ADVISORY ON

GIS MAPPING OF WATER SUPPLY AND SEWERAGE INFRASTRUCTURE

CENTRAL PUBLIC HEALTH AND ENVIRONMENTAL ENGINEERING ORGANISATION

MINISTRY OF HOUSING AND URBAN AFFAIRS

APRIL 2020

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FOREWORD

The Ministry of Housing and Urban Affairs has constituted an Expert Committee under the chairmanship of Adviser (PHEE), CPHEEO to prepare various advisories on Latest Technologies in Water & Wastewater, Integrated Urban Water Resource Management Plan, 24x7 Water Supply towards Equity, Quality and Sustainability, Pipe Materials & Other Appurtenances used in Urban Water Sector, Institutional Strengthening and Capacity Building, Planning and Design aspects of Regional Water Supply Schemes etc. to facilitate implementation of Jal Jeevan Missions for both urban and rural areas.

This advisory on the topic of GIS Mapping of Water Supply and Sewerage Infrastructures is prepared with an aim to develop a road map for planning and design of the water and sewerage projects. The main objective of the Advisory is to familiarise the engineers working in State Public Health Engineering Departments (PHEDs)/Parastatals/Boards/Urban Local Bodies (ULBs) etc. with GIS concepts and its application in the water supply and sewerage infrastructure.

This advisory provides details of basic aspects of GIS, methodology for creating base maps of a city, integration of GIS with the water network technology which is used for design of water supply distribution and sewerage systems. It describes the technique of overlapping present available maps with spatial maps and thus making present available maps useful with actual spatial information.

Various aspects of GIS techniques (using appropriate software) are explained by taking the live examples of the cities of Ahmedabad, Shimla and Talegaon- Dabhade. The advisory also covers the institutional reforms and capacity building of the officials/engineers working in the water supply and sewerage departments at the State and Urban Local Bodies (ULBs) level, as the GIS concepts are new and recently introduced.

I believe that this advisory will encourage and empower the Urban Local Bodies (ULBs), State Authorities and concerned stakeholders to suitably use GIS techniques as a tool for effective planning and decision making.

I congratulate all the concerned officers of the Ministry, CPHEEO and the Members of the Expert Committee, who were involved in the preparation of this advisory.

(Durga Shanker Mishra)

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GOVERNMENT OF INDIA
MINISTRY OF HOUSING AND URBAN AFFAIRS

सत्यमेव जयते

Atal Mission for Rejuvenation and Urban Transformation

PREFACE

The Advisory on GIS Mapping of Water Supply & Sewerage Infrastructure has been prepared by the Expert Committee constituted under the Chairmanship of Adviser (PHEE) to facilitate the implementation of Jal Jeevan Missions for both urban and rural areas.

GIS acts as a powerful tool for planning and creation of Master Plan for the urban settlements. It is a time and cost effective solution for analysing development trends that affects future demand. Formulation of GIS-based Master/Development Plans for 500 AMRUT Cities is one of the important reform under AMRUT. Visualization and mapping features of GIS Software gives an overall, connected view of the city's water or sewer network in relation to customers and surrounding infrastructure.

The size of water supply distribution and sewerage systems in cities is considerably large and it is extremely difficult to manually make design of such large sized systems. Also, the existing drawings are old and inaccurate. The preparation of GIS maps results in better maintained data which can be easily revised, updated and shared.

The Advisory on GIS mapping of Water Supply & Sewerage Infrastructure lays emphasis on bringing in harmony among the spatial, social, economical and environmental aspects of a city/towns, and their inhabitants, for successful timely execution of the projects & effective operation and maintenance of Water supply & Sewerage Systems across India. There is a need to adopt GIS technologies and embrace its best practices across the water supply and sewerage sectors which envisages the integration of various forms of data for informed and facilitative decisions with respect to the designing, modelling, planning and maintaining these projects.

I take this opportunity to congratulate the Chairman and Members of the Expert Committee in bringing out this Advisory on GIS Mapping of Water Supply and Sewerage Infrastructure.

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EXECUTIVE SUMMARY

The GIS maps of water supply and sewerage infrastructure provide a lot of benefits. GIS offers mapping of wide spectrum of ground data to address project constraints and emerging challenges in an interconnected manner with involvement of all key project stakeholders. The digitized maps for the cities/towns are created in different layers indicating street network, hydrology, land use, building structures, water distribution and sewer lines and the contours. It facilitates better co-ordination between different departments like PHED, Road, Electricity, etc. when concerned with the development of an area or laying of pipeline in that area.

Mapping of water supply and sewerage projects also involves preparation of GIS based Hydraulic model which is a necessary for design as well as analysis of water distribution or sewerage systems of a city. However, it is observed that the technique and art of rational preparation of such models is not uniformly practiced in the country. At many places, the old techniques such as assigning elevations to the nodes and demand allocation to the nodes are still practiced; as a result, the design or analysis is not accurate which vitiates the hydraulic performance of network in terms of economy, sustainability and equitable distribution of water.

The advisory describes basic concept of Geographic Information System (GIS), creation of base maps using GIS, GIS used as a planning tool, how to integrate GIS with water network technology, mapping of sewerage system, institutional reforms and capacity building required to bring about the changes in the sector.

This advisory will be helpful for the State Public Health Engineering Departments (PHEDs)/ Parastatals/ Boards/ Urban Local Bodies (ULBs) and others for better planning and management of water supply and sewerage systems based on the maps developed using GIS applications.

I would like to extend my gratitude to Dr. Sanjay Dahasahasra, Former Member Secretary, Maharashtra Jeevan Pradhikaran, Maharashtra & Member of the Expert Committee for providing technical support in preparation of the Advisory. I would also like to extend my sincere thanks to other Members of the Expert Committee and the Officers of CPHEEO for reviewing the Advisory and supporting staff for their effective coordination in completing the task.

(Dr. M. Dhinadhayalan)
Adviser (PHEE) and Chairman of the Expert Committee

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Abbreviations

CPHEEO	Central Public Health and Environmental Engineering Organisation
CI	Cast Iron
DI	Ductile Iron
DPR	Detailed Project Report
ESR	Elevated Service Reservoir
GIS	Geographic Information System
GoI	Government of India
HDPE	High Density Polyethylene
HGL	Hydraulic Grade Line
MS	Mild Steel
PDN	Pipe Distribution Network

Units of Measurement

Ha	Hectare
Km	Kilo meter
LPCD	Litres Per Capita per Day
m	Meter
m^2	Square meter
m^3	Cubic meters
MLD	Million Litres Per Day

Chapter 1

INTRODUCTION

The Advisory on GIS mapping of Water Supply & Sewerage Infrastructure lays emphasis on bringing in harmony among the spatial, social, economic and environmental aspects of a city/towns, and their inhabitants, for successful timely execution of the projects & effective operation and maintenance of Water supply & Sewerage infrastructure across India. There is a need to adopt GIS technologies and embrace its best practices across the water supply and sewerage sectors which envisages the integration of various forms of data for informed and facilitative decisions with respect to Planning, design, modelling and maintaining these systems. GIS offers mapping of wide spectrum of ground data to address project constrains and emerging challenges in an interconnected manner with involvement of all key project stakeholders.

1.1 GEOGRAPHIC INFORMATION SYSTEM (GIS)

A Geographic Information System (GIS) is defined as, "a system designed to capture, store, manipulate, analyse, manage and present or display spatial or geographically referenced information, i.e., data identified according to their locations." Basic GIS concept is illustrated in Figure 1.1.
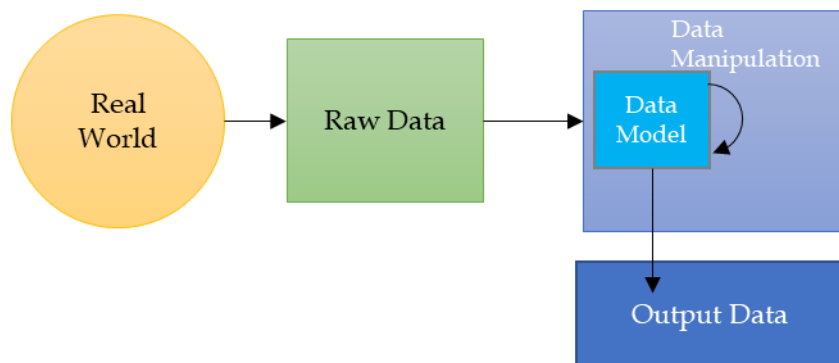
Figure 1.1: Basic GIS Concept
Source: Wikipedia (available at: https://en.wikipedia.org)

1.2 HISTORY/TIMELINE OF GIS

In 1832, Charles Picquet (Figure 1.2) created a map representing cholera outbreak which was spread in the districts of the Paris. It was the first map which gave birth to the GIS concept. In 1854, the same logic was adopted by John Snow to depict cholera deaths in London by making a map.
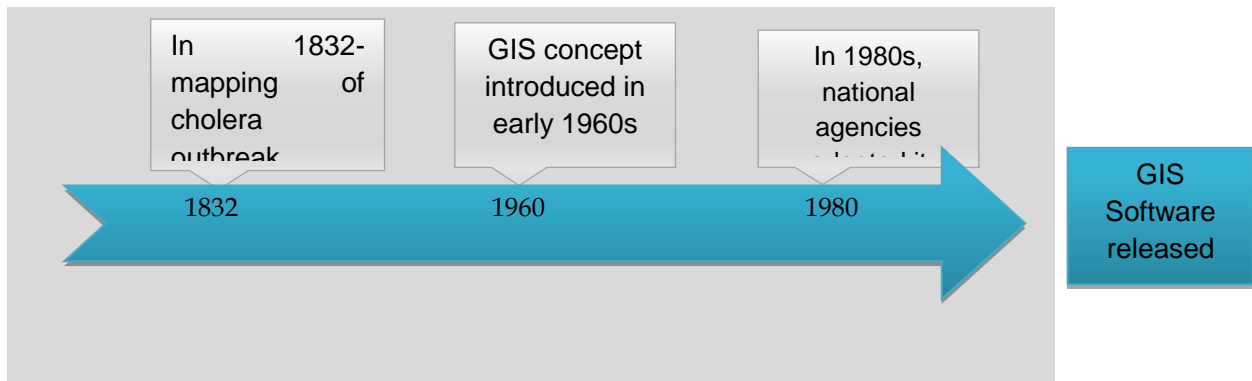
Figure 1.2: History/Timeline of GIS
(Source: www.gislounge.com/history-of-gis)

The concept of GIS was further extended in the early 1960s. The second phase of development in GIS was observed in 1980s. By the 1990s, various GIS Software were released.

1.3 INFORMATION ORGANIZATION

GIS can put information on maps. Here, information refers to things in the real world which are organized into layers. For example, to comprehensively depict its distribution system, a city requires various information like street data, building data, pipes data and contours data which are organized in the layers as shown in Figure 1.3. Integrated data is displayed as a combined map.
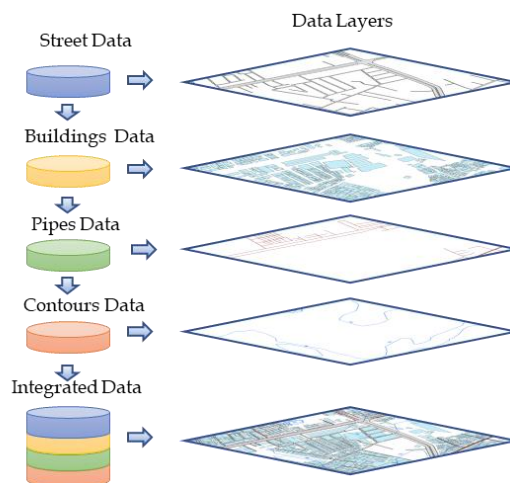
Figure 1.3: Information in Layers

1.4 GIS FUNCTIONS

As per the definition, the first function of GIS is to capture data. The data can be obtained by several methods. For example, scanning, digitizing, aerial photography etc. The data can also be obtained using the Global Positioning system (GPS). After capturing data, it can be stored in the form of hardcopy of map, stored on CD or hard drive of computer. The acquired data can be manipulated. The digital data can be

edited, during the process many attributes can be added or deleted as per requirement.

Queries can be made on the collected data; GIS then can answer the questions made on the data. For example, on the collected consumer data, the number of consumers who are the defaulters can be identified. The data can also be analysed. Again, in consumer data, the consumers can be sorted as per their location and names.

GIS makes visualization of the manipulated data. It has ability to display the data, maps and information.

1.5 GIS BENEFITS

On completing the GIS maps of water and sewer sector infrastructure, a lot of benefits are expected. Some of them are enumerated as below:-

i. Water Supply Department can have better maintained data which can be organized in the standard format and can be easily revised.

ii. Data, maps or records can be easily updated and shared. The units can be easily converted.

iii. It is easier to search any water supply component or consumer data.

iv. Digitized maps for the council are created in different layers indicating street network, hydrology, land use, building structures, water transmission and distribution lines and the contours.

v. Quick overview of the location.

vi. Ready and easy accessibility of the information of major attributes of the Municipal Council from the office.

vii. Quick glance at the water transmission and distribution network by viewing them in the office itself. Thus, GIS maps can be incorporated into the Supervisory Control and Data Acquisition (SCADA).

viii. Reduction in time for identification of the location of water leaks and consumer information.

ix. Current consumer location and new connections to be given, can be easily identified on the digitized map.

x. Better co-ordination between different departments like road, electricity etc. when concerned with the development of an area or laying of pipeline in that area.

xi. Integration of maintenance information.

xii. GIS acts as a powerful tool for planning and creation of the Smart Cities.

xiii.   GIS can save a lot of time and money. It can be used as a tool for better prediction and decision making.

GIS provides a common platform for accessing all the water business data, keeping network information, finding customer information and preparing a report. With built-in spatial analysis tools, it is possible to support network tracing as well as analyse development trends affecting future demand. Visualization and mapping features gives an overall, connected view of the city's water or sewer network in relation to customers and surrounding infrastructure.

1.6 VARIOUS GIS SOFTWARE

There are many companies that provide GIS Software, some of them are: ESRI ArcGIS, ArcGIS Online, Google Earth Pro, Google Maps API, MapInfo, ArcGIS Pro, Maptitude, Surfer, Intergraph, Grass Information Centre (GRASS), AutoDesk, ILWIS (Integrated Land and Water Information System) and so on.

Open-source desktop GIS are:-

1. GRASS GIS – Geospatial data management, vector and raster manipulation - developed by the U.S. Army Corps of Engineers
2. gvSIG – Mapping and geoprocessing with a 3D rendering plugin
3. ILWIS (Integrated Land and Water Information System) – Integrates image, vector and thematic data
4. JUMP GIS / OpenJUMP ((Open) Java Unified Mapping Platform) – The desktop GISs OpenJUMP, SkyJUMP, deeJUMP and Kosmo, all emerged from JUMP
5. MapWindow GIS – Free desktop application with plugins and a programmer library
6. QGIS (previously known as Quantum GIS) – Powerful cartographic and geospatial data processing tools with extensive plug-in support
7. SAGA GIS (System for Automated Geoscientific Analysis) – Tools for environmental modelling, terrain analysis, and 3D mapping
8. uDig – API and source code (Java) available

In this document, appropriate GIS software have been used to demonstrate the concepts.

1.7 NEED/REQUIREMENT FOR GIS

In Water Supply and Sewerage Department of the Urban Local Bodies (ULBs), old records and maps are poorly maintained, not up to date, inaccurate and not able to

share with the other stakeholders. There is no retrieval service for the map. With GIS maps, it is possible to overcome these demerits.

Most of the times, water supply drawings are presented in the form of sketchy flow diagrams (Figure 1.4) which create confusion and very difficult to understand. It is not possible to feed data to such non-spatial maps. Whereas, the spatial or geo-referenced maps represent location on earth surface (Figure 1.5) and are easy to understand. Thus, there is no confusion in reading the water/sewer network maps as they are located along the roads of the city and are easily visible on the satellite images. It is easy to give data to large network by using GIS software. With the application of GIS maps, it is possible to overcome these demerits.
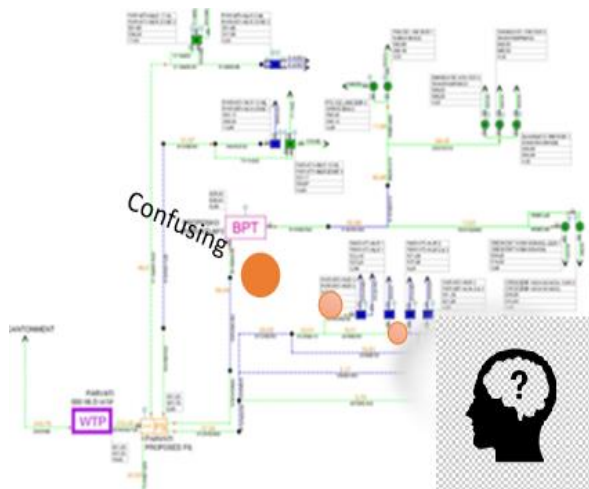
Figure 1.4: Non-Spatial Sketchy Map

Figure 1.5: Spatial or Geo-referenced Map

Chapter 2

BASIC OF GIS

2.1 DATA TYPES IN GIS

There are two types of data being used in GIS application are - Raster and Vector.

2.1.1 RASTER DATA

Raster data can be in the form of cell, pixels or elements. The area is broken into pixels or cells as shown in Figure 2.1. Each cell contains data. Raster data is good for representing dense data, for example, land cover or elevation.
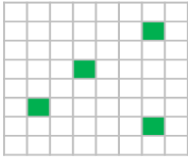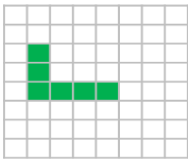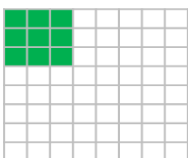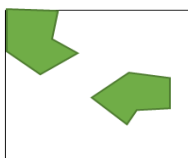
Figure 2.1: Raster and Vector Data in GIS

Raster data is a simple data structure and is a part of cheap technology. Same grid cell can be used for several attributes. Raster data has a large data volume. When computer storage is considered, raster data is not efficient and network analysis is difficult. The maps are not so attractive and are less accurate. When large cell is used, there can also be loss of information.

2.1.2 VECTOR DATA

Any spatial data can be represented by points, lines or polygons which most closely resembles any object in the real world. Vector data is good for representing data (Figure 2.1). It has small memory size. It gives accurate map output. Vector data is a complex data structure and is a part of an expensive technology. Analysis is complex when dealing with the vector data.

The main difference is that raster graphics are composed of pixels, whereas the vector graphics are composed of paths. Extension of the raster graphic is bmp or jpeg, which is an array of pixels of various colours. The pixels together form an image. Comparison of Raster and Vector Data is shown in Table 2.1.

Table 2.1: Comparison of Raster and Vector Data

Type	Parameter	Raster	Vector
Data	Data structure	Simple	Complex
	Data collection	Quick	Slow
	Data volume	Large	Small
Geometrical	Accuracy	Low	High
	Area analysis	Good	Average
Other	Network Analysis	poor	Good

Source: www.geeksforgeeks.org

2.2 COMMON BASIC CONCEPTS IN GIS

Some of the common geographic concepts in GIS are as follows:-

i.   *Scale of Map*: It is defined as the ratio of distance on image to the corresponding true length on the earth's surface. If the length or area on map is more, it is called a large scale and vice versa for small scale.

ii. *Pixel of Image*: Pixel is a physical point in a raster image. It is the smallest element that can be distinguished on a map. In raster image, it is the size of a cell.

iii. *Resolution of Map*: It is the number of pixels in an image. Sometimes, it is by the width and height of the image and the total number of pixels in the image. For example, an image that is 1920 pixels wide and 1080 pixels high (1920 x 1080) contains 20,73,600 pixels or 2.07 Mega pixels.

iv. *Attributes*: It is an important information of spatial data. For example, if a line represents a pipe in map, then pipe's diameter, length, material, C-value could be its attribute. The attributes should be so chosen that they are required in the analysis.

v.   *Spatial data*: This data describes the absolute and relative location of the features. In GIS, generally latitude and longitude of the feature represents the spatial data. For example, a ward in a city has spatial attributes of its latitude and longitude of its centre of gravity.

vi. *Attribute Data*: It describes the properties or characteristics of the geographic features. Attribute data is generally in the tabular format. For example, a ward

in a city has attributes like ward name, ward number, area, population etc. These attributes are stored in the excel sheet which later on can be joined to GIS maps.

vii. *Topology in GIS*: It is generally defined as the spatial relationships between adjacent or neighbouring features. Coverage is the topological data. Coverages used topological relationships of lines to define polygons. Coverage structure was very efficient as far as data storage is concerned. But it is very inefficient for rendering polygons.

viii. *Non topological data structure*: Each geometry is unaware of its neighbours. It can be modified in any way (moving or reshaping) and this will not affect the other geometries.

ix. *Geographic Datasets*: It is the geospatial (geo-referenced) data that identifies the geographic location and boundaries of features on Earth. For example, natural features like oceans, rivers, roads etc.

x. *Creating KMZ files*: KMZ is a file extension. Long form of KMZ is "Keyhole Markup language Zipped" which is a compressed version of a KML (Keyhole Markup Language) file. It is generally used in Google Earth.

Suppose, it is required to prepare KMZ file of location spot of a city, Say Mumbai, it is required to see Mumbai on Google Earth, put the placemark on the location of the Mumbai on Google Earth and 'Save Place as'- Mumbai.KMZ. When right clicked on the placemark, a Latitude 19° 4'30.34"N and a Longitude 72°52'29.09"E of Mumbai is also displayed.

2.3 CO-ORDINATE SYSTEM

In GIS, data is available in an array of numbers. Spatial data comes with some numerical information which can be used to place it on earth's surface. There are some co-ordinate systems that contain the spatial data. The co-ordinates can be expressed in a number of measurement systems like latitude, longitudes, meters etc.

Geographic datasets require a common location for their integration. This capability is provided by the co-ordinate system. Thus, co-ordinate system is a reference system that represents location of geographic features within a common geographic framework.

There are two co-ordinate systems, Horizontal and Vertical, in which data can be represented. Horizontal Co-ordinate System allows to locate data on earth's surface whereas vertical allows the data to be located at relative height.

Horizontal Co-ordinate Systems comprise of three types: Geographic, Projected, and Local. In Geographic Co-ordinate Systems (GCS), a point is referenced by its

longitude and latitude values. This co-ordinate system is generally used for large areas, e.g., map of the rivers in country.

NEED FOR PROJECTED CO-ORDINATE SYSTEMS (PCS)

Latitude and longitude can locate exact positions on the surface of the earth, but they are not uniform units of measure. It is on equator only the distance represented by one degree of longitude can approximate the distance represented by one degree of latitude. For this reason, data is transformed from three-dimensional geographic co-ordinates to two-dimensional projected co-ordinates. PCS is also used to express the spatial data. This co-ordinate system is generally used for water supply and sewerage projects of a city.

In local co-ordinate system, a false origin (0, 0) is used, that can be used anywhere.

2.3.1 PROJECTIONS

Projection is used to convert the information on the curved earth surface to a flat area, say on the computer's screen or on piece of paper. In nutshell, the process of projection means transformation of three-dimensional space onto a two-dimensional map (Figure 2.2).
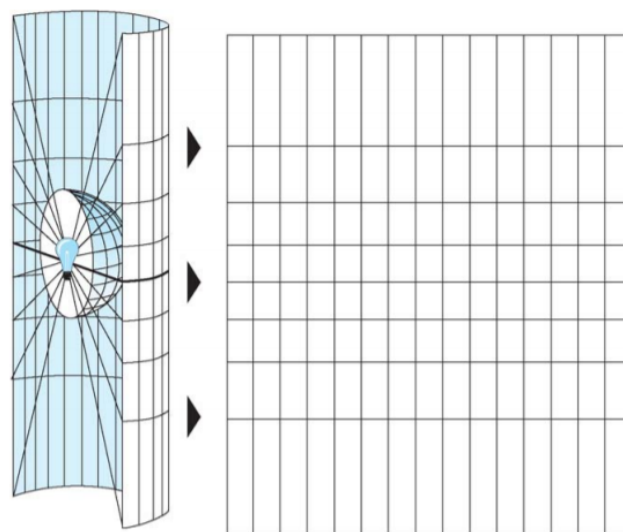
Figure 2.2: Projection from three dimension to two dimensions
(Source: https://nptel.ac.in)

2.3.2 UTM ZONES

World Geodetic System (WGS1984) is the reference system used by the Global Positioning System. The Universal Transverse Mercator (UTM) system is used for assigning coordinates to locations on the surface of the Earth. UTM system divides the surface of the Earth (80°S and 84°N) latitude into 60 zones (Figure 2.3), each with 6° of longitude in width and centred over a meridian of longitude. Zone numbering increases in an easterly direction.
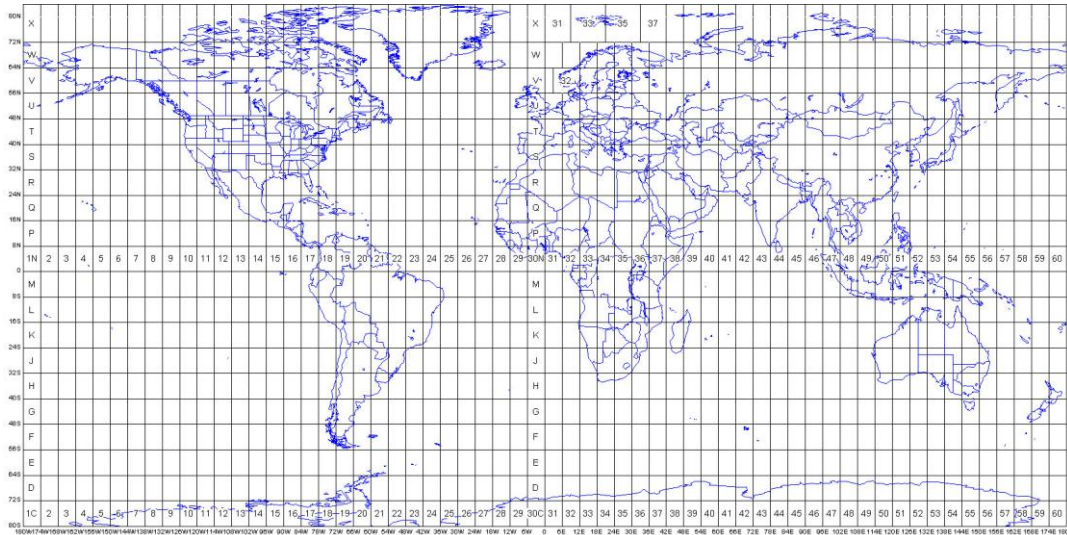
Figure 2.3: UTM Zones

(Source: Lecture materials by Austin Troy and Brian Voigt, 2011; Available at: https://slideplayer.com)

2.3.3 IDENTIFYING CO-ORDINATE SYSTEM IN INDIA

UTM zones 42 to 47 passes over India (Figure 2.4). Shape file of UTM zones are available on internet and can be freely downloaded. Now suppose, the task is to identify the co-ordinate system of the Mumbai city. Since the GIS map is to be prepared for water infrastructure, Projected Co-ordinate System (PCS) shall have to be used. The shapefile UTM Zones is downloaded and placed on the "Layers" which is in the 'Table of Contents' of the GIS software. This Layer (with its co-ordinate system) acts as the parent layer for all the subsequent child layers. The shapefile of the location of Mumbai is also placed in the 'Table of Content' of the GIS software.

Figure 2.4: UTM Zones

The Point of Mumbai can be seen on the online screen of the GIS software. The strip number which passes over Mumbai should be noted. Here, it is passing through the strip whose number is 43 and is placed North of the equator. Hence, the Projected Co-ordinate System of Mumbai is "WGS 1984 UTM Zone 43 N". This co-ordinate

system is then assigned to the 'Layer' in the 'Table of Contents' of the GIS software. When this is done, later on, any shapefile (of the project area) that is dragged or created (with Data Frame) in the container of the 'Layers', shall automatically get the co-ordinate system of WGS 1984 UTM Zone 43 N.

2.4 PROCESS OF GEO-REFERENCING

Geo-referencing is the process of assigning real-world co-ordinates to each pixel of the raster. It can be achieved in a number of ways as follows:

(i) *From JPG File*: Sometimes it is required to make shapefile from the feature like street, airport etc. which is available only on the hardcopy. When such a hardcopy is available, the diagram along with the feature like the 'Airport and Street' is scanned. On scanning its JPG file is created. This JPG file is then geo-referenced and opened in GIS software. It is then exported with "Data Frame" in GIS software to create the shapefile of the street.

Example: Suppose that the non-spatial diagram of the Airport of Ahmedabad and streets surrounding it is available on a hard copy as shown in Figure 2.5. Objective is to geo-reference it and after making it geo-referenced, it should exactly sit on the online satellite image. The satellite image of the corresponding area is identified on the online satellite image of the Ahmedabad (as shown in Figure 2.6).

The first task is to scan the hardcopy and make its JPG file and add it in GIS software (Figure 2.5). Find at least three reference points, (say R1, R2 and R3) in Figures 2.5 and 2.6. These reference points must be identical in both the layers of JPG file as well as on the online satellite image.

Second task is to open the GIS software and choose 'geo-referencing layer' as the scanned image. Add control point R1 on the scanned image and then drag it (after zoom to layer) onto the corresponding reference point R1 on the online satellite image. The process is repeated for rest of the control points R2 and R3.
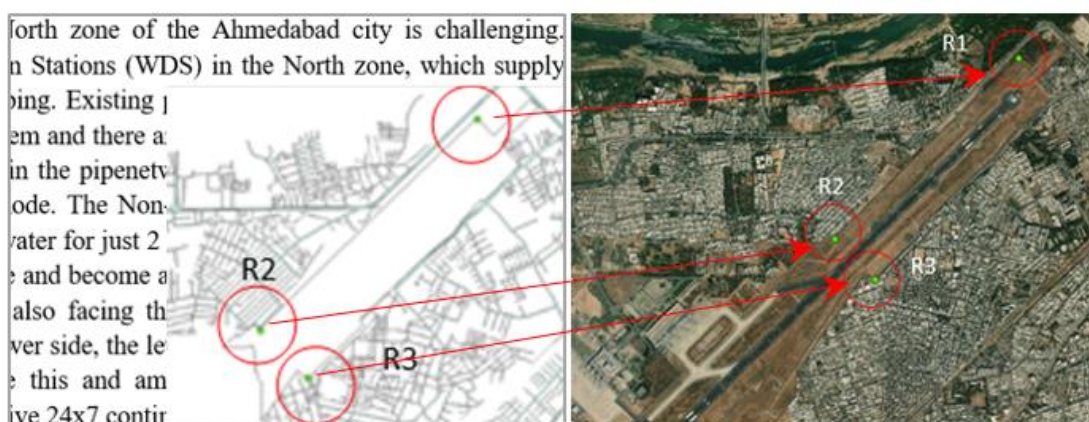
Figure 2.5: JPG file of scanned hardcopy of Airport of Ahmedabad and streets   Figure 2.6: Airport and surrounding streets on online satellite image

Finally, after updating process of geo-referencing, the control points R1, R2 and R3 from scanned JPG image are rubber sheeted on to the corresponding reference points R1, R2 and R3 on the online satellite image. The output is shown in Figure 2.7 which is the geo-referenced image of Airport and streets.

Figure 2.7: Map of Airport of Ahmedabad and surrounding streets: Geo-referenced

(ii) *From AutoCAD Drawings*: Most of the times the drawings are available in AutoCAD format. The process of geo-referencing is illustrated by taking the example of streets of the north zone of the Ahmedabad city.

Example: Suppose that the AutoCAD drawing of streets of the north zone of Ahmedabad is available as shown in Figure 2.8. Objective is to geo-reference it and after that, it should exactly sit on the online satellite image. The satellite image of the corresponding area is identified on the online image of the Ahmedabad as shown in Figure 2.9.

Figure 2.8: AutoCAD drawings of streets in Ahmedabad North
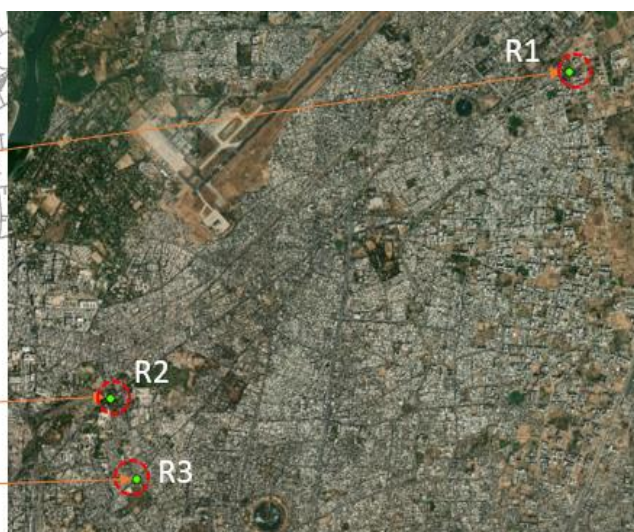
Figure 2.9: Control points on online satellite image of Ahmedabad North

The AutoCAD drawing is added into GIS software. GIS software automatically creates 5 layers- Annotations, Point, Polyline, Polygon and MultiPatch. Select only the layer of polygon and export it to shapefile (Give name as *Street.shp*).

In this case also, at least three reference points, say R1, R2 and R3 should be identified which are same in both- AutoCAD as well as on the online satellite image as shown in Figures 2.8 and 2.9. These reference points are selected as cross of the roads.

Open the GIS software and bring the 'Spatial Adjustment Tools'. Open 'Editor' and choose the shapefile, "*Street.shp*". Open 'New Displacement Link Tool' and add control point R1 on the layer of street and then drag it onto the corresponding reference point R1 on the online satellite image. The process is repeated for rest of the control points of R2 and R3.

Finally, in Spatial Adjustment, choose Adjustment Method as Transportation- 'Affine'. After 'Adjust' command, the reference points R1, R2 and R3 gets rubber-sheeted on to the corresponding points on the online satellite image. The output is shown in Figure 2.10. In this way, AutoCAD drawing is geo-referenced.

Figure 2.10: AutoCAD drawings of streets in Ahmedabad North: Geo-referenced

2.5 SHAPEFILE

A shapefile is a simple, non-topological format for storing the geometric location and attribute information (Figure 2.11) of geographic features. Geographic features in a shapefile can be represented by the primitive geometric shape of points, lines, or polygons (areas).
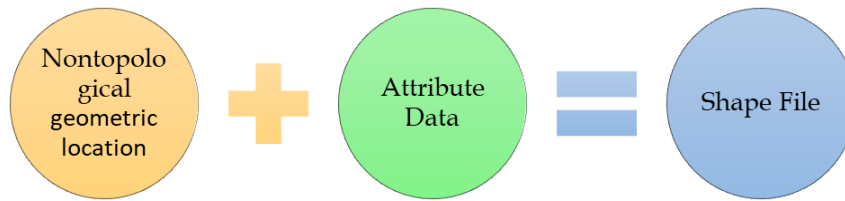
Figure 2.11: Shapefile in GIS

Need for Shapefile

Shapefile stores non topological data and attribute information for spatial features. Geometry of features is stored as a shape having vector co-ordinates like latitude and longitude. Since, processing of the topological data structures is avoided, the shapefiles are supposed to be efficient for rendering and requires less memory space and easy to read and write. Shapefiles are composed of three mandatory files - .shp, .shx and. dbf. Attributes are stored in DBASE format.

2.5.1 METHODS TO CREATE SHAPEFILE

There are a number of ways of creation of the shapefile which are as follows:-

(i) *From KMZ file*: The KMZ file, say 'Mumbai.KMZ' (as discussed above) is added to the GIS software and then its data of point is exported with "Data Frame" to generate the shapefile of Mumbai.shp which represents a point. When it is exported with the Data Frame, the co-ordinate system of the Parent Layer (which is in the Table of Content of GIS software) is automatically assigned to the Child Layer of the shapefile.

(ii) *From Digitization*: In GIS software the feature is digitized. For example, a pond in the Ahmedabad city is digitized as shown in Figure 2.12. While digitizing, give option as polygon. It is then exported with "Data Frame" in GIS software to create the shapefile of the pond. Open the 'Attribute Table' of the newly created shapefile. Save the shapefile as '*pond.shp*'. While creation, one field called as "Name" is automatically added by the GIS software. Using Field Calculator insert the value as "Ahmedabad_Pond1".

Figure 2.12: Digitization of polygon of a pond

2.6 JOINING ATTRIBUTES TO SHAPEFILE

Suppose that the pond has properties as shown in Table 2.2 which is in non-spatial excel format.

Table 2.2: Attributes of Pond

Name	Area_sqm	Depth_m
Ahmedabad_Pond1	500	2

If these attributes are to be attached as data to the shapefile of *pond.shp*, then the attribute table (Table 2.2) is joined with the shapefile *pond.shp* by a command of "Join attributes from a table".

	FID	Shape	Name
▶	0	Polygon	Ahmedabad_Pond1

Name	Area_sqm	Depth_m
Ahmedabad_Pond1	500	2
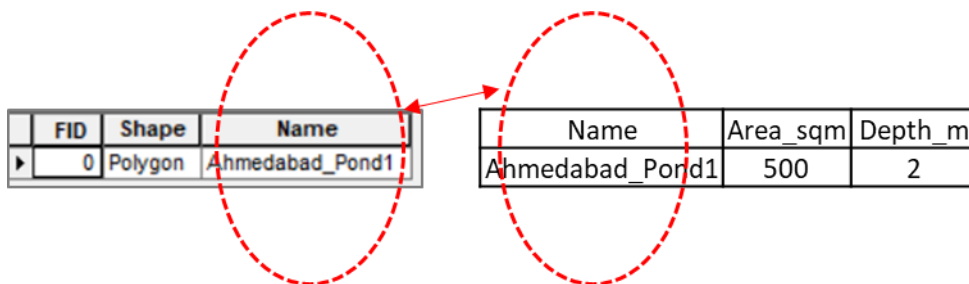
Figure 2.13: Spatial Map   Figure 2.14: Non-Spatial Excel Sheet

The 'Joining filed' in both the tables is 'Name'. In this way non spatial data is joined with the spatial map.

Chapter 3

CREATING BASE MAPS USING GIS

3.1 INTRODUCTION

Base map is a collection of GIS data and/or satellite imagery that form the background setting for a map. The function of the base map in water supply and sewerage system is to provide background details of water and sewerage infrastructure which are necessary to make hydraulic model. After preparing the model, the results are represented by preparing comprehensive drawings of water distribution system or sewerage system. With base maps the drawing becomes aesthetic.

Base map consists of (i) Satellite image (ii) Digitization of features (iii) Landmarks (iv) Existing water & sewer infrastructure and (v) Contours

3.2 SATELLITE IMAGE

Satellite images are full of useful and interesting information of a city. The images show the road network, existing Elevated Service Reservoirs (ESR), Water Treatment Plant (WTP) and pipelines (if they are laid above ground). They can provide information of the changes in the city over a time period. Thus, satellite image is the most important layer of the base map.

Satellite image is automatically available as online service of GIS software. Satellite image can also be obtained from the National Remote Sensing agency (NRSA), Hyderabad. Google Earth also provides satellite image but it is not provided as online service in GIS software.

3.3 DIGITIZATION OF FEATURES

Digitization is the process of converting information into a digital format. When the image is scanned, it converts that to an image file, such as a JPG or bitmap. On digitization, information is obtained which makes it easier to preserve, access and share. There are a number of ways of making digitization which are enumerated as follows: -

(i) *From Hardcopy of Existing Map:* Features like roads, house buildings, reservoirs are scanned to form a JPG file. This JPG file of the existing maps is opened in GIS software. Digitization is carried out in two ways as follows:-

(a) *Catalog Method*: Open Catalog window to access your data. Create 'New File Geo-database' and under it create 'New Feature Dataset' and again under it create a

'Feature Class.' Give name to it and choose either Point, Line or Polygon under 'Type of features stored in this feature class.' This feature class is automatically opened in 'Table of Contents'. Open it under Editor, with 'Create Feature', and start the digitization process.

(b) *Drawing Method*: Ensure that you are in 'Data View.' Under Drawing tools choose either Point, Line or Polygon and start digitization process. After drawing, under 'Drawing', Convert Graphics to Features. Choose Data Frame and give location of output shapefile where the shapefile of the digitized feature is created.

(ii) *From Google Earth*: It is possible to digitize the features on Google Earth. The features like roads, house buildings, reservoirs, tanks etc. are visible on the Google Earth which are digitized using its tools - Add Path, Add Polygon and then using, "Save Place As" to form a KMZ file. The KMZ file is then exported in GIS software to form shapefile.

(iii) *From Online Service Satellite Image*: Features like roads, house buildings, reservoirs are clearly seen on the imagery of online service of GIS software. As discussed above (i) (a) and (i) (b), digitization is carried out either from Drawing Tools of GIS software or by Catalog.

(iv) *From Open Street Map*: Open Street Map (OSM) is a free software which can be freely downloaded and used. Open the site of Open Street Map and choose name of the required city. The extent is decided by clicking on "Manually select different area," a rectangle would appear. By the handles of the rectangle, the extent is adjusted. Then after exporting, the OSM file is created which after exporting, gets converted into shape files.

If the required features of the city have not appeared on the screen, then digitization can be carried out using another free software called as Java Open Street Map (JOSM).

Digitization Using JOSM: Open JOSM. Attach ESRI Imagery. Suppose the task is to digitize some of the building boundaries of the Ahmedabad city. To Locate Ahmedabad, press "Ctrl+J" which opens a dialog that allows to jump to a position (Figure 3.1) after giving latitude and longitude. To draw buildings, install plugin called as 'Draw Building.' The plugin adds a new "Draw buildings" button on the toolbar. Using this tool, a building can be digitized (Figure 3.2) in just three clicks.

Figure 3.1: Identifying Ahmedabad location by Latitude and Longitude
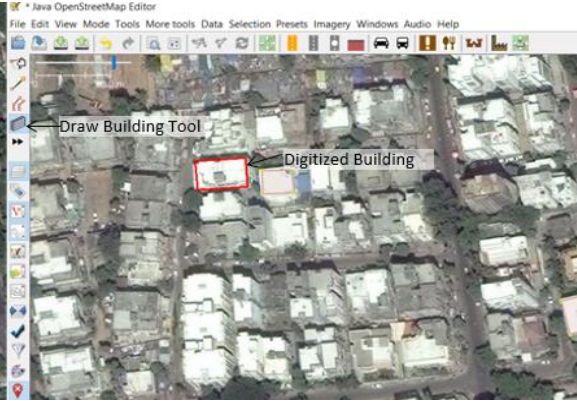
Figure 3.2: Building digitized (shown in red) in 3 clicks

3.4 LANDMARKS

Open the GIS software and add imagery to it. Landmarks can be created by selecting – boundaries, places, transportation besides that of imagery. Shapefile of landmarks can then be created by digitizing the landmarks say, temple, road name etc. and then exporting to shapefile.

3.5 EXISTING WATER AND SEWER INFRASTRUCTURE

Shapefiles of existing water and sewer infrastructure are created by a number of ways as below:-

(i) *From Available Existing Hardcopies of Maps*: Scanning of such maps is carried out to form a JPG file. It is then geo-referenced. This JPG file of scan image is added to GIS software and then digitization can be done. After exporting the digitized layers, the same are converted into shapefiles.

(ii) *From Available AutoCAD Maps*: Generally, AutoCAD maps are available. Such maps are geo-referenced and then after exporting feature from it are converted into shapefiles. Existing pipes, in operational zone of 'Naroda Jalpa' in North part of the Ahmedabad, were available with AutoCAD format which are converted into shapefile. When shapefile of existing pipelines (shown in green colour) is opened in GIS software, the features are depicted as shown in Figure 3.3.

Figure 3.3: Existing and new proposed pipelines

(iii) *From GPS*: When maps of existing pipelines are not available, routes of the existing pipelines can be marked using the GPS instruments. The routes can be identified by interacting with the local residents, meter readers or contractor's person who have laid the pipelines. When no data is available, trial pits are dug at least one in 100m and by actual visualization, pipe material, diameter etc. can be ascertained.

3.6 GIS CONTOURS

Contours are generated using various survey methods which are enumerated as below:-

(i) *Total Station*: Ground elevations are taken along the roads of the city by carrying out the Total Station survey. Presently, the instrument comes with GPS which can note down values of latitude and longitude of the points as Easting and Northing. These points can be directly added into GIS software. If the instrument does not have capability of GPS, then the points can be taken along the geo-referenced roads.

(ii) *3D Stereo Paired Satellite Image*: Sensor of the satellites takes images (Figure 3.4). The same location is snapped by the satellite with an overlapping angle. Overlapping angle provides the depth perception which is used to generate contours by photogrammetric software. The contours thus formed are validated by Differential GPS (DGPS) Survey at one point per 10 square kilometres.
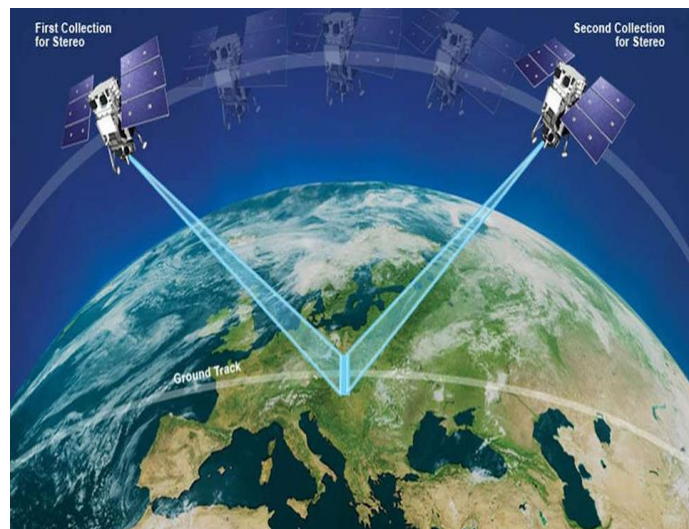
Figure 3.4: Same location snapped by the satellite with two overlapping angles
(Source: Digital Globe)

(iii) *LIDAR*: Light Detection and Ranging (LIDAR) technology is used to generate elevation data. This method gives accurate and dense contours.

(iv*) Drones*: Drones takes high quality images. The area for which contours are to be generated is marked/ digitized on Google Earth and its KMZ file is created (Figure 3.5). The KMZ file is then fed to the controller of the drone and missions are planned

(Figure 3.6) using the controller. Drone flies along the flight path and while passing it takes images at two overlapping angles (Figure 3.7). Hundreds of high-resolution quality images are obtained (Figure 3.8). One image represents very small area of area of interest as shown in Figure 3.8. The images are processed by the "Done to Map" software which gives the Digital Elevation Model (DEM). DEM is then processed in GIS software to generate the contours. The contours, thus formed are validated by Differential GPS (DGPS) Survey.
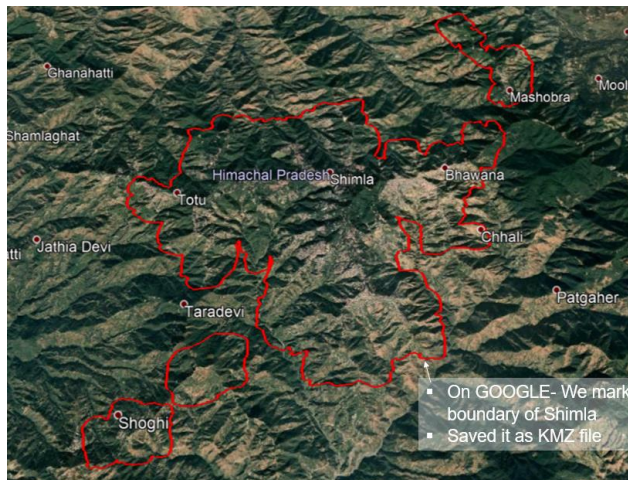

Figure 3.5: KMZ file of area of interest

Figure 3.6: Planning missions
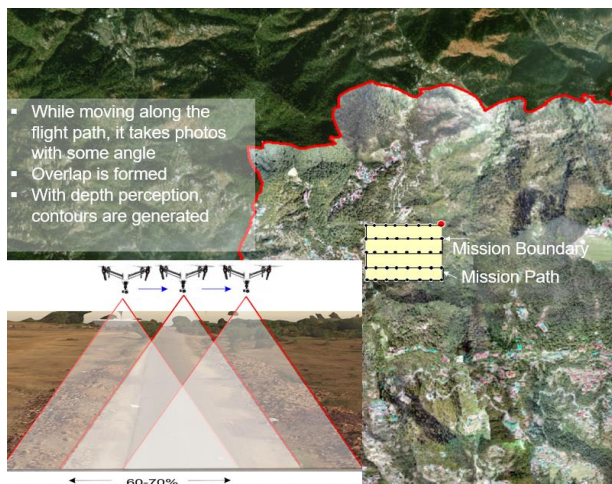
Figure 3.7: Drones taking snaps with inclined angles
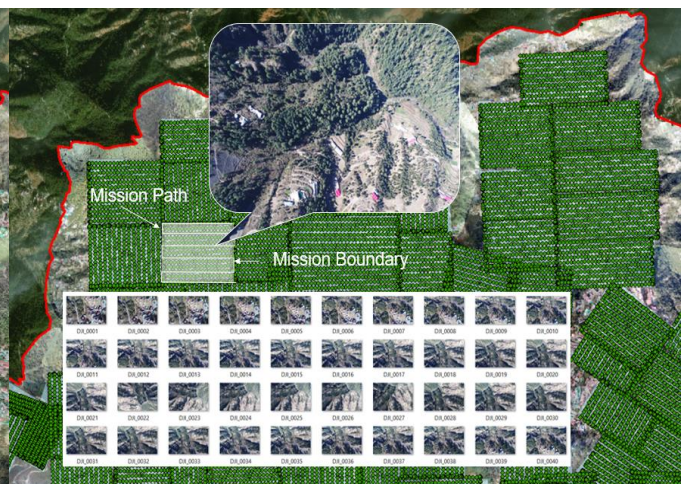
Figure 3.8: High resolution images

Chapter 4

GIS- A PLANNING TOOL

4.1 PLANNING USING GIS

Planning is a set of decisions about how to do something in the future. It is the process of thinking about the activities required to achieve a desired goal. In water supply and sewerage system, it is required to achieve the benchmarks of the service level as set out by the Ministry of Housing & Urban Affairs (MoHUA), Government of India. The objective of planning in water and sanitation sector is to create schemes that help in achieving the goals.

For deciding the goal, the baseline demand (present demand) of water is required. Future demand is then computed for the future prospective population and its need of water. It is required to plan the water resources that are expected to be available to meet those demands (supply). It is to be seen how well the supply would match by looking at the gap between demand and supply.

Thus, population forecast of a city for next 30 years is an important step in planning water supply and sewerage projects. Based on population forecast and knowing the unit demands, demand is estimated for next 30 years. It includes demands for residential, floating population, fire demand, institutional and commercial demands of a city.

Need for Population Density Map

In the large pipe network of distribution system of water supply, or manholes of sewerage system, future demands need to be assigned to hundreds of the nodes. Manual exercise of this demand allotment to nodes is prone to error. In most of the software, the demand is given to the nodes by the tool called as, 'Load Builder.' This tool uses the Population Density Map which is based on the Land Use Maps. Therefore, Land Use Maps are required prior to creation of Population Density Maps.

Creation of the Land Use Map has been illustrated here by taking the case study of the town of "Talegaon- Dabhade" which is located on the Mumbai-Pune highway. The reason for selecting this town is that it includes practically all types of uses including military area, industrial area, water bodies etc.

4.2 LAND USE MAPS

Land Use Maps of a city comprise of the spatial information/ data of the various physical land uses like that of the residential area, areas of commercial activity, transportation, parks & gardens, forest land etc. These land use maps are generally

included in the City Development Plan (CDP). CDP map of the Talegaon- Dabhade town is collected and is geo-referenced. After the process of geo-referencing, the polylines of roads, building etc. are exported to form the shapefile of the different types of the land which are shown in Figure 4.1.

Figure 4.1: Land Use Map of Talegaon- Dabhade town	Figure 4.2: Overlapping of layers of 'Land Use' Map and 'Wards'
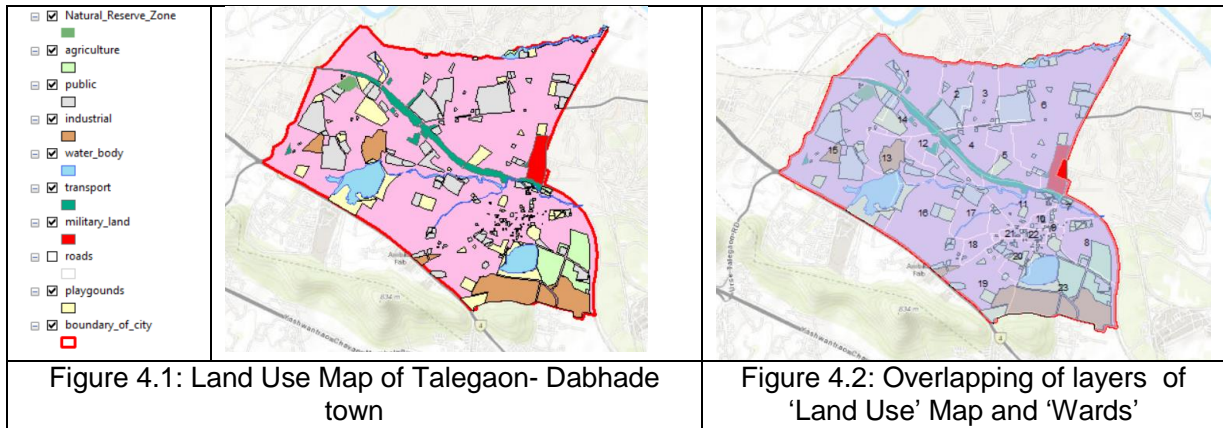
The area under city boundary, other than the land use (Figure 4.1), is that of the residential area which is shown in the pink colour. In the analysis/ design of the distribution system of water supply, ward wise population density for present, next 15 years and 30 years needs to be computed.

4.2.1 DETERMINING POPULATION DENSITY OF WARDS

There are 23 wards in the town of Talegaon-Dabhade. The polygons of different wards are digitized and shapefile of the boundary of all 23 wards of the town is created, the layer of which is shown in Figure 4.3.

Figure 4.3: Wards of Talegaon- Dabhade	Figure 4.4: Wards with density
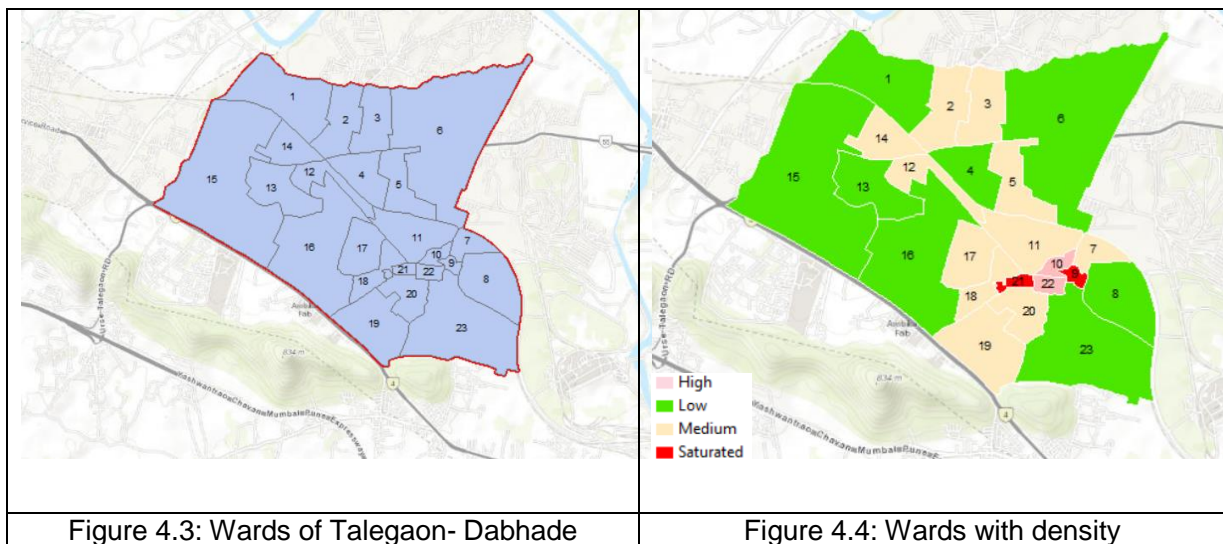
4.2.1.1 Ward Wise Land Use Area: Though the map showing all types of land uses for the entire town is available, it is necessary to find out different types of land use areas (in hectares) for each individual ward. To divide the different type of land use areas for each ward, the '*split*' command from the GIS software is used which is

available in Arc Tool Box. Two overlapping shapefiles - (i) Land Use Map (Figure 4.1) and (ii) Wards (Figure 4.3) are used to form overlapping layers in Figure 4.2. The 'Input Features' would be the layer of 'Land Use', 'Spit Features' would be the layer of 'Ward' and the 'Split Field' would be 'Ward No'. After executing the split command, shape files of each ward with corresponding land use areas (in hectares) are obtained. Information from these shapefiles, after split command, is collected which is shown in in Table 4.1 in Column Numbers 4 to 7.

Table 4.1: Computation of Ward Wise Equivalent Area and Projected Ward Wise Population for Design Year

Ward No.	Ward Area (Ha)	Population (2011)	Type of Land Use from GIS map				Equivalent Area, computed by Eq. 4.1 (Ha)	Present Density on equivalent Area as of 2011 (P/Ha)	Density		Iteration=1		Final Iteration	
			Residential Area (Ha)	Public Area (Ha)	Agriculture Area (Ha)	No Man's Area (Ha)			Main Category	Sub category	Projected density for design year 2049 (p/Ha)	Projected population for design year 2049	Projected density for design year 2049 (p/Ha)	Projected population for design year 2049
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	111.585	1872	77.824	11.973	10.097	11.692	81.827	22.88	Low	L1	250	20457	150	12274
6	184.725	4236	117.029	27.771	7.675	32.25	124.739	33.96	Low	L1	250	31185	150	18711
15	181.617	3650	89.576	30.929	23.198	37.915	99.628	36.64	Low	L2	300	29888	175	17435
1	72.779	4123	59.885	0.997	2.962	8.934	60.431	68.23	Low	L2	300	18129	175	10575
8	46.819	2116	28.884	1.481	14.402	2.052	30.694	68.94	Low	L3	350	10743	200	6139
13	40.253	1693	19.992	4.303	11.163	4.794	22.184	76.32	Low	L3	350	7764	200	4437
23	106.139	1803	10.392	4.97	72.911	17.867	18.925	95.27	Low	L3	350	6624	200	3785
4	31.05	1854	18.597	2.081	0.98	9.392	19.215	96.49	Low	L3	350	6725	200	3843
11	41.136	2771	24.908	2.307	1.797	12.124	25.665	107.97	Medium	M1	400	10266	300	7700
19	51.724	3708	31.365	1.879	13.355	5.125	33.171	111.79	Medium	M1	400	13268	300	9951
3	33.004	3004	25.775	3.265	0	3.964	26.591	112.97	Medium	M1	400	10636	300	7977
17	29.923	2764	21.893	4.8	0.037	3.193	23.096	119.67	Medium	M1	400	9238	300	6929
2	37.268	2340	13.493	18.033	0	5.742	18.002	129.99	Medium	M1	400	7201	300	5401
5	32.634	3304	22.626	2.352	3.583	4.073	23.572	140.17	Medium	M2	425	10018	300	7072
18	18.59	2073	14.513	0.843	0	3.234	14.724	140.79	Medium	M2	425	6258	300	4417
20	24.437	2231	13.455	4.02	4.028	2.935	14.863	150.11	Medium	M2	425	6317	300	4459
14	25.511	1650	9.527	2.227	7.786	5.971	10.863	151.9	Medium	M2	425	4617	300	3259
12	21.699	2484	14.544	0	0	7.155	14.544	170.79	Medium	M2	425	6181	300	4363
7	13.652	1820	10.144	0.444	0.923	2.142	10.347	175.9	Medium	M2	425	4397	300	3104
22	6.276	1476	4.526	0.73	0	1.02	4.708	313.49	High	H	450	2119	400	1883
10	6.559	1758	4.337	0.694	0.357	1.172	4.546	386.74	High	H	450	2046	400	1818
21	4.964	1783	3.84	0.31	0.133	0.682	3.93	453.67	Saturated	S	600	2358	600	2358
9	4.147	1893	3.069	0.256	0.183	0.64	3.151	600.8	Saturated	S	600	1891	600	1891
Total	1126.491	56406	640.19	126.665	175.57	184.068	689.4	163.7				228326	293.48	149780

*　　Public　　　　: This includes Public utility, Public, semi-public, Commercial
**　　Agriculture　　: This includes Agriculture, industrial, play ground
***　No Men's Area: This includes Roads, transport, water bodies, natural reserve zone

Since, population density of each ward with respect to the land use is to be found out, it is required to find out equivalent area of each ward. While determining equivalent area, the general factors - such as 100% for residential, 25% for public and 10% for industries and agriculture have been used which is practiced in Maharashtra Jeevan Pradhikaran (MJP). Computation of equivalent area is shown in Column 8 of the Table 4.1.

Need for Equivalent Area Using General Factors

It is necessary to reach a methodology which is realistic, can be easily adopted, and planned for future demand. It should ultimately result in node wise allocation of demands for making design of water network for future realistic demand. The methodology suggested here is for an urbanised town which essentially comprises of mainly residential area and other land uses such commercial, public, agricultural etc. These land uses are categorised in four categories:-

i.   *Factor for Residential Land Use*: Consumption of drinking water is for all the people living in residential area. This category also includes area having shops on ground floor and residential flats on above floors (which may also include minor commercial activity). In short, this category is having maximum area of the town. For this category, land use factor is 1 (i.e., 100%).

ii. *Factor for No Man's Area*: This category includes water bodies, area covered under roads etc. Since, human consumption is nil, land use factor for this category is zero.

iii. *Factor for Public Area*: This category of land use includes public utilities like schools, colleges, offices, single story market yards but excludes hospitals and lodges. The human consumption of such areas on hectare basis is low compared to residential areas as the human population in such areas is not expected to take bath, cook food etc. as compared to residential area. Hence, 25% of total such area would be comparable with residential area for computation of demand of water and hence, land use factor shall be considered as 0.25 for such areas.

iv. *Factor for Agriculture Area*: This includes the areas having agricultural land, playgrounds, industrial areas having less workers but big area. Such areas will need very low water demand per hectare of land as the human consumption of water is very low. However, it should not be forgotten that the demand so calculated is for the human consumption only and is not including that of the actual requirement of water for agriculture/ horticulture and industrial purpose. Hence, 10% of total such area would be comparable with residential area for computation of demand of water and land use factor shall be considered as 0.1 for such areas. Thus,

Equivalent Area = Residential Areax 1+Public Areax 0.25+Agriculture Areax 0.1+ No Men's Area x 0

$$(4.1)$$

The demand for hospitals and lodges should be worked out through consumer survey and should be extrapolated for future and should be shown as *point loads* in addition to demand determined on equivalent area basis.

Present Population Density: Present Population density is a ratio of present population of each ward to its equivalent area. These are computed in Column 9 of Table 4.1. Next step is to formulate a method to project future ward wise population based on per hectare basis. This method has to be realistic and easy to compute.

4.2.2 METHODOLOGY FOR PROJECTING FUTURE POPULATION

(a) Use of *CDP*: Few progressive Municipal Corporations/ Councils have already prepared their own City Development Plan (CDP) showing ward wise area in hectares, present population and stage wise projected future population for such wards. But the CDP maps do not have ward wise land use areas in it. They only provide maps of the city showing different types of land use areas in different colour coding. Now it is necessary to compute land use areas for each ward as discussed in Clause 4.2.1.1. and then using equivalent area method, the future population for each ward should be computed.

(b) The areas which are already fully developed such as core areas of the city, the density of these areas have already practically reached to the level of saturated density unless Floor Space Index (FSI) is increased. It is recommended not to increase FSI indiscriminately and as far as possible keep the present FSI unchanged. For accommodating small increase for future, the saturation density should be decided very close to present density. Eventually, this density called as saturation density will not be surpassed in any other area of the city. In other words, the saturation density thus determined is upper limit for future density of other areas. For other areas, assign future densities based on the expected new layouts, vertical growth, urban poor, slums, land use pattern, residential, commercial properties, industries, etc.

The rational method developed is iterative (Figure 4.5) and is as follows:-

i.   Sort the ward wise present population densities based on the equivalent area from minimum density at top of the table to maximum density at the bottom of the table, as shown in the Column 9 of the Table 4.1.

ii.   It is necessary to divide the sorted present Densities into 4 categories of Low, Medium, High and Saturated. In the case of Talegaon-Dabhade, the ranges chosen are 0-100 persons per hectare for Low; 100–300 persons per hectare for Medium; 300-450 persons per hectare for High and 450-600 persons per

hectare for saturated densities. Values mentioned in these ranges depend on the size of the town. The more the size, greater is the range.

iii. For understanding the growth pattern in terms of future population density, work out the ratio of future population to the present population. In case of Talegaon-Dabhade, the present population for the year 2011 is 56,406 and future projected population for the year 2049 is 1,49,513 and hence, the ratio works out to 2.65. Total equivalent area for the town is 689.4 hectares. Present population density (on equivalent area) for the total town works out to be 82 (=56406/689.4) persons per hectare and the future population density (on equivalent area) for the total town is 217 (=1,49,513 /689.4) persons per hectare. Eventually, the increase in density is also 2.65 (=217/82) times.

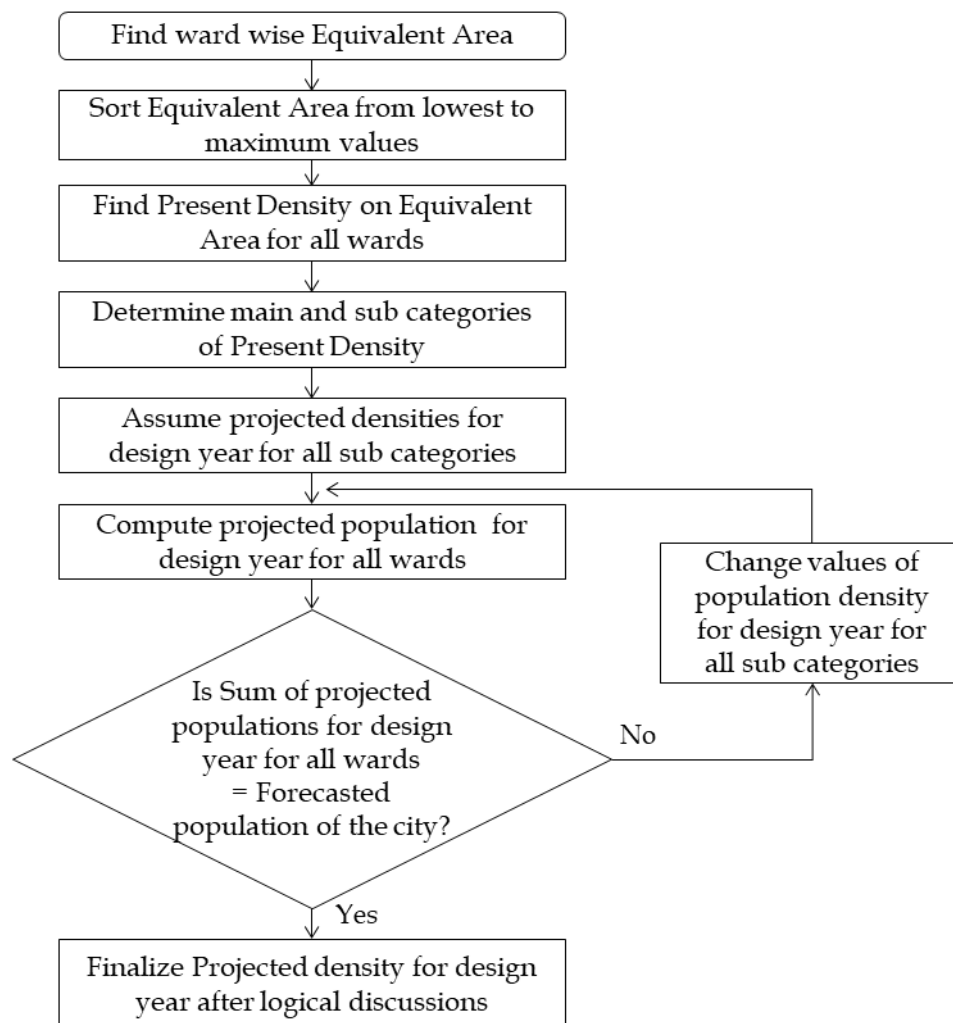
Figure 4.5: Process of computation of future population densities for each ward

iv. Based upon the saturation density and present low density, decide the slabs of future densities. Choose one of the slabs for each ward. For Talegaon-Dabhade, present population density is 82 persons per hectare and future

density is 217 persons per hectare. The saturation density for this town is 600 persons per hectare as shown in bottom row of the Table 4.1. Hence, the slabs to be chosen are from 82x2.65, i.e., 217 to 600 say 250 to 600 persons per hectare. Appropriate population density needs to be now assumed in Column no. 12 for each of the sub category which are shown in Column Number 11 of Table 4.1. In the first iteration (as shown in Columns 12 and 13 of Table 4.1) the sum of the future population for all 23 wards is computed as 2,28,326 which is found to be more than the future projected population of 1,49,513. Thus, the slabs wise population densities, assumed in the first iteration, need now to be reduced. The exercise has been carried out in second iteration, i.e., in Columns 14 and 15 of Table 4.1 and total population works out 1,49,780 which fairly tallies with the total estimated population of 1,49,513. In actual exercise, more than two iterations may be required. In this way, the future population density and future population is finalized for every ward.

v.   The future ward wise population density thus determined in Table 4.1 should be discussed with logical discussions with technocrats, bureaucrats, few knowledgeable people representatives. Based on the outcome of the discussions with them, the future population and population densities of each ward should be finalized. While finalizing, it should not be forgotten that the total population thus finalized must tally with projected population of the whole town. Ward wise future population and population density thus determined should be approved by the local body and then only the engineer/consultant should be allowed to proceed with detailed engineering designs and estimation.

Mapping Future Population Density: Resulting Table 4.1 showing ward numbers and ward wise future population densities is in the non-spatial Excel format. This Table 4.1 should be added in the 'Table of Contents' of the GIS software. For making a spatial GIS layer of Future Population Density, the attributes form the excel table should be joined with the GIS layer of the 'wards' in the GIS software (Figure 4.3). The joining field shall be 'ward number' in both the layers. The layer of 'ward,' shown in Figure 4.3, is already having a field of 'ward number'. The method of "Join attribute from a table" is already discussed in Chapter 2. With colour coding in Symbology, shapefile of the final Population Density Map is prepared (Figure 4.4). This shapefile is important because it is used to allocate the demands to each node.

4.3 GIS BASED CONSUMER SURVEY

Consumer survey is carried out to map the consumers in distribution system. Consumer survey provides information of consumer category, status of meters and current meter readings for billing purposes. GIS based geocoding of consumers provides an information of number of connections in each operational zone of the

service tanks which determines the number of District Metering Areas (DMA) in the operational zone.

Process of conducting GIS based consumer survey has been illustrated by taking a case study of the survey conducted in the Shimla city. To know about consumers and their locations in the city, the entire city is divided into the small elements, say 500m x 500m. This division of city into a number of elements facilitates easy way of gathering information of the consumers. To create such elements, a 'Fishnet' (feature in GIS software) is created across the wards of the Shimla city.

4.3.1 CREATION OF FISHNET

This feature is available in 'Data Management Tools' of GIS software. Fishnet is created across all wards (as shown in Figure 4.6). Values of cell width and height (say, 500) for each element of the fishnet are provided.

Figure 4.6: Fishnet is created across the wards of Shimla City

During creation of Fishnet, GIS software automatically labels each cell. Thus, spread of total 480 elements of fishnet cover all the building boundaries of the entire Shimla city. All consumers in each element can now be easily mapped. Location of property of each consumer residing in each cell are known and therefore, it is easier for survey teams to visit and collect information.

4.3.2 MAPPING CONSUMERS

All the 'Building boundaries' (in polygon shape) of the Shimla city are digitized and its shapefile has been created. A unique number (building_id) is assigned to each building so that it is identified and easily processed in the database. Using GIS software, the polygons are converted into the points (Figure 4.7). Each such point represents a consumer or their group called as society. In Shimla, there are more than one consumer residing in most of the buildings, mostly the shops on ground

floor and the residential flat on upper floors. Hence, consumer survey was conducted with each household (family). A consumer is identified by the 'consumer_id'. These fields are added in the consumer form. Survey teams were given the forms which they filled by visiting location of each consumer. The non-spatial data in the form of excel sheet is then joined with the common primary number of 'building_id' to the layer of the spatial shapefile of buildings which is in the form of a point. Thus, the shapefile of consumer dataset, called as "*consumer.shp*," is created.

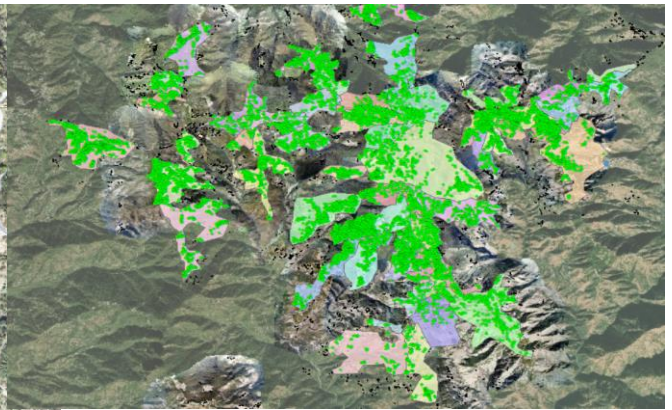Figure 4.7: Each building is shown as red point   Figure 4.8: Consumers in each Operational Zone of Shimla

4.3.3 MAPPING CONSUMERS IN EACH OPERATIONAL ZONE

Operational Zone is a jurisdiction of serving water by each of a service tank. Boundary of each operational zone is created along with its shapefile called as "operational_zone.shp". The concept of operational zone is further explained in Chapter 5. Though the dataset of the consumer in the form of 'consumer.shp' is available, a consumer is not identified by the label of an operational zone in which he resides.

In the shapefile of operational_zone.shp, there is one field called as "Name" which is the name of the Operational Zone. The task is to attach this name of operational zone to each consumer so that consumers residing in each operational zone would be known.

Open GIS software with the two shapefiles - consumer.shp and operational_zone.shp. Choose the layer of consumers and join it with "Join data from another location on spatial location". Choose the layer of operational_zone to join this layer. With this, a new shapefile of consumers with the name of operational zone is created.

The connections in each operational zone are shown in Figure 4.8. Number of consumers per Operational Zone decides the number of District Metering Areas (DMA) in each Operational Zone.

Chapter 5

INTEGRATION OF GIS AND WATER NETWORK TECHNOLOGY

Size of water distribution system of cities in India is considerably large. Distribution system consists of hundreds of the nodes and pipes. It is extremely difficult to manually make design or analysis of such large sized water distribution system which requires Hydraulic Model. Such model is prepared using the software like Epanet (Free software) or any Network software. But merely making a non-spatial hydraulic model is not enough as design or analysis of huge networks require data feeding to large number of its pipes and nodes. This needs a powerful tool that can assign the data of ground elevations and demands to each node and attributes to each pipe. GIS helps to feed data to the network to prepare GIS based hydraulic model for the big systems.

5.1 GIS BASED HYDRAUIC MODEL

Before advent of the hydraulic model, the distribution system used to be designed using simple excel sheet method which was approximate and was not accurate as the design/ analysis involved a large number of iterations. The perception of distribution network was vague like the mindset of the seven blinds about the elephant (Figure 5.1). However, powerful software are available which are used for designing the distribution pipe network. With correct data fed to the models, they give fast and accurate results of analysis and design. This has created a positive mind set (Figure 5.2).

Figure 5.1: Before Hydraulic Model	Figure 5.2: After Hydraulic Model
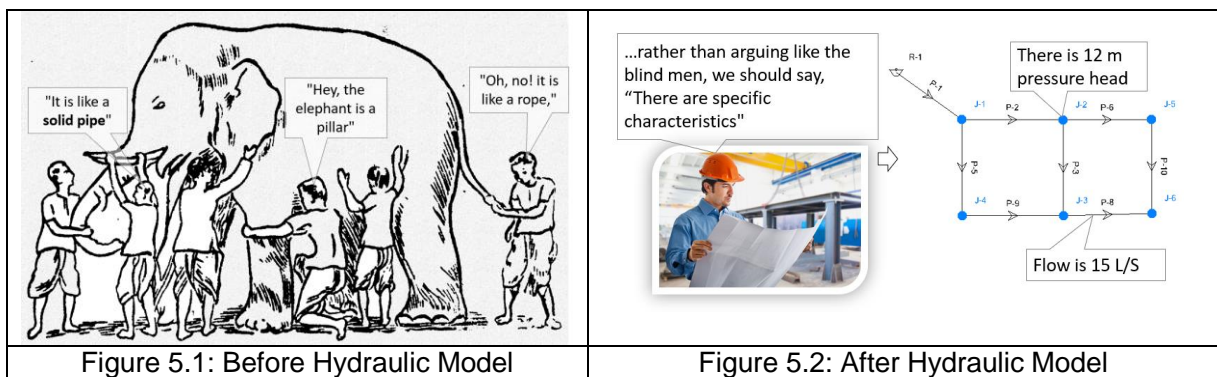
By modelling a system, we gain a full understanding of hydraulic behaviour of the system. Hydraulic model is used as a tool to plan infrastructure improvements, develop Operation and Maintenance (O&M) strategies and proactively manage water system.

Hydraulic model is defined as the process of creating a representation of network modelling of actual water supply or sewerage system using computer software.

5.1.1 MODELLING WITH NETWORK SOFTWARE

Preparing hydraulic model needs base maps. GIS base map, showing foot print of buildings, land use areas like residential area, commercial area, parks, gardens and roads, is added as background layer in Network software. In base map, existing water infrastructure comprising of existing tanks, existing pipelines are added by the respective shapefiles.

Creation of Active Topology: Using shapefile of pipes and employing the Model Builder tool of the Network software, the active topology of the existing and new proposed pipelines is created. New pipes are proposed to make 100% coverage.

Assigning Data to Nodes: Assigning manual data to any huge network is extremely difficult and it is prone to errors and moreover, may it not be accurate. GIS helps to solve this problem by integrating it with the network software (Figure 5.3). Using GIS, values of ground elevations and demand of water are given to each node of distribution system.
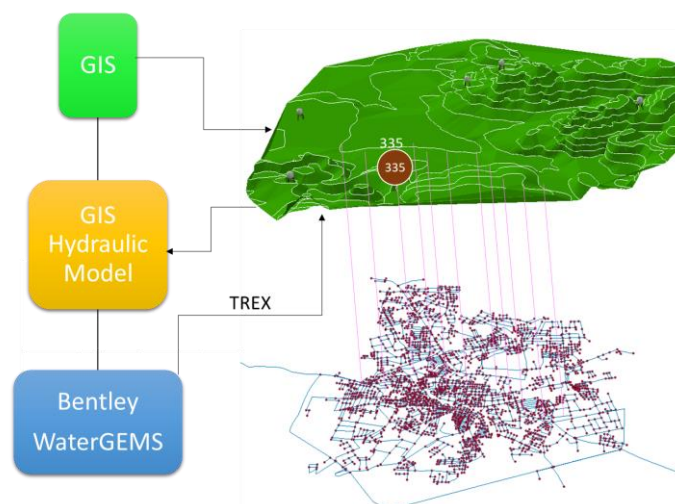

Figure 5.3: Integration of GIS with Network Software

5.2 ASSIGNING GROUND ELEVATIONS TO NODES

The 'Terrain Extractor' (TRex) tool of Network software automatically assigns ground elevations to each node. The computation is based on the nearest value of elevation from the GIS contours. Only condition is that the GIS contour map must exactly sit over the geo-referenced base map that contains the layer of pipe nodes. This requires the same co-ordinate system for both the layers of contours and pipe nodes. The GIS contours are generated using the methods as mentioned in Chapter 3. The procedure of allotment of ground elevations to nodes is explained as below:-

Open Network software. In Tools select TRex Wizard. Select 'Data Source Type' as Shapefiles. In 'Elevation Dataset,' select the contour layer and select 'Elevation

Field' as "Elevation" (this field stores values of elevations) from the contour layer. After selecting units, the ground elevations are assigned to all the nodes.

Alternately, the ground elevations to the node can be assigned by a shapefile of the geo-referenced points surveyed along the roads.

5.3 ASSIGNING DEMAND TO NODES

The 'Load Builder' tool of Network software automatically assigns values of demands (Load) to nodes. The computation is based on the 'Thiessen polygon' and the 'Future Population Density' layer (as detailed in Chapter 4). A Thiessen polygon is generated around each node of the pipe network.

Network software generates polygons by a series of perpendicular bisectors of a line joining the two adjacent nodes (Figure 5.4), forming polygons around each node (Figure 5.5).
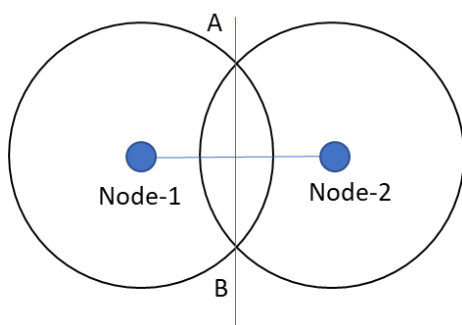

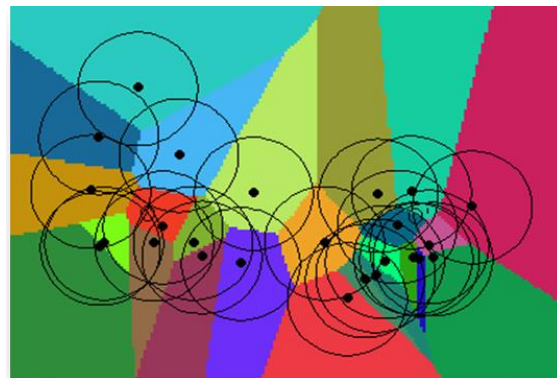Figure 5.4: Perpendicular bisector of a line joining the two adjacent nodes

Figure 5.5: Polygons formed around each node
(Source: http://www-personal.umich.edu)

Second important task is to assign the demands to each node. It is carried out by the tool called as, Load Builder. Load Builder (Figure 5.6) interpolates the population density in each polygon of the Thiessen polygons and then assigns value (depending upon the land use) to the node inside that polygon.
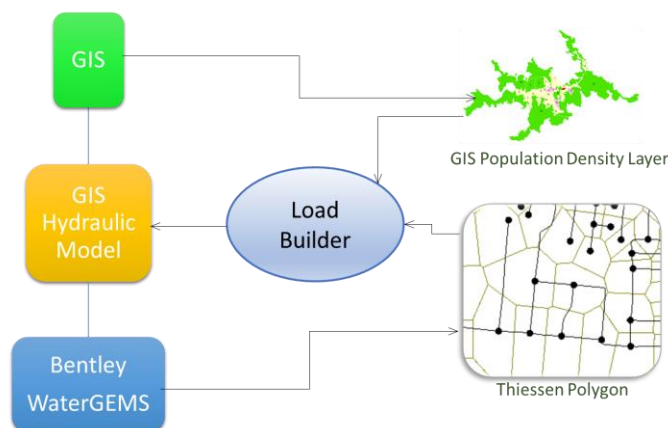

Figure 5.6: Assigning demand to nodes

There are three methods for processing demand data : Point load, Area load and Population/ Land Use Data. If the consumer data generated through survey is to be used, then the method would be Point Load. In this document, the method of Population/Land Use Data is used. The procedure is explained as below: -

Open Network software, in 'Tools' select Load Builder Wizard. Select Thiessen polygon layer in 'Service Area' layer. In 'Population Data', select population layer as the Future Population Density Layer as discussed in Chapter 4. Select Population density field as "PD" (which was earlier created in Population Density Layer). Select unit as Population/Hectare and then give Load Density of 135 (or 150 for metro city) Litre Per Capita Per Day (LPCD) for each ward name inside the 'Load Use Type'. After doing these steps, the demand values are assigned to each node.

5.4 CREATION OF OPERATIONAL ZONES

Operational zone is the jurisdiction of each tank to serve water supply. A schematic of the operation zone is shown in Figure 5.7.
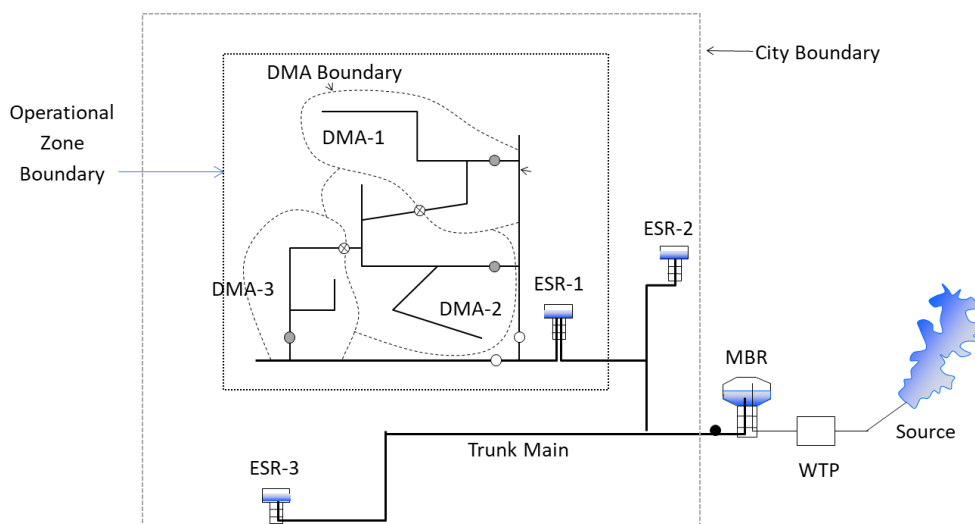

Figure 5.7: Operational Zone

5.4.1 FIXING BOUNDARY OF OPERATIONAL ZONE

Generally, tank's size and volume are determined by making mass curve calculations in excel sheet. It is expected that the tank would not overflow or get empty. To achieve this, a logic is developed as shown in Figure 5.8. This logic needs to be adopted in Excel sheet of mass curve calculations.
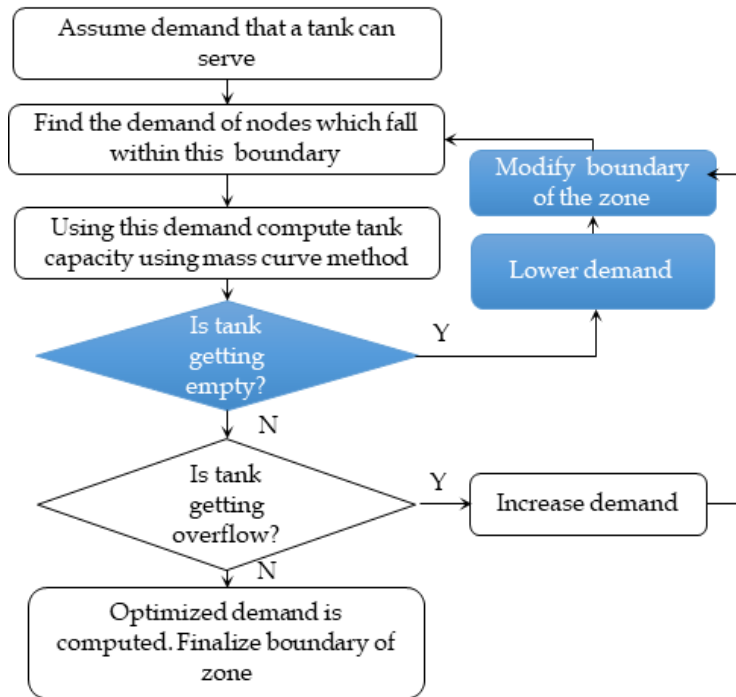
Figure 5.8: Logic for fixing tank boundary

Mapping Operational Zone Boundary: Logic shown in Figure 5.8 involves a number of iterations. To begin, approximate demand is assumed that a tank can serve and the tank is checked for boundary conditions - empty or overflowing. The iterations are carried out till boundary conditions of tank are satisfactory and, in that iteration, optimum demand of a tank is calculated.

Selection of nodes in Network software is also an iterative process. In the first iteration, the nodes are selected and sum of its demand is compared with the value of optimum demand of a tank. If the sum of nodes does not tally with the optimum demand, then the set of nodes is varied and the process is repeated till the sum of demands tallies with the optimum demand of tank. By Group Edit command in Network software, such nodes are exported to form a shapefile and it is then opened in GIS software. The boundary of Operational Zone is then easily determined.

Operational Zones are the building blocks of the 24x7 continuous water supply scheme and hence, above procedure of determining the boundary of the Operational Zone must be adopted while making design of distribution system. Operational Zones, of the Shimla city created by above logic, are shown in Figure 5.9. Red colour indicates Operational Zones for the newly proposed tanks.
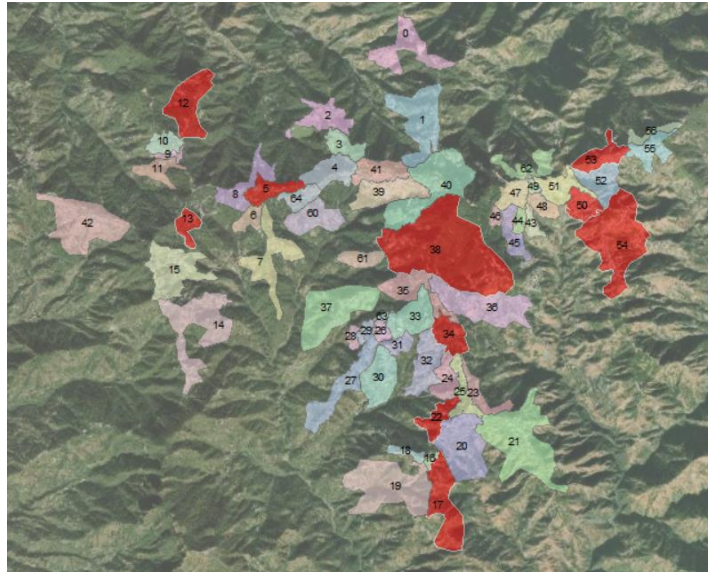
Figure 5.9: Operational Zones of the Shimla City

5.4.2 NEW TANKS

Boundaries of the Operational Zones of the existing tanks should be decided utilizing the above logic. However, after doing so, there still remains some of the areas that are unserved by the tank. New tanks are proposed in such areas and the Operational Zones (shown in red in Figure 5.9) are determined.

5.5 CREATION OF DMA

District Metering Area (DMA) is used to compute Non-Revenue Water (NRW) and prioritize the leak repair program. DMA must be hydraulically discrete and its size is so selected that the number of connections in each DMA remain between 500 to 3000. GIS helps to decide the number of DMAs in each Operational Zone. The Operational Zone, called as, 'Totu' in the Shimla city is shown in Figure 5.10. In this Operational Zone, the number of properties is 925, population is 15367 and number of connections is 4,520. Since, number of connections is more than 3000, two DMAs are created using GIS maps.

GIS helps fixing location of Flow Control Valves (FCV) at the entry point of the DMAs. In Figure 5.10, FCV-1 and FCV-2 are shown at the entry point of the DMA-1 and DMA-2 respectively. Knowing the quantum of water coming into DMA (by bulk meter installed at entry points) and quantity of water consumed (from consumer meters), the value of NRW is computed.
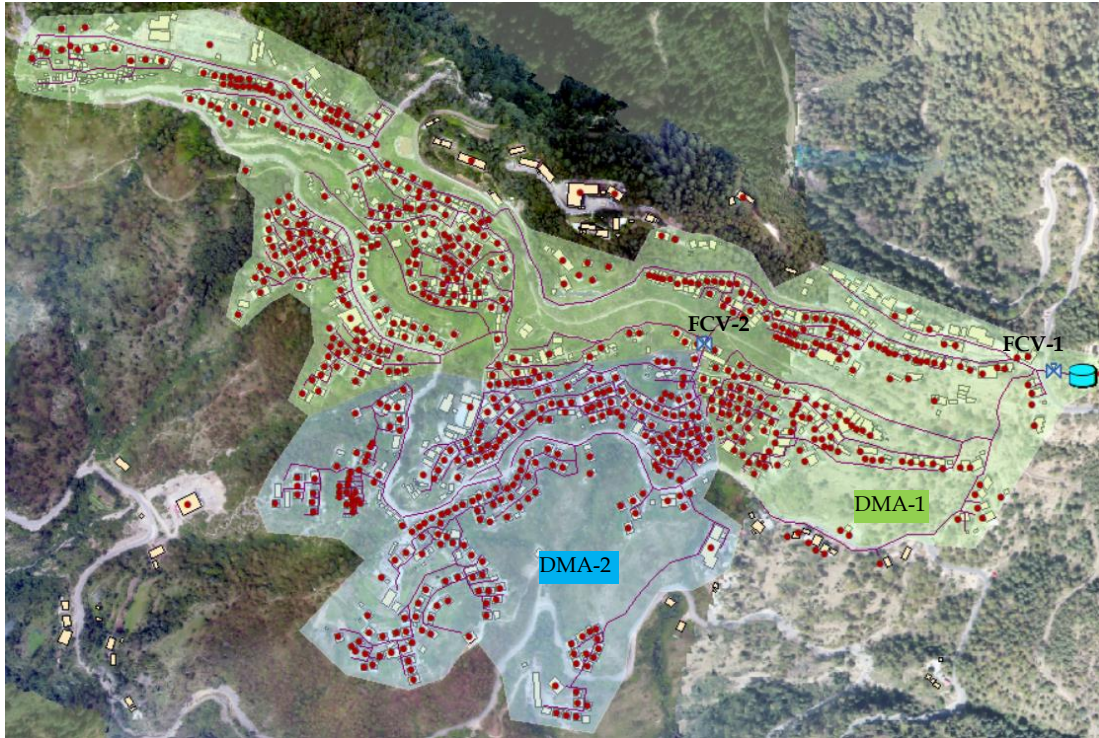
Figure 5.10: Operational Zone of 'Totu' in Shimla (properties in red colour)

GIS and Network software helps to decide location of isolation valves which are used to make segments in distribution system (Figure 5.11). Segments allow O&M team to repair any damaged pipe by closing the respective isolation valves.
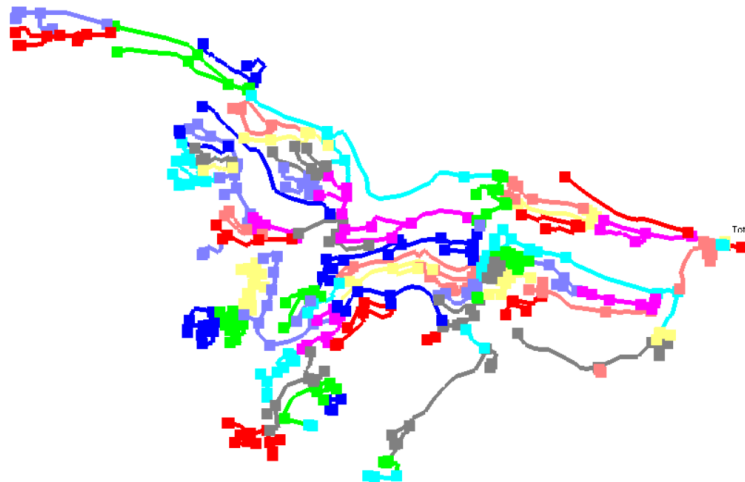

Figure 5.11: Segments in 'Totu' Operational Zone

Chapter 6

MAPPING SEWERAGE SYSTEM

GIS and sewer modelling are useful tools for spatial planning and design of sewerage systems. This chapter discusses integration of GIS with sewer modelling. Appropriate GIS software and sewer network software are used. A case study of Sewer Network Software Model for the *Smart City* of the Solapur (which is in Maharashtra state) is discussed here. Objective is to make design of the underground sewerage system for the area considered under the jurisdiction of the smart city of Solapur. After making the design, a strategy should be recommended that would help the corporation to lay sewer network in the area.

Sewer project is planned for increasing sewer coverage of the city and improving service level. The project focuses on- (i) collection of the domestic sewage by laying laterals and trunk mains in the area of town; (ii) transportation of the collected sewage to the wet wells of sewage pump stations and finally to the sewage treatment plant (STP).

6.1 PREPARATION OF BASE MAP

Base map is prepared by the steps enumerated as below:-

i.   In GIS software, online satellite imagery is added.

ii.   The OSM file is obtained from the Open Street Map (OSM) as explained in Chapter 3. The OSM file is processed by the Arc Toolbox and the shapefile of the road network is created (Figure 6.1).
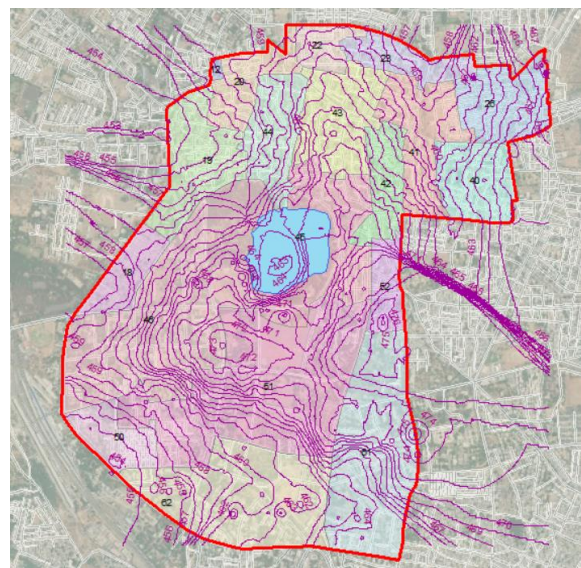

Figure 6.1: Satellite image and road network

Figure 6.2: Base map of Smart city of Solapur

iii.   Map of the ward boundary of the Smart city area available in AutoCAD format is geo-referenced and the shapefile of ward is generated.

iv.   Total Station survey is carried out in the smart city area. The contours which were available in the AutoCAD format are geo-referenced and the shapefile of the contours is generated.

Other shapefiles like lake etc. are added. Thus, the complete base map (Figure 6.2) is created.

6.2 IDENTIFYING LOACTIONS FOR SEWAGE WET WELLS

Wet wells of sewage pumping stations should be located at the lowest elevation. Therefore, it is necessary to map the lowest areas. Inverse-Distance-Weighted interpolation (IDW) surface identifies such areas.

6.2.1 TO CREATE IDW SURFACE AREA

Open GIS software; in Arc Tool box, open 3D Analyst Tools. Under 'Raster Interpolation' choose 'Topo to Raster'. Give 'Input Feature Data' as contour shapefile. The resulting IDW surface is shown in Figure 6.3.
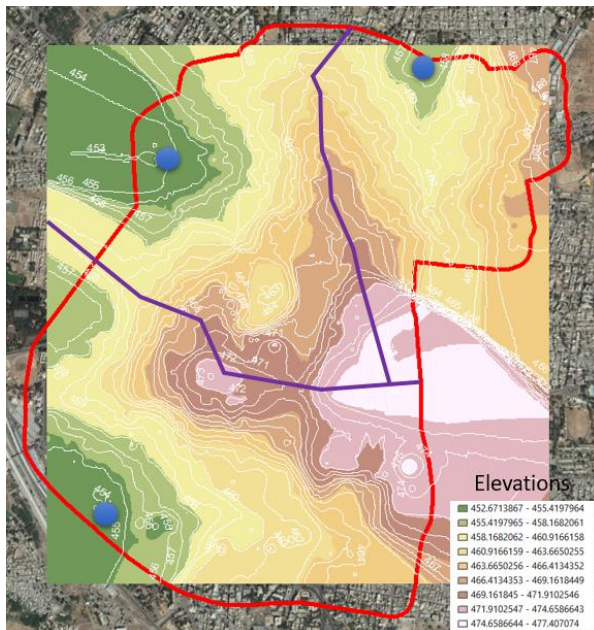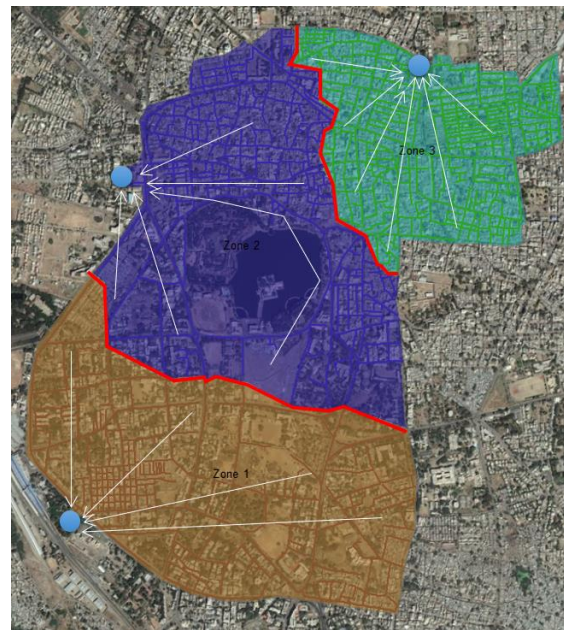

Figure 6.3: Ridge line

Figure 6.4: Formation of three sewer zones

Green areas shown in Figure 6.3 indicate lowest elevation area and blue coloured spot in the same figure represent likely spots for wet wells of the sewage pumping station.

6.2.2 TO CREATE SEWER ZONES

In Figure 6.3, three locations of wet wells and the ridge lines are shown. The ridge line determines the formation of three sewer zones which are shown in Figure 6.4. At these spots, three outfalls are shown in green triangles.

6.2.3 ACTIVE TOPOLOGY OF SEWER CONDUITS

Using the shapefile of road centre line, a sewer model is built up using the 'Model Builder' of the Sewer network software. New sewer conduits, thus formed, are represented by the blue lines. The new sewer conduits are to be connected to the existing trunk mains which are shown in bold red colour. Out of three sewer zones (Figure 6.5), eleven sewer districts are formed which are shown in Figure 6.6.

In Smart City, Smart Highway and Smart Roads are proposed for improving operation of vehicles, traffic lights and street lighting and also for monitoring the condition of the road, traffic levels and the speed of vehicles. Such Smart Roads in Solapur are shown in yellow colours in Figures 6.5 and 6.6. Sewer lines are to be laid on both sides of the Smart Roads.
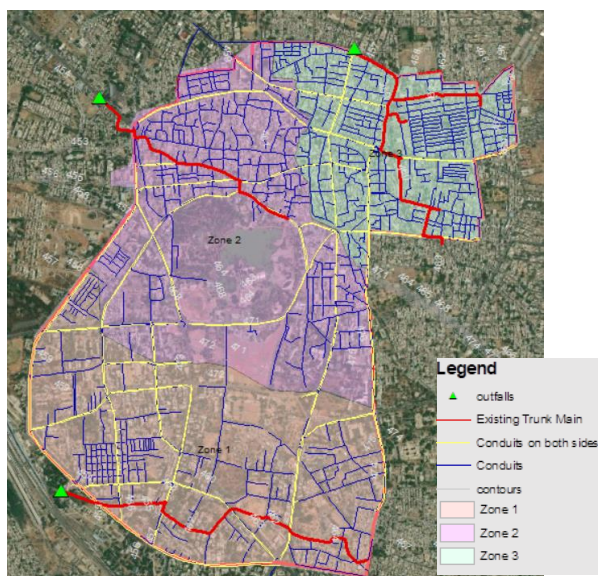

Legend

▲ outfalls
—— Existing Trunk Main
—— Conduits on both sides
—— Conduits
—— contours
  Zone 1
  Zone 2
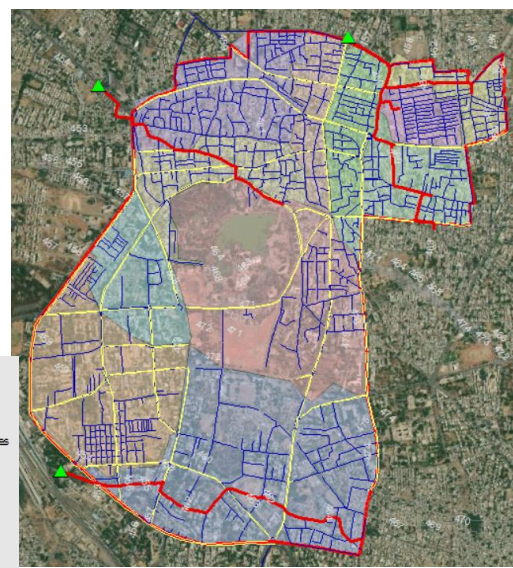 Zone 3

| Figure 6.5: Sewer Zones | Figure 6.6: Sewer Districts |

6.2.4 SURCHARGING AND OVERFLOWING CONDITIONS

(a) Surcharging of Sewer Conduits: Sewer conduits are said to surcharge if HGL > Pipe top but HGL < Ground Level. It is depicted in Figure 6.7. If pipe surcharges, there is a possibility of contamination of ground water and wells as shown in Figure 6.7.

Figure 6.7: Surcharging of sewer conduits	Figure 6.8: Overflowing of Manholes
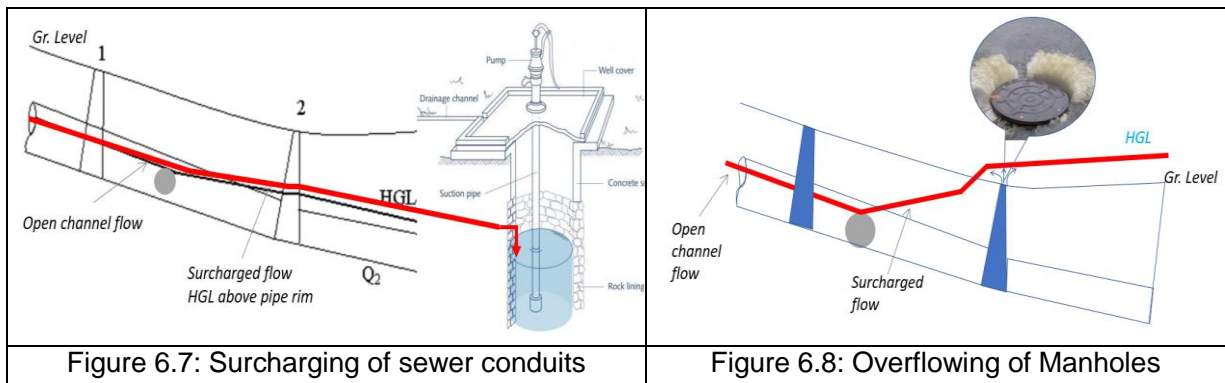
(b) Overflowing of Sewer Manholes: Sewer manholes are said to overflow if HGL > Pipe top and also HGL > Ground Level. It depicted in Figure 6.8.

Using the Sewer network software, the surcharging of sewer conduits and overflow of manholes are easily checked. After making design the scenarios of surcharging and overflowing are shown respectively in Figure 6.9 and 6.10.

In Figure 6.9, one pipe is shown as surcharging. This surcharging of the pipe is later on corrected by adjusting the invert level and changing size of the conduit. In Figure 6.10, one manhole is shown as overflowing which is later on corrected by adjusting the invert levels of the surrounding manholes and conduits.

The shapefiles of the conduits and manholes are created by exporting the conduit and manholes to ESRI shapefiles.

Figure 6.9: Surcharging of pipes	Figure 6.10: Overflowing of manholes
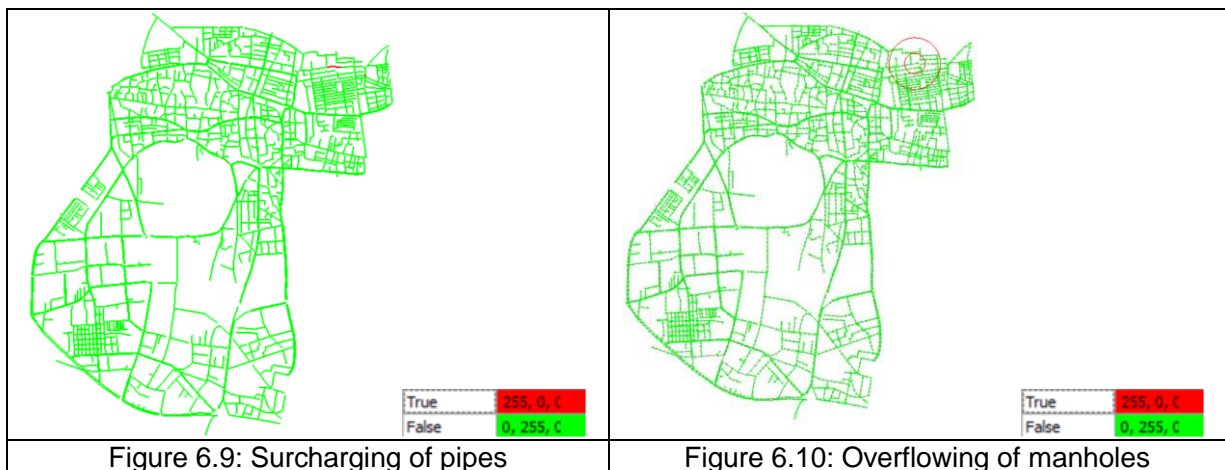
6.2.5 MAPPING PROFILES (L-SECTIONS)

Sewer profile enables to view the graph of pipe slope, Hydraulic Grade Line (HGL), Energy Grade Line (EGL) etc. along the longitudinal section. It helps to view performance of sewers like surcharging of pipe etc. A sample profiles of sewer network between the manholes at locations A and B are shown in Figures 6.11 and

6.12. Ground level is shown in green colour, HGL in blue and total energy in red colours.

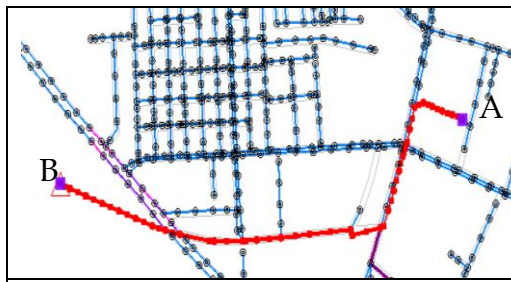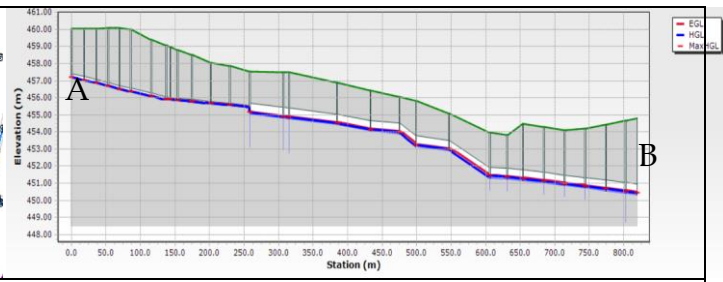|	
Figure 6.11: Sewer conduits from manhole at A to B	Figure 6.12: Profile of sewer from manhole at A to B

Engineering profile is shown in Figure 6.13. This profile provides an information of- (a) of conduit material, its diameter, slope etc. and (b) manhole information like its diameter, ground elevation, invert elevation etc.
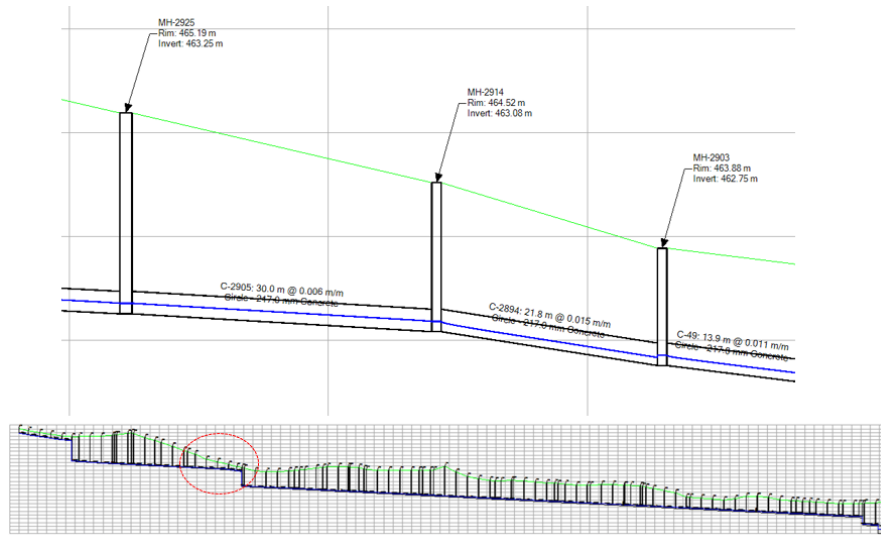

Figure 6.13: Engineering profile of sewer

Chapter 7

INSTITUTIONAL REFORMS AND CAPACITY BUILDING

7.1 INSTITUTIONAL REFORMS

Institutional reform is a process designed to adjust the relationships between an administrator, engineer-in-charge and the other staff working in the drawing section within the Urban Local Body (ULB). Administrative change is required for implementing variety of important modernization practices in water supply system.

Formation of GIS Cell: GIS cell shall be formed under the jurisdiction of engineer in charge. In this cell, a person called as GIS Expert, with qualification of Master in Geo-informatics should be appointed under the Engineer. There can be one assistant for him.

Duties of GIS Expert: GIS Expert shall be responsible for creation of the GIS maps of the water supply and sewerage system of the city. Under this, he shall transfer all maps in hard copy format to GIS software and form GIS maps. He shall be responsible for creation and operation of the following:-

   i.   Geo-referencing of the existing maps
   ii.   Digitization of the existing maps, including that of water source locations, ward maps, existing pipelines & sewer lines, tank locations
   iii.   Base map of city
   iv.   Operation Zone and DMA maps with locations of isolation valves, bulk meters, control valves such as Pressure Reducing Valves (PRVs) and Flow Control Valves (FCVs)
   v.   Information to be supplied to SCADA
   vi.   Consumer survey maps with geo-coding of the consumer's meters and the bulk meters
   vii.   Consumer billing and collection data with GIS coding of the consumers
   viii.   Reports of the defaulter consumers
   ix.   Track the leakage spots of pipelines
   x.   Creation and safety of archives of the shapefiles
   xi.   Custody of GPS instruments
   xii.   GIS reports
   xiii.   Maintenance of assets of water and sewer infrastructures of the city

Software and Equipment: Appropriate software shall be procured and given to the GIS Expert for his working. Equipment like the scanner and plotter, GPS instruments should be made available to the GIS cell.

7.2 CAPACITY BUILDING

Capacity building/ development is the process by which individuals and organizations obtain, improve, and retain the skills, knowledge, tools, equipment and other resources needed to do their jobs competently or to a greater capacity.

Capacity build-up of the engineers working in the water supply and sewerage departments is essential as the GIS concepts are new and recently introduced.

Training: Training is teaching, or developing in oneself or others, any skills and knowledge or fitness that relate to specific useful competencies. Training has specific goals of improving one's capability, capacity, productivity and performance.

7.2.1 TRAINING AT STATE LEVEL

Within the states, regional workshops should be organized for dissemination of knowledge of the GIS technology. All the heads of ULBs should be invited and the importance of the GIS to be used in their daily working should be emphasized. The heads of the ULBs should be directed to organize the training program in their respective cities.

7.2.2 TRAINING AT ULB LEVEL

Training of the GIS technology should be planned for the engineers as well as the staff working in the GIS cell. Reputed and experienced GIS experts should be called as faculty to impart the training. Training should be made mandatory to all the engineers and the staff working in the division. Unless he takes the training, he shall not be promoted. A trained staff shall not be frequently transferred.

7.2.3 TRAINING MODULES

Following topics shall be covered in the training module:-

    i. Overview of GIS in India
    ii. GIS - An essential tool of 24x7 water supply
    iii. Tools and functionality
    iv. Investigating geographic data
    v. Managing map layers
    vi. Symbolizing categorical data
    vii. Labelling map features
    viii. Using co-ordinate systems and map projections
    ix. Making a map layout
    x. Managing tables
    xi. Editing features and attributes
    xii. Creating geo-databases and feature classes
    xiii. Getting locations from attributes
    xiv. Solving spatial problems with query and analysis
    xv. GIS based survey required for 24x7 water supply

xvi. Methods of survey including the drones used for accurate survey

xvii. Generation of GIS based contours for giving levels to the nodes

xviii. GIS based consumer survey

xix. Use GIS in hydraulic model

xx. Imparting attributes to the pipes, nodes and tanks

xxi. Geo-referencing AutoCAD map on satellite image

xxii. Making GIS map of existing pipe lines and creation of shape files

xxiii. Marking of new pipelines in the city for making 100% coverage

xxiv. Giving levels to the nodes using GIS based contours and TREX

xxv. Demand allocation to the nodes

xxvi. Creation of GIS layer of ward boundary - Giving demand to nodes

xxvii. Allocation of population to the wards of the city for next 15 years and 30 years

xxviii. Computation of population density based on land use pattern

xxix. Joining population density data from Excel to GIS

xxx. Scanning, geo-referencing and preparation of Digitized Development Plan Map /Land use Land cover map

xxxi. 2D and 3D visualisation of data

xxxii. Transferring the data on support operating platform

xxxiii. Thematic map preparation with graphs and GIS reports

7.3 TRAINING OF UPDATING GIS MAPS

Once GIS maps of the water and sewerage infrastructures are prepared, ULBs should be able to update them. For this purpose, the intricacies of the GIS maps that are already prepared should be known and its training should be imparted to them. The concept for layers of various attributes is important. For example, if the ward boundary of the city is changed, the particular layer of the ward boundary should be selected and edited using the tools available in GIS software. Likewise if any population figure is to be added, it can be either added using editor tools or separately in excel sheet and the same excel sheet can then be joined with the concerned layer.

If there is need to add a new infrastructure, its shapefile can be created and added to the GIS map as separate layer. The training module as stated above already incorporates the creation of such shapefiles. If new house connections are to be added, the GIS asset management map should be opened and the layer of connections should be edited. The catalogue utility in the software helps to do this.

For making such changes the concerned engineer should approach the GIS cell in the ULB and request them to make the corrections/ additions/modifications. Once such corrections are made then the modification should be exported to the GIS based hydraulic model and after running the model, final correction can be made. The entire team comprising of engineers and the GIS personnel should be trained for carrying out such tasks.

DISCLAIMER

CPHEEO, MoHUA do not endorse any specific name of the company/organisation related to GIS software and their application in water supply and sewerage systems. The name of the company/organisation mentioned in this Advisory is only representative. The other software of various companies/ organisations may also be used for planning and implementation of water supply and sewerage systems by the City Planner & Designer.

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