a compressed document at a later date when it was processed to Level 2, which fundamentally implies the raw data is acclimated to a standard with random errors arising from problems with noise, transmission and digitization remedied. The rectifications to the common errors in the computerised value are known as3radiometric4corrections. Multiple processed data are simplest to download with the "Bulk Data Application" accessible through USGS.

The SRTM Data used for the analysis shown in Figure 3.5.

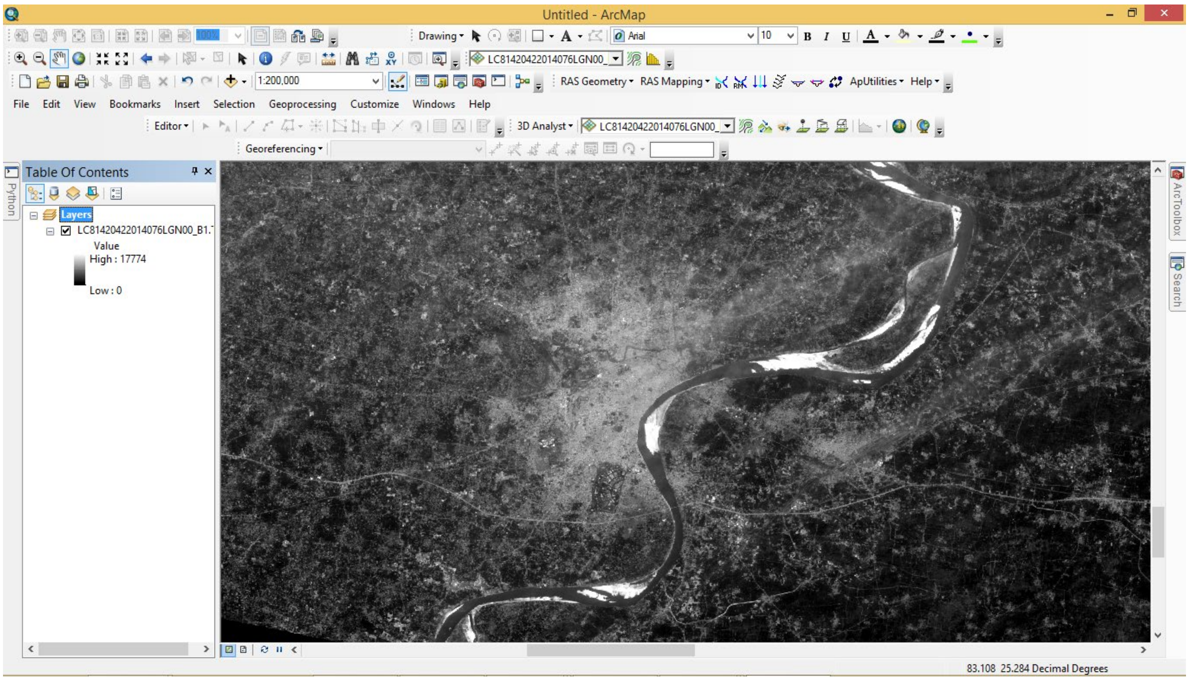
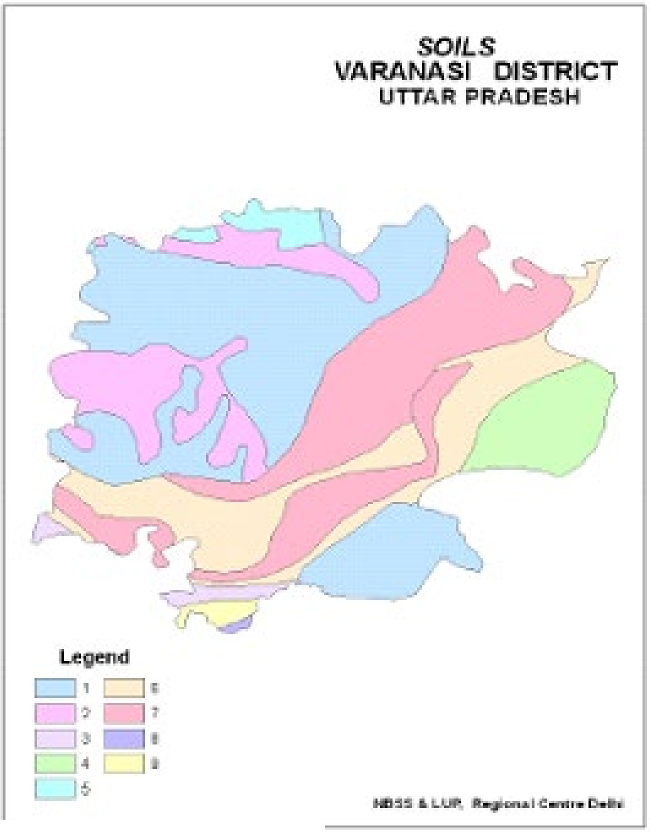


Figure 3.5: Satellite data of Varanasi neing used in Arc-GIS

3.7 Soil information

The Soil map of the Varanasi City is given in Figure 3.6. The area is having alluvial plain, flood plain and plateau region. Silt and silty loam is prominent in alluvial plain whereas sandy and loamy soil is prominent in flood plain.



Alluvial plain (0-1% slope)

1. Deep, loamy soils and slightly eroded.
2. Deep, fine soils moderately saline and sodic associated with loamy soils, slightly eroded.
3. Deep, fine soils and slightly eroded associated with loamy soils slightly saline and moderately sodic.
4. Deep, silty soils with moderately salinity and sodicity associated with loamy soils with moderate salinity and sodicity and water logging.
5. Deep, silty soils and slightly eroded associated with loamy soils slightly saline and slightly sodic.

Active Flood Plain (1-3% slope)

6. Deep, sandy soils with moderate flooding associated with stratified loamy soils and slight flooding.
7. Deep, stratified loamy soils, with severe flooding associated with loamy soils with moderate flooding.

Plateau (Sandstone on 1-3% slope)

8. Deep, loamy soils and moderately eroded
9. Deep, loamy soils and moderately eroded associated with fine soils and moderately eroded

Figure 3.6: Soil map of Varanasi City

(Source: NBBS & LUP, Regional Centre Delhi)

3.8 Proposed Master Plans of Varanasi

The Master Plan of Varanasi City for the year 2031 has been prepared and is shown in Figure 3.7 and storm water drains in the existing system are shown in Table 3.3.

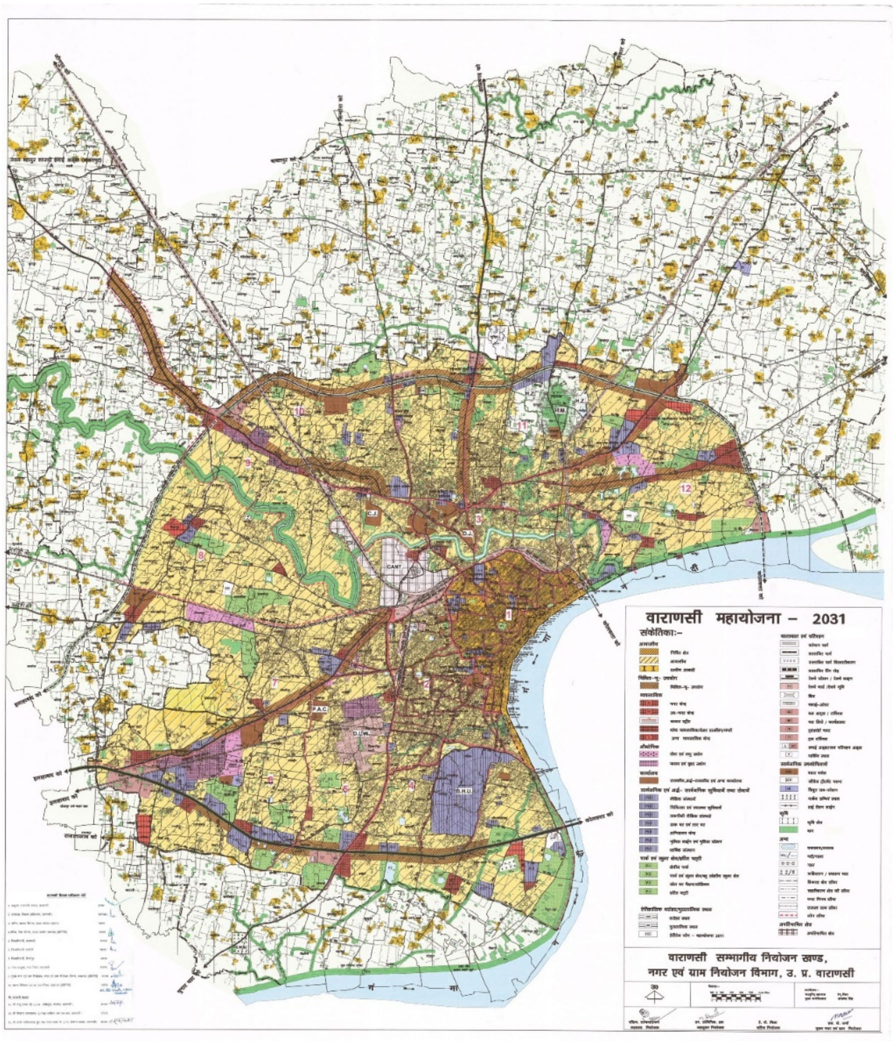


Figure 3.7: Master Plan of Varanasi City for the year 2031

Varanasi has a poor storm water drainage system. Storm water is drained off through a very old and in complete underground and kachcha open drainage system. The underground drainage network isonly 117 km long. Most of the drains have been connected to branch sewers, which leads to the mixing of sewage with storm water. This increases the load on the sewage pumps and the STPs, especially during the monsoons. Apart from this, some storm water drains also empty directly into river Ganga and river Varuna.

The open drains are unlined and contaminate the ground water owing to the porous nature of alluvium. These drains carry the grey water discharged from the settlements along their path and is also used as dumps for solid waste. Most of the old drains are named after the Ghats where they discharge like Ghora Ghat drain, Trilochan Ghat drain, Mansarovar Ghat drain, Harischandra Ghat drain, Shivala Ghat drain, BrahmaGhat drain, Jawala Sen Ghat drain, Mani Karnika Ghat drain, Rajghat drain, Ganesh Ghat drain,Naradghat drain, Telia Nala drain. These drains are known as Nawabi drains. Apart from this AssiNallah and Nakhi drain are two major drain discharge into river Ganga.

The Assi nallah acts as a major outlet for storm and wastewater in the region. The city's drains and nallahs are vulnerable to chocking due to the residents' uncontrolled disposal of solid waste. This leads to stagnant water puddles resulting in health hazards, unhygienic conditions and acting as breeding grounds for mosquitoes. Owing to the heavy siltation, quantity of grey water and industrial waste in the drains, the current drain network cannot be used for water harvesting.

Table 3.3: Storm drains in Varanasi

Sr. No.	Name of drain	Type
1	Phulwaria Nallah	Open channel
2	Sadar bazaar Nallah	Open channel
3	Drain of hotels	Open channel
4	Raja Bazar Nallah	Open channel
5	Teliabagh Nallah	Open channel
6	Nallah near Nakighat	Open channel
7	Konia bypass	Open channel
8	Central Jail Nallah	-
9	Orderly Bazar Nallah	-
10	Chamrautia Nallah	-
11	Nallah of Kajuri Colony	-
12	Banaras Nallah No. 5	-
13	Hukulganj Nallah	-
14	Nallah of Nai Basti	-
15	Narokhar Nallah	-

Source – Storm water DPR, Varanasi

CHAPTER 4

DELINEATION OF THEMATIC MAPS FOR VARANASI

In this Chapter, various thematic maps are developed using remote sensing and GIS techniques. The developed thematic maps would be utilised for assessment of for urban water availability, its uses for different purposes and development of future scenario for it sustainable management using integrated approach of urban.

4.1 Development of DEM and Slope map

The satellite data SRTM with 30 m resolution obtained from USGS website was used to develop contour map, digital elevation map, flow direction, flow accumulation and slope map. Figure 4.1 and 4.2 indicates the DEM and Slope map of the Varanasi city.

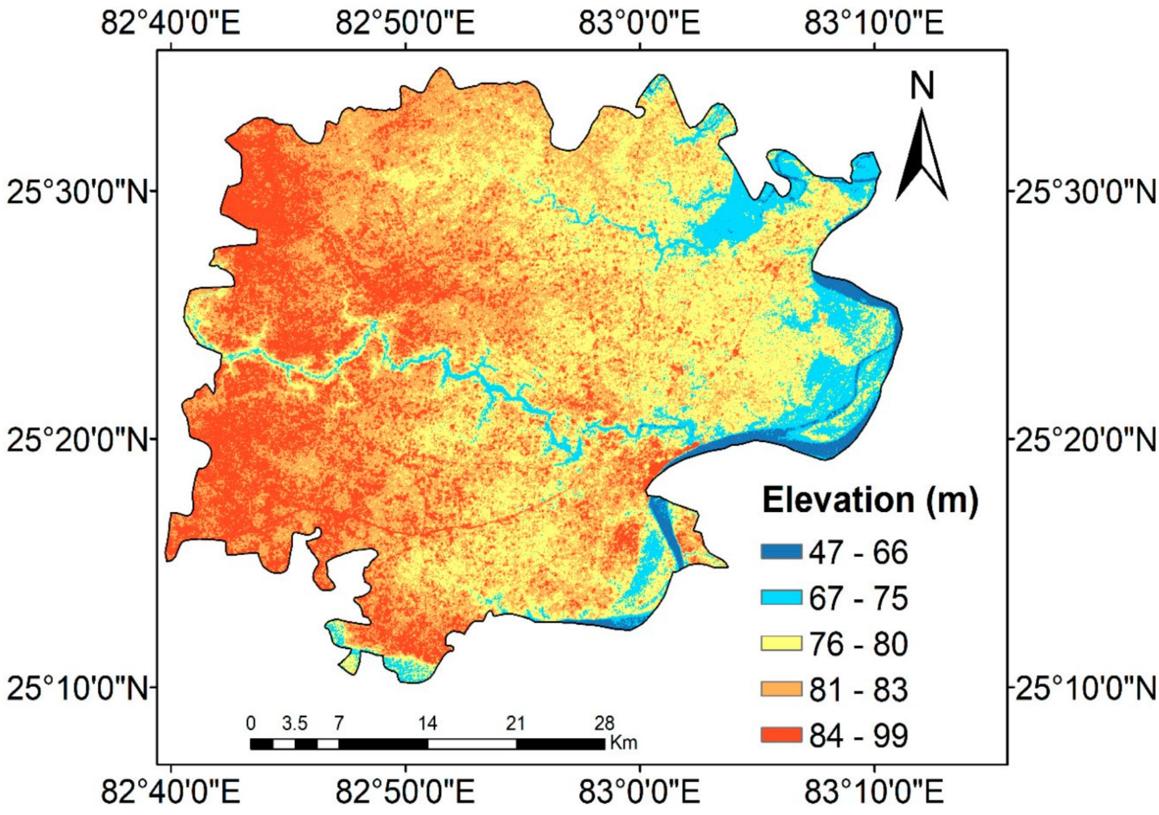


Figure 4.1: DEM of the Study area

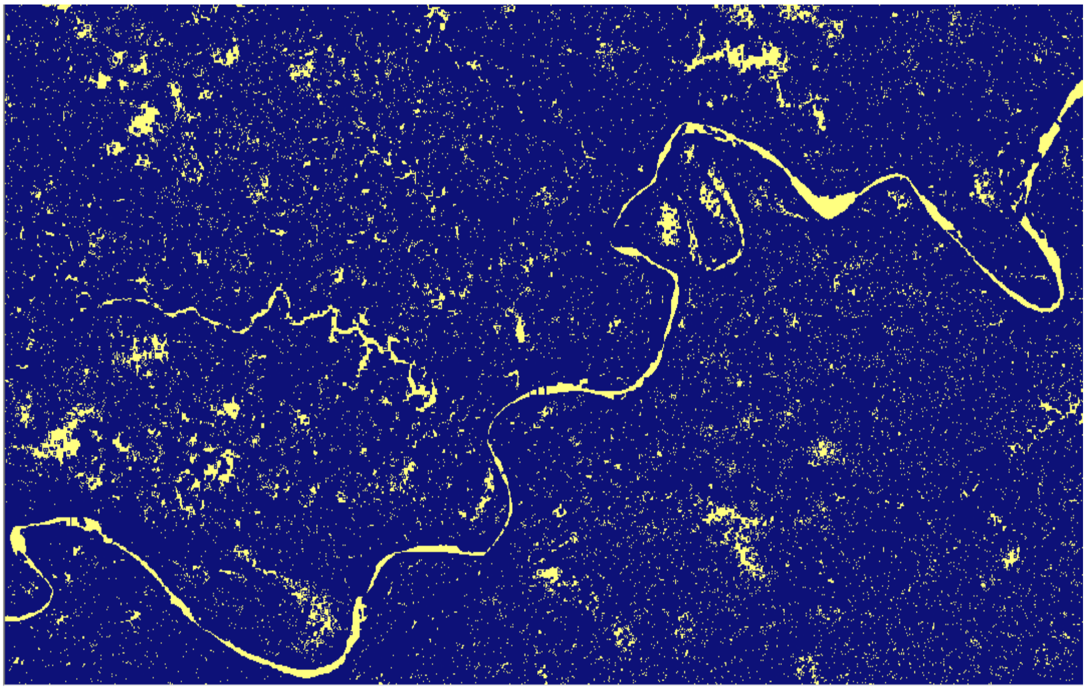
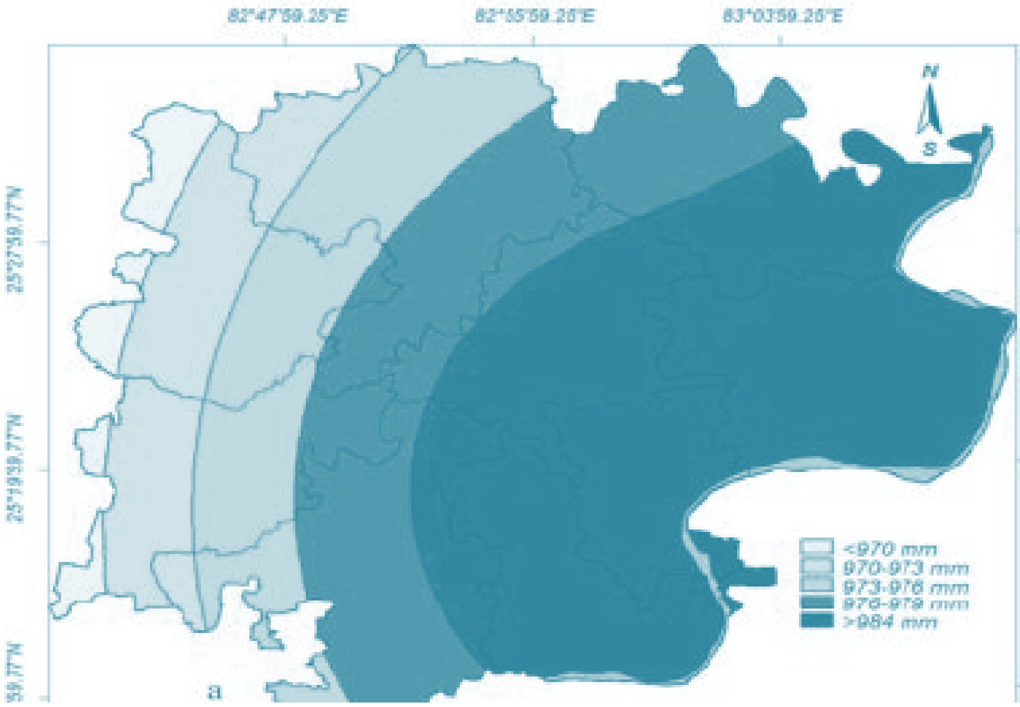


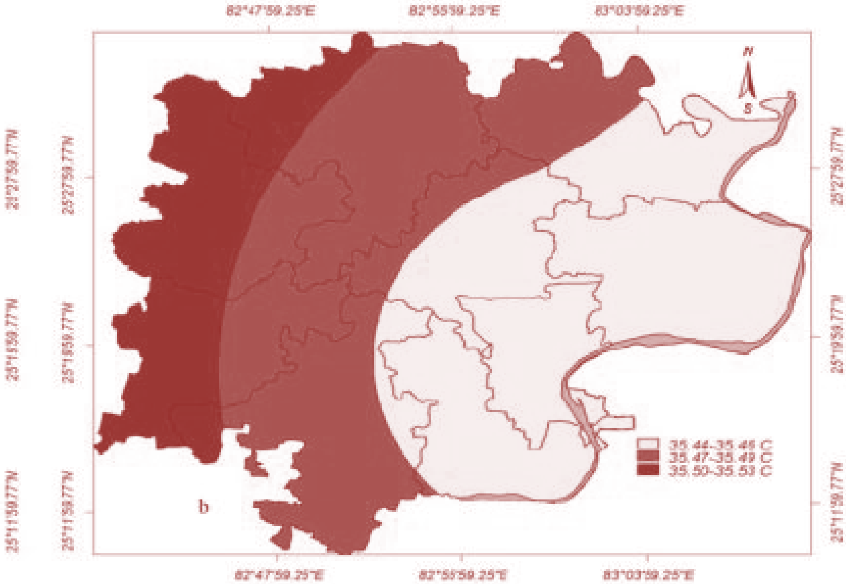
Figure 4.2: Slope map of the Study area

4.2 Rainfall and Temperature Isohyetes

The rainfall and temperature shows some variation at different locations and the Isohyetal maps of rainfall as well as temperature are shown in Figure 4.3.



(a) Rainfall



(b) Temperature

Figure 4.3: Rainfall and Temperature at Varanasi (Source: Rai et al., 2018)

4.3 Geological map

The Varanasi city is having very mild slope with some water bodies in the form of ponds at various locations. Figure 4.4 indicates the city, flood plain and terrace alluvium.

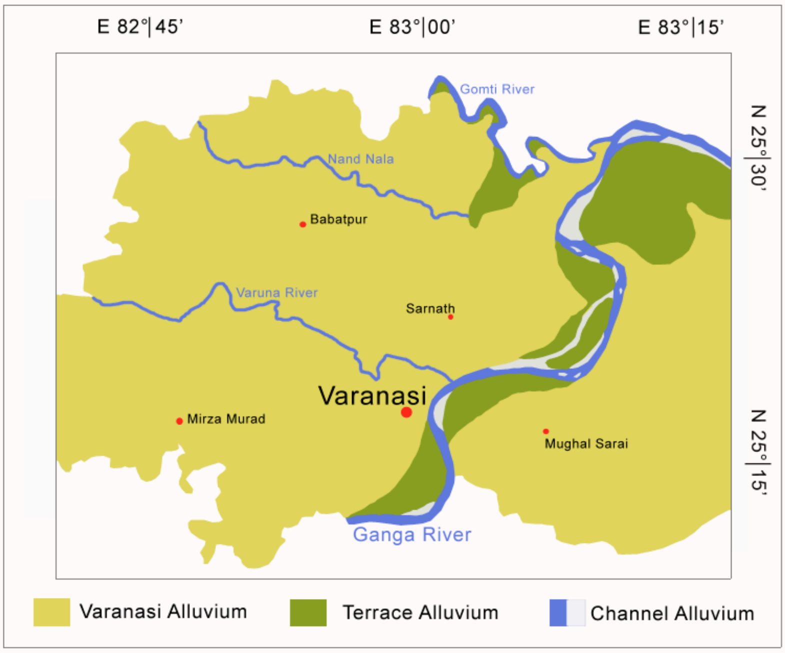
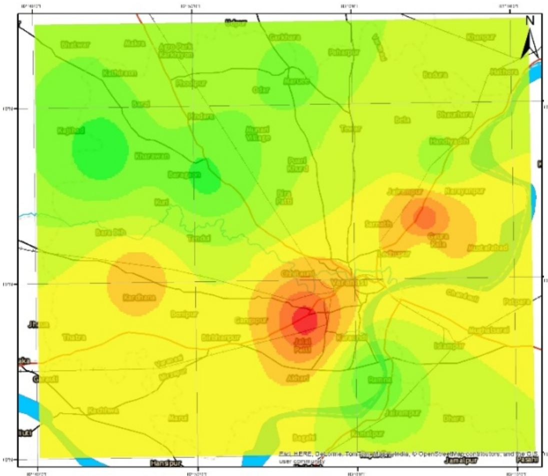


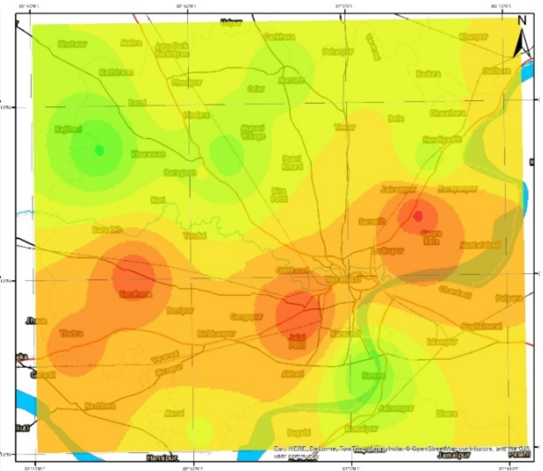
Figure 4.4: Geological map of Varanasi (adapted from Geological Survey of India, 2009)

4.4 Development of Groundwater maps using spatial interpolation techniques

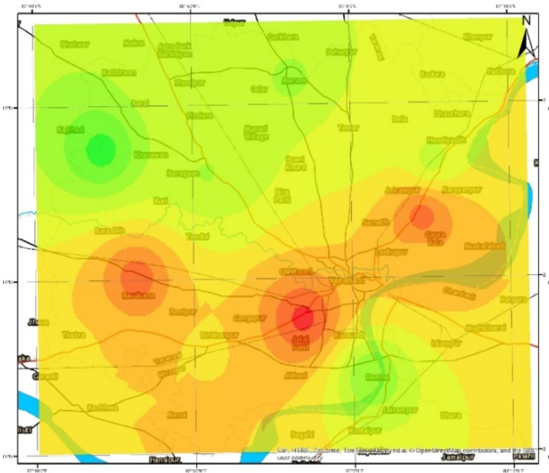
The ground water has been varying in Varanasi due to DEM and slope, rainfall and temperature patter, existing water bodies (wetlands), sewer line for waste water management, and storm water network, Open defecation, poor solid waste management and other anthropogenic activities. Figure 4.5 indicates the spatial interpolation of groundwater levels for the year 2005 to 2013.



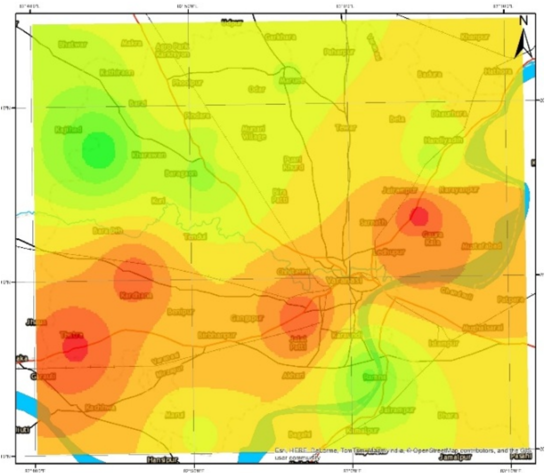
(a) Year 2005



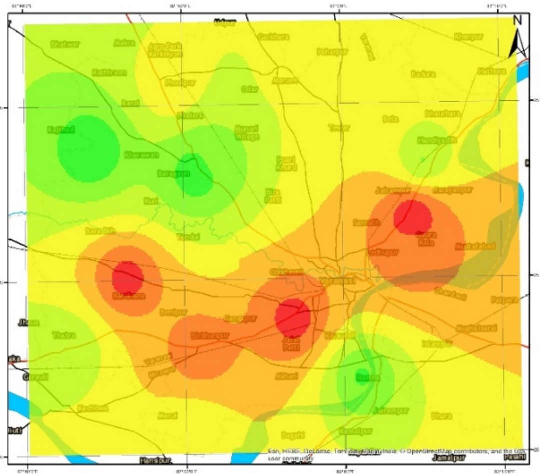
(b) Year 2006

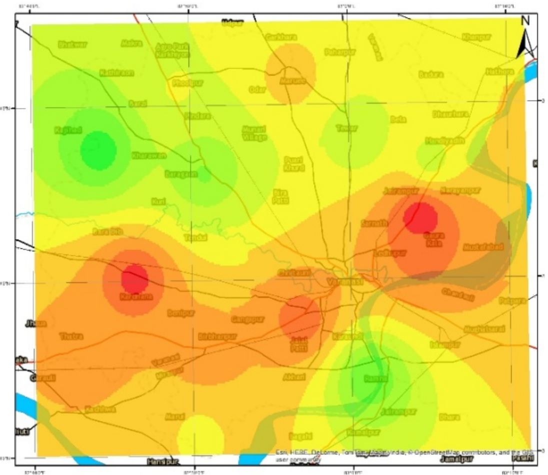


(c)Year 2007

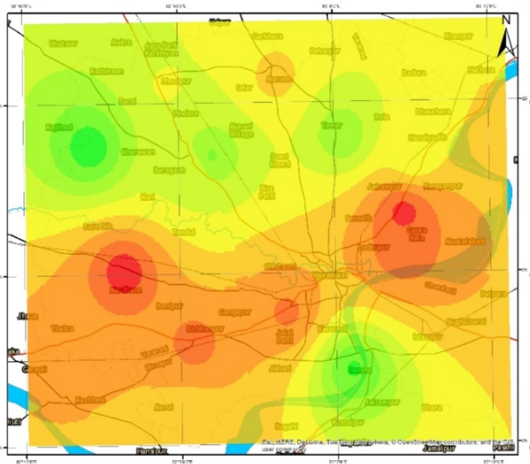


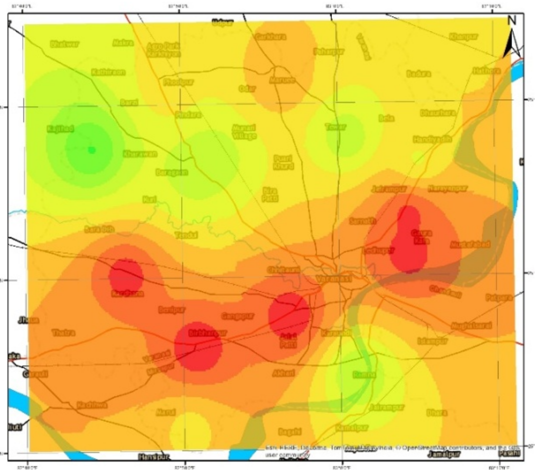
(d) Year 2008



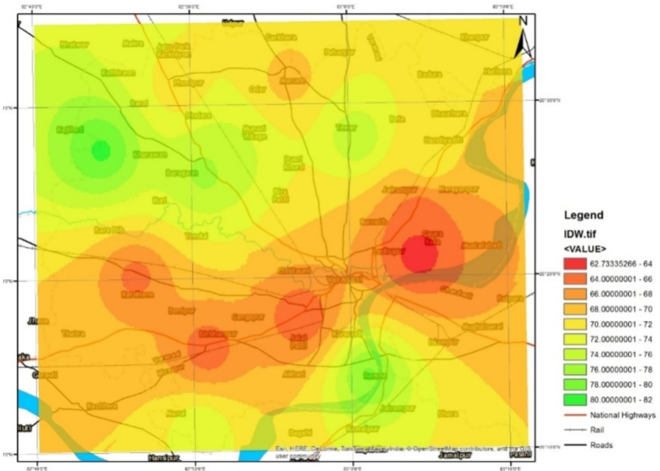


(e) Year 2009 **(f) Year 2010**





(g) Year 2011 **(h) Year 2012**

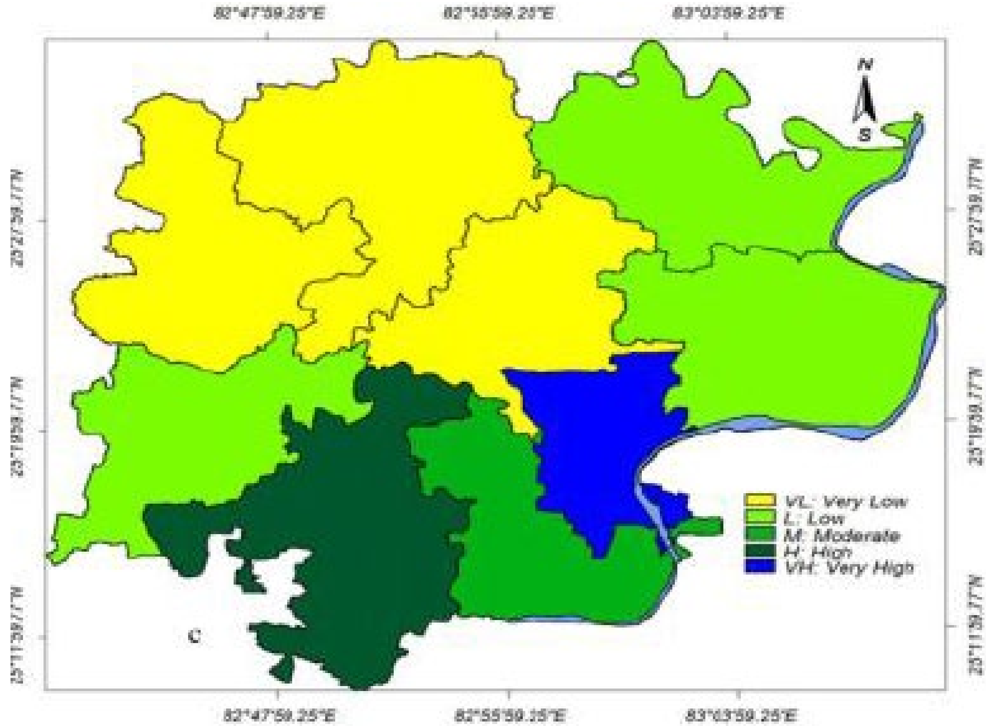


(i) Year 2013

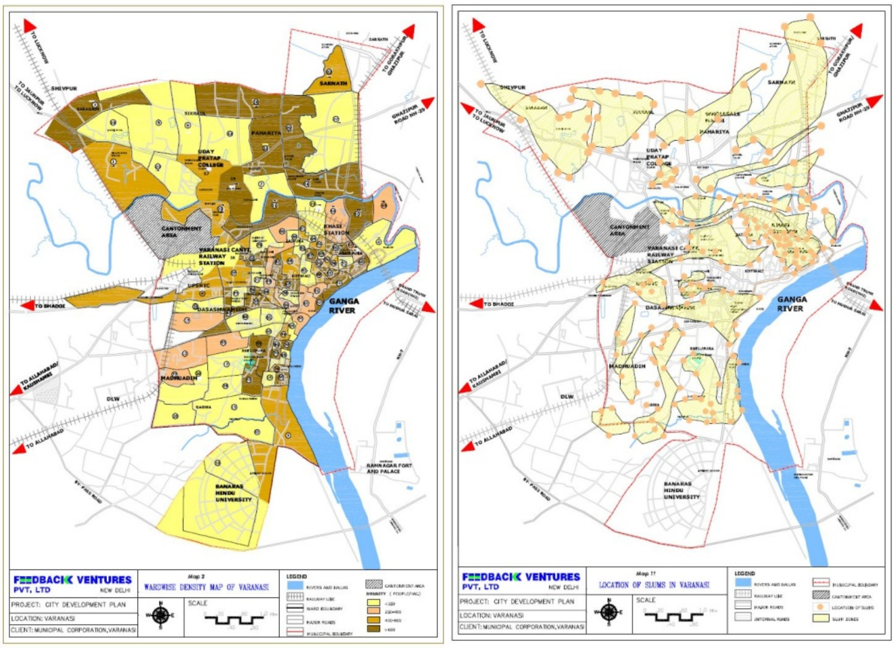
Figure 4.5: Spatial interpolation of Groundwater level at Varanasi

4.5 The Urban growth, floating population and future projections

The district of Varanasi is an important State tourist, cultural, commercial and institutional hub. In terms of population, it is the eighteenth-largest district in the state and occupies the sixth position in the state in terms of urban population. According to the 2011 census, the district of Varanasi had a population of 36.76 lakhs, representing 1.84% of the total population of the State. The district's population increased from 31.38 lakhs in 2001 to 36.76 lakhs in 2011, recording a 17.15% decadal rise. The metropolitan population is about 4%, which is higher than the 22% state average. The district boasts 39 urban centres. Of the 39 urban centres, 3 urban centres make up 80% of the total urban district population. The city of Varanasi accounts for 75% of the total urban population of the district followed by Ramnagar with 3%. In comparison, Lohta accounts for 2% of the urban district population. Overall it shows the predominant presence of Varanasi city in the district. Figure 4.6 demonstrates Varanasi City population density to the year 2011.



(a) Population Density in clusters



(b) Ward wise population density (c) Slum areas

Figure 4.6: Population density at Varanasi

Varanasi is one of the state's largest urban centres and fast-growing towns. The town had a population of 11.98 lakhs according to Census 2011. VMC population accounted for 2% of the total population of the state and 33% of the population of Varanasi district. VMC's population makes up 3.6% of the state's urban population and 75% of the district's urban population. Figure 4.7 presents the contrast of the population of the city of Varanasi with the total population and urban population in the state and district.

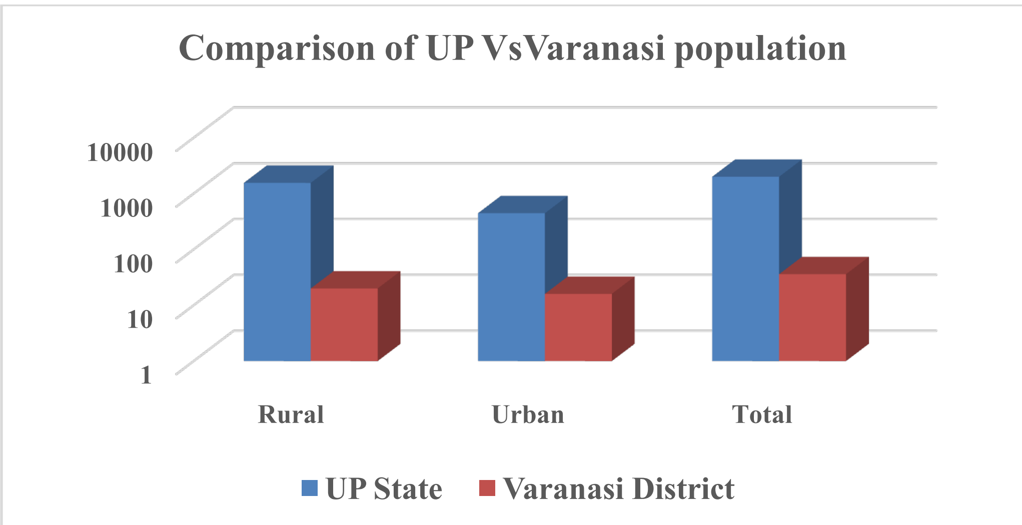


Figure 4.7: Population of Varanasi w.r.t Uttar Pradesh

Varanasi city's population grew from 10.9 lakhs in 2001 to 11.9 lakhs in 2011 at 10% growth rate. Varanasi City's decadal population growth during 2001-11 was below the national average of 17% and the national average of 20%. Population growth dropped from 20% in 1991 to 10% in 2011 (Figure 4.8).

Decade-long wise demographic and population growth were sketched and shown in Figure 4.9. Population growth was the lowest since 1981, in the decade 2001-11. Given the high population density within the city and the city limits remained the same, rapid development was witnessed outside of the city in the peripheral regions. As a result, the peripheral areas grew rapidly, and there was good growth in residential development. The peripheral regions, however, were beyond control of VMC.

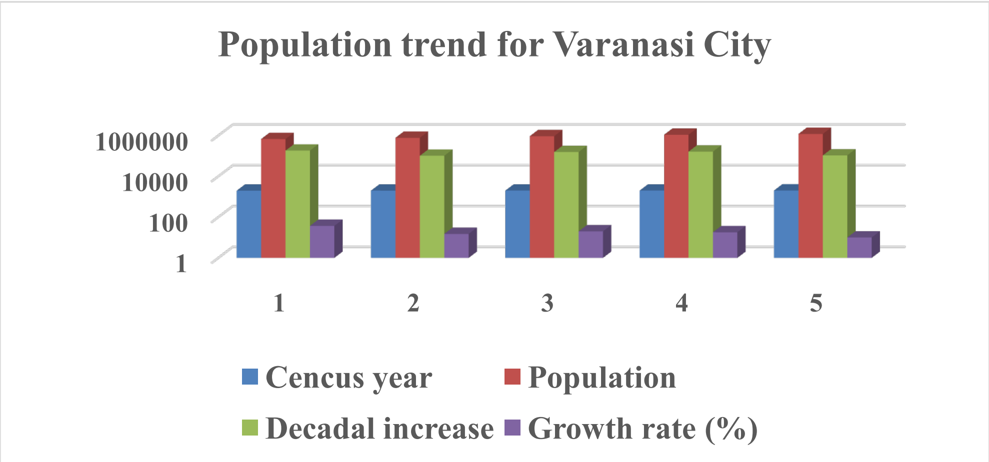


Figure 4.8: Population trend of Varanasi

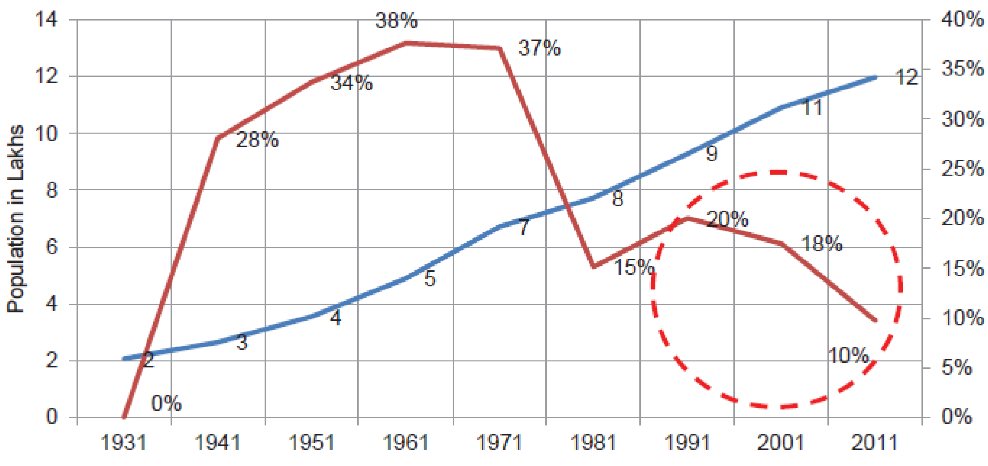


Figure 4.9: Decade wise Population and its growth at Varanasi

4.5.1 Floating population as Tourism

The rich culture and heritage of Varanasi attracts tourist not only from India but also from the world. The place is an important part of Buddhist circuit and as a result a lot of tourists comes from China and Sri Lanka. A brief profile of the tourist visit can be obtained from the Table 4.1 given below. The number of tourists visiting Varanasi from both India and Foreign countries are increasing every year from the year 2013 to 2017.

Table 4.1: Annual Tourist influx in Varanasi

Year	Indian	% Change	Foreign	%Change	Total	%Change
2013	4966161		285252		5251413	
2014	5202236	4.75	287761	0.88	5489997	4.54
2015	5413927	4.07	302370	5.08	5716297	4.12
2016	5600146	3.44	312519	3.36	5912665	3.44
2017	5947355	6.20	334708	7.10	6282063	6.25

It is interesting to note that Floating population in the form of tourist at Varanasi is about four times more than the existing population. It requires due attention for proper urban water management and waste water treatment in Varanasi.

4.5.2 Future projections

From the analysis, it has been observed that polynomial 2nd order population projection, exponential and arithmetic methods give figures below the existing population growth rate for the city. On the other hand, it is very aggressive to projected population by geometric method. It is actually higher than the population projected by the Master Plan draft, 2031. While such approaches can't be approved for population prediction, looking in perspective of historical growth rate and expected developments in the future, it appears that the population projected by incremental method is more realistic. Accordingly, the incremental approach was adopted for this analysis (Figure 4.10).

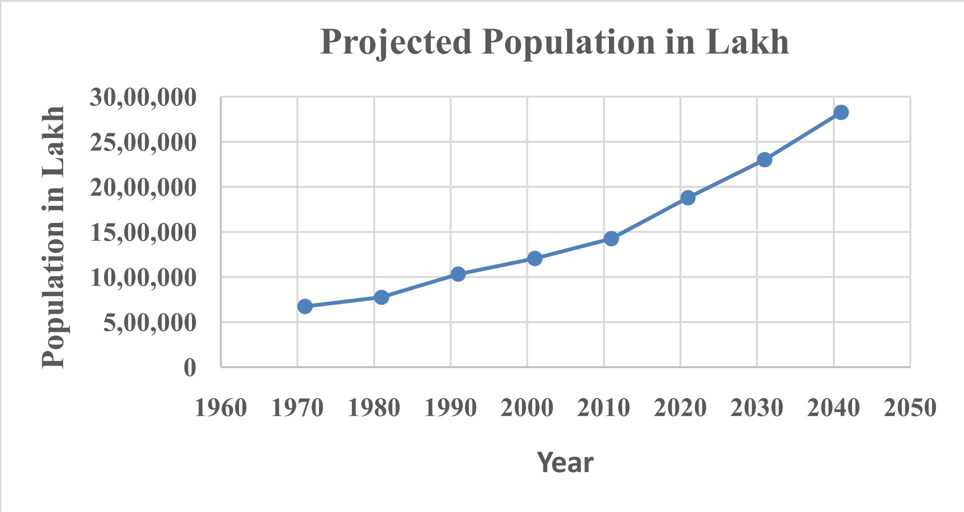


Figure 4.10: Projected population of Varanasi

4.6 Water bodies, Open defecation and Drainage system

Due to the quantity of untreated sewage and waste entering the rivers on a daily basis, the natural water bodies and the river Ganges in town are in critical state. Urbanization has reduced the natural drainage capacity of the town's different water bodies. Around half of the sewerage in water bodies is untreated. Table 4.2 offers the list of major water bodies in Varanasi District.

Table 4.2: List of water bodies in Varanasi

PushkarTalab	KurukshetraKund	DurgaKund
SahotiaTalab	KreemKund	Moti Jheel
BakaraKund	Nadesar Tal	LahartaraTalab
Lahar Tara	Surya Sarovar	SonaTalab
SankhuldharaPokhra	Ram Kund	Lakshmi Kund
PitarkundaTalab	Sonia Pokhara	Chakra Tal
PishachMochan Tal	IshwargangiPokhra	LadhuTalab
SarangKund	PahariaTalab	DaulatpurPokhara
Chancha Tal	Gauri Kund	MansarovarKund
PitriKund	Lotus Lake, BHU	

Of the more than 100 kunds built across the region, only about 88 kunds remain today. This is due to negligence, uncontrolled construction in the respective kunds' catchment areas, lack of awareness among other factors. The access to the kunds is typically through narrow streets. The choking of the ducts through which the kunds were interconnected has dysfunctionalized the flood control system. The majority of the remaining kunds suffer from water pollution and water hyacinth abundant growth. There is also prevailing uncontrolled dumping of solid waste. Edges are not properly lined, and damage to walls and steps. Yet most kunds are widely used for religious and cultural activities, and despite their polluted conditions, clothing washing and routine bathing are common practices. If all the existing Kunds in the city were to be rehabilitated, they would not only provide the residents and faithful with socio-cultural and recreational areas, but would also be a water source again and contribute to a more efficient flood management system in the city. The water bodies are major open defecation hotspots in the region (Figure 4.11).

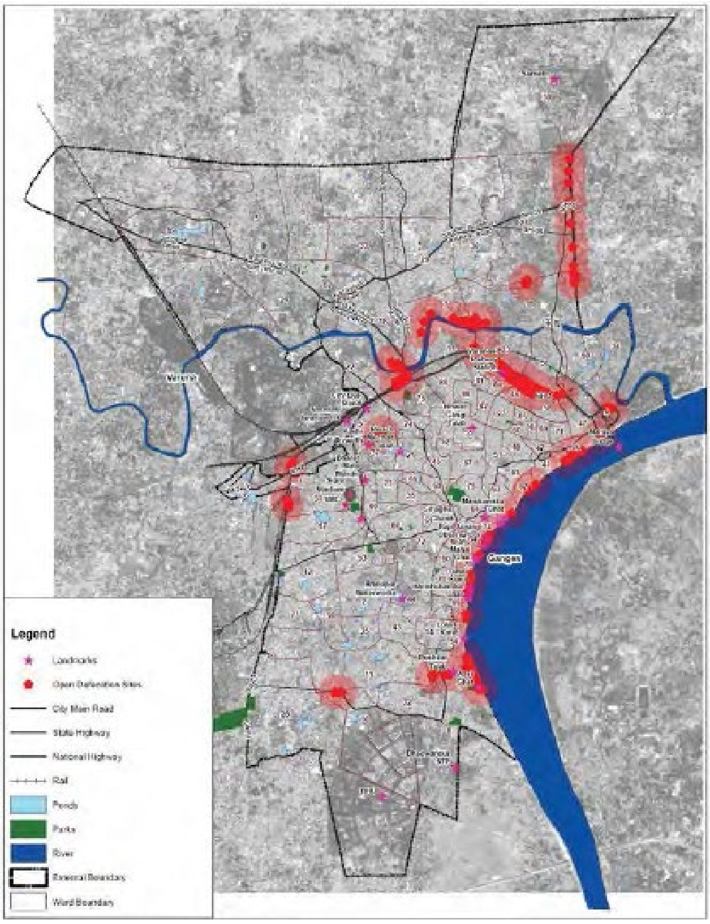
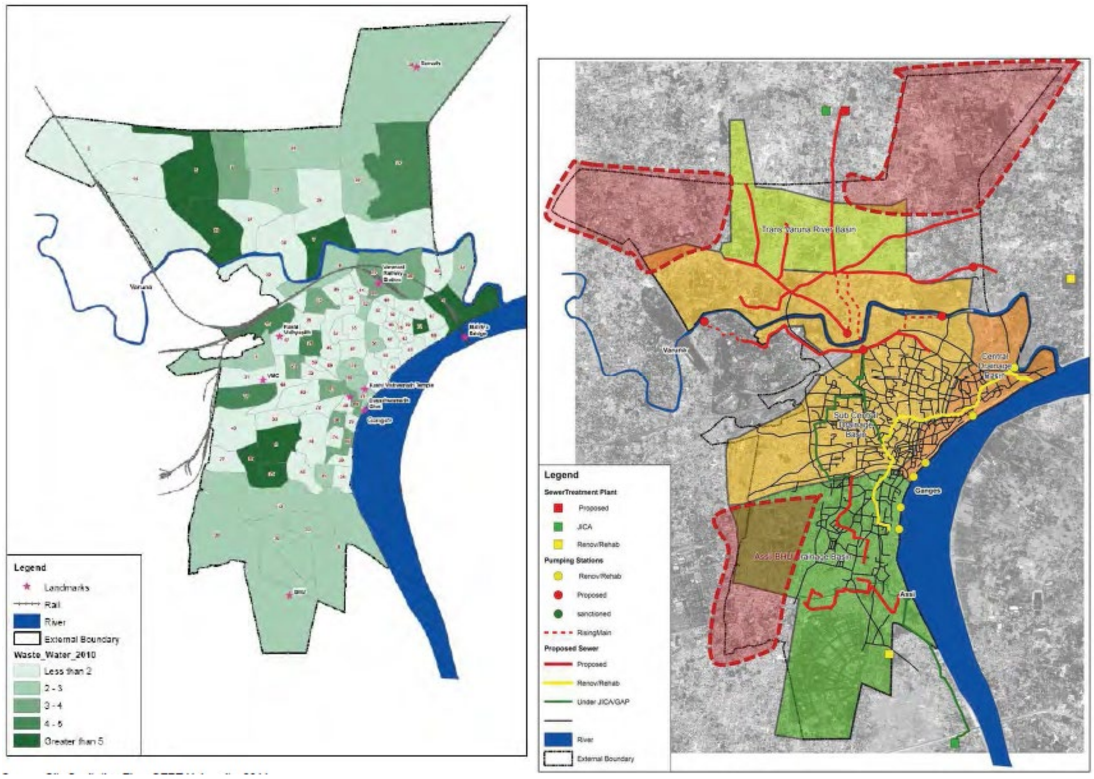


Figure 4.11: Open defecation sites at Varanasi near slums, railway station and public places causing damage to water bodies

The proposed plan for sewer network based on water generation is shown in Figure 4.12, which may be helpful for waste water treatment and management, if STP works properly, the sewer line is maintained and open defecation is reduced.



(a) Waste water generation location **(b) Proposed sewer system**

Figure 4.12: Waste water generation at Varanasi and proposed sewer system

CHAPTER 5

URBAN SPRAWL ANALYSIS AND CHANGE DETECTION

The urban sprawl of Varanasi city, India is visible to the people and significant land use changes are observed in recent past. In this Chapter various methods to analyse the urban sprawl and land use change pattern in different zones and/or different directions from the centre of Varanasi city are discussed and applied for Varanasi city using historical data for the last 29 years (year 1990- year 2018).
Before processing the image for analysis and classification, the acquired data is corrected for noise reduction and reflectance. These corrections facilitate more accurate and meaningful spatial and temporal comparisons of the region.

5.1 Urban Sprawl Analysis using Satellite Data

5.1.1 Visual Image Interpretation

For the present study, a False Colour Composite (FCC) was made with the Red, Green, and Blue bands of each satellite data. It produces an image similar to the colour-infrared aerial photography. The combination is useful for studying land use/land cover changes including urban sprawl, vegetation, soil patterns, drainage, and crop growth. Healthy vegetation pops up in bright red, urban infrastructure is coloured cyan blue, and soils are in shades of brown (Nagi, 2011). The visual interpretation of False colour composite data (FCC) is done by considering the following interpretation keys:

5.1.1.1 Shape

Shape refers to general form, configuration, or outline of individual objects. Height is also one of the parameters which define shape of an object.

5.1.1.2 Size

Size of objects on photographs must be considered in the context of the photo scale.

5.1.1.3 Pattern

Pattern relates to the spatial arrangement of objects. The repetition of certain general forms or relationships is characteristics of many objects, both natural and constructed, and gives objects a pattern that aids the photo interpreter in recognizing them, colour depending upon the film type and filter used.

5.1.1.4 Colour

Colour photographs may be 'True colour' or 'False colour' depending upon the film type and filter used.

5.1.1.5 Shadow

The shape or outline of a shadow affords an impression of the profile view of the object which is helpful for interpretation.

5.1.1.6 Location

The geographical site and location of the object often provide clues for identifying objects and understanding their genesis. For e.g. dense forest are mostly associated with hills.

5.1.1.7 Association

It refers to situation of the object with respect to neighbouring features e.g. canals with agricultural field.

5.1.2 Digital Image Processing

5.1.2.1 Image enhancement

Enhancement techniques involve the mathematical combination of images from different dates which, when displayed as a composite image, show changes in distinctive colours (Pilon et al. 1988). The enhancement change detection techniques have the advantage of generally being more accurate in identifying areas of spectral change.

5.1.2.2 Image classification

The classification process used can be either supervised or unsupervised. The images can then be classified into different "training classes" as defined by the user, to map the land use and land cover of the scene. This is done by grouping together pixels with similar spectral responses and assigning a particular class to them. The program then assigns these classes to the rest of the scene based on the similarity of the pixels within the defined level of confidence.

A. Maximum Likelihood Method

Maximum Likelihood is one of the most effective algorithms for image classification (Jensen, 2005; Bargiel, 2013). In most studies, this method has been distinguished as the most accurate (Hopkins et al., 1988; Richards and Jia, 2005; Halder et al., 2011). The algorithm is used to calculate the weighted distance (WD) or likelihood Z of the unknown measure vector Y, belonging to one of the unknown classes and Mc are based on the original Bayesian Equation (Otukei and Blaschke, 2010).

$$\mathbf{Z=ln(at)-[0.5ln\ (|covt|)]-[0.5(Y-At)T(covt-1)(Y-At)]} \quad (1)$$

In this equation, Z = weighted distance (likelihood), t = a unique class, Y = the measuring vector for targed pixel, At = the mean vector in sample of target class t, a t = percent probability which any target pixel is a member in t class, Covt = the covariance matrix of the pixels in sample of class t, |Covt| = determinant of Covt, Covt-1= inversed Covt (matrix algebra), ln = natural logarithm function, T = translocation function (matrix algebra) (Srivastava et al., 2012).

B. Principal Component analysis

Principal component analysis (PCA) is a commonly used statistical method for many aspects of remote sensing image analysis, including estimation of the underlying dimensions of remotely sensed data, data enhancements for geological studies, and land cover change detection [9]. The PCA technique for change detection requires the separate images first be stacked in a multi-temporal composite image [8].

The major strength of this technique is its ability to reduce the dimensionality of the data with relatively minor loss of overall information content. The major weakness of this technique is that it can be difficult to interpret. Li and Yeh [10] compared principal component analysis to post classification techniques and concluded that principal component analysis was much more accurate than post classification techniques and therefore suggested it as an accurate alternative for detecting land use change.

Now, to detect the urban sprawl in land use /land cover changes in the study area, Principal Component Analysis (PCA) image enhancement technique were adopted. PCA is a very powerful technique for the analysis of correlated multi dimensional data. The n-channel multi spectral data can be considered as n-dimensional data. The PCA builds up a new set of axis, which are orthogonal to each other i.e. non-correlated. The entire data set can be represented in terms of these new axis. The data along the first principal component (PC) have a great variance or dynamic range than the data plotted against either of the original axes. The data along the second PC have far less variance. This is the characteristics of all principal components. Principal component images can be analyzed as separate black and white images or any three components images may be combined to form a color composite. These techniques are particularly appropriate where little priori information concerning a scene is available

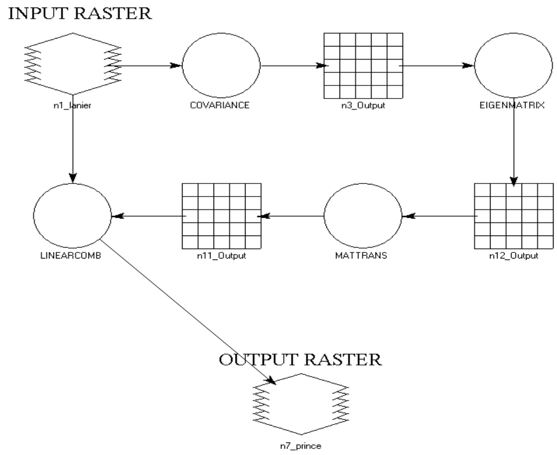


Figure 1: PCA modeling algorithm

C. Band differencing

Image differencing is a technique by which registered images acquired at different times have pixel DN values for one band subtracted from the corresponding pixel DN values from the same band in the second image to produce a residual image, which represents the change between the two dates (Mass, 1990) Ridd and Liu (1998) reported image differencing was fairly effective in its ability to detect change in an urban environment, with TM band 3 producing the highest accuracies. Sunar [8] and Sohl [6] reported that the image differencing technique was extremely straightforward, but with the qualification that image differencing technique becomes slightly more complicated when using multiple bands, instead of single bands, due to the difficulty of interpreting the colours of multiband false colour composites.

D. Normalised Difference Vegetation Index (NDVI)

Satellite data can be used to determine the density of vegetation across a scene. The sensors of each satellite measure different wavelengths of light absorbed and reflected by plants. Depending on the chlorophyll content in the leaves, different types of vegetation absorb different amounts of visible (red) light, and reflect different amounts of Near-Infrared light. Healthy and growing vegetation reflects more NIR light than in the visible range, and less when they are in a stressed, diseased, or dry state. The sensors on board satellites measure these light waves, and therefore, with the use of a mathematical algorithm, this information can be transformed into vegetation indices showing relative biomass levels.

One of the most useful and widely used vegetation indices is the Normalized Difference Vegetation Index. This index displays barren areas, dry soil, and rock show the lowest NDVI values, spare grasslands and shrubs have moderate values, and the highest values indicate dense vegetation at their peak growth stage.

The process of NDVI creation involves the identification of the Red and NIR bands for the specific satellite, and then using the following formula to create a classification.

$$NDVI = \frac{(R_{nir} - R_{red})}{(R_{nir} + R_{red})} \quad (2)$$

where R_{nir} and R_{red} are the reflectance in near infra-red and red frequency bands.

The Normalized Difference Vegetation Index (NDVI) estimates the vitality of vegetation by exploiting the known gap in vegetation reflectance between the visible and near infrared channels. Common change detection methods include the comparison of land cover classifications, multi-date classification, band arithmetic, simple rationing, vegetation index differencing and change vector analysis [11]. The NDVI is calculated as a normalized ratio (ranging from -1 through 1) from the NIR and the red band and emphases apparent vegetation (Sabins,1996).

5.2 Shannon's Entropy Approach

In physics, entropy is a measure of disorder or randomness in a system. The second law of thermodynamics states that in a closed system, the entropy of the system never decreases, but rather is inclined towards a state of thermodynamic equilibrium, where various physical and chemical properties are at equilibrium. Maximum entropy, or maximum dispersion, is at thermodynamic equilibrium.

Shannon (1948) developed the concept of' entropy in his classic paper and proposed a discipline of communication theory which focused on the study of information theory and entropy. This theory makes use of a basic mathematical notion related to thermodynamics. The second law of thermodynamics states that thermodynamic degradation is unalterable over time, e.g., a burnt log cannot be un-burnt and lukewarm water cannot be separated distinctly into hot water and cold water.

The disorder disorganization or randomness of organization of a system is known as its entropy (Miller, 1969). So, entropy is a measure of disorder and information is a measure of order of a system. Since the system changes to a less organized state from a highly organized state and to more probable states from less probable states, entropy is maximized and the magnitude of entropy is described by a set of probabilities.

As an alternative to conventional nearest neighbour technique Medvedkov (1966) has related this notion to the problem of settlement pattern analysis. He has suggested that any settlement pattern has a uniform component and a random component. These components can be measured by the method used for detecting signals in the presence of noise in information theory. Signal is analogous to the uniform component and noise to the random component. . Entropy has been used as a measure of noise in information theory and as a measure of disorder in spatial distributions. Medvedkov suggests that a settlement pattern is a composite of two superimposed sub-patterns, one random and the other uniform. Each of these sub-patterns will have its own mean density of points, and the two densities added together will be equal to the mean density of the composite pattern. Likewise each sub-pattern has its own entropy value, and these summed will be equal to the entropy value of the composite pattern. However, the entropy value of a uniform pattern iszero therefore the entropy value of the random component will be equal to that of the total pattern. If the pattern is not perfectly uniform the entropy function is density dependent and there is no upper limit to the value of the entropy. Entropies for different patterns can be compared precisely only when the cell count data is obtained using the same grid in the same position on the map. Therefore, for comparative studies in time or space, the size and form of the grid must not be altered.

Again, a major difference between entropy and traditional indices of spatial dispersion is that its value is invariant with the value of zones and the number of observations (n) (Thomas, 1981). In contrast, the Gini coefficient and the Lorenz curve, which have been widely used in geography to describe location patterns, are sensitive to the size and shape of the area units under observation. The modifiable area units may exert a significant influence on the results of spatial analysis and lead to the loss of detailed information (Openshaw, 1991). However, entropy has no such problems.

5.2.1 Mathematical formulation

Let an urban area be divided into n zones and x represent a geographical variable to characterize these zones. Then the degree of spatial concentration or dispersion of the geographical variable in the i-th zone (x_i) among n zones can be measured by Shannon's entropy E (Theil, 1967; Thomas, 1981). Entropy can be calculated as:

$$E = \sum_{i=1}^{n} p_i \log\left(\frac{1}{p_i} \right) \tag{3}$$

where $p_i = \frac{x_i}{\sum_{i=1}^{n} x_i}$ is the probability or the proportion of the variable occurring in the i^{th} zone, and x_i is the observed value of the variable in the i^{th} zone, and n is the total number of zones. The value of entropy ranges from *zero* to *log (n)*. If the probability distribution of the variable is maximally concentrated in one zone, the lowest value of the entropy, *zero*, will be obtained. Conversely, an evenly dispersed distribution of the variable among zones will give a maximum entropy value of *log (n)*.

The relative entropy can be used to scale the entropy value into the range from *0* to *1*. The relative entropy E_r is (Thomas, 1981):

$$E_r = \sum_{i=1}^{n} \frac{p_i \log\left(\frac{1}{p_i} \right)}{\log(n)} \tag{4}$$

If the probability distribution is maximally concentrated in one region, equation (4) would yield the lowest E value of zero. Conversely, equation (3) would yield a maximum E value of 1 for an evenly dispersed probability distribution. Equation (3) was utilized for analysis in this study.

Entropy can be used to measure the distribution of a geographical variable and thus a measure of the difference in entropy between time *(t+1)* and *(t)* can be used to indicate the change in the degree of dispersal of land development or urban sprawl (Thomas, 1981). This can be expressed as:

$$\Delta E = E(t+1) - E(t) \qquad (4)$$

in which ΔE is the change in entropy between time *(t+1)* and *(t)*. The dispersal of urban areas from a town centre will lead to an increase in the entropy value. The change of entropy can be used to identify whether land development follows a more dispersed or compact pattern of sprawl.

Using densities of different buffer zones computed in GIS, the probability of urban development in each buffer zone of 1000m were estimated. Thereafter, equation 3 was used to compute distributed entropy at different buffer zones and mean relative entropy for the years 1989, 1998, 2000, 2002.

5.3 Analysis of Results

5.3.1 Visual Interpretation using FCC and Toposheet

The Survey of India toposheets of the scale 1:25000 and 1:50000 scale for the year 1974 were collected and studied along with the False colour composite (FCC) for the years 1990 and 2012. The land use/land cover types are classified as follows: Agricultural land, Barren or fallow land, Sand bodies along river, Built up areas, Plantations, and Water bodies.

5.3.1.1 Agriculture land

It is defined as the land primarily used for food crop production, besides the fibre and other commercial and horticultural crops. It includes land under crops (irrigated and unirrigated) fallow, plantations, etc.

(i) Good grades agricultural land : These are marked by the dark red tone in the satellite imagery. Good grades of agricultural lands are found in the north-east, middle and southern portion of the imagery. Mostly wheat is the dominating crop of this area in the month of February. These areas are mainly low land plain of the region near to the rivers and canals. Within the whole unit coverage of agricultural land is about 95%, 5% grass and scrub in a mixed form.

(ii) Medium grade agricultural land: These are marked by the light red tone in the satellite imagery. Within the whole unit coverage of agricultural land is about 50% and 50% barren sandy patches. These are found mostly in the middle portion of the imagery. In this region crop diversification is the main characteristics.

(iii) Low grade agricultural land: The crop growing conditions are less favorable in these areas. Such areas appeal on imagery by light to very light red tone mixed with white, yellow and brown patches. Low grade agricultural lands are found west, north-west and eastern part of the imagery.

5.3.1.2 Barren or Fellow Land

It is an agriculture land once used left fallow and because of no cover at the time of data recording, the unit appears barren. In fact a part of such parcel are wasteland but it is difficult at this resolution and scale (1:50000) to separate out agriculture fallow and wasteland.

5.3.1.3 Sand bodies along river

These units are mostly associated with river. Different sand bodies are located both side of the river. These reasons are predominately with white sand, it may be dry or wet. Dry sand bodies generally gives whitish tone and wet sand bodies gives light bluish tone.

5.3.1.4 Built up areas

It is define as the area of human habitation developed due to non-agriculture use and that which has cover of building, transport, communication, utilities in association with water vegetation and vacant lands. All man made constructions covering the land surface are included in this category. These are human settlements comparing residential areas, transportation and communications lines, industrial and commercial utilities and services.

5.3.1.5 Plantation

These appeared dark black to brown tone small in size with regular or irregular shapes in the southern and middle part of the imagery. As this is a plain area with monsoon climate so deciduous plants are dominating in the characters.

5.3.1.6 Water bodies

This class comprises area of the surface water, either in impounded in the form off ponds, lakes, reservoirs or flowing streams, rivers, canals etc. these are clearly seen on satellite false colour imagery in blue colour.

The following water bodies are mapped in the area:

(i) River & Stream: The River that can be clearly identified are the Ganga and its tributaries Gomati and Varuna. They meet in Ganga northern and south western part of the study area. The dark blue colour indicates clear water of those rivers.

(ii) Tank pond & Reservoirs: There are many small tank, ponds, reservoirs, scattered in the whole toposheet. They are mainly used to irrigate the agricultural fields and domestic purpose.

(iii) Canal: A canal can be clearly identified in the southern part of the imagery. This is also used for irrigation.

A visual interpretation key is a reference material that is designed to facilitate rapid and accurate identification of features as imaged on imagery. It also serves as record to correct interpretation of land use in doubtful areas.

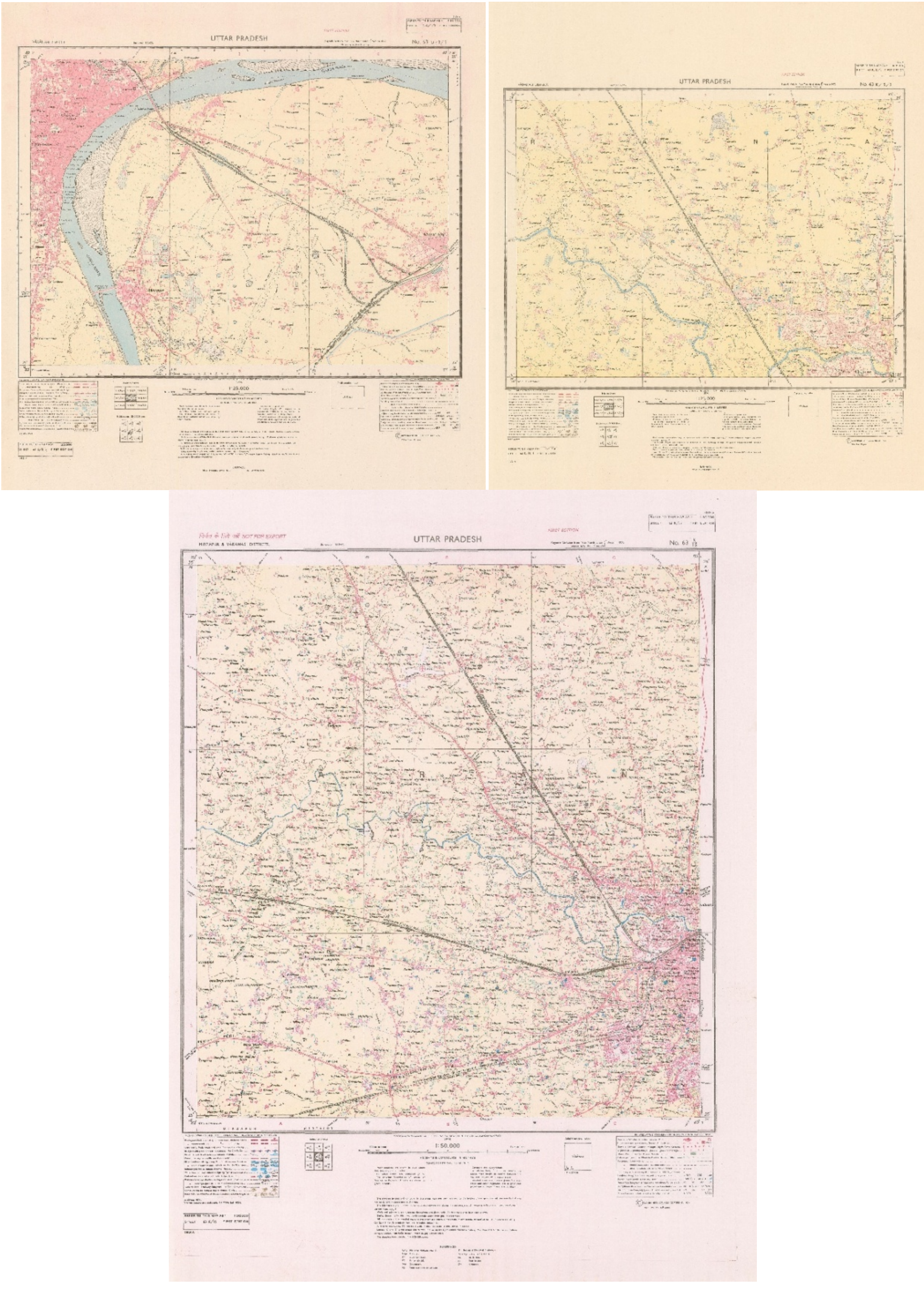


Figure 5.1: Toposheet of the year 1974

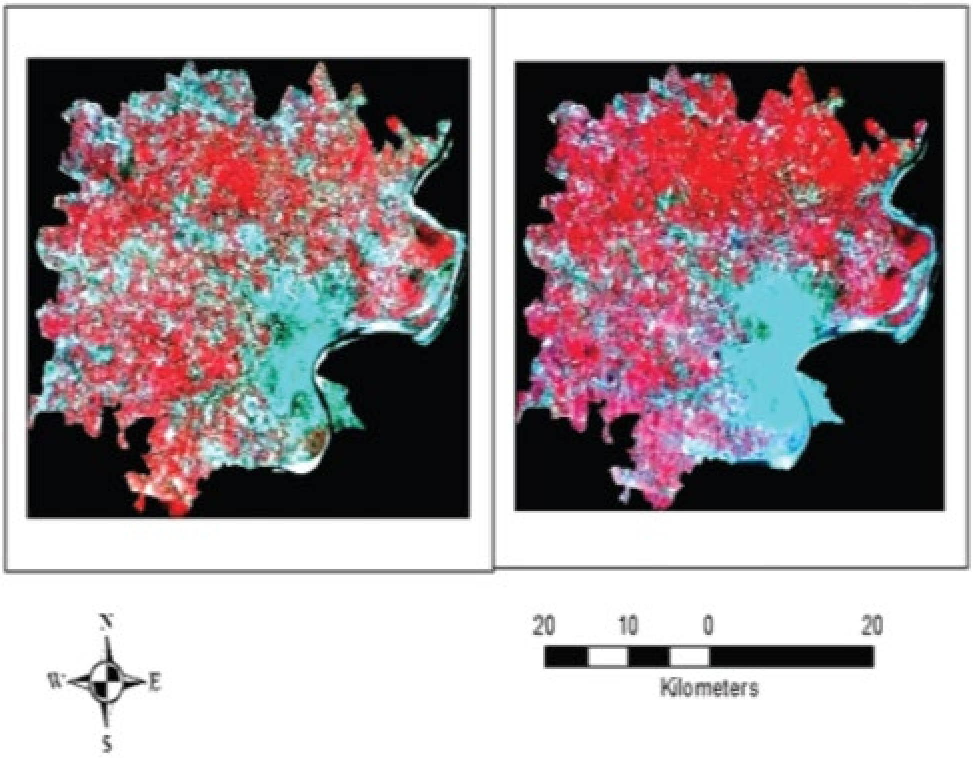
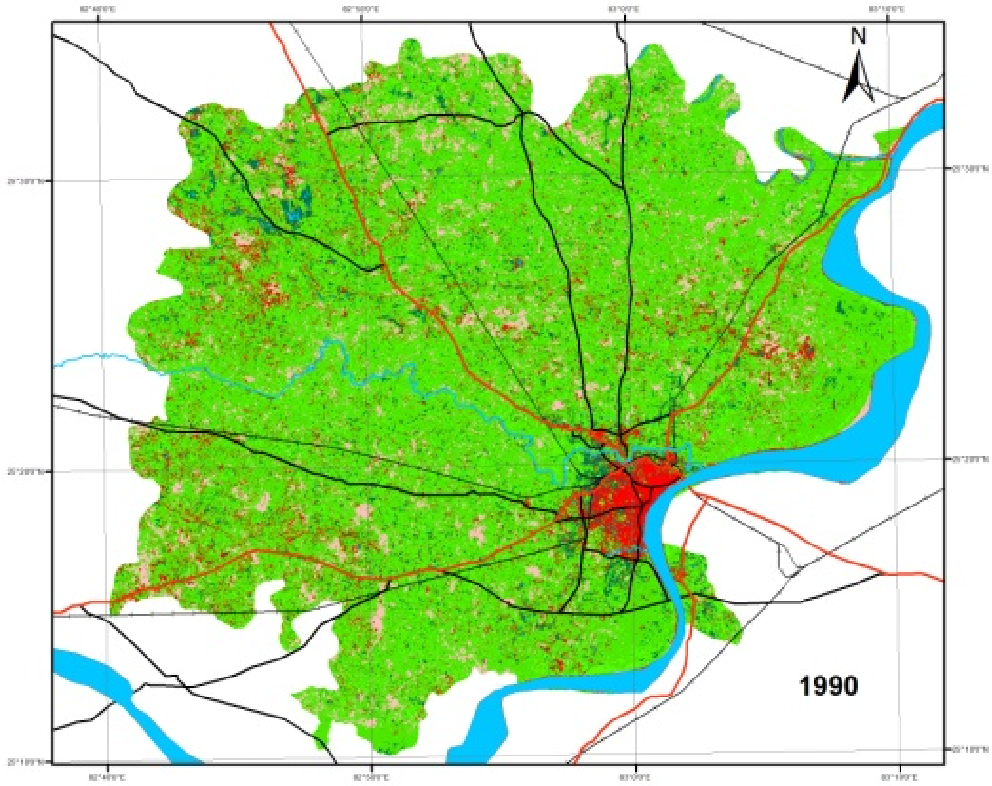
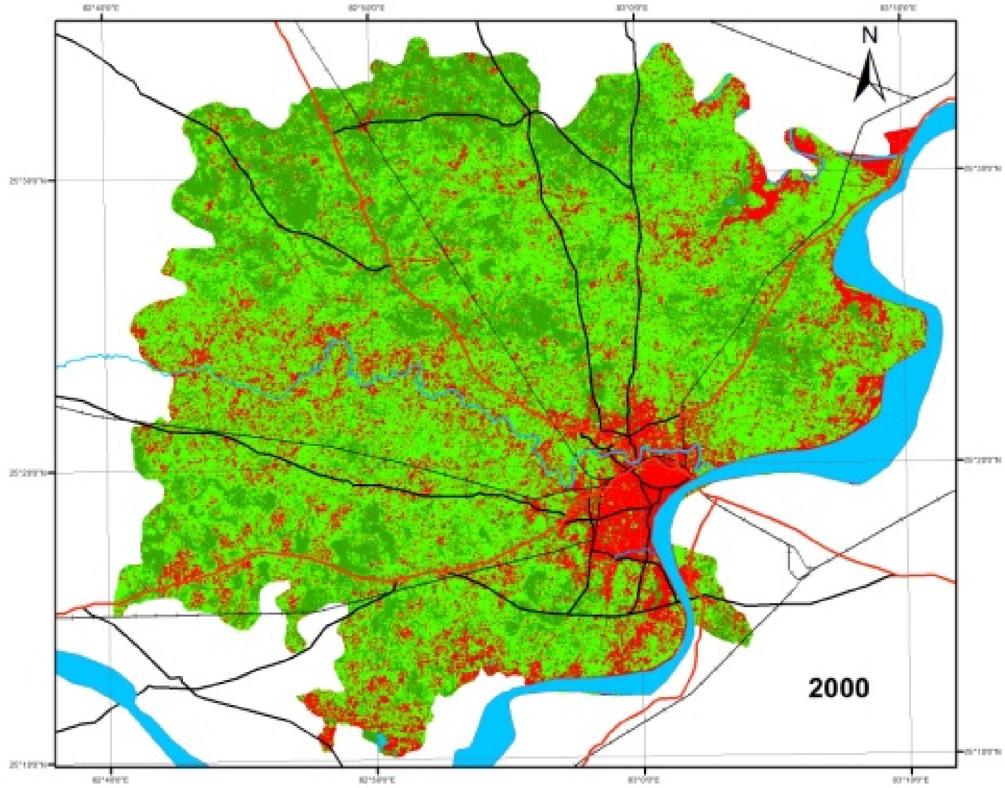


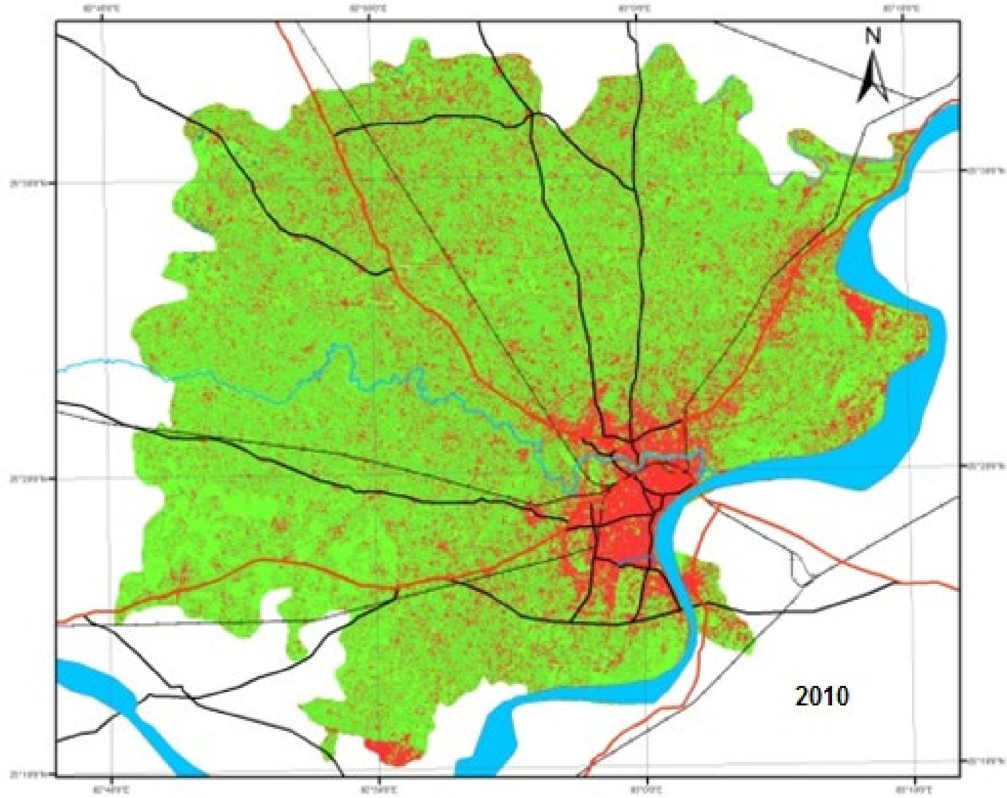
Figure 5.2: FCC for the years 1990 and 2012 maps for the year 1974

5.3.2 Digital Image processing

The land use data of Varanasi district area was analyzed by a number of ways to help interpret the growth of the city and the effects of the said growth – adverse or otherwise – on the population and the resources of the area. The first set of images (Figure 5.3) depicts the land use of the entire district. Even without the statistical data, one can clearly see that the urban area for the district has increased by a significant margin from 1990 to 2014, especially near the Varanasi city area. The graphs (Figure 5.4) shows that there was a lot of open land (non-urban area) in the year 1990. As the time progressed, a lot of the land in the district got converted to urban and agricultural areas. The spread of the central part of the city only begun when all the area of inner cities were fully and completely covered by either buildings or roads. There are many places in the old Varanasi city area where one can see buildings and houses which are touching and there is no distance between their walls. It is needless to say that such areas are not good for sustainable use of groundwater since a lot of groundwater is taken out by the residents of these houses and the recharge of those aquifers is very difficult because of all the built up land covering the soil. This is known problem in many cities in India where small pieces of land are bought by people and then entire house has to cover the entire lad they have bought. Such situations make it very difficult for the government to make any parks or open areas around the area. Another problem caused by this haphazard building up is that the catchment areas for the streams is either blocked or lost. This makes the areas very prone to flooding during monsoon season.




N
2000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2010

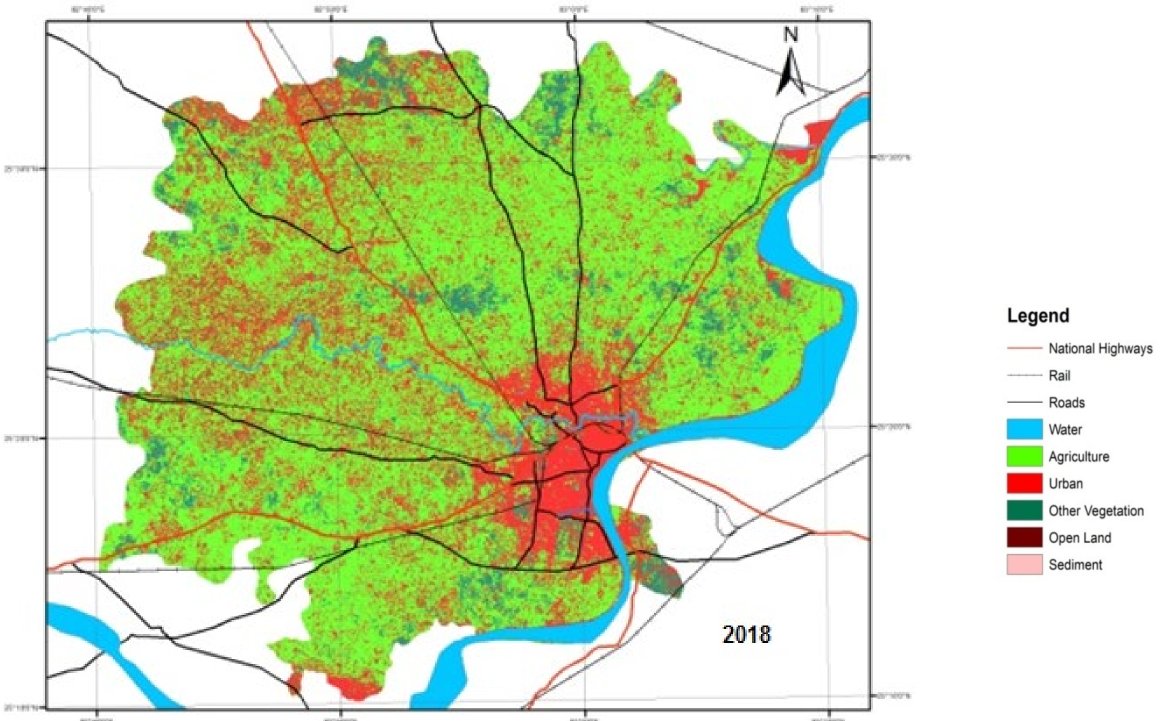


Figure 5.3: Land use images of Varanasi district from year 1990 to 2018

One can find better distribution of built up land and open land/parks in the planned campuses in the city. The Banaras Hindu University (BHU) campus, Diesel Locomotive Works (DLW) campus, and the Cantonment area are good examples. These campuses are like small model cities with buildings which have significant distances between each other, which allows for broader roads, trees and beautiful surroundings. Not to mention such areas allow natural recharge for the aquifers. Of course such areas are also very safe from floods as the rain water easily flows away due to proper planning of drainage. It is very rare for these campuses to ever encounter floods even though the city itself deals with floods on an annual basis.

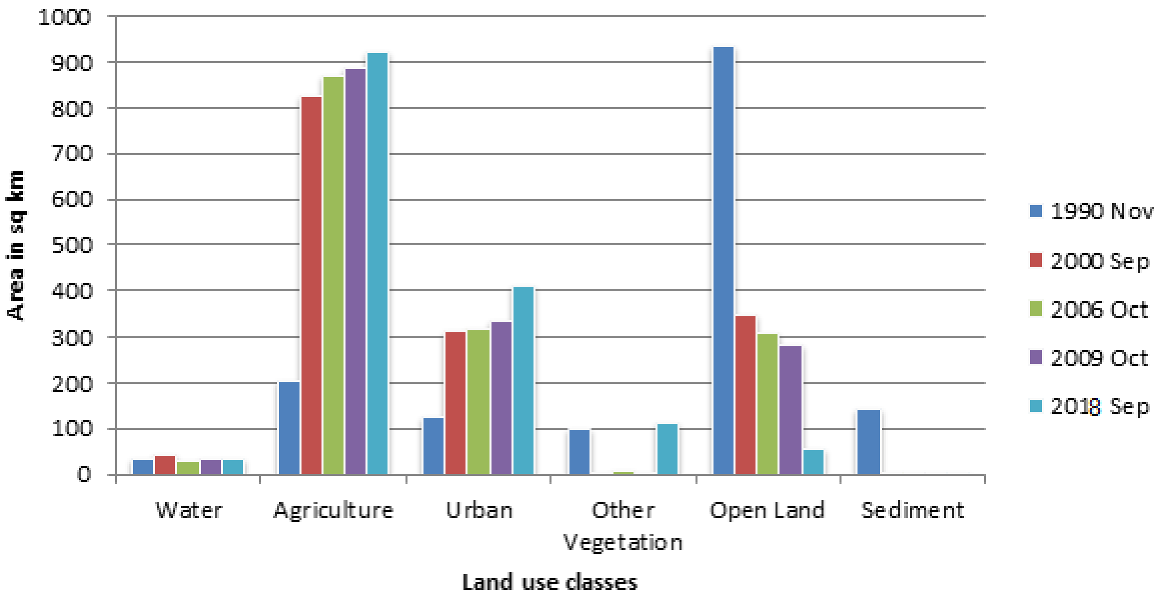


Figure 5.4: Graph depicting the area in sq km for the various land use classes in the Varanasi district from 1990 to 2014

It is also observed that the built up area and the green area has been changing significantly with time in two to three decades. As shown in Figures 5.5 and 5.6 the built up area has increased by two times during the year 2018 in comparison to its value in the year 1990. Consequently the green area got reduced.

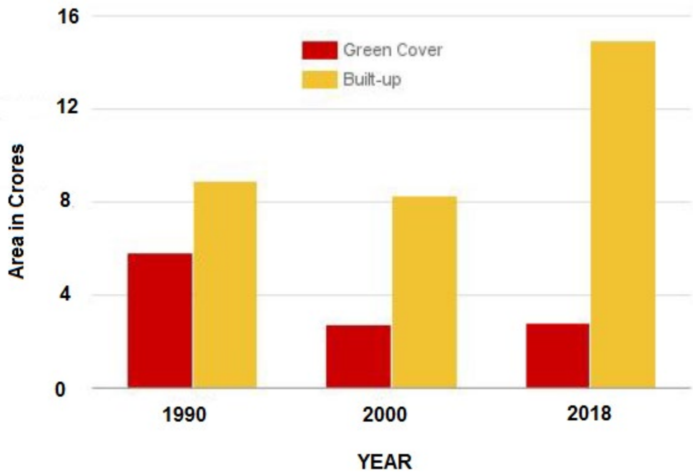


Figure 5.5: Green and Built-up area of Varanasi City

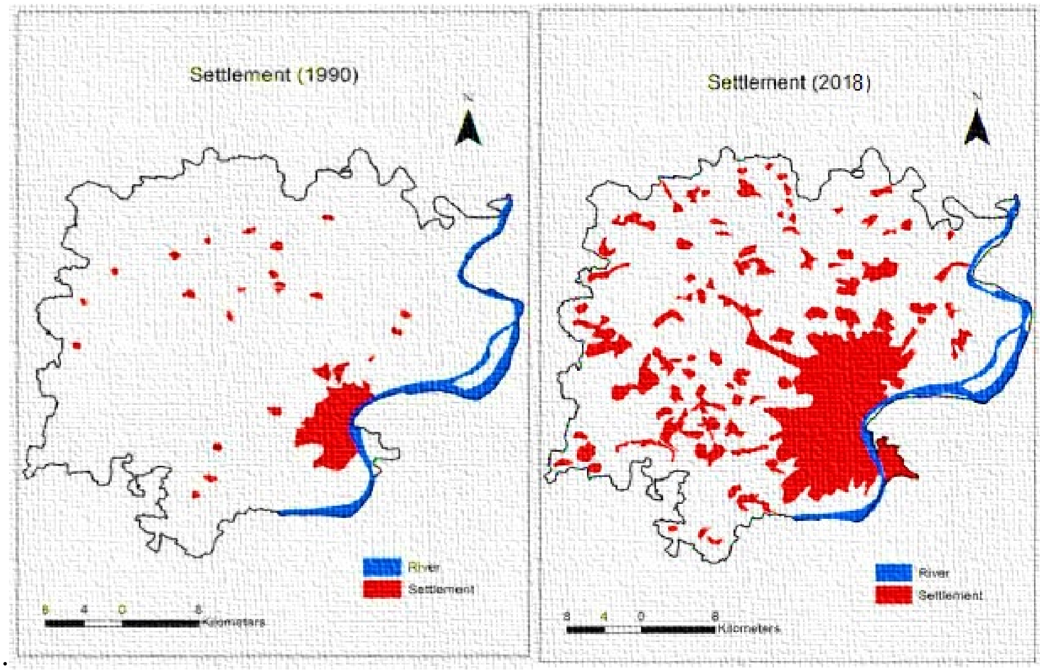
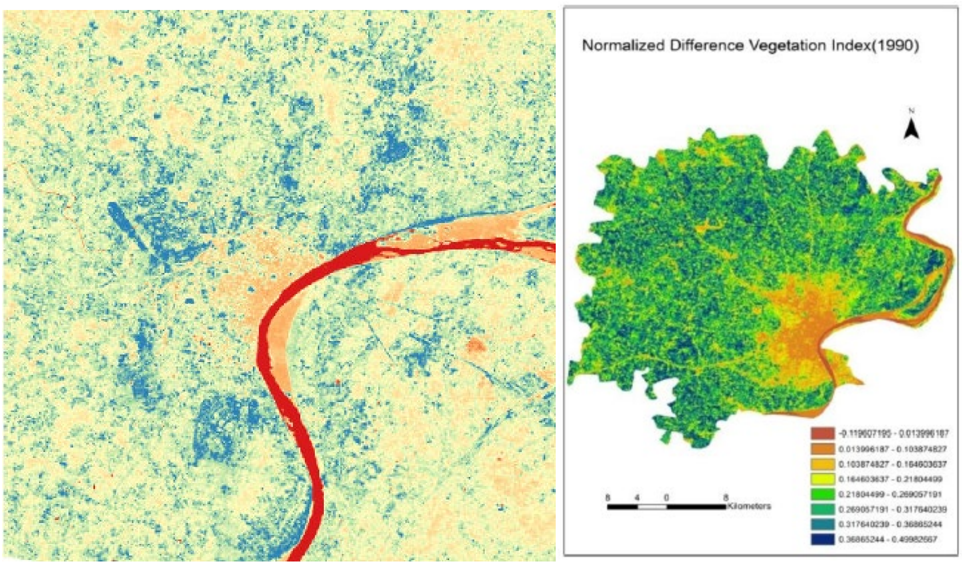


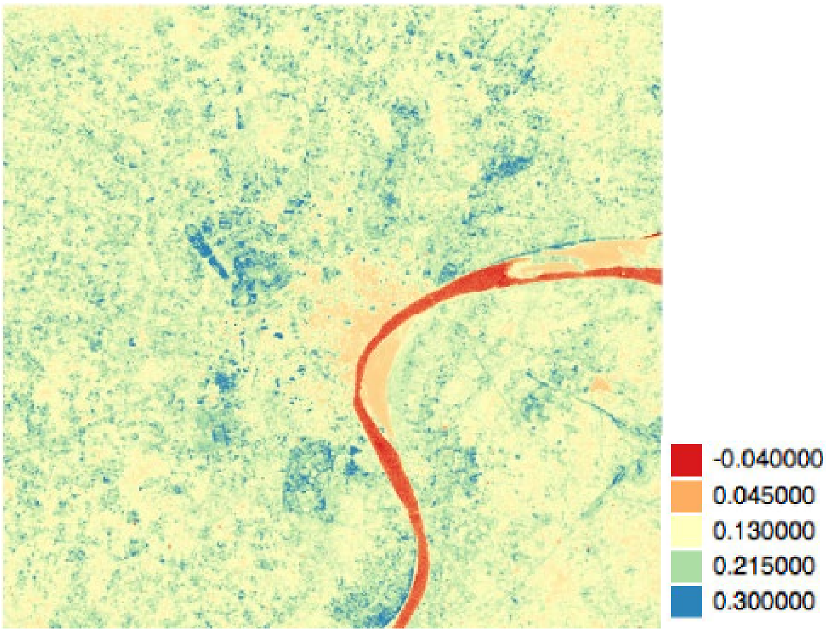
Figure 5.6: Settlements in of Varanasi City

5.3.3 Normalised Difference Vegetation Index (NDVI) analysis

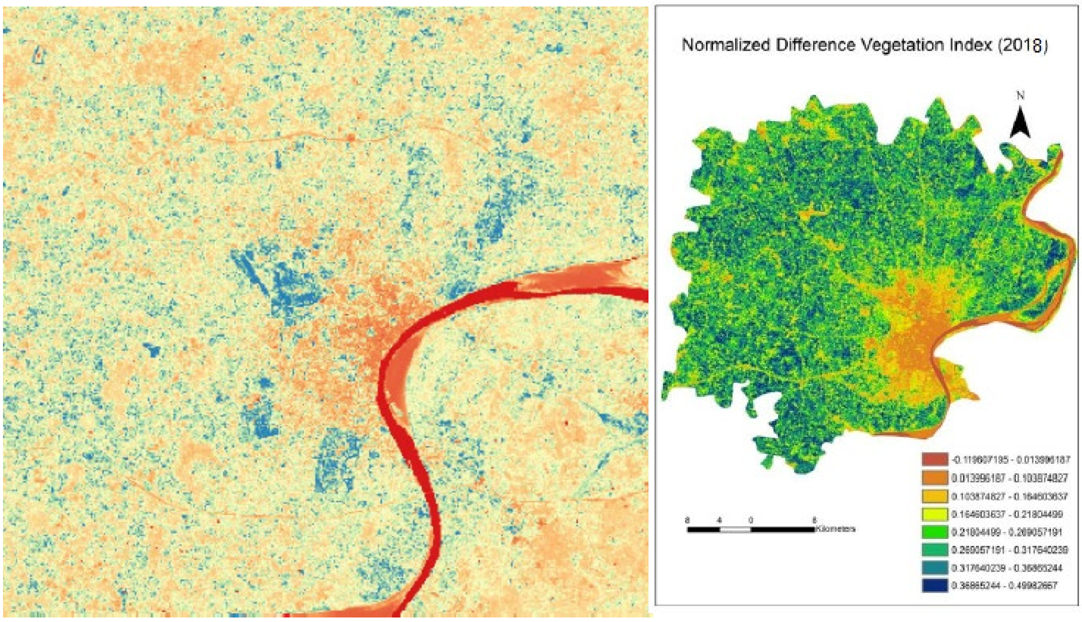
One of the most useful and widely used vegetation indices is the Normalized Difference Vegetation Index. This index displays barren areas, dry soil, and rock show the lowest NDVI values, spare grasslands and shrubs have moderate values, and the highest values indicate dense vegetation at their peak growth stage (Figure 5.7).



(a) Year 1990



(b) Year 2000



(c) Year 2018

Figure 5.7: Estimated NDVI for the urban areas of Varanasi

In the above indices, vegetation appears in shades of blue, sparse grasslands in light blue, open soils and barren lands in pale shades of yellow, and built concrete and stone structures, silt, and water bodies in darker shades of red.

5.3.4 Analysis of Shannon's Entropy Approach

The land use of the district was also analyzed by creating concentric semi circular as per Shannon's Entropy approach. The buffer zones of 2 km each was created around the central part of the city. The demarcation of the areas can be seen in Figure 5.8. As shown in Figure, every circle is 2km further away from the previous one and land use change in each buffer zone is obtained. The build up area and changing urban area pattern with respect central area of the Varansi city is also estimated (Figure 5.9). The circles are labeled from 1 to 17, 1 being the closest to the central city area and 17 being the farthest.

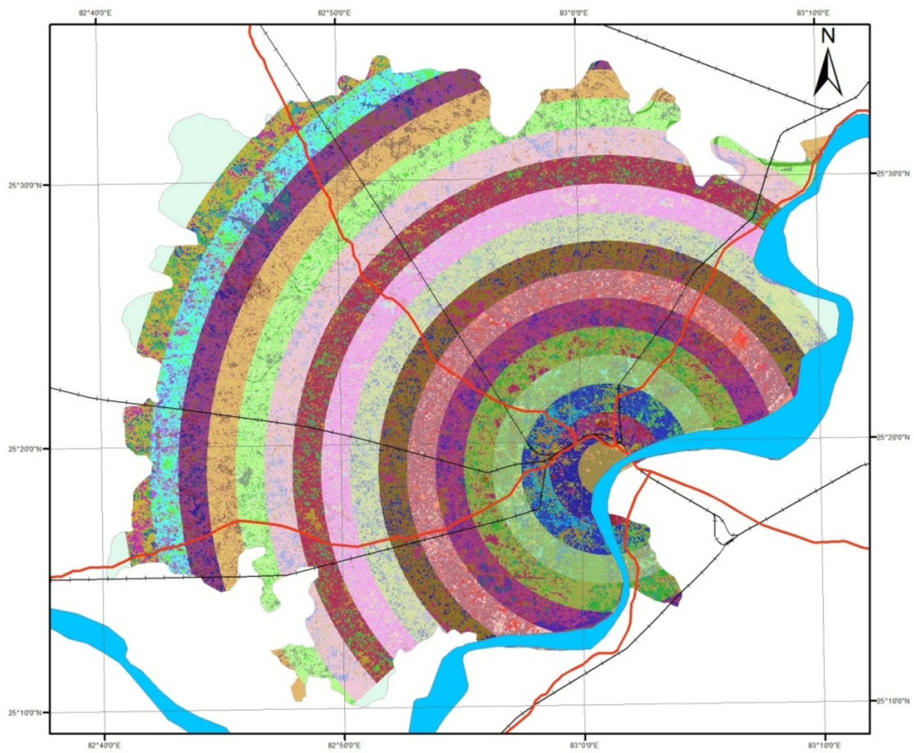


Figure 5.8: Concentric zones created for detailed land use analyses of Varanasi district

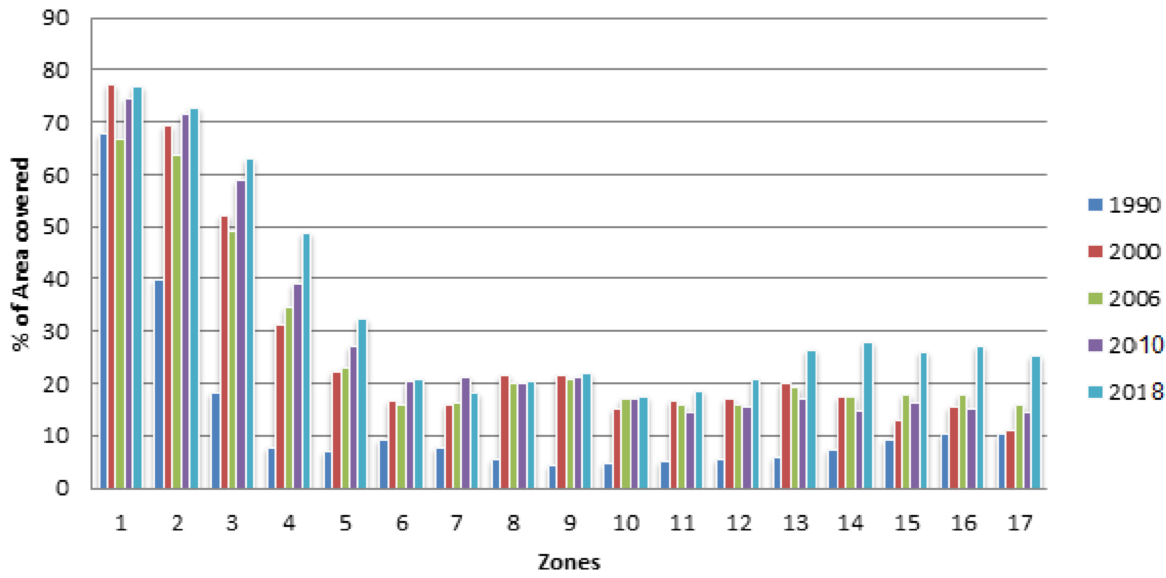


Figure 5.9: Percentage of Urban area within the concentric zones

It is obvious that the total surface area covered by the different zones will be different and so the exact area values for land use classes will be useless. Therefore, percentage values were calculated and plotted (as shown in Figure 5.9) for all the zones. The first clear thing visible on the graph is also the most obvious. The zones closer to the central city area are more built up than the outer areas. On closer inspection, one can see that as we move from zone 1 outwards, the urban area is reducing in percentage till around zone 6 (i.e. 12 km outward). After zone 6, one can see a slight upward trend which peaks at zone 9 and then goes down again. It is to be noted that zone 6 can be considered as the outer ring for the Varanasi city area. The built up areas outside of zone 6 will mainly consist of smaller residential areas and villages. So we can say that the villages are built more close to zone 9 when compared to zone 6,7 and 8. It should be noted that only four zones (viz. zone 4, 5, 7 and 10) show consistent growth of urban area within them through the time period being studied. Zones 1, 2 and 3 show decrease in built up area from the year 2000 to 2006. These areas then again get built up in 2010 which may be an indication of flood damage in the central city area in the year 2006. Another thing to notice is that from 2010 to 2018, there has been sudden increase in built up area in the outer zones of the district. This shows that more and more houses are being built in the villages in the north-western part of the district.

In Figures 5.10 to 5.13, various components of land use land cover are shown with their variation at different buffer zones and at different time span.

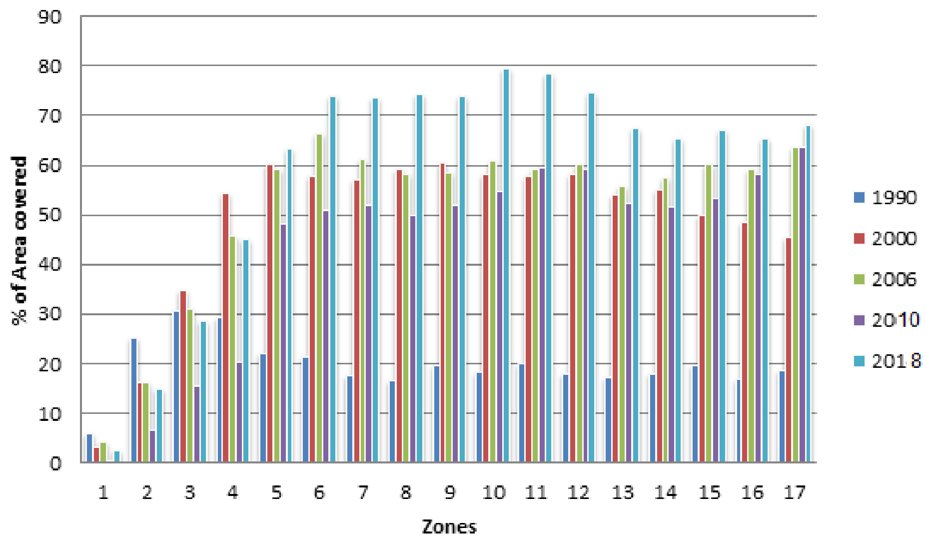


Figure 5.10: Percentage of area covered by Agriculture and Other vegetation within the concentric zones

In Figure 5.10, the percentage of area covered by Agricultural use and other vegetation is plotted. Those two areas were added together as this study is focused on whether the area is built up and therefore impervious or not. As expected, such impervious areas are in very low percentage near zone 1. As we move outwards this area increases and holds around 60% approximately. We see a significant increase in this area from the year 2010 to 2018 especially in zones 4 to 11. This suggests a large conversion of open land area to agriculture.

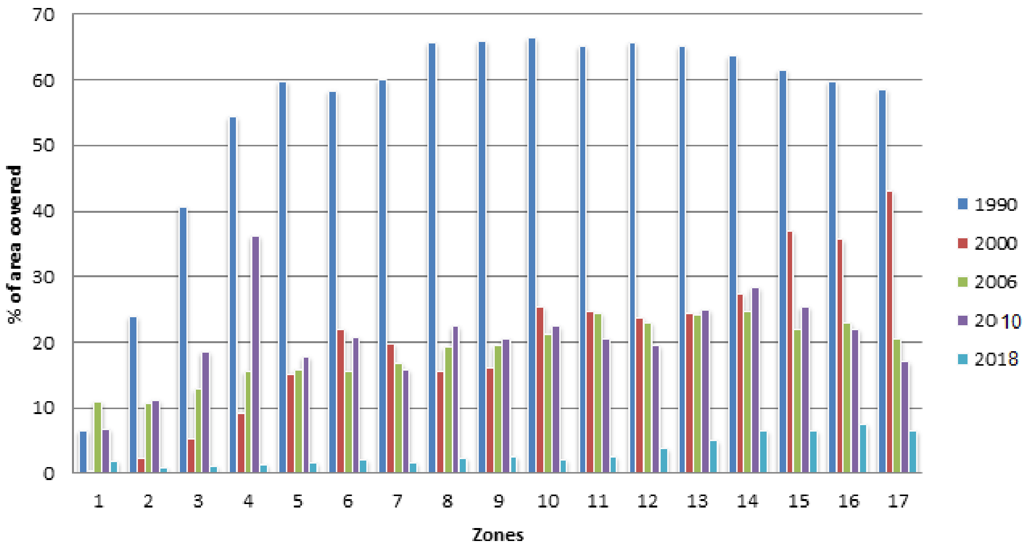


Figure 5.11: Percentage of area covered by open land

This reduction of open land to agricultural and urban areas is clearly seen in the graph plotted in Figure 5.11 where we can see how significantly the open land area has reduced especially from 1990 to 2000. This abrupt fall looks unusual but is probably not since we are dealing with duration of ten years.

The land use of the city area was also studied in another aspect which attempted to see in which direction the city has grown during the time period of this study. Seven triangular zones were created keeping one central point as the common centre (as shown in Figure). In a similar fashion, the data gathered was plotted in graphs and interpreted.

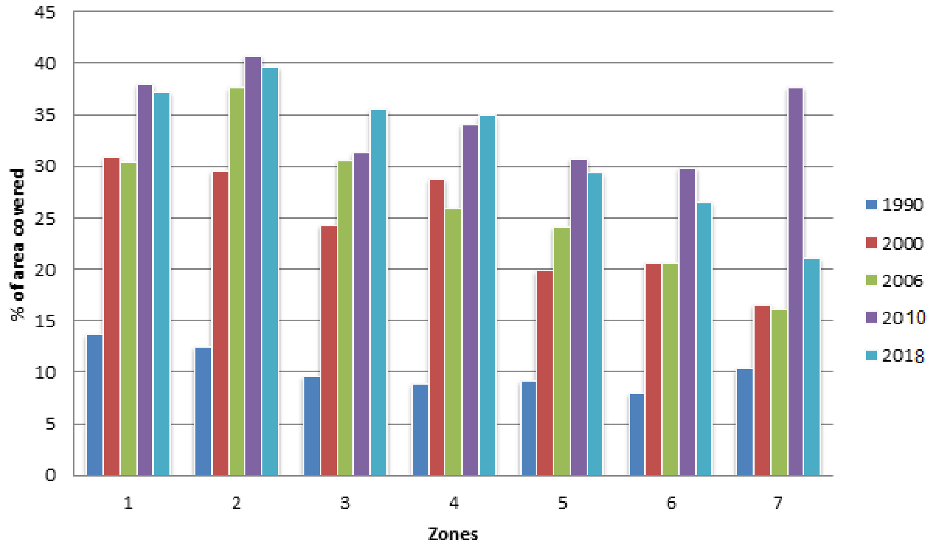


Figure 5.12: Percentage of area covered by Built up land

In Figure 5.12 we can see that the urban growth of the city has happened more in zones 1 and 2 when compared to other zones. Zones 1 and 2 correspond to the south-western parts of the city. So the city has shown bias in urban growth towards the south-west direction. In Figure 5.13, which shows the percentage area of vegetation in the different zones, it is seen that there is more vegetation coverage in the zones 5, 6 and 7 in relation with other zones. In is to be noted that these zones corresponds to the northern parts of the city.

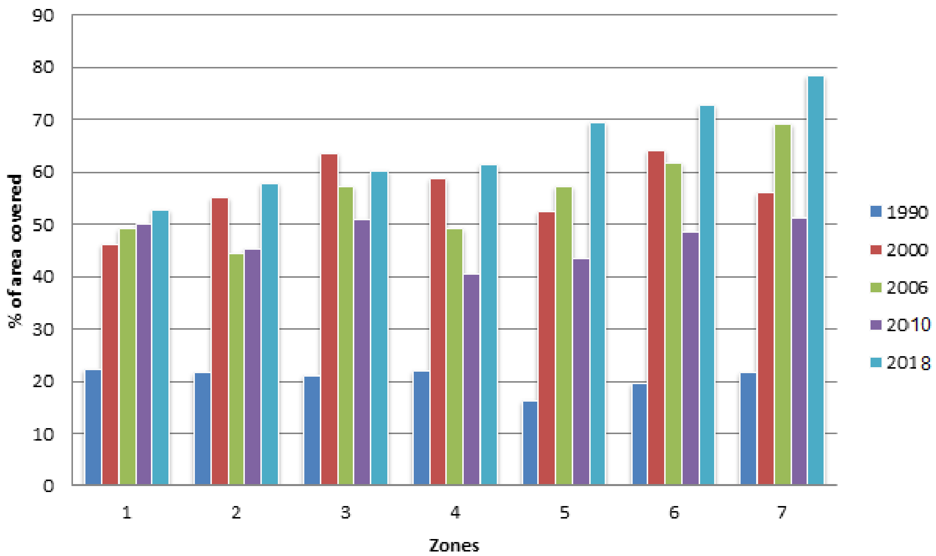


Figure 5.13: Percentage of Area covered by Vegetation

In addition to the previous approach, in entropy analysis, the buffer zones were developed along the Railway line and along the Main Road (National Highway). The results obtained for urban development and open land are shown in Figure 5.14 and 5.15, respectively.

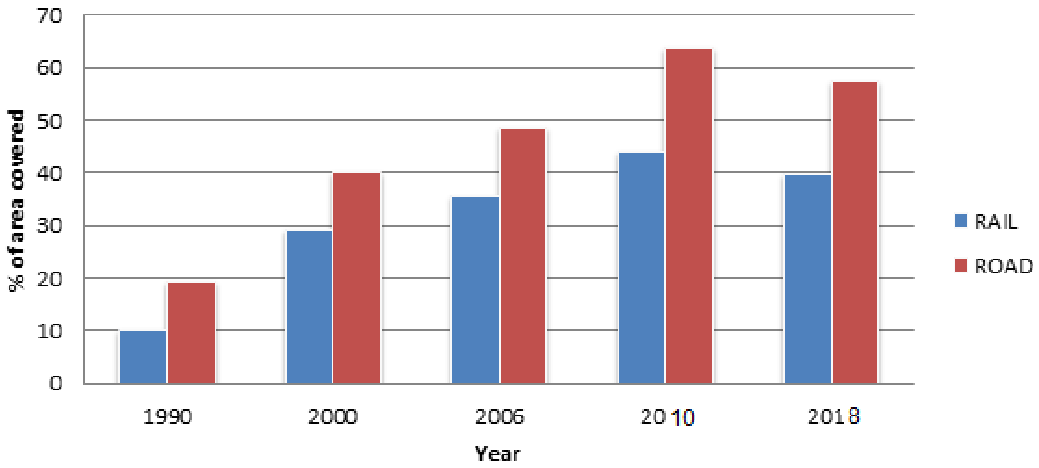


Figure 5.14: Urban area close to railroad and national highways

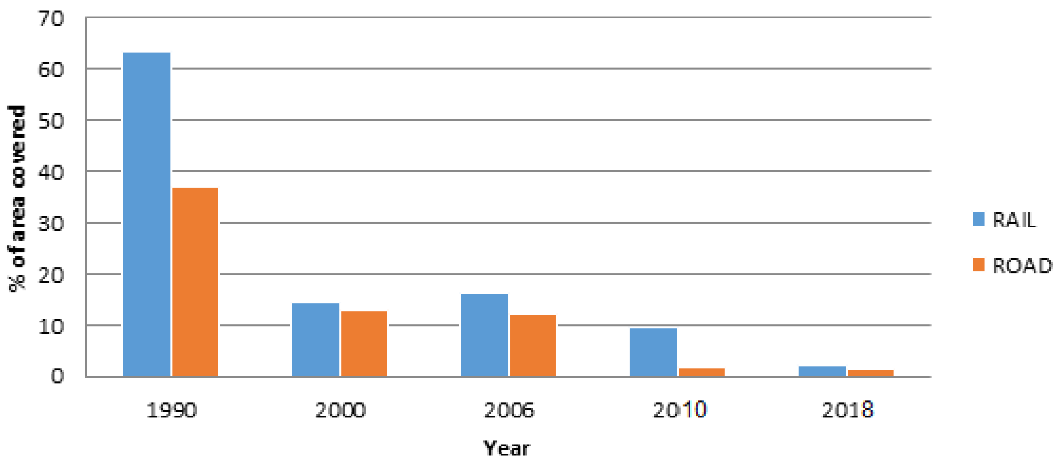
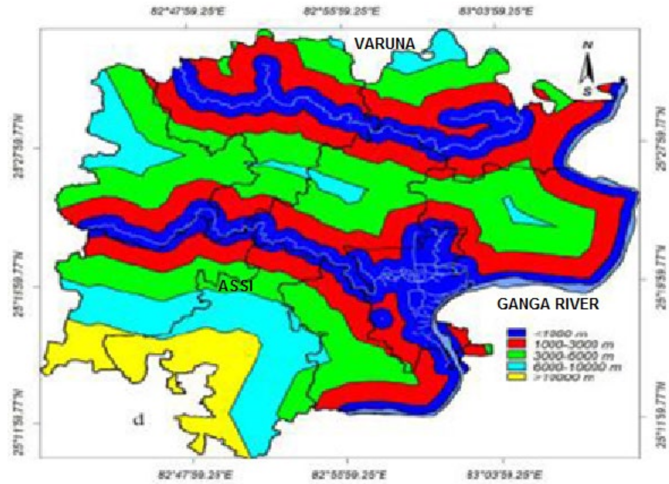


Figure 5.15: Open Land close to railroads and national highways

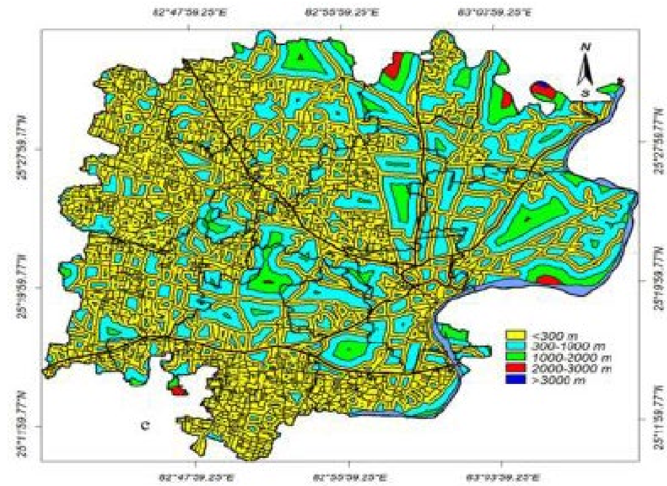
The land use of areas adjacent to the National highways crossing the district was also measured and studied. A buffer of 50m on either side of the railroads and highways was created and land use data was analyzed for that area. As shown in the graphs (Figure 5.14), one can see the significant increase in built up and close to national highways and railroads in the district. It is notable that more area was converted into urban close to national highways when compared to the railroads.

Another thing to be noted is that urban area has reduced slightly from the year 2010 to 2016. This may suggest movement of people from such areas to other areas.

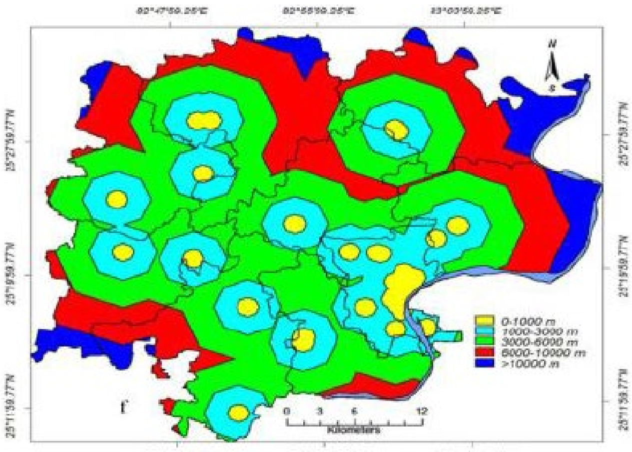
In addition, the maps were also obtained by considering population settlement along rivers, along Road, and along well known hospitals (Source: Rai et al., 2018) (Figure 5.16).



(a) Development along rivers at Varanasi



(b) Development along roads at Varanasi



(c) Development along well known hospitals

Figure 5.16: Urban sprawl along rivers, roads and hospitals in Varanasi

CHAPTER 6

STATISTICAL ANALYSIS OF RAINFALL, TEMPERATURE AND SOLAR RADIATION AT VARANASI

Rainfall, temperature and solar radiation trend of Varanasi has been analyzed using statistical methods to develop the trend and to simulate future scenarios of trend for urban water management.

6.1 Statistical Tests

Rainfall is one of the most important parameter of hydrologic cycle to decide the livelihood of people, enhance irrigation, development of urban and industrial regions, and required to maintain the ecology of the environment. Moreover, the rainfall is an essential input parameter for hydrologic cycle and is the primary source of runoff (Beven, 2001b). It is implied that the rainfall is a natural phenomenon occurring due to atmospheric and oceanic circulation (local convection, frontal or orographic pattern) and has large variability at different spatial and temporal scales. However, this input is subjected to uncertainty and stochastic errors (Jakeman and Hornberger, 1993; Beven, 2001a). Worldwide many attempts have been made to model and predict rainfall behaviour using various empirical, statistical, numerical and deterministic techniques (Namias, 1968; Koteshwaram and Alvi, 1969; Ramamurthy et al. 1987; Jha and Jaiswal, 1992; Chiew et al, 1993; Kuo and Sun, 1993; Langu, 1993; Meher and Jha, 2011(a); Meher and Jha, 2011(b)). They are still in research stage and needs more focussed empirical approaches to estimate and predict rainfall accurately.

Next, it is understood that the steady increase in global temperatures (and accompanying climate changes) in the past 150 years is simply an expression of natural variability, or they are a direct result of mankind's activities (Zoback 2001). In India, continuous increase in temperature has been observed in urban area during recent years, which is mainly due to unplanned urbanization with a rapid population migration from rural areas. In India, 27.78% of the total population is living in urban areas (Census 2001), which is 4.4% greater than in 1981. Several studies have shown that there is a striking difference in temperatures in urban and surrounding rural areas. The urban areas are found to be generally warmer than the surrounding rural parts (Oke 1995) and this phenomenon may be related to the term, "urban heat island."

Solar radiation is the source of energy for all the atmospheric activities. The solar radiation is nearly normal to the earth's surface near the equator. Therefore, the insolation is high at low latitudes whereas it will be low at high latitudes. These differences in insolation are primarily responsible for the general circulation of earth's atmosphere.

Prior to applying tests to identify precipitation trends over the time series from selected stations, data were tested according to the tests' requirements. The trend-free pre-whitening (TFPW) approach was applied to eliminate serial correlations in the time series data. The magnitude of the slope in time series data was calculated using Sen's slope method. The statistical methods used are briefly discussed below.

6.1.1 Autocorrelation and TFPW

Removing serial dependence is one of the main problems in testing and interpreting time series data. Applying nonparametric tests to detect trends can significantly affect the results. Therefore, all of the rainfall time series data was first tested for the presence of autocorrelation coefficient (r_1) at a 5% significance level, using a two-tailed test: The autocorrelation coefficient value of was tested against the null hypothesis at a 95% confidence interval, using a two-tailed test: If falls between the upper and lower limits of confidence interval (the data are considered serially correlated), the methods of pre-whitening, variance correlation (Hamedand Rao, 1998), and trend-free prewhitening (TFPW) approach (Yue et al., 2002) have been proposed. In this study, for the stations where serial correlations were detected in the data, the TFPW approach was applied to remove the correlation for both tests (Mann-Kendall and Spearman's rho). Other researchers (Shadmani et al., 2012; Onoz and Bayazit, 2012; Yaseen et al. 2013; Blain, 2013; Yaseen et al., 2014) have also used this approach to eliminate serial correlation in time series data.

$$r_1 = \frac{\sum_{i=1}^{n-1} \left(X_i - \overline{X}\right)\left(X_{i+1} - \overline{X}\right)}{\sum_{i=1}^{n} \left(X_i - \overline{X}\right)^2}. \tag{6.1}$$

$$r_1\,(95\%) = \frac{-1 \pm 1.96\sqrt{(n-2)}}{n-1}. \tag{6.2}$$

6.1.2. The Mann-Kendall Test

The rank-based nonparametric Mann-Kendall (Mann, 1945; Kendall, 1975) method was applied to the long-term data in this study to detect statistically significant trends. In this test, the null hypothesis (H_0) was that there has been no trend in precipitation over time; the alternate hypothesis (H_1) was that there has been a trend (increasing or decreasing) over time. The mathematical equations for calculating Mann-Kendall Statistics , S, V(S) and standardized test statistics (Z) are as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sig}\left(X_j - X_i\right) \tag{6.3}$$

$$\operatorname{sgn}\left(X_j - X_i\right) = \begin{cases} +1 & \text{if } \left(X_j - X_i\right) > 0 \\ 0 & \text{if } \left(X_j - X_i\right) = 0 \\ -1 & \text{if } \left(X_j - X_i\right) < 0, \end{cases} \tag{6.4}$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \tag{6.5}$$

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S < 0. \end{cases} \tag{6.6}$$

In these equations (6.3 to 6.6), Xi, and Xj are the time series observations in chronological order, n is the length of time series, t_p is the number of ties for pth value, and q is the number of tied values. Positive Z values indicate an upward trend in the hydrologic time series; negative Z values indicate a negative trend. If $|Z| > Z_{1-\alpha/2}$, (H_0) is rejected and a statistically significant trend exists in the hydrologic time series. The critical value of $Z_{1-\alpha/2}$ a p value of 0.05 from the standard normal table is 1.96.

6.1.3. Spearman's rho Test

Spearman's rho (Lehmann, 1975; Sneyers, 1990) test is another rank-based nonparametric method used for trend analysis and was applied as a comparison with the Mann-Kendall test. In this test, which assumes that time series data are independent and identically distributed, the null hypothesis (H_0) again indicates no trend over time; the alternate hypothesis (H_1) is that a trend exists and that data increase or decrease with i (Yue et al., 2002). The test statistics Rspand standardized statistics Zspare defined as

$$R_{sp} = 1 - \frac{6\sum_{i=1}^{n}(D_i - i)^2}{n(n^2-1)} \quad (6.7)$$

$$Z_{sp} = R_{sp}\sqrt{\frac{n-2}{1-R_{sp}^2}}. \quad (6.8)$$

In these equations Di, is the rank of ith observation, I is the chronological order number, n is the total length of the time series data, and Zsp is Student's - distribution with (n-2) degree of freedom. The positive values of represent an increasing trend across the hydrologic time series; negative values represent the decreasing trends. The critical value of tat a 0.05 significance level of Student's - distribution table is defined as $t_{(n-2,1-\alpha/2)}$ (Dahmen and Hall, 1990). If $|Z_{sp}| > t_{(n-2,1-\alpha/2)}$, ($H_0$) is rejected and a significant trend exists in the hydrologic time series.

6.1.4. Sen's Slope Estimator

Sen's nonparametric method (Sen, 1968) was used to estimate the magnitude of trends in the time series data:

$$T_i = \frac{x_j - x_k}{j - k}. \quad (6.9)$$

In this equation, x_j and x_k represent data values at time j and k, respectively. Consider

$$Q_i = \begin{cases} T_{(N+1)/2} & N \text{ is odd} \\ \frac{1}{2}\left(T_{N/2} + T_{(N+2)/2}\right) & N \text{ is even} \end{cases} \quad (6.10)$$

A positive Qi value represents an increasing trend; a negative Qi value represents a decreasing trend over time.

The Cross-correlation between different meteorological variables were also obtained using cross-correlation statistics.

6.2 Development of Intensity-duration Curves

After preliminary trend analysis of rainfall, temperature and solar radiation data the intensity-durationcurve were plotted for each variable. Intensity-duration curve (IDC) is one of the most informative methods of displaying the complete range of rainfall(or other variables) from extremely low values to high values. Itis a relationship between any given rainfall magnitude(or other variables) value and the percentage of time that this rainfall(or other variables) is equalled or exceeded and is the complement of the cumulative distribution function for rainfall(or other variables). In other words, an IDC represents the relationship between the magnitude and frequency of daily, weekly, monthly rainfall(or other variables) (or some other time interval) for a particular river basin/ area (e.g. Searcy, 1959; Institute of Hydrology, 1980; McMahon and Mein, 1986).

The procedure followed to obtain the IDC for rainfall of various return period are as given below (based on Sugiyama, 2003):

1. After construction of IDC curve for each year, read values of daily rainfall at

every 5% probability of exceedance.

2. Make separate table for each year rainfall Vs Probability of exceeedance.
3. Rank in ascending order of the rainfall values read from each frequency curve of a given N year term.
4. Calculate the plotting position with the following Weibull plotting formula, select the type probability paper to be used, and plot the data on the probability paper

$$P = \frac{m}{(n+1)} * 100 \qquad (6.11)$$

   where, P is the probability of all events less than or equal to each rainfall value, mis the rank of the event, and n is the number of events on record.
5. Visually fit a straight line through the estimated values.
6. Using straight line equation, get the rainfall value down from the best fit line at the chosen probability value for various return period (1 year, 2 year, 5 year, 10 year, 20 year, 50 year and 100 year)
7. Repeat steps 3 to 6 at suitable time intervals from 0 to 100 percent of the time axis (in the present case it is taken at every 5%).
8. Plot probability daily rainfall values read at suitable intervals and draw a smooth frequency curve of return period of 1 year, 2 year, 5 year, 10 year, 20 year, 50 year and 100 year.

Similar IDC curves can be developed for temperature, solar radiation and other variables too. Once the Intensity-duration curves(IDC)for different return periods are obtained, it can be readily used for estimating the design rainfall (or other variables) at various probability of exceedance.

It has been observed that the users and field engineers need generic equations instead of intensity duration curves of different return period for ready reference and easy computation of the rainfall (or other variables) values. Keeping this in view several empirical models based on different concepts and algorithms have been evolved in the present work.

Sigmoidal Function model:

$$y = \frac{ab + cx^d}{b + x^d} \qquad (6.12)$$

Here, a, b, c and d are constants and x is the probability of exceedance.

Rational function model:

$$y = \frac{a + bx}{1 + cx + dx^2} \tag{6.13}$$

Hyperbolic function model:

$$y = q_0 (1 + bx/a)^{(-1/b)} \tag{6.14}$$

Truncated Fourier series model:

$$y = a\cos(x + d) + b\cos(2x + d) + c\cos(3x + d) \tag{6.15}$$

Kappa series model:

$$y = \frac{\theta x^\eta}{\kappa^\eta + x^\eta} \tag{6.16}$$

Using equations (6.12) to (6.16), the rainfall, temperature and solar radiation values are estimated.

6.3 Stochastic Autoregressive Integrated Moving Average (ARIMA) Models

A model which depends only on previous outputs of a system to predict an output is called an autoregressive (AR) model. While a model which depends only on inputs to the system to predict an output is called a moving average (MA) model. The model derived from autoregressive and moving average processes may be a mixture of these two and of higher order than one as well, which is termed as a stationary ARMA model with its random shocks independent and normally distributed with zero mean and constant variance. A model for ARMA can be noted as ARMA (p, q) where p is the number of parameters for AR and q is the number of parameters for MA. This only models stationary dataset, i.e. the dataset for which residuals are independent for all periods of time.

ARIMA model is an extension of ARMA model in the sense that including autoregressive and moving average it has an extra part of differencing the time series. If a dataset exhibits long term variations such as trend, seasonality and cyclic components, differencing of dataset in ARIMA allows the model to deal with such long term variations. The ARIMA model includes three types of parameters which are: the autoregressive parameters (p), the number of differencing passes (d*),* and moving average parameters (q). In the notation introduced by Box and Jenkins, models are summarized as ARIMA (p, d, q). For example, a model described as ARIMA (1,1,1) means it contains 1 auto regressive parameter and 1 moving average parameter for the time series after it is differenced once to attain stationary. The general form of the ARIMA model describing the current value X_t of a time series is:

$$\varphi_1 (B) (1-B) X_t = \theta_1 (B) e_t \qquad (6.17)$$

where: φ_1= Auto regressive parameter, and θ_1= Moving average parameter

Seasonal ARIMA is a generalization and extension of the ARIMA method in which a pattern repeats seasonally over time. In addition to the non-seasonal parameters, seasonal parameters for a specified lag (established in the identification phase) need to be estimated. These parameters are analogous to the simple ARIMA parameters: seasonal autoregressive (P), seasonal differential (D), and seasonal moving average (Q). The seasonal lag used for the seasonal parameters is usually determined during the identification phase and must be explicitly specified. For example, a seasonal ARIMA model described as $(1,1,1)(1,1,1)^{12}$ includes 1 auto regressive parameter,1 moving average parameter,1 seasonal auto regressive parameter and 1 seasonal moving average parameter for the time series after it is differenced once at lag 1 and differenced once at lag 12. The general form of the seasonal ARIMA model describing the current value X_t of a time series is:

$$(1-\varphi_1 B)(1-\alpha_1 B^{12})(1-B)(1-B^{12}) X_t= (1-\theta_1 B)(1-\gamma_1 B^{12})e_t \qquad (6.18)$$

where: φ_1=Non seasonal auto regressive parameter, α_1=Seasonal auto regressive parameter

X_t=Current value of the time series, B=Backward shift operator $BX_t=X_{t-1}$ and $B^{12}X_t=X_{t-12.}$

1-B=First order non seasonal difference, $1-B^{12}$=First order seasonal difference

θ_1=Non seasonal moving average parameter, γ_1=Seasonal moving average parameter
e_t =Current error term of the time series

6.3.1 MODEL PERFORMANCE EVALUATION CRITERIA

Diagnostic checks

It is important to carry out diagnostic checks to test the adequacy of each model after the various models have been fitted to the data. One way to achieve this is by analyzing the residuals. It has been found that the overall adequacy of the model chosen is calculated effectively by analyzing a quantity Q known as Ljung-Box statistic (modified Box-Pierce statistic), (Yurekli et. al.; 2005, Sallehuddin et. al.; 2007, Mauludiyanto et. al.; 2010, Martins et. al.; 2011, Landeras et. al.; 2009) which is a autocorrelations residuals function and Chi-square is its approximate distribution. The diagnostic check stage determines whether residuals are independent or not. The residuals independence can be determined by obtaining the residual autocorrelation function (RACF) using the Q(r) statistic suggested by Ljung and Box (1978). A test of this hypothesis can be done for the adequacy of the model by selecting a meaning level and then comparing the value of the calculated X^2 to the actual X^2 value of the table i.e. the Q(r) statistic is compared to the critical values of the Chi-square distribution. If the calculated value is less than the actual X^2 value, then the model is adequate; otherwise, if the model is specified correctly, the residuals should be uncorrelated and Q(r) small (probability should be large). A large value of Q(r) means that the pattern chosen doesn't suit well. The Q(r) statistic calculated by the Ljung-Box statistic which can be expressed as

$$Q(r) = n(n+2)\sum r^2(j)/(n-j) \qquad (6.19)$$

where r (j) is the estimated correlation at lag j and n is the number of observations in the series. Therefore, to obtain the best model, diagnostic checking of non-significance of autocorrelations of residuals via Ljung-Box test (modified Box-Pierce test) (Q-test based on Chi-square statistics) is performed.

Akaike Information Criterion

The criterion for selecting the most appropriate model in time series analysis is that several models appropriate for representing a given set of data may be used.

Sometimes, the choice is easy, but other times, it may be much difficult. Therefore, numerous criteria are introduced for comparing models that are different from methods of model recognition. Some of them are based on statistics summarized from residuals that are computed from a fitted model. In the present study Akaike Information Criterion (AIC) is considered. AIC is an information criterion for model selection based on the statistical likelihood function.AIC can be computed from least square statistics, using the following expression

$$AIC = n\,log\,(SSR/n) + 2k \quad (6.20)$$

where SSR is the sum squared of residuals, n is the sample size and k is the number of parameters. The best model in a set can be the one which has the minimum AIC value.

Error analysis

There is no single performance criterion available to select the best model. Rather many performance criteria are used to select the best one. Each performance criteria indicates a particular capability of the model and hence various measures are used. But all the performance criteria are estimated based on the observed and predicted values. In the present study, to identify the best fitted model, the predicted values using the 9 different seasonal ARIMA models are compared to the observed data of the validation period (1991-2010).

In previous studies of ARIMA model, relative error (Weesakul and Lowanichchai 2005), mean absolute error (Somvanshi et al. 2006) and root mean square error (Otok and Suhartono 2009, Tularam and Ilahee 2010) have been used to evaluate performance of the developed model. However, in the present work, to evaluate the performance of the best ARIMA model at each station, two different measures are used to select the best model: coefficient of determination (R^2) and model efficiency (E_{NS}) which can be expressed as given below in the following equations.

$$R^2 = \frac{\left[\sum(R_o-\overline{R_o})(R_f-\overline{R_f})\right]^2}{\sum(R_o-\overline{R_o})^2\sum(R_f-\overline{R_f})^2} \quad (6.21)$$

$$E_{NS} = 1 - \frac{\sum(R_o - R_f)^2}{\sum(R_o - \overline{R_o})^2} \qquad (6.22)$$

where R_o is the observed rainfall at time t, R_f is the forecasted rainfall at time t, and $\overline{R_o}$ and $\overline{R_f}$ are mean values of observed and forecasted rainfall series. The E_{NS} is the difference, on average, of the observed and predicted data and offers a general picture of the errors involved in prediction. R^2 gives impartial result as it takes mean values of both the observed and predicted data.

6.4 ANALYSIS OF RESULTS

6.4.1 Statistical Test

In the present work daily rainfall data from 12 rain gauge stations of Varanasi region, (Varanasi(BABAER), Gangapur, Gyanpur, Varanasi(1), Varanasi(2), Varanasi(BHU), Varanasi(RGhat), Fatehpur, Haidergarh, Ramsandighat, Bhadohi, Sakaldiha) were collected for the years 1971-2019 (Figure 6.1). It has been observed that magnitude of the monsoon rainfall has gone up and found to be more than 200 to 300 mm in few years. However, it is interesting to note that the total annual rainfall remains almost same (Figure 6.2). This phenomena clearly indicates the increase in intensity of rainfall at Varanasi during monsoon period, which needs to be properly understood and managed. The basic statistics, as shown in Table 6.1, substantiates the same and indicates higher skewness and peakedness (kurtosis) in rainfall data.

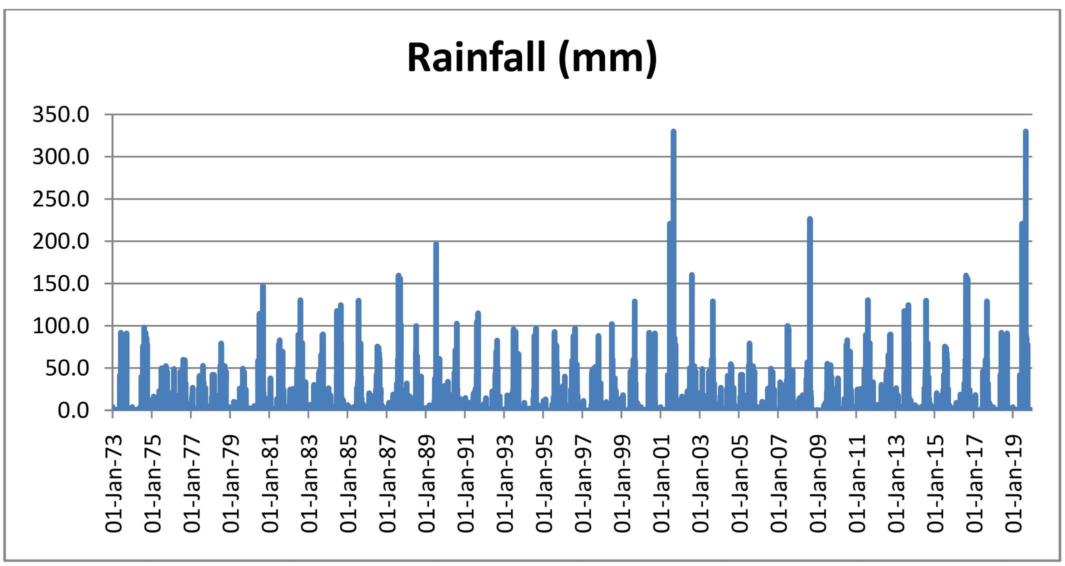


Figure 6.1: Daily mean rainfall hyetograph of Varanasi

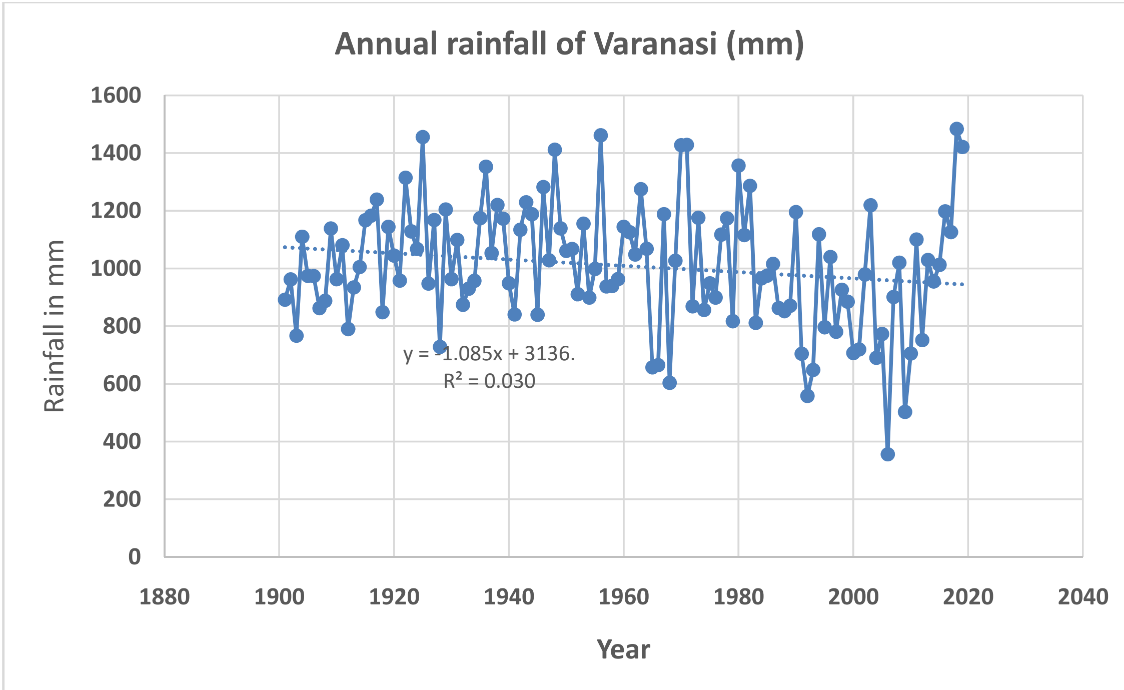


Figure 6.2: Annual Rainfall at Varanasi

Table 6.1: Basic statistics of different variables observed in Varanasi

Statistical Parameter	Rainfall (mm)	Temp(max) in oC	Temp(min) in oC	SolarRAD
Mean	2.88	31.71	19.71	15.6
Standard Error	0.09	0.05	0.05	0.06
Median	0	32.2	21.6	16.1
Mode	0	33	26.2	0
Standard Deviation	11.76	6.05	6.95	7.53
Sample Variance	138.2	36.66	48.37	56.67
Kurtosis	130.72	-0.09	-1.14	7.27
Skewness	8.73	-0.23	-0.38	0.82
Range	330	44.1	36.7	99.1
Minimum	0	4.5	1.4	0
Maximum	330	48.6	38.1	99.1
Sum	49424.6	544396.62	338305.14	267850.74
Count	17166	17166	17165	17165
Largest(1)	330	48.6	38.1	99.1
Smallest(1)	0	4.5	1.4	0
Confidence Level(95.0%)	0.18	0.09	0.1	0.11

The maximum and minimum temperatures of Varanasi are obtained for the years 1971-2019 are collected and are shown in Figure 6.3 and 6.4. It has been observed that the mean of maximum and minimum temperatures are not varying significantly with time. But, two observations are made from these data sets, which are as follows:

(a) The maximum of maximum temperature has increased in last one decade, and;

(b) The variability in maximum temperature has also increased.

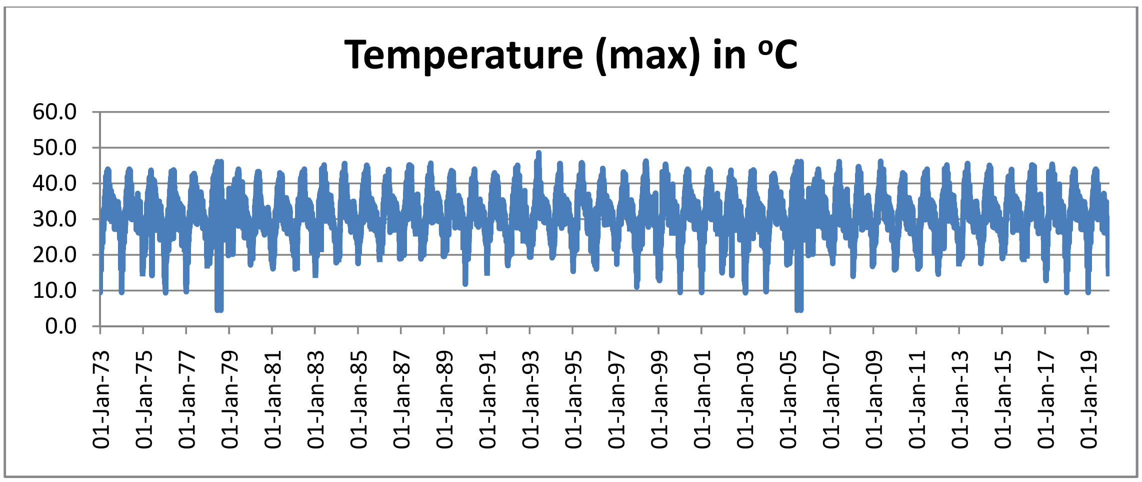


Figure 6.3: Maximum Temperature variation at Varanasi

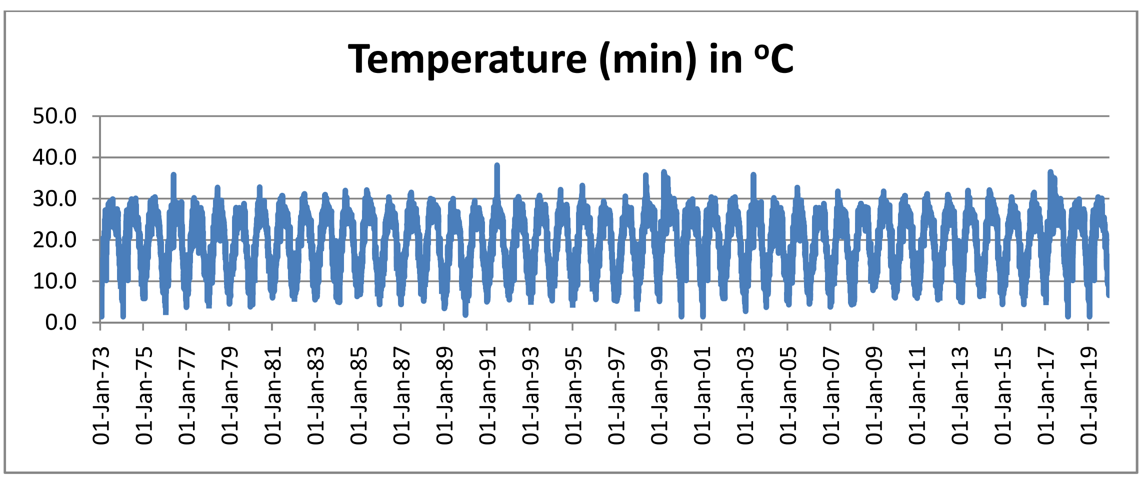


Figure 6.4: Minimum Temperature variation at Varanasi

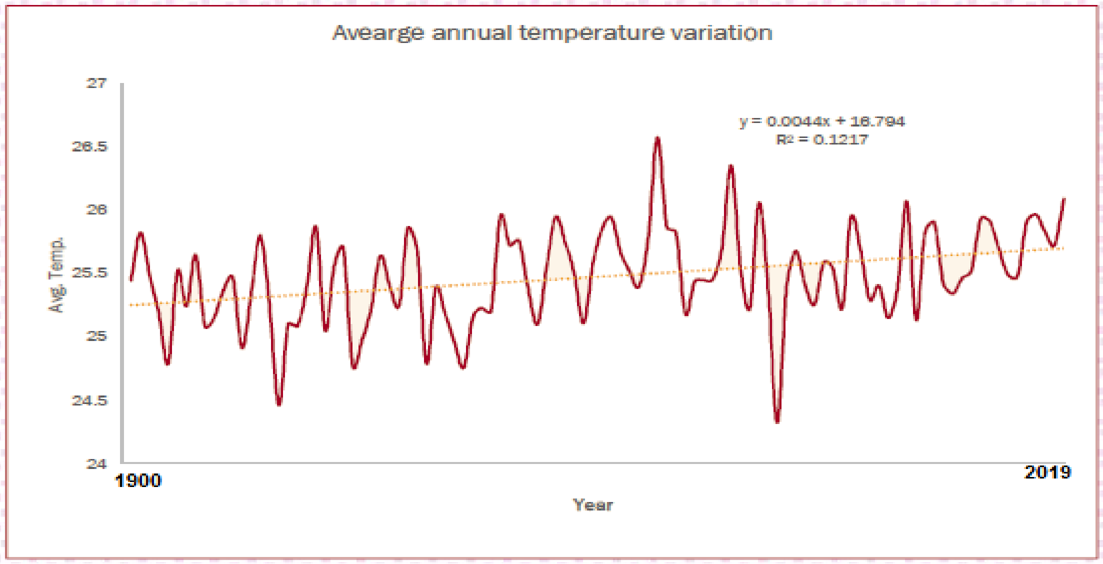


Figure 6.5: Minimum Temperature variation at Varanasi

Solar radiation time series data plotted are given in Figure 6.6. There is no significant variation, but slight reduction in recent past. However, some spike are observed, which may be due to solar position and its intensity.

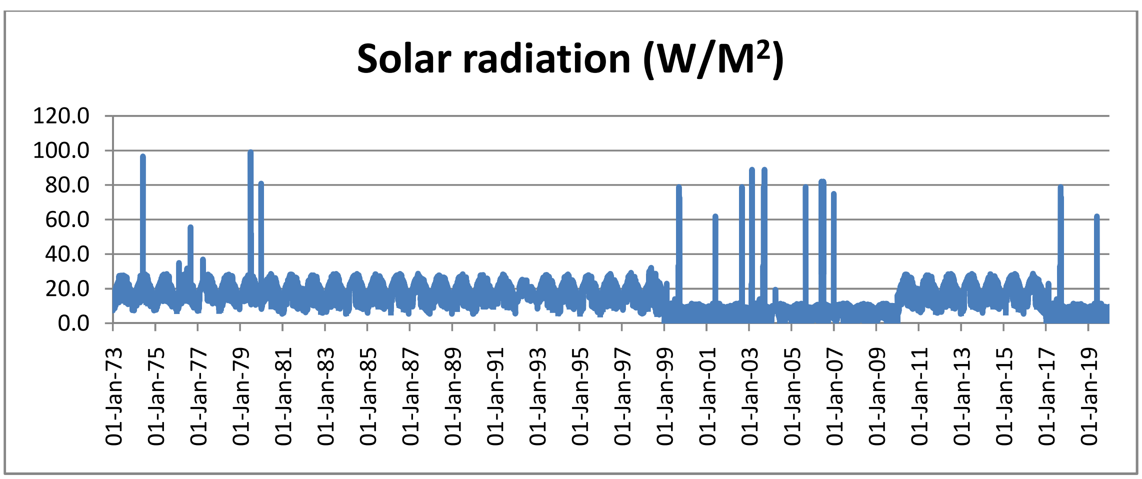


Figure 6.6: Solar Radiation at Varanasi

A cross-correlation between all the variables is developed and shown in Table 6.2

Table 6.2: Cross-correlation and Co-variance between various parameters

Cross-correlation

Parameter	**Temperature (Max) in ^{0}C**	**Temperature (Min) in ^{0}C**	**Solar radiation (cal/cm^2)**	**Rainfall (mm)**
Temperature (Max)	1			
Temperature (Max) in ^{0}C	0.77	1		
Solar radiation(cal/cm^2)	0.35	0.16	1	
Rainfall (mm)	-0.01	0.16	-0.13	1

Co-variance

Parameter	**Temperature (Max) in ^{0}C**	**Temperature (Min) in ^{0}C**	**Solar radiation (cal/cm^2)**	**Rainfall (mm)**
Temperature (Max)	36.77			
Temperature (Max) in ^{0}C	32.74	48.25		
Solar radiation(cal/cm^2)	16.13	8.38	20.93	
Rainfall (mm)	-0.56	12.74	-10.96	124.07

6.4.2 Intensity-duration Curves

After preliminary trend analysis of rainfall, temperature and solar radiation data the intensity-duration curve were plotted for each variable. Intensity-duration curve (IDC) is one of the most informative methods of displaying the complete range of rainfall (or other variables) from extremely low values to high values. Some of the models provided reasonably good results are given below in Figure 6.7.

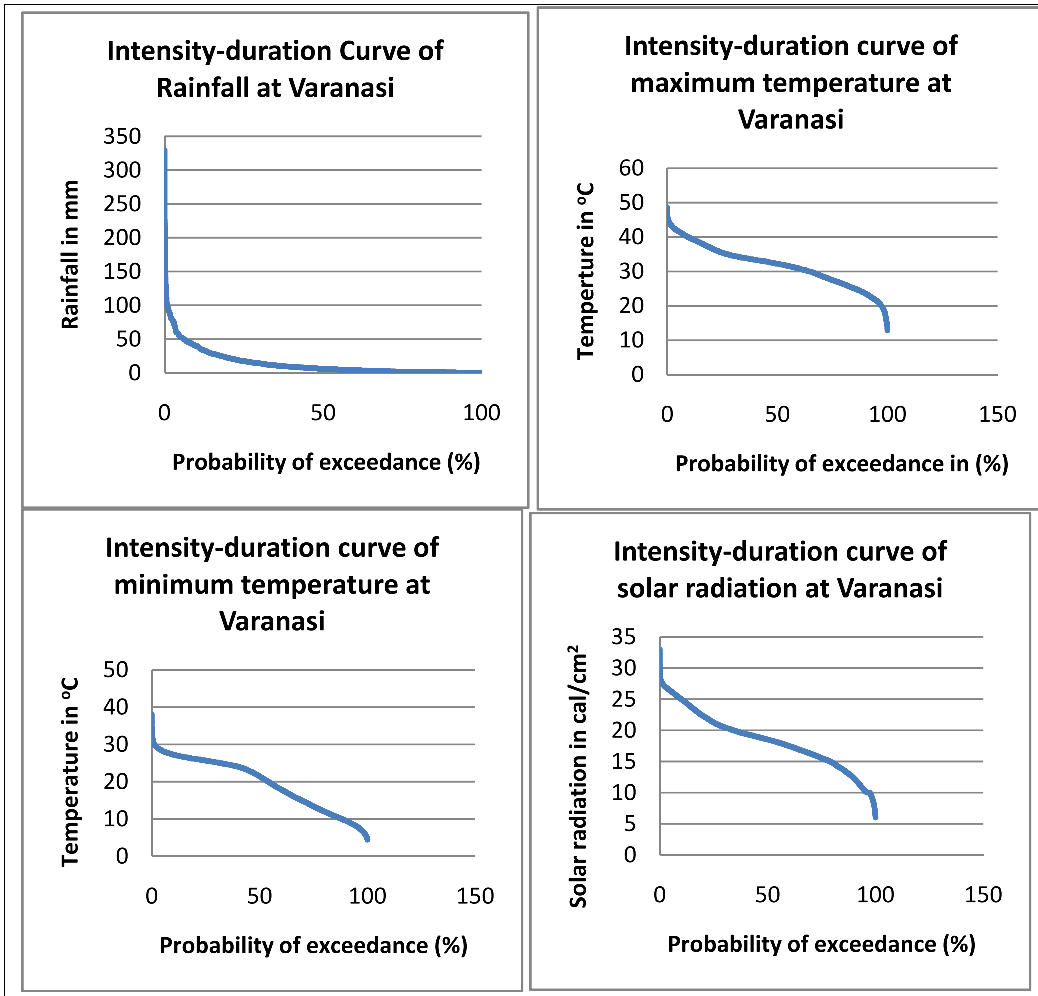
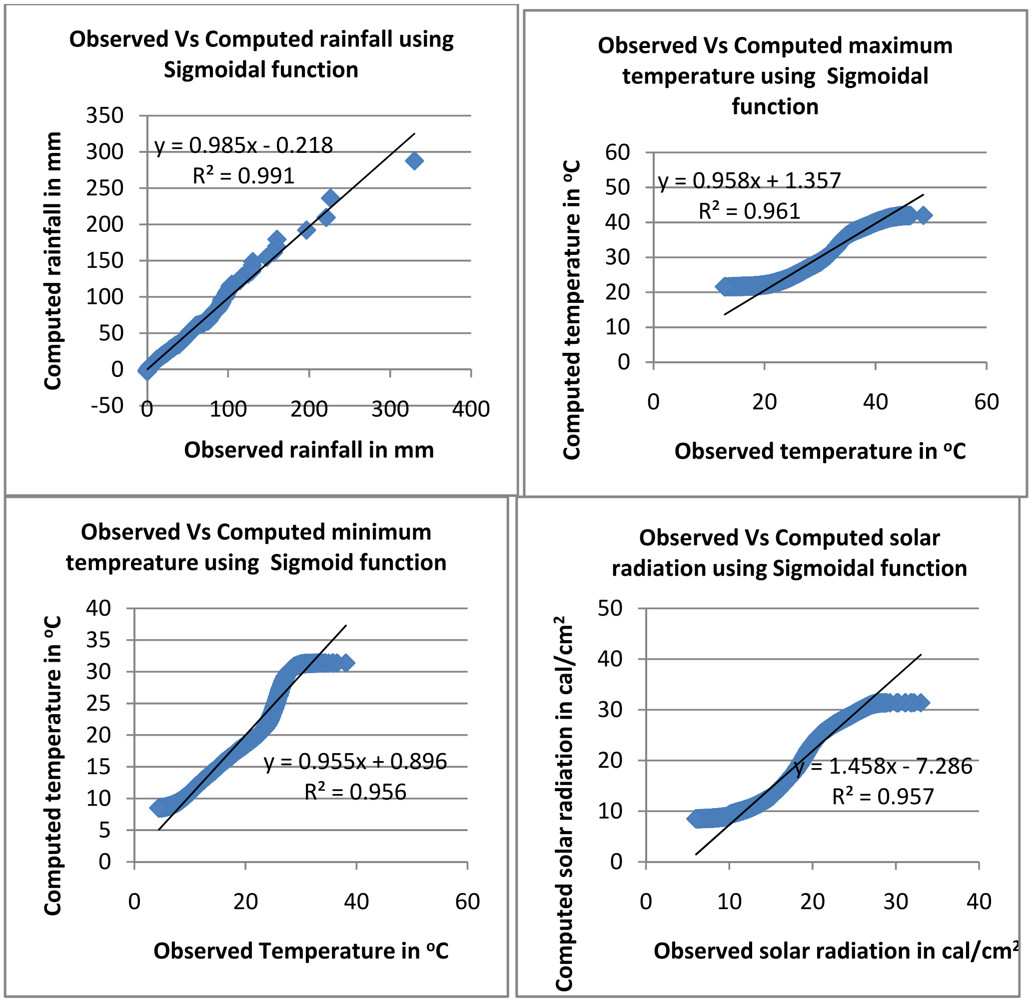
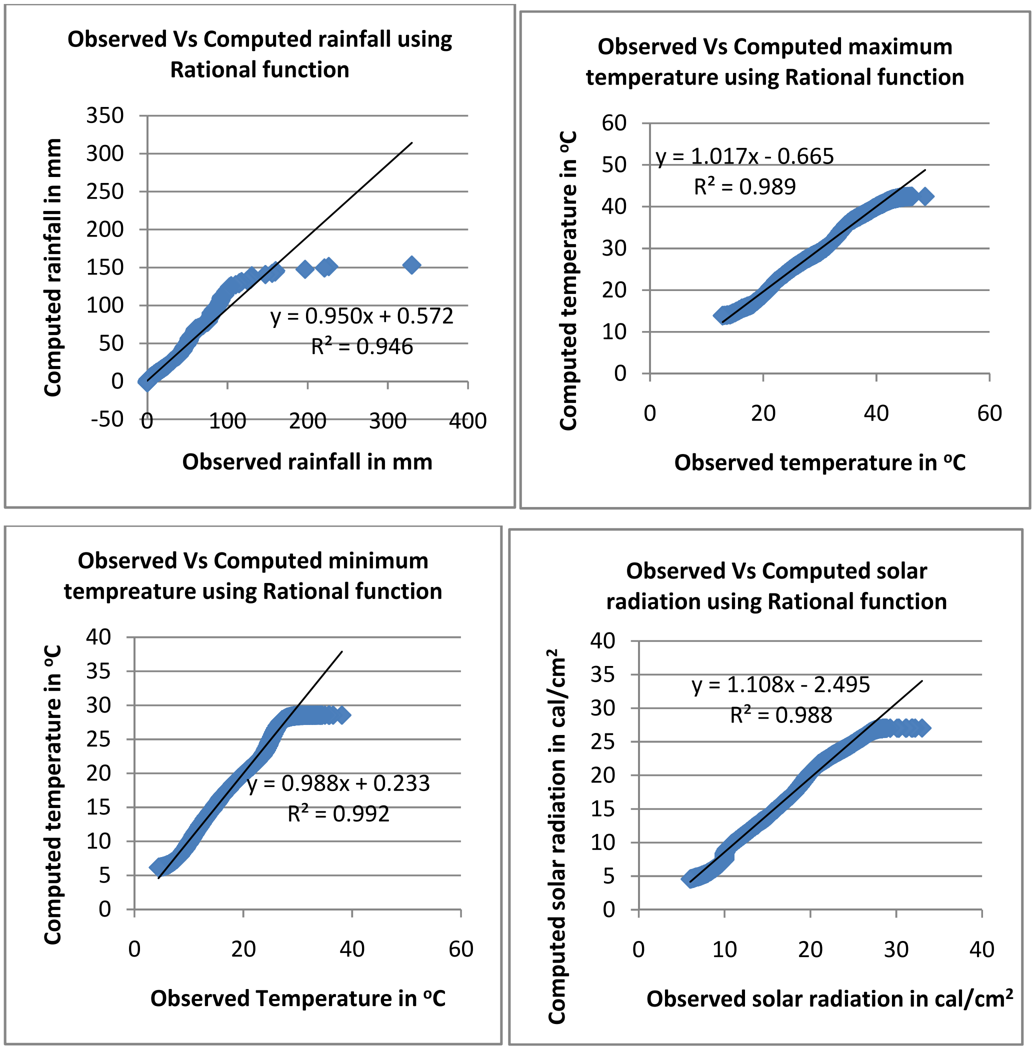


Figure 6.7: Intensity-duration curves for all the variables

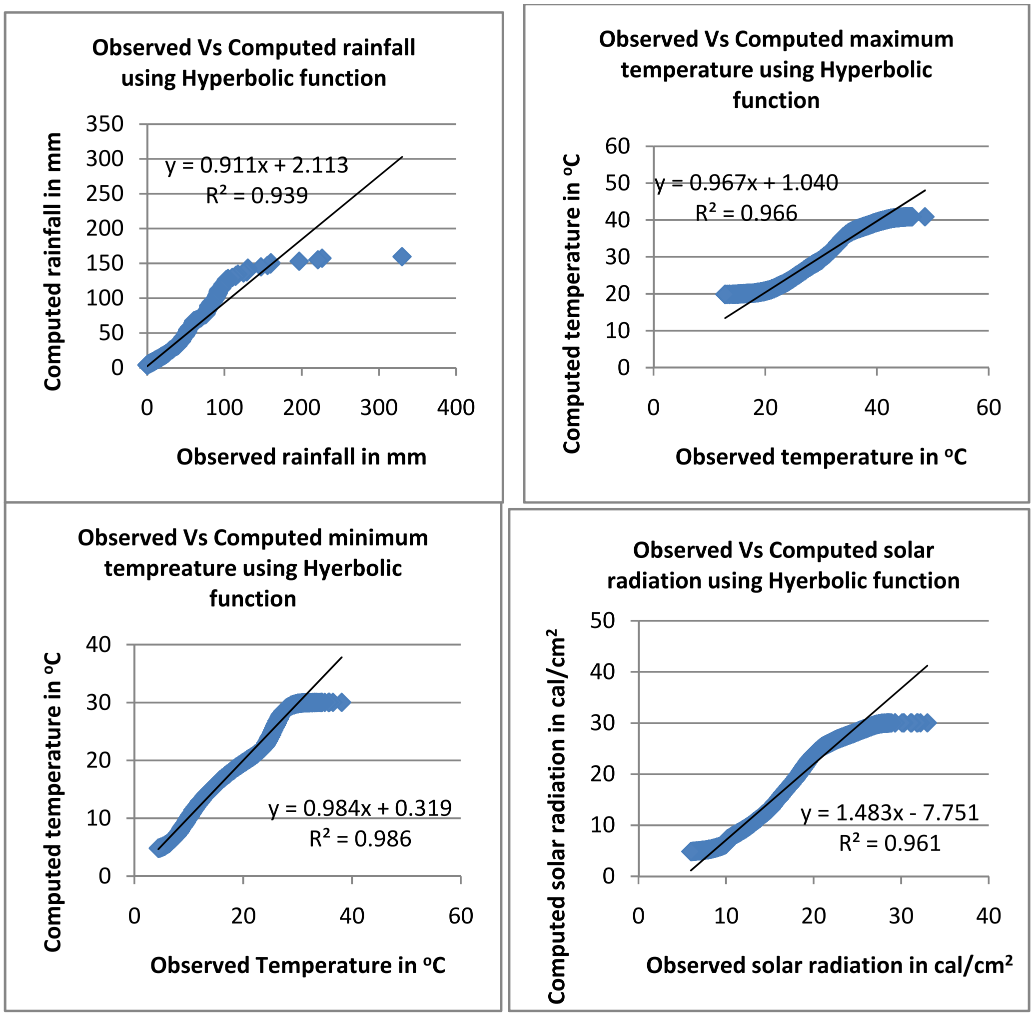
In case of rainfall the Sigmoidal function model provided best results followed by Rational function model and Hyperbolic function model (Figure 6.8). However, in case of maximum temperature, minimum temperature and solar raditation, the Rational function modelprovided best results followed bySigmoidal function model and Hyperbolic function model. It is also observed that there is not much variation in the correlation statistics and in all the cases values of r^2 has been observed higher than 0.9.



(a) Sigmoidal function model



(b) Rational function model



(c) HyperbolicRational function model

Figure 6.8: Sigmoid, Rational and Hyperbolic function models for rainfall, temperature and solar radiation variable at Varanasi

6.4.3 ARIMA Model for forecasting and scenario development

The rainfall, and temperature data for minimum and maximum values were plotted and time series analysis was done. In the next step, all the data except solar radiation data were decomposed and are shown in Figure 6.9. In each figure the 1st row, 2nd row and 3rd row indicates signal, trend and seasonality respectively for rainfall, minimum temperature and maximum temperature.

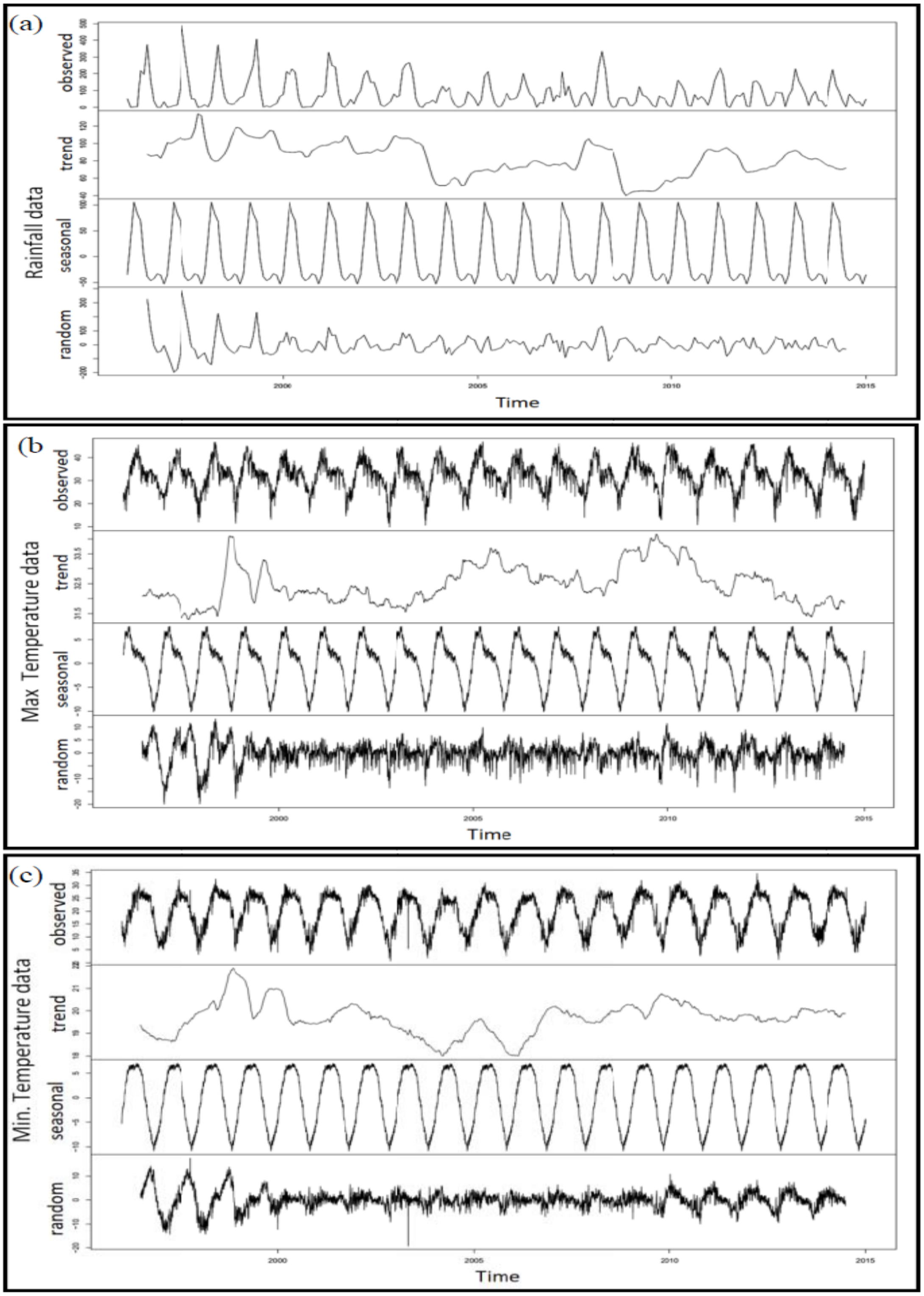


Figure 6.9: Decomposition of Rainfall and Temperature Data to test trend and seasonality

The ACF and PACF were calculated and ARIMA model parameters p, d, q were estimated. The Table 6.2 indicates the best fit ARIMA model for Varanasi and forecasted rainfall, maximum and minimum temperature using ARIMA model in Figure 6.10.

Table 6.2: ARIMA Models with variation in input parameters

Sl. No.	Variable	ARIMA Model
1	Rainfall	(1,1,1)
2	Temperature (Max.)	(1,0,1)
3	Temperature (Min.)	(1,0,1)

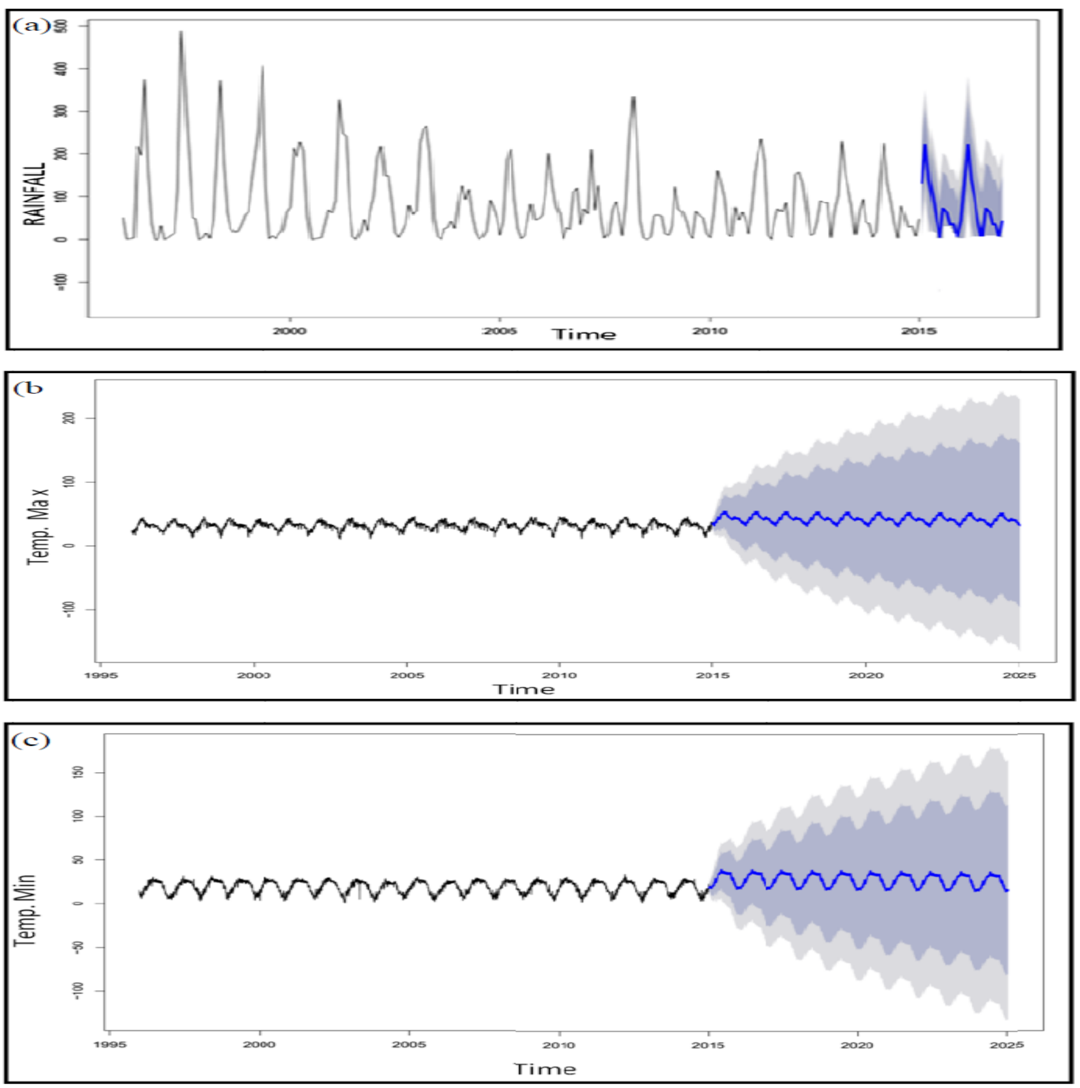


Figure 6.10: Forecasted Rainfall, Maximum Temperature and Minimum Temperature using ARIMA model

CHAPTER 7

WATER QUALITY MONITORING AND ANALYSIS

7.1 Water Quality Analysis of River Ganga at Varanasi

All over the world, rivers are now under severe threat. Even though non-existence of life without freshwater is a recognizable and acceptable fact everywhere on the planet, the pure rivers and freshwater sources are being abused. Rivers which are lifeline to any city or society are being treated as sewage drains and are used to throw away all kinds of wastes so that the river can take it away downstream. The present work is undertaken in order to address the increasingly deteriorating water quality of the Ganga River, which triggers the dumping of raw sewage, solid waste, dead animal carcasses etc. from the city directly into the river without second thoughts. Rapidly increasing population and the city's growth with the lack of sanitation system to cope with the city's development has taken the city's and Ganga river situation to such a bad level.

The River Ganga is the medium of life for many at Varanasi. Few areas along the river ghats have very high population density which also includes areas with slums where the inhabitants depend on the river both for their religious and drinking water needs. Every day around 60,000 people are at the Ganga ghats for their holy dip. Some of these people either don't care, or don't think the River Ganga water is contaminated. This was not the case in Varanasi before. During the British period in India the town was given its due importance. During that time , the city received its first underground gravity sewage system which was built for a maximum population of 200,000 people (Mishra, 2005). The sewage then flowed into the river but the locations of the outlet sewage pipes into the river were selected so as not to affect the quality of the water near the city's ghats. It's been over 60 years now and the city's population has grown from a mere 200,000 to over 3.6 million (Directorate of Census Operations, Uttar Pradesh, 2011). Construction of settlements along and on the low-level lands along the Assi and Varuna rivers has caused severe detrimental effects on those rivers due to rapid population growth. Now, Assi River is nothing more than a drain from which only the city sewage flows and reaches the Ganga River. Some proposals have been and are being made for cleaning the River Ganga, city sanitation, city development, etc. but due to political constraints they are often postponed, scrapped or modified because of which they can not achieve their goals. In 1986, the Government of India passed the Ganga Action Plan (GAP), which aimed to reduce or eliminate River Ganga pollution by installing more treatment plants and a better sewage system to prevent the dumping of untreated raw sewage directly into the river. Even after Phase I of the GAP was completed in 1993, there was no significant change in the water quality of the river (Hamner et al., 2006; Pandey et al., 2005). Indeed the level of faecal coliform was higher than ever before. Raw sewage from various types of point sources still flowed freely into the river. Even today, a walk along the ghats or a boat trip along the river would feature many drains, ditches, drainage pipes and other outlets that continually bring more raw sewage and other toxic wastewater from the city's small-scale industries. Varanasi has endured very haphazard and unplanned growth in the last 50 years. Solid waste disposal is also a big issue in the city, as it lacks any good system. Because of this, a lot of solid waste is either thrown into the river or it flows down into the sewage lines and/or open drains and gets dumped into the river through about 30 such point sources along the city's ghats.

Water quality data of Ganga river water was collected from various ghats of the city as primary source and from literature as secondary source (Figure 7.1).The Dissolved Oxygen (DO in mg/l),Biochemical oxygen demand (BOD, Faecal Coliform Count (FCC/100ml), turbidity, coloured dissolved organic matter (CDOM), Chlorophyll and total suspended matters were given the most importance in this study and all the data were collected from Tulsi Ghat, Assighat, Dashaswamedh ghat, Panchganga Ghat, Rajendra Prasad Ghat and and Varuna river for the years 1999-2008 and years 2016-2019. The selection of the time periods was made with the intention of choosing the same months in different years so that an overall pattern can be seen regardless of the different weather. Various published research articles were collected on the quality of the Ganga river and waterborne diseases, and the studies conducted in those articles were incorporated into this study. Often collected were other papers such as media reports and secret government studies that talk about water quality status and its connection to waterborne diseases.

7.1.1 Water quality sampling and lab analysis

For the assessment of the flow and water quality at various locations of River Ganga at Varanasi, extensive sampling on monthly basis was conducted. The water samples were collected at about 15 cm depth toavoid floating material from three points across a location of theriver 1/3, 1/2, and 2/3 using the Hydro-Bios standard watersampler using the dip/grab sampling method and stored in precleanedpolythene bottles. A current meter was used to measurethe velocity of water and the levelling staff was used to measurethe water depth. The cross-sectional area was measured at all thelocations using a measuring tape and levelling staff precisely. The sampling was done on monthly basis on the dates coinciding with the satellite pass dates (±5 days) of LANDSAT-8 from the points located at Kanpur, Allahabad, Varanasi and Bhagalpur. Weekly sampling was done from the points at Patna also considering the satellite pass dates.

All the analysis is done using standard methods (APHA 1985; APHA/AWWA/WEF 2005). The physical parameters, temperature, turbidity, and pH, were measured in the field (in situ measurement) by means of portable meters. Temperature is an important factor influencing the rates of biochemical processes, which accompany the changes of concentration, and content of organic and mineral substances. The pH values were found to vary between 7 and 9. DO values were determined by the Winkler method with theaddition of divalent manganese solution and alkali–iodide–azidereagent. For BOD computations, BOD_5 values were determinedby incubating the unpreserved samples for 5 days in place ofUltimate BOD (APHA/AWWA/WEF 2005)because (1) the ratiobetween ultimate BOD and BOD_5 are found to vary only between1.1 and 1.5; and (2) the time involved for the analysis of ultimateBOD values were estimated to be in manyfold in comparison tothe BOD_5 analysis. Therefore, it was difficult to analyse BOD_U for each sample.

The samples for Chlorophyll, Colour dissolved organic matter and Suspended particulate matter were filtered and stored using histo-prep tissue capsule in a

Cryocan of 3 litres for further analysis. The Whatman GF/F filters of pore size of 0.7 µm having diameter 47 mm and 90% aqueous acetone used for chlorophyll analysis. For Colour dissolved organic matter (CDOM) analysis cellulose acetate filters of pore size of 0.2 µm and diameter 47 mm was used. Nylon membrane Whatman GF/F filters of pore size of 0.4 µm and diameter 47 mm was used for SuspendedParticulate Matter (SPM) analysis.

Figure 7.1: Sampling at various Ghats of river Ganga at Varanasi

7.1.1.1 Chlorophyll Analysis

Water samples from each sampling site and depth are filtered through Whatman GF/F filters of pore size of 0.7 µm and diameter 47 mm. The filter papers containing the cells of phytoplankton are placed in a test tube filled with 90 per cent aqueous acetone 10ml. The filtrates are gently homogenized using probe sonicator for the extraction of pigments from the cells and incubated for 24 hrs under cool and dark conditions. The solution is then centrifuged at 5000 rpm for approximately 15 minutes. The supernatant 's optical densities are then determined using a UV-VIS spectrophotometer at different wavelengths such as 664 nm, 647 nm and 630 nm, the maximum chlorophyll-*a*, *b* and *c* absorption wavelengths respectively. For tiny turbidity blanks the extinction values are corrected by subtracting the 750 nm optical density from that of 664 nm, 647 nm and 630 nm. In the extracts the individual concentrations of chlorophyll pigments were calculated using the following formula:

$$Chl_a = 11.85\ (O.D)_{664} - 1.54\ (O.D)_{647} - 0.08\ (O.D.)_{630} \quad (7.1)$$

where, Chl_a is the chlorophyll-*a* concentration in mg/L, $(OD)_{664}$, $(OD)_{647}$ and $(OD)_{630}$ are the corrected optical densities with their respective wavelengths. The quantity of pigment per unit sample volume has been as follows:

$$\text{Chlorophyll-}a\ (mg/m^3) = Chl_a * \text{volume of extract (L)/ volume of sample } (m^3) \quad (7.2)$$

7.1.1.2 Coloured Dissolved Organic Matter (CDOM)

Water samples from each sampling site are filtered through filters of pore size of 0.2 µm anddiameter 47 mm. Optical densities of the dissolved part is then determined using UV-VISspectrophotometer at a wavelength of 440 nm.

$$CDOM_{440} = 2.303 * [\ (O.D.)_{440} / I\ ] \quad (7.3)$$

where, I is the cuvette path length (0.01m for 1 cm).

7.1.1.3 Suspended Particulate Matter (SPM)

The nylon membrane filter papers were incubated in cool and dark conditions for 5 hrs at 100˚C and weighted before filtering. Water samples from each sampling site are filtered through Whatman GF/F filters of pore size of 0.4 µm and diameter 47 mm. The filtrates were then again incubated in cool and dark conditions for 5 hrs at 40˚C and weighed.

$$SPM = \text{Difference of Weights/ Volume of sample} \quad (7.4)$$

The quality assurance of generated water quality data was ensured on a regular basis during sample collection, sample transportation, sample storage, and sample analysis. The chemicals used for analyses were of Merck analytical grade. Further, the reagent blank and standards of variable ranges were analyzed prior to performing the analysis of water samples and also after every five readings to ensure proper calibration of the instruments used. In titrimetric analyses, the titrating solutions were standardized against respective standard solutions. Samples were analyzed in triplicates to further enhance the analytical precision of the data.

7.1.1.4 Turbidity

To measure Turbidity Nephelometric Turbidity meter was used. To measure Turbidity First calibrate meter with a known Sample and then we test our Sample. We find turbidity in NTU.

7.1.2 Collection of Satellite Data

Satellite Data is collected in form of Landsat-8 Images. Landsat-8 images is collected from Earth explorer. Earth explore is an online interface to collect the satellite data developed by USGS. From Earth explorer we collect Landsat Collection 1 Level 1 Data for Landsat-8. Because it is Landsat Collection 1 Level 1 Data so atmospheric correction as well as reflectance correction is necessary before processing the image. Data is collected according to the path and row of the images in which our selected location was come. Detail of collected Landsat-8 images is shown in Table 7.1.with their collection Date, Row and Path.

Table 7.1: Details of Landsat-8 Data

S.No.	City	Date	Path	Row
1	Varanasi	23/01/2018	142	042
2		21/02/2018	142	042
3		28/03/2018	142	042
4		15/05/2018	142	042
5		16/06/2018	142	042
6		22/10/2018	142	042
7		23/11/2018	142	042
8		22/12/2018	142	042
9		10/01/2019	142	042
10		11/02/2019	142	042
11		31/03/2019	142	042
12		26/11/2019	142	042
13		13/01/2020	142	042

7.2 Analysis of Resultsfor Water Quality Variable

The flow chart indicates the process following for the water quality data analysed along with satellite data on the dates of pass of satellite (Figure 7.2).

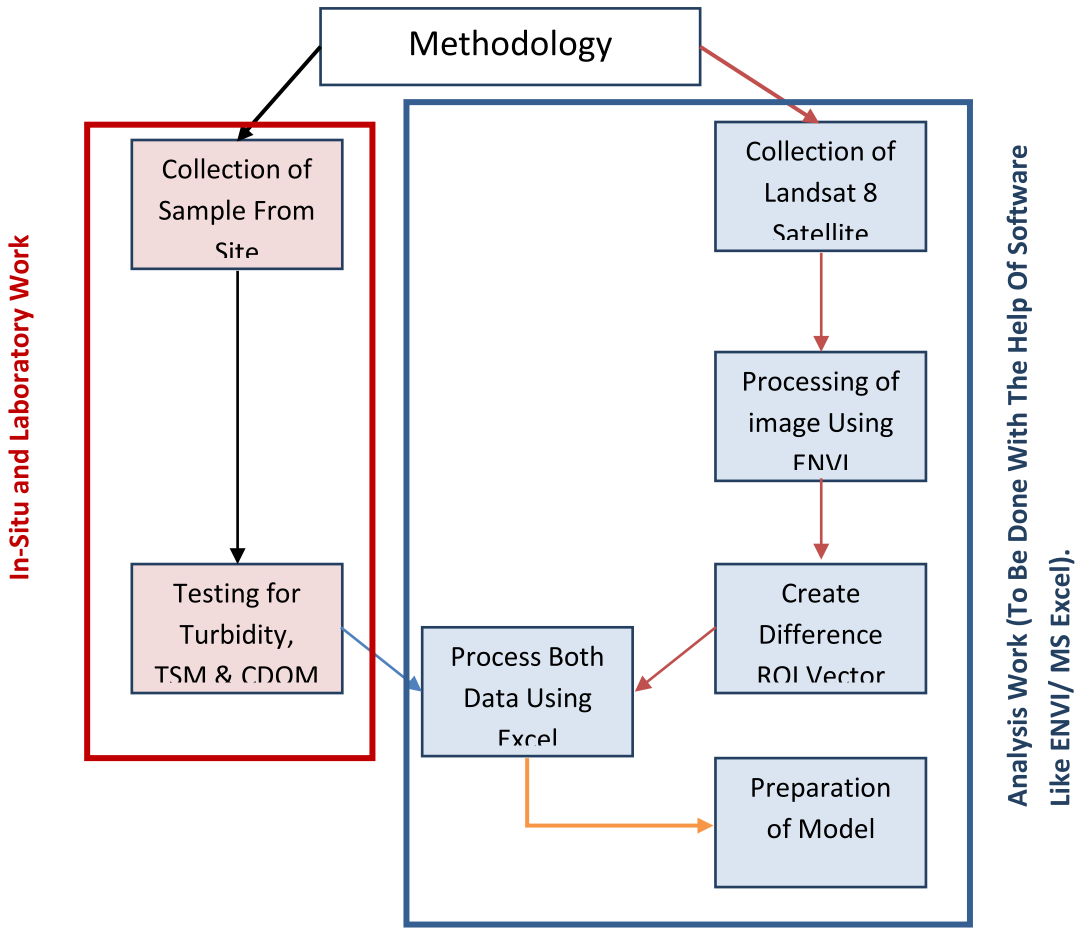


Figure 7.2: Flow chart indicating the methodology used in the present work

The primary and secondary data collected for the period 1999-2008 and 2016-2019 were analysed and the results are discussed below. Figures 7.3, 7.4, 7.5 and 7.6 shows DO, BOD, Total Coliform and Fecal Coliform Values for the water quality data for the years 2016 -2019. It has been observed that the DO Values are constant and do not show any trend where as the BOD, Total Coliform and Fecal Coliform are showing decreasing trend in the graphs. The results indicate improvement in river water quality at Varanasi u/s as well as downstream location. The presence of Coliform is a matter of concern for policy makers and stake holders.

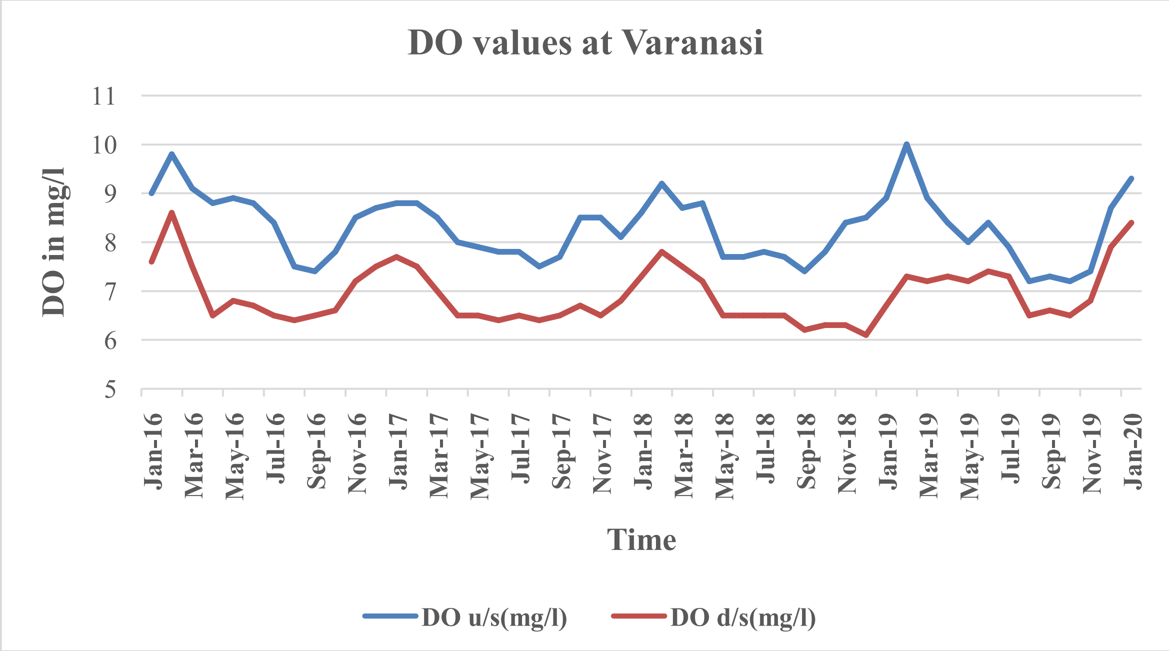


Figure 7.3: DO values at upstream and downstream location of Varanasi

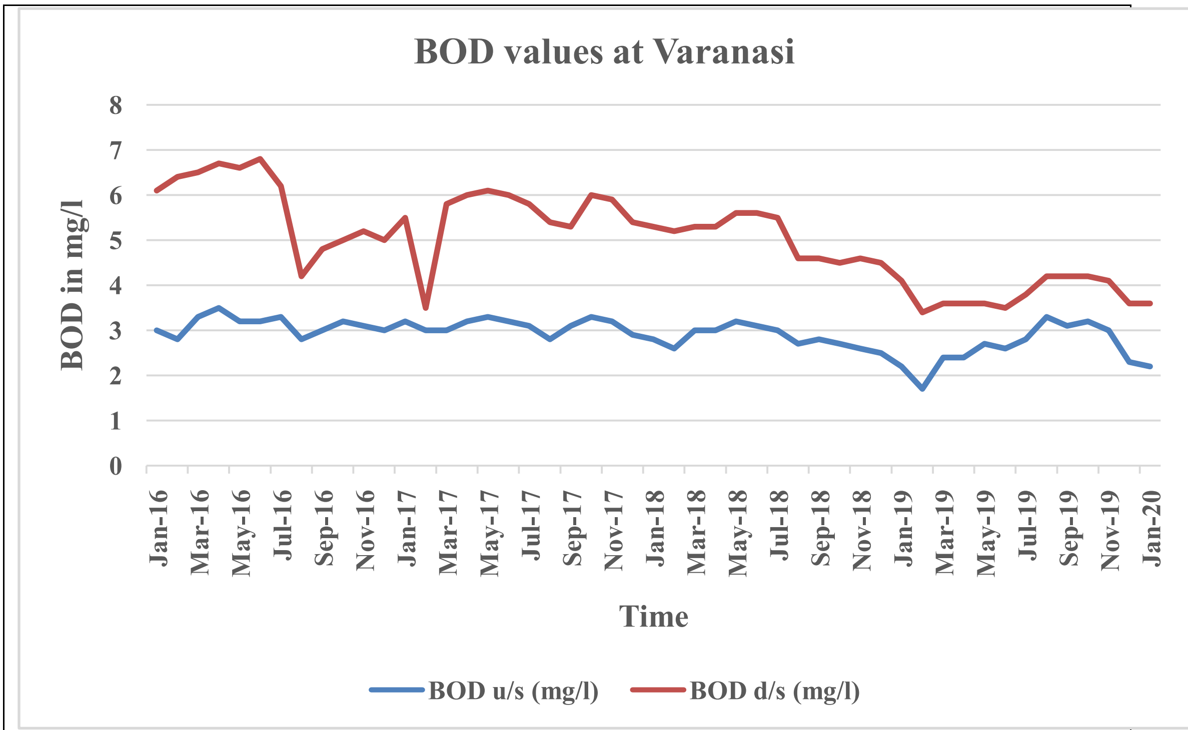


Figure 7.4: BOD values at upstream and downstream location of Varanasi

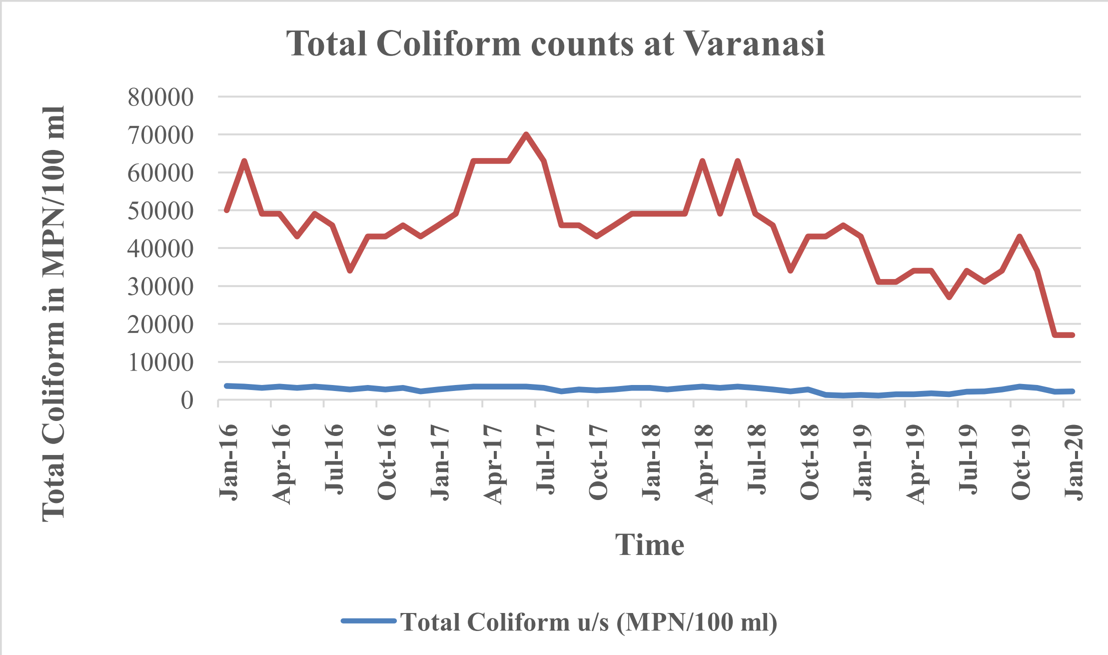


Figure 7.5: Total Coliformcounts at upstream and downstream location of Varanasi

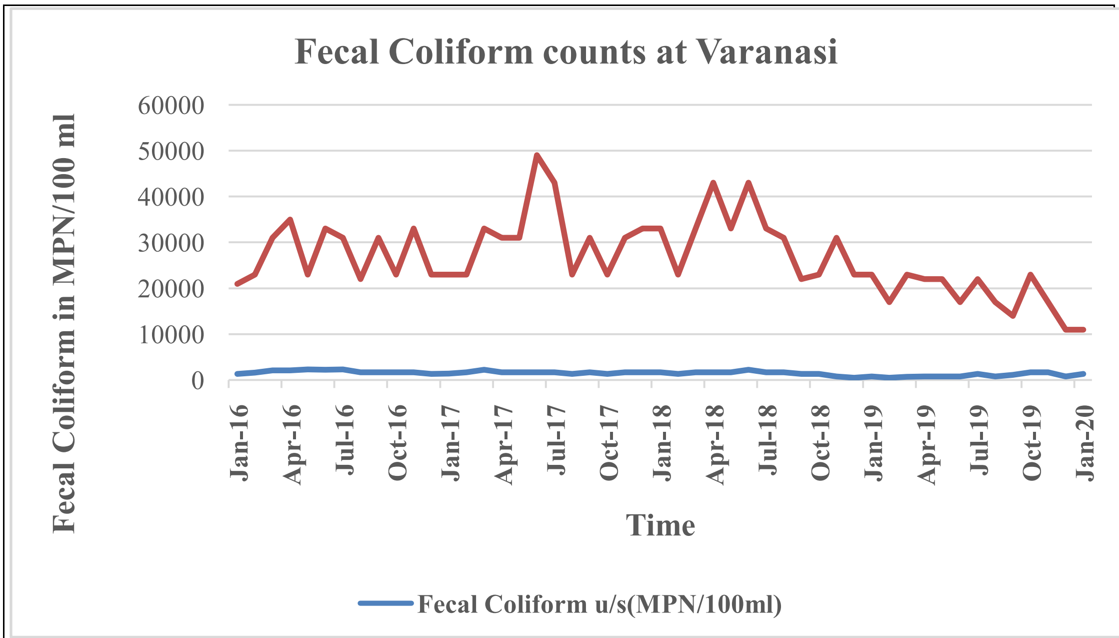


Figure 7.6: Fecal Coliformcounts at upstream and downstream location of Varanasi

In addtion to that, the water quality data collected for the years 1999-2008 from different sources are discussed. Figure 7.7 shows the DO values at upstreama and downstream of River Ganga at Varanasi, whereas Figure 7.8 shows the BOD values at upstreama and downstream of River Ganga at Varanasi. DO values are fine, but BOD at downstream location is found high during the years 2002-2008. However, it can be seen from Figure 7.4 that there is a significant improvement in BOD values during the year 2016-2019.

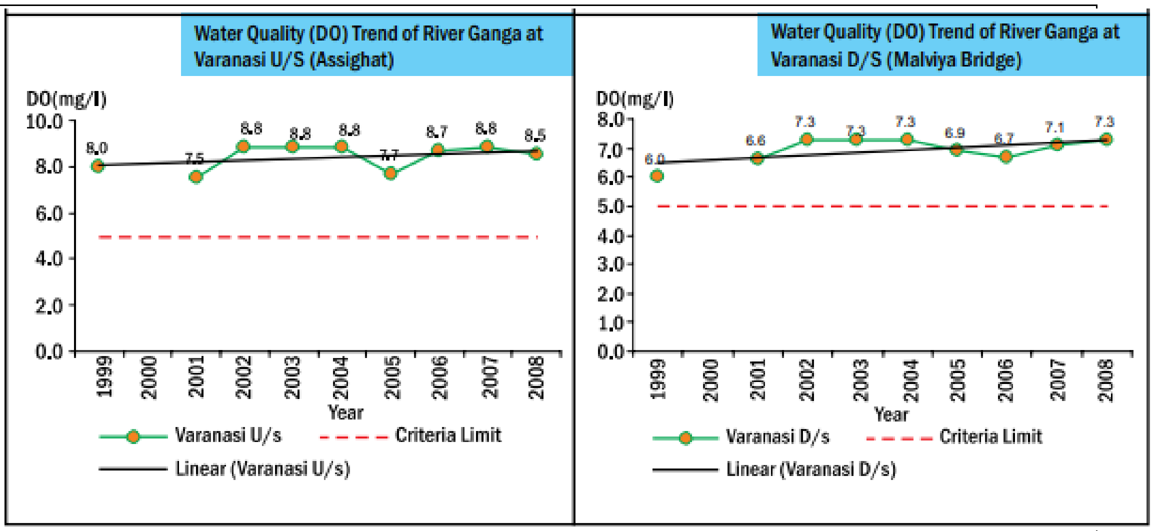


Figure 7.7: DO values at upstream and downstream location of Varanasi (1999-2008)

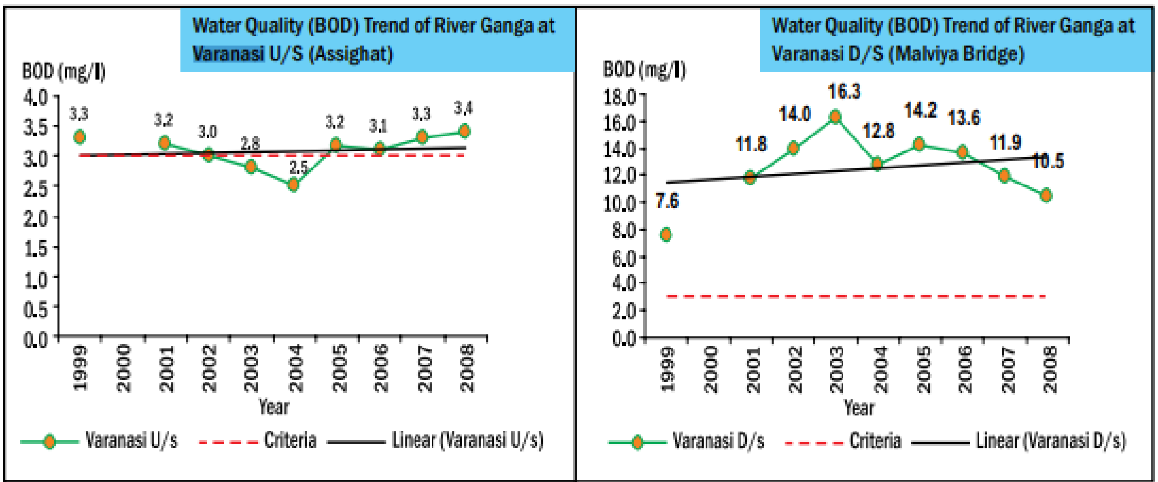


Figure 7.8: BOD values at upstream and downstream location of Varanasi (1999-2008)

Finally, the water quality of the Ganga River in Varanasi is found to be unacceptable for drinking purposes, but may be used for bathing, recreation and irrigation purposes.

The results obtained for the water quality variables Chlorophyll-a, Coloured Dissolved Organic matter (CDOM), Suspended particulate matter (SPM) and turbidity (NTU) are shown in Figures 7.9, 7.10, 7.11 and 7.12.

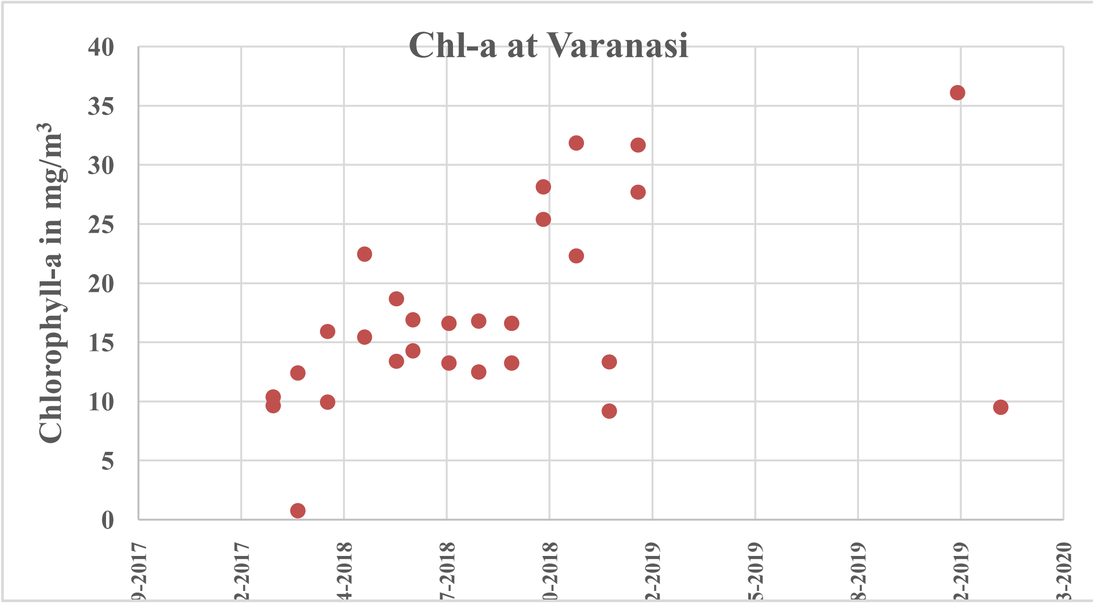


Figure 7.9: Chlorophyll-a at Varanasi using grab sample

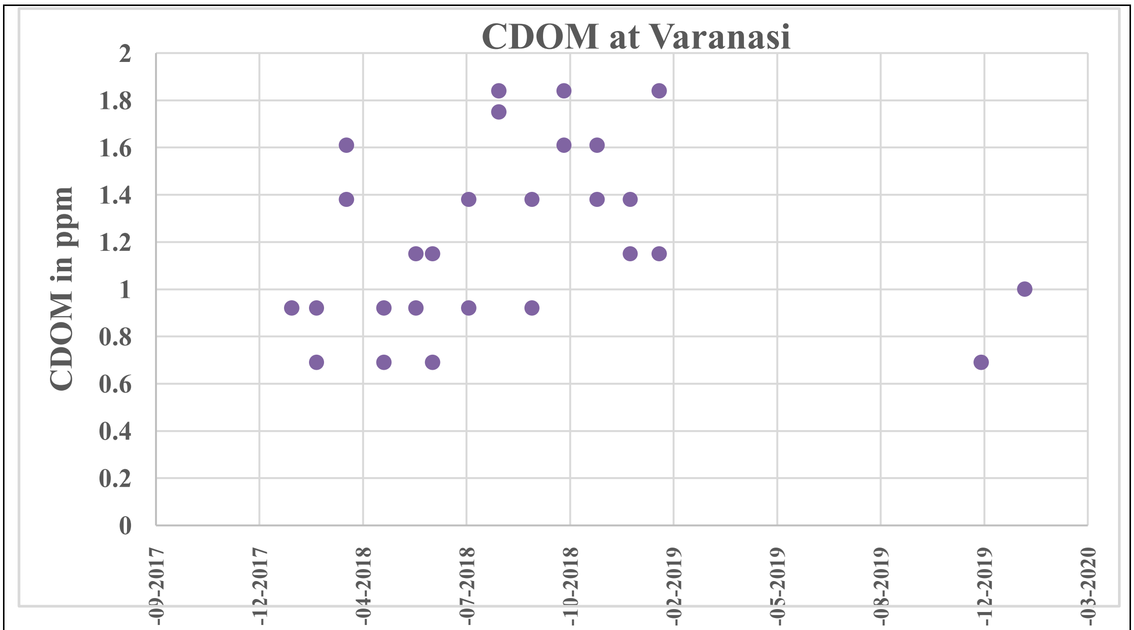


Figure 7.10: Coloured Dissolved Organic Matter at Varanasi using grab sample

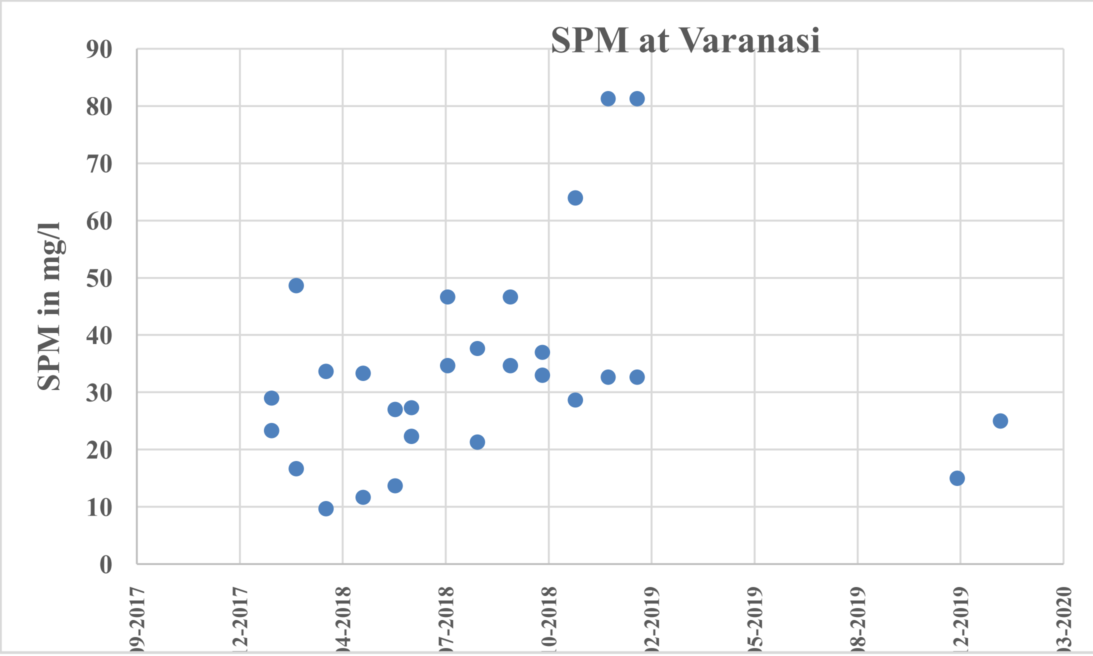


Figure 7.11: Suspended particulate matter at Varanasi using grab sample

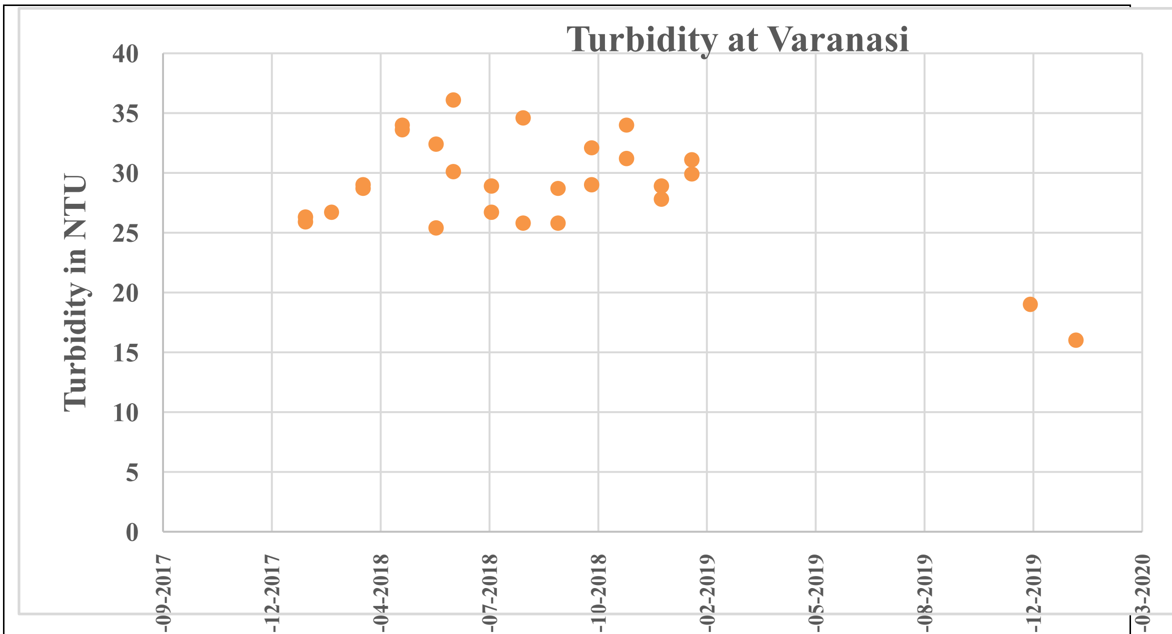


Figure 7.12: Turbidity at Varanasi using grab sample

7.3 Analysis of results using Satellite Data

To measure the Satellite Data first the Satellite data in form of Geotiff fileswere collected from USGS website { https://earthexplorer.usgs.gov}. The United States Geological &Survey(USGS) provides on-demand generation of

Landsat 8 Thermal Infrared Sensor (OLI/TIRS) Surface Reflectance data through Earth Explorer Surface Reflectance items give a check of the surface spectral reflectance as it would be measurable at ground level without barometric scattering. Figure 7.13 shows the CDOM values obtained using satellite data at Varanasi. The colour in the river stretch indicates the quantity of CDOM in river stretch of Varanasi. The values estimated from the satellite data at Assig ghat, Dasasheamedh ghat and Manikarnika ghat are plotted in Figure 7.14. The results were compared were the actual water quality samples collected in the field and it is observed that the satellite data underestimates CDOM values due to poor resolution and poor visibility of color dissolved organic matter.

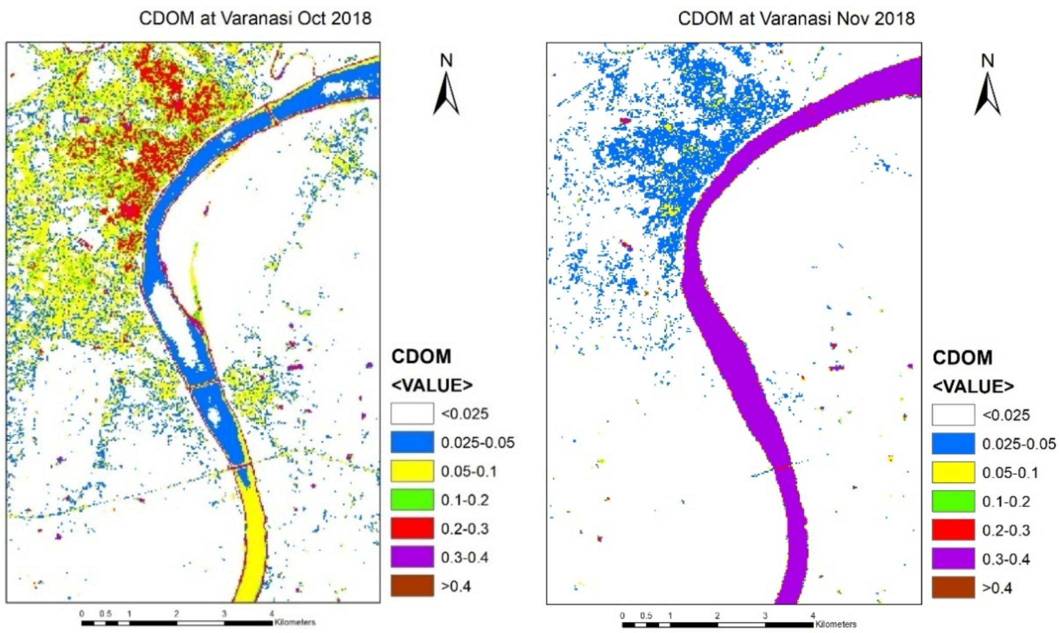


Figure 7.13: CDOM values at Varanasi obtained from satellite data

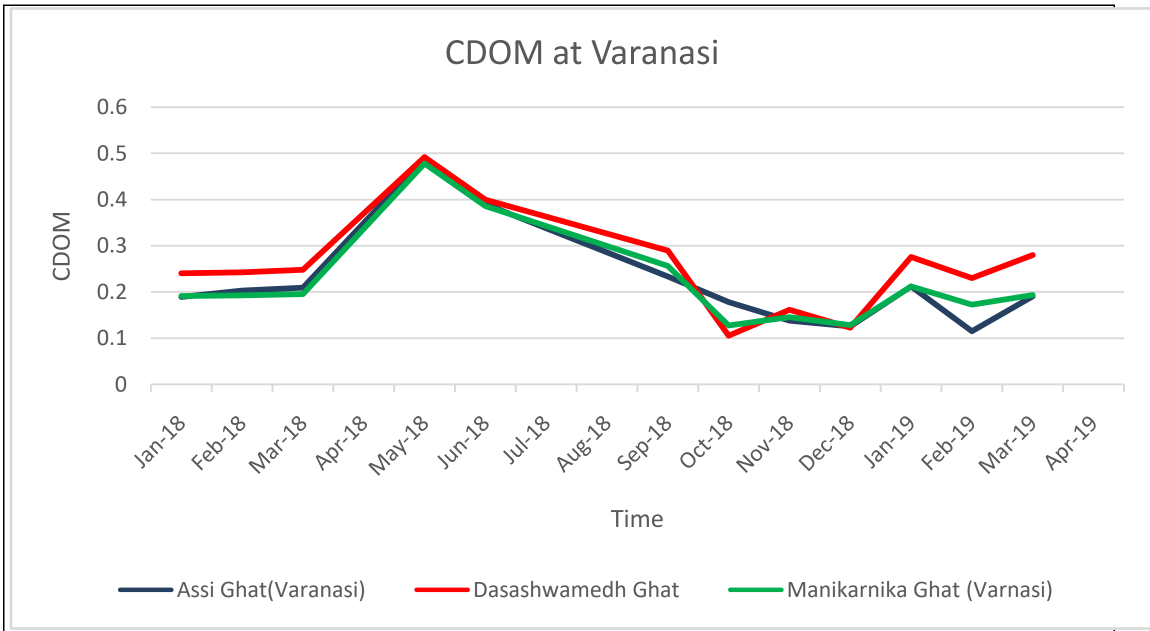


Figure 7.14: Variation of CDOM values at Varanasi obtained from satellite data

Similarly, Figure 7.15 shows the Suspended Particulate Matter (SPM) or Total Suspended Matter (TSM) values obtained using satellite data at Varanasi. The colour in the river stretch indicates the quantity of TSM in river stretch of Varanasi. The values estimated from the satellite data at Assig ghat, Dasasheamedh ghat and Manikarnika ghat are plotted in Figure 7.16. The results were compared were the actual water quality samples collected in the field and it is observed that the satellite data has good agreement with water sampling done in the Laboratory.

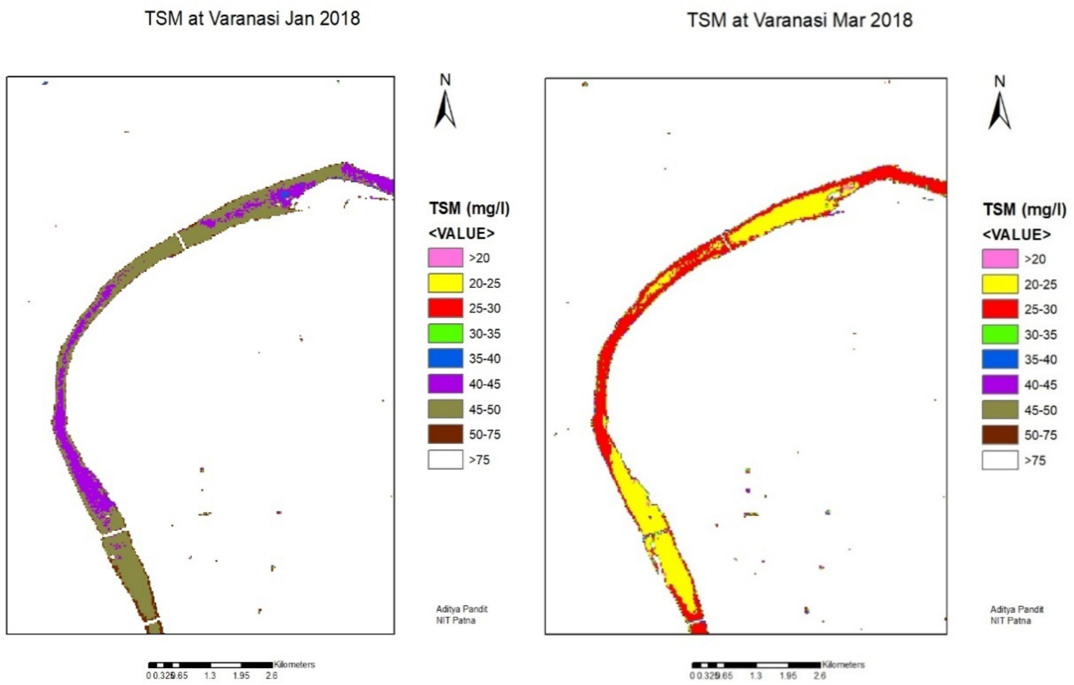


Figure 7.15:TSM (SPM)values at Varanasi obtained from satellite data

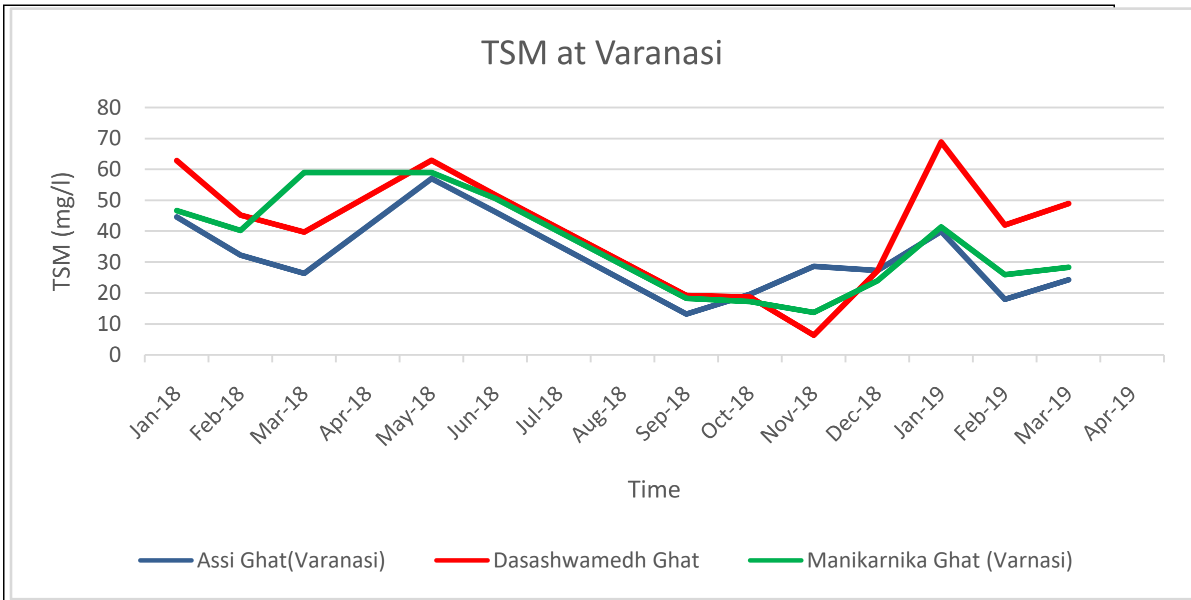


Figure 7.16: Variation ofTSM (SPM)values at Varanasi obtained from satellite data

Again, Figure 7.17 shows the Turbidity (NTU) values obtained using satellite data at Varanasi. The colour in the river stretch indicates the quantity of Turbidity in river stretch of Varanasi. The values estimated from the satellite data at Assig ghat, Dasasheamedh ghat and Manikarnika ghat are plotted in Figure 7.18. The results were compared were the actual water quality samples collected in the field and it is observed that the satellite data has good agreement with water sampling done in the Laboratory.

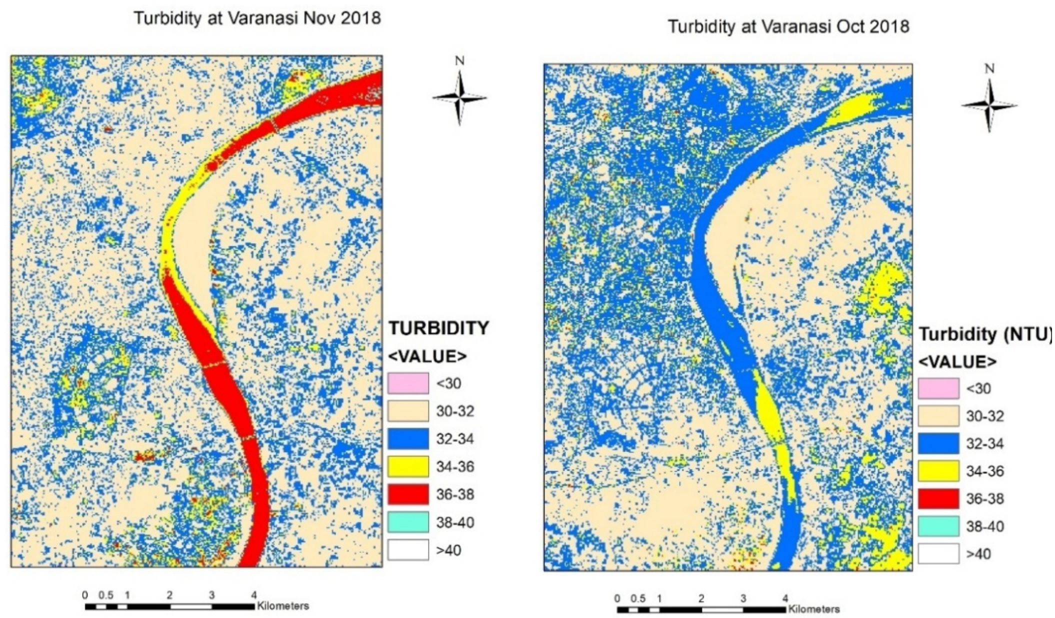


Figure 7.17:Turbidityvalues at Varanasi obtained from satellite data

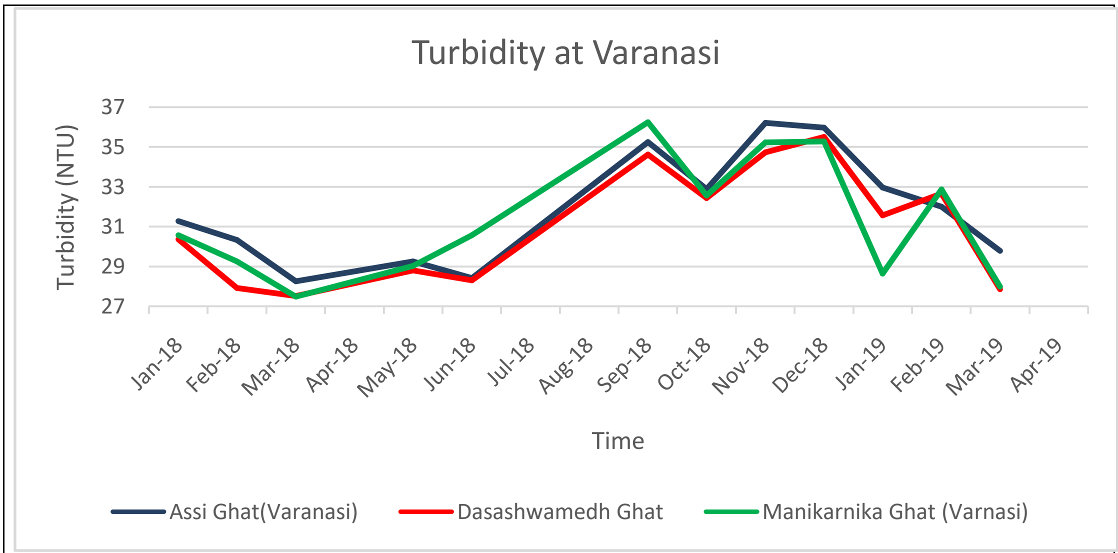


Figure 7.18: Variation ofTSM (SPM)values at Varanasi obtained from satellite data

CHAPTER 8

CLIMATE CHANGEAND URBAN WATER MANAGEMENT

8.1 Climate change and sustainable development

Human activities have released massive quantities of carbon dioxide and other greenhouse gasses into the atmosphere for decades. Majority of greenhouse gases originate from fossil fuel burning. Deforestation, industrial processes and some farming practices also release gasses into the atmosphere. This has led to climate change, which refers to any significant climate change that lasts for an extended period of time. In other words, climate change includes, among other effects, major changes in temperature , precipitation, solar radiation, evapo-transpiration, moisture or wind patterns that occur over several decades, or longer. The climate change impacts are evident from various disaster events that have occurred and present challenges for societies and the environment. Planning to mitigate the impact of climate change and reduce greenhouse gas emissions is becoming increasingly important for sustaining our present societies and saving future generations. This is possible by adopting measures to develop sustainable and low carbon emissions.

At present, the warming climate is leading towardsless mean precipitation and higher mean temperatures. Many of the worldwide debates are addressing the spatiotemporal impacts (Chattopadhyay and Hulme, 1997;Parry et al., 2004) of global warming on climatic variables and dependent ecosystems. Various climatic and hydrological parameters, rainfall, temperature, relative humidity, solar radiation, sunshine and evapotranspiration are expected to face the unpleasant consequences of climate change. According to Shaveret al. (2000), owing to the changing climate, the Earth ischanging its weather conditions. In consequence, the regional climatic conditions are also changed mainly for rainfall and temperature (Shan et al., 2015). Different regions of the world show differential responses to global climate change. The changes in temperature and rainfall patterns, combined with other complex anthropological factors, govern the regional and local hydrological variables (Pravalie, 2014; Pravalieet al., 2014; Nistor et al.,2018). Reduced precipitation coupled with high temperatures could have a negative impact on surface waters and groundwater (Loáiciga et al., 2000; Bachu and Adams,2003; Brouyère et al., 2004; Nistor, 2019).

Various studies have been conducted regarding the impacts of precipitation, potential evapotranspiration(ET_0) and actual evapotranspiration (AET_0) on ecosystems and the regional water balance (Allen, 2000; Gerritset al., 2009; Cheval et al., 2011; Pravalieet al., 2014; Yu et al., 2002; Tabari et al., 2011; Espadafor et al., 2011; Palumbo et al., 2011).Papaioannou et al. (2011) reported a decreasing trend of annual ET_0 between 1950 and 1980 in Greece, but itreverses after 1980 and continues increasing after that point. Similarly, ET_0 decreased abruptly during the 1990sin the Wei River area of China and it has continued to increase further ever since (Zuo et al., 2012).

In the South Asia, the climatic characteristics of the rainfall regime are heterogeneous. Thus, rainfall variability indicates a declining trend of rainfall with a more regular deficit monsoon (Watson, 2001; IPCC, 2013;Jiménez Cisneros et al., 2014). The regional differences in climate change impacts and warming trends in continental interiors are strongest in Asia. Rainfall increased in the last century over Northern and Central Asia and decreased over Southern Asia. Mean seasonal rainfall in South Asia are declining perceptibly with the regular occurrence of monsoon deficient seasons under spatial irregularities.

8.2 Climate change impact at urban city Varanasi

Over India, and in some regions of South Asia, the number of heavy rainfall events is increasing atthe expense of decreasing low-intensity rainfall events(Jiménez Cisneros et al., 2014).In addition to climate change, human water demand at various locations are the reasons for the water crisis (Wang and Dickinson, 2012; Fu et al., 2014). The change in water availability under climate change signals the necessity for its adaptation. In Varanasi district and inthe entire Uttar Pradesh state region due to the population growth, water withdrawals from the main rivers' basins (i.e. Ganga,Yamuna, Ghaghra) have increased significantly. Figure 8.1 and Figure 8.2

indicates the percentage increase in population at Varanasi and projected population at Varanasi by the year 2040. Various studies have examined the changes in water supply under climate change, but few have considered the joint pressures from climate change, land cover and socioeconomic development. It becomes indispensable to develop a quantitative approach to evaluate future water scarcity in a changing environment at the regional scale.

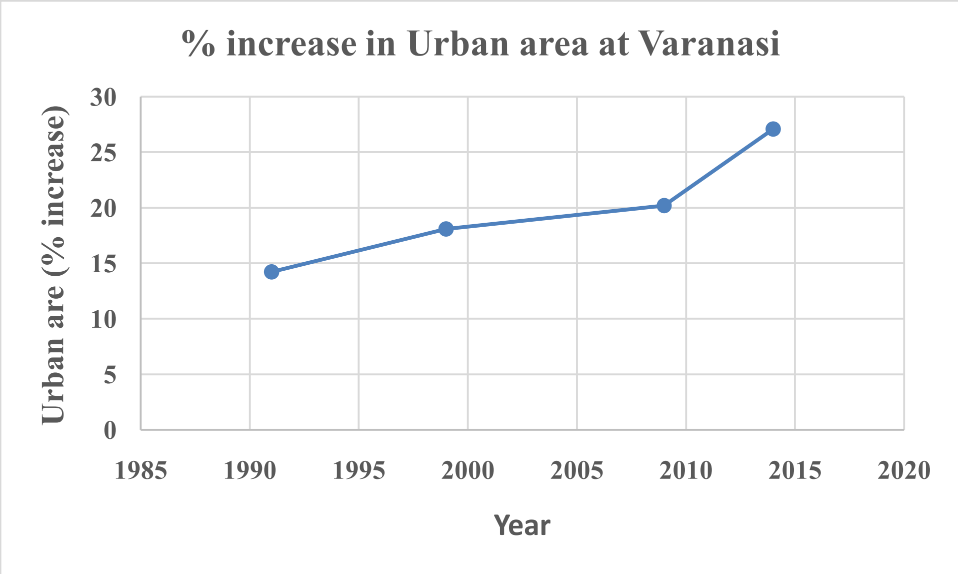


Figure 8.1: Percentage increase in urban areas of Varanasi, India

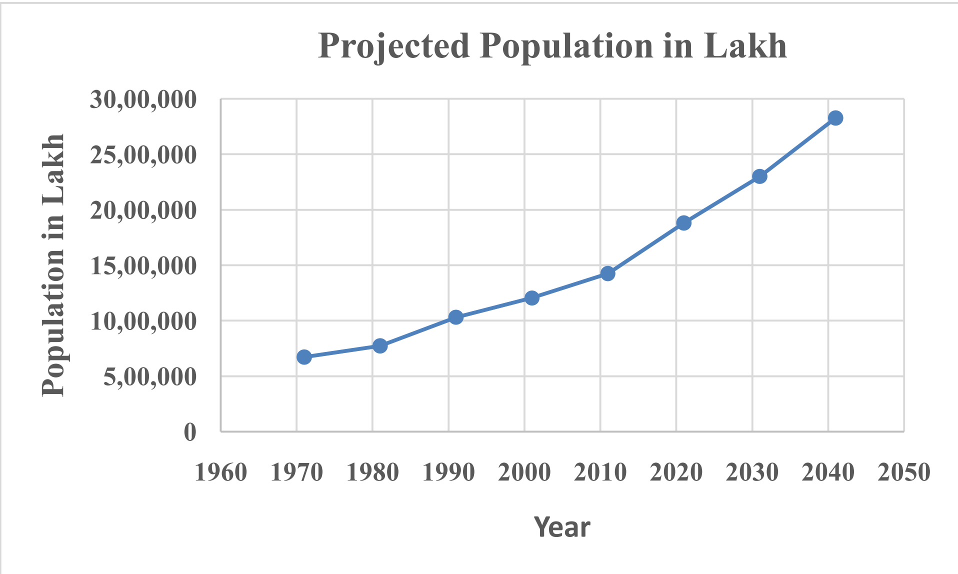


Figure 8.2: Projected population in urban areas of Varanasi, India

In addition to increasing population, the variation in various wate quality variables such as Do, BOD, turbidity, Suspended particle, Chlorophyll were found to be within the range at different locations of Ganga river systems at Varanasi.

Given that half of the world's population started to live in cities by 2007, it is no exaggeration to say that the battle against climate change will be lost or won by urban cities. Urban sprawl is also often associated with climate change. The wider the urban sprawl, the greater would be the carbon emissions. Energy consumed in lighting of residential and commercial buildings generates nearly a quarter (25%) of greenhouse gases (GHGs) globally and transport contributes 13.5%, of which 10% is attributed to road transport. We can safely assume that a sizeable portion of this volume of emissions is generated in cities. According to the Clinton Foundation, large cities are responsible for about 75% of the GHGs released into our atmosphere. Given that the most valued infrastructure is usually located in cities, the economic and social costs of climate change is much higher in cities including Varanasi, UP, India. Climate change impacts the physical assets used within cities for economic production, the costs of raw materials and inputs to economic production. The variation in annual rainfall is found decreasing at Varanasi whereas the rainfall based on daily data having minimum of 10mm rainfall, the trend is found decreasing again (Figure 8.3 and Figure 8.4).

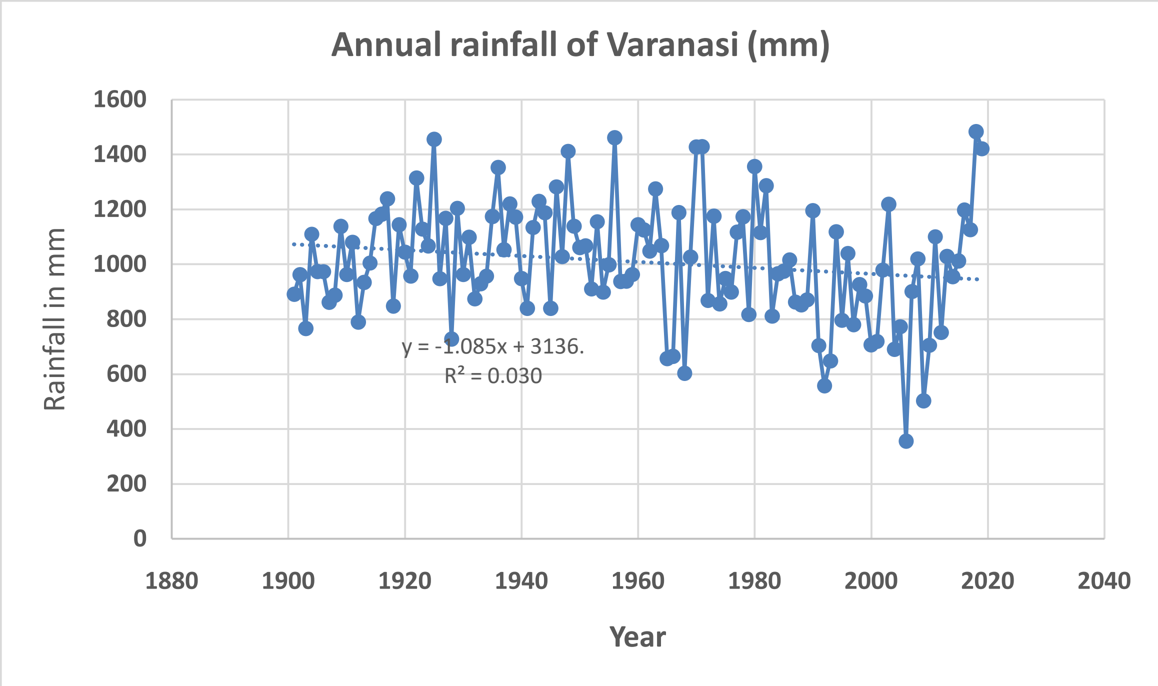


Figure 8.3: Annual rainfall at Varanasi

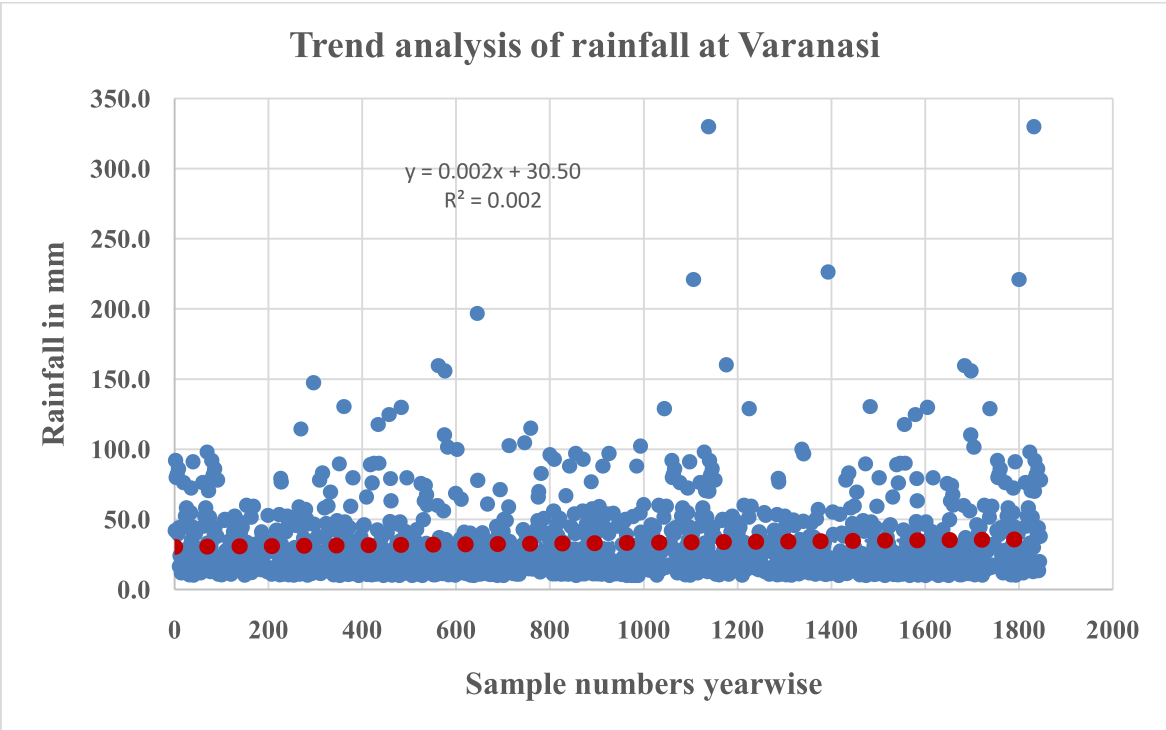


Figure 8.4: Trend analysis of rainfall considering 10mm minimum rainfall at Varanasi

Similarly, the variation in annual temperature is found increasing at Varanasi whereas the minimum and maximum temperature were found marginally increasing again (Figure 8.5 and Figure 8.6).

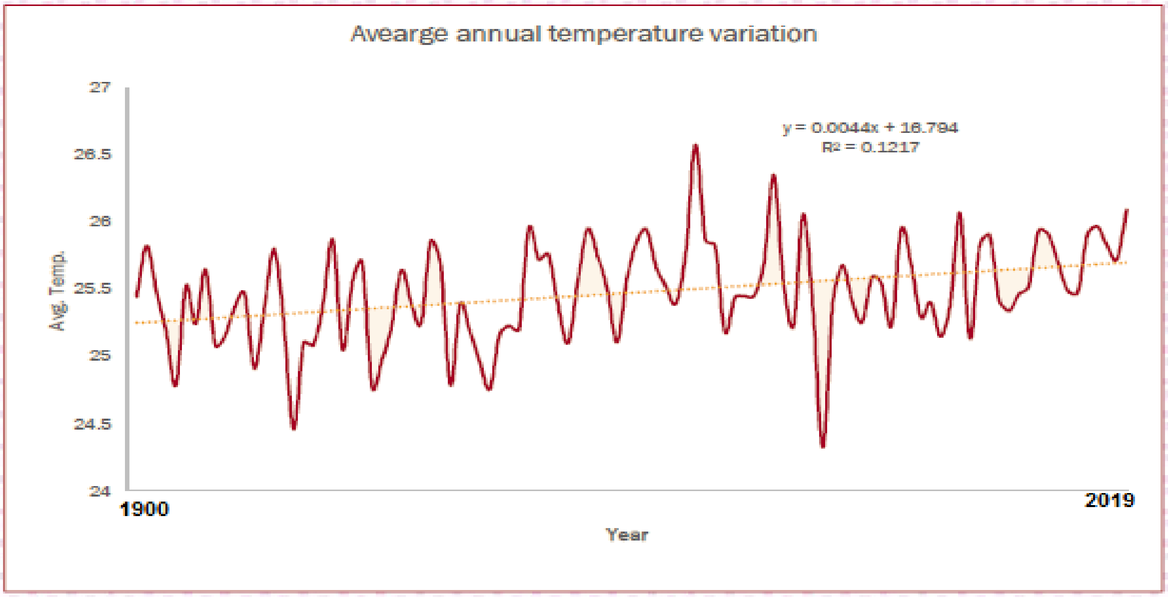
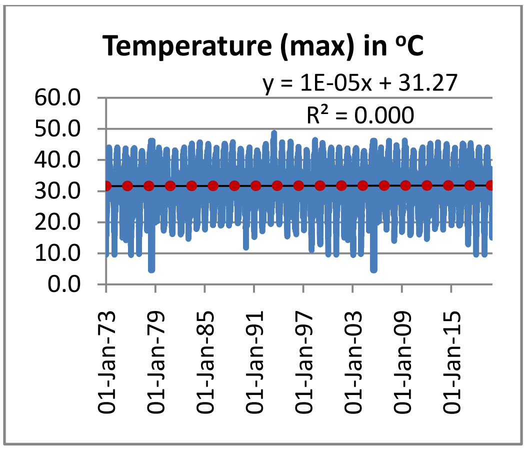


Figure 8.5: Average annual temperature variations at Varanasi



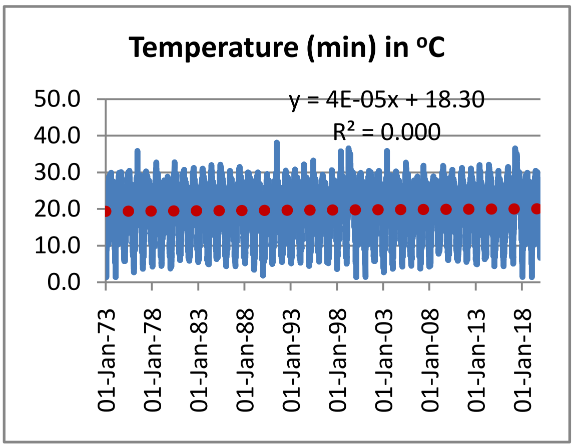


Figure 8.6: Maximum and Minimum annual temperature variations at Varanasi

8.3 Urban water demand and supply at Varanasi

From the previous studies it has been confirmed that there has been significant increase in water demand due to urban sprawl and due to increase in population density. Figure 8.7 and Figure 8.8 indicates the water supply (surface and groundwater) and water demand at Varanasi.

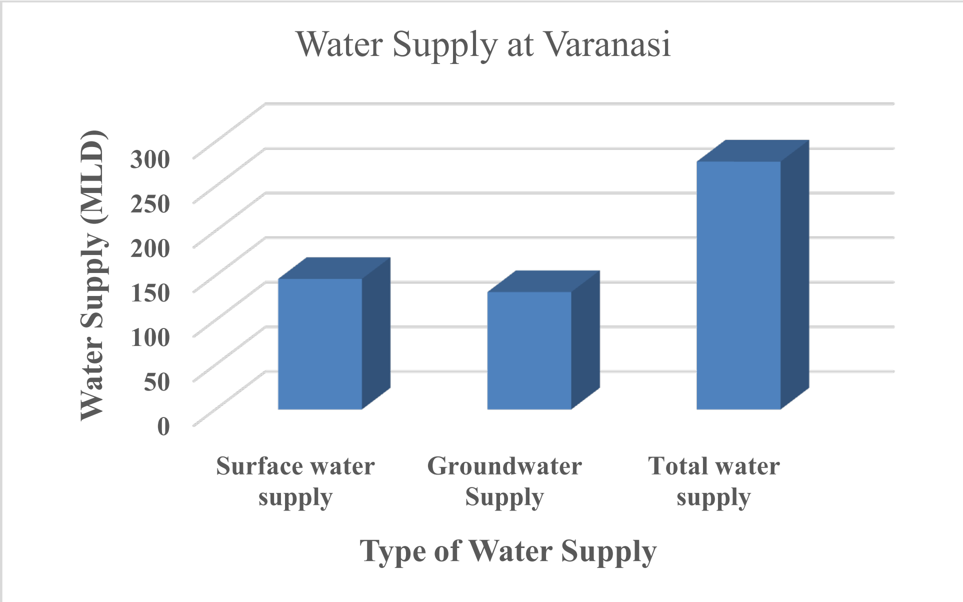


Figure 8.7: Surface and Groundwater supply at Varanasi

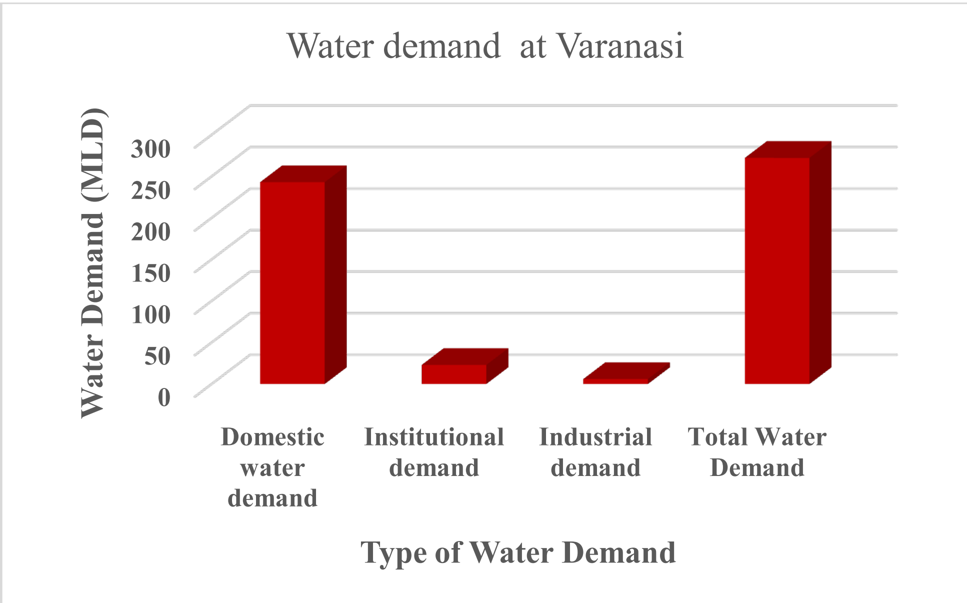
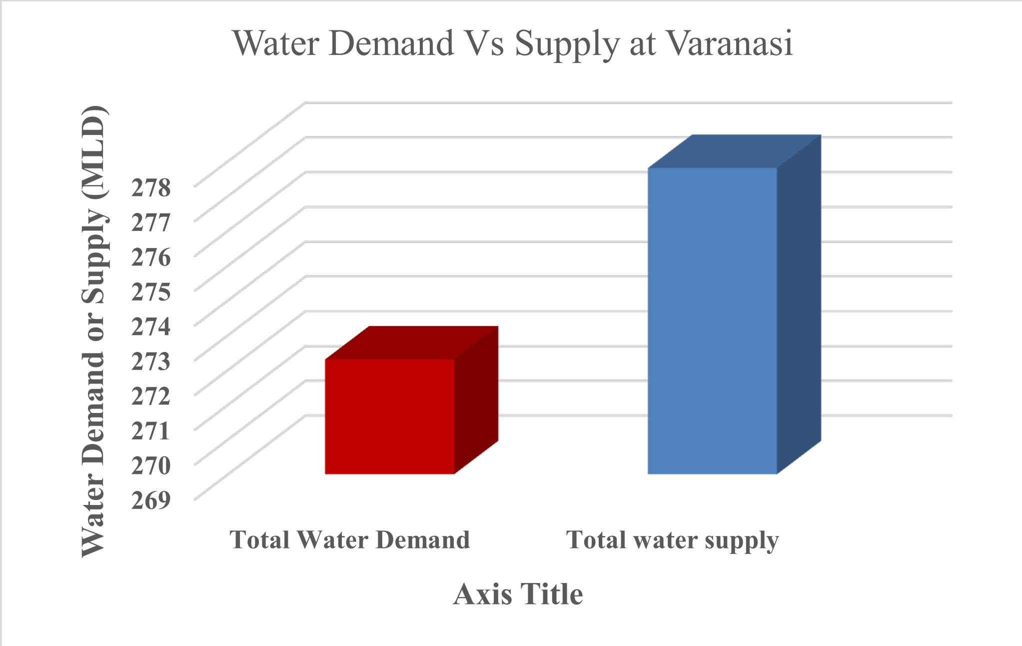


Figure 8.8: Domestic, Institutional and Industrial water demand at Varanasi

A comparison is done between water denad and supply in the present scenario and is shown in Figure 8.9. As shown in Figure, the available surface water as well gorund water is more than the water demand. However, the groundwater is being overexploited in some of the regions.



Now, a water demand and water supply scenario at Varanasi is developed based on available historical information and literature survey. Table 8.1 indicates the water demand and supply scenario for the years 2020, 2030, 2040 and 2050 and it has been observed that from the year 2030, the water stress would start and by the year 2050 Varanasi would be water scare City.

Table 8.1: Scenario for water supply and demand at Varanasi

year	population (millions)	Demand (MLD)	Supply (MLD)	Storm water storage potential	Return to wastewater (MLD)	Treated wastewater	Total water available	Water balance (Annual)
2020	1.6	**240**	277	30.68	189.48	47.37	**355.05**	**115.05**
2030	2.4	**360**	304.7	30.68	273.48	68.37	**403.75**	**43.75**
2040	2.9	**435**	335.17	30.68	325.98	81.5	**447.35**	**12.35**
2050	3.5	**525**	368.69	30.68	388.98	97.25	**496.62**	**-28.38**

CHAPTER 9

CONCLUSIONS

The following conclusions are drawn:

1. The first research object for this study was to analyze urban population density, floating population, water demand and urban sprawl at Varanasi with remote sensing and GIS support. The results have showed that using remote sensing and GIS techniques; the process of urbanization can be analyzed effectively. The easily available temporal Landsat TM and Landsat ETM data along with demographic information from census data has helped in detection of the change in land-use and land cover over the period of time in Varanasi city. It has been observed that there is 14% increase in urban built up area during the year 1990-2019.Agriculture and open land area are the categories which are mostly affected by the urban growth. The increase in urban built up has been observed more significant in the last 10 years (2009-2019).
2. The NDVI analysis was done for Varanasi to look for the vegetation index variation during the years 2000 and 2018. It has been observed that the crop zone is reducing and transforming into urban areas.
3. The Entropy analysis was done for the Varanasi city and buffer zones were created from the centre of the town with an interval of 2.0 km interval. (starting from zone 1 at the centre to the zone 17 at the end) to study the urban built up area at Varanasi. It is observed that in the year, the highest development was at zone 1 and was reducing up to zone10 and then increasing from zone 11 to zone 17. Similar pattern is observed in the year 2018 also. However, increase in urban built up area is found to be more prominent and exponentially high in zones 11 to 17. The entropy analysis for development along rivers, roads and well known hospitals was also done and found significant development along rivers, roads and near hospital.
4. At Varanasi, floating population is a serious problem in addition to consistent population. From the analysis it has been observed that the population density of the Varanasi city is about 19 lakhs at present and will reach up to 28.5 lakhs in

the year 2040 with an average increase of 23% in ten years. It is interesting to note that the floating population is also about 52 lakhs to 63 lakhs in last one decade, which needs freshwater for drinking and bathing, and disposes off human excrete, urine and wastewater. It requires addition planning for urban water management.

5. To carry out the study further, it was essential to have knowledge of oen defecation zones, waste water drains, sewer lines, slope of the area using digital elevation model, drainage network, geology, groundwater in spatial domain and meteorological information. All the thematic maps developed are found to be very useful for further analysis.
6. At Varanasi about 29 water bodies were existing in the present scenario and about 15 storm water drains were found in working condition. At many locations, the waste water generation was found due to unplanned urbanisation and sewer system were proposed accordingly.
7. In the present work Rainfall, temperature and solar radiation trend of Varanasi has been analyzed using statistical methods to develop the trend and to simulate future scenarios of trend for urban water management. In addition ARIMA (p,d,q) models for Rainfall (1,1,1), minimum temperature (1,0,1) and maximum temperature (1,0,1) were developed and rainfall forecasting was done for Varanasi city. The scenario indicate increase in temperature in general where as the rainfall has decreasing trend.
8. It has been observed that the DO and BOD are at alarming situation, whereas the total coliform and fecal coliform were found to be significantly high. The field samples of Chlorophyll-a, turbidity, colored dissolved organic matter and suspended particulate matter were compared with the satellite data digital values and found in good agreement. A multiple regression model was also developed between observed and satellite data obtained from Landsat 8 Level 2 satellite.
9. Keeping all in view, the urban water requirement with respect to possible climate change has been discussed and proposed in the present study. Specially, the floating population were never considered and climate change impact were ignored in previous studies of urban water management.

10. From the analysis, it is observed that the water supply from surface and groundwater sources at Varanasi is 277 MLD (+ 30.68MLS stormwater+47.37 MLD treated waste water) and water demand for different purposes is 273 MLD. The available water is high.
11. A Scenario was also developed to study the water demand for different purposes including floating population and supply at Varanasi in future. It has been observed that by the year 2030, severe water stress would be observed at different location of Varanasi with marginal difference in water supply and water demand. Moreover, the groundwater would be exploited to fulfill the water demands. As per scenarios, in the year 2040, there would be deficit in water availability with respect to water demand and the whole Varanasi city would be under water scarcity.

PARTICULARS OF THE CANDIDATE

NAME OF CANDIDATE	: SHIKHAR KUMAR
DEGREE	: DOCTOR OF PHILOSOPHY
DEPARTMENT	: GEOLOGY
TITLE OF THESIS	: EFFECTS OF RAPID URBANIZATION ON THE POTABLE WATER RESOURCES USING GIS TECHNIQUES AND WEAP MODEL – A CASE STUDY OF VARANASI, INDIA
DATE OF ADMISSION	: 24-07-2018
APPROVAL OF	
RESEARCH PROPOSAL	
1. DRC	: 08-03-2019
2. BOS	: 05-04-2019
3. SCHOOL BOARD	: 26-04-2019
MZU REGISTRATION NO	: 1807295
Ph.D. REGISTRATION NO	: MZU/Ph.D./1283 of 24.07.2018
EXTENSION	: N/A

HEAD

DEPARTMENT OF GEOLOGY

MIZORAM UNIVERSITY

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RESUME

Personal Details:-

- Name : Shikhar Kumar
- E-Mail Address : shikhar5070@gmail.com
- Date of Birth : 8th July 1987
- Linguistic Proficiency : English, Hindi
- Nationality : Indian
- Marital Status : Single
- Address : Pu Nghaklianmawia Building
  Near Kulikawn Police Station
  Kulikawn, AIZAWL – 796005
  MIZORAM
  Mobile: +91-9862305070

Educational Qualifications:-

Degree	Year of Passing	Major	Board/University	Institution	Percentage/Class
M.Sc.	2010	Geology	Mizoram University	Mizoram University	71.8/I
B.Sc.	2008	Geology	Mizoram University	Pacchunga University College	62.6/I
AISSCE	2004	Math, Biology	CBSE	Kendriya Vidyalaya	65.2/I
AISSE	2002	Science	CBSE	Kendriya Vidyalaya	72.6/I

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ABSTRACT

The urbanization cycle poses a challenge to the environment that has a detrimental effect on human health. The major concerns are the unplanned urban sprawl, potential climate change, the demand for urban water and the impact on water resources of pollution. Water is a major supporter of life. Consequently, sufficient protection of water resources must be provided to avoid the depletion of water supplies by quality and quantity.

The Ganges River, the Hindus' ganga maa, is India's most holy river since its inception. It is still considered the most important river in the Hindu religion as one of the seven sacred rivers of the world. Ganga traverses the Indian states of Uttar Pradesh , Bihar and West Bengal in its 2.510 km course. The Brahmaputra River in central Bangladesh joins the combined waters called the River Padma to form a delta about 354 km in the Bay of Bengal. One of the most fertile and populated areas in the world is the Gangetic Plain. Situated along the 7 kilometers river side from River Assi, on the left bank of the Ganga river, in the north, Varanasi is one of Asia's oldest cities. The town of Varanasi, also known as Kashi, is called, according to Hindu mythology, the column of light and the Lord Shiva headquarters. Of course, the river Ganga and the city of Varanasi are both significant for Hindu and symbolic.

In the current scenario, there were about 29 water bodies at Varanasi and 15 storm water drains in working condition. Due to unexpected urbanization and sewer systems, wastewater production was found in many places.

The urban expansion of Varanasi, India is noticeable for people and significant changes in land use have recently been observed. In this work, different methods for analysis of urban expansion and land use changes are discussed in different regions and/or directions from the city centre, along highways, along river systems and in major hospitals. Remote sensing and GIS techniques along with the historical evidence for the last 29 years (1990-2018) have been applied to obtain population density urban development and floating population using the maximum

likely capability of visual image and digital classification. The acquired data for noise reduction and reflection is corrected before processing the image for analysis and classification. The Entropy strategy is used to achieve wise regional development in metropolitan areas and the areas that are projected to be extended in the future. Population growth in buffer zones 13 11 to 17 has been observed from about 10 to 20 per cent, although its value remains about 70 and 80 per cent.

Rainfall is one of the most important hydrological parameters for deciding people's livelihoods, improving irrigation, urban and industrial development, and finally the ecological environment. The rainfall is also an important input parameter and the main source of runoff for the hydrological cycle. Precipitation is a natural physiotherapy caused by atmospheric and oceanic circulation, with large variability at different spatial and temporal levels. (locally convected, frontal or orographic) It is implied. In terms of urban development other meteorological parameters, like temperature , solar radiation, moisture, wind speed, sunshine time, etc. Rainfall has been analyzed with statistical methods to develop the trend and to simulate future trend scenes for urban water management by means of temperature and solar-radiation trends. ARIMA models (p, d, q) have also been developed, and predictions have been made in respect of the Varanasi city for rainfall (1,1,1), minimal temperature (1,0,1) and maximum temperature (1,0,1). The scenario shows an increase in general temperature where a decreasing trend occurs in rainfall.

Gangas is now one of the world's biggest and most sacred rivers, which is heavily polluted by the flow of pollutants from several waterways along its banks. Almost every kind of waste from Varanasi, in other words. In the Ganga River was dumped sewage inflow, toxic waste, animal carcass, unclaimed human dead bodies, open defeat and practically all other forms of biodegradable and non-biological waste. The DO and BOD were found to be alarming while the total coliform and fecal coliform were found to be significantly high. Compared and well-agreed with the satellite data, the field-samples of chlorophyll-a, turbidity, coloured dissolved organic matter and suspended particulate matter.

All of this has been discussed and proposed in this study regarding the requirement for urban water in relation to possible climate change. Specially, in past studies of urban water management, floating populations have not been considered and the impact of climate change has been ignored.