APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM FOR WATER DISTRITBUTION NETWORKS THROUGH QUANTUM GIS PLUG-IN WITH HYDRAULIC SIMULATION FOR INFRASTRUCTURE AND DEVELOPMENT PLANNING

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ABSTRACT: Globally the vital renewable natural resource at present and for the future scenario is considered to be water. Globally all country has been striving to address on many research aspects by which we can sustain this resources considering various aspects such as quality, optimization, maintenance etc. In order to ensure the availability of sufficient water, it becomes almost imperative in a modern society, to plan and design sustainable water distribution network (WDN) to the various section of the community in accordance with their requirements and demands.This study combines application of Geographic Information System(GIS) as a framework for managing and integrating data by Quantum GIS i.e(QGIS) with mainly three hydraulic plugins i.e.Ghydraulics, Open layer and Qgis2threejs.Ghydraulics allows to analysis WDN with Epanet, open layer with open street maps whereas Qgis2threejs plugin helps in exporting terrain data, mapping canvas image and vector data to the web browser and later analyzing through hydraulic simulation in EPANET. The main challenge faced is the decisions to ensure delivery of water to several locations with optimally sized, and compatible with existing infrastructure considering the demand and supply.The application of Geographical Information Systems (GIS) is to visualize, and simulate entire WDN from source to household and creating a technology with considerable potential for achieving remarkable gains in efficiency and productivity. Generally, the planning of the pipeline grid is carried out using Survey of India toposheets and preliminary ground survey which are demanding and time-consuming.In this research, use of remote sensing via spatial data, along with digital elevation model (DEM) is carried out for assessment of pipeline grids. DEM generated are used to understand the possible topographic profile which indicates the possible routes of gravity flow and outlines a procedure for pre-feasibility analysis and least pipe network could be laid thus optimizing the project considering all above-said parameters.

1. INTRODUCTION

Water distribution systems serve the community and help power the economy by delivering water from a source(s) to its consumers. Water Distribution System (WDS) is comprised of three primary components; water source, treatment, and distribution network. Water sources can be reservoirs, rivers, and groundwater wells. Water treatment facilities disinfect the water to drinking water quality standards prior to delivering it to its consumers. The distribution network is responsible for delivering water from the source or treatment facilities to its consumers at serviceable pressures and mainly consists of pipes, pumps, junctions (nodes), valves, fittings, and storage tanks. WDS is required to supply water to domestic, commercial, and industrial entities above or at a threshold pressure with consumer demands that vary throughout the day, week, season and year. The minimum pressure that should be observed at junctions throughout the system varies depending on the type of water consuming sector and regulations governing the distribution system.

This paper presents a brief summary of the work carried out by various researchers on analysis and optimization of water distribution network & their effectiveness in the water distribution industry. The objective of the study is to determine various parameters in water distribution network of the study area such as discharge, velocity, pressure, head loss etc which actually controls the design of pipe i.e. diameter and also based on its merits different pipe materials will be assigned such as galvanised iron, cast iron steel, concrete etc and its adherence to the design parameters will be compared. To make the problem more realistic the water distribution network is simulated for a single period analysis i.e. (24 hours run with a demand pattern). Keeping the junctions and pipes as per city map and after assigning roughness coefficient for different pipe materials used various iterations is done and based on the result obtained the most efficient and effective pipe material can be finalised to make the network more sustainable.

Ingeduld P. et al. (2006) studied the intermittent water supply scheme with two case studies of Shillong, India and Dhaka, Bangladesh using EPANET tool. The alternate emptying and refilling of water pipelines make it difficult to apply standard EPANET based hydraulic models because of low pressure and empty pipes. There is various layouts of water distribution networks such as Dead End System, Grid Iron System, Ring System and Radial System.
EPANET 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, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated. EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. https://cfpub.epa.gov

India is the seventh largest country by geographical area, second most populous country and the most populous liberal democracy in the world. It is estimated that half of the Indian population will live in urban areas by the turn of the year 2050. The percentage of population residing in urban areas of the world (**World Urbanization Prospects, United Nations, 2014**) will reach 70% in 2050. A study (**Goldman Sachs Economic Research, 2011**) carried out estimated that 460 and 700 million people will move to Indian urban cities by the year 2020 and 2050 respectively. Rapid increase in population exerts tremendous burden on the infrastructure of the cities. Government has planned to upgrade large number of cities in India to ensure about the continuous supply through various schemes to improve and set infrastructural development for the coming future called Atal Mission of Renewal of Urban Towns (AMRUT) to convert 100 cities to urban cities **(waterworld.com).** The timeline of water distribution system modeling is shown below from 1930 till date to future in **Fig No.1**

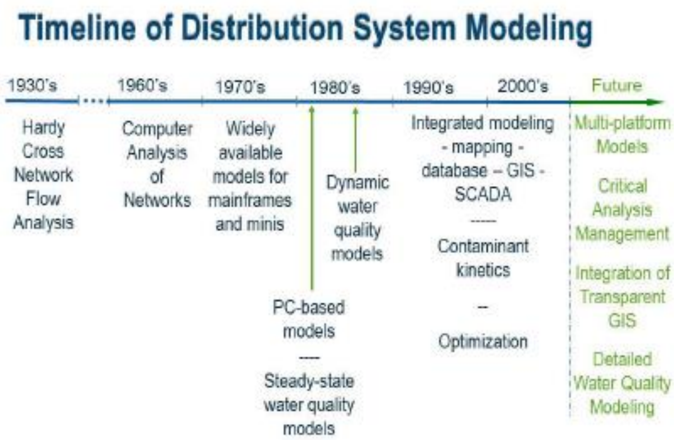

Fig No.1: Time Line of Distribution System Modelling

The Geographic Information System (GIS) is taken as an aid to visualize the sources and feeders and conceptualize the entire distribution network. **K. Vairavamoorthy et al. (2007)** This paper presents the development of a new GIS-based tool which predicts the risks associated with contaminated water entering water distribution systems from surrounding foul water bodies such as sewers, drains and ditches. **Baiyi Jiang1 et al. (2012)** Dynamic pipe network hydraulic modeling is the realization of the municipal water supply network to optimize an effective means of scheduling and science operations.. A detailed analysis of the operation, using WaterGEMS provides practical examples to establish a water supply network model based on SCADA data**. A Saminu, Abubakar (2013)**The application of GIS in spatial planning support tools have an important advantage through changing the valuation standards to visually illustrate and depict where the implications of different spatial decisions and alternatives are convenient. **I Soo Lee et al.(2014)** This study used geographic information system (GIS) to predict the spatial distribution of water demand according to building unit by applying the basic unit of water use by purpose. Based on the results, the buildings were then grouped into blocks to produce a methodology for controlling small districts using a microscopic approach to decrease water supply load based on water demand per block.

2. STUDY AREA AND METHODOLOGY

The study area on which the research is carryout out is an upcoming city near the vicinity of Navi Mumbai airport (Kunde Vahal) . The area is on the verge of becoming a prime location as it is in midway between Mumbai Pune Corridor. As the area is in planning stage, there are no water distribution networks as on today .The location of the study area (Kunde Vahal) lies in Navi Mumbai city in Maharashtra state, India lying between latitude 18°.58'.44.61" to 19°.0'.57.16" and longitude 73°.02'.54" to 73°.05'.39.61". General Elevation at Coastal area is

(RL 1.5 mts.), for plain (RL 3.0 mts) and Hills (RL 82 mts.) . As shown below in Fig.2(a) , the study are lies on both sides of the S- curve road highlighted in the image where at the present time no urbanization is done but future plans for that area is in progress as it is beside the upcoming Navi Mumbai Airport. The area, Kunde Vahal , is a town called Dapoli and its tentative street layout is uploaded in Google street map which is considered in my study to map the network. This study deals with laying of water distribution networks for which application of spatial and non spatial data were collected. For collecting saptial data remote sensing and GIS approach is was applied so that a birds eye point of view the whole topography is considered which can be further overlapped over non spatial data by using a hydraulic software known as EPANET .

2.1 Spatial Data: For collecting spatial data satellite image of the said location were downloaded from bhuvan website which is an Indian geo platform of ISRO (Indian Space Research Organisation) https://bhuvan.nrsc.gov.in/bhuvan_links.php .
From open data archive NRSC/ISRO Open data and product archive facilitates the user to select, browse and download data from this portal under three major categories. Ref. **Fig.No.2**

a) Satellite / Sensor
b) Theme / product and
c) Program /project.

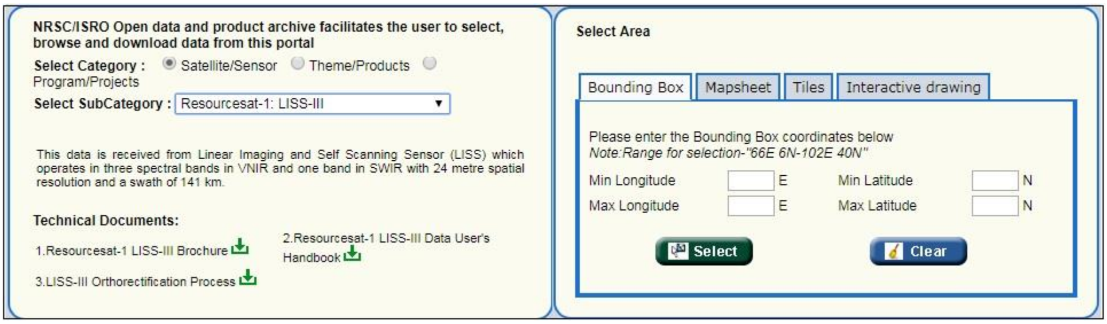

Fig.No.2 Open data archive NRSC/ISRO Open data and product archive facilitates-Bhuvan
(Source : http://bhuvan.nrsc.gov.in/data/download/index.php)

Resourcesat-1(Satellite) and LISS-3 (Sensor) was considered for this study as it merges with the objective of the research. **Table No 1** below gives a brief description of the tile, projection and image related spatial data.

Table No 1 : Brief description of Resourcesat-1 ans LISS-3 sensor are stated below

Tile related		
Tile size	**Collar**	**Naming Convention**
15' x 15'	40 pixels	As per SOI OSM
Projection Related		
Projection	**Datum**	**Resolution**
Geographic Lat / Long	WGS-84	0.000225 (~25 m)
Image Related		
Image File format	**Number of Bands**	**Radiometric Resolution**
GeoTIFF	4 (Band 2,3,4,5)	8 bits

This data is received from Linear Imaging and Self Scanning Sensor (LISS) which operates in three spectral bands in VNIR and one band in SWIR with 24 meter spatial resolution and a swath of 141 km. **Table No 2** gives the Metadata of satellite image tile

Table No 2: Metadata of Tile No:E43H01

1	Tile Name:	E43H01
	Number of Bands	4
2	Name of the Dataset	L3_SAT_8B_v1_73E18.75N_E43H01 _01feb13
3	Keywords	Resourcesat-2, LISS-III, 24m, India, ISRO, NRSC,Ortho
4	Geographic Location	Spheroid / Datum GCS, WGS-1984
5	Data Prepared by NRSC	Original Source Resourcesat-2 LISS-III(24m)
6	Resolution	0.000225 Deg
7	File Format:	Geotiff

For downloading the satellite image, image taken on 1st February 2013 was selected as it was the lasted updated image in Bhuvan portal .Either by giving reference of the topo sheet number or by selecting latitude and longitude we can select the tile but in this study the top sheet was available from http://www.lib.utexas.edu/maps/ams/india/ website which eased the work of selecting the tile by the combination of topo sheet and visual selection as shown in **Fig No.3**.

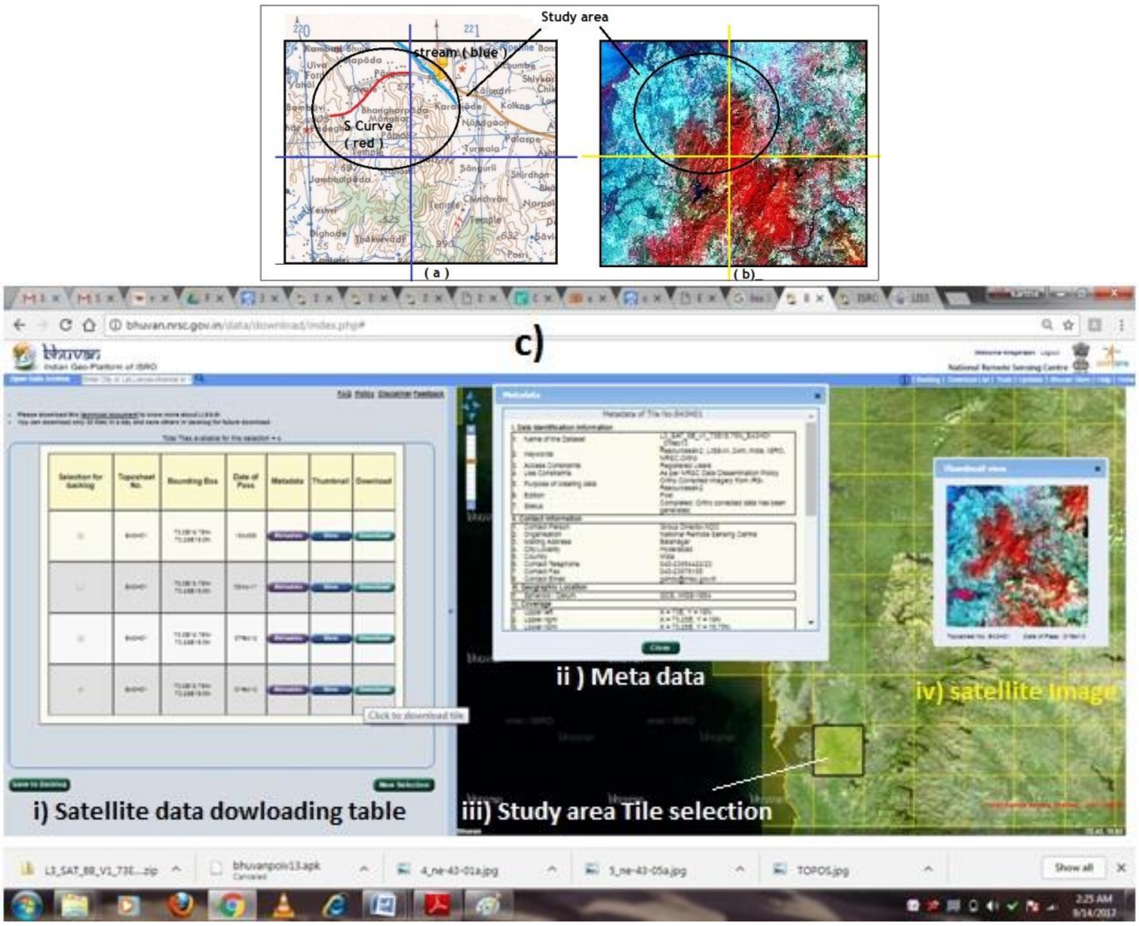

Fig No.3 : a) Topo sheet of the study area b) Image taken on 1st February 2013 c) satellite data downloading table along with metadata , Study area tile selection and satellite image.

Source: a) http://www.lib.utexas.edu/maps/ams/india b- c) http://bhuvan.nrsc.gov.in/data/download/index.php

After downloading all the four bands the image are stacked together which helped the research to understand the topography of the study area. Below **Fig No.4 show** the layer staking which helps to understand the topology and other spatial parameters helpful for digitization.

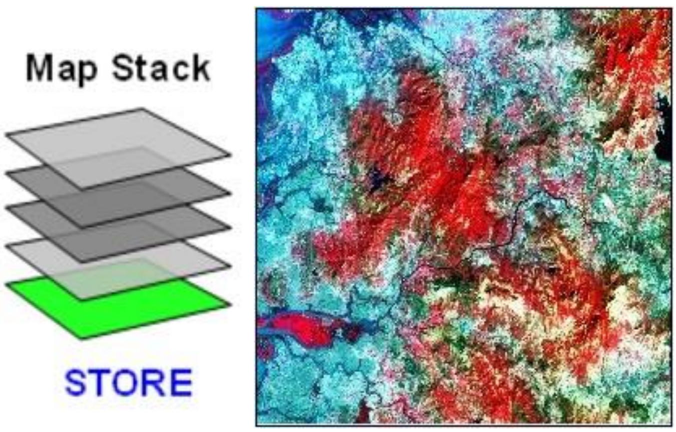

Fig No.4: False color composite FCC Image of Toposheet No E43H01, Date of pass 1st February 2013

These layers are later geo referenced so as to get accurate understanding of latitude and longitude.After geo referencing is done digital elevation model (DEM) can be generated in Quantum Geographic Information system (QGIS) which help to understand the ground slope which helps to lay the water distribution networks in the direction of gravity which reduces the introduction of pumps.

Quantum GIS Plug-in : To consider this gravity flow, QGIS (http://www.qgis.org)plays a good role in finding solution to lay the best possible network with the geo referenced topography. Refer **Fig.No.5** shows the simulation of water distribution network including tank , adding nodes and pipes with the application of QGIS.

Open Layers Plug-in: Google Maps, Bing Maps, OpenStreetMap layers and more .Qgis-openlayers-plugin is a QGIS plug-in embedding Open Layers functionality.

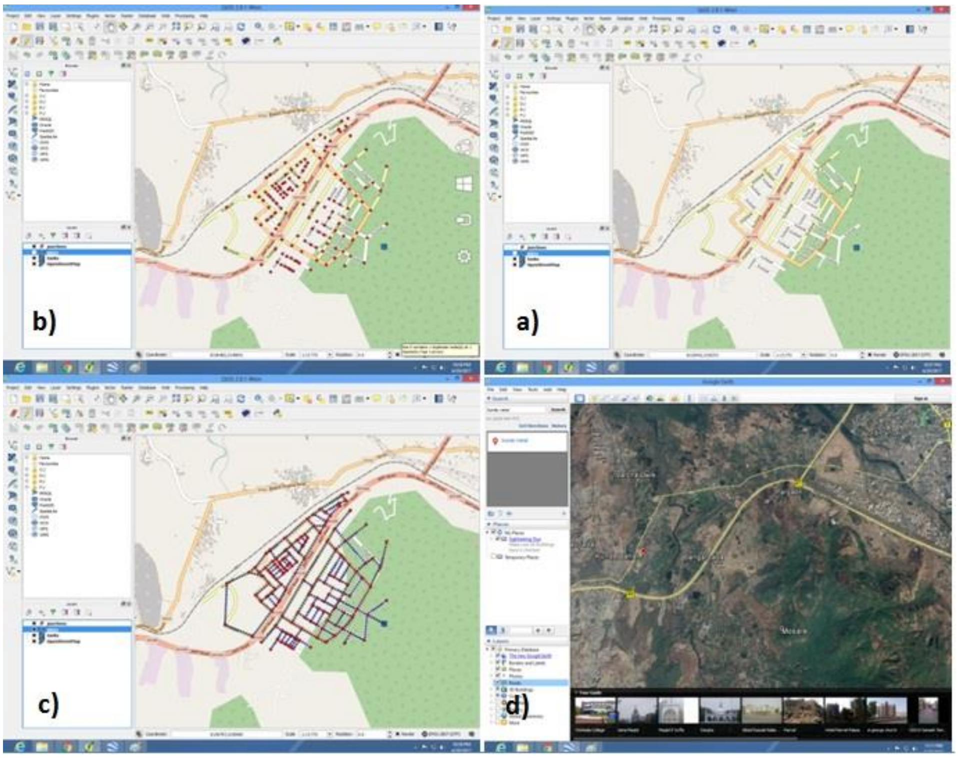

Fig No.5: QGIS plotting, networking and extraction of study area Anticlockwise from 1st quadrant
a) Adding a Tank**, b**) Plotting nodes (junctions) in a assigned network**,**
c) Joining all the said nodes with links (pipes) d**)** Google earth map of the study area

G Hydraulics: http://epanet.de/ghydraulics/index.html.en Hydraulic analysis of water supply networks (using EPANET).GHydraulics allows to analyze water supply networks using EPANET. It allows to write EPANET INP files as well as running an EPANET simulation from QGIS complete with loading the result data. GHydraulics contains a function to calculate economic diameters based on given flowrates. The functions are accessible from the Quantum GIS plug-in menu and toolbars.

Qgis2threejs: 3D visualization powered by WebGL technology and three.js JavaScript library. Qgis2threejs plugin exports terrain data, map canvas image and vector data to your web browser. You can view exported 3D objects on web browser which supports WebGL.

Keeping the objective of the study at the center, research is carried out radially to cover the circumference of the study area. The study area is selected keeping in view where there is no existing water distribution network. From Google Street Map the layout of the roads is taken and pipes are laid parallel to those roads and a water tank is placed on a hill beside the study area. The flow in the distribution system is kept through gravity and it is seen that no pumps are used so as to optimize the network and make the system sustainable and effective.

2.2 Non spatial data: The Land use Land cover(LULC) map was collected by the local authority as shown in Fig. No.5(a)This extracted map was then converted to a suitable AutoCAD file format (.dwg) refer Fig.No.5 (b).Further, this AutoCAD file was converted into a file format (.inp, .wmf) to be loaded in EPANET which is a public domain software which can be efficiently used to design any sort of network. It provides a variety of advantages like water quality analysis, extended period simulation, residual chlorine calculations for disinfection, etc. It can also be used to renovate or restore the existing water supply systems. It is available as public domain software with the relative nomenclature as EPANET 2.0 (Source**:** https://www.epa.gov/water-research/epanet)**.**

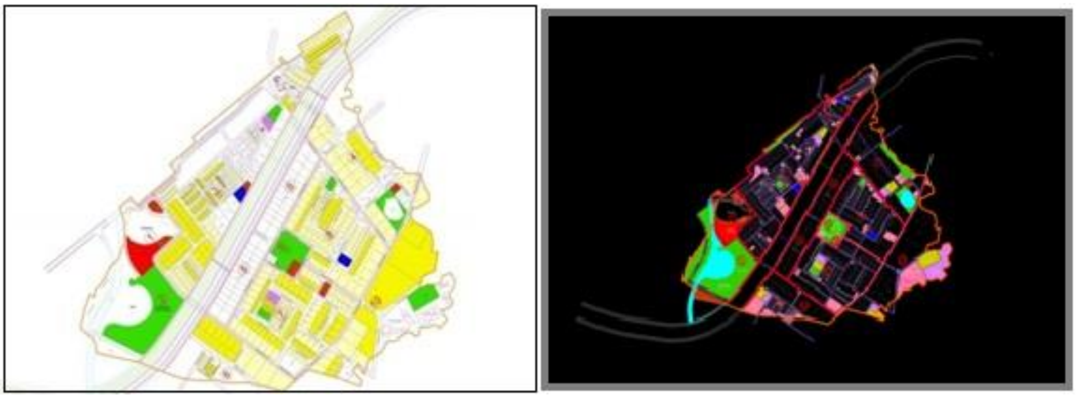

Fig.No.5 : (a) Land Use Land cover map (b) AutoCAD extraction of study area

For this project, Hazen-Williams (H-W) formula will have to be considered and the reason for the is explained in Table .1 below and the flow units are as MLD. The map of a location (which is to be studied) is obtained with help of GIS is converted to a suitable file type which is supported by EPANET. The number of junctions (nodes) is 142 in number with 207 pipes (links) and a reservoir.
The water distribution network will be solved using the Hazen William's formulae as it is the best-suited method for solving the gravity based water distribution networks. Hydraulic software EPANET will be used for determining discharge, velocity, headloss, etc. for the given WDN.

Table No.3 : Formula Selection criteria for the study area

	Parameters for Formula selection	**Darcy-Weisbatch**	**Hazen-Williams**	**Manning**
1	**Fluids**	* all fluids	* only water	* only water
2	**Friction factor "f" or roughness co eff "C"**	tedious to obtain "f "	* Easy to obtain " C"	Easy to obtain "n"
3	**Flow type**	* Any flow	* smooth flow	rough flow
4	**Open / Closed**	* Closed pipes	* Closed pipes	Open channels
5	**Selection for formula for this study**	Not Applicable	Applicable	Not Applicable

The hydraulic head loss by water flowing in a pipe due to friction with the pipe walls can be computed using one of three different formulas: Refer **Table no.3**
a) Darcy-Weisbach formula b) Hazen-Williams formula and c) Chezy-Manning formula
The Hazen-Williams formula is the most commonly used headloss formula all over the world.
It cannot be used for liquids other than water and was originally developed for turbulent flow only. The Darcy-Weisbach formula is the most theoretically correct. It applies over all flow regimes and to all liquids. Chezy-Manning formula cannot be applied as it is for open channels

Hazen William Formula:

1. Headloss (H_f) $= \frac{10.70Q^{1.852}L}{D^{4.87}C^{1.852}}$ **(i)**
2. Velocity (V) $= .354CD^{.63}S^{.54}$ **(ii)**
3. Discharge (Q) $= .278CD^{2.63}S^{.54}$ **(iii)**

Where,
Q = Discharge; C = Hazen William Coefficient; D = Diameter; S = Hydraulic Gradient
L = Length of the pipe; V = Velocity of flow; H_f = Head Loss

The roughness coefficient is an expression of the resistance to flow of a surface such as the bed or bank of a stream. Refer **Table No. 4**. and **Fig.No.6**

Table No.2: Different roughness coefficients for different types of pipes

Sr.No	Material Type	Roughness co efficient
1	# Vitrified clay	110
2	Galvanized Iron	120
3	Concrete (lined)	130
4	Cast Iron	140
5	Fiber /PVC	150

Fig.No.6: Different Pipe Materials (a): Cast Iron (b): Concrete (c): Fiber (d): PVC.

Each formula uses a different pipe roughness coefficient that must be determined empirically. Be aware that a pipe's roughness coefficient can change considerably with age.

3. RESULTS AND DISCUSSIONS:

A hydraulic model of the study is will be set up in the EPANET. All the nodes and the pipes will be installed in the desired location depending upon the demand of the given water system. For the node's parameters, such elevation and demand will be predefined based on surveys and the studies conducted for the given water distribution system. For the pipes data such as length and diameter are defined as suitable for the proposed system itself. Reservoirsor tanks are also set wherever necessary and boundary conditions for them are also being defined.The steps for simulation water distribution network

1. Set program defaults (naming convention, pipe roughness, unit system, head loss formula).
2. Draw the distribution system by inserting nodes and connecting with links.
3. Edit the properties of the objects that make up the system, eg, pipe length, and diameters, nodal elevations.
4. Describe how the system is operated.
5. Select a set of the analysis options time step, duration.
6. Run hydraulic analysis
7. View results and change parameters and repeat as necessary

Running single period analysis: In a single period analysis, the network is setup and then it runs for that instant only. The system basically checks all the parameters and determines whether the system will be able to meet the water demands or not. After running the simulation various diameters and flow variation can be seen as in **Fig.No.7**

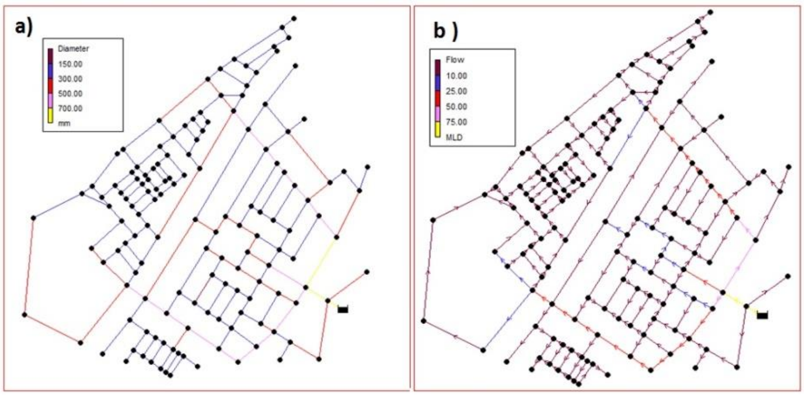

Fig.No.7: Network showing diameters and flow variations

Note that flows with negative signs mean that the flow is in the opposite direction to the direction in which the pipe was drawn initially. Demand pattern and Time series plot are created and discussed ahead. A demand pattern **Fig.No.8 (a**) basically represents a factor by which the demand will be multiplied depending upon the time of the day. Generally, a 24-hour pattern is set at one-hour time step. Following is the demand pattern which is being used for the given network. After the demand pattern is set up the system it is run again and results are obtained. Times series plot can be made for all nodes from any range between 24 hours demand pattern as shown in **Fig.No.8 (b).** After networking is done the program can be run and it gives us various Frequency plots for distribution of pressure, head and demand at any interval of time can be made so as to know the proper inter connection between every parameter. **Fig.No.9** shows graphical output of various nodal parameters.

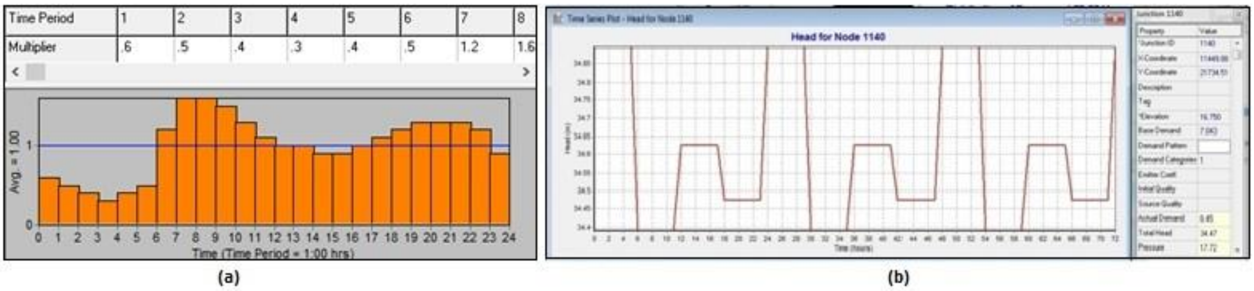

Fig.No.8 (a) Demand Pattern and **(b)** Time series plot

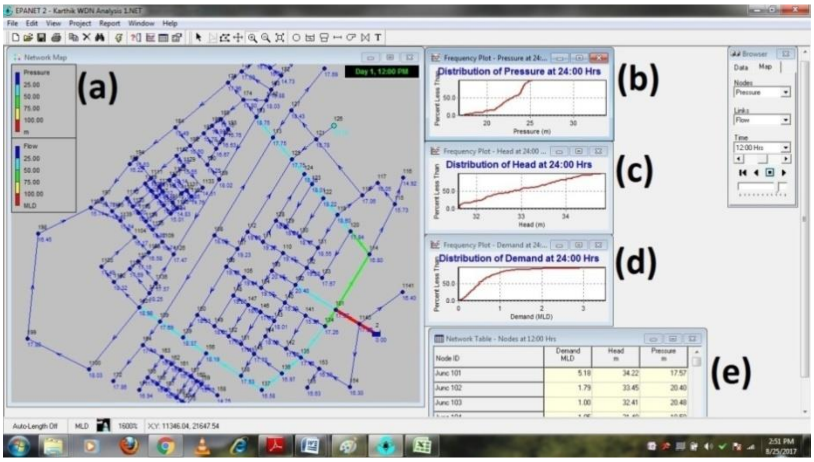

Fig.9 (a) Network simulation showing pressure and flow distribution **(b)** Frequency plots for pressure distribution **(c)** Frequency plots for head distribution **(d)** Frequency plots for demand distribution **(e)** Nodal table showing demand ,head and pressure.

The results which are obtained from running the system can be represented in a graphical manner as well. For each of the node as well as pipe various graphs relating to pressure, head, velocity, flow, etc. can be obtained. Some of the graphs for the given system are shown in **Fig.No.10**

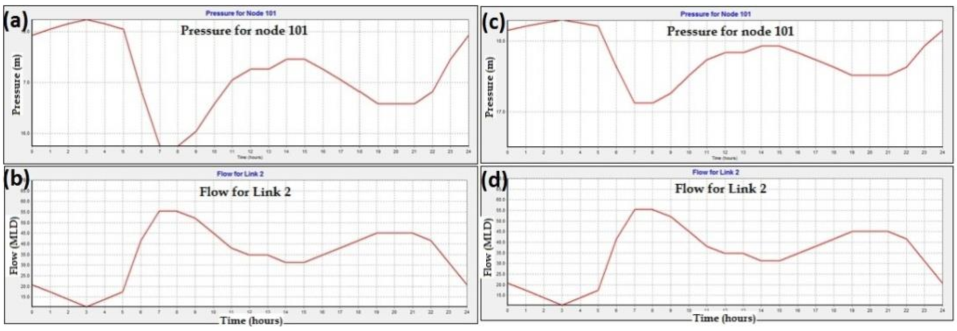

Fig.8 Graphical Results :(a)Pressure[Iron] (b) Flow[Iron] (c) Pressure[PVC] (d) Flow[PVC]

1. Using cast iron pipe: Using cast iron pipe for the system, negative pressure creeps in. In order to combat that higher quality pipes will have to be used in the system.2. Using PVC pipe:By using PVC pipe instead of cast iron pipe the problem of negative pressure can be solved easily.

4. CONCLUSIONS: With the help of simulation, discharge, velocity, and head loss of the proposed water network were found out along with respective graphs of all parameters vs. time is created which gives a better understanding of the pattern. The velocity of flow was determined easily and without any flaws and velocity vs. time graph was also produced. A graph of pressure vs time was also created which helped in determining whether adequate pressure was present in the system or not. Determining head loss in the proposed network helped the study to find values of roughness factor. When the cast iron pipe was used the head loss was in the higher ranges while when PVC pipes were used in the system the head loss decreased drastically. After running the single period analysis various design parameters such as head loss, pressure, velocity and direction of flow were determined for the proposed water network. The system was run with different pipe materials having different roughness factors and the results were used to determine the superior pipe material to be used for the water distribution network. It was found that roughness factor is a deciding criterion in the selection of pipe materials.

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