Continuous Water Distribution Network Analysis Using Geo-informatics Technology and EPANET in Gandhinagar City, Gujarat state, India

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Abstract—In the present study, the Indian Remote Sensing (IRS) LISS-IV data covering Gandhinagar city was analyzed for understanding the road transport network, study area and various infrastructure in the city. CARTOSAT Digital Elevation Model (DEM) data and LISS-IV data were used to generate 3-D visualization image of LISS-IV image of Gandhinagar city. The specific objective of this study was effective planning, development of water distribution network and water distribution system analysis using EPANET software. For this analysis, the present data of water distribution system was acquired from Gandhinagar Municipal Corporation (GMC), Road and Building Department and Town Planning Department, Govt. of Gujarat, Gandhinagar. The population forecast of Gandhinagar City for next three decades was carried out using three methods namely, Arithmetic Increase Method, Geometric Increase Method and Incremental Increase Method. The water demand for next three decades for the estimated population was also carried out. The Google Earth Image of Gandhinagar city was downloaded and the elevation of nodes, length of pipe was recorded for 285 nodes and equal number of pipes. These data was used in EPANET Software for analysis of pressure, head loss and elevation. This analysis resulted in pressure and elevation at various nodes and head loss at various pipes. The results of data analysis in EPANET Software indicated that there is less head loss which is very essential for continuous pressure required for continuous water supply system in Sector-8, Gandhinagar.

The design and analysis of water distribution system of Sector-8, Gandhinagar indicated appropriate water distribution network and provide minimum head loss, maximum pressure and efficient diameter. This study would help the water supply engineers in saving time as this process is fast, less tedious, easy to incorporate the changes etc under one parasol.

Index Terms—Indian Remote Sensing Satellite (IRS), LISS-IV digital data, CARTOSAT-1 DEM, Geo-spatial method, EPANET 2.0, Pipe Network, Water Supply, Water Demand, Population Forecast, Google Earth Image, Elevation of Nodes, length of pipe

1. INTRODUCTION

Water makes life possible as without it; life and civilization cannot develop or survive. There is an increasing awareness that water resources exist in limited quantities, and for that available supply varies considerably during the course of a year. Apart from drinking, man also requires water for various other uses such as cooking, washing, sanitation, agriculture, industrial production, hydro-electric power, etc. to provide these various uses, the supply of water should meet the demand of the user, and should be satisfactory in quality and adequate in quantity, be readily available to users with pressure, and be relatively cheap and easily disposed of after it has served its purpose. Ineffective water supply and demand management, operational inadequacies improperly weaken and physical infrastructure in many urban areas. As the pressure to fill the gap in water and sanitation access grows, any people are making a case that all the nations of the world, particularly the poor ones, should go beyond just planning for basic water access and target for continuous water supply. Thus the municipal water sector in recent years has been subjected to a process of constant changes.

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1.1 Urban Water Scenario

The urban water supply and sanitation sector in the country is suffering from insufficient levels of services, an increasing demand supply gap, poor sanitary conditions and deteriorating financial and performance. According to Central Public Health Engineering Organization (CPHEEO) estimates, 88 percent of urban population has access to a potable water supply. Transmission and distribution networks are old and poorly maintained, and generally of a poor quality. Consequently physical losses are typically high, ranging from 25 to over 50 per cent. Low pressures and intermittent supplies allow back siphoning, which results in contamination of water in the distribution network. Mainly water is typically available for only 2-8 hours a day in most Indian cities. The situation is even worse in summer when water is available only for a few minutes, sometimes not at all.

Though 82 % of the urban population has access to safe drinking water, only 63 % of them have access to tap water. Besides, as against a target of 140 liters per capita per day (LPCD), the average per capita water supply in the country varies from 57 to 160 LPCD. In slum areas, the LPCD stands at a mere 27. Some of these statistics are really staggering. For example, the infant mortality ratio in India is 70, which is closer to some of the African countries. One of the main reasons for this state-of-affairs is the inaccessibility of safe drinking water and intermittent water supply. In Asia only 8 cities, Hong Kong, Kualalampur, Changdu, Osaka, Phnum Penh, Seoul, Shanghai and Tashkant get continuous water supply. Currently, no Indian city gets 24x7 water supply.

1.1 Need of Continuous Water Distribution System

Continuous water means water supply system, in which water is available in the tap round the clock on all days on a continuous basis as in case of electric supply. In a continuous supply, the distribution system remains continuously pressurized so that no contamination can come into the water pipelines even when there are small leaks in the system. It also means water with sufficient pressure so that it can flow automatically up to the third floor of the houses without need of any in-home storage or pumping. And, most importantly, it means water, free from contamination that can be drunk right from the tap without fear of illness.

In an intermittent supply, when the water supply is stopped, pressure in the pipelines is turned off, and there is a great risk of raw sewage being sucked directly into the water lines due to the negative pressure developed inside. Only continuous positive pressure in the water lines can protect the system from contamination.

In order to maintain a continuously pressurized 24x7 system, it is important that leakages be minimized and that consumers exercise 'Demand Management' through metering and tariffs, appropriate to promote conservation and recover costs while still protecting the poor. In a continuous water, the resources should be so effectively managed that the water lines are extended even into poor neighborhoods and that everyone has access to safe, sustainable and affordable 24x7 Water.

According to (A.Adeniran) a number of factors ranging from population expansion to inadequate existing facilities were thought to be responsible for the frequent shortage in watersupply to the metropolis. The study delineated the areas withinthe Municipality that are unserved or underserved by theMunicipality. Using EPANET 2.0 water model software, demand for the underserved and unserved area were calculated. A framework for taking management decisions such as an extension of the supply network and location of new facilities was given.
According to (Dr. H. Ramesh) water supply system is a system of engineered hydrologic and hydraulic components which provide water supply. The major objective was to generate satellite based thematic layers, tow and ward boundary maps and Geospatial Information System based census data and to estimate water demand, design of transmission lines and main pipe lines to meet the requirement of future demand. GIS has been used to integrate and estimate quantity of earth work to be excavated in terms of cutting and filling through Digital Elevation Model (DEM). The pipe network system is simulated to understand its behavior for different inputs using EPANET 2.0. Simulation has been carried out for hydraulic parameters such as head, pressure and flow rate. Total Energy Line and Hydraulic Gradient Line were prepared for the simulated results.

2. Study Area

Gandhinagar is the capital of the state of Gujarat in Western India. Gandhinagar is located approximately 23 km North from Ahmedabad, the largest city of Gujarat and lies on the banks of the Sabarmati River. The concept of the city is based on the grid-iron pattern similar to that of Jaipur and Chandigarh cities, India. The rectangular blocks of land known as sectors measure 1 km x 0.75 km and that have been presented sequentially. It is the second most planned city after Chandigarh. Gandhinagar is spread on an area of 57 km2. It is located at of 23.22′ N and 72.68′ E. The weather is hot in Gandhinagar from March to June. The maximum temperature ranges from 36˚C and 42˚C, the minimum ranges from 19˚C and 27˚C. The rainfall occurs from mid-June to mid-September. The Gandhinagar is planned for 30 Sectors, each having an area of 75 hectares approximately. This study deals with the analysis and design of water distribution system for Sector-8, Gandhinagar. The water supply for Gandhinagar city is based on Narmada canal from Nabhoi pumping station through Gujarat Water Supply and Sewage Board. The Sector-8 is supplied by the SaritaUdhyan head works. This sector include residential area, garden, commercial area, shopping area, school and Government quarters. The location map of Gandhinagar city along with road network is shown in **Figure-1.**

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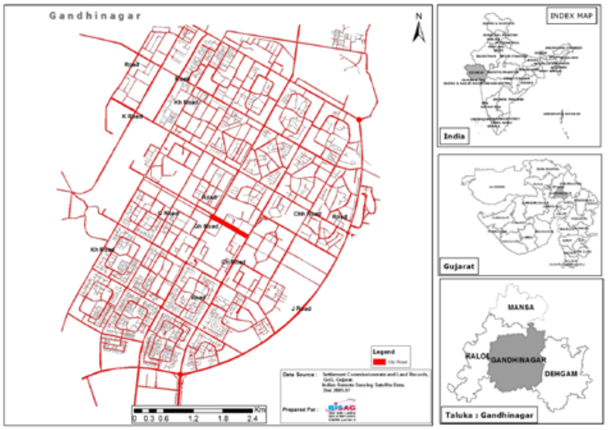

Figure-1: Gandhinagar city map along with road network

Google earth image covering Gandhinagar city was also downloaded and used for recording elevation of each node and length of pipes. The google image of Gandhinagar city along with details of sector-8 is given in **Figure-2.**

Figure-2: (a) Google Earth Image of Gandhinagar City; (b)Details of Sector-8 on Google Earth Image

3. METHODOLOGY

3.1 Data Used

3.1.1 Satellite data

Indian Remote Sensing Satellite (IRS-P6) LISS-IV and CARTOSAT digital data covering study area was analyzed and DEM was generated for the Gandhinagar city. The LISS-IV image of Gandhinagar city is shown in **Figure-3.**

Figure-3: IRS LISS-IV image of Gandhinagar city showing infrastructure and various Sectors

3.1.2 GIS data

The GIS layers like roads transport network, water bodies, district boundaries, etc. were used in this study.

3.2 Data Analysis

3.2.1 Satellite data analysis

The IRS LISS-IV digital data covering study area was analyzed and it broadly consists of following steps:

i) Image processing and geo-referencing using GCP library
ii) Administrative boundary superposition on satellite data
iii) Satellite data extraction covering study area using district boundaries
iv) Digital Elevation Models (DEM) generation using CARTOSAT data and LISS-IV data

The CARTOSAT DEM image of the Gandhinagar city is given in **Figure-4.**

Figure-4: CARTOSAT Digital Elevation Model image of Gandhinagar city

v) Identification of natural depression and elevation of study area
vi) 3-D visualization

Digital Elevation Models (DEM) are required for several tasks like generation of ortho-images,flood planning, erosion control, generation of contour lines, visibility check, 3-Dviews and others. The achievedaccuracy of DEM based on spaceimages is mainly depends upon the image resolution, the

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height-to-base-relation and the image contrast. A digital elevation model (DEM) is based on a higher number of points with X-, Y- and Z coordinates describing the area under consideration. Digital Elevation Models do play a fundamental role in mapping as well as in visualization. Cartosat-1 stereo-data was used to generate spatial resolution Digital elevationModel (DEM) covering the study area.The IRS LISS-IV digitalimage of Gandhinagar city is given in **Figure-5**.

3.2.2 GIS data analysis

The present canal network along with pumping station, main pipelines and distributaries pipelines in Gandhinagar district

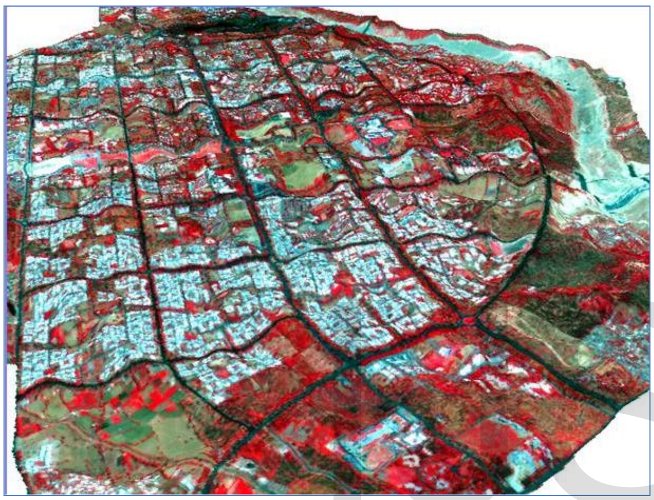

Figure-5: Digital Elevation Model draped on IRS LISS-IV data covering Gandhinagar City

were mapped in GIS environment to understand the present water supply system along with main pipelines and various distributaries which is given in **Figure-6.**

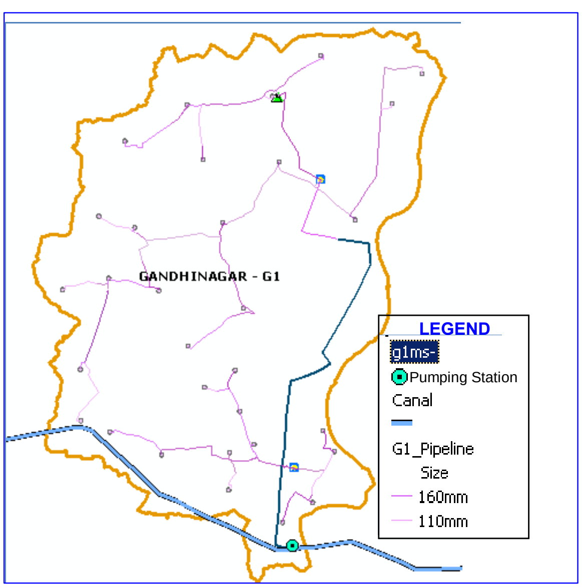

Figure-6: Gandhinagar city along with canal and major pipelines

Data Analysis and Geo-referencing was carried out in Arc GIS 9.1 software. In Analytical method, the sites were determined by generating the Digital Elevation Model (DEM) of LISS-IV and CAROSAT image of given area of interest and 3-D visualization of the same in Arc SCENE software. Using EPANET 2.0 water distribution system is prepared for the study area.

3.2.3 Google Image

The Google Earth Image of Gandhinagar city was downloaded and the elevation of nodes, length of pipe was recorded for nearly 285 nodes and equal number of pipes. These data was used in EPANET Software for analysis of pressure, head loss and elevation. These data has been utilized in EPANET 2.0.

3.3 Population and water demand forecast for Gandhinagar city

The population was forecasted using three methods as shown below with formulae:

Arithmetic Increase Method: $P_n = [P_0 + n\cdot\bar{x}]$,
Geometric Increase Method: $P_n = P_0[1 + r/100]^n$ and
Incremental Increase Method: $P_n = P_0 + n\cdot\bar{x} + (n(n+1))/2\cdot\bar{y}$

Where:
P_n= Prospective or forecasted population after n decades from the present, P_0= Population at present, n = No. of decades between now and future, $\bar{x}$ = Average (arithmetic mean) of population increases in the known decades, r = Assumed growth rate (%), $\bar{y}$ = Average of incremental increase of the known decades.

The estimated population in Gandhinagar City for the next three decades using these methods along with water demand is plotted in **Figure-7**. The population was forecasted up to the year of 2041. And for the same the water demand has been calculated. The population forecasting is carried out from the projection of the year of 1991, 1981, 1991, and 2011 from the Census Department, Government of India. From the results Incremental Increase Method gave good idea about the growth of population. The results for the future decade population are 2014 (213978), 2021 (236766), 2031 (260386) and 2041 (273491).

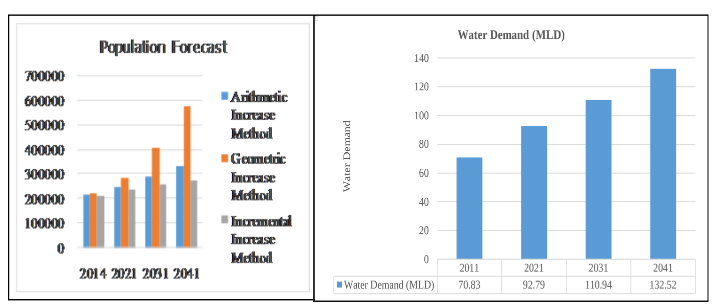

Figure-7: (a) Population Forecast; (b) Water Demand

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3.4 Water distribution system:

The layout of water distribution system can be divided into four types:

i) Dead End System,
ii) Grid Iron System,
iii) Ring System,
iv) Radial System

From the above four layouts Grid Iron System is appropriate because the roads of Gandhinagar city are designed and developed in a Grid Iron pattern, and the pipelines in such places can follow them easily.

3.5 EPANET SOFTWARE:

EPANET is developed by the US Environmental Protection Agency. It is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, etc. SaritaUdhyan elevated tank is selected as a water source for water supply in Sector-8 which has been situated at a distance of 704.72 m. Main pipe lines are provided based on the required discharge, pressure and the velocity of flow using Hazen-Williams hydraulic equations.

$$V=0.849C_{HW}R^{0.63}S^{0.54}$$

In which V= average velocity of flow in m/s, C_{HW} = Hazen-Williams coefficient, R=hydraulic radius (=A/P) in m, S = Slope of the energy line (=h_f/L).
The simplification becomes

$$h_f = \frac{10.68LQ^{1.852}}{C_{HW}^{1.852}D^{4.87}}$$

In which L is length of pipe and D is diameter in meter and Q is in cubic meter per second.

3.5.1 Elevation and base demand of nodes

The main objective of a distribution system is to developed adequate water pressures at various points of the consumers' taps. Depending upon the level of the source of water and that of the city, topography of the area, and other local conditions and considerations, the water may be forced into distribution system by gravitational system, by pumping system and by combined gravity and pumping system. The topography of the study area, Sector-8 in Gandhinagar city, is virtually flat. The maximum difference between highest and lowest elevation of each node is not more than 3.0 meter. The figures of elevation at various junction location is worked out using Google Earth. And the length between all to nodes has been recorded from the Google Earth image.

Gandhinagar city is planned in such a way that proposed pipe network for water distribution system is distinct which includes layout of City, dimensions of plot and road network. Every intersection for the pipe network of water distribution system is identified as a node. The base demand of each node is calculated in accordance with the forecasted population (in the year of 2041) served by particular node and per capita demand per day. The sample figure of node ID, elevation, base demand, pipe ID, length is shown in **Table 1.**

Table-1: Sample example of Node ID, Elevation, Base demand, Pipe ID and Length

Node ID	Elevation (m)	Base Demand (lps)	Pipe ID	Length (m)
Node 98	76.50	0.30	Pipe 83	50
Node 99	76.20	0.12	Pipe 87	52
Node 100	77.11	0.15	Pipe 89	116
Node 101	77.42	0.18	Pipe 84	97
Node 102	76.20	0.36	Pipe 86	51

The expected material selected for the pipe distribution analysis was cast iron with the roughness co-efficient for Hazen-Williams is 130-140. These pipes are sufficiently resistant to corrosion and may be last as long as 100 years or so.

Pipe network and nodes are created on the map and water demands at each junction were provided using EPANET. All the elevation of the nodes and length of each pipes are recorded from the Google Earth Image. Here one of the example is given in **Figure-8** showing the identification of node 115 and its elevation taken from Google Earth Image. At the same way, the length of the pipe was decided from the Google Earth image. The same procedure has been adopted to each pipe and node for the study area Sector-8, Gandhinagar.

Figure-8: (a) EPANET image showing Node detail; (b) Google Earth Image showing the same Node

4. RESULTS AND DISCUSSION

4.1 Area Calculation and 3D-visualization

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The purpose of the system of pipes is to supply continuous water at adequate pressure and flow. However, pressure is lost by the action of friction at the pipe wall and it also depends on the water demand, pipe length, gradient and diameter. The calculated area of Sector-8 was 1,281,142.35 square meters which had been recorded from ArcGIS. The area measurement of Sector-8 was carried out using ArcGIS as shown in **Figure-9.**

Figure-9: Area Measurement of detail study area; Sector-8

Visualization of the study area is done by the tool "3-D ANALYST" provided by Arc GIS (v.10).It is a technique which enables a user to visualize the image in a 3-D pattern. The advantage of 3-D lies in the way we see the information about the terrain. Geographic Visualization depends on psychological signs to create a natural 3-D scene on a 2-D computer monitor. In a sense, visualization models are not photographs, but pictures or renditions. Hence, the process of generating a scene is termed rendering. The LISS-IV DEM was draped on the IRS LISS-IV data Sector-8 for generating 3-D visualization images showing terrain and natural depressions and elevation. . Visual interpretation was done on basis of image characteristics like tone/color, texture, pattern, shape, size, location, shadow as well as associated elements in order to get idea regarding the infrastructure i.e.; red color shows the vegetation, white color shows built-up area, etc. (**Figure-10)**.

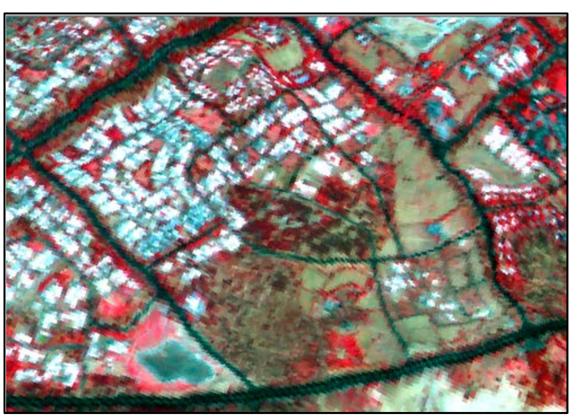
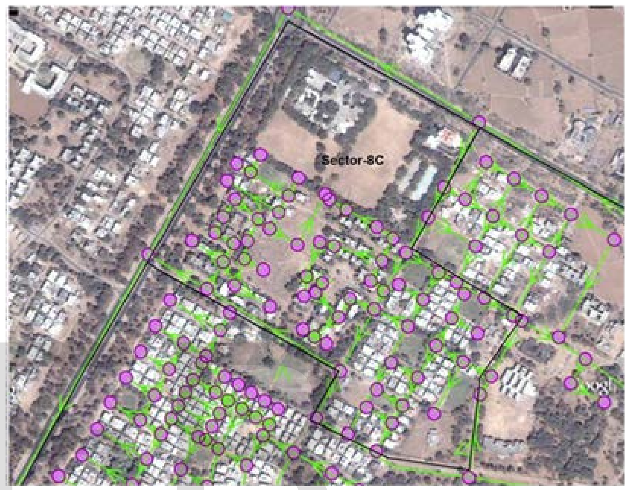


Figure-10 Digital Elevation Model draped on IRS LISS-IV data for 3-D Visualization indicating Sector-8

4.2 Outcome Results from EPANET 2.0

After deciding the layout of water distribution system for Sector-8, by providing data like elevation, length, demand at each node, diameter of each pipe, the results had been obtained for velocity, head loss, pressure from EPANET which suffice the requirement for the continuous water supply system with less head loss and at high pressure. One of the analysis and result parts of Sector-8 is described here. The water distribution network was drawn in EPANET 2.0 and superimposed on Google image of Sector-8, Gandhinagar. The **Figure-11** gives the idea of both google image and water distribution network for one of the part of Sector-8 of Sector-



8C.

Figure-11: Water distribution Network from EPANET 2.0 superimposed on Google Earth Image (A part of Sector-8C)

The results and analysis of Sector-8C is given below in **Figure-12 and Figure-13**.The graph of Elevation and Pressure gives good indication of the type of land and pressure into the pipes. Here for one of the Node Id 193, the elevation was 75.29 m which is less in Sector-8C and the outcome result from the EPANET for the pressure was 62.89 m. In general the analysis results show that if the elevation is less, then the pressure would be higher for those particular nodes.

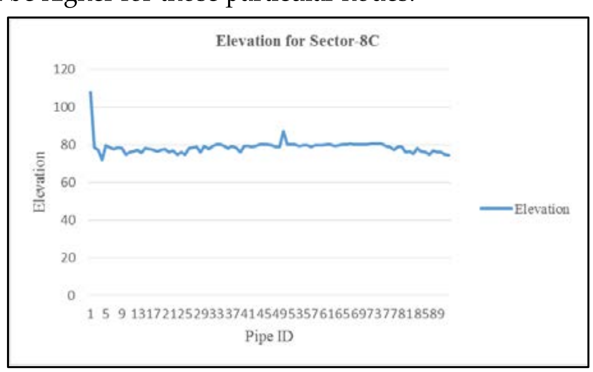


Figure-12: Elevation for Sector-8C

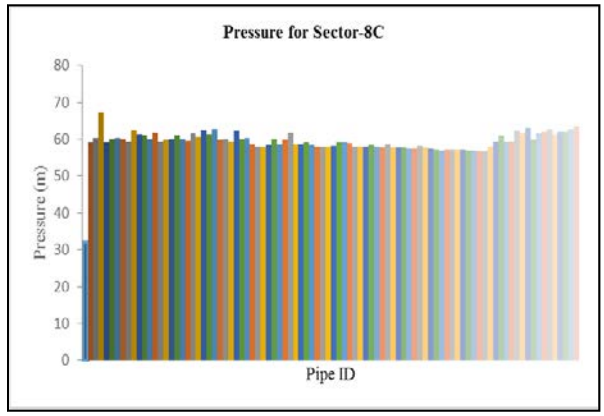


Figure-13: Pressure for Sector-8C

The **Figure-14** shows the representation of head loss (m/km) in each pipe of Sector-8C. From the analysis result, it could be clearly identified that if the pipe diameter is less for more flow, the head loss would be higher with high pressure. In this graph the maximum head loss recorded was 5 m/km. It can be decreased by increase in pipe diameter because the flow in the pipe, diameter, velocity, pressure and headloss are interrelated to each other that can be seen from the results and analysis.

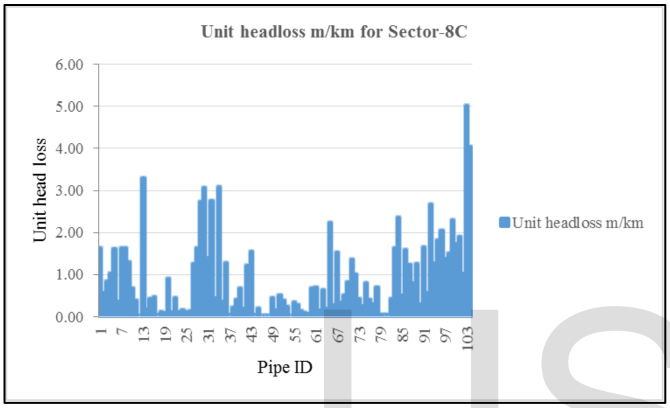


Figure-14: Unit head loss for Sector8-C

In briefly, to get efficient results the variable parameters such as pressure, head loss, velocity should be controlled. By keeping these parameter constant, the diameter can be changed to fulfill the requirement of efficient continuous water distribution system.

From IRS LISS-IV data of Sector-8 was extracted and water distribution network from EPANET 2.0 software was superimposed. This was comapred with the pipe network map of Road and Building department, Government of Gujarat and matched perfectly.The detail layout plan of water distribution system of Sector-8 from EPANET 2.0 superimposed on IRS LISS-IV image is shown in **Figure-15**.

Figure-15: Water distribution network from EPANET superimposed on IRS LISS-IV image of Sector-8, Gandhinagar

5. CONCLUSIONS

The study on "Continuous Water Distribution Network Analysis Using Geo-informatics Technology and EPANET 2.0 in Gandhinagar City" was carried out with the basic objective of analyzing present water distribution system and method to improve it.

- The population for Gandhinagar city was estimated using Arithmetic Increase method, Geometric Increase method and Incremental Increase method. From that Incremental Increase method was used for next three decade estimation and for that population the water demand was estimated.
- The present pipeline network was analyzed using EPANET 2.0 software, so that the idea of continuous water supply system can be implemented with proper pressure and without more head loss.
- The Google Earth image for Gandhinagar city was downloaded and elevation of nodes and length of pipes was recorded for nearly 285 nodes and equal number of pipes. And these data was used in EPANET 2.0 software for the analysis of pressure, head loss, etc.
- The Indian Remote Sensing (IRS) LISS-IV data covering Gandhinagar city was analyzed for understanding the road transport network, study area and various infrastructure in the city.
- CARTOSAT Digital Elevation Model (DEM) data and LISS-IV data were used to generate 3-D visualization image of LISS-IV image of Gandhinagar city.
- This study indicated that the outcome result from EPANET 2.0 software i.e.; pressure, head loss, etc. were checked with hydraulic equation and found to

be in agreement which can be used for modelling the water distribution system in Gandhinagar city.

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