Eco-city Plan Generation using RS-GIS: A Case Study of Vadodara

THE THESIS SUBMITTED
TO
THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA
FOR THE DEGREE
OF

DOCTOR OF PHILOSOPHY
IN
BOTANY

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CERTIFICATE

This is to certify that the thesis entitled "**Eco-city Plan Generation using RS-GIS: A Case Study of Vadodara**" which is submitted by Ms. Usha Joshi in partial fulfillment of the requirement for the award of degree Doctor of Philosophy in Botany, to The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat is a record of the candidate's own work and due acknowledgement has been made in the text to all other materials used. The matter embodied in this thesis is original and has not been submitted for the award of any other degree.

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I certify that the above statement is correct.

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ACKNOWLEDGEMENT

It gives me immense pleasure to express my heart-felt gratitude to all those who have been there all the while, during my research period extending their help in every possible way in accomplishing the course.

With all sincerity and high regards I express my deep sense of gratitude to my guide Dr. (Mrs.) Sandhya Kiran Garge, Associate Professor, Department of Botany, for her meticulous guidance, constant encouragement, inspiring discussions and valuable suggestions throughout this research.

I express my gratitude to Prof. Arun Arya, Head, Department of Botany, for his constant motivations, encouragement and advices in my work. My sincere thanks to Prof. Nikhil Desai, Dean, Faculty of Science, for providing me research facilities.

My sincere thanks are due to Shri. Paritosh Shah, Vadodara Urban Development Authority (VUDA) and Shri. Saurin Mehta, GIS analyst, Mascon Pvt. Ltd. for providing me with necessary information during my research work.

I am greatly indebted to late Dr. S.K.Pathan, SAC-ISRO whose remarkable guidance helped in giving new dimension to my research. I take this opportunity to thank Dr. R. J. Bhanderi, Scientist, SAC-ISRO for his valuable suggestions and inspiration.

It gives me pleasure to express my thanks to my teachers, Dr. Aruna Joshi, Dr. Vinay Raole , Dr. Geeta Padate and other teachers for their cooperation during my research tenure.

I specially thank my cordial friend and lab mate Ms. Ashwini Mudaliar for her help, encouragement, inspiration that provided the pleasant environment and much needed lighter moments during the crucial stages of my work.

I wish to record my thanks to my lab mates Ms. Preeti Baria, Mrs. Alpana Revdandekar, Ms. Ramandeep Kaur Malhi, Ms. Kinnary Shah & other research colleagues & friends. Cooperation given by all non-teaching staff of my department during my research tenure is thankfully accredited.

Research Scholarship from The M. S. University of Baroda for my Research work is gratefully acknowledged.

Last but not the least, the prayers & solace afforded by my parents and other family members whose encouragement and constant support kept me going through the entire tenure of my research.

Above all, my offering of thanks from the depth of my heart to the Almighty without whose blessings my research work would not have been fructified.

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LIST OF ABBREVIATIONS

CO_2	Carbon dioxide
CPCB	Central Pollution Control Board
MoEF	Ministry of Environment and Forest
GTZ	German Technical Co-operation
ASEM	Advisory Services in Environmental Management
NEERI	National Environment Engineering Research Institute
PEN	Participatory Employment Net
UNDP	United Nations Development Program
GEF	Global Environment Facility
SGP	Small Grants Program
HCC	Hindustan Construction Company
m	Meter
IT	Information technology
ITES	Information Technology Enabled Service
IE	Industrial Estates
Ind.	India
Co.Op	Co operative
BIDC	Baroda Industrial Development Corporation
VUDA	Vadodara Urban Development Authority
S.E.	Shannon’s Entropy
U.S.I	Urban Sprawl Index
L.C.R.	Land Consumption Rate
L.A.C.	Land Absorption Coefficient

LIST OF ABBREVIATIONS (Cont.)

VMSS	Vadodara Municipal Seva Sadan
UGS	Urban Green Space
UHI	Urban Heat Island
GIS	Geographical Information System
NDVI	Normalized Difference Vegetation Index
EM spectrum	Electromagnetic Spectrum
NIR	Near Infrared
WHO	World Health Organization
FAO	Food and Agriculture Organization
sq.m.	Square Meter
LST	Land Surface Temperature
P.D.	Population density
NDBI	Normalized Differential Building Index
B.D.	Building density
LSA	Land suitability analysis
SOI	Survey of India
IRS	Indian Remote Sensing Satellite
LISS	Linear Imaging Self-Scanning System
MIR	Mid Infrared
SWIR	Short Wave Infrared
Pan	Panchromatic
Erdas	Earth Resources Data Analysis System
GCP	Ground Control Points

LIST OF ABBREVIATIONS (Cont.)

ISRO	Indian Space Research Organization
A	areal extent of the city
P	population
NNRMS	National Natural Resources Management System
Landsat ETM+	Landsat Enhanced Thematic Mapper Plus
DN	Digital Number
L	Radiance
W	Watt
sr	steradian
µm	micrometer
lm	lumen
K	Kelvin
BT	Brightness Temperature
USAP module	Urban Suitability Analysis Package module
km	Kilometer
NH	National Highway
R.C.Dutt Road	Romesh Chunder Dutt Road
GIDC	Gujarat Industrial Development Corporation
UNEP GEO	United Nations Environment Programme-Global Environment Outlook
T.P.	Town Planning
GB	Greenbelt
^{o}C	Celsius
Veg.	Vegetation

LIST OF ABBREVIATIONS (Cont.)

PCA	Principal Component Analysis
PC	Principle Component
SPSS	Statistical Package for the Social Sciences
CNG	Compressed Natural Gas
APTI	Air Pollution Tolerance Index
AA	Amino Acid
RWC	Relative Water Content
TCh	Total Chlorophyll

CHAPTER 1

INTRODUCTION

(1.1) Eco-city - An introduction:

The world is increasingly urban. The number of urban residents is expected to grow continuously, especially in some of the developing Asian countries like India. Some 1.1 billion people are anticipated to move into Asian cities in coming decades **(Kallidaikurichi and Yuen, 2010)**. This includes 11 megacities, each with a population exceeding 10 million, for example, Beijing, Shanghai, Kolkata (Calcutta), Delhi, Jakarta and Tokyo. With the exception of Tokyo, the rest cities are in developing countries. Such expanding urban population will require a whole range of infrastructure, services, housing and jobs, including land. This is expected to threaten agricultural land supply, increase the traffic volumes and pressure on the environment. These trends are very unsustainable for the country and the rest of the planet. Today, most Asian cities are characterized by the following unsustainable trends **(Lehmann, 2010)**:

- A high number of inefficient older parts of the city which are in need of regeneration, with mature housing estates desperate for rejuvenation;
- An existing building stock which is out-dated and not energy-efficient;
- Structural problems, e.g. expansion of large shopping malls, but lack of noncommercial, catalytic, mixed-use, socially sustainable city projects;
- High carbon energy supply due to burning fossil fuels for generating energy
- Inefficient water, waste and transport operations accompanied by population growth

Such unsustainable practices are leading to the higher energy prices and increased emissions of carbon dioxide (CO_2). Traditional urban environmental issues such as urban pollution, traffic congestion and inappropriate waste collection are also the results of rapid urbanization and climate change. The environmental conditions are more degraded in the developed world and are getting worse in developing world, especially in the fast growing economies of China and India. The global shift of manufacturing industries from advanced nations (since the oil crisis in the mid-1970s) to developing countries is also transferring sites of industrial and household wastes, and carbon emissions to the developing world **(Randolph, 2004; Dicken, 2005; Jayne, 2006; Roberts *et al.*, 2009)**. There is an urge to use domestic consumption as means to support such high rate economic growth of cities and their more rapidly rising urban population. In addition, low levels of environment-led technologies, management and civic awareness in environmental protection all contribute to the urgency for action. This urgency has generated a need for reconsideration of the priorities for the future of cities in developing countries like India. There is a need to direct urban development towards minimizing the use of land, energy and materials, and deterioration of the natural environment while maximizing human well being and quality of life. In such situation, implementation of planning process which promotes sensitive urban development for preserving the open space for developing green areas and the ecological integrity of land and water becomes essential. This can be achieved through Eco-city planning.

An eco-city planning considers the city as a single integrated system (holistic approach) and not as a combination or result of many sectoral developments planned in isolation. The eco-city protects and even improves the environment. It is conceptualized as a city that decreases environmental burden/stress, improves living conditions and helps in achieving sustainable development. “Eco” in "eco-city" means the harmonious relationship between people and their natural and social environment while "City" means a self organizing and self-regulating symbiotic system, i.e., an integral organic body made up of nature, the city and people **(Linan *et al.*, 2004)**. It is also referred to as a 'sustainable city' or a 'green city' or "clean city" **(Modak, 2004)**. It is determined by the human ecological values and it is the inevitable trend of urban development in future, being a sustainable development mode of human living. It suggests an ecological approach to urban design, management and towards a new way of lifestyle. Eco-cities are designed with consideration of socio-economic and ecological requirements dedicated to the minimization of inputs of energy, water and food, and waste output of heat, air pollution, etc. so as to create an attractive place to live and work.

(1.1.1) <u>History of Eco-city:</u>

The idea of ecological cities or Eco-cities arose in the 1980s from new urbanism and was initially discussed mainly by German Scholars. New Urbanism is the integration of an array of related concepts including ecology, community design and planning for a livable and walkable environment. It emerged in the 1980s as a strategy with new typologies in land use to deal with the ecological weakness arising from the massive scale of postwar sprawling suburbanization. The earlier Eco-city concepts were focused primarily on the urban metabolism (→ circles of energy, water, waste, emissions, etc.) as well as the protection of the environment within an urban context **(Hahn, 1988)**. The German definition of an Eco-city is an environmentally, socially and economically responsible city. This definition corresponded to the global strategy for sustainable development set out by the **World Commission on Environment and Development (1987)**.

The term "eco-city" was traced to Richard Register's **(1987)** book, "*Eco-city Berkeley: Building cities for a healthy future*." Register's vision of the eco-city was a proposal for building the city like a living system with a land use pattern that supports the healthy anatomy of the whole city, enhances biodiversity, and makes the city's functions resonate with the patterns of evolution and sustainability. Some of the strategies implemented to manage this balance included:

- Building up instead of sprawling out,
- Giving strong incentives not to use a private four wheelers,
- Use of renewable energy and green tools to make the city self-sustaining

Since then, several similar themes such as "eco-neighbourhoods", "urban eco-village" and "eco-communities" emerged, all emphasizing ways of making the city more environment-friendly and sustainable **(Roseland, 1997; Barton, 2000)**.

(1.1.2) <u>Eco-city In India:</u>

In the year 2002, the Eco-city Project was initiated by the **Central Pollution Control Board (CPCB)** with the grants-in-aid from the **Ministry of Environment and Forest (MoEF)**, Government of India in partnership with the **German Technical Co-operation (GTZ)** under the India-German Environment Programme on **"Advisory Services in Environmental Management" (ASEM)** as a part of the X Plan activities. The Eco-city Project was an innovative and proactive measure intended to be implemented in a phased manner, starting with initial project coverage of small to medium towns. The Eco-city programme was conceptualized for improving environment and achieving sustainable development through comprehensive urban improvement system employing practical, innovative and non-conventional solutions.

The Eco-city Project in India aimed to ameliorate the existing environment, addressing mainly to those aspects that are causing the environmental damage. The review on various aspect of the project was carried out by G.**Sandhya K. and Joshi, 2009.** The focus of the project was to control pollution, improve environmental quality, protect environmental resources like rivers and lakes, improve sanitary conditions, improve the needed infrastructure and to create aesthetic environs in the chosen towns. This project anticipated to pave a way for transforming the identified **project towns (Table 1)** into places that are clean, orderly and sustainable.

Table 1: Towns identified for coverage under the X Plan

Sr.No.	Town	State
1.	Rishikesh	Uttaranchal
2.	Mathura	Uttar Pradesh
3.	Vrindavan	Uttar Pradesh
4.	Bharatpur	Rajasthan
5.	Baidyanath Dham (Deoghar)	Jharkhand
6.	Vapi	Gujarat
7.	Shillong	Meghalaya
8.	Puri	Orissa
9.	Ujjain	Madhya Pradesh
10.	Tirupati	Andhra Pradesh
11.	Thanjavour	Tamil Nadu
12.	Kottayam	Kerala

(1.1.3) <u>The specific objectives of the Eco-city project were</u>:

- To identify the environmental problems/hotspots in the selected towns
- To identify priority environmental improvement projects through participatory approach;
- Designing and detailing the prioritized environmental improvement projects
- To create landmarks that shows visible environmental improvement.

- To improve environment by increasing green belts, urban green spaces in the city
- To protect environmental resources (water bodies, forest etc.)
- To plan development activities compatible to environment
- To improve infrastructure-water, electricity, transportation
- To improve sanitary conditions-sewerage, garbage, storm water, etc.

(1.1.4) Criteria for selection of the towns/cities covered under the Eco-city Project were as followed:

- Size of the town/city
- Cultural/historical/heritage/tourism importance
- Environmental Improvement Needs
- Scope for public-private partnerships and private investment
- Generators of economic momentum/urbanization
- Public participation in decision-making process
- Regional distribution of towns

(1.1.5) Following are few towns described in which Eco-city program was implemented by government of India:

(1) <u>Vrindavan:</u>

Eco-city plan of Vrindavan addressed several issues like, improvement of sanitary conditions including solid waste management and drainage system, improvement of traffic and transportation system, development of tourist friendly routes, and improvement of environmental quality. **Plate 1** is showing the part of town where project was implemented along with the location of eco-zone, transportation route and green belt. Trained manpower was also introduced in the Vrindavan Nagar Palika Parishad to fulfill all these objectives and to improve urban management and planning.

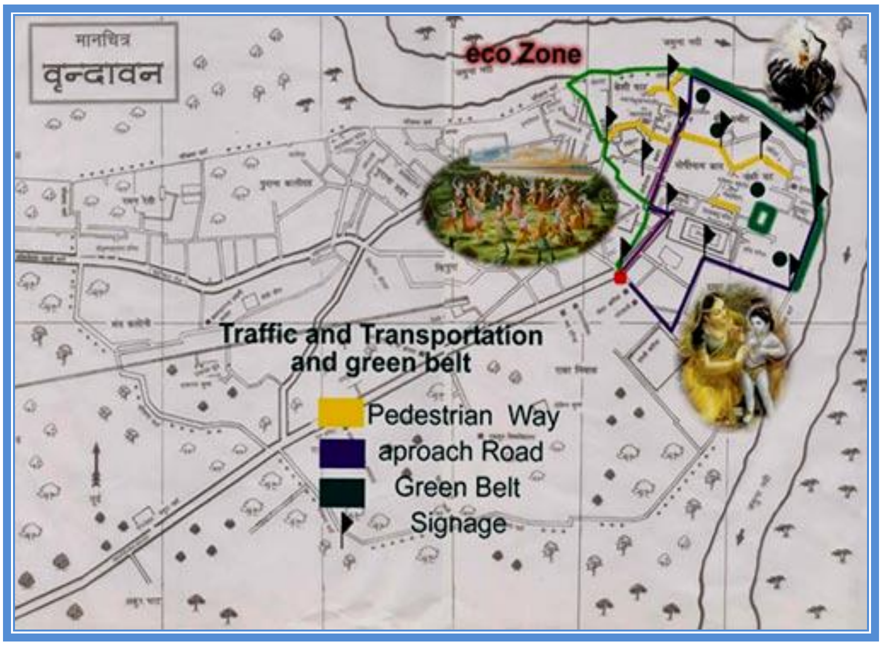


Plate 1: Vrindavan Eco-city plan

(2) <u>Kottayam</u>:

The Kottayam Municipality (Kerala) implemented 'Eco-city' programme to renovate Kacheri Kadavu Boat Jetty Canal and Rejuvenate Munda River which were severely degraded because of siltation, weed growth and disposal of domestic waste **(Plate 2)**. The municipality carried-out the following activities:

- Removal of weeds and vegetations in the Jetty canal and river
- Dredging activity was done in the canal (upto 1100 m) and river (upto 600 m).
- Construction of Sitting steps and retaining wall
- Renovation of parking area.

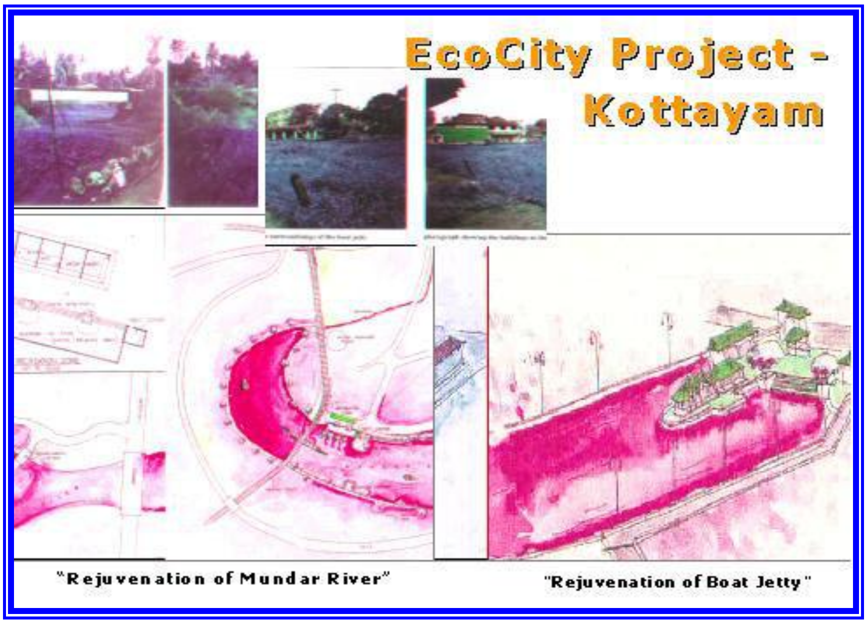


Plate 2: Eco-city plan Kottayam

(3) <u>Kancheepuram (Tamil Nadu)</u>:

To propagate the environmental friendly concept Department of Environment has prepared an "eco-city plan" for Kancheepuram Town through **National Environment Engineering Research Institute (NEERI)**, Chennai. The overall objective of the programme was to incorporate environment considerations into urban planning and prepare an Environmental Management plan for improving the environment quality. Specific objectives of the project were:

- To map the environment profile of study area and to identify the environmental pollution hotspots.
- To prepare an environment management plan that include rehabilitation and mitigation measures
- To recommend guidelines for environmentally compatible land use planning.

(4) Tirupati :

Eco-city project of Tirupati was a joint mission of the Tirupati Municipality and **Participatory Employment Net (PEN)**, India in collaboration with **GTZ-ASEM**, **United Nations Development Program (UNDP)**, **Global Environment Facility (GEF)** and **Small Grants Program (SGP)**. The activities carried out were:

- The storm water drains in the Northern, Southern and Western sides of the temple were covered
- Narasimh Theertha tank was connected with Koneru pond through the pipeline to bring the fresh water to the pond
- Cleaning and de-silting of drains in the core area of the Koneru was done **(Plate 3)**
- The core area of the town around Govinda Raja Swami temple was improved

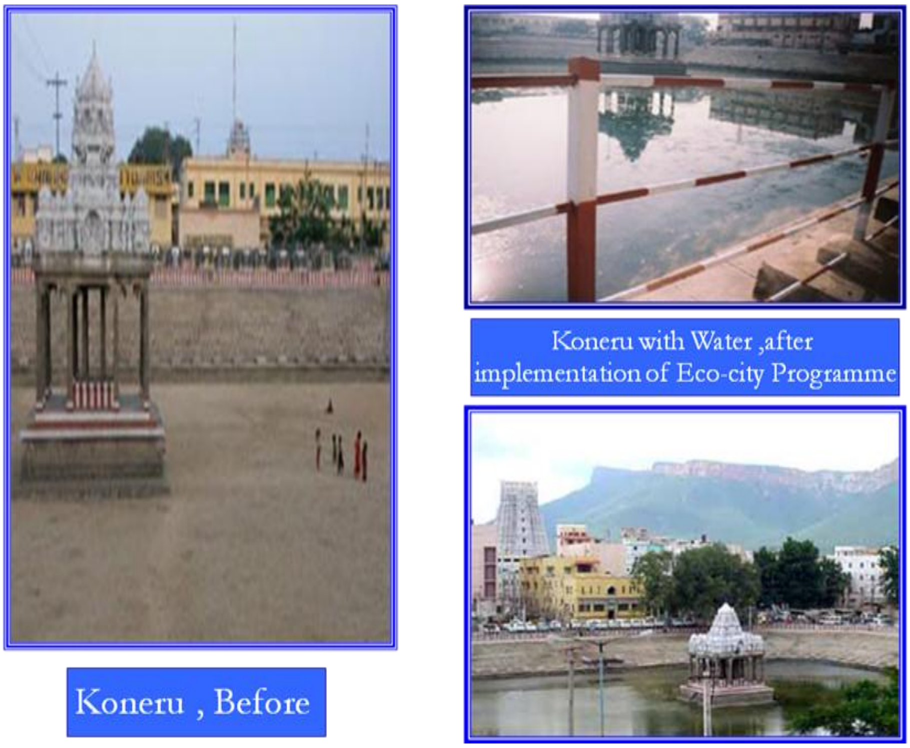


Plate 3: Koneru pond of Tirupati before and after implementation of Eco-city Program

(5) Puri:

The project concentrated on the areas surrounding Lord Jagannath Temple, Grand Road, the religious tanks and commercial and old residential areas near the temple **(Plate 4)**. The main results expected to be achieved from the Eco-City Project were:

- Improved environmental quality
- Improved condition of traditional water bodies
- Improved sanitary conditions by efficient management of solid waste and drainage system
- Improved management of traffic and transportation system

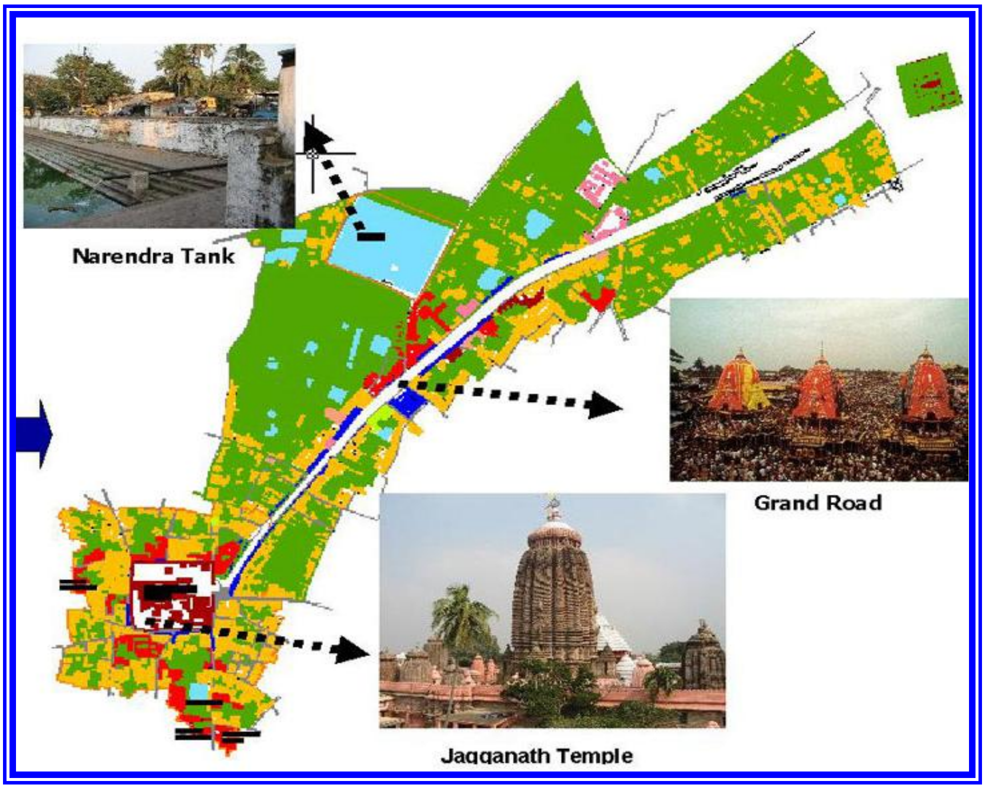


Plate 4: Map showing the locations of Eco-city project implementation in Puri

(6) <u>Ujjain:</u>

The Project on Ujjain focused on Mahakal Temple area including Harsidhhi Temple, Bada Ganapati Temple, Rudra Sagar and Old Residential areas. The main results expected to be achieved from the Project were:

- Revival of Rudra Sagar by improving the water quality of the pond **(Plate 5),**
- Improvement in sanitary conditions including solid waste management and drainage
- Improvement in environmental quality and traffic management

Plate 5: Rudra Sagar Lake of Ujjain

(7) <u>Eco-city of the Magarpatta (Pune):</u>

It is the first city of its kind in the India and has been built considering all the aspects of the Eco-city construction. Everything is within walking distance, to live, work, study, play and shop **(Magar, 2009)**. There is a presence of abundant greenery surrounding residential areas of the city **(Plate 6)**. Magarpatta City is an effort to restore life's harmony, completeness, balance and fulfillment in the living process.

Plate 6: Residential View of the Magarpatta City

(8) <u>Lavasa (Pune): A Dream city</u>

Lavasa lake city is being developed by Hindustan Construction Company (HCC) near Pune within the Western Ghat ranges **(Karunakaran, 2007)**. This sustainable town aims to reduce the environmental stress and enhance residents' quality of life. This will be achieved by minimizing the commute time. This Eco-city will try to attain the balance between urbanism and environmentally friendly surroundings to have a unique way of life as can be seen in **Plate 7**. Life in this city has been envisioned as energetic yet calm, aspirational yet affordable, hi-tech yet simple and urban yet close to nature.

Plate 7: Eco-city of Lavasa

(1.1.6) Vadodara as an Eco-city:

The cities are the major sources of air pollution, water contamination and depletion of supply, excessive fossil fuel consumption, the consumption of materials made from non-renewable resources; and, of the depletion of agricultural land through low density sprawl and expansive waste management (**Breheney, 1992; Steward and Kuska, 2008**). As a consequences environment quality of some cities of developing countries like India is degrading constantly due to wasteful use of resources. This is proving to be costly to present and future generations. Same is the case with Vadodara city also. The city is growing very rapidly consuming all the natural resources most importantly the land. To make the best use of resources and to prepare the ground for the improvement and the development of Vadodara city there is a call for preparing a sound strategic plan. This can be achieved by implementing an Eco-city plan for the city. This plan will aim to attain a balance between the development of the urban areas and protection of the environment by decreasing the environmental damages and depletion of nonrenewable resources.

For preparing the eco-city plan different steps to be carried are mentioned below:

- To generate thematic maps based on various themes, viz. Transportation network, Water body, Gardens, Greenbelts, Population density and slope map of the city.
- To carry out land use change analysis,
- To perform suitability analysis of Urban Green Space (UGS)
- To perform Land Suitability Analysis (LSA) and
- To perform Air Pollution Tolerance Index (APTI) of various plants

Each of these points is discussed separately in different sections.

(1.2) Different types of Maps:

Maps are universal medium for communication, easily understood and appreciated by most people, regardless of language or culture. A map is a set of points, lines and areas that are specified both by their location in space with reference to a coordinate system and by their non-spatial attributes. They are an effective way of presenting a great deal of information about objects and spatial relationships of objects. Incorporated in a map is the understanding that it is a "snapshot" of an idea, a single picture, and a selection of concepts from a constantly changing database of geographic information. They are one means by which scientists distribute their ideas and pass them on to future generations **(Merriam, 1996)**.

Maps can be classified into two main groups: general purpose maps and thematic maps.

(1.2.1) General purpose maps:

General purpose maps are often used for reference purposes and can exhibit a variety of information including physical land features and political boundaries. The most common type of general purpose map is a topographic map. A topographic map is simply a two-dimensional representation of a portion of the three-dimensional surface of the earth. Topography in the topographic map is the shape of the land surface. Topographic maps represent existing condition of the land surface. They are often used as reference maps, and typically display both natural land features (such as coastlines and water bodies) as well as political boundaries. They are the tools used in geologic studies because they show the configuration of the earth's surface.

(1.2.2) Thematic maps:

Thematic map is a simple map made to reflect a particular theme about a geographic area. They are referred to as graphical essays that portray spatial variations and interrelationships of geographical distributions of various objects present on the earth surface. Thus, a thematic map is defined as a two dimensional scale model of a part of the surface of the earth, using symbols to represent certain objects and phenomenon. The term “thematic map” is very widely and loosely applied and is used not only for maps showing a general purpose theme such as “soil” or “landform”, but for much more specific properties such as the distribution of the value of the soil pH over an experimental field, the variation of the incidence of a given disease in a city, or the variation of air pressure shown on a meteorological chart. A useful and attractive thematic map successfully combines the mapped data with physical and political elements that constitutes the base map. They help in classifying an area on a particular theme and identifying regions within that area where intervention is required. For example, a thematic map plotting the ground water levels in a given area can be used to design a geo-morphology map **(Upadhyay, 2005)**. These maps concentrate on the spatial variations of a single phenomenon or the relationship between phenomena. They portray the structure of a given distribution and may be used to characterize a wide variety of terrain characteristics. In these maps different tone, colors, and shading patterns are used to convey the different values assigned to each predefined polygonal area. They portray physical, social, political, cultural, economic, sociological, agricultural and many other aspects of a city, state, region, nation, or continent.

Thematic maps serve three primary purposes:

- They provide specific information about particular locations.
- They provide general information about spatial patterns.
- They can be used to compare patterns on two or more maps.

Thematic mapping began in 1686 with Edmund Halley. His maps dealt with sailing and navigation, but were more specialized and went beyond the subject of coastlines and places. One of those early thematic maps showed trade winds of the world **(Cuff and Mattson, 1982)**. In Roman times, the Agrimensores or land surveyors, were an important part of the government, and the results of their work may still be seen in vestigial form in the landscapes of Europe today **(Dilke, 1971)**. The decline of the Roman Empire led to the decline of surveying and map making. Only in the eighteenth century did European civilization once again realize the value of systematic mapping of their lands. National government bodies were commissioned to produce topographical maps of whole countries. These highly disciplined institutes have continued to this day to render the spatial distribution of the features of the earth's surface, or topography, into map form. During the last 200 years many individual styles of maps have been developed, but there has been a long, unbroken tradition of high cartographic standards that has continued until the present. In the twentieth century, the demand for maps of the topography and specific themes of the earth's surface, such as natural resources, accelerated greatly which led to introduction of various cartographic techniques for generation of maps more quickly. Stereo aerial photography and remotely sensed imagery were used by photogrammetrists to map large areas with great accuracy. The same technology had also given the earth resource scientists- the geologist, the soil scientist, the ecologist, the land-use specialist enormous advantages for reconnaissance and semi-detailed mapping. The resulting thematic maps provided useful information about status of various resources. These maps also helped in estimating the land requirements for producing food and supporting populations.

There are five techniques for thematic mapping which are used most often:

(1.2.2.1) <u>Choropleth map</u>:

The first and most commonly used technique of preparing a map is a Choropleth map. A Choropleth map is a thematic map in which areas are shaded or patterned which shows the measurement of the statistical variable being displayed on the map, such as population density or per-capita income. These maps are particularly suited for charting phenomena that are evenly distributed within each enumeration unit (set area). Choropleth techniques are used when the derived data are obtained from raw data such as population densities. Both quantitative and qualitative information can be expressed as a Choropleth map, i.e., areas of equal value separated by boundaries and typical examples are soil maps, land use maps or maps showing the results of censuses. These maps portray quantitative data as a color and can show density, percent, average value or quantity of an event within a geographic area.

(1.2.2.2) <u>Proportional or graduated symbols map</u>:

These maps represent data associated with point locations such as cities. Data is displayed on these maps with proportionally sized symbols to show differences in occurrences. Circles are most often used with these maps but squares and other geometric shapes are suitable as well. The most common way to size these symbols is to make their areas proportional to the values to be depicted with mapping or drawing software. **Plate 8** shows distribution of different plants according to their size which is an example of proportional symbol map.

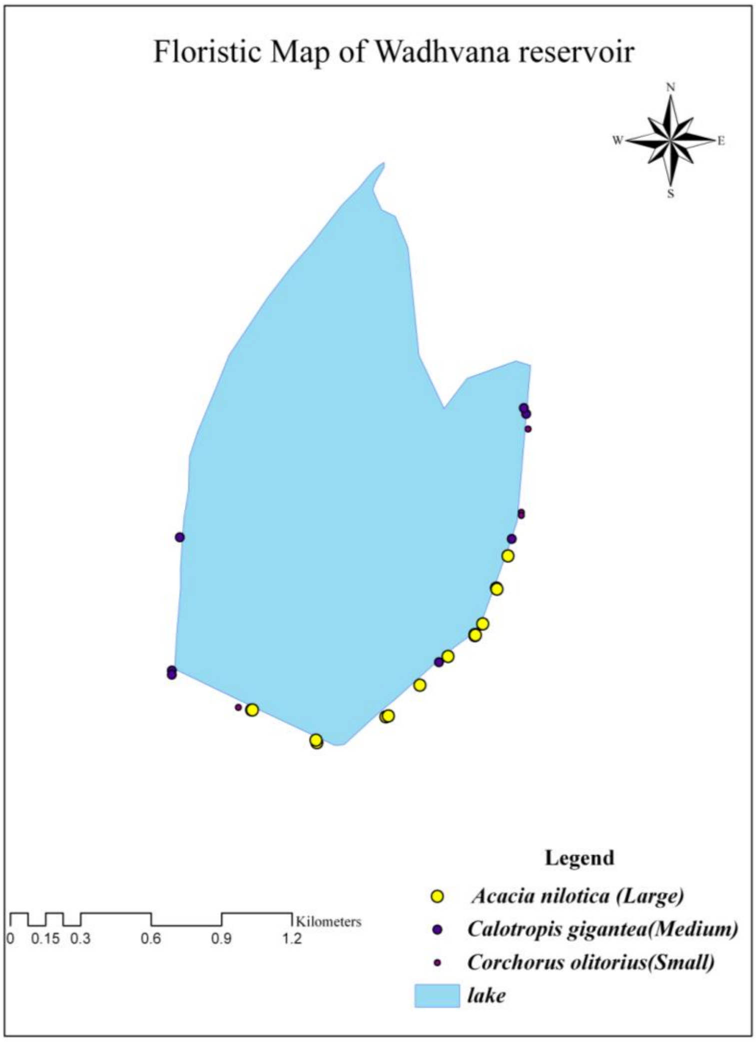


Plate 8. Map showing distribution of different plants according to their size.

(1.2.2.3) <u>Isarithmic or contour map</u>:

In these maps third variable is represented in two dimensions by colour or by contour lines, indicating gradations. It uses isolines to depict continuous values. Data for these maps is gathered via measureable points (e.g. weather stations) or is collected by area (e.g. tons of corn per acre by state). Contour lines are used to determine elevations and are lines on a map that are produced from connecting points of equal elevation (elevation refers to height in feet, or meters, above sea level). There is a high and low side in relation to the isoline in these maps. For example in elevation, if the isoline is 500 feet (152 m) then one side must be higher than 500 feet and one side must be lower. These lines showing different levels of contour have following general characteristics like:

1. They do not cross each other, divide or split.
2. Closely spaced contour lines represent steep slopes, conversely, contour lines that are spaced far apart represent gentle slopes.
3. They trend up valleys and form a "V" or a "U" where they cross a stream.

In most maps, contour lines are generally darker and are marked with their elevations. The contour interval is stated on every topographic map and is usually located below the scale. **Plate 9** shows the contour map of Gujarat.

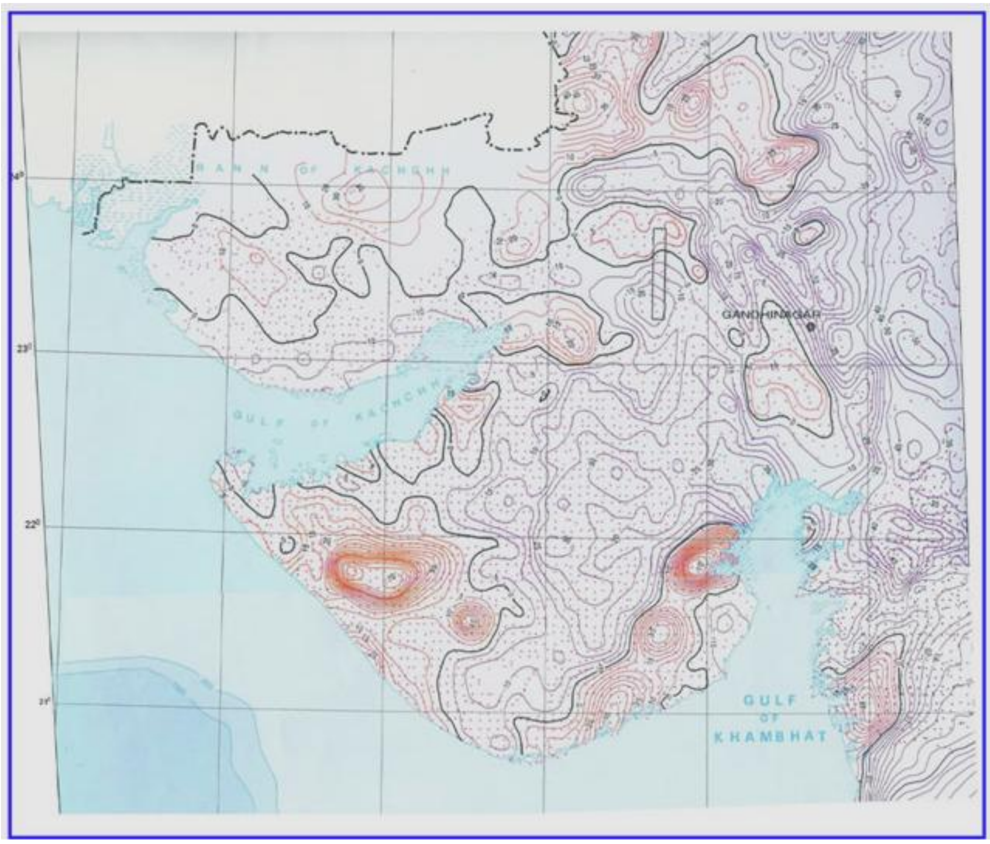


Plate 9: Contour map of Gujarat*

*Source:http://isr.gujarat.gov.in/gravity2.shtm

(1.2.2.4) <u>Dot map</u>:

These maps use dots to show the presence of a theme and display a spatial pattern. Dot density maps are particularly useful for understanding global distribution of the mapped phenomenon and comparing relative densities of different regions on the map. On these maps, a dot can represent one unit or several, depending on what is being depicted within the map e.g. the dot map given in **Plate 10** is depicting floristic composition of Wadhwana reservoir wherein each dot represents a specific type of plant species.

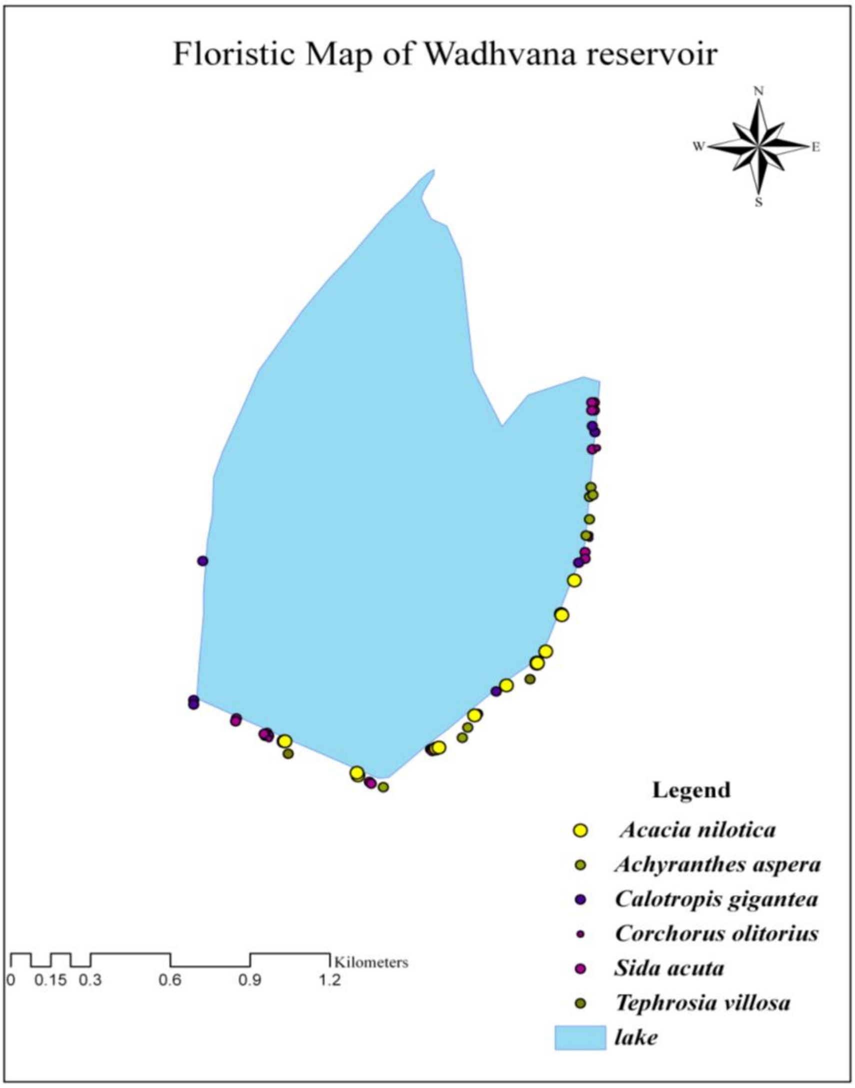


Plate 10: Floristic map of Wadhwana Reservoir

(1.2.2.5) <u>Dasymetric map</u>:

This method of thematic mapping uses aerial symbols to present data spatially. It is a compromise between the Isopleths map and Choropleth map because it utilizes standardized data and at the same time places the symbols by taking into consideration actual changing densities within the boundaries of the map. This map utilizes the ancillary data. It is superior to Choropleth map in relaying statistical data within areas of interest. This map corrects the error, termed "ecological fallacy", that may occur with Choropleth mapping. Dasymetric maps are not widely used because of the limited options for producing them with automated tools such as GIS. Researchers in various fields of science are trying to make dasymetric mapping techniques more easily applicable with modern technology. These maps are becoming more prevalent in developing fields, such as conservation and sustainable development.

(1.2.3) <u>Importance of Thematic maps</u>:

The urban ecosystem constitutes of various components like, water bodies, vegetation, built-up areas, etc. Mapping spatial distribution of these components becomes essential for designing a sound development plan. Thematic maps provide accurate and updated information of spatial distribution and present condition of these various resources. This information plays a vital role in formulation of planning, management and monitoring programs at local, regional and national level. Intense conflicts between socioeconomic development and environmental protection for these resources have increased the attention paid to sustainable urban development **(Rees, 1992; Rees, 1997; Pickett *et al.*, 2001; Pickett *et al.*, 2004),** especially in developing countries like India. This is because megacities of the country are grappling with the complexity of balancing urbanization with preservation and maintenance of supplies of these resources **(Arreguin, 1996; Goldenstein, 1998; Robles *et al.*, 1999; Baykal *et al.*, 2000; Ren *et al.*, 2003)**. Updated information of these resources acquired in the form of thematic maps is a foundation to develop an Eco-city. In such situation, eco-city development becomes an imperative and healthy process towards sustainable development within the carrying capacity of local ecosystem in which generation of thematic maps play a fundamental role.

(1.2.4) <u>Designing the thematic maps</u>:

Designing a thematic map requires a balance of number of factors in order to effectively represent the data. It is necessary to consider a number of key map design elements while designing a thematic map which include the frame of reference, the projection used, the features to be mapped, the level of generalization, annotation used and symbolism employed. All these design elements are presented in a legend which is a key for linking the non-spatial attributes to the spatial entities. Non- spatial attributes may be indicated visually by colour, symbols or shading. Spatial accuracy, aesthetics, quirks of human visual perception and their presentation are also taken into account while generating these maps. Definition of thematic maps depends upon the requirement of the users who will read the maps. For example, a political scientist might prefer having information mapped within clearly delineated state or town boundaries (Choropleth maps) whereas a state biologist could certainly benefit from natural boundaries of resources like water bodies, vegetation, etc. being on a map.

(1.2.5) Role of Remote Sensing (RS) and Geographical Information System (GIS) in generation of thematic maps:

Satellite RS offers varied advantages and has been widely accepted as a technique for urban thematic mapping. Compared to more traditional mapping approaches, mapping using satellite imagery has the advantages of low cost, large area coverage and repetitivity. Consequently, land-use information products obtained from satellite imagery such as land-use maps and data have become essential tools in many operational programs involving land resource management. The increasing availability of satellite imagery with significantly improved spectral and spatial resolution has offered greater potential for more detailed thematic mapping. Recent studies have demonstrated that the higher information content of imagery data combined with the improvement in image processing power result in significant improvement in classification accuracy. Products derived from RS are also important for GIS database development because they provide spatial information that can be incorporated directly into GIS **(Lee, 1991)**.

GIS is defined as a set of tools for collecting, storing, retrieving, transforming, and displaying geographically referenced spatial data with its corresponding attribute information. It is responsible for a major shift in techniques used for generating thematic maps. It comprises of computer hardware, software, digital data, people, organizations, and institutions for collecting, storing, analyzing, and displaying georeferenced information about the Earth **(Nyerges, 1993)**. GIS has two kinds of data bases:

1. Specific characteristic of a location called spatial data, and
2. Attribute data (Statistics of written text tables and so on)

The spatial data is classified into two categories i.e., raster data and vector data. The vector-based GIS, gives an attribute value for each predefined polygon using which the system is instructed to shade or colour the interior of each polygon appropriately. On the other hand the raster-based system is typically more complex. It often uses colour to code different contour line values and other attributes. It aids in generating precise map and integrate them as different themes. Thus, it has a database of multiple information layers that can be manipulated to evaluate relationships among the chosen elements in the different layers of typology. Application of RS-GIS technology therefore has several advantages as are enlisted below:

1. Make existing maps quickly and cost effectively for specific use and needs.
2. Makes map production possible in situations where skilled staff is unavailable.
3. Allows experimentation with different graphical representations of the same data.
4. Facilitates map making and updating when the data are already in digital form.
5. Facilitates analysis of data that demand interaction between statistical analysis and mapping.
6. Aid in generating maps which are difficult to be made by hand, e.g. 3-D maps or stereoscopic maps.
7. Aid in generating maps in which selection and generalization procedures are explicitly defined.

Thus, wide applicability of this technique has been exploited by several workers and in the present study for understanding land use change analysis of Vadodara city.

(1.3) Land use change analysis: An Overview

There are many problems confronting most contemporary cities in the recent time particularly among the less developed countries around the world. These problems have been recognized to be the product of lack of urban planning by the authority in-charge as well as individual members of the society **(Chandrasekar, 2010)**. The understanding of relationship between urban population and urban development using different methodologies has therefore become imperative. This is because expansion of human settlement and its accompanying activities especially the rapid urbanization plays an important role in changing the land use at both global and local scale. Land use is referred to the way in which, and the purposes for which, humans employ the land and its resources **(Meyer, 1995).** The land use pattern of a region is an outcome of several factors and their utilization by man in time and space. These factors driving land use changes are called as 'development attractors.' Such attractors also exist in one of the cities of India, i.e. Vadodara city of Gujarat state. The city has witnessed a rapid urban development during past few decades resulting into enhanced land use change, parallel to the increased population and economic growth. The city has expanded in all directions, resulting in large-scale changes in the land use. According to the projections made by VUDA, the city is expected to have a population of 21, 15,000 by 2021**(Dash and Kumar, 2010)**. Such rapid population growth due to urbanization and industrialization processes would definitely increase the pressure on land making proper land use planning imperative.

The term "Planning" stresses mainly on assessment of future and making provisions for it. In order to achieve proper urban planning and to check haphazard development, it is necessary that authorities associated with the urban development generate planning models. These models should help in utilizing every bit of the available land in most rational and optimal way. They should aid in selection, planning and implementation of land use schemes to meet the increasing demands of the city. Such models require data on present and past land use information of the area and pattern of changes with respect to urban settlements and other local resources **(Chaurasia *et al.*, 1996)**. It is subtle to acquire such volumetric information using conventional ground methods. Such methods are labor intensive, time consuming and are done relatively infrequently. The maps produced using these techniques soon become outdated with the passage of time, particularly in a rapid changing environment. Therefore, in order to use land optimally, it is not only necessary to have the information on existing land use but also a technique to monitor the dynamics of land use resulting out of both changing demands of increasing population and forces of nature acting to shape the landscape. According to **Olorunfemi (1983)**, monitoring changes and time series analysis is quite difficult with traditional method of surveying. At this point the advanced remote sensing techniques have proved to be of immense value for gathering all the possible information in quick and cost-effective manner. It aids in both preparing accurate land use maps and monitoring changes at regular intervals of time. The potential of remote sensing to detect the growth of urban land use changes and determination of statistics has already been demonstrated by several workers **(Chen and Xie, 2000; Saleh and Al Rawashdeh, 2007; Li *et al*., 2011)**. Integration of such spatially retrieved data into Geographic Information Systems further has improved the analysis of the land use dynamics **(Sreenivasulu and Bhaskar, 2010)**. These systems integrate different spatial and statistical data relevant in understanding the changes. Such integration and organization of information on land use in these systems give the planners a broad view of the current situation. It aids in taking proper land related decisions for shaping the way in which land can be used and the built environment can be managed as it assesses the future more accurately. This has become a need for Vadodara city as it is facing the grave problem of both urbanization and industrialization.

In the recent years, Vadodara city has experienced significant growth in Information technology (IT) and IT Enabled Service (ITES) industries like the software and electronics. Demand for the Processing industries and other allied industries contribute about 41% share of the total industries because of the increasing demand related to plastics, and pharmaceuticals. Vadodara has nine Industrial Estates (I.E.) located dispersed in all the four corners of the city *viz*., Makarpura I.E., Baroda I.E. (BIDC Gorwa), Sardar Patel (I.E.) (Ajwa Road), Baroda Ind. Co.Op. Estate (Chhani Road), Patel I.E. (Yamuna mill Road), Sahajanand I.E. (Atladra Road) and R.C. Patel Estate (Akota). Apart from these VUDA have industrial complexes like Nandesari, Ranoli, Bajwa and Undera **(VUDA report)**. Such industrial growth has brought in the population inflow from nearby rural areas resulting into a complex phenomenon of urban sprawl. This phenomenon has both environmental and social impacts and is measured in terms of Shannon’s Entropy (S.E.) **(Leta *et al.*, 2001; Yeh and Li, 2001; Barnes *et al.*, 2002; Sudhira *et al*., 2004; Sun *et al*., 2007)** and urban sprawl index (U.S.I).

S.E. determines the distribution of built-up as a function of the area of built-up within a defined spatial unit **(Jat *et al.*, 2007).** The change of entropy identifies whether land development (sprawl) is of more dispersed or compact pattern. The U.S.I. developed by **Yuan *et al.*, 2005** on the other hand also is an important index providing information on the degree of sprawl in a city. Other indicators along with S.E. and U.S.I. determining the sprawl are the Land Consumption Rate (L.C.R.) and

Land Absorption Coefficient (L.A.C.). These indicators provide good input in the understanding of the land use change both at spatial and temporal scale. L.C.R. is a measure of compactness of the city indicating a progressive spatial expansion of urban area. Land absorption coefficient (L.A.C) on the other hand, is a measure of consumption of new urban land by each unit increase in urban population **(Fanan *et al.*, 2011, Sharma *et al.*, 2011)**.

In the present study land use changes in Vadodara city have been measured over a period of 129 years. Estimation of different urbanization related parameters for Vadodara city have also been attempted. These changes have been assessed at two different levels, i.e. Vadodara Urban Development Authority (VUDA) level and Vadodara Municipal Seva Sadan (VMSS) level**.** VUDA covers the entire city and adjoining village areas while VMSS covers urbanized area of the city.

(1.4) Analysis of Urban Green Space:

Analysis of the Urban green space is segregated into three different parts, i.e., Suitability analysis, economic evaluation and assessment of impact of various biophysical and socio-economical parameters on UGS.

(1.4.1) Part 1: Suitability of Urban green space:

Urban areas presently cover about 4% of global land area. More than 50% of the global population currently live in cities and it is expected to increase to 70% (or 6.4 billion people) by 2050 (**Kasih, 2009**). These areas are multiplex ecological system made up of three subsystems i.e., social, economic and natural (**Haung and Chen, 2002**). The green spaces present in these areas are termed as Urban Green Spaces (UGS). These spaces are the foundation of the natural system in a city and the principal part of the natural productivity in the urban structure. They are the base for developing a city into Eco-city. **Wu (1999)** has described this as the area covered with the natural or man-made vegetation in the built-up areas. Landscape features like parks, public gardens, squares, traffic circles, sport fields, fallow lands, and family gardens as well as individual street trees form a component of the 'urban forest' **(Pauleit, 2003; Colding, 2007)**. UGS are managed intensively by different agencies or people. They provide many amenities for city dwellers like, aesthetic enjoyment, recreation, with an access to clean air and quiet environment. They also absorb atmospheric carbon, maintain a certain degree of humidity in the atmosphere, regulate rainfall, moderate the temperature, restrain soil erosion, produce vitamin ''G'' for health and form the basis for the conservation of flora. Conservation of the UGS therefore acts as a backbone for natural ecological network and support the sustainability of the cities. They act as the link between residential and industrial areas. The different social, economical and environmental benefits accrued from these areas in the urban region makes them very significant. Rapid urbanization and the accelerated urban sprawl are leading towards the conversion of these areas into a largely artificial environment like urban built-up, industries, etc. made up of concrete and asphalt. Increased built-up area results into the several regional environmental and climatic changes **(Landsberg, 1981; Oke, 1987; Oke *et al*., 1992)**. It has already been proved that the urban temperature rises because surface covered with vegetation gets replaced by artificial facilities of impervious cover of asphalt and concrete **(Lee, 1993; Kato, 1996; Gallo *et al.*, 1996; 1999)**. As cities grow in both population and physical size, the urban-rural difference in atmospheric and surface temperature also increases **(Kalnay and Cai, 2003, Voogt and Oke, 2003)**. This difference in temperature leads to generation of urban heat island (UHI) effect. However, many researchers have proved that UGS and UHI are inversely proportional i.e., higher the amount of UGS, the lower the intensity of UHI **(Wu and Zhang, 2008)**. The role of UGS becomes very significant in such circumstances. It plays a very significant role in maintaining the temperature in the urban settings. Despite of this fact there is a total apathy towards the management of vegetation in many cities. Similar situation prevails in Vadodara city also wherein areas allotted for UGS are not maintained properly. They are getting converted to concrete jungles. In addition, no new areas are being allotted for development of UGS.

Above facts emphasize the need for not only developing green areas in the city but also to identify suitable sites in the city where these areas can be planned, managed and sustained. This can be accomplished using suitability analysis technique. This technique helps in determining the fitness of given tract of land for a defined use **(Steiner *et al.*, 2000)**. It is the process to determine whether the land resource is suitable for the given specific use by estimating the suitability level of that area in terms of all different parameters. It is an important analytical method for ecological planning. Several methods exist for suitability analysis viz., sieve mapping, landscape unit method, grey tone method and computer based Geographical Information System (GIS) method. GIS method has been used for this work because GIS in combination with remote sensing provides precise information about the present status of various parameters used for suitability analysis. In addition, spatial statistics algorithms within GIS help in accurate, consistent, unbiased assessment of UGS. This aids in determining the UGS suitability as it takes into account various parameters viz., vegetation, temperature, land use, transport, water body, population density, slope, location of greenbelts and gardens for the suitability analysis **(Tajima, 2003)**. All these parameters have been discussed separately in the following sections.

(1.4.1.1) Vegetation:

The spatiotemporal distribution of vegetation is a fundamental component of the urban environment. From the view of ecological balance, environmental protection and improvement, allocation of certain areas for UGS is prerequisite. It plays an active role in terms of ecological benefit. Acquiring information on the condition and distribution of areas with and without vegetation is in the centre unit which using conventional technique is a difficult task. Satellite data enables the retrieval of such information through various algorithms in the form of various indices. In the present study one of such indices viz. Normalized Difference Vegetation Index (NDVI) has been utilized to understand vegetation status. This index identifies the photosynthetic affinity or 'greenness' of the vegetation through the reflective proprieties of the chlorophyll and mesophyll layers within the plants in the NIR and red part of the EM spectrum. In case of photo-synthetically active vegetation, low red reflectance is observed along with very high NIR reflectance producing a NDVI, approaching the value of +1 and vice versa approaching the value -1.

Per capita vegetation and change in vegetation was assessed based on the quantification of vegetation by this method which proved to be a key input. Per capita green space is an index to assess the green space system in accordance to the population status. According to the International minimum standard suggested by World Health Organization (WHO) and adopted by the publications of United Nations Food and Agriculture Organization (FAO) the minimum area allotted for UGS should be 9 sq.m. per city dweller. Except for Gandhinagar and Chandigarh most Indian cities are far behind in their per capita urban forest availability **(Chaudhry *et al.*, 2011)**. Same is true for the Vadodara city also. Ward wise estimation of Per capita vegetation can provide an exact idea of availability of vegetation per city dweller which would help in identifying potential sites for developing UGS in different wards of the city.

(1.4.1.2) Temperature:

Land surface temperature a component which is also sensitive to vegetation and soil moisture has become a preliminary cause for converting urban areas in UHI. Utility of satellite thermal image for understanding such temperature changes is frequently used in recent years. LST changes for Vadodara city has been taken up as an important component for suitability analysis **(Eliasson, 1992; Dousset and Gourmelon, 2003; Bartholy *et al.*, 2003).**

(1.4.1.3) Land use:

Land use gets changed constantly by human activities from the past to the present and it is one of the most visible causes of ecosystem change **(Singh, 1996; Weng, 2001)**. This makes it necessary to construct accurate and up-to-date data on land use for correct assessment and management of urban environment and climate **(Assefa, 2004)**. Mapping the existing land use also provide a significant input for suitability analysis because it expresses the human impact, and influences the feasibility of developing UGS. It provides an idea about presence of open space in the city for developing the UGS and has been considered as an important input for site suitability analysis.

(1.4.1.4) Transport:

Importance of information on transportation for site suitability analysis is in the terms of road accessibility as it provides link between the settlements and UGS. The distance of UGS from the road has a significant impact on the character of UGS, due to noise, movement, pollution and the physical presence of the corridor. According to **Davies *et al*. (2008), t**he total length of the road network act as a strong negative predictor of extent of green space and needs to be considered as a good input for suitability analysis for identifying potential sites for UGS development.

Elevation and slope are the two main topographic factors that control the distribution and patterns of vegetation. Availability of the ground water in the urban areas has a very significant effect on the growth of vegetation. Population density is one of the reasons for underdevelopment of UGS. Location of green belts and gardens provide the information on their present status of same in a specific ward. These theme layers therefore have been considered for the suitability analysis.

(1.4.2) Part 2: Economic valuation of Urban Green Space (UGS):

Not only identification but economic evaluation of the UGS is also essential for the sustenance of the existing UGS. It is a prerequisite for the Eco-city planning. It has been noted that the appreciation of Urban Green Spaces changes with each society (Jim, 2004). It is related with societal changes and depends on the historical context. Their lack of value, expressed in financial terms, prevents these UGS from being properly considered in the cost-benefit analysis of public urban planning policies. One of the main reasons for this is that there is no market to represent these green spaces or in other words, there exists no representation of the green spaces within the market prices of houses (**Hanley and Spash, 1993; Shechter, 1995; Callan and Thomas, 2000; Lange and Schaeffer, 2001**; **Willis *et al*., 2001**). In the absence of market price the remnant UGS gets shrunk in size and gradually gets encroached by urban development and sprawl **(Lockeretz, 1989; English *et al*., 1990; Leiva and Page, 2000)**. Besides this, the UGS are being overexploited in order to meet housing demand because of fast population growth (**Cohen, 1996; Bateman and Willis, 1999; Thompson *et al.*, 2001).** Estimation of their economic value in urban settings in such cases becomes mandatory. Economic valuation of any resource can be expressed in terms of direct or indirect economic benefit **(G. Sandhya K. and Malhi, 2011)** and for UGS these benefits are not direct. From an economic point of view; these services are public goods without a market price. Economists use two broad methods to evaluate such open spaces, i.e. by way of stated and revealed preference approach. The revealed preference approach stresses on the market choices that individuals make to reveal their underlying preferences and to estimate their values for goods and services **(Freeman, 1993)**. Example of this approach is hedonic price model in which the value is indirectly obtained by the influence exercised by the environment on the market price of another good. It enables the 'price' of amenities for which markets do not exist, such as open spaces and urban parks, to be inferred from observing and analyzing the price of goods from which markets do exist, for example housing **(Dunse *et al.*, 2007)**. Using this methodology the private benefit of UGS can be analyzed. Benefits produced by UGS make a neighborhood nice place to live, and these benefits are reflected in the prices of surrounding properties. Hence, the amenity of UGS can be valued in terms of money based on the price people pay for such benefits in their housing. This approach was applied for UGS valuation of Vadodara city for which real estate prices were taken into account. In this valuation GIS provided the descriptive framework for location of properties. One of the most basic advantages provided by GIS was the position of properties on a local map in terms of their geographic coordinates **(Din *et al.*, 2001)**. It also provided a means of organizing very large datasets spatially which helped in assessing UGS **(Dwyer and Miller, 1999; Pauleit and Duhme, 2000)**. In addition, spatial statistics within a GIS provided a consistent display of UGS along with their importance in adding the valuation to the property in a fast and efficient manner. It also aided in measuring the price difference of houses located in nice, safer, cleaner communities relative to similar homes located in less desirable communities. These price differentials provided an estimate of the value placed on UGS **(Comrey and Lee, 1992)**.

(1.4.3) Part 3: Assessment of impact of various biophysical and socioeconomic parameters on Property Value (P.V.) at VMSS level

The value of the UGS affected by various biophysical parameters like LST, NDVI, Normalized differential building Index (NDBI) and Building density (B.D.) and socio-economical parameter like population density (P.D.). It was therefore essential to assess impact of these parameters on the value of Property Value. At the same time UGS also influences both the biophysical and socioeconomic variables in and around the dwellings which is reflected in housing property prices. To explain this relationship and the impact created by biophysical and socioeconomic parameters, remote sensing and GIS based approach has been used in the present work.

(1.5) Land suitability analysis and Air Pollution Tolerance Index (APTI) for Eco-ward planning:

Sustainable use of resources can be achieved by implementing the **Land suitability analysis (LSA)** while preparing an Eco-city plan. The aim of LSA is to determine the suitability of land for alternative, actual or potential, land uses that are relevant to the area under construction. It provides information on the constraints and opportunities for the use of the land and therefore, guides decisions on optimal utilization of land resources **(FAO, 1983).** It predicts land performance, both in terms of the expected benefits from and constraints to land uses, as well as expected environmental degradation due to these uses. In the qualitative and quantitative context, LSA allows planner to allocate major land uses, including residential, industrial, office/retail, and green space etc. based on the local need for land. This helps in improving the existing situation of the city **(Tan and Lebron, 2011)**. The environmental condition can be further improved by understanding the effect of pollution on various plants of the city. This can be understood by two methods, i.e., Active and passive bio-monitoring. In this study active bio-monitoring method was adopted (**Klumpp *et al.*, 2003**). **Singh and Rao (1983)** have developed the Air Pollution Tolerance Index (APTI) from leaf parameters to evaluate the tolerance level of plant species to air pollution. This index is based on four biochemical properties of leaves, i.e., ascorbic acid content **(Lee *et al.*, 2007),** total chlorophyll content **(Flowers *et al*., 2007)**, relative water content **(Rao, 1979)** and leaf extract pH. Plant sensitivity and tolerance to air pollutants varies with these parameters. The APTI of plants present in the three selected wards of the Vadodara city was carried out to evaluate their tolerance level. The results will help in suggesting different plants in different wards for converting them to Eco-ward.

(1.6) Need of development of Vadodara as an Eco-city:

There is an urgent need for studying the environmental condition of the Vadodara city and nearby areas because of rapid urbanization. Developing Vadodara city as an Eco-city will help in decreasing environmental stress, improving living conditions and in achieving sustainable development through a comprehensive urban improvement system involving planning and management of land and its resources. Urban degradation will get reduced when environmental considerations will be adequately getting incorporated into plans (Master Plans). The eco-city proposal will have positive contribution to sustainability, quality of life and health, and planning and designing of built environment of Vadodara city. Implementation of environmental improvement measures will prove as a major step in eco-city development. This process will not only benefit the citizens of Vadodara through renewed and effective management, but will also help in formulating the policies for future development.

Keeping these facts in mind the following objectives has been designed for the study:

(1.7) Objectives:

- **Generation of different thematic maps required for Eco-city planning.**
- **Monitoring of land use changes in the city over past two decades.**
- **Suitability analysis for Urban Green Space identification in different areas of the city for proposed changes.**
- **Eco-city/Eco-ward plan generation and recommendations**.

CHAPTER 2

STUDY AREA

(2.1) <u>Study Area:</u>

Vadodara also known as Baroda, is the third most populated town in the Gujarat after Ahmedabad and Surat (the Three towns with a population of over 1 million in Gujarat) and 16th most populous city of India. It is located at 22º17´59 North latitude and 73º15´18 East longitude. It is situated on the bank of Vishwamitri River and is known as the "Cultural Capital" of Gujarat. Total area covered by the Vadodara Maha Seva Sadan (VMSS) is approximately 145 km^2. The name "Vadodara" has originated from the Gujarati word "Vad" which means Banyan tree. The city has many banyan trees growing along the road side and gardens thus manifesting the name of the city. The city is also known as the "City of Gardens". As the name suggests the city has got as many as 51 gardens located in different areas.

The city has lot of potential to develop as the Eco-city because area and size of the city is very small and thus the planning can be done easily. Moreover, the river Vishwamitri which flows from the middle of the city has much of the green vegetation along the riverside which contributes in maintaining the ecological balance in the city **(Plate 11)**. The university campus itself is located on the banks of Vishwamitri and thus having good vegetation all around the campus. In addition to this the city also has roadside vegetation which constitutes prominent part of the urban forest.

2.2. Geography:

Geographically the city is so located that it played the role of a corridor for the movement of people, cultures and armies from the time immemorial. It is in Vadodara that the traditional route connecting the Makran Coast (Indus Delta) with the central India and Malwa Plateau, branches off. The ancient route from northern Maharashtra across the Dangs and the Saputara hills passes from Chandod on the Narmada River and joins with main transcontinental route at Vadodara. The Vadodara district is surrounded by Panchmahal, Dahod (North), Bharuch, Narmada (South), Anand and Kheda (West) districts. To the east is the state of Madhya Pradesh. The Mahi River also passes through the district.

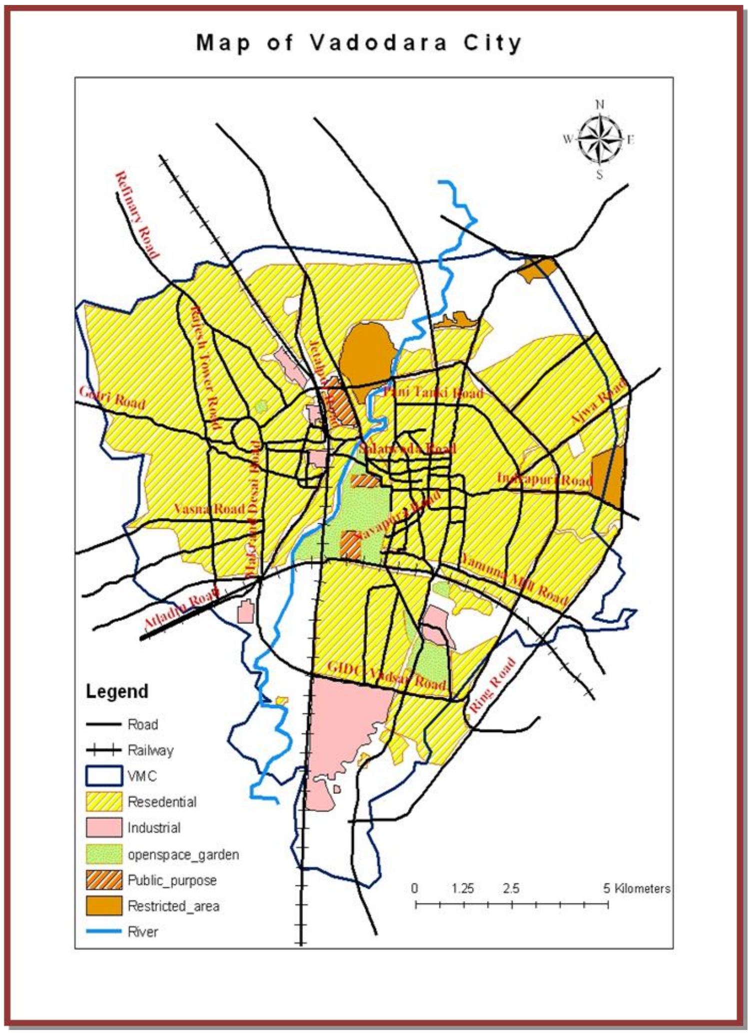


Plate 11: Map showing the study area

(2.3) Regional setting:

Vadodara has become an important flourishing centre of trade and industry, because of its location between Mumbai in the South west and Ahmedabad in the North.

Geographically the city is so located that it played the role of a corridor called "Gujarat Region". The agglomeration is in advantageous position of the growth of the whole western and North western corridors of the country. This is a challenge and opportunity, too.

(2.4) History of Vadodara:

The earliest mention of Baroda is in a grant of charter of [812] that identifies it as Vadapadraka replaced Ankottaka as the main town. The city was once called Chandravati, after its ruler Raja Chandan, then Viravati , the abode of the brave, and the Vadpatra because of the abundance of Banyan trees on the banks of the Vishwamitri.

The archaeological evidences suggests that Vadodara originated as a small hamlet called Ankottaka (present day Akota) on the western banks of the river Vishwamitri, a tributary of Dhadhar. The hamlet existed 2BC to 600AD.

Evidence shows that the inhabitants lived in well-built houses of burnt brick. Ankottaka was the seat of nonferrous foundry, molding bronze sculptures known to be better than the Chola bronzes. Gujarat artisans in metal foundry were prior to any other culture in the world. Ankottaka was the centre of Jainism.

Around 600 AD, a massive flood in Vishvamitri washed away Ankottaka; its inhabitants took refuse in Vadapadraka to the east and a little away from the Vishwamitri. The new settlement of Vadapadraka (present day Kothi), that grew to the east around 600 AD, perhaps, brought the development of Ankottaka to an end. Vadapadraka served the administrative centre during Mauryan, Gupta and Chalukyan rule from 900AD to 1500AD.

The wall city of Kille e-Daulatabad was founded further east by the Muslims in 1511AD. Located on a plateau and inhabited by Hindus and Muslims, the city was square form with major roads on east west and north-south axis and at cross junction the dominant institution of Mandvi was located.

The first expansion in 1650AD, was a planned growth to the south (present day Wadi), mainly inhabited by Muslims. The rule of the Mughal Sultanate came to an end after the Marathas took over the city and made it their capital in 1725AD, naming it Barode.

After the Treaty Bassein in 1802AD, the British became powerful and constituted themselves as arbitrator in all transactions of the Gaekwads. They further consolidated their position around 1818AD after their treatise with the Gaekwads. Subsequently, the establishment of the British Residency, the Cantonment to the northwest, and the Railway station to the west took place.

Baroda began to experience the first aspects of urbanization during the rule of Sir Sayajirao Gaekwad III (1875-1939 AD). Sayajirao III was a visionary and institution builder. Under his able guidance, the princely state of Baroda became one of the most progressive states in the country. **Plate 12** shows the Map of Baroda state of year 1909.

Sayajirao III also had the foresightedness to realize that planned development has to be supported by infrastructure development. He initiated the construction of an eastern dam across the river Surya at Ajwa. The city began to receive filtered water through pipelines in 1894AD.The flow in the entire network was through gravity. Piped sewerage was put in place in 1896AD. The first water boosting station with elevated reservoir and the sewage treatment plant were commissioned in 1952, although localized collection of sewage by pumping was in practice prior to that. Surface runoff was directed to detention tanks interconnected by storm water drains. Surplus water from the tanks was directed by underground tunnels to Sursagar. Water from Sursagar was emptied into the river Vishwamitri when in excess.

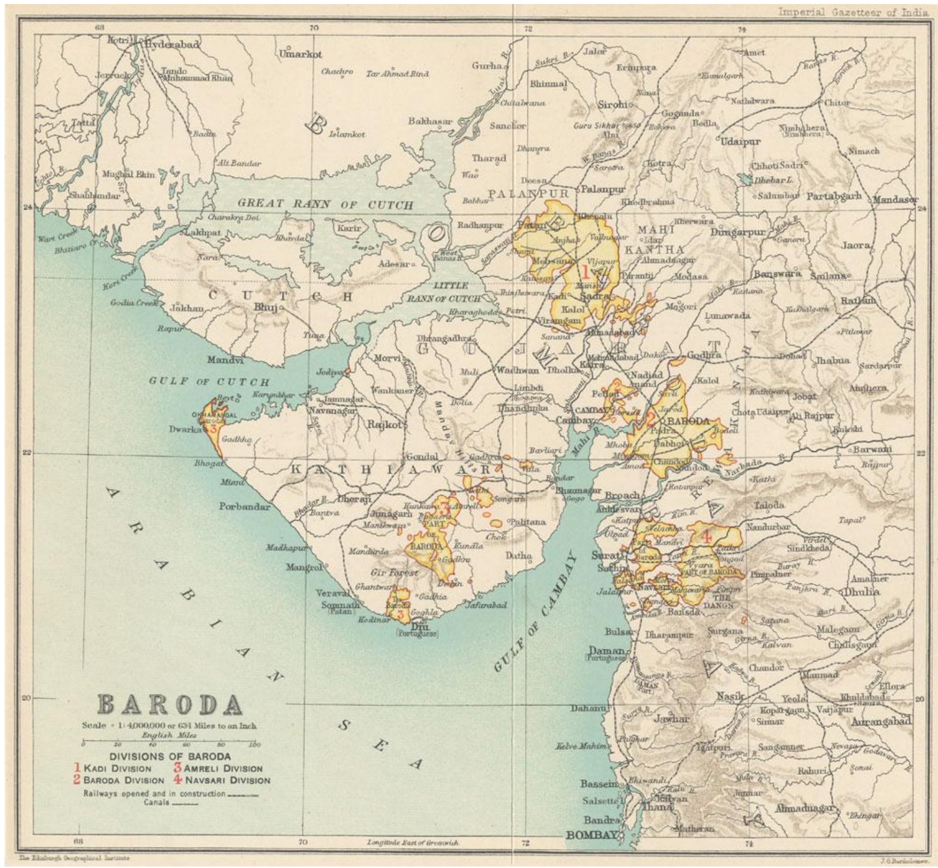


Plate 12: Map showing Baroda state in 1909

(2.5) Topography, Natural Drainage and water Bodies:

Vadodara has a flat terrain, with five rivers i.e. Mahisagar in the north going along the boundary of the VUDA whereas the Mini, Vishvamitri, Surya Jambuvai and the Dhadhar flowing in the south. Apart from this there are smaller drains which cut across the landscape and form important part of the natural drainage system. Vadodara city has a general slope from east to west and north to south.

CHAPTER 3

MATERIAL AND METHODS

(3.1) Materials:

(3.1.1) SOI map: The Survey of India (SOI), topographical maps at 1:50,000 scale were used for generating thematic maps of the study area.

(3.1.2) Ancillary data: Population data for various years were obtained from the census for the year 1991 and 2001. Information regarding the location of gardens was obtained from the map published by Ananda Sahitya Prakashan of Ahmedabad. Datasets for land use for various years were obtained from the VUDA report.

(3.1.3) Field Survey: A reconnaissance survey was carried out to collect the ground control points of the Gardens and Greenbelts present in the study area for generation of thematic map. Field survey was also carried out for the post classification verification of the classified output.

(3.1.4) Table 2: Satellite data used in the study

Sr. No.	Data used	Year of data acquisition	Wavelength width in µm/ band	Spatial resolution (m)	Swath (km)
1.	IRS-P6 LISS III	2000	0.52-0.59 (green)	23.5	141
			0.62-0.68 (red)		
			0.77-0.86 (NIR)		
			1.55-1.70 (MIR)		
2.	IRS-P6 LISS-IV	2005 2009	0.52-0.59 (green)	5.8	23.9 (MX) 70 (P)
			0.62-0.68 (red)		
			0.77-0.86 (NIR)		
3.	Landasat ETM+	11 November, 2001	0.45-0.515(blue)	30m (60m thermal, 15m pan)	183 km
			0.525-0.605(green)		
			0.63-0.690 (red)		
			0.75-0.90(NIR)		
			1.55-1.75(SWIR)		
			10.40-12.5 (thermal IR)		
			2.09-2.35 (SWIR)		
			0.52-0.90 (pan)		

(3.2) Software used:

Software utilized for digital data processing and preparing the maps were Erdas imagine 9.1, Arcinfo 7.2, ArcGIS 9.2 and Geomedia 5.2. Erdas Imagine is used primarily for geospatial raster data processing and for preparing, displaying and enhancing digital images. ESRI's ArcGIS is a geographic information system (GIS) and it is used for creating maps; compiling geographic data; analyzing mapped information and sharing and discovering geographic information.

(3.3) Methods:

Methodology followed for generating thematic maps, land use change detection, suitability analysis and Eco-city plan generation are discussed separately.

(3.3.1) Methodology for thematic map generation:

The development of Eco-city plan requires the generation of different thematic layers for Vadodara city. Generation of six different thematic maps is given as shown in the flow chart **(Figure 1)**. Thematic maps for **Water body and Transport network** were generated from **Survey of India (SOI), Greenbelts and Gardens location maps** from ancillary data and **ward map of population density** from census information. **Contour** and **slope** were extracted from the satellite data.

Contour map was generated using spatial analyst tool of the ArcGIS software. Ground Control Points (GCP) collected from different locations **(Table 3)** were integrated in the spline module of the spatial analyst tool. The output was obtained in the form of contour map. Contour lines evenly spaced and close together indicated a uniform, steep slope.

The slope map was generated from contour map. Slope inclination is a measure of the relationship between change in horizontal and vertical distances between at least two points usually expressed in percentage. The output slope raster is calculated as percent slope or degree of slope using following formula:

$$\textbf{Percent slope} = \frac{\textbf{change in elevation (Rise)}}{\textbf{Distance (Run)}}$$

Table 3: GCPs of Vadodara city

GCP_ref_Nu	Location_N	Lat	Long	Northing	Easting	Z_value_M
BRD-209	Corner of compound wall (outer) Novlakhi Maidan	22°17'47.12" N	73°11'09.06 "E	2466760.20	313111.17	32.3680
BRD-202	Jaibhavani sainik mahavidayalaya right back side corner terrace, Ghanshayam park	22°18'57.24" N	73°13'24.88 "E	2468870.86	317024.28	41.6890
RBRD-206	On Culvert	22°18'16.00" N	73°07'39.43 "E	2467721.97	307122.15	37.4560
BRD-216	Prathan upwan compound wall	22°16'43.32" N	73°08'32.56" E	2464852.23	308607.66	29.3600
BRD-220	Anshuya Nagar,shri dwarkesh showmills plot no. e-3, baroda-Timber Industrial estate,dabhoi road inner compond wall sw coner	22°16'43.70" N	73°13'33.93" E	2464760.27	317234.93	32.2480
BRD-233	Tarsali Bypass Bharat petrolium,building nt in front of petrolpump back side corner	22°14'27.29" N	73°12'44.03" E	2460581.51	315756.84	27.4310
BRD-237	Mahashivhari Guest House terace back side right corner behind hotel Baba Ramdev no- 1 NH-8	22°13'31.85" N	73°11'20.12" E	2458904.86	313333.78	39.3970
BRD-236	Maretha villag	22°13'27.97" N	73°10'13.98" E	2458808.33	311438.19	26.1560
BRD-225	Kalali village	22°15'34.19" N	73°10'02.16" E	2462694.61	311146.70	39.9880

Table 3: GCPs of Vadodara city (Cont.)						
GCP_ref_Nu	**Location_N**	**Lat**	**Long**	**Northing**	**Easting**	**Z_value_M**
BRD-190	Standard Radiator pvt. Ltd. H-12/13 Industrial Estate Gorwa Baroda-16,ompound wall corner(sw)	22°19'50.27" N	73°09'46.96" E	2470576.64	310807.46	39.1490
BRD-192	Ajita Nagar, A & B provision stors corner of compound wall gate se corner	22°20'04.83" N	73°12'17.11" E	2470972.68	315109.41	37.6410
BRD-181	Pramukh preet residency Ananad deep society canal road, TP-13 compound wall NE corner channai jakat naka	22°20'54.95" N	73°09'48.41" E	2472565.46	310873.32	42.5200
BRD-169	4. jin compound ,terrace SE corner bajwa Hpgas agency office terrace	22°21'57.34" N	73°08'31.81" E	2474511.45	308705.31	41.3410
BRD-222	Bund of farm near Khhatamba village	22°16'54.61" N	73°15'47.34" E	2465051.43	321057.88	34.7710
BRD-195	agriculture production market corporation near NH-8	22°20'08.34" N	73°15'05.83" E	2471023.96	319938.45	43.6900
BRD-185	Golden tubaco company Ltd.near toll tex vadodara halol express way	22°21'19.68" N	73°14'34.71" E	2473228.51	319073.80	44.6520
BRD-179	Undera village farm house terrace backside corner	22°20'42.57" N	73°07'36.53" E	2472231.31	307094.98	39.0970
BRD-158	ONGC compound wall corner(SE), opp- eefluent channel project Ltd Head works dhanora	22°22'58.83" N	73°06'13.76" E	2476452.176000	304779.404000	37.1630
BRD-150	Village Ranoli Railway line overbridge	22°24'01.04" N	73°07'22.44" E	2478340.958000	306768.154000	43.3840
RBRD-171	On Building corner Near NH-8	22°22'05.69" N	73°10'58.30" E	2474717.302000	312899.167000	38.5660

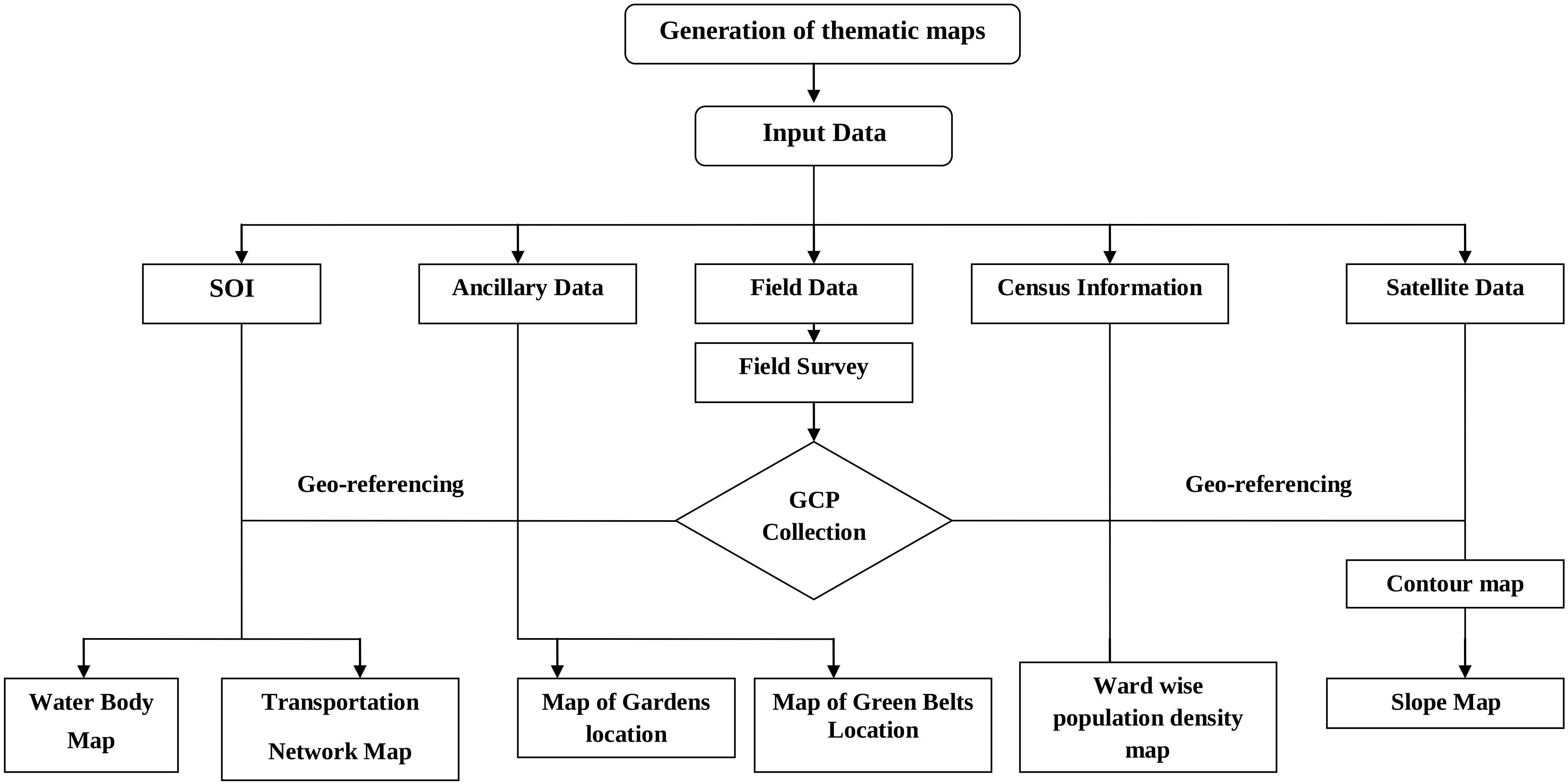


Figure 1: Methodology for thematic map generation

(3.3.2) Methodology followed for Land use change analysis:

The methodology followed for the entire study is brought out distinctly in the flow chart **(Figure 2)**. The land use change at VUDA level was attempted using six different datasets procured from different sources covering a span of 126 years, i.e. from the year 1880 to 2006. Land use change at VMSS level was carried out using seven datasets covering a span of 129 years, i.e. from the year 1880 to 2009. Data for the years 1880 and 1960 were procured from **Barodawala *et al.* (1992)** whereas for the years i.e. 1980, 1996 and 2006 were procured from the VUDA report. All these datasets were geo-referenced using ERDAS Imagine 9.1 software and were brought to one scale. Digitization was performed for these data sets and area under different land use classes was computed using the ArcGIS software. LISS III and LISS IV satellite data were used for the years 2000 and 2009, respectively. The classification scheme adapted is given in **Table 4 (ISRO, 2005)**. Land use training sets each having its own signature files were generated for both LISS III and LISS IV images. These were then subjected to supervised classification which was performed using the algorithm maximum likelihood as it provided better accuracy. Percent change in land use and the related statistics were computed for all the datasets for VUDA as well as VMSS area. L.C.R., U.S.I. ad L.A.C. were calculated only for VUDA level. Estimation of entropy using Shannon's entropy method was carried out for all the data sets at VMSS level.

TABLE 4: URBAN LAND USE/ LANDCOVER CLASSIFICATION AT DIFFERENT LEVELS AND THEIR CODES ACCORDING TO NNRMS STANDARDS

SR. NO.	LUC-CODE	LEVEL - I	LEVEL - II	LEVEL - III
		Built Up		
1.	01-01-00-00		Built Up (Urban)	Residential
2.	01-02-00-00		Built Up (Rural)	
3.	01-01-03-07		Habitation with Plantation	
	01-03-00-00		Transportation	
4.	01-03-01-01			Road
5.	01-03-02-01			Rail
		Agricultural Land		
6.	02-01-00-00		Crop Land	
7.	02-02-00-00		Fallow	
8.	02-03-00-00		Plantation	
		Forest		
9.	03-01-01-00		Dense/Closed	
10.	03-01-02-00		Open	
11.	03-03-00-00		Forest Plantation	
12.	03-05-00-00		Forest Blank	
13.	04-00-00-00	Natural/Semi natural grassland & Grazing land		
		Wastelands		
14.	05-01-00-00		Salt affected land	
15.	05-02-00-00		Gullied/Ravenous land	
			Land with or without scrub	
16.	05-03-01-00			Land with scrub
17.	05-03-02-00			Land without scrub
18.	05-04-00-00		Sandy area	
19.	05-06-00-00		Barren Rocky/Stony waste	
	06-00-00-00	Wetlands		
	06-01-00-00		Inland natural	
20.	06-01-04-00			Waterlogged (Seasonal)
	06-02-00-00			
	06-03-00-00		Coastal Natural	
21.	06-03-05-00			Marshy/Swampy
22.	06-04-00-00		Coastal Manmade	
	07-00-00-00	Water bodies		
23.	07-01-00-00		River/Stream	
24.	07-02-00-00		Canal/Drain	
25.	07-03-00-00		Lakes/ponds	
26.	07-04-00-00		Reservoir/Tanks	

Methodology for estimation of different parameters is explained separately as shown below:

Shannon's entropy (S.E.): S.E. is the measure of the degree of dispersion or concentration of a random geographical variable, i.e. the built-up and is related with urban sprawl. It is calculated according to **Araya (2009)** where entropy is denoted as

$$H_n = \sum_{i}^{n} p_i \log(\tfrac{1}{p_i})$$

where, pi is the probability or proportion of occurrence of a phenomenon in the ith spatial unit out of n units, and thus, is given by:

$$p_i = x_i / \sum^{n} x_i$$

where, *xi* is the density of land development, which equals the amount of built-up land divided by the total amount of land in the *i*th zone in the total zone of *n* zones. The number of zones means the number of buffer zones around the city center or around selected roads.

For estimation of entropy five concentric buffers of 3 km each were laid around the city centre, i.e., Mandvi. The seven land use maps of the years 1880, 1960, 1980, 1996, 2000, 2006 and 2009 were simplified into two major classes, viz. built and non-built areas. Using the above mentioned formulas the entropy for each year was calculated which varied from 0 to 1. If the distribution is maximally concentrated in one region, the lowest value of entropy 0 is obtained while an evenly disperse distribution across space results into the maximum value of 1.

Since entropy measures the distribution of a geographical phenomenon, the difference in entropy between two different periods of time was used to indicate the change in the degree of dispersal of land development or urban sprawl using the formula:

$\Delta En = En(t+1) - En(t)$ where, ΔEn is the difference of the entropy values between two time periods; En (t+1) is the entropy value at time period (t+1); En (t) is the relative entropy value at time period t.

Urban Sprawl Index (U.S.I.): It is a measure of the built environment in a city.

U.S.I. = Urban expansion / Population increase

Land consumption rate (L.C.R.): It estimates the rate at which the land is consumed by the developing area.

L.C.R = A / P (A = areal extent of the city and P = population)

Land Absorption Coefficient (L.A.C.): It estimates the rate at which the developing city absorbs the new urban land **(Yeates and Garner, 1976)**.

$$L.A.C. = A_2 - A_1 / P_2 - P_1$$

A1 and A2 are the areal extents for the early and later years, and P1 and P2 are population for the early and later years respectively.

Materials and Methods

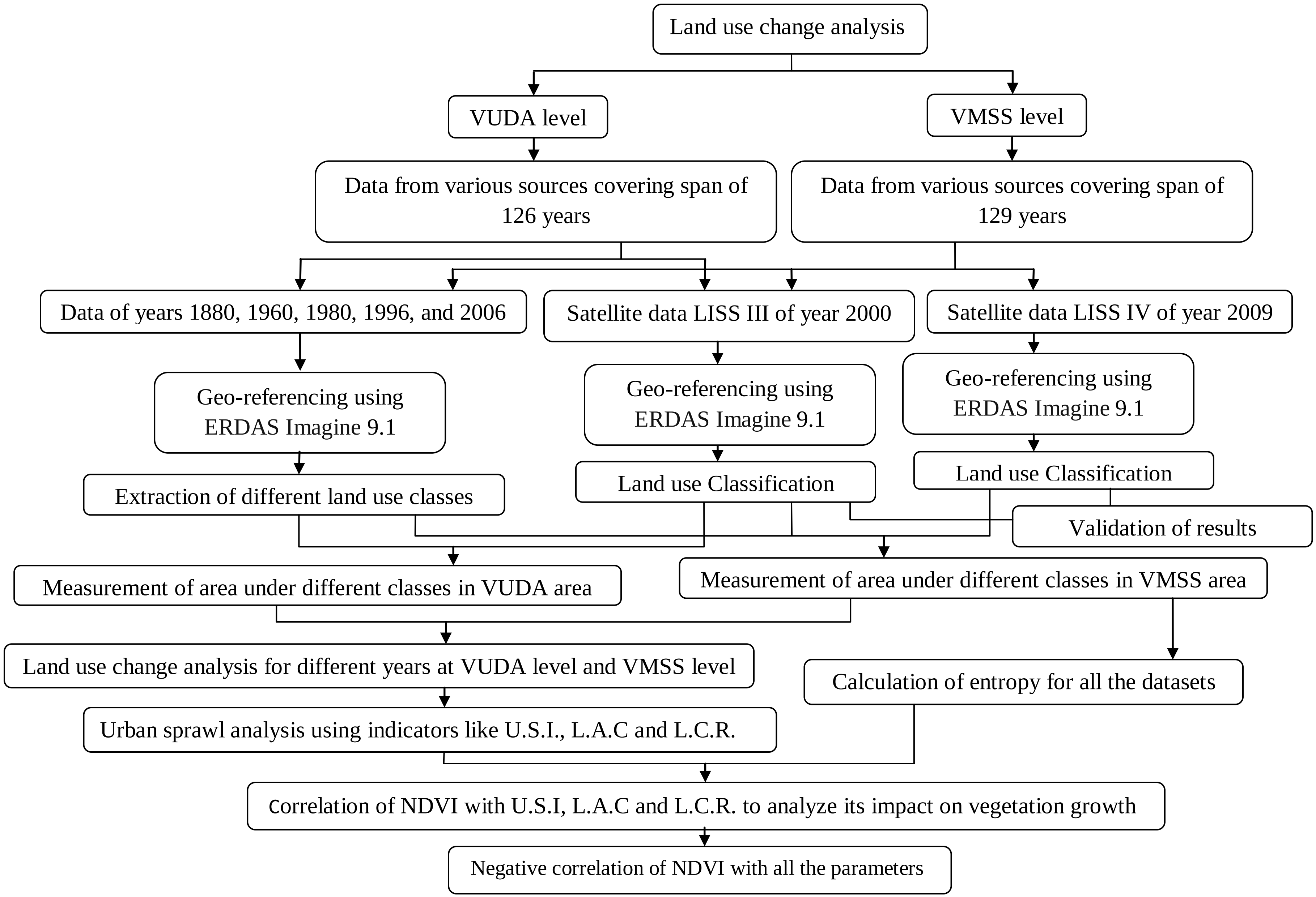


Figure 2: Flowchart showing the methodology adopted for land use change detection

(3.3.3) Methodology followed for Urban green space analysis:

Methodology followed for suitability analysis of UGS, economic valuation of UGS and assessment of the impact of various biophysical and socioeconomic parameters on property value has been segregated in three different parts, i.e. **Part 1, Part 2** and **Part 3,** respectively. All these studies were carried out at VMSS level.

(3.3.3.1) Part 1: Suitability Analysis: Vadodara city is comprised of 13 different wards out of which 10 wards were selected for the UGS suitability analysis depending upon the availability of data for different themes. Various themes considered for identifying suitable sites for UGS development were Slope, Land use, transportation, water body and ground water status **(Figure 3)**. These themes were integrated in GIS to obtain the suitable sites for UGS. Buffers were created around the water bodies and transportation network. Sites which were near the water body and transport network were preferred. Sites with the slope of 0-1% and good ground water status were preferred. More importance was given to open spaces while identifying the suitable sites. Various other themes like temperature, vegetation and related parameters, Population Density (P.D.), Greenbelts and gardens provided additional information in analyzing their influence on the suitable sites. Areas with low P.D., per capita vegetation, slope, and LST were preferred for designating suitable sites. Priority was given to the wards in which total vegetation decreased, which have less gardens and greenbelts.

Methodology for all the parameters viz. Slope, Land use, Population density, Transport, water body, green belt and gardens have already been described in the earlier section while methodology for Vegetation and Temperature are described in this section.

Vegetation: The status of vegetation was analyzed from the biophysical parameter NDVI derived from satellite data LISS III of the year 2000 and LISS IV of the years 2007 and 2009 using the formula:

NDVI = (NIR- Red) / (NIR + Red) (Lillesand *et al.*, 2007)

Temperature: Estimation of changes in temperature was carried out using Landsat ETM+ data (Xu, 2009). The DN values of band 6 were converted into spectral radiance L [W/ (m^2 sr μm)] using the following formula,

$$L = \frac{L_{\max} - L_{\min}}{Q_{\text{cal max}} - Q_{\text{cal min}}} \times (Q_{\text{cal}} - Q_{\text{calmin}}) + L_{\min}$$

Calibration of thermal band was then performed in two steps:

Conversion of the spectral radiance L to sensor Brightness Temperature (BT) into the Kelvin. The conversion formula is given by:

$$\text{BT} = \frac{K_2}{\left[\ln\left(\frac{K_1}{L} + 1\right)\right]}$$

where, BT is the at-sensor brightness temperature (K),K_2 is a calibration constant (1,282.71 K), K1 is another calibration constant (666.09 W m^{-2} sr^{-1} lm^{-1}) and L is the spectral radiance at-sensor (W m^{-2} sr^{-1} lm^{-1}).

$$\text{TS} = \frac{K2}{\left[1 + \ln\left(\frac{\lambda \cdot \text{BT}}{\rho} \cdot \ln \varepsilon\right)\right]}$$

where, TS is the land surface temperature (K), λ is the wavelength of emitted radiance (11.5 lm); ρ is h×c/r=1.438×10^{-2} mK and ε is the spectral surface emissivity.

(3.3.3.2) <u>Part 2: Economic valuation of Urban Green Space (UGS):</u>

For the economic valuation of the UGS, real estate property values were collected from the information available on the internet and from the local information and newspapers. These values were then classified in three main classes, i.e., low, medium and high prices **(Figure 4)**. NDVI values were retrieved from IRS LISS IV 2009 satellite data to understand the vegetation status around these properties. These NDVI values were classified into four classes, viz. High, moderate, less and no vegetation classes. These values were integrated with property prices using the ArcGIS software for economic evaluation of UGS.

(3.3.3.3) Part 3: Assessment of impact of various biophysical and socioeconomic parameters on Property Value (P.V.) at VMSS level

Assessment of impact of various parameters on property value was determined at VMSS level. Methodology adopted for the study is shown in **Figure 5**. Different biophysical and socioeconomic parameters selected for assessing the impact were NDVI, LST, NDBI, B.D. and P.D. The methodology for P.D., NDVI and LST has been described earlier in this chapter where as methodology for NDBI and BD is described in the following section. NDBI is the measure of built-up area of the city and is measured as follows:

$$\mathrm{NDBI} = (\rho(\mathrm{band5}) - \rho(\mathrm{band4}))/(\rho(\mathrm{band4}) + \rho(\mathrm{band5}))$$

B.D. is the ratio of built-up area to the total area which was calculated ward-wise.

The values for all the above parameters were extracted and integrated with property values using the ArcGIS software. The impact of individual parameters was analyzed using correlation analysis while impact of integrated parameters was analyzed using Principal component analysis (PCA). PCA is a data compression technique which was carried out using SPSS 10.00 in this study.

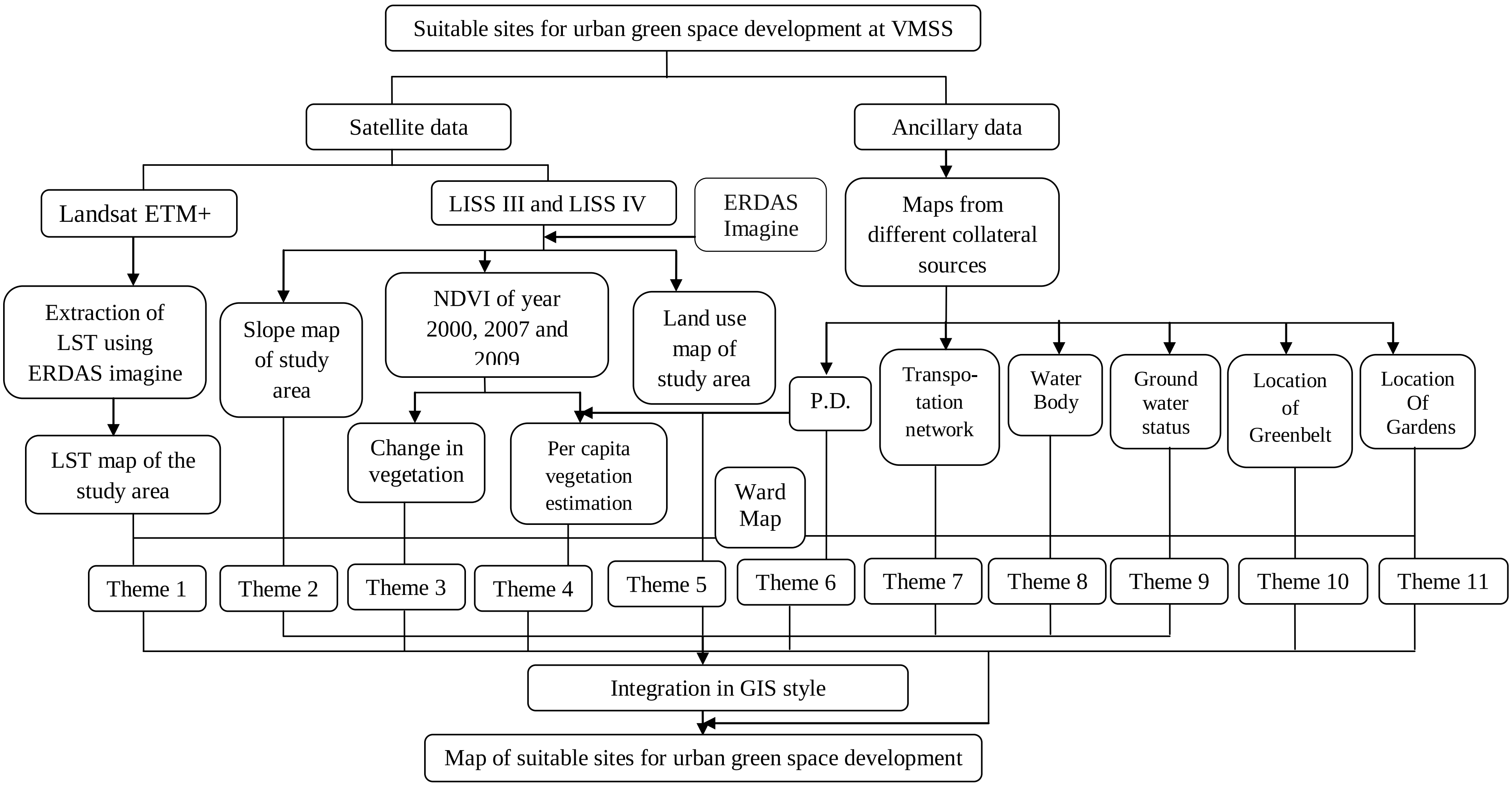


Figure 3: Methodology for identifying potential sites for Urban Green Space development

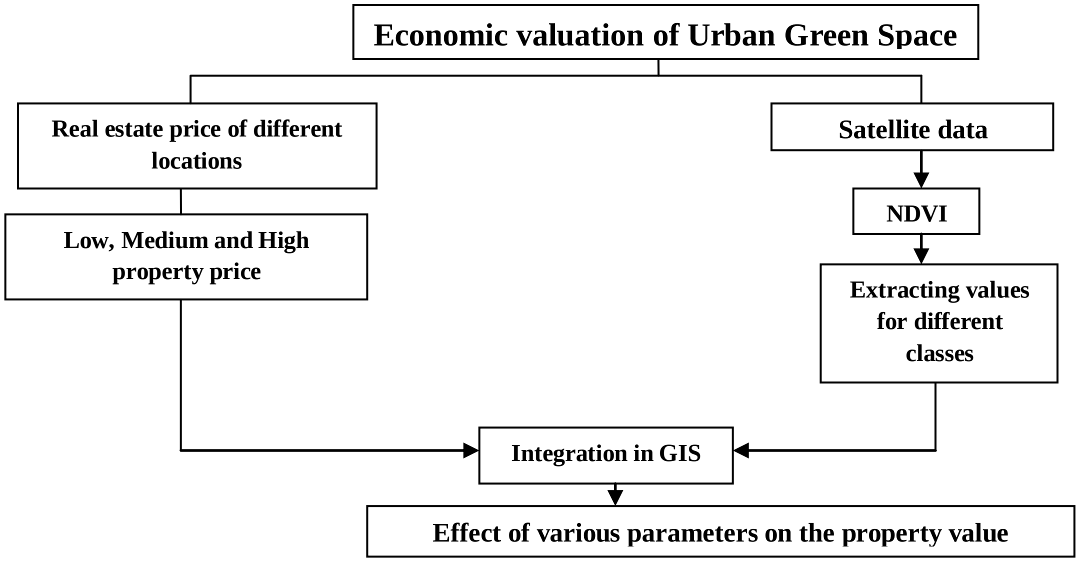


Figure 4: Flowchart showing methodology adopted for Economic valuation of Urban Green Space (UGS)

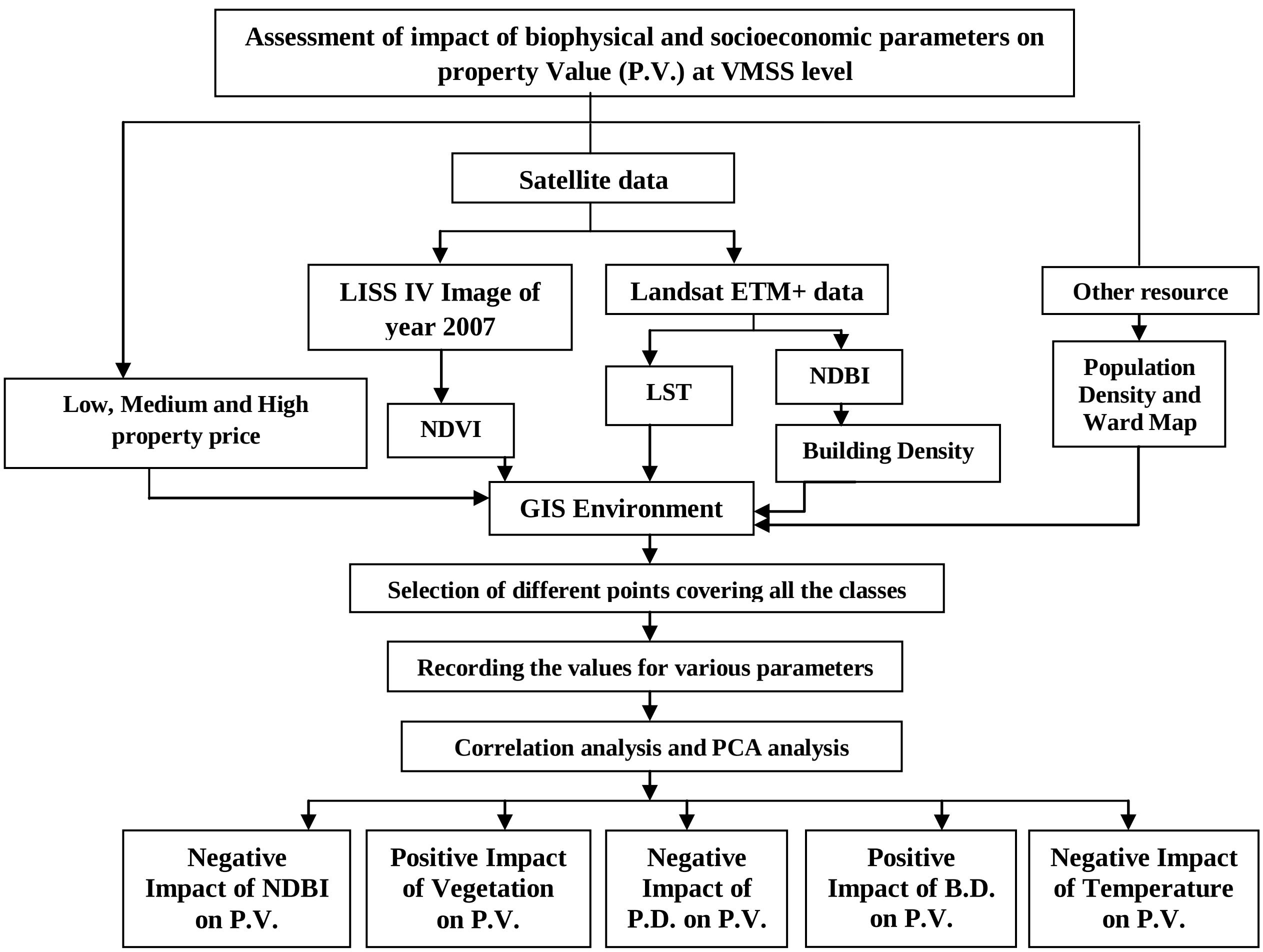


Figure 5: Flowchart showing the methodology adopted for assessment of impact of biophysical and socioeconomic parameters on UGS value

(3.3.4) Methodology followed for Eco-city plan generation:

Three wards comprising the core of the Vadodara city i.e., City Ward, Shiyabaug Ward and Panigate Ward were selected for the Eco-city plan generation. **Figure 6** shows the Flowchart followed for Eco-city plan generation for selected wards. Land suitability analysis was carried out for selected wards using the information utilized for urban green space suitability analysis. This information was integrated in Arcinfo 7.2 based Urban Suitability Analysis Package (USAP) module to get the precise output. This module was having four models depending on preference given to different parameters **(Table 5**). Ranks were given to different parameters to determine the suitability (**Table 6**). Model No. 4 was considered for the Eco-city plan generation. Output of questionnaire survey carried out for participation of local people was also considered while generating the plan. List of questions are given in Annexure I.

Table 5: Various Suitability models with their preferred parameters

Model	Preferred Parameters	Suitable locations
1	Network and water body	• Area in buffer zone of 50 m around water body and road network is considered not suitable • Area in the buffer zone of 50-100 m is considered as less suitable for the urban development • Area out of this buffer zone is considered as moderately suitable to highly suitable depending upon the distance
2	Slope, Road network and soil depth	• Slope of 0-1% is preferred • Area beyond the buffer zone of 100 m of Road network is preferred more
3	Road network	• Areas along the roadsides are considered as highly suitable
4	Land use	• Land use types like barren land, open space etc. are considered suitable • Land use types like agriculture, vegetation etc. are considered not suitable

Table 6:_Ranks given to different categories

Name of the parameter	Categories	Rank
Slope type	**0 – 2 %**	4
	2 – 4 %	3
	4 – 6 %	2
	Above 6 %	1
Water body buffer	**500 and above 500 m**	4
	200 m	3
	100 m	2
	50 m	1
Road buffer	**100 m**	4
	200 m	3
	500 m	2
	Above 500 m	1
Rail Buffer	**2000 m**	2
	5000 m	1
Land use type	**Land with scrub**	4
	Open space	3
	Vegetation, Water body ,Crop land, Vegetation	1
Ground water type	**Built-up**	4
	Moderate	3
	Good to moderate	2
	Good	1

(3.3.5) Methodology for estimation of Air Pollution Tolerance Index (APTI):

The plants which were commonly available in all the wards were selected for the APTI estimation. Ten replicates of fully matured leaves of different plants were collected in the morning (9:00 a.m. to 11:30 a.m.) and immediately taken to the laboratory for the analysis. The Air Pollution Tolerance Index (APTI) was determined by estimating biochemical and biophysical parameters, viz. ascorbic acid, chlorophyll, pH and relative water contents of leaf samples. Ascorbic acid content was estimated using **Roe method (1954)**, Chlorophyll was estimated using **Arnon (1949)** and pH was determined by digital pH meter. Relative water content of leaf material was estimated according to **Ekanayake (1993)** taking the initial weight, turgid weight and dry weight of leaf material. The APTI was calculated using the following formula:

$$APTI= [A (T+P) + R] /10$$

Where, A= Ascorbic acid (mg/g dry wt.)

T= Total Chlorophyll (mg/g dry wt.)

P= pH of leaf extract.

R= Relative water content of leaf tissue (%).

Gradation of APTI:

The spectrum of APTI was divided as four grades of air pollution tolerance: tolerant (T or grade I), moderately tolerant (MT or grade II), intermediate (I or grade III), and sensitive (S).

The tolerance grades were defined as follows:

(1) Tolerant: $APTI > mean\ APTI+SD$;

(2) Moderately tolerant: $mean\ APTI < APTI < mean\ APTI+SD$;

(3) Intermediate: $mean\ APTI-SD < APTI < mean\ APTI$;

(4) Sensitive: $APTI < mean\ APTI-SD$.

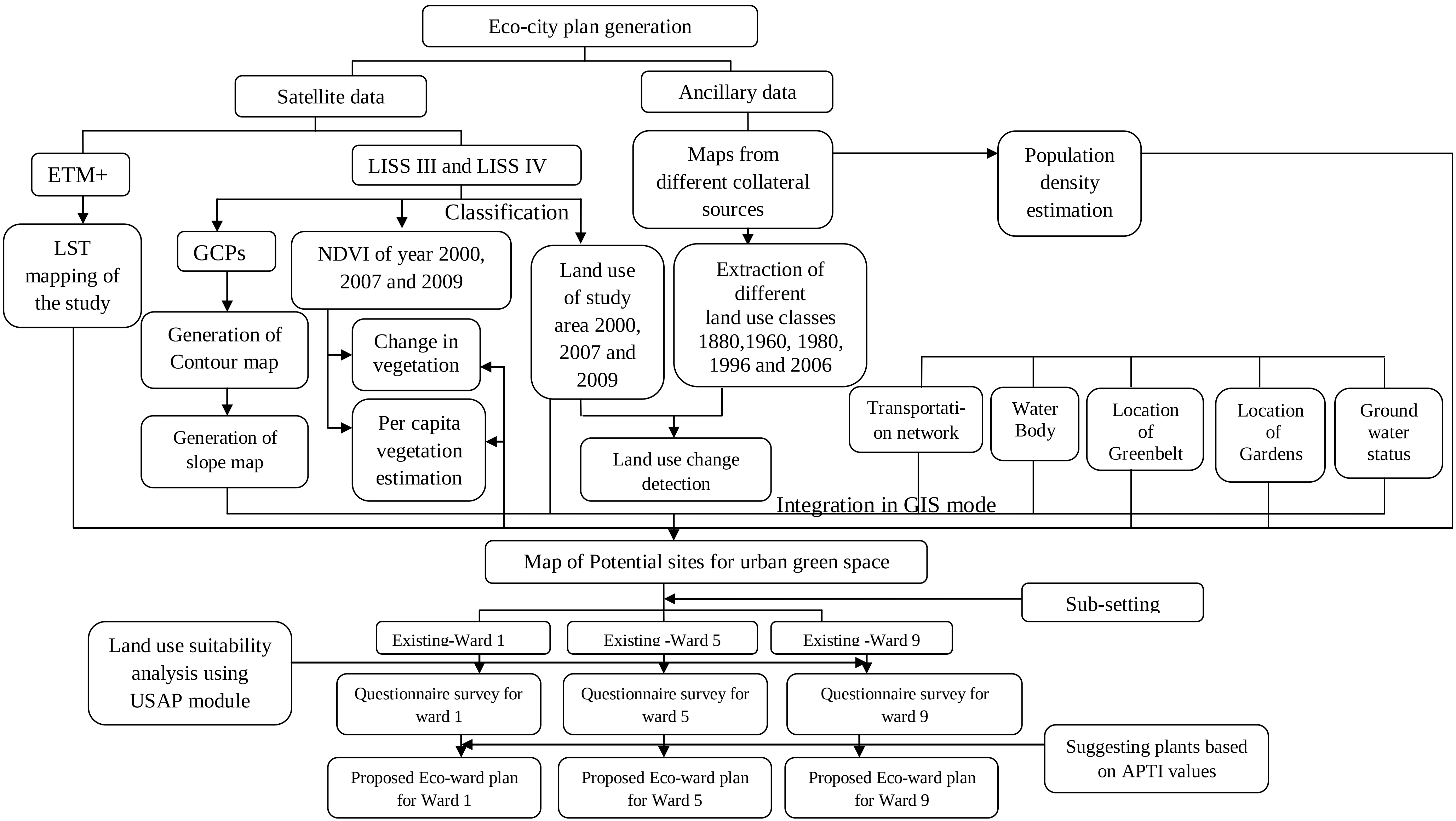


Figure 6: **Flowchart showing methodology adopted for Eco-city plan generation**.

CHAPTER 4

RESULTS

(4.1) <u>Thematic map generation:</u>

The provision of basic services and infrastructure in many developing metropolitan areas is still in its infancy. Therefore, making existing cities and new urban development more ecologically based and livable is an urgent priority in the global push for sustainability. Changing urban development from its present unsustainable forms and patterns is a very challenging process. Not only does the urban pattern, transportation systems, water, waste and energy technologies have to change, but also the value systems and underlying processes of urban governance and planning needs to be reformed to reflect a sustainable agenda. Clean water, transportation infrastructure, solid waste management and pollution control are well accepted as essential elements for such a change. In addition, up to date and recent information on various resources of the city is required. The thematic maps generated in present work have provided accurate information about the existing status of all these elements of Vadodara city. Thematic maps of different component generated for this city have been briefly explained separately.

(4.1.1) <u>Thematic layer of Transportation Network of Vadodara city</u>:

Transport is the single biggest issue for urban environmental debates **(Jenks *et al.*, 1996).** In Vadodara, the inefficiency or lack of urban transport services and infrastructure is one of the major impediments to economic growth and urban productivity. Every day more and more vehicles are being added to the Vadodara transport network. Many of the citizens are having more than one vehicle. Increasing motorization, poorly operating public transport services, inadequate road maintenance, insufficient bikeways and walkways, poor traffic management, lack of enforcement, transport education and culture are contributing factors to congestion, road accidents, and air pollution. The morning and evening traffic congestion leads to loss of work and time, increased fuel consumption and emissions, and high accident rates. The form of cities is the reflection, to a large extent of the transport technologies that were dominant at different stages of their development **(George, 1996)**. Looking to present city structure and major arteries linking the city with the region gives a sound network but with few flaws and so it still need to be strengthened for future requirements and developments. For example location of railway station and bus stand in the same area has created heavy conjunction though both gives sound link off the city with the region, state and other parts of the country. Total length of the paved and unpaved roads of the city is 711 km. As per the estimate of the VMSS, the road network accesses 70 % of the city area and more than 80 % of the population. All these facts make necessary the study of transport system of the Vadodara city. Moreover, Vadodara city is well connected with the adjacent areas by National highway (NH) 8 and State Highways **(Plate 13)**. Major roads leading to the other cities are Savli road, Godhra road, Waghodia Road, Ajwa Road, Dabhoi Road on eastern side and Jambusar, Gotri road on the western side **(Table 7)**. Broad gauge railway line passing through the city is also an important link to different regions. A narrow gauge railway line towards Dabhoi and Jambusar also connects a good network for the nearby small cities.

Table 7: Different roads of Vadodara city

Location	Road
East - Western Area	• Vinoba Bhave Road, connecting Tilak Marg, Salatwada, Nagarwada, Bhutdi zampa upto Champaner gate, north of the walled city; • R.C.Dutt Road, Tilak Marg, Raopura road connecting Jubilee baug, Nyay Mandir, Mandvi,Panigate and further east to Waghodia road and Ajwa road; • Indira avenue diversion from Tilak road at the Vishwamitri river bridge, Jawaharlal Nehru Marg, Dandia Bazar upto Nyay mandir; • Rajmahal Road from Laxmi Vilas palace to Nyay Mandir • Vishwamitri Road between Padra Road in the western side of the river; and • Jawaharlal Nehru Road and east to Dabhoi road Via Lalbaug
Western area	• V.S.Marg • R.C.Dutt Road • Jetalpur Road • Gotri Road • Padra Road
Around the central city	• Ring road along the Padra road in the west, Vikram Sarabhai Marg, Subhash Bridge, University Road, Harni Road, Waghodia Road to Tarsali and via Makarpura GIDC to Padra Road Junction
Northern – Southern area	• Fatehgunj road in the west side of Sayajigunj • Long Road connecting Baucharaji road, Prof. Manek Rao Road, R.V. Desai Road upto Pratapnagar • Link connection Godhra Road State Highway with Harni Airport and southwards to Bank road; and • Gendigate road, Pratapnagar Road up to the railway crossing

Vadodara which is predominantly administrative, business and industrial city in recent years is facing a rapid development and population increase resulting into traffic congestion and parking problems. Some of the city areas like, area within four gates, Raopura, Dandia Bazar, Chowkhandi, and Bhutdizampa have become overcrowded. During the peak hours they suffer from the heavy traffic creating chaos thereby requiring special attention. A large number of people have to commute from the eastern part of the city to different direction and in the evening to return to their residence. Thus, a proper road network planning becomes imperative to avoid large volume of traffic and undue delay. This leads to high rates of traffic accidents and excessive strain on the public transit during the peak hours. This situation exhibits the urgent requirement of well developed and proper transportation network in the city.

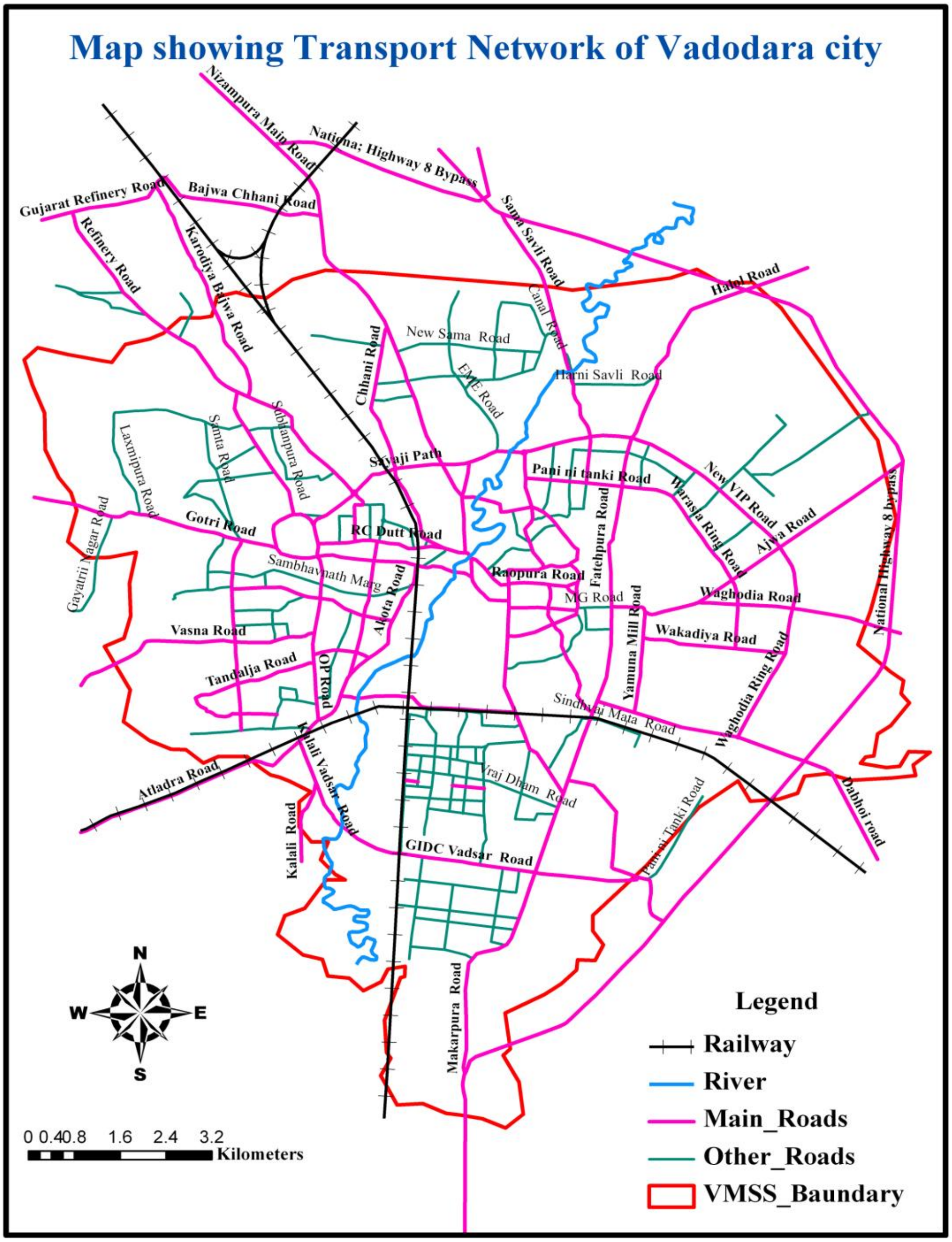


Plate 13: Transportation network of the Vadodara city

(4.1.2) Thematic layer of Water body of Vadodara city:

Freshwater resources are fundamental to agriculture, food production and human development. While freshwater supplies are clearly limited, for most people water scarcity is caused by competition between water uses and by political, technological and financial barriers that limit their access to water **(Falkenmark and Lundqvist, 1998)**. The UN Environmental Programme reports that "if present trends continue, 1.8 billion people will be living in countries or regions with absolute water scarcity by 2025, and two thirds of the world population could be subjected to water stress **(UNEP GEO-4 2007)**." Every city needs enough water for its population and industries, and hence it needs water resources. Accelerated urban growth, increasing poverty and low investment in water supply is contributing to water shortages in many cities. Drainage and infilling of wetlands through the process of illegal urbanization means natural loss of water storage areas and reduction in groundwater recharge, reducing dry season flows and the options available for coping with drought. In such situation mapping the water resources becomes essential because a sustainable urban water system is a basic feature of an eco-city. The eco-city approach to urban management combines water with environmental management and focuses on long-term urban sustainability. Its purpose is to make water treatment more sustainable and protect the quality of drinking water sources.

From the thematic layer it is clear that, many water bodies exist as a part of the hydraulic network of the city. Some of them like Sursagar in the heart of the city are provided with built walls **(Plate 14)**. Eastern part of the city has good number of water bodies some of which are located in the vicinity of gardens **(Plate 15).** The quality of water in all lakes is not suitable for human consumption. There is no aquatic life, barring some stray cases. Weed growth is abundant. Lakes provided with stoned walls are found to be in dilapidated conditions and require major repairs or replacement. Slums have also developed on the banks and in some cases, even the tank bed is encroached upon. The garbage dumping has further degraded the environment leading to unhealthy living conditions for the slum dwellers and people in the vicinity. Some of the lakes like Gorwa lake, Harni pond, etc. are now acting as breeding grounds for mosquitoes. Lakes, which served the basic needs of society and provided a healthy environment, are in disuse and are turning into health hazards. It is therefore, imperative to preserve and revive these water bodies and also protect the water quality.

The Vadodara branch canal of the Sardar Sarovar Project, running on north and east boundary is a perennial canal and is a recent addition to the hydraulic system. The lakes are an integral part of the hydraulic system of Vadodara city and have influenced the development of the city so far. The Vishwamitri river passes across Vadodara City.

Plate 14: Sursagar lake of Vadodara city

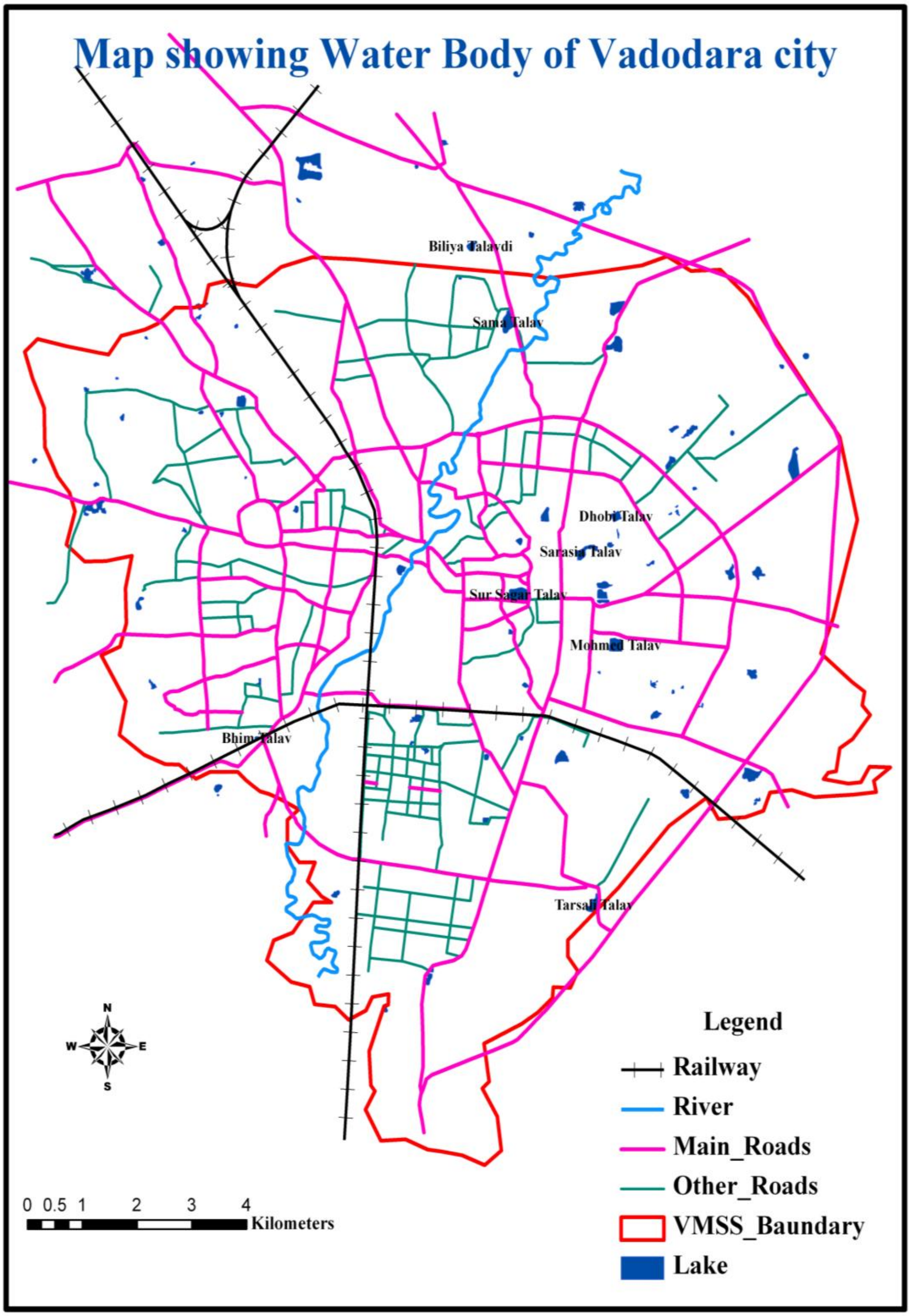


Plate 15: Map showing different water bodies of Vadodara city

(4.1.3) <u>Thematic layer of Gardens of Vadodara city</u>:

Vadodara is known as the "city of gardens" due to presence of many gardens in the city. These gardens have been set up for recreation by VMSS (Vadodara Mahanagar Seva Sadan). Gardens of the city have been expanding from time to time, under successive gardeners to its present state. These parks and gardens are of great importance; as they act as the great green lungs that make city fit to live in. These are profusely green, with plantations of major plants, shrubs and herbs. They play a very important role in preserving the biodiversity of the urban ecosystems. They serve not only to retain precipitation, recharge the water tables, clean the air, and provide wildlife habitat but also act as wind breaks and cool and refresh the summer breeze. **Table 8** shows the list of the gardens present in the city. Total 51 gardens have been reported from the city covering the area of 400 ha. The largest garden of the city is Sayaji garden located in the Sayajigunj area while the smallest one is the Navi Dharti garden which is situated in the Navi Dharti area. Few new gardens have also been reported during the survey of the city of which three are located in the Manjalpur and one each in Akota, Maneja, Subhanpura and Gajrawadi. Some of these gardens like, Sayaji Garden, Suryanarayan Baug, Kevda baug, etc. are located along the roadside while some of them like Makarpura baug, Tarsali housing baug are located in between the residential areas. These gardens are located all around the city and provide many amenities to the people living in near vicinity **(Plate 16). Plate 17** shows photographs of various gardens of the city.

Table 8: List of the gardens present in the city

Sr. No.	Name of the Garden	Area (Ha)	Location
1.	Sayaji Garden	113.00	Sayajigunj
2.	Suryanarayan Baug	0.36	Raopura
3.	Jubilee Baug	3.00	Nr.Amdavadi Pole
4.	Lal Baug	9.31	Nr.Lal railway crossing
5.	Varasia Baug	2.20	Sant Kanvar Society
6.	Chandan Baug	1.00	Shankar Baug soc. Manjalpur
7.	Makarpura Baug	1.06	Nr.Makarpura Village
8.	Maneja Baug	0.14	Nr. Maneja Village
9.	Market Baug	0.33	Nr.Khanderao Market
10.	Kevda Baug	0.26	Nr. Shiya Baug
11.	Sardar Baug(Vadi)	6.06	Nr. Sarabhai Chemicals
12.	Hirak Baug	0.11	Nr. Railway Station
13.	Akota Baug	5.00	Nr. Akota water tank
14.	Shankar tekri Baug	1.24	Nr. Technical College
15.	Maharishi Baug	2.20	Fatehgunj
16.	Channi Jicon Baug	-	Nr. Channi
17.	V.I.P Trikon Baug	0.20	VIP Road
18.	Harni Housing Baug-1	0.64	Nr. Harni Atithi Gruh
19.	Harni Housing Baug-2	0.64	Nr. Harni Housing
20.	Moti Baug	0.10	Rajmahal Road
21.	Navapura Baug	0.60	Bh. Navapura Market
22.	Azad Baug	0.92	Opp. Moti Tambudivad
23.	Sarasiya Baug	2.74	Mohammed Lake wadi
24.	Shantinagar housing board	0.10	Tarsali
25.	Danteshwar	1.00	Danteshwar Village
26.	Tarsali Housing Baug 1-2	0.30	Tarsali Housing
27.	Tarsali Sewage Baug	2.20	Tarsali pumping Station
28.	Gajrawadi Baug (Shashtri Baug)	-	Gajrawadi
29.	Khaswadi Smashan Baug	4.18	Bahucharaji Road
30.	Ramnath Smashan Baug	1.07	Gajrawadi
31.	Navroji Baug	0.11	Sayajigunj Police Station
32.	Pratapgunj Statue Baug	0.10	Pratapgunj
33.	Premanand Hall Baug	0.10	Mahammed lake wadi
34.	Panigate Gruh Baug	-	Panigate
35.	Hariomnagar Baug	0.18	Gotri Road
36.	Wadi Sewage Baug	3.00	Gajrawadi
37.	Jambua Baug	2.00	Jambua Village
38.	Ajwa Garden	100.00	Nr. Ajwa lake
39.	Nimeta Garden	25.00	Nr. Nimeta Filteration
40.	Navi Dharti Baug	0.03	Navi Dharti,Nagarwada
41.	T.P.12 Baug	0.33	Ellora Park
42.	T.P.7 Baug	-	-
43.	T.P 11\2	-	Nr. Sama crossing
44.	Saii Udhyan	4.40	Manjalpur
45.	Dr.Hedgevar Udhyan	11.00	Sama,Bhadrannagar
46.	Veer Sankar udhyan	-	New Sama Road
47.	Shantinagar Plot-1	-	Shantinagar Tarsali
48.	Shantinagar Plot-2	-	Shantinagar Tarsali
49.	Sharadnagar Plot-1	-	Sharadnagar Tarsali
50.	Sharadnagar Plot-2	-	Sharadnagar Tarsali
51.	Sharadnagar Plot-2	90	Sharadnagar Tarsali

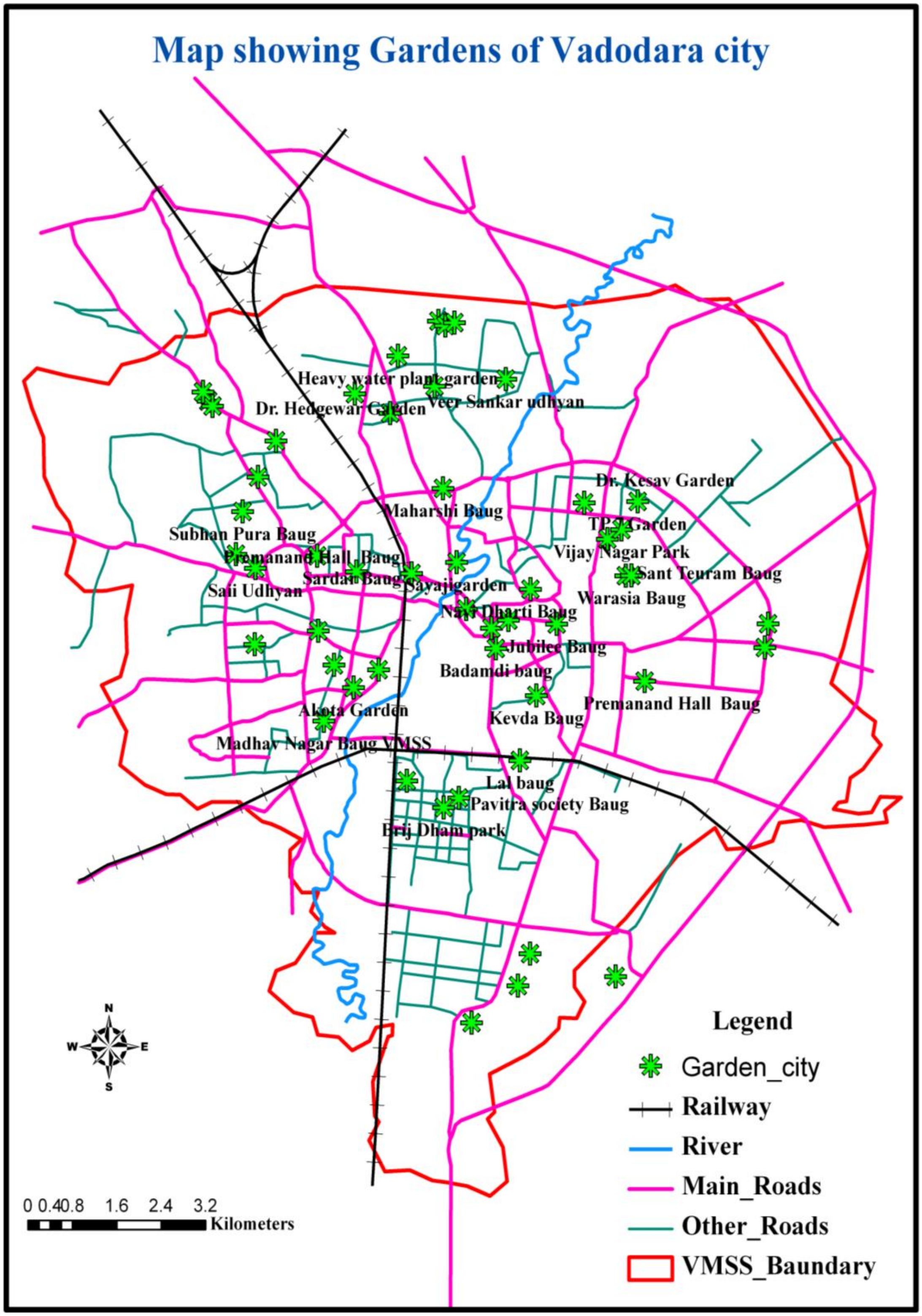


Plate 16: Map showing different Gardens of Vadodara city

T.P 7 Udhyan, Karelibaug

Maharshi Arvind Udhyan, Fatehgunj

Hirak Baug, Sayajigunj

Vijay Nagar Garden, Vijay Nagar

Sant kanvarram Baug, Gajrawadi

Sardar Baug, Race course

Plate 17: Photographs of different Gardens of Vadodara city

(4.1.4) <u>Thematic layer of Greenbelts of Vadodara city</u>:

A Greenbelt (GB) refers to a physical area of open space, e.g., forest, or other green space, that surrounds a city or metropolitan area, and it is intended to be a permanent barrier to urban expansion. **Plate 18** shows different Greenbelts of the city. Any type of development is strictly regulated or prohibited on GB land. It is an important part of complex urban ecosystem services including: flood control, air filtration, carbon storage and erosion prevention. The GBs are gaining greater importance day by day as the urbanization is degrading the environment very rapidly. GBs also connect urban dwellers with nature and so it is imperative that all cities should earmark certain areas for the GB development to bring variety to the built-up city and a healthy environment to the urbanities **(Sharma and Roy, 1999)**. These GBs also play an important role in sustainable development, i.e. Eco-city planning. Planning, management and development of GB therefore become imperative. Vadodara city has 19 GBs identified by V.M.S.S. (Vadodara Mahanagar Seva Sadan). The total area encompassing the GBs is approximately 20344 sq.m**.(Table 9)**. These GBs are located either along the road side or in between residential areas depending upon the area alloted. As less as only 37% of them are fuctional and performing the functions of reducing the pollution and restricting urban sprawl. Few of the GBs were not reported during the survey of the city and few of them were lacking any type of vegetation. Hence, such GBs were categorised as non-functional GBs. Few selected green belts as observed on ground are shown in **Plate 19**.

Table 9 : Important Green belt Areas of City

Plot	T.P no.	Location	Area (Sq. m.)	Status
234	1	Guru Prasad Society Near Akota Playground	3114	Functional
127	4	Varishta Nagrik Mandal Bapod	379	Non-functional
281	5	New V.I.P road New Snehal Printing Press	1766	Non-functional
961	3	Relok youth Club and Charitable trust	474	Non-functional
401	3	Senior Citizen Bapod	564	Non-functional
234	3	Near Kailash Society Bapod	595	Non-functional
428\1	3	Near Prabhat Society Vaghodia Road (GB transformed into Garden)	1841	Functional
248	3	Near Uma Society Vaghodia	1179	Non-functional
498-499	3	Chandanben Vithaldas Parekh Bhavan	-	No location available
272	19	Vallabh Foundation Trust Manjalpur	3201	Functional
42	19	Yogi Foundation Trust Swami Narayan Mandir Manjalpur	192	Non-functional
133	19	Yogi Foundation Trust Swami Narayan Mandir Manjalpur	352	Non-functional
180	5	Lokseva Federation	500	Non-functional
303	2	Behind Natubhai Circle Race cource circle	925	Functional
146	9	Near Dhanlaxmi Society Karelibaugh	1036	Functional
33	9	Mangal Jyot Society Karelibaugh	1160	Functional
353	9	Near R.R.Park Society	1253	Functional
50	7	Sangam Chaar Rasta Harni	929	Non-functional
10	4	Vaghodia Road	884	Non-functional

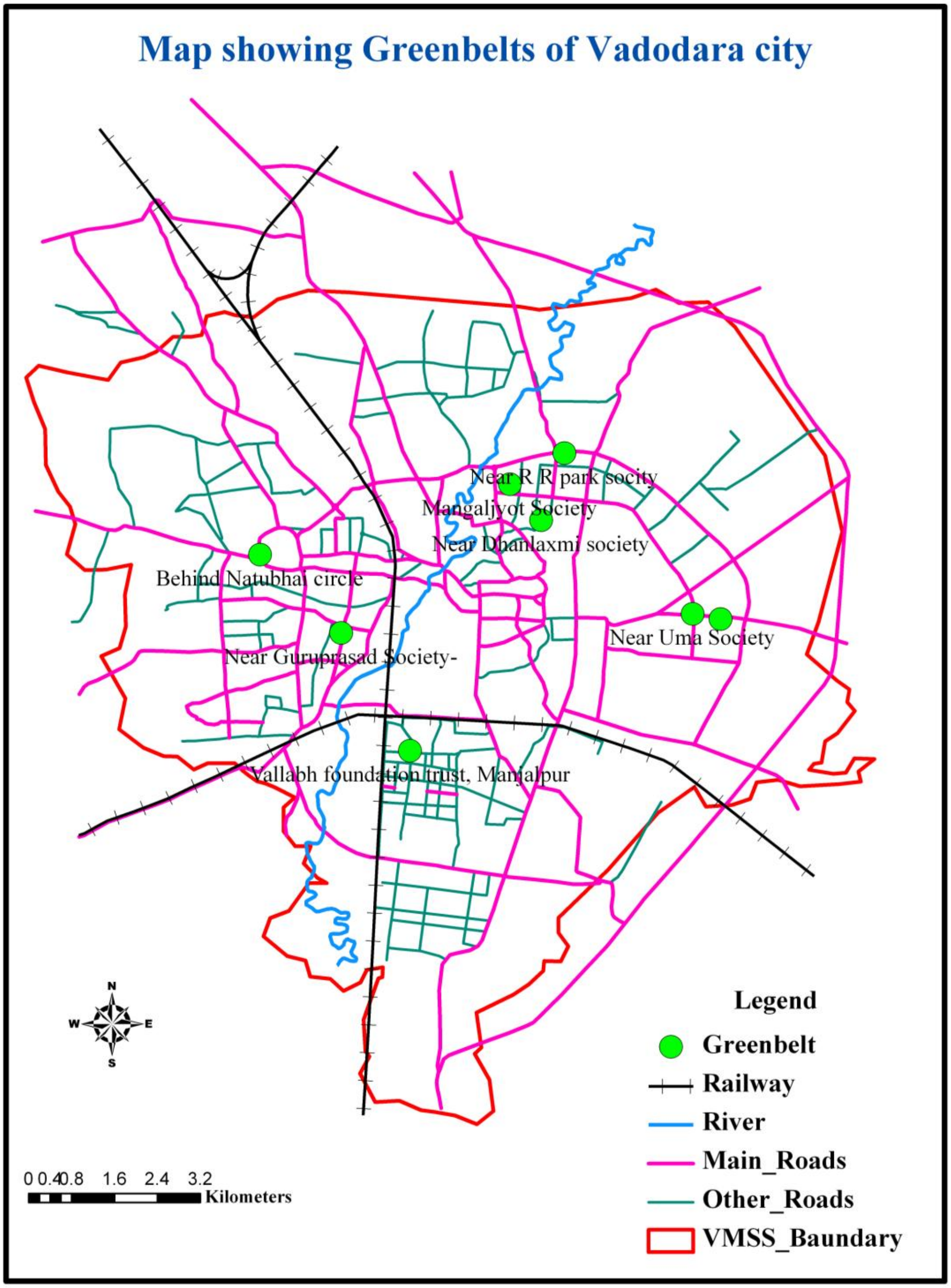
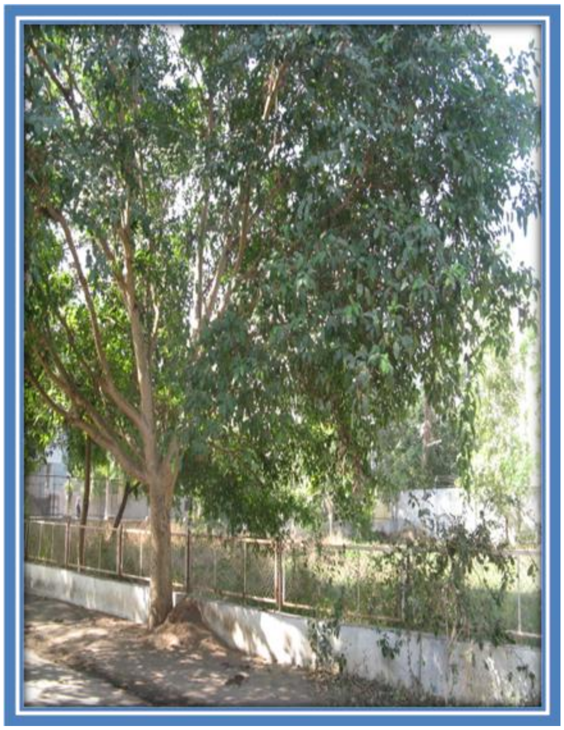


Plate 18: Map showing different Greenbelts of Vadodara city



Greenbelt at Guruprasad Society

Greenbelt at R.R. Park Society

Greenbelt at Mangaljyot society

Greenbelt at Near Prabhat Society

Plate 19: Photographs of different Greenbelts of Vadodara city

(4.1.5) Thematic layer of Population density of Vadodara city:

At any level of development, human impact on the environment is a function of population size, and the environmental damage caused by the technology used to produce what is consumed. Widespread poverty, environmental conditions, the use of natural resources along with economic and social development is closely linked to population growth and distribution. In spite of covering only 1.5% of the total land area of the earth, 50 % of the global population currently lives in cities and it is expected to increase to 70% in 2050 (**De and Soni, 2009).** The urban population in India is 285 million, which is 10 per cent of world and 21 per cent of Asia **(Singh and Manoj, 2009)**. Such magnitude of urban population growth for a developing country is a direct indicator of the degree of spatial concentration of people, industries, commerce, vehicles, energy consumption, water use, waste generation, and other environmental stresses. This leads to unsustainable patterns of consumption and production which is responsible for depleting natural resources and causing environmental degradation. The understanding of demographic trends of the Vadodara city becomes important as the development of city into an eco-city is highly influenced by socioeconomic conditions and population density **(Hald, 2009)**. The city is the third most populated town in the Gujarat after Ahmedabad and Surat. It is one of three towns with a population of over 1 million and the 16th most populous city of India. The city has developed as one of the major industrial and commercial centers of Gujarat. The population of Vadodara city has increased from 1, 03,790 in the year 1901 to 16, 66,703 in the year 2011 **(Figure 7)**.

It was difficult to trace the demographic trends of the city prior to the 1901 Census. According to 1901 census the population of Vadodara was 1,03,790 **(Table 10).**

Around 1902, the city faced a locust invasion, resulting in a heavy loss of agriculture output. Plague followed by famine in 1906, made the conditions very abject. These factors declined population by 4.66 % from the year 1901-1921. The third decade was a transitory period in the population history of city due to increased population during this time. The highest change in population was observed in the year 1981 at both VMSS and VUDA level. The reason behind such increase was rapid industrialization during this time. The trend of growth set during the first three decades of the post-Independence era, continued during the last two decades of 1981-1991 and 1991-2001. Rapid urban-rural migration during these decades resulted into the rapid increase in population. The population increased by 5,88,147 during this time.

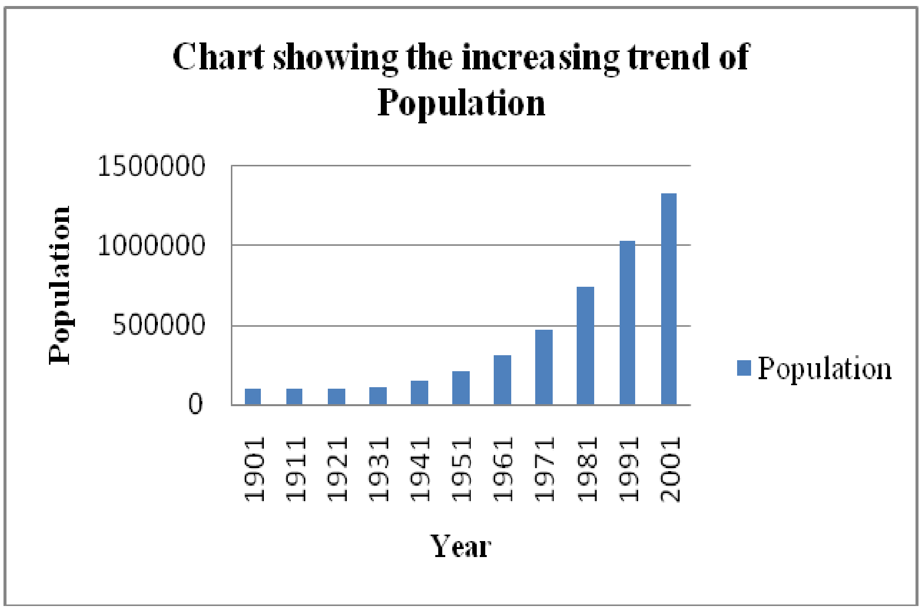


Figure 7: Chart showing the increasing trend of population

Table 10: Population statistics of Vadodara city

Year	Population	% Change VMSS	% change VUDA
1901	1,03,790	-	-
1911	99,345	-4.28	-
1921	94,712	-4.66	-
1931	1,12,860	19.16	-
1941	1,53,301	35.82	-
1951	2,11,407	37.90	-
1961	3,09,487	46.50	36.80
1971	4,67,487	50.94	45.80
1981	7,34,473	57.10	49.77
1991	10,21,084	39.02	21.97
2001	13,22,620	40.00	34.05

The change in population density of different wards of Vadodara city exhibited that the City ward (No. 1) was having the highest density in both the years. The second highest density was reported by Raopura and Sindhvai Mata Road wards in the years 1991 and 2001, respectively **(Plate 20).** The lowest population density was reported by Gajrawadi ward in both the years. The City ward showed decline in population from the year 1991 to 2001. It was partly because of high cost of land in the inner city and partly because the inner city is being commercialized and many residential buildings are being converted into shops and other buildings. Added to this is the wards have become congested due to high residential building density affecting environment condition of these wards. Increasing vehicular traffic has made the situation worse due to heavy pollution load. New residential colonies are coming up in the wards like Panigate, Subhanpura, Sindhvai Mata road, etc. These areas are developing away from the congested core around the periphery of the city. More citizens prefer to live in these areas with good environment condition.

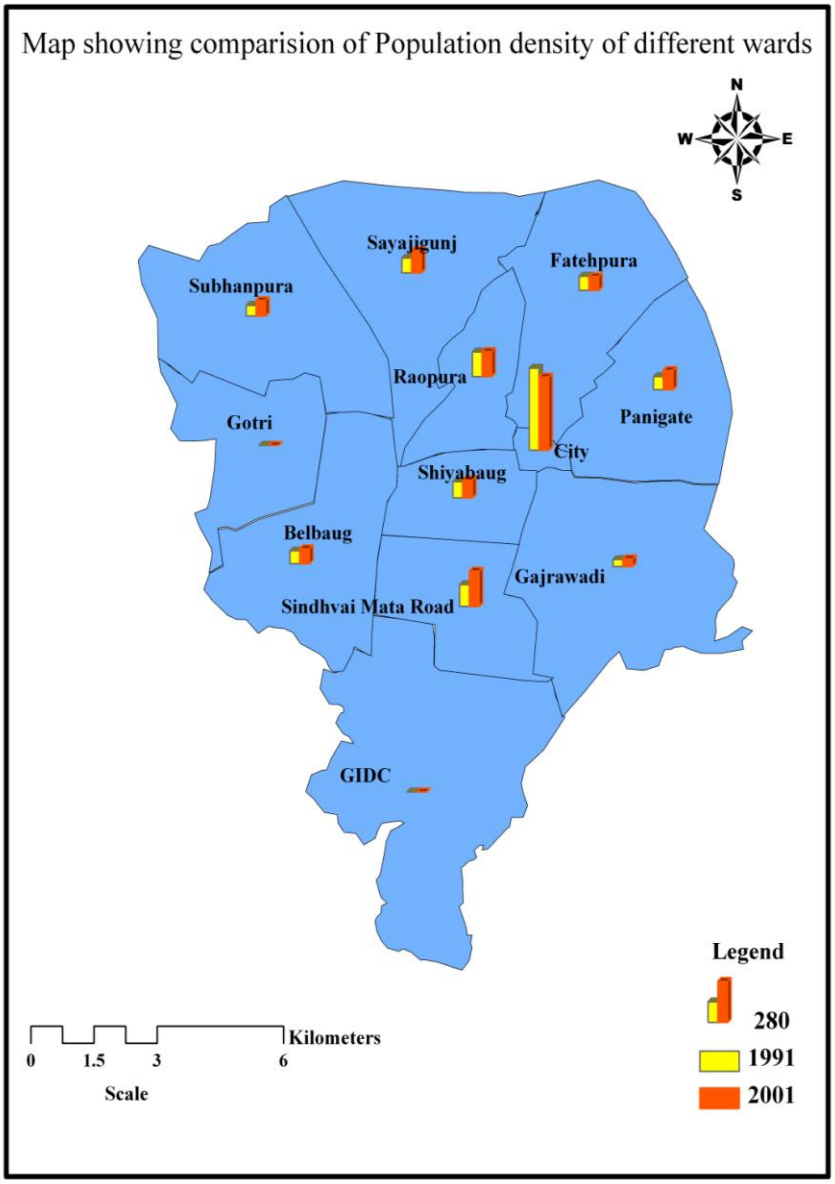


Plate 20:Map showing the Population density of different wards in the year 1991 and 2001

(4.1.6) <u>Contour and Slope of Vadodara city</u>:

Contour and Slope map of Vadodara city explained the terrain characteristics of the city. The results showed that the highest peak in the Vadodara city was reported in Fatehpura area with the elevation of 43 m while lowest peak was observed in GIDC area with elevation of 26 m **(Plate 21)**. The slope map generated from the information of contour map exhibited that the city has a relatively flat terrain. The city showed gentle slope ranging from 0.001 to 0.87 %. The contour lines were found be spaced evenly indicating a uniform and gentle slope in the northern parts of the city while they were spaced closely indicating the steeper slope in the southern side of the city. The high percent of slope value was seen in GIDC ward while areas like Subhanpura, Gotri etc. showed lower percent values of slope **(Plate 22)**.

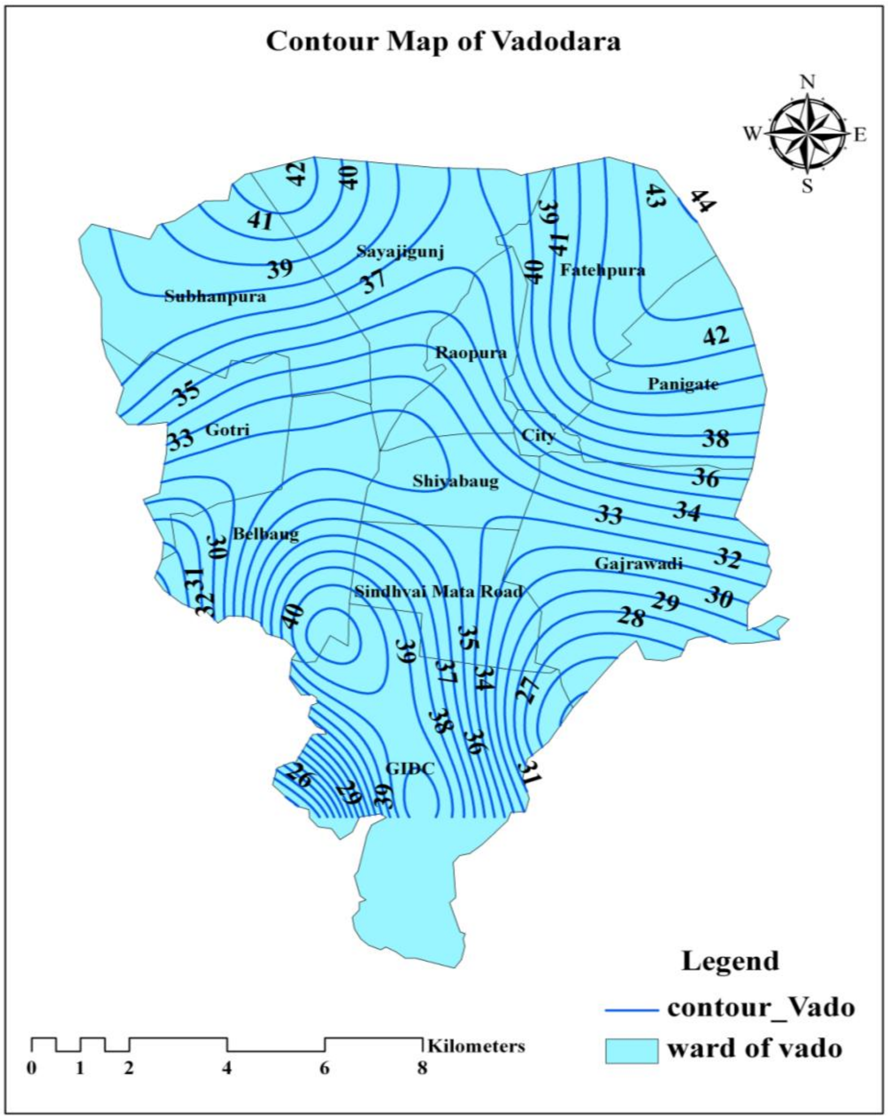


Plate 21: Contour map of Vadodara city

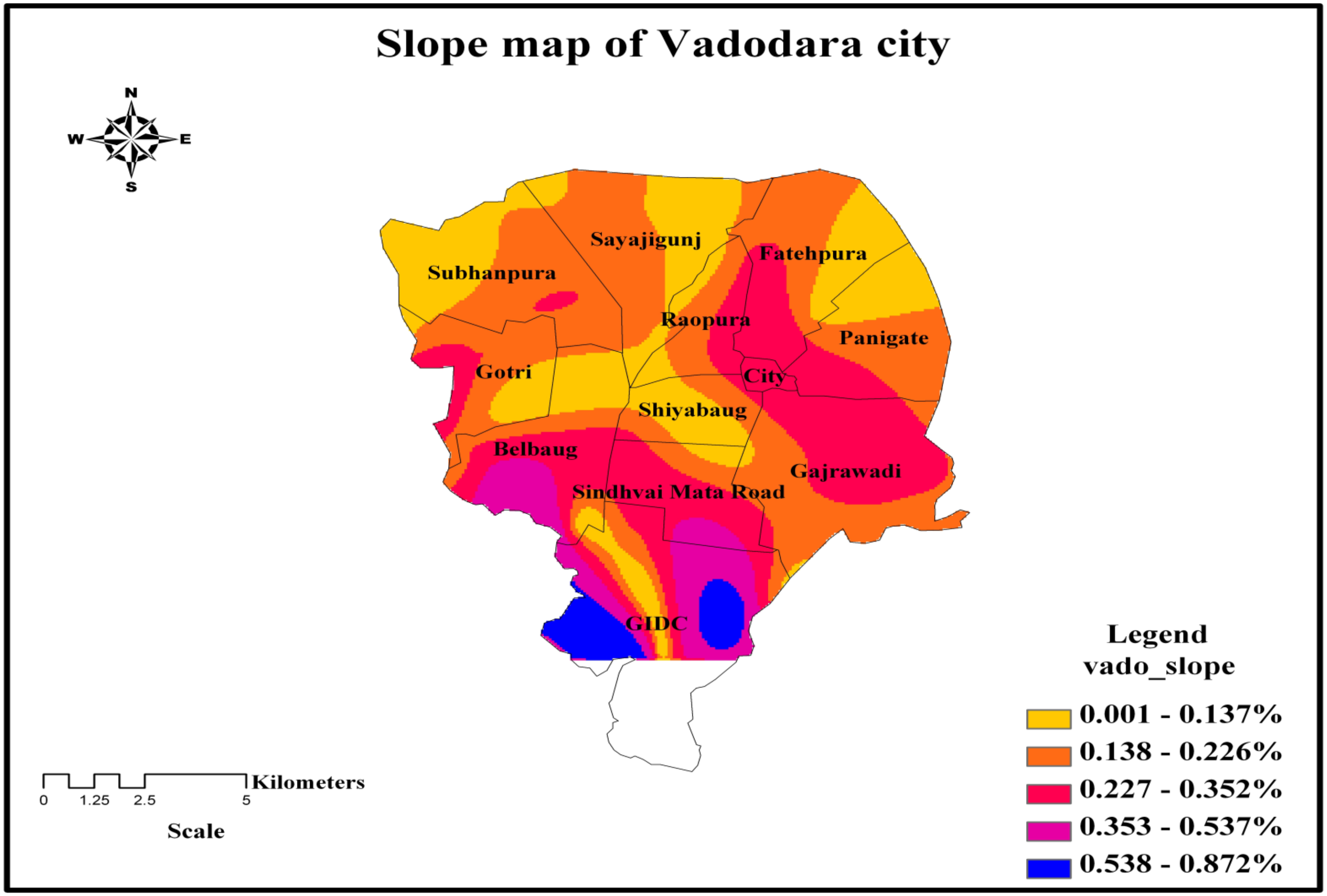


Plate 22: Slope map of Vadodara city

(4.2) Land use change analysis:

The change in any form of land use is largely related either with the external forces or with the pressure built up within the system. It has been noted that these changes lead to very unfavorable secondary effects on fragile natural environment. Many shifting land use patterns driven by a variety of social causes have resulted in land use changes that have affected biodiversity, water, trace gas emission and other processes. These processes also affect climate and biosphere (**Riebsame *et al.,* 1994).** Assessment of such spatial and temporal changes in land use pattern in Vadodara city has proved to be very effective in understanding changes occurring not only in land use but also in evaluating the environmental degradation. It has become a central component in formulating the current strategies for Vadodara city. The results have shown that in past few years the city has spread itself encroaching nearby areas enhancing the consumption of various natural resources. During earlier years, the development was along the four axes of Mandvi (the city centre, Wall city) and the municipal limits of the city covered only 22.68 km^2 in 1960. With increasing development more residential areas were required to accommodate the teeming inflow of people and the city began to grow rapidly outside the city wall. It expanded outwards in the west and northwest directions. In June 1964 this led to expansion of VMSS limit by 3.5 fold, covering an area of 72.44 km^2. With passage of time, industrial and commercial activities developed along the major arterial roads running on north-south and east-west direction of the city. This further accelerated the development of new residential colonies. The city in turn got a new extended structural form. This again induced the expansion of city administrative limits. It increased gradually to 97.22 km^2, 108.22 km^2 and 149.72 km^2 in the years

1973, 1975 and 2003, respectively. The city witnessed tremendous growth and distinct changes in the land use since it has been planned to be developed into an industrial hub.

Estimation of the dynamic process of the spatial and temporal characteristics of land use changes for study area was carried out at two different levels, i.e. VUDA (1880 to 2006) and VMSS (1880 to 2009). Overlay analysis of the thematic maps of different years brought out when the changes has occurred? and which type of land has been transformed into what? Land use changes detected in each class at VUDA and VMSS levels have been discussed separately.

(4.2.1) Agriculture:

Among all the resources agriculture is one of the prime and most important for the survival of the mankind. The proportion of land area under agricultural use in India (46%) is much large compared to world (11%) **(Kushwaha, 2008)**. Same is the case with Gujarat state which has 45% of total area of land under agriculture land use. In order to meet the food requirement of increasing population, there is a further need to increase the land under the agriculture. However, in view of rapidly growing cities, the change of agriculture land to other forms is increasing rapidly. Every year, some land at the outskirts of the city which is under cultivation gets degraded due to urbanization. Some of this arable land goes for the industrial developments while other for the infrastructure development leading to lowering in agricultural productivity **(Basawaraja *et al.*, 2011)**. The encroachment on arable land due to urban sprawl and probable consequences in terms of reduction in total arable fertile land have already been demonstrated by several workers **(Olson, 1996; Mohan, 2010)**. It has been observed that the growth of cities and progress of industries and services sectors increases the demand for conversion of agricultural land use. In other words, the agricultural land use changes are basically urban-induced negative changes **(Bryant and Greaves, 1978)**. This has been proved by the results obtained for the Vadodara city. In Vadodara also area occupied by various crops like Cotton, Bajra, Tobacco, Pulses, Wheat, Paddy, Maize, Sugarcane etc. have reduced drastically.

(4.2.1.1) <u>VUDA level (1880-2006):</u>

The change statistics for the agriculture class from the year 1880 to 2006 showed that the area decreased by 132 km^2 at Vadodara Urban Development Authority (VUDA) level. Since the data for these years were procured from different sources except for the year 2000, no categorization was done in agriculture class **(Plate 23)**. In case of data for 2000, two sub-classes of agriculture were identified viz. Crop land and Fallow land. These classes also exhibited distinct decreasing trend **(Table 11)**. In Vadodara city the highest reduction in agriculture land was observed during the years 1960 **(Plate 24)** to 1980 **(Plate 25)**. The reduction of -7.1 % can be attributed to the construction activities carried out on prime agricultural land on account of urban expansion and industrialization (**Table 12**). From the year 1980 to 2000, only 10.15 km^2 area of agriculture was converted to other land uses with annual rate of change of -1.42% **(Plate 26)**. The reason behind this was the slower rate of urban sprawl during these years. The area covered by Fallow land was more compared to crop land in the year 2000 **(Plate 27)**. In the year 2006, agriculture land decreased by 5.42 % with the annual rate of change of -0.32%. This decrease was due to discontinuation of agricultural activities in expectation of conversion to urban areas due to expanding VMSS limits **(Plate 28)**.

Table 11: Land use classification of VUDA area

Sr. No.	Level – I	Level - II	Level-III	Land Use Code	1880 km^2	1960 km^2	1980 km^2	1996 km^2	2000 km^2	2006 km^2
1.	Built - Up	Built Up(Urban)	Residential	01-01-00-00	9.14	42.69	58.87	63.03	73.79	100.33
	Built - Up	Built Up(Rural)		01-02-00-00	-	-	29.93	29.93	29.93	36.35
2	Agriculture Land			02-00-00-00	704.85	663.24	616.12	612.54	605.97	573.1
	Agriculture Land	Crop Land		02-01-00-00	-	-	-	-	152.34	-
	Agriculture Land	Fallow		02-02-00-00	-	-	-	-	453.63	-
3	Water Bodies	River		07-01-00-00	6.76	6.76	6.76	6.76	6.76	6.76
	Water Bodies	Canal		07-02-00-00	-	-	-	-	3.3	3.3
	Water Bodies	Lakes		07-03-00-00	-	5.1	2.27	1.69	1.35	1.25
	Water Bodies	Tanks		07-04-00-00	-	2.96	2.96	2.96	2.96	2.96

Table 12: Percent change in different land use classes of VUDA area

Sr. No.	Level – I	Level - II	Level-III	Land Use Code	1880-1960 %	1960-1980 %	1980-1996 %	1996-2000 %	2000-2006 %
1	Built - Up	Built Up(Urban)	Residential	01-01-00-00	367.06	37.90	7.06	17.07	35.96
	Built - Up	Built Up(Rural)		01-02-00-00	-	-	0	0	21.45
2	Agriculture Land			02-00-00-00	-5.9	-7.1	-0.58	-1.07	-5.42
	Agriculture Land	Crop Land		02-01-00-00	-	-	-	-	-
	Agriculture Land	Fallow		02-02-00-00	-	-	-	-	-
3	Water Bodies	River		07-01-00-00	0	0	0	0	0
	Water Bodies	Canal		07-02-00-00	-	-	-	-	0
	Water Bodies	Lakes		07-03-00-00	-	-55.49	-25.5	-20.1	-7.4
	Water Bodies	Tanks		07-04-00-00	-	0	0	0	0

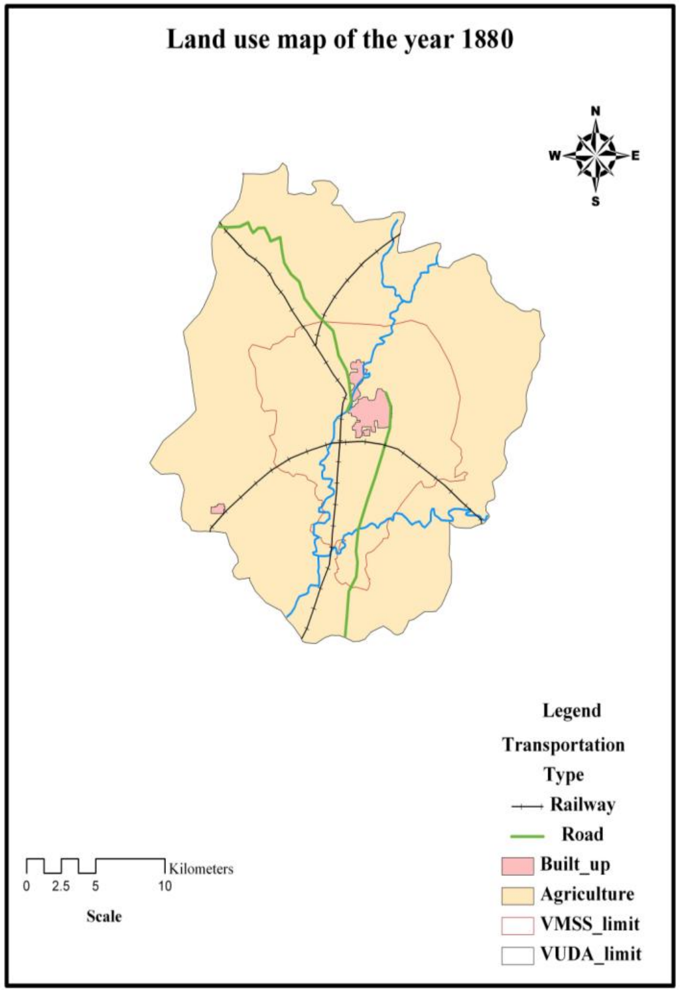


Plate 23: Map showing the land use of year 1880

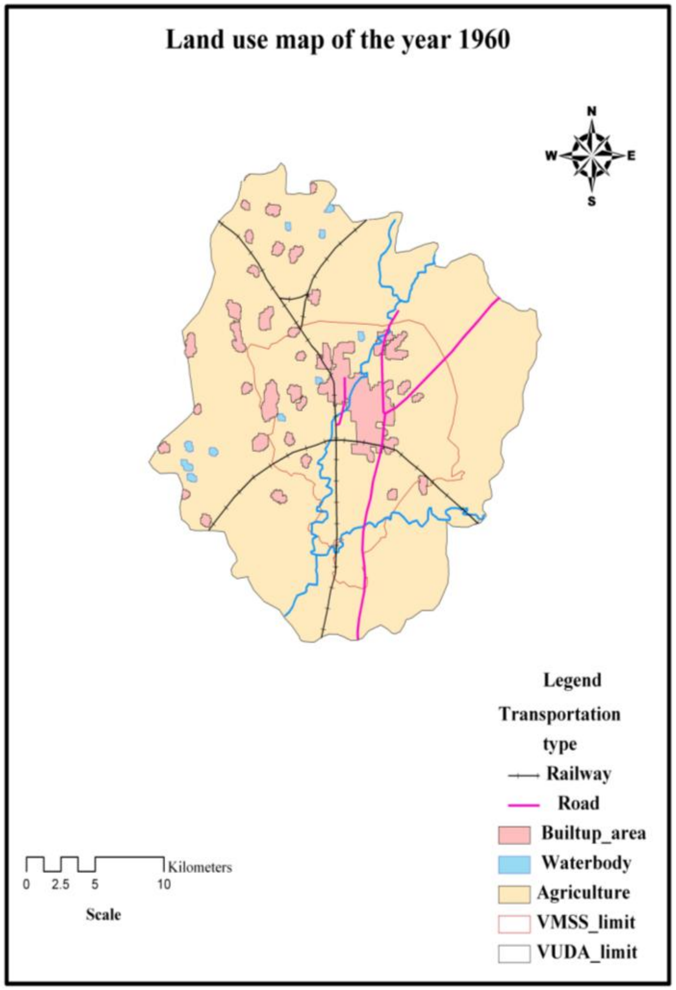


Plate 24: Map showing the land use of year 1960

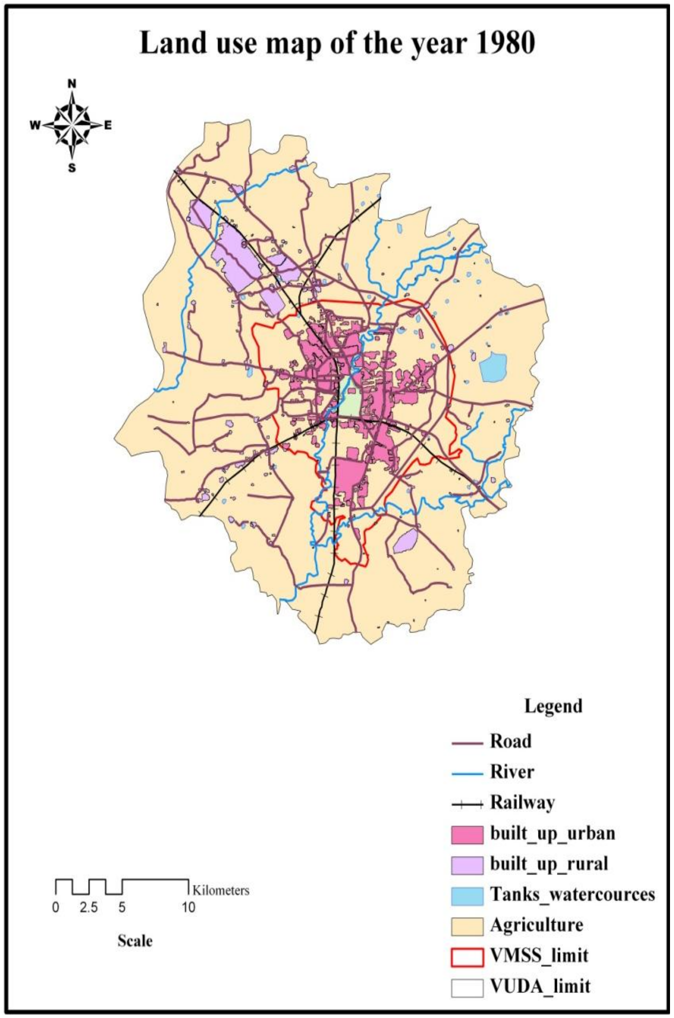


Plate 25: Map showing the land use of year 1980

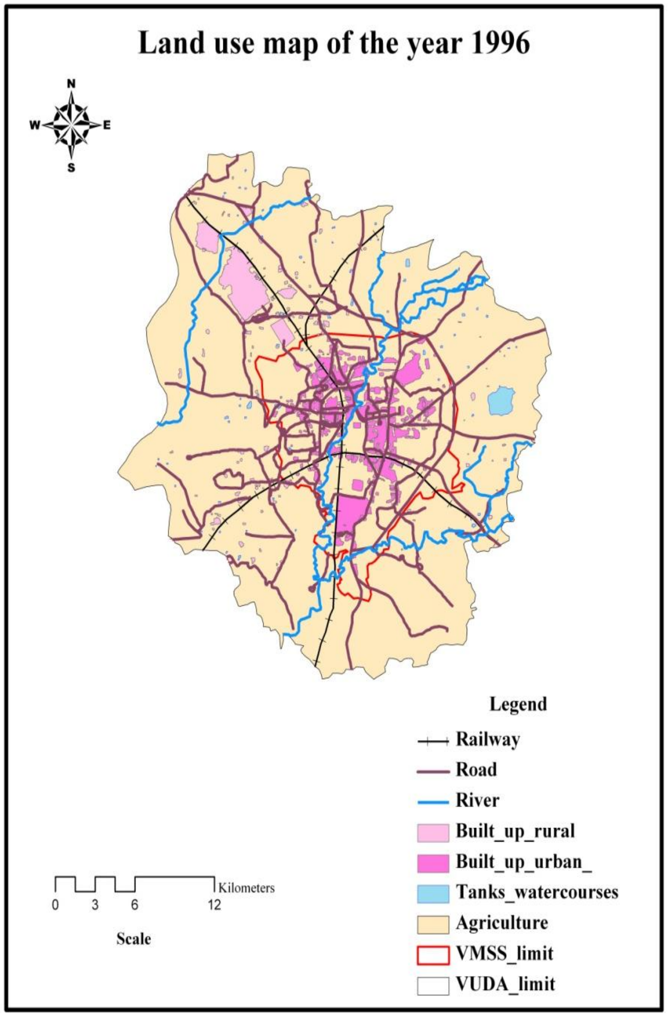


Plate 26: Map showing the land use of year 1996

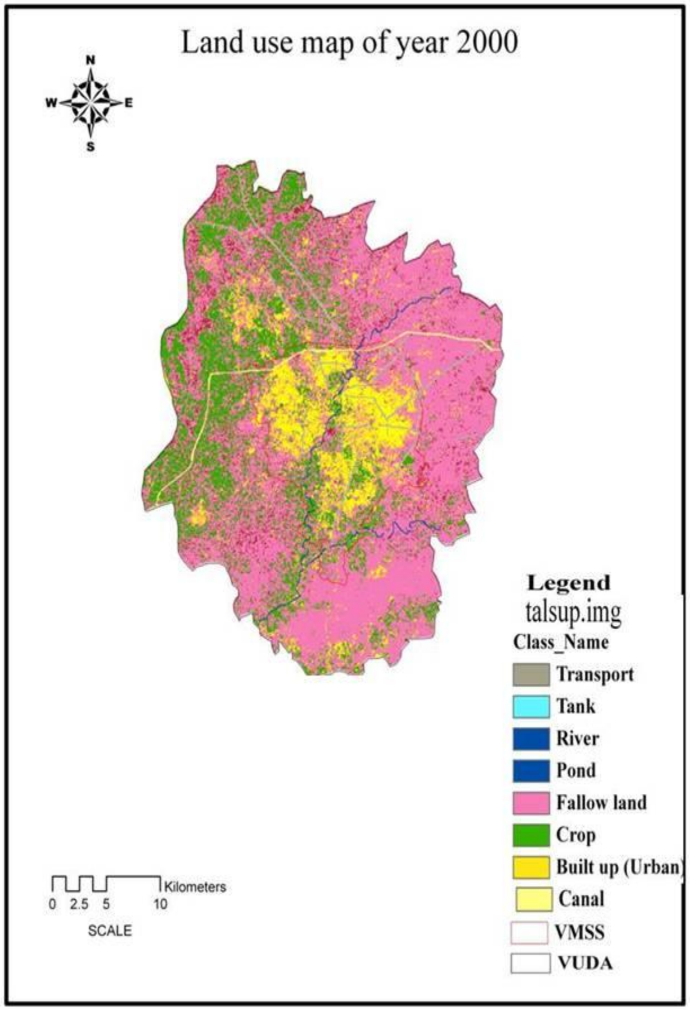


Plate 27: Map showing the land use of year 2000

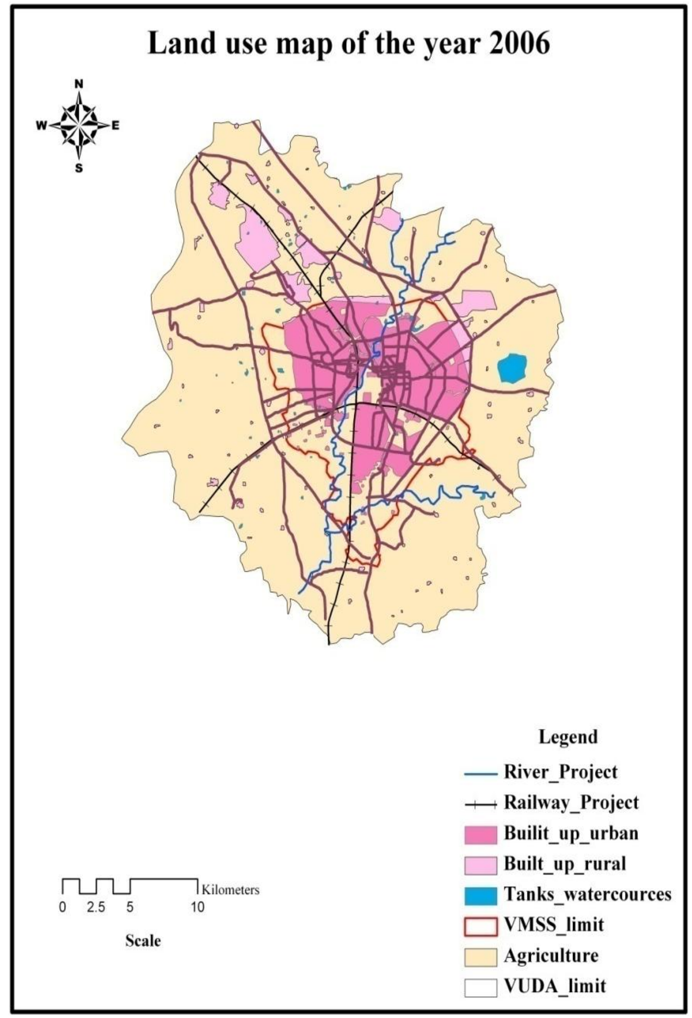


Plate 28: Map showing the land use of year 2006

(4.2.1.2) <u>VMSS level (1880-2009):</u>

Vadodara Mahanagar Seva Sadan (VMSS) covers the entire city area or urban area. The area occupied by agriculture reduced very rapidly from the year 1880 to 2009 **(Table 13).** In the year 1880 almost entire area of Vadodara Municipal Seva Sadan (VMSS) was occupied by the agriculture land which reduced significantly by 24.62% in the year 1960 (**Table 14).** Most of the industries established during the years 1960 to 1980 were beyond the VMSS limit which is apparent from the low annual rate of change (-6.6%) in agricultural land. The highest decrease of 77.53% in agriculture land was observed between the years 2000 to 2006. This decrease was attributed to the conversion of agriculture land into residential and commercial areas to meet the demand of increasing population. The classified output of 2009 was categorized into crop land and fallow land covering an area of 1.2 km^2 and 2.51 km^2, respectively **(Plate 29)**.

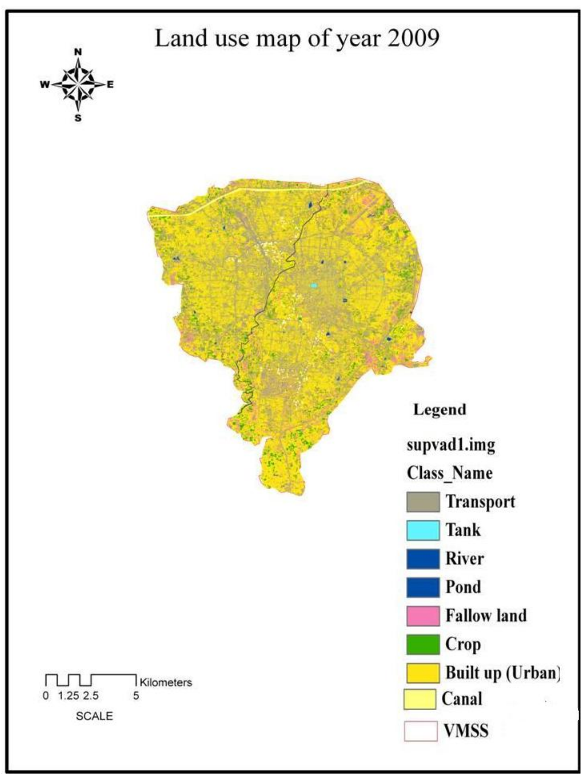


Plate 29: Map showing the land use of year 2009

Table 13: Land use classification of VMSS area

Sr. No.	Level – I	Level - II	Level-III	Land Use Code	1880 km^2	1960 km^2	1980 km^2	1996 km^2	2000 km^2	2006 km^2	2009 km^2
1.	Built - Up	Built Up(Urban)	Residential	01-01-00-00	9.14	42.69	74.58	77.32	102.45	138.61	145.6
	Built - Up	Built Up(Rural)		01-02-00-00	-	-	-	-	-	-	-
2	Agriculture Land			02-00-00-00	140.58	105.96	70.79	68.27	47.13	10.59	3.71
	Agriculture Land	Crop Land		02-01-00-00	-	-	-	-	15.12	-	1.2
	Agriculture Land	Fallow		02-02-00-00	-	-	-	-	32.00	-	2.51
3	Water Bodies	River		07-01-00-00	2.9	2.9	2.9	2.9	2.9	2.9	2.9
	Water Bodies	Canal		07-02-00-00	-	-	-	-	1.05	1.05	1.05
	Water Bodies	Lakes		07-03-00-00	-	0.97	0.42	0.39	0.34	0.32	0.30
	Water Bodies	Tanks		07-04-00-00	-	0.1	0.1	0.1	0.1	0.1	0.1

Table 14: Percent change in different land use classes of VMSS area

Sr. No.	Level – I	Level - II	Level-III	Land Use Code	1880-1960 %	1960 - 1980 %	1980 - 1996 %	1996 - 2000 %	2000 - 2006 %	2006 - 2009 %
1	Built - Up	Built Up(Urban)	Residential	01-01-00-00	367.06	74.7	3.67	32.5	35.29	5.04
	Built - Up	Built Up(Rural)		01-02-00-00	-	-	-	-	-	-
2	Agriculture Land			02-00-00-00	-24.62	-33.19	-3.55	-30.96	-77.53	-64.96
	Agriculture Land	Crop Land		02-01-00-00	-	-	-	-	-	-
	Agriculture Land	Fallow		02-02-00-00	-	-	-	-	-	-
3	Water Bodies	River		07-01-00-00	0	0	0	0	0	0
	Water Bodies	Canal		07-02-00-00	-	-	-	-	0	0
	Water Bodies	Lakes		07-03-00-00	-	-56.7	-7.1	-12.82	-5.88	-6.25
	Water Bodies	Tanks		07-04-00-00	-	0	0	0	0	0

(4.2.2) <u>Water Bodies:</u>

Cities and towns of India are getting deficient in the quality of services they provide. Rapid urbanization in India has led to a tremendous pressure on urban infrastructure systems like water supply, sewerage and drainage, solid waste management, transport, etc. This situation was visualized even in Vadodara city.

(4.2.2.1) <u>VUDA level (1880-2006):</u>

Many water bodies existing within the Vadodara Urban Development Area (VUDA) limit have changed during the span of five decades. No records were found for the year 1880. Water body class was categorized into four sub-classes, viz. River, Canal, Lakes and Tanks. The area under river and tanks did not exhibit any changes, whereas a distinct change was noted in the lakes from the year 1960 to 2006 **(Table 11).** A rapid decrease of 55.49 % in area under the sub-class lakes was noted from the year 1960 to 1980 **(Table 12)**. The reason for which was the occurrence of three consecutive drought years of 1965, 1966 and 1967. From the years 1980 to 1996, a decrease of 0.58 km^2 was noted due to their conversion into settlements, waste lands, etc. A very small difference of 0.1km^2 was observed from the year 2000 to 2006. The Narmada canal was constructed in the year 2000 and since then this class came into existence covering an area of 3.3 km^2.

(4.2.2.2) <u>VMSS level (1880-2009):</u>

The area occupied by water body decreased in Vadodara Maha Seva Sadan (VMSS) from the year 1880 to 2009 **(Table 13)**. No change was observed in the area occupied by the sub-classes; river and tanks from the year 1960 to 2009. In the year 1960 the area occupied by lakes was 0.97 km^2 which decreased to almost half in the year 1980 **(Table 14)**. A continuous decreasing trend was observed from the year 1996 to

2009. The reason behind such fluctuation in the area can be attributed to occurrence of eutrophication in many lakes of the city like Gorwa Lake, Mohamed Lake, etc. **(Plate 30)**. In addition to this problem, these lakes were also misused for dumping untreated waste water mixed with substantial amount of solid waste (**Dey *et al.,* 2006**). Perennial pond of Harni of the city shrunk due to encroachment by the people residing in near vicinity. Sursagar Lake situated in the middle of the city is also facing stinking problem. In addition to this, many wetlands of the city have disappeared in last few decades. The reason for this was lack of control over construction activity and improper planning.

Plate 30: Lake with vegetation growth on the periphery

(4.2.3) **<u>Built-up land:</u>**

Urban built-up areas are the regions which contain structural information about the urbanized land, including buildings and open space. These areas are also often referred to as “impervious surfaces” **(Yang *et al.*, 2003**). These impervious built-up lands have significant impacts on the ecosystem, hydrologic system, biodiversity, and local climate which can result in the negative aspects such as the urban heat island phenomenon. This was also proved by the results obtained for Vadodara city in which the urban built-up area has increased several folds at both the levels.

(4.2.3.1) VUDA level (1880-2006):

This class was classified into two sub-classes urban built-up and rural built-up except for the years 1880 and 1960. The change in this class as observed over a period of 126 years was notable on all sides except the northern region. The eastern spread was predominantly residential though it had industrial component in it. The open areas, close to the outskirts of the city mostly turned into big townships, new colonies, and apartment complexes **(Desai, 2009)**. The southern spread had well marked large sized Industrial estates and emerging residential complexes. On the western side, residential use was quite pronounced. The change detection results revealed that from the 1880 to 1960 the built-up area increased by 33.55 km^2 **(Table 11)**. Between the years 1980 to 2000 the area occupied by rural built-up remained the same but it increased in the year 2006 **(Table 12)**. Due to rapid industrial development, area occupied by Urban built-up increased by 4.16 km^2 from the year 1980 to 1996. The urban built-up area increased by 10.76 km^2 from the year 1996 to 2000, due to higher rate of urbanization experienced by the city. An increase of 26.54 km^2 with annual rate of change of 0.06 % was observed from the year 2000 to 2006. Such high rate of urbanization led to conversion of agriculturally productive land into residential and other uses **(Balogun *et al.*, 2011)**.

(4.2.3.2) VMSS level (1880-2009):

At the VMSS level, from the two sub-classes, i.e. Urban built-up and rural built-up, the change in only one sub-class of urban built-up was analyzed for 129 years. The highest change in the built-up area was observed from the year 1880 to 1960 **(Table 13)**. This increase was attributed to development of many industries during this time. The area under this class increased significantly from the year 1960 to 1980 occupying almost half of the VMSS area. Further increase in the urban built-up area was due to development of new residential colonies around the erstwhile villages of Gorwa, Gotri, Sama, Nizampura, Harni, Jetalpur, Akota, Makarpura, Tarsali and Maneja, which surrounded the old city. These areas were then gradually included in the municipal area. From the year 1980 to 1996 increase of only 2.74 Km^2 was observed in area covered by this class. During the last decade the area under this class increased very exponentially occupying majority area under VMSS boundary. The area increased by 45.15 km^2 between the years 2000 to 2009.

(4.2.4) Transportation Network:

The transport infrastructure of many larger and medium sized cities of India has expanded considerably and it is expected to grow by 2.6 times by 2016 in larger and medium sized cities of India **(Nagdeve, 2002)**. In recent years the pressure on urban transport has increased substantially because of high rate of urbanization in the country **(Anonymous, 2011).** The number of vehicles on roads has increased considerably which has resulted into increased environmental degradation due to high rate of air and noise pollution. The cities are confronting with the twin challenges. The first challenge is of providing adequate road space for future use. The second is of improving the poor condition of existing roads due to the neglect of maintenance over the years. Most of the cities of the country are facing urban transport problems for last many years, affecting the mobility of people and economic growth of the urban areas. One of such cities is Vadodara in which the transportation length has increased very rapidly.

(4.2.4.1) VUDA level (1880-2006):

Transportation class of the city was segregated in two sub-classes, i.e., railway and road network. No change was observed in length of the railway during 126 years. But, significant increase was observed in the length of road network. It increased approximately five folds from the year 1880 to 2006. The highest increase of 348.7 km in the road length was observed during the years 1960 to 1980. This increase can be attributed to the rapid industrial development during this time. Such highly developed road network helped in establishing better communication with other parts of state which resulted into heavy traffic load on the roads of the city. From the year 1980 to 2000 only 13.88 km were added into this class showing slower rate of expansion of road network. From the year 2000 to 2006 the road length increased by 21.74 km with annual rate of change of 0.27 % **(Figure 8)**.

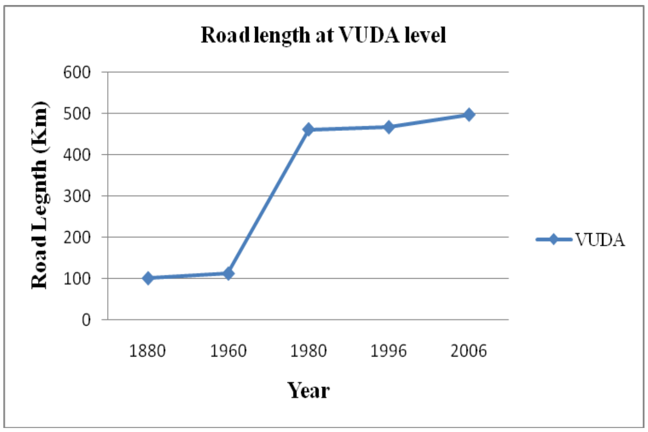


Figure 8: **Chart showing increasing road length at VUDA level**

(4.2.4.2) VMSS level (1880-2009):

No change was observed in rail length at this level also but road length increased five times during 129 years from the year 1880 to 2009 **(Figure 9)**. Infrastructural activity, like construction of new-bypass roads and ring roads has contributed to this increase. Highest increase in the road length was observed during the year 1960 to 1980 at this level also. This has resulted into the increased vehicular traffic on the roads which led to environment degradation due to higher consumption of fossil fuels. Further, as high as 87.17 km was added into the road network from the year 1980 to 2009. Despite of such development, current road designs do not adequately provide for facilities such as footpaths and cycle tracks. The available road space is getting encroached by commercial establishments, street vendors, and on-street parking due to poor enforcement of the existing regulations. These problems are due to inadequate transport infrastructure and its sub-optimal use; lack of integration between land use and transport planning. **Plate 31** shows the Station road which is one of the busiest roads of the city.

Plate 31: Station road of the city

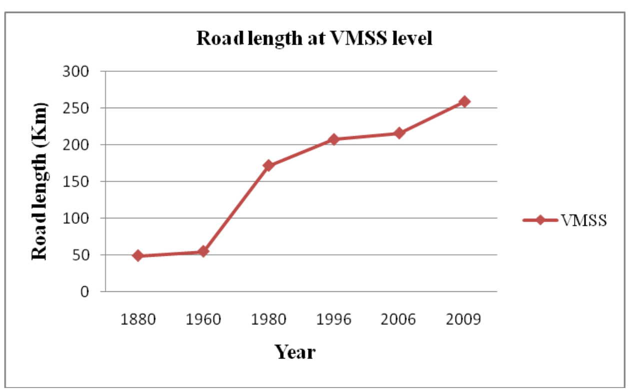


Figure 9: Chart showing the increasing road length at VMSS level

(4.2.5) <u>Validation of results:</u>

Accuracy assessment was performed using the random stratified sampling method for classified output of the years 2000 and 2009. The results exhibited the classification accuracy of 86% with kappa coefficient 0.80 in the year 2000 while for the year 2009 it was 95% with Kappa coefficient of 0.93.

(4.2.6) <u>Urban sprawl analysis:</u>

Urban sprawl analysis was performed using four different parameters, i.e. entropy, U.S.I., L.C.R. and L.A.C. Out of these parameters entropy was calculated at VMSS level whereas U.S.I, L.C.R. and L.A.C. were calculated at VUDA level. All these parameters are discussed separately.

(4.2.6.1) <u>Entropy:</u>

Entropy calculation is based on area computation which is best facilitated by the integration of spatial measurement facility correspondingly offered by remote sensing and GIS. It is a good indicator for identifying and monitoring urban land development i.e., dispersion and concentration of built-up areas. It helps in understanding the nature of urban sprawl of the city. In this context, entropy values calculated for each dataset of Vadodara city from the year 1880 to 2009 varied from 0.43 to 0.64 **(Table 15)**. The value of Log N where n=5, which is 0.6989 was taken as the reference value as it was treated as a critical limit or threshold for expansion of an area. As evident from the results the pattern manifested by built-up area of the city was dispersed distribution from the city center. In the earlier years the urban development was concentrated within Mandvi area of the city which got confirmed by the low entropy value of 0.43 in the year 1880. The expansion of built-up area from a city centre led to increase in the entropy value to 0.47 in the year 1980 which was lower than the Log N value. This indicated the concentrated nature of urban sprawl. The entropy value decreased in the years 1996 and 2000 indicating less fragmentation of the city explaining the homogenous distribution of built-up areas due to rapid growth. As a result, the space became very limited and built-up areas became concentrated within the VMSS limits. Similar results were observed by **Verzosa and Gonzalez (2010)** for Baguio City of the Northern Philippines. In the year 2006 the entropy value increased very significantly to 0.64 approaching the Log N value. This high value of entropy can be attributed to the increased urban sprawl and more dispersed development. This implied massive movement of residents from congested built up centre to outskirts of the city. Increasing trend of the entropy has also been observed by **Joshi and Bhatt (2011)** at Vadodara taluka level. In the year 2009 the value again decreased to 0.63. This estimation of Shannon entropy confirmed the dispersed development of urban built-up. In addition to this, entropy showed strong negative correlation (r^2 = -0.9) with total vegetation in the corresponding years which supported the fact that increasing disorder in the urban areas led to the degradation of vegetation in the city.

Table 15: Entropy values of different years

Year	Log N	Entropy
1880	0.6989	0.43
1960	0.6989	0.47
1980	0.6989	0.60
1996	0.6989	0.59
2000	0.6989	0.58
2006	0.6989	0.64
2009	0.6989	0.63

Investigation of entropy values for succeeding years aided in monitoring the progression of a random component, i.e. the built-up sprawl. The measurement of the difference in entropy between (t) and t+1 showed the degree of dispersal of this. The results showed that highest difference in entropy, i.e., 0.13 was observed between the years 1960 to 1980, corresponding the high degree of dispersion **(Figure 10).** The lowest difference of -0.009 was observed between the years 1980 to 1996 indicating the concentrated pattern of urban sprawl.

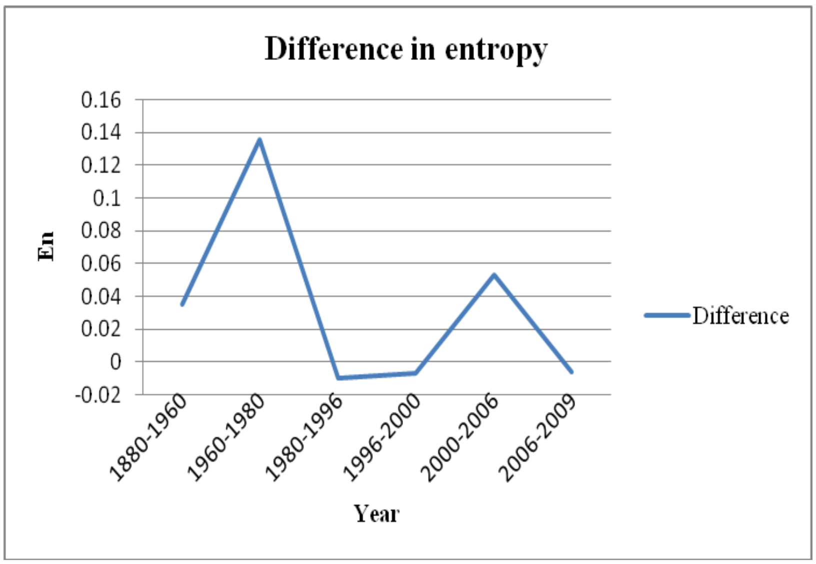


Figure 10: Chart showing difference in entropy in various years

(4.2.6.2) U.S.I.:

U.S.I value estimated to determine the urban sprawl pattern of the city fluctuated between the years 1880 to 2006 (**Table 16**). The U.S.I. value was 0.009 between the years 1880 to 1960 which indicated sparse development pattern. The value decreased by 0.001 during the years 1960 to 1980 indicating slow urban expansion rate due to increased population growth. The value decreased very rapidly by 0.007 between the years 1980 to 1996 due to low urban expansion during these years. The U.S.I. increased rapidly to 0.012 from the year 2000 to 2006, due to addition of 2220.67 ha of built-up areas into the city. The correlation analysis was carried out between the U.S.I. and NDVI values to understand the relationship between the two. A correlation value of (r^2= -1) indicated the urban induced negative effect of USI on the growth of vegetation of the city.

Table 16: U.S.I. of the study area

Year	Urban Expansion (ha)	Population growth	U.S.I
1880-1960	3354.67	3,54,182	0.009
1960-1980	4611.30	5,46,000	0.008
1980-1996	415.61	3,56,000	0.001
1996-2000	1075.58	3,99,000	0.002
2000-2006	3296.25	2,63,000	0.012

(4.2.6.3) L.C.R. and L.A.C:

Land Consumption Rate (L.C.R.) was constant whereas Land absorption rate (L.A.C.) differed slightly from the years 1880 to 1980. The span of 1996 to 2006 observed changes in both the components **(Table 17)**. A distinct drop in L.C.R by 0.006 and an increase in L.A.C. by 0.013 was seen in the year 2000 **(Figure 11)**. This implied that something was responsible for the decline in L.C.R. of the urban areas of the city which has ultimately decreased the consumption rate. L.A.C and L.C.R. between the years 1880 to 2006 as such exhibited inverse relation having negative correlation of -0.3.

Table 17: L.C.R. of the study area

Year	Area (A) (ha)	Population (P)	L.C.R. (A/P)
1880	914.85	1,01,818	0.009
1960	4269.51	4,56,000	0.009
1980	8880.81	10,02,000	0.009
1996	9296.42	13,58,000	0.007
2000	10372.00	17,57,000	0.006
2006	13668.25	20,20,000	0.007

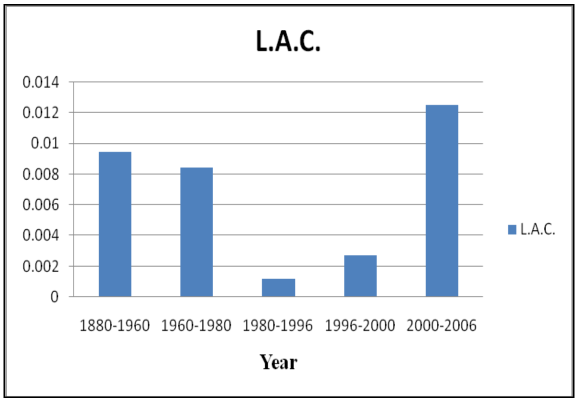


Figure 11: Chart showing change in L.A.C. of the study area

(4.3) <u>Analysis of Urban green space (U.G.S.):</u>

Urban green space analysis was carried out in terms of finding out suitable locations for its development and its economic relations with property surrounding it and its impact on various biophysical and socioeconomic parameters. Hence the results are also explained in three different sections viz., (1) Suitability analysis, (2) Economic evaluation and (3) Assessment of Impact of various biophysical and socio-economic parameters.

(4.3.1) <u>Suitability analysis:</u>

Urban expansion usually goes without considering the effect of ecological and environmental problem. In most of the cases urban sprawl fails to take up agriculture and green space planning which leads to unsustainable urban development. In recent years therefore planning for green spaces has been made imperative. Introduction of more green areas in the city is compulsory. Suitability analysis for UGS system has become prerequisite to identify potential sites for their development which will aid in developing city into an Eco-city. The selection of such potential sites for UGS is usually based upon a specific set of local criteria and the relationship of different factors to ensure that most benefits of UGS are attained by the community. These factors are simple characteristics of land that are grouped as attributes **(Pease and Coughlin, 1996)**. In the present study integration of different themes, i.e. Slope, Land use, transportation, water body and ground water status which generated were based on various natural and social factors which aided in generating a precise map exhibiting potential sites in Vadodara city for UGS development. UGS suitability analysis was carried out purely on the basis of different heterogeneous parameters viz. at level 1, i.e., land is suitable for developing it into an UGS or not. This section explains the vegetation status and temperature as other themes already have been explained in earlier sections of this chapter.

(4.3.1.1) Vegetational Status:

NDVI aided in the generating the vegetation status of different wards of the city for the years 2000, 2007 and 2009 **(Plates 32, 33 and 34)**. Vegetation of a city plays a significant role in moderating the physical stresses which are typical of the urban environment. A decreasing trend in total vegetation of eight wards was noted except for the Panigate and Gajrawadi ward of the city **(Plate 35)**. These two wards exhibited variations from the year 2000 to 2009. In case of Panigate the vegetation increased in the initial years i.e. from 2000 to 2007 but in the later years rapid decrease was observed. Gajrawadi ward on the other hand had a decreasing trend in the initial years but exhibited a significant increase in the later years i.e. from year 2007 to 2009 **(Plate 36)**. As the City ward is densely built commercial ward, it showed negligible amount of vegetation in all the years. These findings indicated that the urban sprawl has occurred in land covered by vegetation in one or other form.

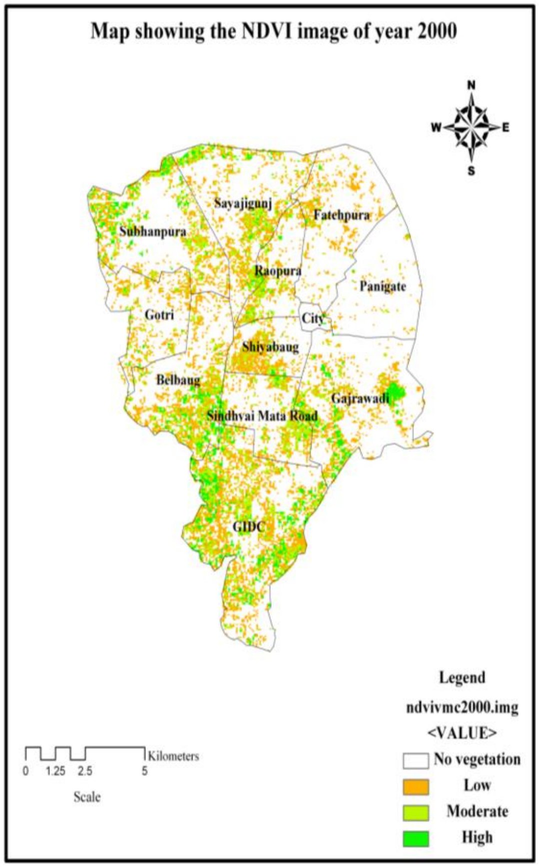


Plate 32: NDVI map of Year 2000

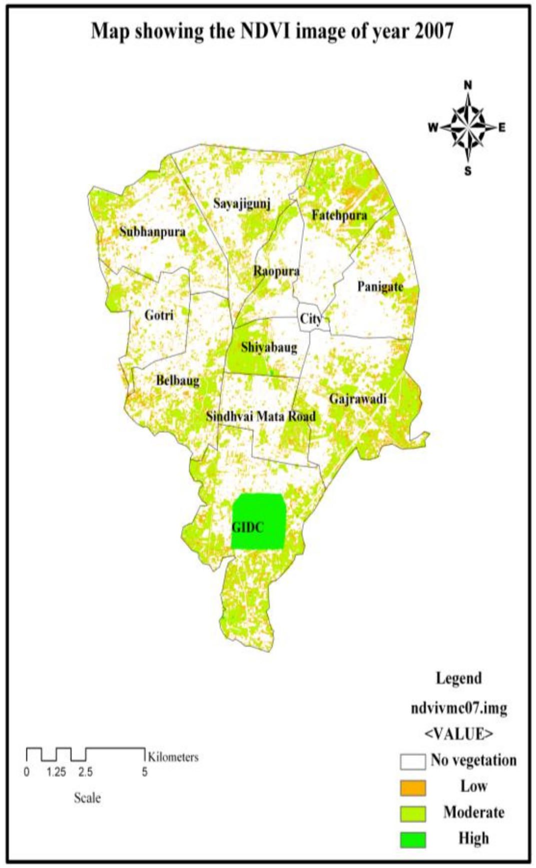


Plate 33: NDVI map of Year 2007

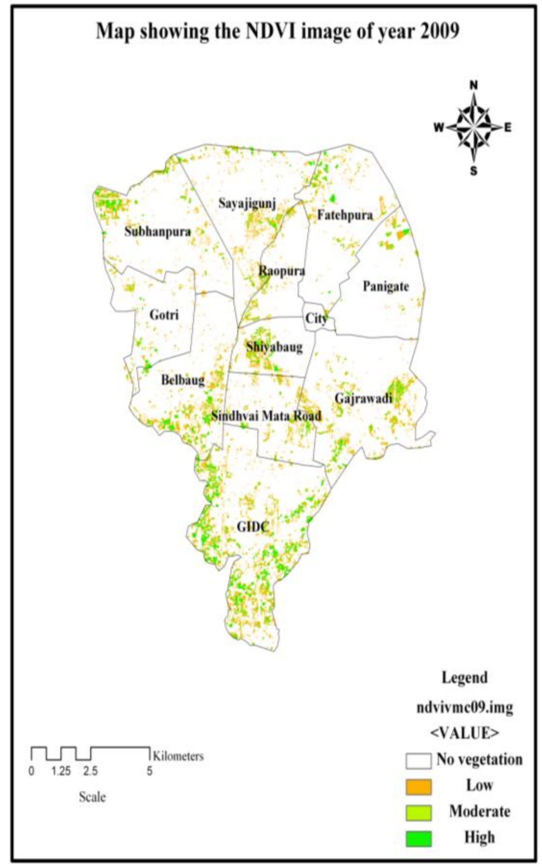


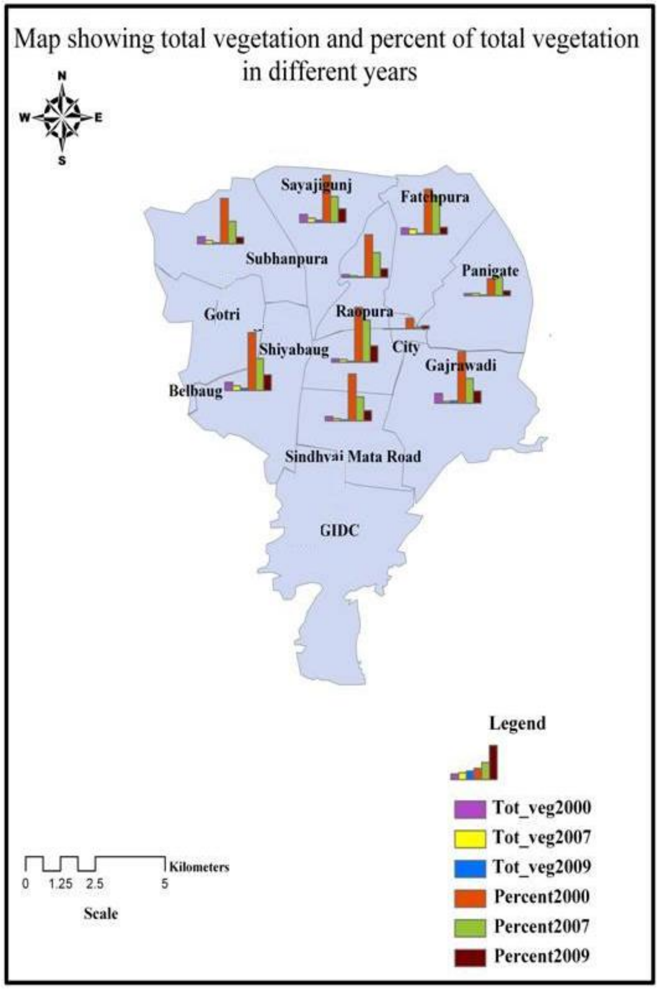
Plate 34: NDVI map of Year 2009

The NDVI values exhibited the strength of vegetation **(Mukherjee and Banerjee, 2005).** To analyze the changes in vegetation more precisely, different classes of the vegetation was identified based on the NDVI values. Based on these values four different classes were identified, *viz.*, pixels with values ranging from -0.34 to -0.17 were categorized as areas without vegetation, from -0.17 to 0.01, 0.01 to 0.022 and 0.022 to 0.38, were considered as low, moderate and high vegetation classes, respectively. **Table 18** revealed the ward-wise distribution of area occupied under different vegetation classes in different years. It was observed that the area occupied by high vegetation was less when compared to the areas having moderate and low vegetation. This indicated lack of dense greenery in Vadodara city. Area with high vegetation varied from 1.6 ha to 104.9 ha in the year 2000. Area under this class increased in all the wards in the year 2007 except for the City ward. After 2 years, i.e. in the year 2009 this area reduced in all wards except for City ward in which an increase of 0.22 ha was observed. Areas under moderate vegetation class showed a distinct decreasing trend in all the wards in all the years except for wards like City, Panigate and Fatehpura. These three wards are very congested wards and no space was available to built new buildings and hence, no encroachment of vegetation observed in these wards. Area occupied by low vegetation also decreased in all the years in all the wards except the Gajrawadi ward in which increase was observed from the year 2007 to 2009.

Table 18: Ward wise change in high, medium, low and total vegetation

Ward No.	Ward Name	Total area of Ward (ha)	2000					2007					2009				
			H (ha)	M (ha)	L (ha)	T. Veg. (ha)	T.P. (%)	H (ha)	M (ha)	L (ha)	T. Veg. (ha)	T.P. (%)	H (ha)	M (ha)	L (ha)	T. Veg. (ha)	T.P. (%)
1	City	94.73	1.6	4.21	5.46	11.30	11.92	0.00	1.09	0.81	1.91	2.01	0.22	1.98	1.17	3.37	3.55
2	Fatehpura	1419.88	5.0	236.75	473.4	715.21	50.37	76.45	242.86	277.39	596.70	42.08	8.41	28.43	76.39	113.23	7.99
3	Gajrawadi	1909.78	104.9	437.37	549.91	1092.24	57.19	36.15	71.41	76.89	184.44	27.66	8.81	72.17	177.27	258.26	13.49
4	Sindhvai Mata	894.20	24.25	280.88	159.23	464.38	51.93	29.22	91.15	117.76	238.13	26.63	2.20	29.61	70.03	101.83	11.38
5	Shiyabaug	630.91	7.67	251.36	125.38	384.42	60.93	73.14	141.92	81.16	296.22	46.95	5.02	38.24	71.77	115.03	18.23
6	Sayajigunj	1693.89	41.09	497.49	348.83	887.43	52.38	42.19	180.96	260.12	483.27	28.73	6.12	46.77	212.59	265.47	15.14
7	Belbaug	1427.03	76.47	525.38	323.14	925.00	64.81	66.33	199.32	261.69	527.33	35.77	14.24	67.90	175.16	257.3	17.57
8	Raopura	666.63	12.42	201.85	101.66	315.93	47.39	36.15	71.41	76.89	184.44	27.66	0.86	18.95	43.98	63.79	9.56
9	Panigate	1267.98	1.93	51.48	188.39	241.81	19.07	16.18	89.82	154.86	260.87	20.75	1.95	19.24	48.98	70.17	5.56
10	Subhan-pura	1577.84	63.5	411.73	322.82	798.10	50.58	41.83	124.53	227.86	394.22	24.95	5.08	28.20	85.55	118.83	7.54

H= High vegetation
M= Moderate Vegetation
L= Low Vegetation
T.Veg. = Total vegetation
T.P. =Total percent



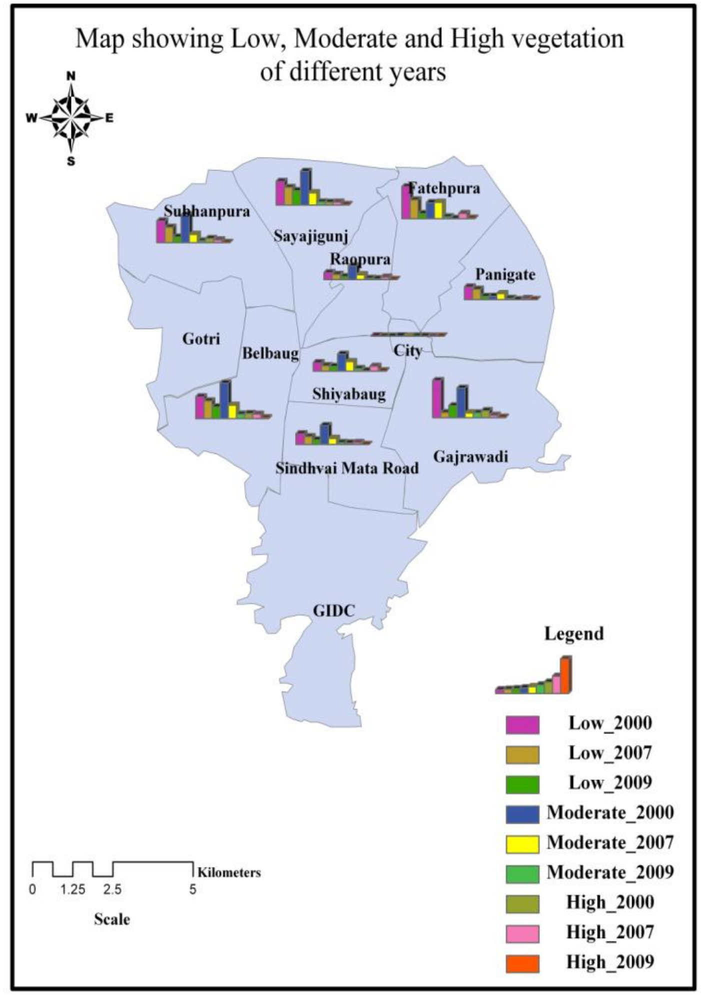


Plate 35: Map showing total vegetation and percent of total vegetation in different years

Plate 36: Map showing Low, Moderate and high vegetation of different years

(4.3.1.2) **<u>Per capita change in Vegetation:</u>** The Per capita vegetation in the year 2000, 2007 and 2009 showed a distinct decreasing trend in the availability of the per capita vegetation in different wards **(Plate 37)**. Ward No. 1, City ward showed the lowest values of per capita vegetation in all the years. The reason behind this is that this ward was densely populated and showed negligable amount of vegetation and hence resulted into the lower values of per capita vegetation. This fact proved the negative correlation of vegetation and population density (r = -0.11) indicating a very high anthropogenic pressure on vegetation of this area. Same observation was also made by **Faryadi and Taheri (2009)** for some regions of Tehran. The highest per capita vegetation was reported by Gajrawadi ward in the year 2000 and 2009 while by Fatehpura ward in the year 2007. Fatehpura ward is one of the greenest ward of the city due to presence of ample of vegetation in this ward. Results also proved the fact that vegetation was not properly distributed in different wards of the city.

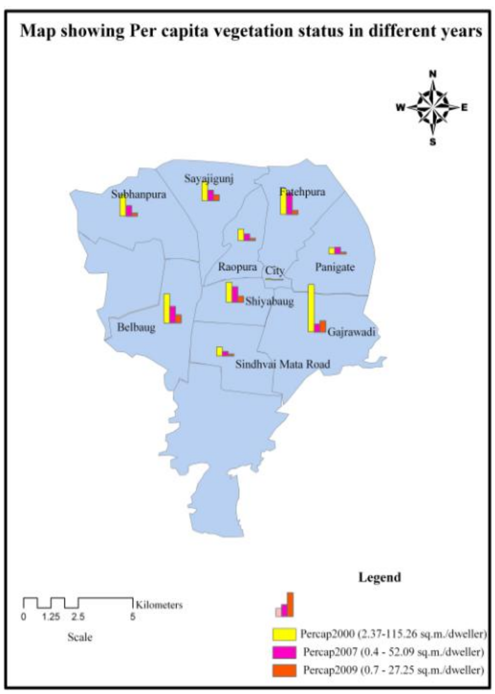


Plate 37: Ward wise Per capita vegetational status in different years

(4.3.1.3) <u>Temperature:</u>

The Land Surface Temperature figures as retrieved for the Vadodara city from Landsat ETM+ data ranged between 27 ^{o}C to 50 ^{o}C. The temperatures for the entire city area was categorized in three classes viz. temperature values ranging from 27 ^{o}C to 35 ^{o}C, 36 ^{o}C to 42 ^{o}C and 43 ^{o}C to 50 ^{o}C were categorized into areas with low, medium and high temperature, respectively **(Plate 38)**. The majority parts of the city had medium temperature values corresponding to the high building densities. Eastern parts of the city i.e. some parts of Fatehpura ward, Panigate ward and Gajrawadi ward showed slightly higher temperatures. Areas with vegetation, mostly along the banks of Vishwamitri river showed low temperatures revealing the impact of vegetation of temperature. A negative correlation between temperature and vegetation has already been proved by **Carlson *et al.* (1994)** and **Weng *et al*. (2004**).

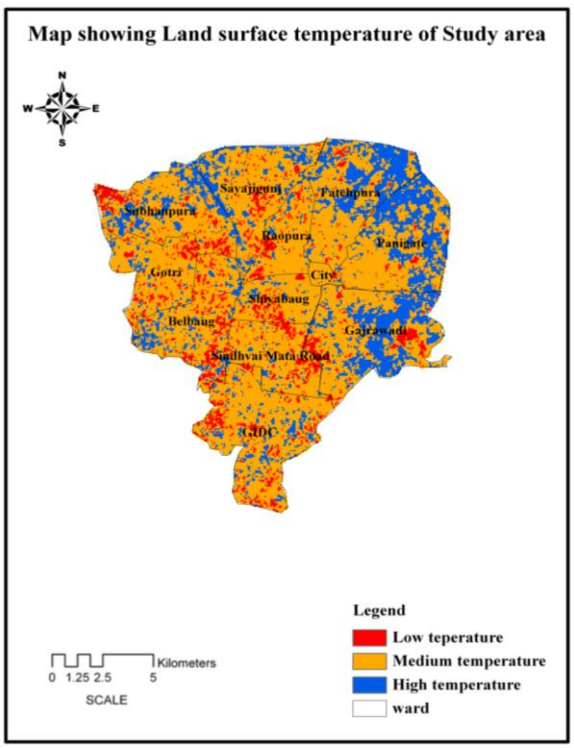


Plate 38: Map showing temperature profile of Vadodara city

(4.3.1.4) Identification of Suitable sites:

Suitability for UGS was carried out using parameters like transportation network, slope, ground water, water body and land use of the study area. The results revealed that 98 % area of the city was found not to be suitable for the green space development **(Plate 39)**. Areas which were suitable were the existing green spaces, vacant areas and government reserved areas. The highest suitable area has been observed in Sayajigunj ward. This may be due to the presence of ample of open spaces and government offices in this ward. The City ward showed the lowest area under the suitable sites corresponding to the low availability of open space **(Table 19)**. It was noted that parameters like P.D., L.S.T and slope influenced the suitability of an area negatively while parameters like Per capita vegetation, Gardens, water body and green belts influenced the suitability positively. Suitable sites identified for the city are more accessible and available for the public to use and in a location which will be accessible to current and potential new users.

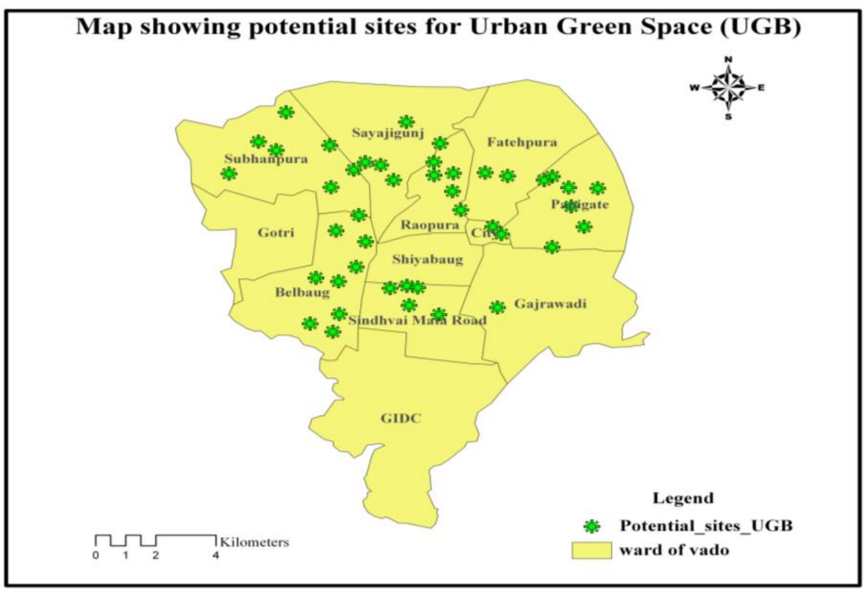


Plate 39: Map showing the potential sites for Urban Green Space

Table 19: Status of various suitability factors in different wards

Ward No	Ward Name	Population Density	Per Capita Vegetation	Vegetation Change	Land Surface Temp (LST)	Open space	Slope	Gardens	Greenbelts	Water body	Potential site (ha)
1	City	Very High	Low	Decreased	Medium	Very low	Medium	0	0	3	0.06
2	Fatehpura	Low	Medium	Increased	High	Low	Low	6	1	5	1.58
3	Gajrawadi	Low	Medium	Increased	High	Medium	Medium	1	0	7	3.41
4	Sindhvai Mata Road	Medium	Very High	Decreased	Medium	Low	Medium	4	1	3	1.77
5	Shiya Baug	Low	Low	Increased	Low	High	Low	2	0	3	0.66
6	Sayajigunj	Low	Medium	Decreased	Medium	High	Low	11	0	1	4.76
7	Belbaug	Low	Low	Decreased	Low	High	Medium	5	1	1	4.16
8	Raopura	Medium	Medium	Decreased	Medium	Medium	Low	5	2	2	2.22
9	Panigate	Low	Low	Increased	High	Low	Medium	2	2	3	1.84
10	Subhanpura	Low	Low	Decreased	High	High	Medium	8	0	3	3.25

(4.3.2) Economic valuation of Urban Green Space (UGS):

The results for economic valuation of the UGS brought out that areas like Sama (Amar Complex), Gotri, southern part of O.P road and Atladra showed houses with lower property prices **(Table 20)**. Such low values of the houses were due to the absence of vegetation as proved by slight positive correlation between vegetation and property price (r^2 = 0.283). In recent years citizens has become more aware of benefits green surroundings around their houses as exhibited by positive correlation. This correlation may increase to higher side with passing years. Areas with moderate value of NDVI like, Akota, Ellora park, Gotri, and Hari Nagar showed moderate property prices. The high property prices were seen in the areas like Kareli Baug, Alkapuri, etc. attributing to the high NDVI values of these areas. Interestingly, areas like Sama and O.P. road were having houses categorized into all the three classes as their prices were differing with the varying distance from the densely vegetated areas.

Table 20: Comparison between vegetation and Property price

Low Price (1000-2000) (Rs/Sq Mt.)	NDVI	Moderate Price (2000-3000) (Rs/Sq Mt.)	NDVI	High Price (3000 and above) (Rs/Sq Mt.)	NDVI
Gotri, near jakat naka	No Veg.	Shree nagar soc,Akota	No Veg.	Akota,Villa	Moderate Veg.
O.P. Road	No Veg.	O.P.Road,Apt	No Veg.	Akota House	High Veg.
Atladra,Apt	Low Veg.	Ellora Park	Low Veg.	Alkapuri,Chikuvadi apartment	High Veg.
Sama,Amar complex	No Veg.	Gotri,Narayan gardens	Low Veg.	Kareli baug, Villa	Moderate Veg.
Villa,O.P Road	No Veg.	Hari Nagar	No Veg.	Alkapuri Apt	High Veg.
Navapura	Low Veg.	Nizam pura, house	Moderate Veg.	Alkapuri House	High Veg.
Ajwa,Jay Yogeshwar Township	No Veg.	O.P. Road, bunglows	Low Veg.	Kareli baug,Harish nagar	High Veg.
Raopura	No Veg.	Subhan pura	Moderate Veg.	Manjalpur,Ranchod Nagar	High Veg.
Dutta Nivas	No Veg.	Tandalja	Low Veg.	Kareli baugh, House	High Veg.

(4.3.3) Assessment of impact of various biophysical and socioeconomic parameters on Property Value (P.V.) at VMSS level:

In this study, the impact of various biophysical and socio-economic parameters on the property price was analyzed. Six biophysical and socio-economic parameters were considered for assessing the impact out of which status of LST and NDVI of the city has already been described earlier in this section.

NDBI index describes the spatial pattern of urban impervious surfaces. It was used in this study to extract the built-up land from the urban area of the city **(Plate 40)**. The values of this index were classified into four different classes, viz. No, Low, Moderate and High built-up land. The areas with high vegetation either showed negative values or very low positive values for this index. Wards like Panigate, Subhanpura, and Gotri showed higher values of NDBI while wards like Sindhavai mata Road, Belbaug showed moderate values of the same.

Mapping of Building Density (B.D.) gave the idea about the quantitative distribution of built up areas in different wards of the city **(Plate 41)**. Wards like Subhanpura, Panigate, etc. showed high B.D. corresponding to higher values of NDBI of these wards while wards like Belbaug, Gajrawadi etc. showed moderate value of the B.D. as NDBI values of these wards were found to be moderate.

The impact of various parameters was analyzed at two different levels, i.e., impact of individual parameters and impact integrated parameters. It has been described separately in the following sections:

(4.3.3.1) Assessment of Impact considering Individual Components:

Impact of individual parameters on property price was assessed using correlation analysis between six different components viz. NDVI, NDBI, Property price, Building density, Population density and LST (**Table 21)**. It was observed that property price had a positive correlation with NDVI. This fact has already been proved in the earlier section. The reason can be attributed to willingness of citizens to pay more prices for the properties located in green environment. NDBI and LST had a negative correlation with property price. This is because the increasing builtup area and temperatures deteriorates the environmental condition around the property. Interestingly, some high populated areas of the city like Mandvi was having the high property values despite of high population density (r^2=0.546 at 0.01 level of confidence) and building density. This area is highly commercialized area which compelling the citizens to reside there due to easier availability of the amenities despite of high property prices.

Table 21: Correlation Matrix

Parameters	NDBI	NDVI	PP	PD	LST	Building density
NDBI	1.0	-0.438*	-0.158	0.006	0.441*	0.235
NDVI	-0.438*	1.0	0.283*	-0.050	-0.203	-0.173
Property price (PP)	-0.158	0.283*	1.0	0.546**	-0.255	0.344
PD	0.006	-0.050	0.546**	1.0	0.241	0.184
LST	0.441*	-0.203	-0.255	0.241	1.0	0.058
Building density	0.235	-0.173	0.344	0.184	0.058	1.0

*. Correlation is significant at the 0.05 level (2-tailed)
**.Correlation is significant at the 0.01 level (2-tailed)

(4.3.3.2) Assessment of Impact considering Integrated Components:

The integration of these six correlating components at different level of significance, using principal component analysis (PCA) enhanced the precision regarding the understanding of specific component influencing value of property price.

Percentage of variance of each PC is shown in **Table 22**. Maximum variance of 60.95% of the data was seen in the PC1 and PC2. **Table 23** illustrates the loading of variables of the first two components. The loading above 0.71 is high; 0.63 is very good; 0.55 is good; 0.45 is fair and 0.32 is poor. These ranges of loadings for interpreting component weights are already given earlier workers **(Li and Weng, 2007)**. The PC1 is highly influenced by NDVI followed by LST, Building density, Population density and property price. This indicated that as compared to other parameters vegetation has major impact on the property price. PC2 is characterized by NDBI, building density and property price.

Table 22: The percentage of variances and principal Components loading matrix

Components	Initial Eigen values		
	Total	% of Variance	Cumulative %
1	1.921	32.025	32.025
2	1.736	28.928	60.953
3	0.968	16.138	77.091
4	0.689	11.478	88.570
5	0.490	8.171	96.740
6	0.196	3.260	100.00

Table 23: Component Matrix

Components	Component	
	1	2
NDVI	0.805	0.175
LST	-0.721	-5.4E-02
Buld. Den.	-0.497	0.783
NDBI	-3.26E-02	0.802
Pop. Den.	0.685	0.162
Property price	0.192	0.648

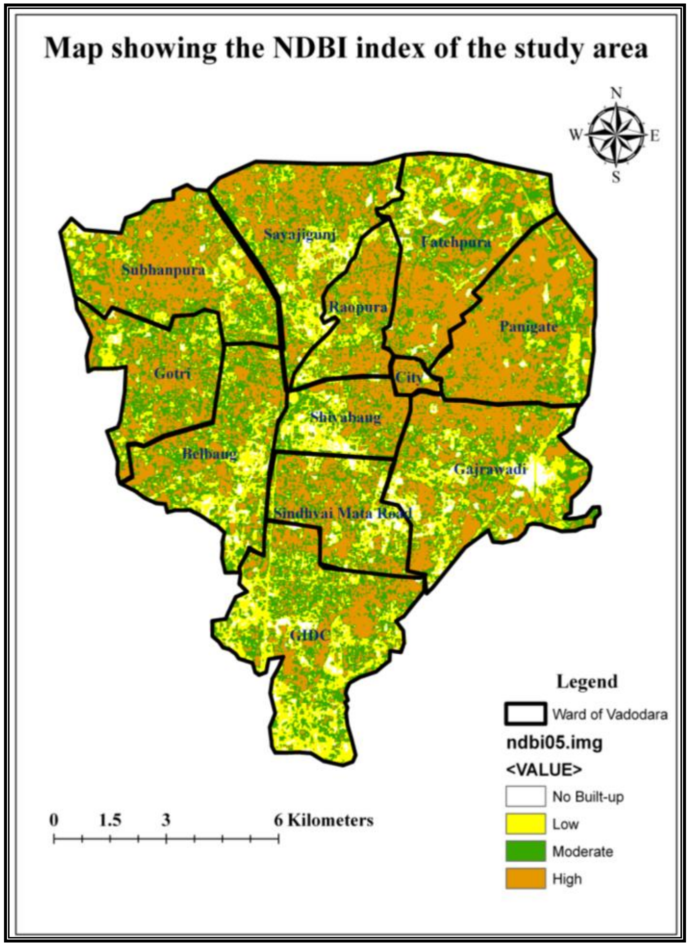


Plate 40: Map showing NDBI of Vadodara city

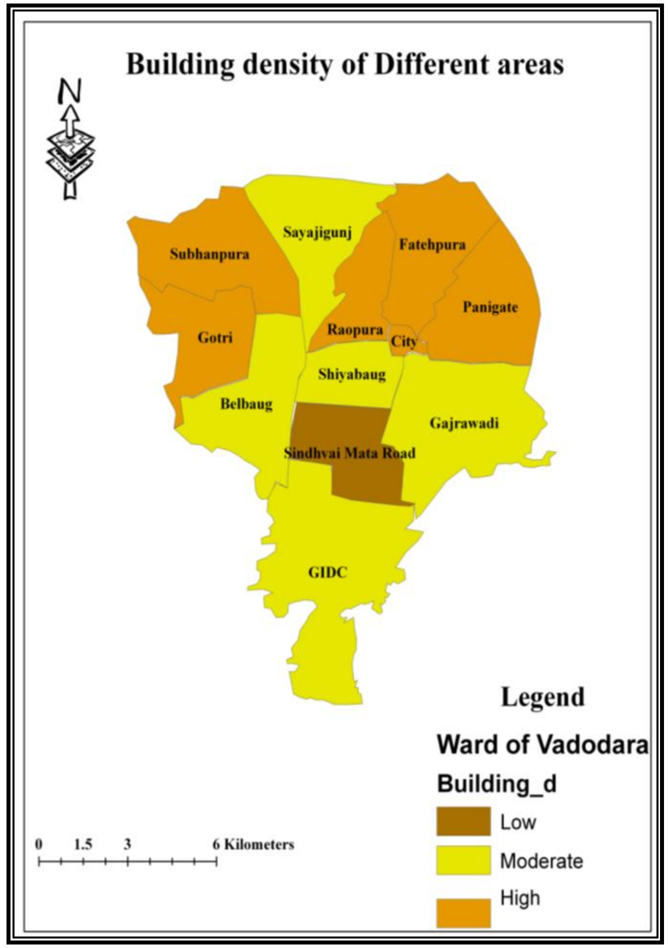


Plate 41: Map showing the building density of Vadodara city

(4.4) Eco-city plan generation:

An eco-city is the city which is in balance with nature. It aims to minimize the required inputs of energy, water and food, its waste output of heat and finally the gases such as carbon dioxide and methane that cause atmospheric and water pollution. To achieve this, the ecological approach of sustainable utilization of resources must be implemented. This implies that instead of using traditional environmental technologies more eco-friendly technologies should be utilized for utilizing the resources. For this Eco-city guidelines and objectives should be woven together with local requirements **(Gaffron *et al.*, 2005)** in which the suitability analysis can play a vital role. Hence, at first instance land use suitability analysis was carried out for the selected wards. Ward-wise explanation of the results is presented in the following sections.

(4.4.1) Ward No. 1- City Ward:

Landuse suitability analysis (LSA) carried out for converting Ward no. 1 into an Eco-ward is based mainly on physical constraint at Level 1, i.e., land suitable for built up and conservation purpose only. Based on the different parameters LSA analyzed the fitness of land of this ward for urbanization. The physical constraints become progressively greater from highly suitable to not suitable class. The area occupied by the highly suitable class generated by all the models for this ward was the least **(Table 24)**. Output generated by Model No.4 was considered for further development as it was based on the Land use. In this model the area occupied by highly suitable, moderately suitable, less suitable and not suitable classes was 2.91%, 18.44%, 65.04% and 13.59%, respectively **(Plate 42)**. Maximum area occupied by the highly suitable, moderately suitable and less suitable class is already covered by high–density buildings. These buildings are associated with commercial activities, which in turn pose excessive traffic pressure on the roads leading to high emission of pollutants. This increased building density has deteriorated the environmental condition. Major sub-arteries of roads of this ward lack the capacity of catering the needs of these densely populated areas. Approximately 7% of the area occupied by moderately suitable class is covered by open space. 5% area of the area occupied by not suitable class is also covered by buildings and remaining area is covered by water body. This water body is eutrophicated due to anthropogenic activities **(Plate 43)**. Available vegetation is very less **(Plate 44)**.These facts revealed a need for significant improvement in the ward and therefore, this ward was taken up for developing it into the eco-ward.

Table 24: Area covered by different classes of suitability in City ward

Ward Name	Model	Highly suitable (km^2)	Moderately suitable (km^2)	Less suitable (km^2)	Not suitable (km^2)
City	**1**	0.02	0.42	0.43	0.16
	2	0.03	0.35	0.48	0.17
	3	0.02	0.47	0.47	0.07
	4	0.03	0.19	0.67	0.14

Plate 43: Lake showing the eutrophication due to *Eicchornia crassipes* (Mart.) Solms.

(4.4.1.1) Air Pollution Tolerance Index (APTI) estimation: APTI of the different plants of this ward when estimated suggested that the plants were attenuating the air pollution in various parts of the ward. The results revealed that APTI differed based on various biochemical parameters of tree species, i.e., pH, AA, TCh and RWC. The highest pH value was exhibited by *Ficus bengalensis* L. while that of *Ficus religiosa* L. was the lowest **(Table 25).** *Ficus bengalensis* L. also exhibited the highest value of AA content when compared to other plants of the ward. *Alstonia scholaris* L. R. Br. reported the highest TCh content with lowest RWC while *Caesalpinia pulcherrima* (L.) reported the lowest TCh content with the highest RWC content. APTI estimated using these parameters showed that *Ficus bengalensis* L. was having the highest APTI value while that of *Ficus religiosa* L. was the lowest. Tolerance level of each plant was determined based on the APTI value of all the plants. Results exhibited that out of five plants examined, one plant was tolerant, two were intermediately tolerant and two were moderately tolerant. *Ficus bengalensis* L. seemed to be the most tolerant plant and can be utilized for road side plantation.

Table 25: APTI values of different plants in City Ward

Plants	pH	AA (mg/g)	TCh (mg/g)	RWC %	APTI	Tolerance Level
***Azadirachta indica* A.Juss.**	5.1±0.8	4.18±0.56	0.4±0.09	85.71 ±0	10.85±0.59	MT
***Caesalpinia pulcherrima* (L.) Sw**	7.75±0.05	2.57±1.27	0.3±0.008	100±0	12.03±1.01	MT
***Alstonia scholaris* L. R. Br.**	7.9±0	4.45±0.13	0.72±0.002	61.16±0	9.71±0.10	IT
***Ficus bengalensis* L.**	6.05±0.65	6.31±0.39	0.41±0.014	84.24±0	12.3±0.16	T
***Ficus religiosa* L.**	4.5±0	4.96±0.38	0.55±0.02	64.73±0	8.9±0.19	IT

T=Tolerant, **MT**=Moderately Tolerant, **IT**=Intermediate Tolerant, **S** = Sensitive

(4.4.1.2) Eco-ward generation:

Planning based on the suitability analysis has encouraged the understanding of spatial settlement patterns of the ward to provide easy access to basic necessities such as workplaces, schools, health care, places of worship, goods and other services, and leisure, thereby reducing the need to travel. Land Suitability Analysis (LSA) along with the suggestions from the participants of questionnaire survey played a major role in converting City ward into an Eco-ward.

Output of Model 4 showed that highly suitable class of this ward was seen near Mandvi gate which at present is covered with buildings. In addition, majority of the area categorized into moderately suitable, less suitable and not suitable classes are the completely built up areas. For converting this ward into the Eco-ward, renovation of these existing buildings is recommended. This will give various environmental, economic and social benefits. This will attract residents of all ages and classes back, to live in these inner-city residential centers. For renovation of these buildings modular prefabrication of entire building elements, such as add-on balconies or double-skin front wall systems are recommended. As suggested by various participants, large commercial buildings, office complexes, hotels etc. of the ward situated in the highly suitable category are recommended to develop rainwater-harvesting systems in the buildings (**Anonymous, 2004)**. This will increase the availability of water in this ward. Questionnaire survey revealed that residents of this ward were facing many environment related problems due to lack of greenery. Establishment of gardens or other green vegetation on the roof top will not only improve the surroundings of the ward but also provide insulation and filter the rainwater. This helps in reducing the energy consumption **(Plate 45)**. To improve the condition further, more vegetation can be introduced in between the building gaps by planting small plants. Transportation is one of the important planning elements which can be used to improve the present condition in the ward. This can be achieved by coordinating land-use and transport.

The existing roads of the Ward i.e., M.G.Road, Gendigate Road and Hathikhana are narrow with buildings on both sides. In addition, the footpaths of these roads are covered by the local vendors and patharavalas. As revealed from LSA, there is no available space for widening. This has lead to generation of heavy traffic on the roads. Many participants complained that due to the soft attitude of the controlling authority and indifference towards law enforcement agencies, vehicles are parked haphazardly **(Plate 46)**. This creates traffic jams and pedestrians face great inconvenience. No parking space is available in the entire area for four-wheelers except for one private pay and park facility in the Nazar baug palace ground. Many participants felt that there is a lack of greenery in the ward. Therefore, there is need to increase the vegetation of the ward which will also help in reducing the pollution level. Plantation of small shrub like *Alstonia scholaris* L. R. Br. along both the side of the roads is recommended as no space is unavailable for tree plantation. The road towards the Panigate i.e., Panigate road is somewhat wider with ample of open space available on both side of road as revealed from the LSA. Hence, plantation of shrubs and trees in the middle of the road and along the road side are recommended as suggested by participants. There is a need of comprehensive effort to deliver new public transportation options while upgrading and enhancing the efficiency of existing services. More CNG-based Auto-rickshaws and city buses should be introduced into the public transport systems to decrease dependency on the private transport as suggested by the participants. Many participants felt that the roads were unsafe for them. Therefore, encouragement of the use of an optimal combination of modes of transport, including walking, cycling and private and public means of transportation, through appropriate pricing is required.

Plate 46: Photograph showing the unorganised parking of vehicles

The open spaces present in the ward which is occupied by the moderately suitable class can be used for the further building development. These buildings should be eco- buildings developed using the eco-friendly material. Some sites for parking can also be suggested in the open spaces of this moderately suitable class.

Some area of the less suitable class was seen to be covered by open spaces. These lands have to be protected and conserved in the form of natural landscape or can be converted in the garden.

Major part of non suitable class was seen to be covered by water body which needs rejuvenation. Plantation of trees around it is recommended. This will help in attenuating the pollution and will add to the beautification of the water body. In addition, pollution tolerant trees with high APTI values like, *Ficus bengalensis* L., *Azadirachta indica* **A.Juss., etc.** can be planted in the compound of Nazar baug palace of the ward which is situated in the category of non-suitable class. The broken and dilapidated tree guards of the road side trees should be removed or replaced.

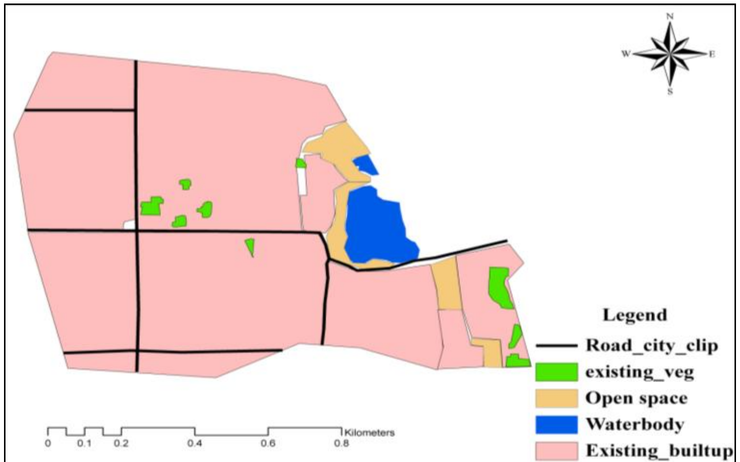


Plate 44: Map showing Existing situation of Ward No. 1

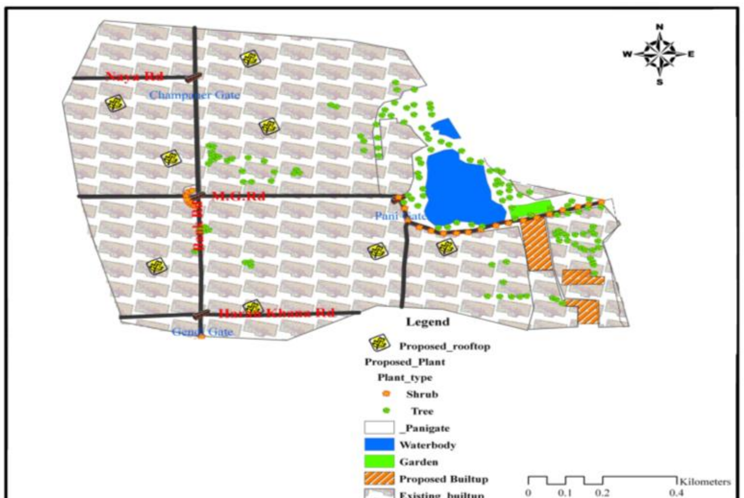
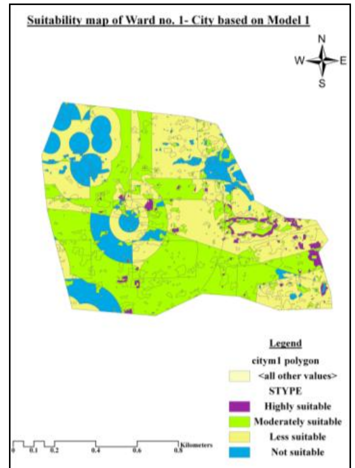
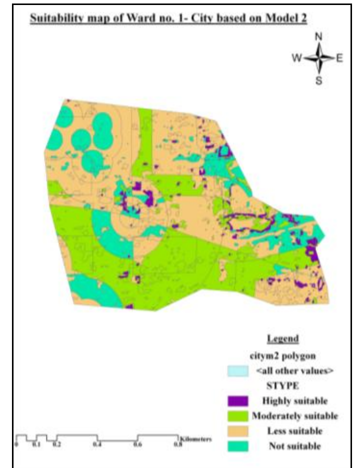


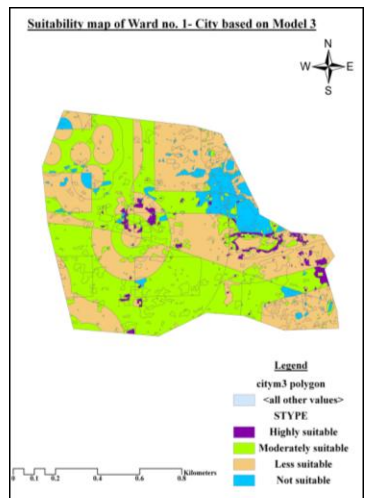
Plate 45: Map showing Eco-ward plan of Ward No. 1



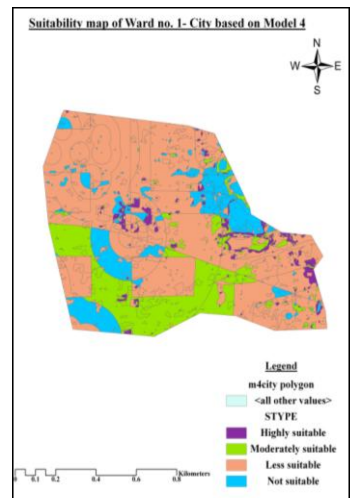
Model 1



Model 2



Model 3



Model 4

Plate 42: Suitability map of Ward No.1 based on different models

(4.4.2) Ward No.5 Shiyabaug:

Land use suitability maps obtained using USAP module for this ward showed that various suitability classes generated by 4 models differed in terms of area occupied by each class **(Table 26).** The output of Model no. 4 showed 33.33% of the entire ward to be non-suitable class which is mostly occupied by Rajmahal compound (**Plate 47**). Part of non-suitable land is covered by SRP campus. Highly suitable, moderately suitable and less suitable classes covered 11.85, 27.08 and 27.72 % of the area of the ward, respectively. All these classes are almost covered by buildings with few play grounds and gardens **(Plate 48)**. This ward is characterized by the presence of good amount of vegetation with many recreation areas and water bodies. It is highly residential with scattered commercial activities.

Table 26: Area covered by different classes of suitability in Shiyabaug ward

Ward Name	Model	Highly suitable (km^2)	Moderately suitable (km^2)	Less suitable (km^2)	Not suitable (km^2)
Shiyabaug	1	1.32	1.52	3.08	0.32
	2	0.73	2.34	2.8	0.37
	3	1.5	1.45	1.2	2.09
	4	0.74	1.69	1.73	2.08

(4.4.2.1) Air Pollution Tolerance Index (APTI) estimation:

Estimation of APTI of different plants revealed that it differed based on different biochemical parameters. The pH value of various plants varied from 5.9±0 to 6.7±0. The Ascorbic acid content varied from 1.29±0.21 mg/g in *Azadirachta indica* A.Juss. to 20.081±1.47 mg/g in *F.bengalensis* L. *Pithecellobium dulce* (Roxb.) Benth. showed the highest TCh content while *Alstonia scholaris* L. R. Br. showed the lowest

TCh content. The RWC of the plant varied from 43.035±4.57 % in *Delonix regia* (Boj.) Raf. to 92.695±3.04% in *Mangifera indica* L. The APTI estimated using these parameters revealed that *Ficus bengalensis* L. showed the highest APTI value while that of *Delonix regia* (Boj.) Raf. was the lowest. Tolerance level estimation of different plants showed that out of the nine plants analyzed two plants were tolerant, one was moderately tolerant, five plants were intermediate tolerant while one plant was found to be sensitive **(Table 27)**. The results implied that *F. bengalensis* L. and *F. religiosa* L. plants can be planted in this ward to attenuate the air pollution and improve the environmental condition of the ward.

Table 27: APTI values of different plants in Shiyabaug Ward

Plants	pH	AA (mg/g)	TCh (mg/g)	RWC %	APTI	Tolerance Level
***Azadirachta indica* A.Juss.**	6.2±0	1.29±0.21	0.60±0.08	83.75±3.75	9.25±0.24	IT
***Caesalpinia pulcherrima* (L.) Sw**	6.7±0	1.52±0.16	0.50±0.01	88.60±2.56	9.95±0.14	IT
***Alstonia scholaris* L. R. Br.**	6.3±0	4.39±0.19	0.24±0.02	79.73±9.15	10.84±0.78	IT
***Pithecellobium dulce* (Roxb.)Benth.**	5.9±0	7.08±1.68	0.85±0.13	83.33±16.67	13.09±2.70	MT
***Ficus bengalensis* L.**	6.6±0	20.08±1.47	0.39±0.02	87.85±10.3	22.82±0.04	T
***Ficus religiosa* L.**	6.4±0	15.33±6.54	0.37±0.06	77.38±4.6	18.17±4.99	T
***Mangifera indica* L.**	5.9±0	4.06±0.68	0.48±0.08	92.69±3.04	11.86±0.77	IT
***Polyalthia longifolia* (Sonn.)Thw.**	6.6±0	4.46±1.7	0.38±0.05	79.82±8.69	11.10±2.08	IT
***Delonix regia* (Boj.) Raf.**	6.7±0	4.67±1.87	0.69±0.2	43.03±4.57	7.71±0.82	S

T=Tolerant, MT=Moderately Tolerant, IT=Intermediate Tolerant, S = Sensitive

(4.4.2.2) Generation of Eco-ward plan:

Questionnaire survey for this ward revealed that Ward No. 5 is having good environmental conditions with good amount of vegetation. This ward has proper planning and therefore a few inputs are required to convert this ward into Eco-ward. This was also proved by the output generated from the Land Suitability Analysis (LSA).

Highly suitable class present in this ward is covered almost by both old and new residential buildings. Many buildings are used for commercial purpose also. Old buildings which are present in the ward can be improved by modular prefabrication of entire building elements, such as add-on balconies or double-skin front wall systems. New buildings should apply the innovative integration of greenery into buildings, rooftop gardens, increased practice of recycling, water collection and storage and the use of solar energy as suggested by participants of questionnaire survey. The various roads of the ward include Makarpura-Lalbaug Road, R.V. Desai road, Tagore road, etc. Majority of the participants were not satisfied with road sweeping and other cleanliness maintained in their vicinity. Therefore, there is need for further improvement in general cleanliness maintained in the ward. Makarpura-Lalbaug road is wide with divider in the middle which lacks any kind of vegetation. Plantation of shrubs on divider is suggested to improve the vegetation status of the ward. This will reduce the pollution level of the ward. Plantation of trees like, ***Azadirachta indica*** **A.Juss.,** ***Polyalthia longifolia*** **(Sonn.)Thw., etc.** along both the sides of roads can also improve the status as suggested by participants. There is presence of ***Alstonia scholaris*** **L. R. Br.** on both the side of R.V.Desai road but they are not maintained properly. Plants are growing out of the tree guard which needs to be removed or replaced. This is necessary for generating the sound eco-ward plan.

As low as 2 % area of less suitable class is covered by recreational areas including play grounds and gardens. However, many participants do not visit gardens very frequently. Therefore, plantation of suitable trees like, ***Pithecellobium dulce*** **(Roxb.)Benth.,** ***Ficus bengalensis*** **L.,** ***Ficus religiosa*** **L., etc.** in periphery of these play grounds and gardens is recommended **(Plate 49)**. This will decrease the noise pollution and will enhance the aesthetic value of the play grounds which will attract more citizens by providing them with Vitamin G which is a basic concept of Eco-ward planning. Various gardens namely; Badamdi baug, Kevda baug, Khanderao market and Lal baug present in this ward are providing many amenities to the people. These gardens are having positive effects on the people living in the nearby vicinity. Many participants felt that Kevda baug need improvement as it is not maintained properly. Almost 10% area of non-suitable class is occupied by two water bodies of the ward. As suggested by many participants these water bodies need improvement. The one present near the Kashi Vishwanath temple is suffering from the eutrophication. The whole water body is covered with the vegetation due to which it has become shallow which creates the problem of flooding on main road during monsoon season. Therefore, cleaning of this water body is recommended. Siddhnath Lake present on R.V.Desai road is also not in proper condition and needs improvement.

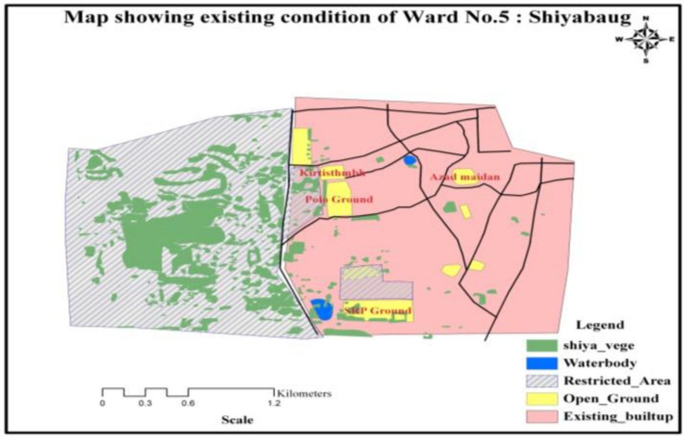


Plate 48: Map showing existing condition of Ward

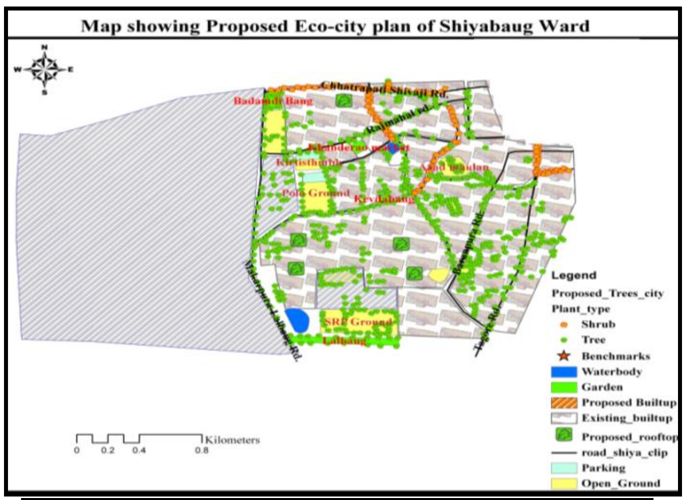
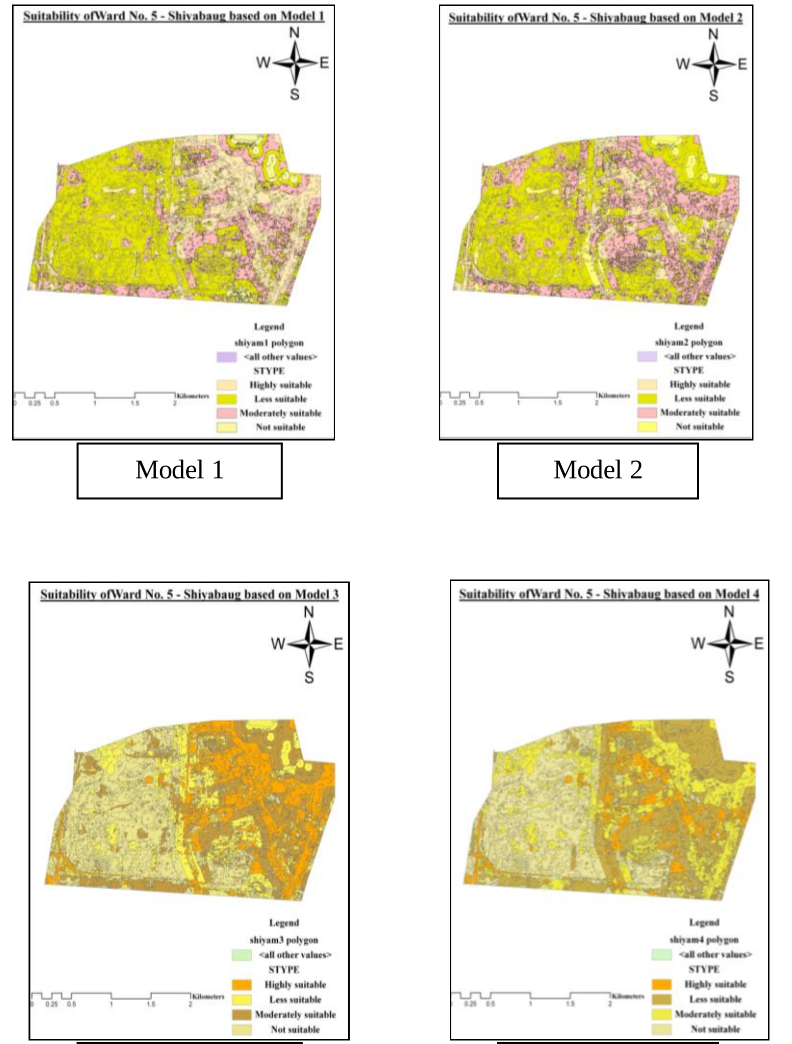


Plate 49: Map showing Eco-ward plan of Ward No.



Model 1

Model 2

Model 3

Model 4

Plate 47: Suitability map of Ward No.5 based on different models

(4.4.3) <u>Ward No.9: Panigate Ward:</u> Land Suitability Analysis (LSA) for this ward showed that different land suitability classes differed in terms of area depending upon different models **(Table 28)**. Various suitability classes like highly suitable, moderately suitable, less suitable and not suitable occupied 9.8, 58.71, 23.05 and 8.4 %, of the total area of ward, respectively **(Plate 50)**. Most of the existing built-up area of the ward was categorized under highly suitable, moderately suitable and less suitable class. 1% of highly suitable area was occupied by open space which can be utilized for further development. Almost whole area under the category of not suitable class was occupied by agriculture, water body and open space. All these landscape should be preserved and should not be utilized for built up areas. This ward also showed the presence of scattered vegetation with agriculture fields **(Plate 51)**.

Table 28: Area covered by different classes of suitability in Panigate ward

Ward Name	Model	Highly suitable km^2	Moderately suitable km^2	Less suitable km^2	Not suitable km^2
Panigate	**1**	3.03	5.84	2.57	0.83
	2	4.16	4.19	3.16	0.76
	3	1.21	7.30	3.07	0.69
	4	1.22	7.31	2.87	0.87

(4.4.3.1) <u>Air Pollution Tolerance Index estimation</u>:

Estimation of APTI of this ward showed that different components of the APTI, i.e. pH, AA, TCh and RWC, varied substantially in different plants **(Table 29)**. The pH value was the highest in the *Alstonia scholaris* L. R. Br. while it was the lowest in *Mangifera indica* L. Total chlorophyll content varied from 1.33±0.29 to 0.24±0.68 (mg/g) in various plants. Ascorbic acid content and RWC of *Mangifera indica* L. was as high as 18.97±0.06 (mg/g) and 88.56±1.9 %, respectively which imparted it the highest APTI value. The lowest APTI value was of ***Caesalpinia***

pulcherrima **(L.) Sw.** Tolerance level estimation of the nine plants of this ward showed that one of them was Tolerant, two were moderately tolerant, two were intermediate tolerant and one was sensitive plant. *Mangifera indica* L. was having the highest APTI value in this ward and was graded as Tolerant plant. This plant can be utilized for the roadside plantation. The lowest APTI value was of *Caesalpinia pulcherrima* (L.) Sw. and was graded as sensitive plant. This plant should not be utilized for plantation because it will not be able to survive in the polluted environment. Various other plants like *F. bengalensis* L. and *Polyalthia longifolia* (Sonn.)Thw. can also be utilized for planting in various gardens and greenbelts of the ward.

Table 29: APTI values of different plants in Panigate Ward

Plants	pH	AA (mg/g)	TCh (mg/g)	RWC %	APTI	Tolerance Level
Azadirachta indica **A.Juss.**	6.9±0	6.2±0.04	0.86±0.31	67.93±4.78	11.36±0.70	IT
Caesalpinia pulcherrima **(L.) Sw**	5.9±0	5.08±1.46	0.74±0.23	44.99±1.66	7.71±0.95	S
Alstonia scholaris **L. R. Br.**	7.25±0	9.35±0.032	0.63±0.03	70.74±4.5	14.10±0.46	IT
Pithecellobium dulce **(Roxb.)Benth.**	5.9±0	6.7±2.02	0.54±0	78.14±7.56	12.39±2.13	IT
Ficus bengalensis **L.**	6.6±0	12.47±4.27	0.24±0.68	76.21±2.56	16.98±2.19	MT
Ficus religiosa **L.**	5.9±0	8.04±3.84	0.40±0.09	78.25±.22	12.87±3.09	IT
Mangifera indica **L.**	5.4±0	18.97±0.06	0.5±0.79	88.56±1.9	22.67±1.64	T
Polyalthia longifolia **(Sonn.)Thw.**	6.6±0	14.40±2.69	0.65±0.19	79.13±0.87	17.98±1.70	MT
Delonix regia **(Boj.) Raf.**	5.9±0	8.31±1.77	1.33±0.29	59.47±2.58	11.22±0.63	IT

T=Tolerant, MT=Moderately Tolerant, IT=Intermediate Tolerant, S = Sensitive

(4.4.3.2) Generation of Eco-ward plan:

The Land Suitability Analysis (LSA) results of the Panigate ward revealed that improvement at several levels is required to convert this ward into eco-ward. Almost whole area occupied by highly suitable class was found to be present along the roadside of the ward. This area is already covered by existing built up. It is recommended that these existing buildings should develop roof top gardens along with rain water harvesting system to improve their microclimatic condition. Few of the main roads of the ward like Ajwa, Waghodiya and Waghodiya ring road showed the presence of open space on both the sides of road. Some area of this open space is covered by trees but they are not properly managed. Plantation of more pollution tolerant trees like ***Mangifera indica* L., *Ficus bengalensis* L., *Polyalthia longifolia* (Sonn.)Thw., etc.** in rows along the roadside is recommended. This will reduce the pollution level of the ward and will improve the environmental condition. As suggested by the participants broadening of these roads is also recommended to avoid the traffic jam in this ward. The traffic rules should be followed properly because many participants felt that roads are unsafe for them. Many participants of questionnaire survey complaint about the road-side illegal encroachments which covered half of the space on busy roads. This has to be removed for the convenience of travelling and walking people. This will encourage people to go by walk to nearby areas which is one of the major objectives of eco-ward planning. Majority of participants were not satisfied with road sweeping and cleanliness maintained in the ward. Garbage bins present along the roadside are inadequate and people dump their waste on road side leading to stench and breeding ground for mosquitoes. More dustbins should be placed to keep the surroundings clean and healthy. Along with that frequency of door to door waste collection need to be increased as suggested by many participants.

Open space present in the highly suitable area is recommended for future construction activity **(Plate 52)**. New buildings to be developed in this ward have to should follow sustainable architecture and green design. Ample of green space should be kept in between the new buildings as the questionnaire survey revealed lack of greenery in the ward. Care should be taken to conserve the existing vegetation while developing these buildings. In addition, new buildings should be provided with the facility of recycling the waste water. This type of arrangement will avoid the water waste by enhancing the availability.

The built-up area of the ward has reached up to agriculture fields present along the NH8 passing through the ward which are located under the category of non-suitable class. These fields need to be protected from encroachment. Plantation of more trees is proposed in the open space present in the compound of leprosy hospital. This will help patients to improve their health and feel close to the nature. Establishment of gardens and green belts on open spaces which are covered under the category of non-suitable class is recommended. The presence of four water bodies covered under the non-suitable class is improving the micro-climate (Gehl, 1971). All these water bodies should be connected with each other which will reduce problem of flooding during monsoon. Plantation of suitable shrubs and trees along the periphery of these water bodies is recommended. This will enhance the beauty of the water bodies.

LSA along with the suggestions from the participants of questionnaire survey played a major role in converting various wards of Vadodara city into Eco-wards. Same methodology can also be applied for the generation of Eco-city plan for the city. Various other measures which are saving energy, decreasing pollution and improving the environmental conditions can also be applied to develop the city in balance with nature.

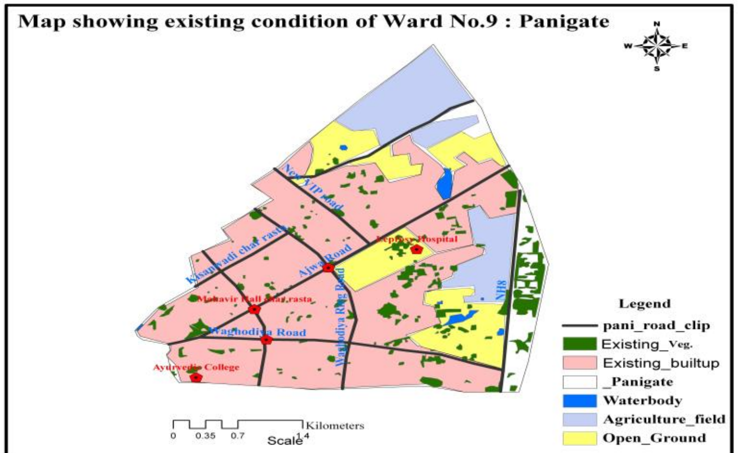


Plate 51: Map showing existing condition of Ward No. 9

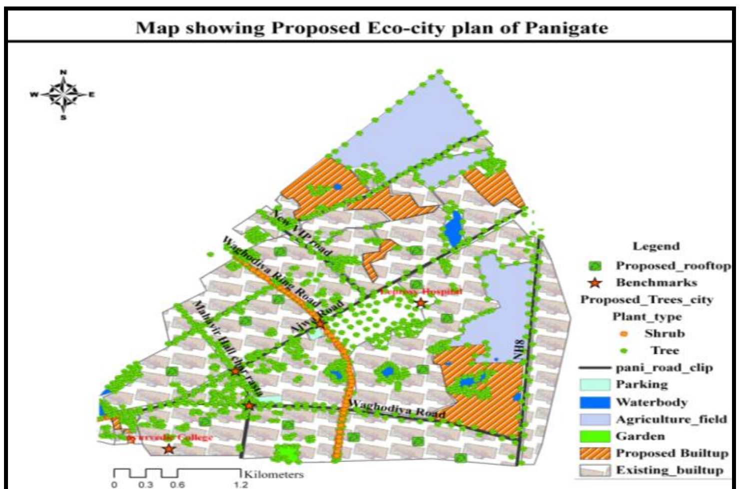
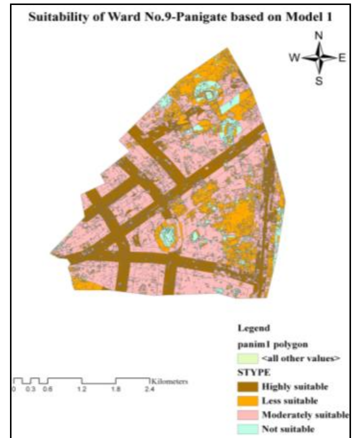
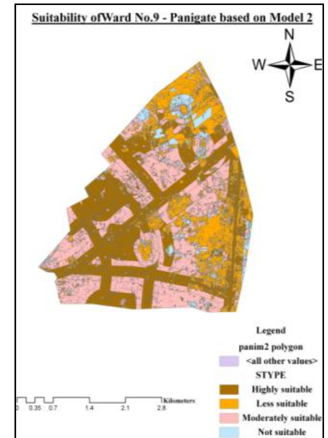


Plate 52: Map showing Eco-ward plan of Ward No. 9



Model 1



Model 2

Model 3

Model 4

Plate 50: Suitability map of Ward No.9 based on different models

(4.4.4) <u>Converting the existing city into an Eco-city</u>:

In recent times cities have become places of environmental degradation and wasteful use of resources, which is proving to be costly to present and future generations. Vadodara city is also facing the problems of air quality pollution, green house gases, unsustainable consumption and of inadequate sanitation and water supply. Realizing the urgency of the situation this study has been taken up to propose the changes to be carried out to convert Vadodara city into an Eco-city. The aim of Eco-city development is to control environmental damages, depletion of nonrenewable resources and rising levels of pollution in cities. Eco-city tries to achieve a balance between the development of the cities and protection of the environment along with providing various basic services like employment, shelter, social infrastructure and transportation in the cities. Municipal corporations of developing cities like Vadodara with limited budget cannot invest in incremental changes. Modifying existing cities like Vadodara into an Eco-city require lesser changes. Precise changes can be proposed by performing the Land Suitability Analysis for the city. Open space redevelopment within existing cities can be proved as an excellent strategy to transform unusable or damaged land into functional and profitable area. Existing cities are able to retain existing embodied energy and amenities which reduces costs.

First step to convert the city into an eco-city development is to carry out the questionnaire survey of the residents of the city. This will help the planners to receive ideas for the proper input and strategy for development thereby providing various amenities in vicinity their home. In addition, the city planners should aim at energy efficiency in transport and buildings, optimal planning solutions in terms of locations, distances and spaces. Energy sources should be solar cells on grass rooftops, wind turbines, biomass plant using waste from agriculture production to generate steam/electrical power, and methane gas from digested sewerage and waste materials. This will reduce air and noise pollution. Eco-house which includes very good insulation all round, large windows facing southwards to provide passive solar heating (possibly with double glass wall-greenhouse area to trap sun with vents to cool in summer) and a heat pump. Other features such as reimbursed power return to grid, solar water heating, biomass wood or waste heating should be included. Citizens should be encouraged to implement the concept of ‘walk-to-work and walk-to-school’. High density and mixed use are characteristic for pedestrian-oriented settlement patterns. This requires a radically different approach to city planning, with integrated business, industrial, and residential zones. In addition, there is a need to reduce land demand and sealed-up area. This can be achieved by designing compact urban patterns (avoiding urban sprawl) which allows the preservation of natural green areas and agricultural lands. This will provide land for both human use and also as habitats for other living organisms and for natural processes (such as the water cycle and carbon-fixing in green plants). City should also aim to increase urban green space as it provides many benefits to citizens. Waste should be recycled for fertilizers. Eco-city should include improved public transport to reduce vehicular emissions. Cities should also try to develop the key performance indicators that provide guidance to city administrators.

CHAPTER 5

DISCUSSIONS

(5.0) Discussions:

(5.1) Thematic Map generation:

Today in this urbanizing world eco-city concept should be guiding means, representing the public interest, protecting the health of the environment and for carrying out construction in line with the surrounding environment. Hence, for upgrading and adjusting the concept of ecological planning in the city's overall planning, thematic planning has become imperative. Thematic maps are indispensable tools in any development and planning programme both at the national and regional levels (**Olomo *et al.*, 1998**). In case of Vadodara city, these maps have provided baseline information for further updation of various resources required for implementation of planning strategy of the city (**Anonymous, 2010**). RS-GIS approach has aided in improving these maps. The cost effective, quick and repetitive characteristics of spatial data have already been proved by **Xu Zhenhua (2005)**. RS- GIS approach together helped in analyzing the spatial and non-spatial attribute, offering possibilities of generating various options (modeling), thereby optimizing the whole planning process. **Verma *et al.* (2009)** has shown how this approach facilitates updating of base maps wherever changes have taken place in terms of land development, etc. by superimposition of two maps of different scales or by insertion of fresh survey or modified maps into existing base maps. Digital information also aided in understanding land use change, providing inputs for urban green space suitability analysis for Vadodara city and finally providing the Eco-city maps for selected wards of the city. To be precise, integration of spatial data with other information provided an important linkage in the total planning process, making it more effective and meaningful. Thematic map generation also aids in the land use change analysis of the study area.

(5.2) Land use change analysis:

Human beings are the most progressive creatures on the earth. For their progress they have made several changes on this earth through industrialization, urbanization and many others. In this competitive world they have migrated from rural area to urban cities. As a result growing cities are creating an alarming situation in all countries of the world. This process is very rapid and explosive in developing world (**Klaus and Jose, 2002**). These rapidly growing cities are constantly demanding land for making new settlement and sprawl which are the two major drivers for the land use changes **(Oluseyi, 2006)**. These land use have important impacts on the water and energy balance, directly affecting the climatic condition of the urban areas.

Similar situation also exists in Vadodara city. The extent of the city is increasing rapidly due to a huge increase in population density and demand for dwelling places. Poor urban planning and housing development has led to construction of informal settlements that lack access to basic infrastructure and provide poor living conditions. As pointed by **Zeug and Eckert (2010)** this type of situation, increased unregulated traffic, noise, and underdeveloped sewage and waste management causing further environmental degradation. The overall rise in the population in the city resulted into increase in travel times due to congestion of the road network. Consequently length of the road network increased several folds catering the demand of increasing traffic. This resulted into the huge increment in the growth rate of the city as a consequences, the city has expanded its boundary several times from the year 1880 to 2009 to accommodate increasing population. This type of expansion has evolved by addition of built-up pockets to already existing urban development zones. Similar results were observed by **Ji (2008)** for Kansas city of USA. In addition, the upcoming chemical, Engineering and other industries in the city led to an increased sprawl in northern and southern part of the city. This has not only reduced the agricultural land, but also raised the traffic volumes with increased pressure on the environment. Such factors have created unsustainable surroundings in the city **(Wong and Yuen, 2011)**. The current spatial and physical planning focus of the planning system does not provide an effective means to achieve resource management planning at local level as already proved in China **(Yip, 2008)**. As a result, sustainability of cities is under pressure. This is seen as a threat in the developing country like India **(Reiner, 2005)**. At this point, an immediate solution for sustainable development of urban land is required which can be achieved by sustainable land use planning. According to **Lavalle *et al.* (2001),** understanding of land use change is a prerequisite for this type of planning. In this view, Land use change analysis in this study was carried out using the integrated approach of Remote sensing and Geographical information system (GIS) which gave a key input in Eco-city planning.

Remote sensing and GIS provided a fast and efficient method to carry out a land-use inventory and detect changes. These changes in the city over a period of time cannot be neglected but require proper monitoring and assessment so that no further deteriorative step are taken unknowingly. As such remote sensing data are capable of detecting and measuring a variety of elements related to the morphology of cities, such as the amount, shape, density, textural form and spread of urban areas **(Webster, 1995; Mesev *et al.* 1995).** The spatial technology along with GIS act as an ideal tool to identify, locate and map various types of lands associated with different landform units

(Dhinwa *et al.*, 1992; Palaniyandi and Nagarathinam, 1997; Murthy and Venkateswara, 1997). The GIS technology provided a platform for integration of various data sets which helped in identifying the problem areas and in suggesting conservation measures. This required the planning process to be carried using spatial information along with other non-spatial information which is linked with the development of the city. Accordingly RS-GIS tool employed for understanding the land use changes in Vadodara city over a period of 129 years have proved to be fast, effective and cost-effective method. Change detection carried out for the city on two levels, i.e. VUDA level and VMSS level has shown a notable decrease in the area under classes like water body, vegetation, and agriculture with a parallel increase in built-up and industrial area. The whole city experienced a vast expansion of urban areas at the expense of agricultural land. It decreased very rapidly from the year 1880 to 2009. This was due to the conversion of agriculture land in other land use classes like built-up, industrial area, etc. As observed by **Brown (1995)**, this high rate of conversion of the agriculture land has threatened the food security, also. Due to high rate of urbanization, the extent of natural land uses like, water bodies also decreased very rapidly during the study period converting them in other land uses. This fact indicated that if the same trend will continue unchecked then there will be water crisis as already experienced in some parts of the city.

Conversion of natural land uses like water bodies, vegetation, etc. made it crucial to determine the rate and direction of urban sprawl for which several parameters were estimated. It aided in the understanding of the causes and effects of urbanization processes. Shannon's Entropy gave the distribution of the loss of these natural land uses to the built-up. It played very significant role in identifying, measuring and monitoring the spatial distribution of urban sprawl **(Jat *et al.*, 2008)**. Same approach was applied by **Punia and Singh (2011)** for Jaipur city of India. Entropy calculation for Vadodara city showed that the value was low in the year 1880 which increased by 0.29 during the span of 129 years indicating the high rate of urbanization. In addition, high value of entropy also indicated dispersed type of developmental pattern of the Vadodara city. Estimation of the U.S.I. showed high values between the years 1960 to 1980 while it decreased during the recent time due to more compact development. Land Consumption Rate a function of increased urban land use which increased with increasing population density. Parallely, Land absorption Coefficient (L.A.C.) also showed a rapid consumption of land during years 1960 to 1980 due to industrialization.

Land use change and associated parameters played a major role in strategic planning of urban green space. It also helped in proposing new buildings with vegetation in gaps of existing structures which helped in harmonizing its built and natural environments. It also aided in generating the eco-ward plan of selected wards.

(5.3) Urban green space Analysis:

Urban Green spaces are a part of nature and play a key role in improving the environmental quality, livability, and sustainability of cities. They provide many environmental and social services that contribute to the quality of life in cities and play social, planning, economic and ecological functions. Factors such as the size, shape, accessibility, diversity and distribution of green spaces within a city as well as the design and management of the green spaces play a decisive role in defining these functions of them. Despite of these functions provided by urban green spaces, they are not properly managed in the Vadodara city. Urban sprawl is leading towards the loss and increased fragmentation of them, thereby diminishing their positive functions **(Wang and Moskovits, 2001)**. These urban green spaces are getting converted to other land uses due to expansion of the city. As a consequence, UGS is becoming a scarce source in the city due to their loss over a period of time. This makes it essential to map the location and quantify amount of green space areas in the city. This allows the urban planners to identify existing green space areas to protect from urban development, or to target certain areas of conversion into new green space areas, e.g., vacant lots into city parks, or unused rail lines into greenways, etc. Moreover, there is a deficiency of information about the quality of these spaces of the city. Not only that but, the available information is incomplete and fragmented and needs improvement. Because of such lacuna of information, some of the wards of the city have high amount of vegetation while some of them have least or negligible vegetation. The reason for such unbalanced distribution is lack of application of advanced technology for planning and mapping of urban green spaces. Most of the planners are still designing urban green spaces based on subjective judgments, that is, the accumulation of knowledge, inspiration, insight, imagination and even speculation **(Shen *et al.*, 2011)**. Therefore, in this study, suitability analysis using advanced technique of Remote sensing and GIS approach was applied for identifying suitable sites for UGS development to ensure their roles and functions **(Gilbert, 1989)**.

With the help of remote sensing and GIS the database generation for suitability analysis became fast and reliable **(Sathish and Niranjana, 2010)**. Remote Sensing and GIS helped in mapping different themes related to physical and social factors utilized for suitability analysis. The use of remote sensing techniques helped in describing a variety of satellite-derived data sets and their application to understand changes in the landscape **(Kouchoukos, 2001)**. GIS offered a flexible and powerful tool to manage all these data.

It provided a tool for integrating and analyzing of land resources to determine the suitability for urban green spaces. It played a significant role in spatial display of different biophysical and socio-economical parameters depending on the location of housing property. It provided a means of taking large volumes of different kinds of data sets and manipulating and combining them into new data sets which was displayed in the form of thematic maps **(Foote and M, 1996; Marble and Amundson, 1988).** This helped in determining to what extent the urban land can be used for green space development which is the main objective for suitability analysis **(Kerkstra and Vrijlandt, 1990).**

One of the various themes utilized for the suitability analysis was the vegetation and related parameters. This theme was analyzed using satellite derived NDVI index which played a very important role in analyzing present status of urban green space of the city. The results revealed that there was rapid decrease in the urban green space from the year 2000 to 2009. Per capita vegetation also showed decreasing trend due to increase in population density. This implied that existing green spaces in Vadodara city are far from satisfactory according to the quantity. The spatial dispersion of urban green spaces is also unbalanced. Various socioeconomic variables in combination with biophysical variables like land use, slope, presence of water body, transport, location of Greenbelt and gardens also influenced the suitability of UGS. Land use was found to be a dominant factor affecting the tree cover and hence, played a key role in suitability analysis. The results revealed majority area of the wards was not suitable for the development of the UGS. However, certain areas found to be highly suitable for development of UGS because of their attributes like medium slope, proximity to the road and water bodies. From the management perspective it was interesting to note that the majority of the suitable sites are either under the ownership of public and government.

These urban green spaces in the form of suitable sites not only provide opportunities for people, they also improve social and economic life, and contribute to the ecological and planning system, and as a whole the urban quality of life. Therefore, the analysis of market demand of the urban green spaces is an important factor for their development. However, there is no real market for urban green spaces and thus it is hard to determine the market demand of urban green spaces and therefore, it is also difficult to determine the extent of supply and development of urban green spaces **(Goede *et al*., 2001)**. The value of urban green spaces is related to the value of nature. Many studies have shown that presence of public green spaces parks, natural areas and golf courses in near vicinity raise the property price **(Marancho, 2003 and Kong *et al.*, 2007; Bolitzer and Netuzil, 2009)**. Many real estate professionals agree that houses with mature trees are preferred to comparable houses without mature trees **(Dombrow *et al*., 2000)**. City dwellers prefer to live closer to the green spaces. **Burgess *et al.* (1988); Coles and Bussey (2000) and Grahn and Stigsdotter (2003)** stated that green spaces will be more often visited if they are closer to the dwellings. Therefore, value of green space in residential areas was estimated for the city. The results obtained showed that there is a positive correlation between house prices and the existence of green spaces. **Similar** results were obtained by **Altunkasa and Uslu (2004)** for development area of Adana (Turkey)**.** This study also demonstrated the importance of spatially retrieved parameters in understanding the economic valuation of area in urban cities to mark out importance of UGS. Modeling of cost through integration technique like PCA based on biophysical and socioeconomic data demonstrated the significance of NDVI, LST, and Population density on green space availability.

Above results revealed that urban green spaces are not evaluated effectively in the Vadodara city according to the potentials and dynamics of sustainable urban development. The existing green space has to be preserved and numbers of usages of these areas and their functions should be diversified so that more people can benefit from them in the city. Therefore, there is a need of a process of suitability analysis to be put into planning, designing and management of green spaces for the city by taking into consideration the ecological, scientific, and technical criteria. This will also aid in Eco-ward plan generation of selected wards.

(5.4) <u>Eco-ward plan generation:</u>

The urban areas of the country are facing problems of deteriorating environmental and socio-economic conditions. There are several reasons creating these problems such as, population migration, environmental consideration not adequately being incorporated into master plans of cities, uncoordinated and haphazard development, weak implementation of plans and laws and inadequate institutional competences. One of the major issues is resource crunch. There is severe lacking of infrastructure facilities. Urban sprawl onto cheaper land is the major driver of urbanization. Waste stemming from energy consumption tends to affect areas beyond their administrative boundaries **(Ryser and Franchini, 2009)**.

Application of non-conventional solution of Eco-city development is imperative after bring into the above facts. Such city is vital to have the valuable trend of city planning, construction and development in the modern world as it is based on the reformation and rebuilding the city's ecosystem with structural integrity and explicit function on the basis of human beings' activities. It is necessary road to realize city's sustainable development; it reflects the radical distinctions between the new and traditional strategies of development about "comprehensive construction of a well-off society" **(Hildebrand, 1999)**. The Eco-city development should consider the scientific theories of modern ecology and sustain by scientific regulation of ecosystem. An Eco-city, as a civic human residence model, is built for many reasons as follows: it utilizes material, energy and information very effectively; it provides a perfect harmony of city population, resources and environment, it leads to coordinated growth of society, economy and nature **(Fazeng and Shengnan, 2007)**. Such non-conventional solution has been applied to Vadodara city.

The physical development of the Vadodara city has exacerbated their environmental deficit over recent times. The existing space in Vadodara built-up areas is not enough to bear the weight of more and more population followed by the future urbanization, and the support in the promotion of city status. This situation is worse in the old city zone. Hence, transformation of old city zone was the main aim of this study. Therefore, the three wards comprising the core of the city were selected. This task for Vadodara city was carried out by performing the Land suitability analysis using Arcinfo 7.2 based USAP module for selected wards. It played a non-substitution role in the preparing the Eco-city plan for selected wards. This module examined the combined effects of selected set of parameters such as slope, Land use, road buffer, water buffer, etc. by overlaying in the GIS environment. It allowed the construction of models from which a new thematic map (e.g. land suitability map) was produced from a set of thematic maps **(Harasheh, 1994)**. Suitability map generated based on the model four gave precise output for further development. Suggestions of participants were also incorporated for proposing the Eco-ward plan. Different land uses were allocated considering current potentials of land. The most suitable land was used first for urban development. Care was taken to protect natural sources for the next generations. Same practice was performed by **Tuncay *et al.*, 2011**. This ensured the proper utilization of existing space of the city. New built-up areas were proposed on the open space present in highly suitable category.

New gardens and green belts were proposed on the open spaces present on the land which was non-suitable for construction. These urban green spaces will form the main component of ecological environment in city ecological system **(Wang, 1997; Tang, 2002**). Air pollution tolerance index (APTI) of various plants present in the wards was estimated to analyze their tolerance to pollution. The tolerance of these plants differed drastically based on the response of their biophysical and biochemical parameters. Polluted environmental condition was responsible for the higher level of leaf extract pH which imparted them the tolerance to the air pollutants **(Kuddus *et al.*, 2011).** The leaf pH decline was greater in sensitive plant than the tolerant plant **(Scholz and Reck, 1977).** Plants with the higher ascorbic acid level under polluted condition indicated that these plants were tolerant to air pollutants (**Senthilkumar and Paulsamy, 2011**). Several researchers have proved that pollution stress decreases the chlorophyll level in plants as the chloroplast is the primary site of attack **(Speading and Thomas, 1973, Santhoskumar and Paulsamy, 2006).** Similar results were obtained for the plants of all the wards. Tolerance level of the plants was estimated based on the APTI values of all the plants of particular ward. Results revealed that plants having high APTI values were tolerant to pollution. It was observed that plats like, *Ficus bengalensis* L., *Ficus religiosa* L., *Mangifera indica* L., etc. were found to be most tolerant plants and was recommended for planting the green belts and gardens. This type of planning will help in improving the microclimatic conditions of the Eco-wards.

For conversion the existing situation into more sustainable form, more compact, space-saving and mixed use settlement structures interrelated with an environmentally compatible transport system convenient for pedestrians, cyclists and public transport was suggested. The buildings must make best use of the sun, wind and rainfall to help supply the energy and water needs of occupants. Further, the buildings should be multi-storey to maximize the land available for green space. Nearby wards should be threaded with natural habitat corridors to foster biodiversity and to give residents access to nature for recreation. It was recommended that the settlement structures should serve as a framework for sustainable development across all sectors, such as energy (including solar architecture), water supply and management, social and economic development and sewage and waste management.

This type of planning practice will help in directing urban development towards minimizing the use of land, energy and materials, and impairment of the natural environment while maximizing human well being and quality of life.

CHAPTER 6

CONCLUSIONS

(6.0) Conclusions:

In India, the need for environmental and urban planning has reached a critical point and thus implementation of novel approach for planning and development has become mandatory. In line with sustainable development, the reactions to current urban planning and design have led to a new alternative and futuristic approach called Eco-city planning and design which is non-damaging to the environment, brings efficient uses of resources with local skills, turns the negative aspects of technological advances to positive, guides good land use planning with compact forms, uses natural analyses in site selection and planning, combines environmental technologies in terms of renewable energy, explores sustainable transportation and infrastructure, uses geographic information technologies for ecological issues in the settlements. A strategic approach for generating the Eco-city plan of the three selected wards of the city using remote sensing and GIS approach has provided a case study for transforming any city into Eco-city at local scale.

The study has brought out changes that have occurred in Land use of Vadodara city over a period of 129 years. The analysis showed that the authorities have lost total control on the management of the city. Reason being that the land under vegetation had decreased rapidly while development at the periphery has not been properly monitored. The results also revealed that water body had reduced significantly. This suggests that if the trend will continue unchecked, there would be a time when there will be water crisis as already experienced in some parts of the city. The planning authority should endeavor for carrying out regular urban audit on land use changes. This will aid in determining the trend and direction of development in the light of the booming urban population. If precautions will not be taken, problems like poor accessibility, sprawl development at the fringe and other environmental problems are imminent. In other words, eco-ward plan proposed for three wards of the city will play a significant role in preventing the implications of dynamic and complex phenomenon of urban land use change.

Suitability is a powerful tool for green space system planning. It can help in finding a balance between different land-uses in the city as well as in formulating policies for UGS management. Suitability analysis carried out using GIS, identified suitable sites for the urban green space development. These sites will play a good ecological role and create elegant landscapes in the Vadodara city. Continued development and refinement of suitability analysis, particularly with GIS technology, helped in proposing suitable green space in the Proposed Eco-ward plan.

Eco-ward plan proposed for three different wards stated that the existing water areas, urban green spaces and other important natural resources should be strictly preserved. If wards are to be transformed in to the eco-wards, a greater awareness of the ecosystem services provided by an urban forest must not only be fostered among practitioners and scientists, but also among political leaders and the public. Urban vegetation cannot be occupied by other land uses. The green space system in the proposed plan is more systematic and decentralized than the existing situation. Very central to this is the need to establish green belts within the city, which would serve as reserve zones to support the urban populace to prevent sprawl taking hold of the functional region. More opportunities should be created to formally and informally educate the public on the roles that urban nature plays in reducing a city's resource and energy use, in improving air and water quality, in decreasing flooding, and in maintaining our physical and psychological well-being. Such education provides the foundation for change. This novel approach of Eco-ward development will not only help in improving the environment but will also improve the relationship between people and their natural and social environment which will lead to more sustainable urban growth. This developmental process will benefit the citizens of Vadodara through renewed and effectively managed environment system.

Transforming Vadodara into Eco-city implies a new vision of not only its physical form, but also of the way in which it is governed. It will be necessary to re-think the roles and responsibilities of municipal government, as well as those of other orders of government, to bring it into line with an integrated vision of sustainable development. Citizens must also be oriented to new and more significant forms of participation in urban planning and management. Despite of the progress of Vadodara city, its goal of becoming an eco-city is far from realized.

CHAPTER 7

SUMMARY

(7.0) Summary:

Developing Vadodara city as an Eco-city will help in decreasing environmental stress, improving living conditions and in achieving sustainable development through a comprehensive urban improvement system. It will involve planning and management of land and its resources. Implementation of environmental improvement measures will be proved as major step in eco-city development. It will bring reduction because of incorporation of environmental considerations into plans (Master Plans). Eco-city construction will pursue the beautification of natural environment and also achieve development of the green environment by means of increasing the amount of green belts, trees and gardens. The aim of the present study was to identify the potential sites for urban green space development and updating of various resources which will help in their sustainable utilization in future. Application of remote sensing and Geographical Information System (GIS) aided in identifying these sites and in preparation of Eco-city/Eco-ward plan.

RS-GIS facilitated the most crucial information for preparing a plan which was an accurate and updated base map of the city. They helped in updating the maps of road networks, spatial extent of development and the information on the use of each parcel of land. GIS supported both spatial and non-spatial attributes. It integrated all this information in the single system by putting maps and other kinds of spatial information in digital forms. It combined both representational techniques and analytical techniques which helped decision making for systematic planning and maintenance. In present study use of RS-GIS was a novel approach for generation of Eco-ward plan. Over and above all the utility of advance tools of remote sensing and GIS aided in making the developmental plan and facilitated updating, retrieval and analyzing urban related resources.

Various findings related to studies are as followed:

1. For the generation of Eco-city plan various thematic maps based on various themes were prepared which helped in analyzing the present status of various resources.
2. The study also updated the transportation map and water body map for Vadodara city.
3. Thematic maps showing the location of various Gardens and Greenbelts of the city helped in analyzing their distribution in the city.
4. Slope map and contour map generated for the city helped in land suitability analysis of the city. These maps will also help in generation of flood prone areas of the city.
5. The study delineated land use changes occurred over 129 years at two i.e., Vadodara Urban Development Authority (VUDA) and Vadodara Municipal Seva Sadan (VMSS) level. VUDA includes Vadodara city and adjoining village areas like while VMSS includes Vadodara city only. The results revealed that the Vadodara city is expanding very rapidly.
6. The land use change analysis revealed that urban area of the city has expanded from 9.14 km^2 in the year 1880 to 145 km^2 in the year 2009 at VMSS level. Such high rate of urbanization has occurred at the expense of various resources like waterbody, vegetation and agriculture.

7. This fact was proved by the rapid decrease in the area occupied by agriculture fields. The area under agriculture reduced very rapidly from 704.85 km^2 to 573.1 km^2 at VUDA level. Such rapid decreases will not only implication on economy of the city but also on the environment.
8. Many water bodies of the city like Gorwa Pond, Gotri Pond, Harni Pond, etc. have shown decrease in area occupied by them resulting into water scarcity in those areas. Many wetlands of the city have disappeared over a period of time due to the rapid urbanization. Study also revealed that some of the water bodies of the city are facing the problem of eutrophication.
9. Rapid increase in the road length has been observed which has led to increase in the traffic volume resulting into the increased level of pollution. This will help in optimizing the demand for roads.
10. Study also examined the type of the urban sprawl by estimating the entropy of the Vadodara city. High entropy value showed that growth of the city is not uniform and the development of the city is of dispersed type.
11. Estimation of Urban Sprawl Index (U.S.I), Land Consumption Rate (L.C.R.) and Land absorption Coefficient (L.A.C.) revealed that increased population rate is responsible for rapid sprawl of the city.
12. Status of Vegetation mapped for three different years i.e., 2000, 2007 and 2009 showed the distinct decreasing trend in vegetation. These findings will help in formulating the policies for conserving the vegetation of the city.
13. The study also highlighted constant decrease in per capita vegetation of the city from the year 2000 to 2009.

14. Estimation of Land Surface Temperature (LST) showed that the vegetation and temperature are correlated negatively with each other. This fact was proved by the lower temperatures of the area with vegetation.
15. Estimation of LST revealed that the nature of temperature variation may lead to the formation of Urban Heat Island (UHI) in the city.
16. Urban green space (UGS) suitability helped in identifying various potential sites for Vadodara city. This results if implemented will help in improving the vegetation status of the city.
17. Land suitability analysis (LSA) carried out for three different wards played a key role in generating the Eco-ward plan of three selected wards of Vadodara city.
18. Survey carried out for the city revealed perspective of citizens for the city. Many participants felt that more gardens and parks should be developed in the city. Also there is a need to improve the transportation system along with development of more flyovers and bridges.
19. The study provided Eco-ward plans for development of three different wards which will help in sustainable development of these wards.
20. Eco-ward plans will not only improve the living standards of the citizens but will also help in decreasing the environmental stress caused by different anthropogenic activities.

CHAPTER 8

RECOMMENDATIONS

(8.0) Recommendations:

- Ecological awareness will help people of Vadodara city to understand their place in nature, responsibility for the environment, and help them to change their consumption behavior and enhance their ability to contribute to maintaining high quality urban ecosystems and to reduce their ecological footprint.
- Public participation is main objective of eco-city planning. Citizens of Vadodara city must get involved in formulating and implementing new land use and transportation policies and practices, preserving agricultural lands and open space, and reclaiming natural habitat.
- The area buzzing with vehicles round the clock which are currently nightmare for pedestrians and residents should be converted to vehicle-free zone. The stretch between Nyay mandir court complex and Fire Brigade building can be made vehicle-free zone. The stretch can be initially made vehicle-free on weekends. Similarly, the stretch can be made vehicle-free during evenings. This will reduce the traffic related problem.
- City authorities should pass a regulation that makes mandatory to include solar heaters and rain water harvesting strategies for every new construction.
- Encourage mass transit rather than personal transport by providing easy means of public transportation. Ensure that citizens are using fuel-efficient and cleaner fuel vehicles.
- Many of the roads in the city are dugged-up and left as such after laying pipelines and cables. This leads to traffic problems in the city. Therefore, care should be taken to cover roads immediately after completion of any repairing work.

- The corporation had planted some banyan trees near Kalabhavan but due to lack of maintenance these trees has to be trimmed every year so that they do not fall on the roads. Instead of carrying out this unfruitful exercise, proper areas have to be selected to grow specific trees with proper planning.
- Many areas of the city are facing parking related problems. Multi-story parking should be built in city to control the traffic.
- Preserve existing green and water elements and create additional green and water elements within the city: trees, lawn, green facades and green roofs, fountains, water courses and surfaces, bioswales, green-infrastructure, etc. to increase the greenery.
- The city should be engaged in a comprehensive effort to deliver new public transportation options while upgrading and enhancing the efficiency of existing services.
- The city authorities should regularly update the information on the change and current levels of ground water, average level and fluctuation of river water, amount and variation of annual water fall, usable amount of ground water for drinking and precipitation purposes. This will help in generating the sustainable future planning.
- Special attention should be paid to renovation of existing buildings and the technical conditions of the buildings. Only buildings with adequate technical conditions should be renovated, and houses in poor condition dismantled and recycled for new construction.

- Provide all citizens - regardless of age, income, race or ability - with safe, accessible, efficient, and affordable transportation options. Prioritize walking, biking, and public transit in order to discourage single-occupancy vehicles.
- The corporation should reduce the environmental footprint of travelling by introducing, designing and encouraging sustainable methods of transport and infrastructure.
- The campus of the M.S.University and one of the largest gardens of city, Kamatibaug are situated very close to each other. Both of these should be connected with each other through a green corridor in order to establish a green zone within the city.
- The authorities should try to minimize sealed surfaces by implementing permeable pavements along the roadsides and pathways.
- The corporation should try to produce energy locally and sustainably, through installation and promotion of the use of renewable and efficient energy technologies, like solar power, wind power, etc.
- Integration of green building and sustainability standards into all private and public development, including historic preservation, renovation, and new construction.
- Encourage the preservation and adaptive reuse of existing buildings, and promote the reuse and recycling of building materials in all development.
- Maximize mental well-being and community feeling**:** health and recreation, cultural identity.

- There is a need of balance between residential, employment and educational uses as well as distribution, supply and recreational facilities.
- Instead of resorting to landfills for solid waste disposal system, re-cycling of solid waste must be resorted to, in order to avoid contamination of ground water, soil, stoppage of flooding due to rain water, etc. to ensure quality of water.
- Watershed management plan should be prepared for the whole city to avoid water shortage during summer season. Scientific method should be adopted for maintaining good quality of ground water.
- New areas should be developed on neighbourhood principle providing all the facilities and amenities according to their priority. All housing should be designed to be within few minute walk of public transport and easy access to social infrastructure such as hospitals, schools and work.
- Government officials should prepare annual environmental status report of the city considering various aspects. This will help in setting annual targets of environment improvement for the city and evaluation of the same at the end of the year.
- Vadodara Municipal Seva Sadan (VMSS) should prioritize the issues to be addressed and formulate strategies through city consultation process for effective implementation.
- VMSS should try to improve access to affordable land and low cost housing finance to achieve goals of shelter for all and slum free city.
- Various departments of VMSS should maximize the use of Geographical information systems (GIS) for decision making.

- The VMSS should formulate the policy for exploiting and redeveloping of wasteland and other empty urban spaces (in the centre and periphery).
- The authorities should carry out the survey of the construction sites. This will help in preserving the existing vegetation wherever possible and replantation of healthy trees. For example, an attempt was made to carry out the eco-development study during the construction of new terminal building of Vadodara airport. During the study a pre-survey of the area was carried out. Based on this survey and detailed study recommendations were given for eco-friendly development. Case study has been described in Annexure II.
- A separate cell for carrying out regular energy audits and formulating the budgets so as to increase the energy efficiency. City should try to reduce energy demand by 64% and should minimize the emissions for energy production, which will save carbon dioxide emissions.
- The VMSS should formulate the policy for extracting biogas from municipal solid waste and sewage.
- The individual buildings of the city can contribute in energy savings by installing photovoltaic cells and micro wind turbines on terrace.
- The energy usage should be charged reasonably up to certain limit, beyond that limit charges should be raised by two to three folds. This type of policies will minimize the energy usage.
- A separate space should be provided to grow food producing plants using sustainable methods, such as organic cultivation. This will not only contribute to

healthy diets for local communities but also enhance biodiversity, provide jobs, and offer educational opportunities for all ages.

- Waste should be recycled to prepare organic manure and the organic manure produced here would be used in producing organic farm-fresh fruits and vegetables.
- Optimize tree plantings and other vegetative cover to facilitate the creation of favorable micro-climatic conditions. Restoration of natural vegetation is essential for reducing irrigation requirements for ornamental landscaping.
- City people should try to maximize the eco-friendly green buildings using natural resources to generate power (**Plate 53**). These houses have their own rainwater harvesting, solar panel system, and water recycling system.

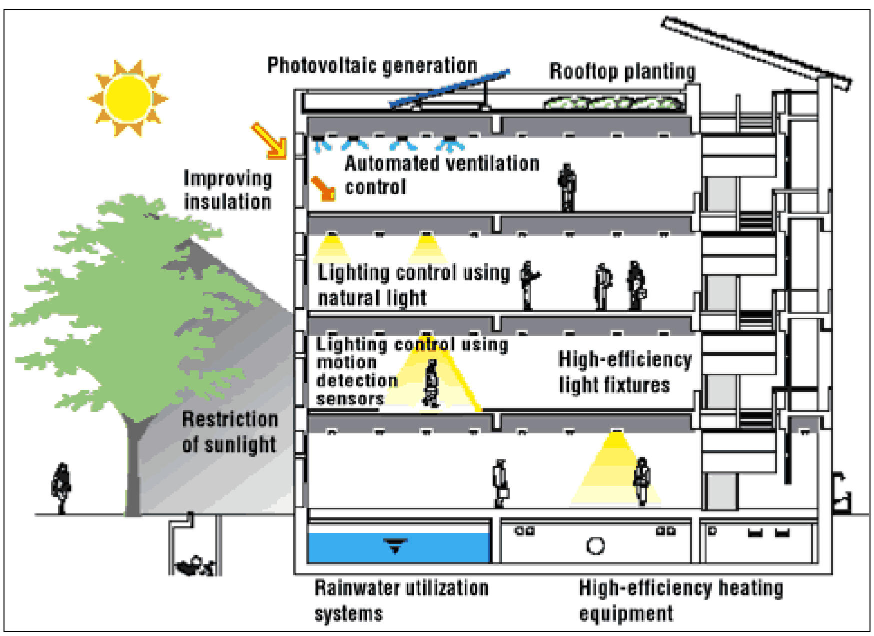


Plate 53: Conceptual drawing of Eco-friendly house

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Annexure I: Survey for Eco-city planning

Name: ____________________________ Age:____
Ph.no.:____________________________

Address:
____
__________________________ Email: ___________________________

1. **Is there any industry located in your area?**

☐ Yes ☐ No

2. **Do you face any kind of pollution problems?**

☐ Yes ☐ No

3. **Are there any health related problems caused by the pollution?**

☐ Yes ☐ No

4. **If yes, what do you think could be the solutions for that?**

____
____

5. **Are you happy with your surroundings?**

☐ Yes ☐ No

6. **What kind of environmental problems are you facing?**

Air pollution	☐	Improper Drainage system	☐	Lack of Greenery	☐
Noise Pollution	☐	Undrinkable water	☐	Unhygienic surroundings	☐
Other	☐				

7. **What kind of changes you want for better surroundings?**

____________________________________ ____________________________________
____________________________________ ____________________________________
____________________________________ ____________________________________
____________________________________ ____________________________________

8. **According to you, which other areas of the city require improvement?**

________________________________ ____________________________________
________________________________ ____________________________________

9. **Do you have any Green belt\ Garden in near vicinity?**

☐ Yes ☐ No

10. If No, how far is it?

11. What is the strength of trees?

12. How many times do you visit that Garden or Green belt?

Daily ☐ Three times a week ☐ Twice in a Week ☐ Once In a Week ☐

Three Times in a month ☐ Twice in a month ☐ Once in a Month ☐

13. Does greenery help you feel better?

☐ Yes ☐ No

14. Urban Green Space in the city is: ☐ Too little ☐ Too much ☐ Moderate

☐ Concentrated ☐ spersed

☐ Accessible N ☐ Accessible

☐ Neglected ☐ Is very well looked after

☐ Not visited frequently ☐ Visited frequently

15. More amount of green space is required in the city.

☐ Yes ☐ No

16. New green space development is really required.

☐ Yes ☐ No

<u>Transportation:</u>

17. How do you Travel?

☐ Bus ☐ Cycle ☐ wo wheeler ☐ uto ☐ r/4 wheeler

18. Are you satisfied with your Transportation System?

☐ Yes ☐ No

19. In your opinion what are the major reasons for traffic congestion.

- Poor Public transport – Lack of sufficient buses/routes, frequency of service
- Growing economic activity in the city
- Lack of maintenance of roads

- Increase in population of the city
- Indiscriminate parking of vehicles
- Hawkers occupying roads for trade
- Encroachment in footpath resulting in people walking on the roads
- In sufficiency of flyovers

20. Do you think 'pay and use' facilities would be better?

☐ Yes ☐ No

21. Do you think that parking charges should be made high so that usage of private vehicles is reduced?

☐ Yes ☐ No

22. Are the manholes on your road maintained?

☐ Yes ☐ No

23. Do you think Vadodara roads are safe for you?

☐ Yes ☐ No

24. What do you think will be the solution for solving the traffic congestion in the city?

- State transport buses should be available in many more Routes
- State transport buses should be more frequently available
- Roads should be broadened
- More flyovers should be constructed
- Traffic should be controlled in a better way by the traffic police
- Roads should be made free of hawkers and encroachments
- Private vehicles like cars and two wheelers should be discouraged by imposing petrol cess and road tax
- We should have more autos
- We should have modern systems like sky bus and metro
- There should be separate lanes for bicycles and buses
- Footpaths should be provided in all roads for the comfort of pedestrians
- Separate parking space should be provided so that roads are free for traffic
- Pay and park concept should be introduced

<u>Water Management</u>

25. Do you have a water connection within your premises (in the house)?

☐ Yes ☐ No

26. If no, where do you get water from?

____

____

Waste Management

27. Where do you keep the garbage for collection?

28. Is the waste asked to be separated into dry and wet waste?

☐ Yes ☐ No

29. Are you satisfied with the door-to-door collection of waste service provided by Municipal Corporation?

☐ Yes ☐ No

30. What is the frequency of collection of waste by the municipal corporation from community waste bins in your area?

____

City Surroundings

31. Does your locality get flooded during rains?

☐ Yes ☐ No

32. For how many days the roads remain waterlogged after rain?

☐ 0.5 to 1 ☐ 1-2 ☐ 2-3 ☐ More than 3 days

33. Are you satisfied with the road sweeping and general cleanliness undertaken by the municipal corporation/ its contractors?

☐ Yes ☐ No

34. What is your dream for Vadodara?

- Clean and green city
- Safe and peaceful city
- Modern city with world class infrastructure
- City known for its culture and heritage
- Growth engine for central India
- Industrial hub
- Other please specify

____
____

Signature

Annexure II

Eco-friendly development of new building: A case study of new terminal building construction of Vadodara airport

Each construction site has its own unique set of soil, tree species, and building process conditions. To understand these factors precisely a reconnaissance survey is required. Reconnaissance survey is the preliminary field inspection of the entire area to be covered and collection of relevant data. For vegetation specifically, initially quantitative floristic survey is done. These inventories provide useful information on the distribution and abundance of species and insights into processes that control tree diversity. It aids in determining the environmental effects of proposed projects that affect rare, threatened, and endangered trees and plant communities and to determine the presence/absence of invasive trees in that area. It also helps in discriminating the healthy and diseased or damaged trees which make the decision making easier. Information such as no. of trees, their species and their condition is gathered during this inventory. It also gathers information on the attributes of individual trees, like location, size, and health of tree.

Floristic inventory if supplemented with tree enumeration information become an important tool for studying the vegetation of an area. Tree enumeration data can be valuable source of information which can be used to develop efficient management system at the construction site. Hence, each tree was numbered for making the process of inventory accurate. Maintaining the details of inventory and enumeration of the trees for any area before construction is prerequisite as it helps in coordinating the different activities of that site. Present study highlighted the details of floristic inventory that was carried out at construction site of new integrated building at Vadodara Airport.

The construction site was visited five times. The flora was inventoried by random walks that covered primarily the plain terrain. In the survey, density of the herbaceous ground cover and shrub layer was not characterized. The survey and enumeration analysis of the site showed the presence of total 237 species of trees at construction site. Many of these were non- native, exotic trees with the exception of *Azadirachta indica* A.Juss. Twenty-eight different woody species were found along transects during vegetation analysis **(Plate 54).** Many trees reported from the site were found commonly in Gujarat.

Use of computer and satellite aided technology of GIS (Geographic Information System)-GPS (Global Positioning System) helped in tree inventory at the site of construction. Both of these data collection systems provided a very comprehensive analysis for tree management. GPS was used to record the location of individual trees, and GIS to store and record all information related to the trees through graphical representation. In handling this data and generating the map GIS played a major role. It provided a means of organizing very large datasets spatially ensuring integrity, compatibility and accuracy of the data collected from the field. One of the most basic advantages of a GIS was to position trees on a local map in terms of their geographic coordinates. The spatial analysis using these tools improved understanding of how location affected health status of the tree, leading to more effective interventions.

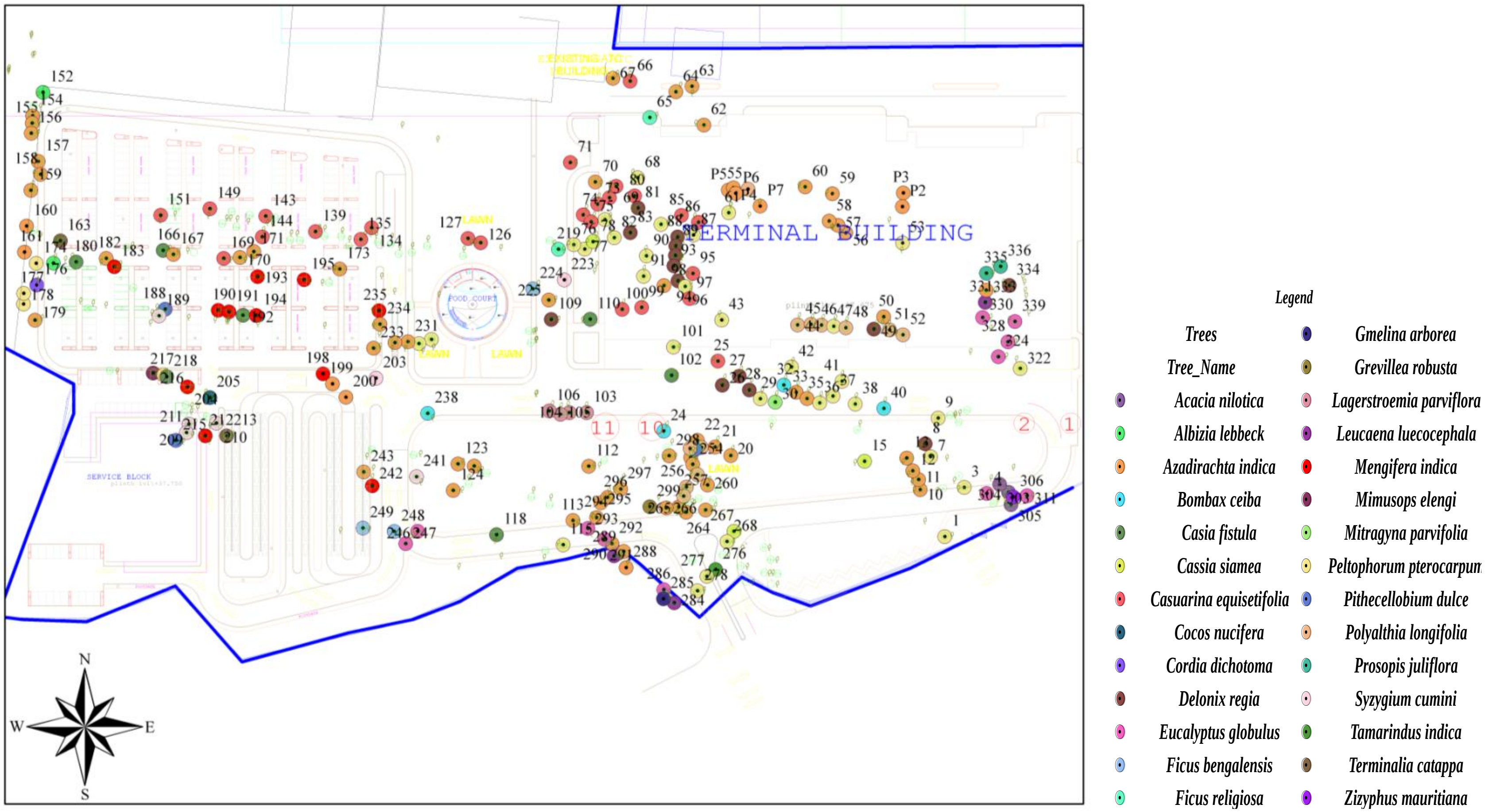

Plate 54: Map showing the location of different trees with their name

Tree health assessment before initiation of construction activities is a means of establishing the relative usefulness of existing trees on potential construction sites. It is the matter of great concern for any construction site as it can prevent damage occurring to the trees. Damage may be so minor that the tree's value, growth, and probability of survival are not affected. Conversely, damage may be so severe that the tree's value has been destroyed, its growth potential reduced to a fraction of normal, or its survival chances severely reduced. It helps in saving money by determining which trees to preserve and which to remove. Trees marked for preservation should have a good chance to survive construction activities, adapt well to the new environment, and look good in the new landscape. Thus, the decision to regenerate requires sound judgments about individual trees. With this information, reasoned judgments can be made on which layout design will optimize the retention of the best trees. Therefore, proper inspection is required for the decision making. Hence for this study, extensive ground survey of trees of the study area using GPS was carried out and plant health was evaluated morphologically.

An initial walk-through survey of the construction area of the airport was carried out. It helped in the identifying valuable trees which should be saved. All the trees were examined visually for any disease and damage. Trees located more than 20 feet away from buildings, and not directly in driveways and sidewalks, were considered for saving. Trees located less than 20 feet from a new building were recommended for removal. Trees with very few leaves and many dead branches should be removed as early as possible. Large trees that lean or exhibit rot, deep trunk cracks, or extensive top dieback are potentially hazardous. These trees should be carefully removed by professionals so as not to damage the remaining trees. Dead trees are excellent for wildlife, but dangerous to people and buildings and therefore should be removed.

Almost all the signs of deteriorating tree health were seen in most of the trees present in the study area except for the few healthy trees**. Plate 55** shows the photographs of trees with very poor, poor, moderate, good and excellent health condition. Overall health condition of the trees was found to be poor indicating stressful environmental conditions prevailed over there, causing adverse effect on tree structure. About 37 trees were having very poor health. About 84 trees were having poor health. About 21 trees were having moderate tree health. About 84 trees were having good health status. About 8 trees were found to have excellent type of health.


Very poor


Poor


Moderate


Good


Excellent

Plate 55. Photographs showing the health status of the trees

Based on the health status evaluation of trees decision can be made for the replantation of trees. Trees having the health status of very poor to moderate were not feasible for replantation and thus were not considered for replantation. Trees having good health condition can be considered for the replantation but they may face difficulties in survival. Trees with excellent health condition were considered for replantation as they were healthy. The study carried out for the construction site of the new integrated airport site revealed that out of 237 trees almost 139 trees were found in the status where they cannot be replanted while 93 trees were found to be in good condition **(Plate 56)**.

Plate 56: Photograph showing replantatation of some trees

Replantation of the trees is time consuming and expensive task and therefore, tree health assessment before initiation of construction activities becomes mandatory. It plays a major role in identifying the potential trees for replantation. Study of this construction site revealed that, many trees present in the campus were having poor health condition and must be removed. Few trees were having excellent health condition and should be replanted. Use of computer aided and satellite based tools of GIS and GPS made the study more efficient and effective. It helped in establishing the relative usefulness of existing trees on potential construction sites. Protection and the highest quality of care are the keys to preserving trees in construction sites.