WEB BASED WATER UTILITY MANAGEMENT USING GEOSPATIAL TECHNIQUES – A CASE STUDY OF DEHRADUN CITY, INDIA.

Thesis submitted to the Andhra University, Visakhapatnam in partial fulfilment of the requirement for the award of
Master of Technology in Remote Sensing and GIS

Submitted by:
V.V.Sai Krishna

Supervised by:
Mr. B.D.Bharath
Mr. Kamal Pandey

Indian Institute of Remote Sensing, ISRO
Dept. of Space, Govt. of India Dehradun-248001
Uttarakhand, India

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Disclaimer

This work has been carried out in partial fulfilment of Masters of Technology program in Remote Sensing and Geographic Information System at Indian Institute of Remote Sensing, Dehradun, India. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the Faculty.

Dedicated
To
My parents

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(V.V.Sai krishna)

CERTIFICATE

This is to certify that the dissertation entitled **"Web Based Water Utility Management Using Geospatial Techniques – A Case Study of Dehradun City, India"** is the original contribution of **Mr. V.V.Sai krishna** towards partial fulfillment of the of the requirement for the award of Master of Technology in Remote Sensing and GIS at Urban and Regional Studies Department, Indian Institute of Remote Sensing (IIRS), Dehradun. The project contains original work carried out by him and he has duly acknowledged the sources of data and resources used.

……………………… ………………………

(Mr. B.D. Bharath)
Project Supervisor

(Mr. Kamal Pandey)
Project Supervisor

……………………… ……………………...... ………………………

(Mr.Pramod kumar)
Head, URSD, IIRS

(Dr. S. K. Saha)
Group Director, ERSSG and Dean (Academics), IIRS

(Dr.Y.V.N. Krishna Murthy)
Director, IIRS

Abstract

Geographic information systems (GIS) plays a prominent role in water utility management like the asset creation and management, infrastructure capital improvement, planning and analysis, optimizing field operations, water conservation etc. A case study was taken for Dehradun city to demonstrate the role of remote sensing and GIS in water utility management. This study explains the design of water utility model, creation of geospatial water utility database from various sources such as remote sensing data, DGPS surveys, utility surveys, scanned maps, CAD files etc. The existing water supply system of Dehradun was analyzed at both city and ward level with the help of GIS and geospatial water utility database.

A risk analysis was carried out for the overhead tank (OHT) asset in the water utility network. Analytical hierarchical process (AHP) based multi criteria decision making (MCDM) was used for calculating the weightages of all spatial and non-spatial factors. This study has identified and analyzed all the possible risk of failure parameters of OHT. They were classified as spatial and non-spatial factors. This study identified and analyzed all the possible risk of failure parameters of OHTs that are classified as spatial and non-spatial factors. A model was developed in the Arc GIS model builder to automate the geo processing tasks for calculating the risk factor of OHT. Finally a risk factor map of all the overhead tanks in the city was created.

A water information system (WIS) has been created with the help of free and open source software (FOSS) for the purpose of visualizing, updating, deleting and editing (WFS service) the data at city and zonal level. PostGIS is used for hosting the geospatial database and Asp.Net server side scripting language, C# command language was used for designing and creating the web portal.

The research highlights importance of RS&GIS techniques for water utility management and open source tools can be effectively utilized for the creation of online water information system which can provide necessary input at all levels for effective decision making.

Keywords: water utility management, overhead tank (OHT), GIS, water information system (WIS), Geoserver, C#.net, Microsoft Visual studio.

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List of abbreviations

AC	Asbestos cement
AHP	Analytical hierarchical process
CDP	City Development Plan
CGWB	Central ground water board
CI	Cast iron
CPHEEO	Central Public Health Engineering and Environmental Organization
CWR	Clear water reservoir
DI	Ductile iron
DNN	Dehradun Nagar Nigam
ERW	Electric resistance welding
FOSS	Free and open source software
GCP	Ground control point
GI	Galvanized iron
GIS	Geographical Information System
GoI	Government of India
GoU	Government of Uttarakhand
IIS	Internet information system
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KL	Kilo liters
Lpm	Liters per minute
M.S.	Mild steel
MCDM	Multi criteria decision making
MDDA	Mussoorie Dehradun Development Authority
OHT	Overhead tank
PVC	Polyvinyl chloride
SCADA	Supervisory Control and Data Acquisition
SWOT	Strength, Weakness, Opportunity & Threat
UJS	Uttarakhand Jal Sansthan
UPJN	Uttarakhand Pey Jal Nigam
UUSDIP	Uttarakhand Urban Sector Development Investment Program
WIS	Water information system

1 INTRODUCTION

Utilities include telecommunications, electric, oil, gas, transportation, water and wastewater treatment services(“ESRI UTILITIES,” 2012). Water is one of the most important utility service which helps improving the quality of life and enhances the productive efficiency of the people. One of the biggest challenges in the cities with aging water, wastewater, and storm water infrastructures is creating digital databases, managing information about maintenance of existing infrastructure and construction of new infrastructure. The utility providers confront various challenges while planning, designing and implementing their operations(“Cad Drawing Services, Cad Outsourcing, Cad Services,” 2008). The decision of improving infrastructure will require a large amount of diverse information which plays a key role in management. So an information system should be development for any water infrastructure improvement initiatives.

1.1 GIS for water utilities

A GIS is a special type of information system in which the data source is a database of spatially distributed features and procedures to collect, store, retrieve, analyze, and display geographic data(Shamsi, U. M, 2002). In other words, a key element of the information used by utilities is its location relative to other geographic features and objects. GIS technology offers combined power of both geography and information systems an ideal solution for effective management of water utility infrastructure. The effective management of water utility network can be possible by proper representation and analysis of network data(ESRI, 2011). The most important applications of GIS for water utility management are mapping, monitoring, modelling, infrastructure planning, maintenance, water conservation and response to emergencies (CPHEEO, Government of India, 2005). GIS is one of the most promising and exciting technology of the decade for utilities. It provides an ideal platform to integrate various business operations and technologies. GIS applications increase work productivity and save time and money, and are critical to garnering financial support for the GIS departments of an organization. They equip us with better communication and decision-making tools.

GIS-based data management of utility networks helps in improving operational efficiency, cost efficiency, data storage and retrieval etc. (Grise et al., 2012). The other advantages of Utility mapping are as follows(GIS Landmark, 2014):

- Asset locations are stored systematically.
- Comparison of base maps with different types of utility lines.
- Effective updating of asset information.
- Modelling of interdependencies among different utilities.
- Project planning and policy making.
- Map sharing and retrieving is very simple through digital or hard copy
- Integration with billing for easy updates

A sum of assets will make up the water utility network. The assets of a water utility network include pipelines, storage reservoirs, pump stations, hydrants, valves, meters, manholes, and any other components that make up the system(Santosh Kumar Garg, 2010). Some of the assets are present on the surface of the earth (vertical assets) and some are below the surface of the earth (horizontal assets). These vertical assets includes OHTs, pumps, reservoirs, and treatment facilities and the horizontal assets are water pipelines, the backbone of the water utility network. The overall financial matter of water utility network depends on management of each and every asset of that network(Kokkinaki et al., 2011).

Assets can contain other assets(Becker et al., 2011). For example, a water treatment plant can have other assets of electric utility such as motors and other electrical equipment that support the water treatment plant (WTP). A small fault in the water utility network can create a big problem which effects lot of people and can damage the property as well. The main motive of pipe-replacement projects are to safeguard the health of people in urban areas, to improve the efficiency of pipe networks, service delivery to the public as well as the economic factors like operation and maintenance of pipeline networks. Existing water utility networks are at higher risk due to lot of factors so for the sustainable management of urban water utility networks should include new methodologies for monitoring, repairing or replacing aging infrastructure.

The technologies that are commonly used for water resource management in conjunction with GIS are remote sensing, GPS and GPR surveying, internet, wireless technologies etc. are commonly referred to as GIS-related technologies(Thorat et al., 2012). Remote sensing has a wide range of applications in water resource management like water shed management at macro and micro level and many other("India WRIS," 2012). GPS and GPR technologies are used for mapping the assets of water utility network(Jaw and Hashim, 2013).

A web mapping application is very helpful for the utility providers to maintain, update and operate the services very easily(Sinha and Sekar, 2011). This is helpful to share and visualize the data among other department which can be possible to avoid the repetition of work.

1.2 Motivation and problem statement

Most of the investments are happening in infrastructure sector development. But these investments are not fully or properly utilized due to the deficiencies in the system. The infrastructure services are provided to public by different departments at a city level. There is no common body which will regulate all these services like water supply, waste water, electric, oil and gas utilities at one point. The limitations of infrastructure utilities are either the data availability, data types, storage or maintenance. Due to poor coordination and strategic planning there is more repetition of work, wastage of time, money and labor.

All these scenarios are having a serious consequences on the lives of the people like the quality of life, life expectancy is decreasing and the cost of living is increasing. **"This motivates to understand the present situation of the society, the social behavior of the people, the institutional setup of city's administration and various challenges faced by utility providers which ultimately leads to take up this project for creating, analyzing planning and development of geo database of water utility networks with the available data" for sustainable and planned growth of city.**

1.3 Research objectives

- To create a geospatial database of water supply utility network for Dehradun Municipal Corporation.
- To assess the existing water supply system and finding the risk factor of overhead tank asset in the water supply utility network.
- To create a web portal for visualizing and editing of water supply utility network data at different levels by using free and open source software.

1.4 Research questions

- What are the issues in creating a geospatial database from different sources?
- What are the issues in analyzing the water supply system and what are the possible methods to find out the 'risk of failure' parameters for an overhead tank asset in the water supply utility network?
- What are the issues in creating web application with respect to spatial data and analysis?

1.5 Scope

The scope of the projects is to create the geospatial database of water supply utility network up to primary and secondary pipelines and will not consider the household water supply connections. Also the mapping of assets limits to the data availability.

2 LITERATURE REVIEW & THEORETICAL CONCEPTS

2.1 Technologies for utility mapping

There are various advanced technologies for mapping the sub-surface utilities. They include Induction Utility Locators, Magnetic Locators, Electromagnetic Surveys, Ground Penetrating Radar, Acoustic Location Methods, and Non-Destructive Air-Vacuum Excavation ("Preparation of utility maps of cities using Advanced technology," 2013). Also there are technologies for mapping the surface assets of utilities which includes DGPS, mobile GPS, Total station, interpretation from the satellite imagery or aerial photographs etc. Different technologies are used for mapping the utilities at different accuracies based on the objective of mapping of utilities.

Image interpretation can be enhanced by merging the high resolution data with coarse resolution data(Kumar et al., 2008). Cartosat-1 and LISS-IV data was merged together to get high spatial resolution(Gupta and Jain, 2005) with good spectral information which was then used for monitoring the Waste water disposal, drainage problems in the event of rains, encroachment of tanks, stagnant water bodies through the creation of environment GIS(Ghouse Shaik Mohamed et al., 2012).

2.2 Database design and creation

The basic thing for the preparation of geospatial databases of water supply and storm water utilities is the preparation of respective utility models("AM/FM system for storm water and underground water facilities," 2013). This project mainly aims at creating the database of water supply and storm water utilities and it explains "stages and the method for implementation of AM/FM system as well as the advantages and opportunities of utilizing high-resolution satellite images and RTK survey for AM/FM systems". In this project they have done an exclusive DGPS survey's for mapping the assets of utility networks and integrate the attribute data collected from the municipality. Finally they have concluded that "minimum requirement expected from urban imagery is: 1m or a better resolution, Ortho-rectification to have map precision (e.g.: 1/1000 to 1/5,000), i.e. to produce Ortho photo maps".

The most challenging task in water utility management is creation of authoritative repository of water, waste water, storm water utility networks. Asset data in the GIS must be accurate w.r.t geographic location, descriptive, and temporally up-to-date. As a result, water, wastewater, and storm water utilities are now heavily focusing on quality assurance (QA) and quality control (QC) to ensure the GIS data truly meets their needs. The relevant tools and techniques which are helpful in maintaining the quality assurance and quality control are infrastructure editing toolbars, capital investment planning, production mapping, JTX, workflow manager etc. for creating, storing, analyzing, developing and manipulating the asset data(ESRI, 2011).

(Crawford, 2012) has designed and implemented a Geographic Information System (GIS) for the Water, Sewer, and Electric Departments for the City of Calhoun, Georgia. He has collected CAD drawings of utility networks and geo reference it for creating the database which helps in efficient management of utilities and sustainable development of Calhoun city. His thesis concluded that after implementing the GIS the efficiency has increased in all those departments comparing with CAD drawings.

2.3 Urban water supply analysis

(M. R. Jelokhani et al., 2013) has explained that the integration of GIS with GPS for cost-effective water utility disaster management. The GPS device used by lineman gives his location. The location based service group helps in finding optimal path by considering various situations to reach the water leakage point. A cost model was created which combines different criteria with specific weights in order to provide the costs for streets to be used in the optimal path finding process. The network analyst tool provided in ARCGIS helps in performing the network analysis.

There are different models available for the representation of utility networks like Industry Foundation Classes (IFC), ARCGIS and INSPIRE but there are advantages and limitations to represent in 3D space. So a new model is created for the representation of utilities in 3D space with the help of NetworkFeature and Feature Graph and it is shown in the following figures 2-1 and 2-2. The "main concept of modeling approach is the dual representation of a NetworkFeature according to which each network component can be represented both by its 3D topography and by means of a complementary graph structure called Feature Graph (Becker et al., 2011).

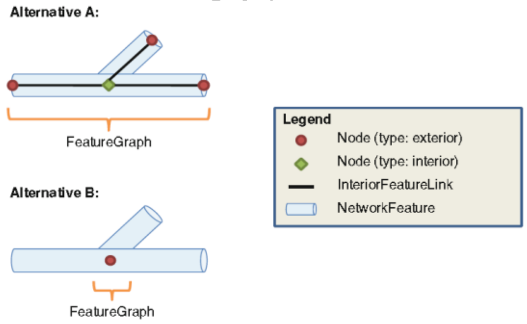

Figure 2-1: Feature graph

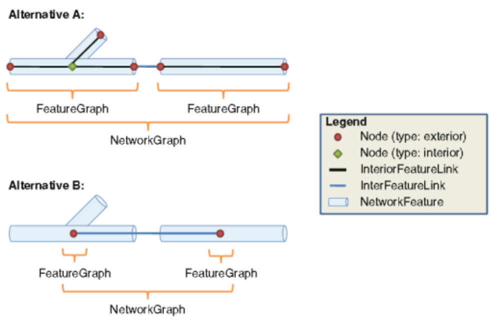

Figure 2-2: Network graph

The concept of digital city is where all the data repository of different sectors water supply, storm water, sewer and all the data like city plans, its rules, regulation etc. should be present at one place. With the help of these data, urban floods can be managed very effectively. GIS techniques can be used to calculate the risk of pre-disaster, during the disaster and after the disaster(Price and Vojinovic, 2008).

(B.Sundararaman et al., 2012) has explained the role of remote sensing and GIS in designing the water distribution system. A land use/land cover map was generated with the help of LISS-IV data. Sewage & Water Distribution Network is digitized by using toposheet's and overlaid on Land use & Land cover Map. Present population and expected rate of growth are critical factors in design of Water Distribution and Sewage Network in Madurai City. The overlay analysis shows the problematic areas of water supply and sewage in the city and also helped in finding out feasible solution.

2.4 Risk factor analysis of assets in a water utility network

(Schultz, 2012) Alexander John Schultz has described that the risk factor of the pump station asset in water utility network is mainly based on the probability and criticality factors. "Probability is defined as the likelihood that a given asset (i.e., a pump) will fail in a given length of time. Criticality is defined as the consequence of asset failure or the severity of the impact ". There are both spatial and non-spatial criterias for each factor. By using weighted overlay analysis an overall criticality and probability factors are found. Finally an overall risk factor was calculated by multiplying both the criticality and probability factors. And then the pump stations are classified as very low, low to moderate, moderate to high, high and very high risk.

(Christodoulou et al., 2009) has found the risk of failure of pipeline assets in a water utility network. To transform the patterns of the pipeline network behavior and their characteristics into a knowledge-repository and a DSS, they have used the artificial neural networks (ANN) and fuzzy logic. The neurofuzzy technique helps in "allowing the system to incorporate both objective and subjective (or linguistic) judgments". It also helps in incorporating the imprecise data for pattern identification and generalize them into a knowledge repository". The study has concluded that the major factors like water pipeline's age, material, diameter, breakage history etc. can contribute to the risk factor calculation of urban water pipeline network.

GIS plays an important role in utility asset management. A multi-purpose utility model consists of a database of all the utility networks like water pipelines, sewage system, electric, telephone, telecommunication and roads. This multi-purpose utility model is an aid for management and development of future plans. The "various dimensionalities of GIS (2D, and 3D) can be used to accomplish various tasks in multi-purpose utility model". This model is very useful in incorporate the exact location of breakdown of water, drainage pipelines in GIS with the help of leak detectors(Abdelgiom et al., 2012).

Hamilton city is an island city in New Zealand, the Waikato river flows through the city which acts as a source of drinking water. The water supply system was established in 1970 since then the water demand is increased heavily. The project mainly focuses on analyzing the distribution system and treatment station capacities, the need for a new reservoir and the interrelationship between these assets. MIKE NET was used in mapping, developing and analyzing water supply distribution system and gave a sound recommendations for water predictions(*Water Distribution System Strategic Planning*, 2006).

2.5 Web portal creation

2.5.1 Microsoft Visual Studio

Microsoft Visual Studio is a collection of many tools and services for developing wide range of applications that works on the desktop, web, devices, and the cloud. It can support multiple languages like HTML, JavaScript, C# and C++ etc. so that one can use their own existing skills to develop the applications with Microsoft Visual Studio's state-of-the-art development environment. It provides a platform to integrate the applications developed by using different languages/scripts by different people for a desktop/web application. The development tools used for this integration of applications are developed with different languages like Eclipse and Xcode etc.("Application Development," 2014). It supports other languages such as Python, M, XML/XSLT, XHTML, and CSS.

Microsoft Visual Studio provides a code editor for supporting the IntelliSense and code refactoring. The debugger works at two levels such as source-level debugger and a machine-level debugger. Microsoft Visual Studio has built-in tools like class designer, web designer, form designer for building GUI applications, and database schema designer. It allows the plug-ins which enhance the functionality of the tools and services at almost every level by adding new toolbars like visual designers and editors for domain-specific languages, support for source-control systems and toolbars for software development lifecycle("Microsoft Visual Studio," 2014).

There are so many open source software for creating the static and interactive websites for with the spatial data. One among such software is MapwinGIS which is a library used with .NET for creating the user interactive desktop application. A study on this is carried by (Himanshu Deshmukh, 2013) and a desktop based user interactive mapping application for valuation of real estate was created. The spatial database of real estate properties is also created by using Postgre SQL an **open source** software, then MapwinGIS library was used for displaying the spatial data. The front end was designed by using visual basic in Microsoft visual studio. Also a basic toolbar with zoom in, zoom out, pan, full extent tools and a map box for displaying the spatial data was created. The user will get a chance to do querying the database according to their needs.

(Crawford, 2012) The author main aim is to have an easy access to all the GIS data, so he has created a web portal in ARCGIS viewer for flex which is able to locate, query and analyze the dataset. The application was built using ESRI's ArcGIS Server Enterprise Advance and Adobe's Flex Builder software. This application can be used by the workers in the field for easy navigation to water leakage sites.

3 STUDY AREA

The study area part – I consists of the whole Dehradun municipal corporation. Dehradun is the administrative center and capital city of newly formed Uttarakhand State and is situated in the south central part of Dehradun district, India. Dehradun city is having the highest urban population in comparison with surrounding cities of the state. The major urban centers nearer to the Dehradun are Mussoorie, Haridwar and Rishikesh which are located in a radius of 30-50km. According to the census 2011 Dehradun is the only city having the municipal corporation in the state. The other main organizations of Dehradun and its surrounding region that strives for the urban planning and management are Development Authority of Mussoorie Dehradun, Development Authority of Special Area of Doon Valley, Development authority of Hardwar – Rishikesh and Jal Sansthan of Garhwal. The Municipal Corporation of Dehradun works for the development of the city and its neighboring areas.

The area chosen for the present study is Dehradun Municipal Corporation which consists of 60 wards. Areal extent of the city is 64.88 sq.km.(Urban Development Department, GoU, 2011). The following figure 3-1 shows the study area.

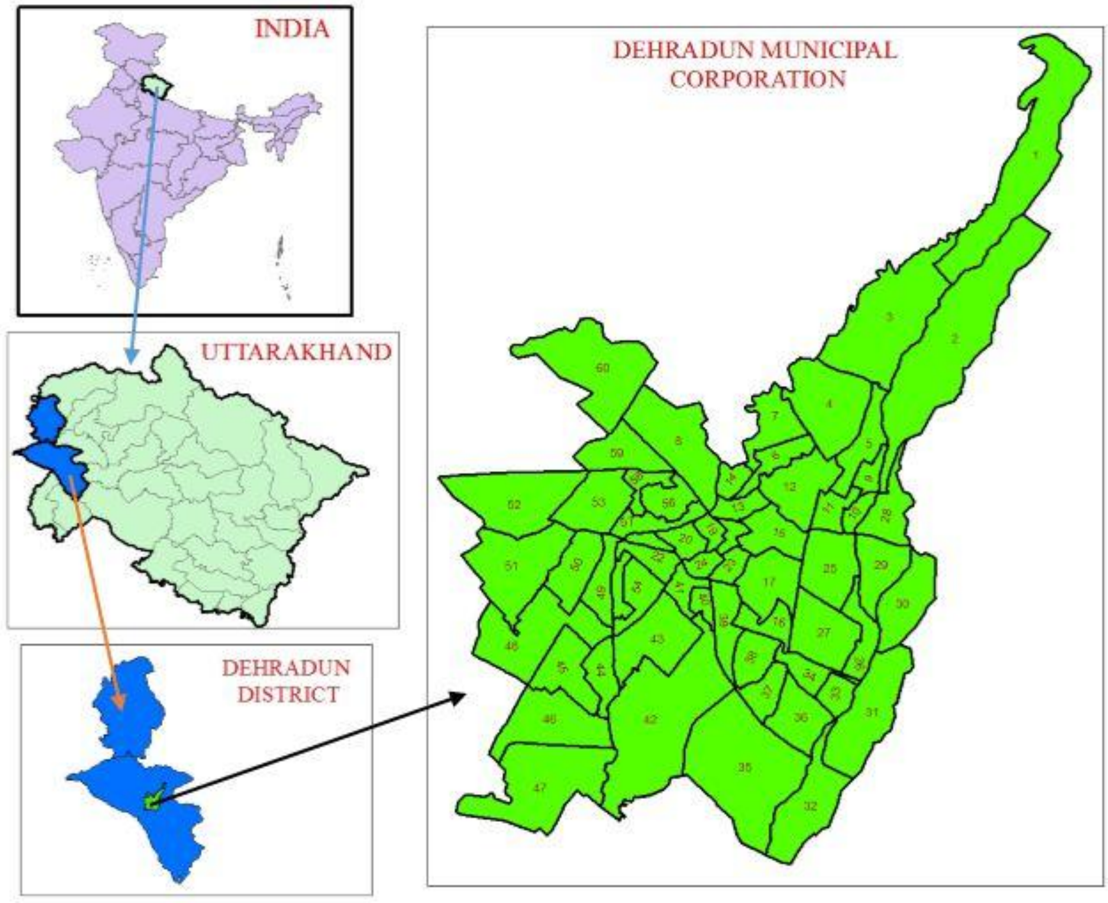

Figure 3-1: Study area

3.1 Dehradun City profile

3.1.1 Location

Dehradun is located between 77°59'5" west, 78°6' 4"east longitudes and 30°16'10” south, 30°24' 19" north latitudes. According to the UDPFI guidelines, Dehradun is classified as a large city in the hierarchy of urban settlements which is having a municipal corporation as per the census 2011(“Census of India Website : Office of the Registrar General & Census Commissioner, India,” 2014) (*UDPFI*, 1996). Dehradun is having a good connectivity to all the major towns in India through road, rail and airways. The nearest airport from Dehradun is the Jolly Grant Airport situated at 25 km away from the city. The city is well connected by daily direct trains coming in from Delhi, Calcutta, Mumbai, Varanasi, Lucknow and other major places.

3.1.2 Topography and climate

Dehradun is situated in the most fertile region of Doon Valley between rivers Yamuna and Ganga. It is the most developed city in the foothills of Shiwalik Mountains. The city is bounded by Himalayan ranges on the north, Sal forests in the south, river Song on the east and river Tons on the west. The high hills around the Dehradun gives a picturesque setting to the city. The city is located at 640 meters above the mean sea level. The lowest altitude is 600 meters in the southern side and the highest altitude is 1000 meters in the northern side(“City Development Plan of Dehradun,” 2007). The city is sloping gently from north to south and southwest having a gradient of 1:37.5 and is heavily dissected by number of seasonal streams and nallas which are locally known as Khalas. The direction of flow of streams and nallas in the eastern part is from north to south and in the western part is north to south west side. The drainage of city is borne by two major rivers namely river Bindal and river Rispana.

Dehradun enjoys a salubrious climate due to its location in the hilly region. In general the climate is temperate and the year is divided into four seasons namely cold, hot, monsoon and post monsoon seasons. The period of these seasons is from middle of November to February, March to June, July to third week of September and third week of September to middle of November respectively(MDDA, 2008).

3.1.3 Temperature and rainfall

The maximum and minimum degree of average temperature is 36.6° C and 5.2° C. In summer the maximum and minimum temperature is 36.6° C and 16.7° C where as in winters it is 23.4° C and 5.2° C. January is generally the coldest month and minimum temperatures sometimes even goes below the freezing point of water. The average annual rainfall of Dehradun is 2208.9 mm(“World Weather Information Service - Dehradun,” 2014). About 87% of rainfall is received through monsoon in the June to September.

3.1.4 Humidity and Prevailing winds

The relative humidity is high in the monsoon season normally exceeding 70% than an average. The mornings are more humid than the evenings. The driest part of the year is during the summer season with the relative humidity less than 45 percent. The direction of wind flow is from south- west to north-east throughout the year except in the month of October and November.

3.2 Demographic profile of Dehradun

Growth and development of a city is depends upon its population size and its economic profile(*UDPFI,* 1996). A study of changes in the population and extent of the city therefore enables to foresee the requirements of city from all aspects which includes the infrastructure facilities like roads, drinking water, streetlights etc. Table 3-1 shows the population data Dehradun city from 1901 to 2011.

Table 3-1: Population of Dehradun city

Year	Population	% Increase	Decadal growth rate
1901	30995		
1911	42568	37.34	27.19
1921	50858	19.47	16.30
1931	43206	-15.05	-17.71
1941	59535	37.79	27.43
1951	116404	95.52	48.85
1961	126918	9.03	8.28
1971	166073	30.85	23.58
1981	211838	27.56	21.60
1991	270000	27.46	21.54
2001	426674	58.03	36.72
2011	569578	33.49	25.08

Source: Census of India.

According to the census 2011 the household size of the city is 4.588. The population density of Dehradun Municipal Corporation is 88.6 persons per hectare. The sudden jump in the decadal growth rate from 21.54% to 36.72% in 1991-2001 is because Uttarakhand was made a separate state with Dehradun as a capital city. As Dehradun is a tourist place, the number of tourists visiting the city every day is quite high. But there is no estimate available with the Nagar Nigam, in this case the commuter population is taken as 5% of the total population.

3.3 Water supply system of Dehradun

Uttarakhand Jal Sansthan (UJS), an institution working under Department of Drinking Water, Government of Uttarakhand (GoU) operates and maintains and constructs small works of water supply system. Uttarakhand Pey Jal Nigam (UPJN) also working under Department of Drinking, Government of Uttarakhand (GoU) is mainly responsible for large capital works and overall planning of water supply system. Although it is supposed to be a municipal function, but the Dehradun Nagar Nigam (DNN) is not involved in the planning, design, construction, operation, maintenance and service delivery of this important Urban Infrastructure.

Dehradun's water supply system was introduced in 1885 which is almost 30 years old since then the demand and consumption of water has increased enormously. So from time to time the water utility network should be well maintained, updated to cater the population. Previously the main source of water comes from Kolukhet springs situated about 25 km from Dehradun. This was a gravity flow system and subsequently more surface water was tapped and more area was covered under gravity flow in the northern part of Dehradun. Presently this source is not in use. Subsequently due to limited surface water sources, ground water sources is being exploited to supplement the water demand of the town which has been found to be successful("City Development Plan of Dehradun," 2007). The water supply system was remodeled and undergone major augmentation. For the ease of administration the city was divided into three major divisions, eleven subdivisions and fifty one zones(Officials in UJS, 2014) and the details of these is given in the table 3-2.

Table 3-2: Administration of water supply in Dehradun

S.no	Division	Sub-division
1	North	North
		Adhoiwala
		Kaulagarh
		Rajpur
2	South	Dharampur
		Dhanda
		Jalkal
3	Pithuwala	Pithuwala
		Jogiwala
		Saraswati
		Rajivnagar

Source: Uttarakhand Jal Sansthan

The north division is mostly supplied with surface water source and south, Pithuwala divisions (peri urban areas) are supplied with ground water from tube wells located at various places in the city.

3.3.1 Source of water supply

(Santosh Kumar Garg, 2010) has stated that source of water for any town/city can be either the sub-surface or surface source which is nearer to the town. In case of Dehradun source of water supply is the combination of both surface and sub-surface source. The various surface sources of water supply includes two mountain falls, two rivers and one canal. At present (2014) a total of 46.6 MLD is being drawn against installed capacity of 48.85 MLD and it is given in the following table 3-3.

Table 3-3: Source of water supply

Source	Present Drawal	Design Drawal
Bandal	8 MLD	10 MLD
Bijapur canal	12 MLD	12 MLD
Shikar fall	14 MLD	14 MLD
Galogi	12 MLD	12 MLD
Kolukhet	0.6 MLD	0.85 MLD

Source: Uttarakhand Jal Sansthan

Presently sub-surface source is the main source of water for Dehradun city. According to the city development plan 2007("City Development Plan of Dehradun," 2007) the number of tube wells are 57 and according to the survey done by ADB (Urban Development Department, GoU, 2011) in 2011 the number of tube wells are 96. At present(2014) the total number of both tube wells and mini tube wells are 122 in number according to UJS(Officials in UJS, 2014). The yield from both tube wells and mini tube wells is 146 MLD. The average life of the tube wells is 20 years and these tube wells are working for an average of 16 hours per day.

3.3.2 Water quality

From the discussions done with the officials of water supply department it is informed that, the ground water quality is good and only chlorination is required for potable supply to the consumers. And the water from the various surface sources are of acceptable standard which requires only conventional water treatment, except in Galogi water source having excessive hardness requires softening treatment. Officials also said that sometimes water quality is deteriorated due to malfunctioning of the treatment plants. As the water supply network is very old, many old pipes have buried under the roads in course of road widening works. So the pipelines remain undetected and developed leakages. This results in sucking of outside water/sewage when supply is closed consequently polluting the water.

3.3.3 Intakes

Among the four major intakes three are collecting the water with required amount and at good condition. The condition of the fourth intake is very bad because the structure is buried and cannot be repaired. So it is not able to cater the required 12 MLD water coming from Galogi source (Officials in UJS, 2014).

3.3.4 Rising mains

The pipelines that are laid for the purpose of collecting the water from the source to the either the intake or the water treatment plant or till to any asset in the water utility network before the stage of distribution. The characteristics of the rising mains are given in the table 3-4.

Table 3-4: Rising mains

Source to WTP	Length	Material	Condition	Present Capacity	Designed Capacity
Bandal to Dilaram Bazar	14 km.	C.I.	Not satisfactory	8 MLD	10 MLD
Shikar fall to Shahensai Ashram	2 km.	M.S	Incrustation inside pipe	14 MLD	14 MLD
Bijapur canal to Dilaram Bazar	4 km.	D.I.	Satisfactory	12 MLD	12 MLD
Galogi to Purukulgram	3.5 km	M.S	Satisfactory	12 MLD	12 MLD

Source: Uttarakhand Jal Sansthan

3.3.5 Water treatment

Surface source:

According to city development plan 2007(“City Development Plan of Dehradun,” 2007) and survey done by ADB in 2011 (Urban Development Department, GoU, 2011) there are 2 water treatment plants (WTP) one at Dilaram Bazaar and other at Shehenshai Ashram having capacities of 22 and 14 MLD respectively. At present (2014) there are three WTPs in Dehradun according to the officials in Uttarakhand Jal Sansthan (UJS). The WTP at Dilaram Bazar is able to treat about 20 MLD as received from Bijapur Canal (12 MLD) and Bandal River (8 MLD) and it is working to under capacity. The WTP at Shahensai Ashram is able to treat about 14 MLD as received from Shikar fall (14 MLD) and it is working to its full capacity. The WTP at Purukulgram is able to treat 12 MLD received from Galogi (12 MLD) and this water will go to Dilaram WTP for distribution in the town. This WTP needs replacement as it is buried under deep siltation, also it is working to its full capacity. From the discussions with the officials and field visits it is found that the efficiency and working condition of WTP at Dilaram Bazar is good even though it is very old. The quality of water produced is potable. But there are no required equipment for softening the incoming hard water at Shahensai ashram WTP.

3.3.6 Pump house and pumping equipment

There are 3 pump stations which house the motors and other equipment needed for pumping the water, all of them are working at its full capacity. Other than this, the pumping equipment is present at all the tube wells and overhead tanks. All the machinery is in working condition and satisfactory. The machinery that requires replacement is carried out in the ongoing project UUSDIP(Urban Development Department, GoU, 2011)(Officials in UJS, 2014).

3.3.7 Overhead tanks and clear water reservoirs

The number of overhead tanks (OHT) and clear water reservoirs (CWR) at present in the year 2014 are 70 and 16 respectively. The total capacity of OHTs and CWR's are 63940 and 12068 kl. These assets are located at various water supply zones in the city.

3.3.8 Distribution system

Dehradun is broadly divided into three water supply zones; gravity flow zone, pumping flow zone and mixed flow zone. The northern part of the town mainly Rajpur Road and localities around it falls under the gravity flow zone, while the southern part of the town including old city area receive water through pumping. The third zone has come into existence which is in between these two zones and can be called as mixed zone where the water is supplied through pumping as well as gravity("City Development Plan of Dehradun," 2007).

As per the survey done by ADB in the year 2011(Urban Development Department, GoU, 2011) the total distribution network of water supply is about 564 km laid periodically. Most of these pipelines are very old and have out lived their service life. In many stretches these pipelines have gone to deeper depths due to road widening and now it became inaccessible for repairs. The details of the distribution mains are given below in the table 3-5.

Table 3-5: Distribution mains

Distribution Pipes	Total length(in km)
GI (25-200 mm dia.)	87.5
CI (50-600 mm dia.)	47.7
ERW (125-200 mm dia.)	4.5
PVC (40-200 mm dia.)	289.7
AC (50-450 mm dia.)	134.4
Total length	563.8

Source: **Uttarakhand Urban Sector Development Investment Program, 2011**

Generally, the water supply hours in the piped areas are about 4 hours twice a day but in low lying areas the supply continues beyond closing hours and also in some areas supply is available only once and that too in late night hours. There are at least 30 crisis localities where water supply is provided through tankers("City Development Plan of Dehradun," 2007).

There is no metering system in the city, the bill is calculated on the basis of house tax per connection basis. According to the survey done by ADB, there is 60% of water losses in the distribution network. The pipelines have gone to deeper depths due to improvements made in road surface and they are inaccessible for repairs(Urban Development Department, GoU, 2011). Presently(2014) the leakages in the existing system also accounts for 35.5%(Officials in UJS, 2014).
Therefore the total water production both surface and sub-surface is 192.6 MLD and the distribution losses, friction losses together account to 68.4 MLD. The remaining 124.2 MLD which is supplied to the customers is not totally generating the revenue because of unbilled authorized consumption of water(Officials in UJS, 2014).

3.3.9 Water supply system of Dehradun at glance:

Table 3-6: Water supply at glance

Parameters	Present status (Jan 2014)
Population	7,09,000
No.of water supply connections	1,31,007
Population covered with water supply	95% coverage
Production of potable water	192.6 MLD
Losses	68.4 MLD (35.5%)
Total supply	124.2 MLD
Transmission mains Length: Condition:	 23.5 Km Leakages and incurstated
Distribution mains Length: Condition:	 2816 km Leakages
No.of distribution hours	4-6 hrs.
No.of tube wells	122
Total Storage capacity	72108 KL
No.of employees	429
Water meters	Nil
Yearly revenue assessment	32 crores (2012-2013)
Yearly revenue received	28.91 crores (2012-2013)

Source: Uttarakhand Jal Sansthan

4 MATERIALS/DATA AND TOOLS USED

This chapter has mainly three parts. The first part describes about all the data sources used for the research work. The second and third part describes the software and the technologies used in the research work.

4.1 Data source

In order to analyze the water supply system of Dehradun, data from both primary and secondary sources were collected and analyzed. To supplement the analyzed secondary data and to characterize the level of service delivery, the primary data was collected through surveys conducted with the officials in Uttarakhand Jal Sansthan. For further understanding of water supply system spatially, remote sensing data was used.

4.1.1 Primary data

The primary data includes all the field visits, surveys conducted for geo referencing the satellite image as well as for creation of water utility database.

4.1.2 Secondary data

The secondary data includes data collected from all the secondary sources likes Directorate of Census Operations, Census of India, Dehradun Nagar Nigam, Uttarakhand Jal Sansthan, Uttarakhand Peyjal Nigam, Mussoorie Dehradun Development Authority (MDDA), and Survey of India (SOI). The details of Toposheet and guide map used in the study is given below in the table 4-1.

Table 4-1: SOI Toposheet's

SOI Map no	Scale	Year of publication
Toposheet 53 J/3	1:50,000	1988
Guide Map	1:20,000	1982

4.1.3 Condition of data availability with the UJS

- There are no detailed maps for house hold water supply connections, and there are only hand drawn map of primary pipeline with the UJS.
- There are no digital databases and the data is stored till sub-divisional level only in the form of records.
- The data of past years are stored in the form of hand written documents which are at bad condition.

4.1.4 Remote sensing data

The remote sensing data was obtained from NRSC Hyderabad. The specifications of satellite images used in the research are given below in the table 4-2.

Table 4-2: Remote sensing data

Satellite	Sensor	Date of acquisition
1. QuickBird	Multispectral and Panchromatic	• 6th December 2007
2. Cartosat- 1	Panchromatic	• 28th March 2010 • 27th December 2010
3. IRS-P6	LISS-IV	• 28th March 2010 • 7th March 2013

Digital Globe's QuickBird satellite sensor was successfully launched on October 18, 2001 at California, USA. The detailed specifications of QuickBird imagery is given below in the table 4-3.

Table 4-3: Specifications of QuickBird imagery

Sensor/ satellite parameter	Specifications
Orbit Altitude	450km
Orbit Inclination	97.2 degrees, sun-synchronous
Orbit Time	93.5 minutes
Revisit Time	1-3.5 days, depending on latitude (30° off-nadir)
Swath width	16.5 Km x 16.5 Km at nadir
Spatial Resolution	MS: 2.44 m (nadir) to 2.88 m (25° off-nadir)
	PAN: 61 cm (nadir) to 72 cm (25° off-nadir)
Spectral Resolution	4 bands
Spectral bands	Multispectral- 0.45 -0.52 µm(Blue), 0.52 -0.6 µm(Green), 0.63 -0.69 µm(Red), 0.76 -0.9 µm(Near IR)
	Panchromatic -0.445 – 0.9 µm
Radiometric resolution	11bits

QuickBird satellite is able to give the data at a resolution of sub-meter accuracy. It collects both Panchromatic and multispectral imagery. Figure 4-1, 4-2 shows the QuickBird PAN and MSS data.

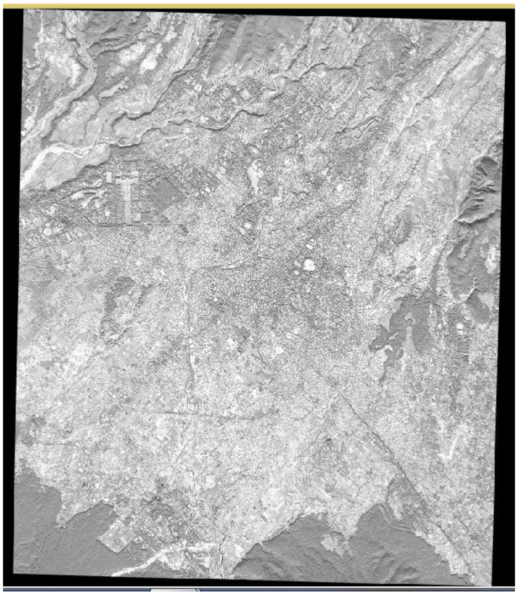

Figure 4-1: QuickBird PAN 2007

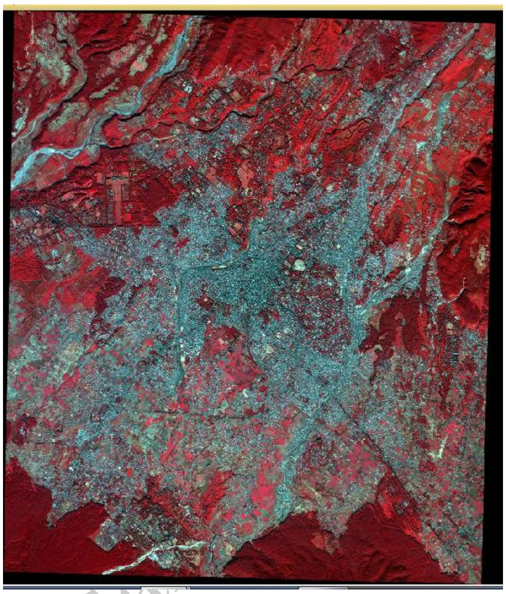

Figure 4-2: QuickBird MSS 2007

CARTOSAT – 1 is the first Indian Remote Sensing Satellite built by ISRO and was launched by PSLV on 2005 which is capable of providing stereo images.

Figure 4-3: Cartosat 28th March 2010

Figure 4-4: Cartosat 27th Dec 2010

The two high resolution sensors which are mounted on the satellite records the stereo pairs in visible spectrum (Murthy et al., 2008). The Cartosat stereo pair is used for generating ortho images, Digital Elevation Models and is useful in various Geographic information system (GIS) applications. The spatial resolution of the sensor is 2.5 meter by which we can even distinguish a small car and the swath is 30 km. Figure 4-3 and 4-4 shows the Cartosat-1 data acquired at different dates and table 4-4 gives the specifications of cartosat-1 data.

Table 4-4: Specifications of Cartosat-1 data

Sensor/satellite parameter	Specifications
Orbit Altitude	618 km
Orbit Time	97 minutes
Number of Orbits Per day	14
Repetivity	126 days
Revisit Time	5 days
Swath width	30 Km x 30 Km
Spatial Resolution	PAN: 2.5 meter
Spectral Resolution	0.445 –0.9 µm
Radiometric resolution	11bits

RESOURCESAT-1 is the tenth satellite of ISRO in IRS series. RESOURCESAT-1 is the most advanced Remote Sensing Satellite built by ISRO as of 2003. The payload's of IRS-P6 are LISS-4, LISS-3, AWiFS-A, AWiFS-B. The LISS-IV camera is a high resolution multi-spectral camera operating in three spectral bands (B2, B3, and B4). LISS-IV can be operated in either of the two modes.

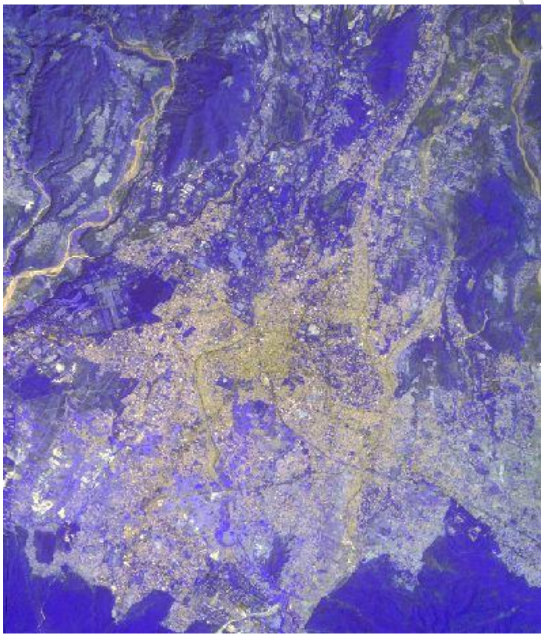

Figure 4-5: LISS-IV 28th March 2010

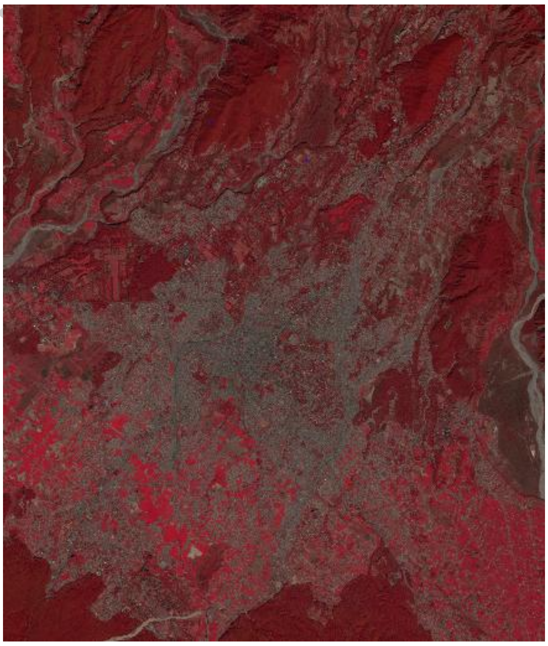

Figure 4-6: LISS-IV 7th March 2013

In the multi-spectral mode (MS), a swath of 23 Km (selectable out of 70 Km total swath) is covered in three bands, while in mono mode (Mono), the full swath of 70 Km can be covered in any one single band, which is selectable by ground command. The LISS-IV camera can be tilted in the across track direction thereby providing a revisit period of 5 days. Figure 4-5 and

4-6 shows the LISS-IV data acquired at different dates and the table 4-5 gives the specifications of LISS-IV sensor.

Table 4-5: Specifications of LISS-IV sensor

Sensor parameter	Specifications
Swath width	23.9 Km(MX) / 70 Km(Mono)
Spatial Resolution	5.8 meters at nadir
Spectral Resolution	3 bands
Spectral bands	Multispectral- 0.52 -0.6 µm(Green), 0.63 -0.69 µm(Red), 0.76 -0.9 µm(Near IR)
	Panchromatic – Blue or Green or Red

4.2 Software used

The software used in the present study includes

- ArcGIS 10.1
    - Infrastructure editing tools
    - ArcGIS Diagrammer
- Auto CAD Map 3D 2014
- ERDAS IMAGINE 2013
- Microsoft visual studio 2012
- Microsoft SQL server 2008
- OpenGeo Suite 4.0
- uDig 1.0.6

4.3 Instruments used

- Trimble R7 GNSS System.
- Trimble YUMA tablet.
- Handheld GPS.

5 METHODOLOGY

The methodology adopted for the present study is divided into five major steps. They are

- Understanding the present water supply system of the city.
- Creation of water utility data model.
- Capturing and storing of water utility data from different sources into a Geodatabase.
- Analyzing the water supply system and finding the risk factor of overhead tanks.
- Creation of web portal.

The entire process of methodology is shown below in the following figure 5-1 and it is explained step by step.

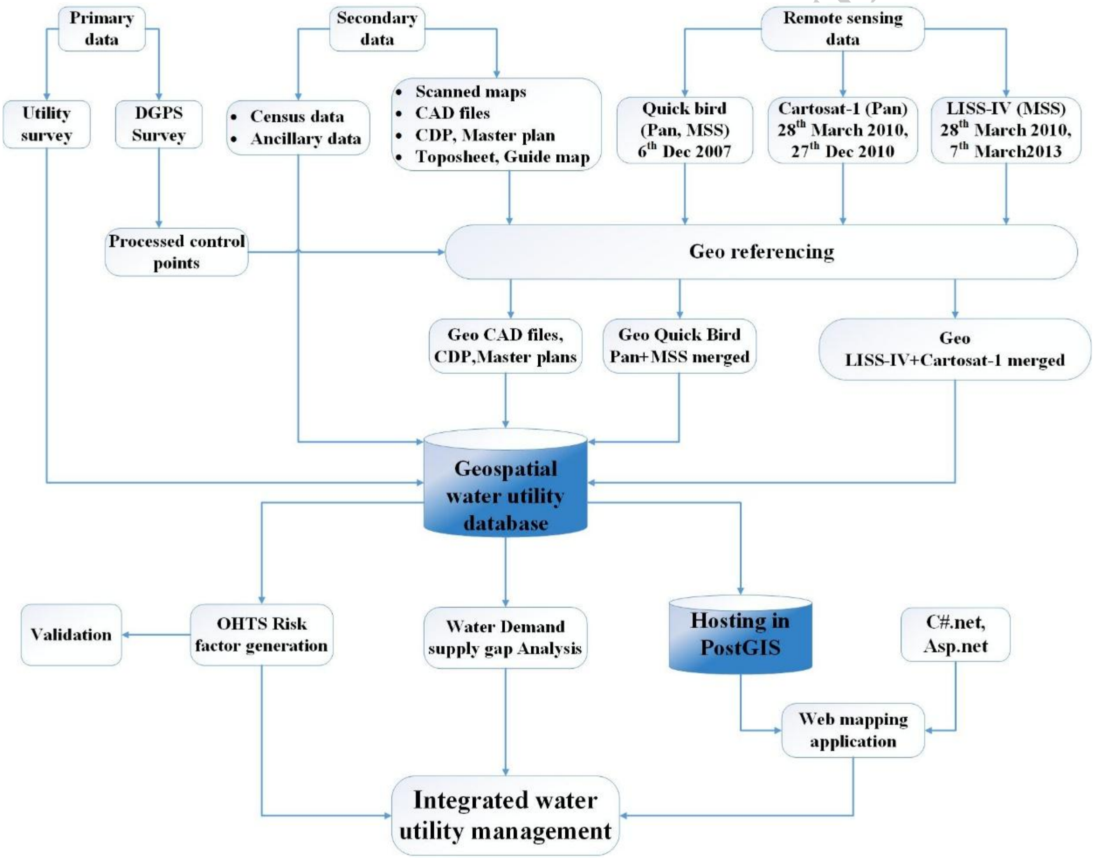

Figure 5-1: Methodology

5.1 Layout of existing water supply system

The Dehradun's water supply system is a bit complicated because the city developed in an irregular fashion and the layout of water supply system followed it. It is very diverse from the stage of water collection to water distribution. The logical diagram of the water supply system is represented in the figure 5-2.

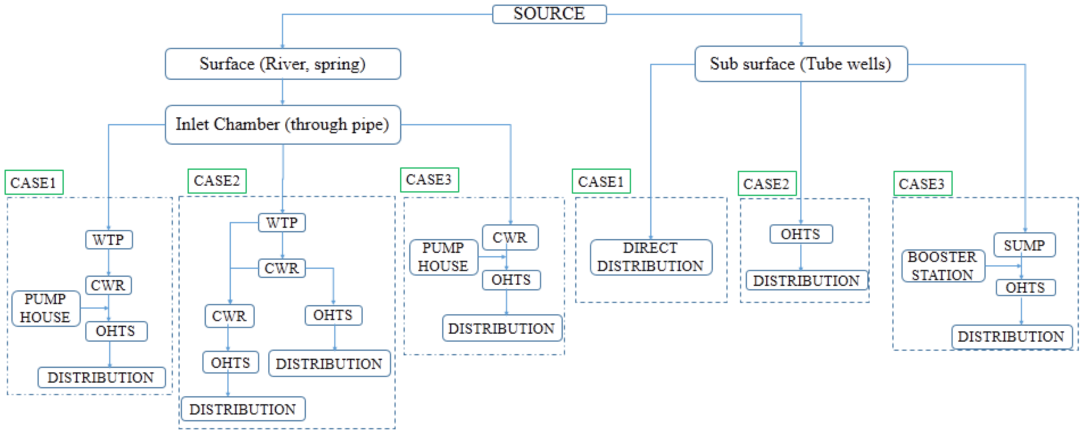

Figure 5-2: Logical diagram of water supply system

As it is known that city is getting water from both surface and underground sources, the water collected from the surface source is sent to the chamber with the help of transmission mains. The further process of distribution of water supply can be of either the three cases mentioned below for both the surface and sub-surface sources.

Surface source:

Case1: The collected water from the chamber is sent to the water treatment plant where the water get treated and sent to the clear water reservoirs, with the help of pump station the water was pumped to overhead tanks and then distributed to public.

Case2: The water in the chamber is sent to the water treatment plant for treatment, then the treated water is sent to the clear water reservoirs, from CWR's the water can either go to another CWR or OHT directly. From OHTs the water will be distributed to the people.

Case3: Water from the chamber is sent to CWR's directly without any treatment, from there the water is going to OHTs through pumping which will be distributed to households.

Surface source:

Case1: The collected water from the tube wells is directly distributed to the public.

Case2: The collected water from the tube wells is pumped to the OHT first and then sent for the distribution.

Case3: Water collected from the tube well is sent to the sump for the chlorination and the pump to the OHT for distribution.

The logical diagram of the water supply utility network is very useful in preparing entity-relationship (E-R) diagram. An entity-relationship model is a systematic way of representing and describing the things in a process(“Entity–relationship model,” 2014). Therefore E-R diagram is prepared by considering all the assets of water supply utility network as the entities and the relationships are created based on the connectivity of assets with each other(“Crow’s Foot Notation,” 2014) and it is shown in the figure 5-3.

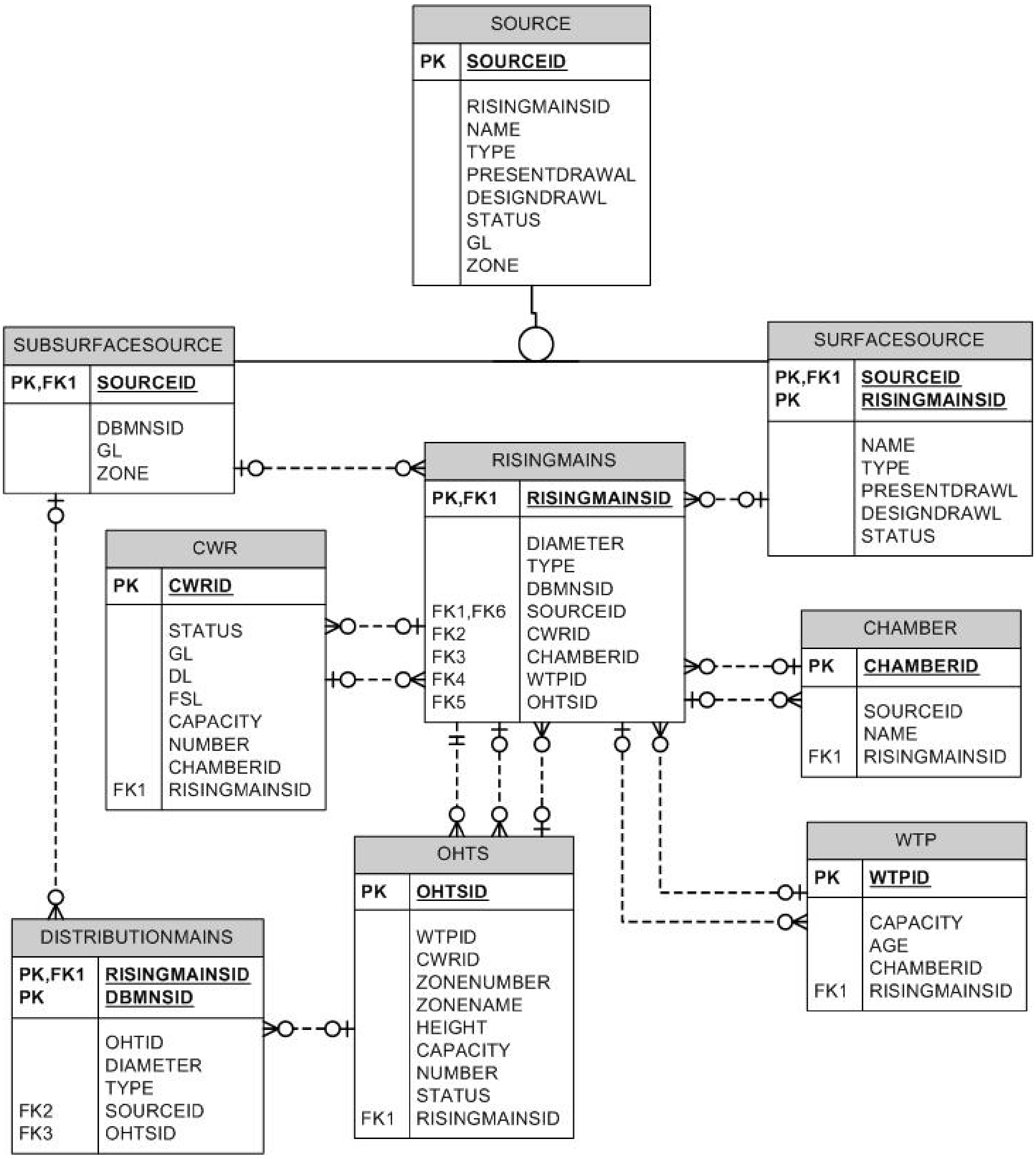

Figure 5-3: E-R diagram of water utility network

5.2 Water utility model and Geodatabase design

A geodata model is designed that supports a variety of object relationships and its behavior which suits the real world situation(“Handbook on Water Supply,” 1999). A geospatial database is created with a schema which matches the entity-relationship model of water utility network(Grise et al., 2012). The required tools of water utility data model are installed and then the physical model is created. The tools include infrastructure editing toolbar, plan capital projects. To this database, the data is added and created a new database(Grise et al., 2012)(Halfawy and Figueroa, 2006). The Geo database design is shown in the figure 5-4.

5.2.1 Initial schema of water utility model

The attributes which are required for the feature classes are all created. At the time of creation of data these attributes are filled up with the help of domains attached to it. The schema is represented in the following table 5-1.

Table 5-1: Initial water utility model schema

Assets of Water utilities				
S.no	**Feature classes**	**Attributes**		
1	Surface-source	Type	Name	
2	Tube well	Depth	Diameter	
3	Water chamber	Capacity		
4	WTP	Capacity		
5	CWR	Capacity		
6	Overhead tanks	Zone name	Height	Capacity
7	Pump house	No.of Pumps	Capacity	Condition
8	Booster station	No.of Pumps	Condition	
9	Rising mains	Length	Diameter	Type
10	Distribution mains	Length	Diameter	Type

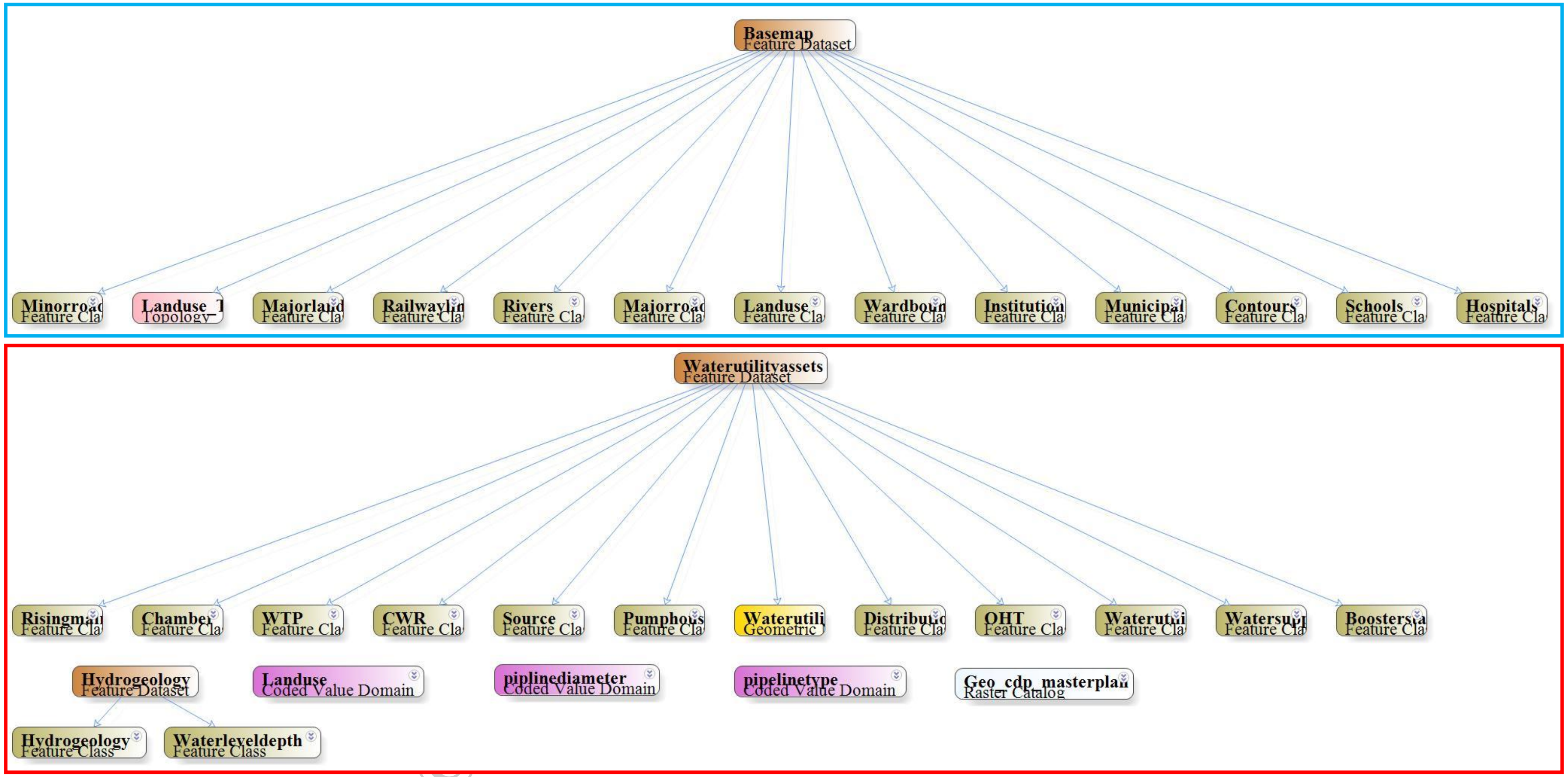

Figure 5-4: Geodatabase design

5.3 Data creation

Among all the available datasets, the resolution of QuickBird data is high. So the QuickBird data is geo referenced first, and this data is considered as a base layer to geo reference all other data. This process is carried out in a sequence of steps, first the QuickBird PAN image is divided into 1KM by 1KM grids and in all the grids some control points are selected so that these are clearly visible both on the satellite image and on the ground. Secondly a DGPS survey is conducted by establishing a base station in IIRS continuously for a period of 80 hours and rover is carried throughout the city on the selected control points. Handheld GPS is used while going to the field to know the location.

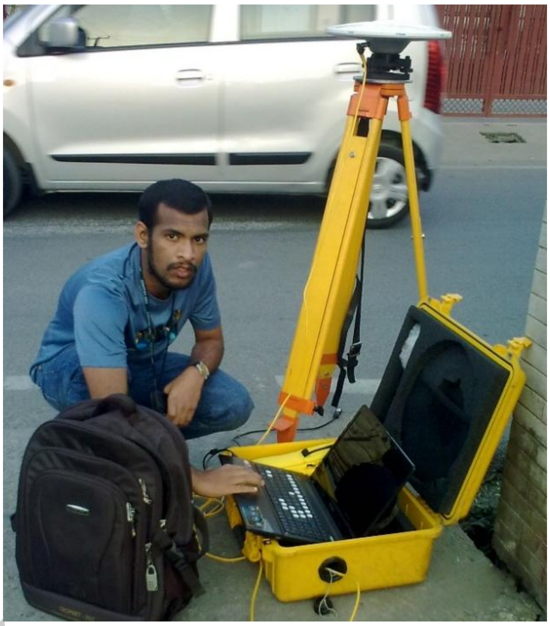

Figure 5-5: Field photograph taken while collecting GCP at shanti nagar

A total of 20 control points are collected. On an average 2 to 3 control points are taken per day. After doing the differential corrections the accurate ground control point are obtained. The field photographs is shown in the figure 5-5. With the help of these GCP's the QuickBird imagery is geo referenced. The rest of the data is also geo referenced with the help of geo PAN imagery. The panchromatic and multi spectral imagery of geo referenced QuickBird data was merged so that the interpretation of water utility assets will be easy.

Figure 5-6: Geo referenced QuickBird PAN + MSS merged

The QuickBird panchromatic and multi spectral merged imagery is shown in the following figure 5-6. The requirement for mapping the assets of water utility network is the high resolution data with good spectral information. Therefore resolution merge technique is used for merging the imageries. There are three methods namely principal component, multiplicative, brovey transform used for doing resolution merge. Here the method and resampling technique used are principal component and nearest neighbor because this better suits the requirement.

The cartosat-1 imagery acquired on 28th March 2010 is merged with LISS-IV data of same date and it is shown in the figure 5-7.

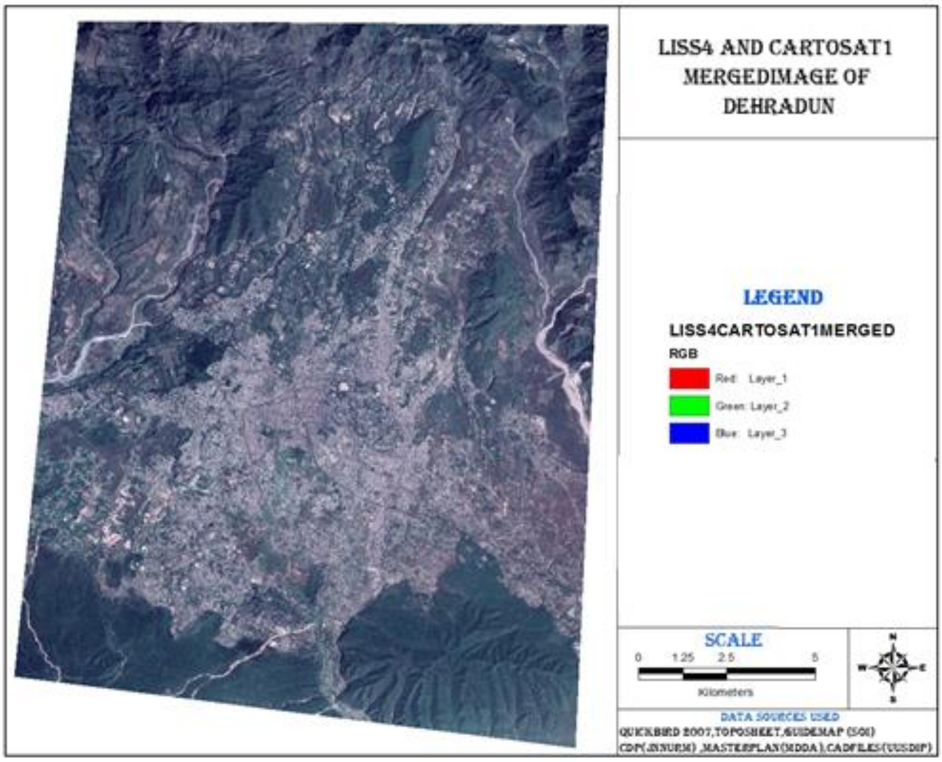

Figure 5-7: LISS-IV and CARTOSAT-1 merged image

The data collected from all other sources like Uttarakhand Jal Sansthan, MDDA, Nagar nigam etc. are all geo referenced and spatial adjusted properly. The computer aided design files (CAD) which are obtained from Uttarakhand Urban Sector Development Investment Program (UUSDIP) does not have a geographic reference, so a proper projection is given to these files and with the help of the DGPS data, benchmarks obtained from the Toposheet, they are geo referenced properly. The geo referenced CAD files are not aligned properly on the satellite image, then these files are divided into grids and performed spatial adjustment grid wise. The similarity transformation method of spatial adjustment is used because it doesn’t differentially scale or skew the data. Figures 5-8, 5-9, 5-10, 5-11, 5-12 shows the Geo referenced CDP JPEG, Geo referenced master plan JPEG, Hand drawn maps taken from UJS, CAD files taken from UUSDIP and Geo referenced Hydrogeological map.

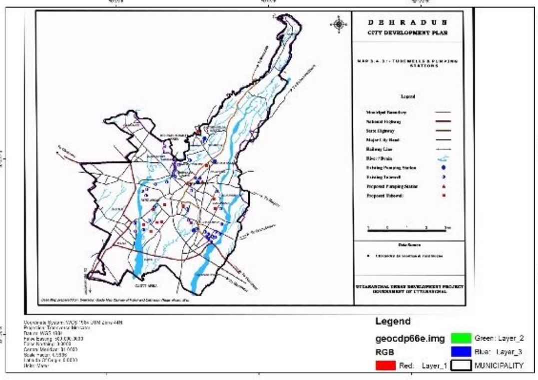

Figure 5-8: Geo referenced CDP JPEG

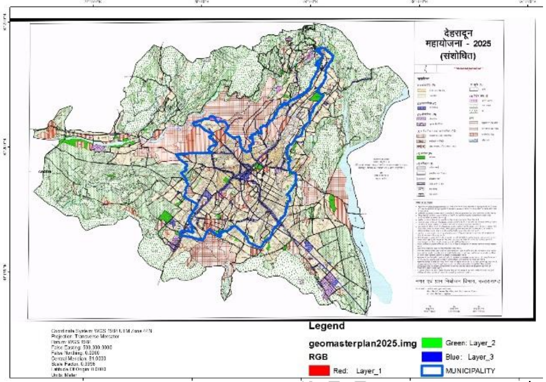

Figure 5-9: Geo referenced master plan JPEG

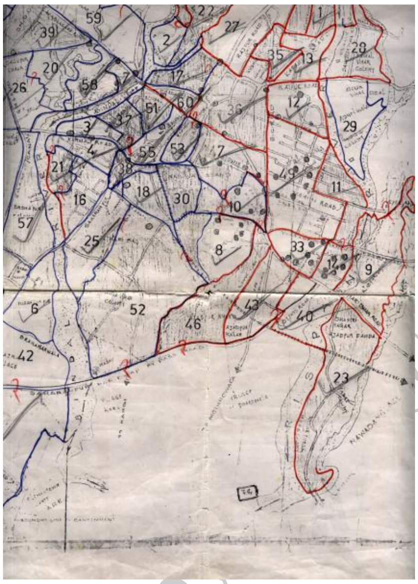

Figure 5-10: Hand drawn maps taken from UJS

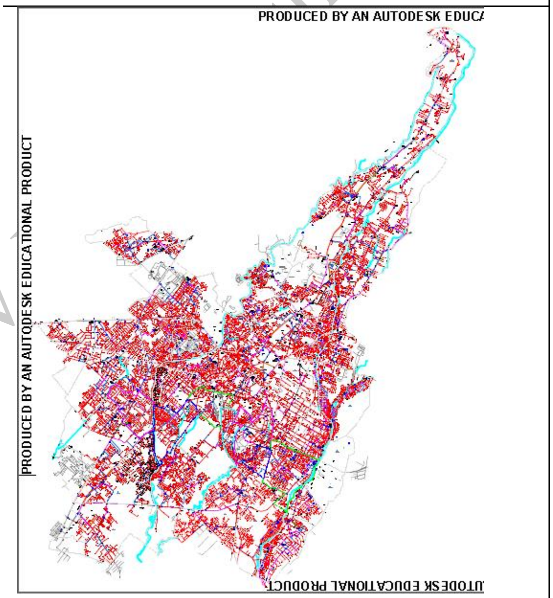

Figure 5-11: CAD files taken from UUSDIP

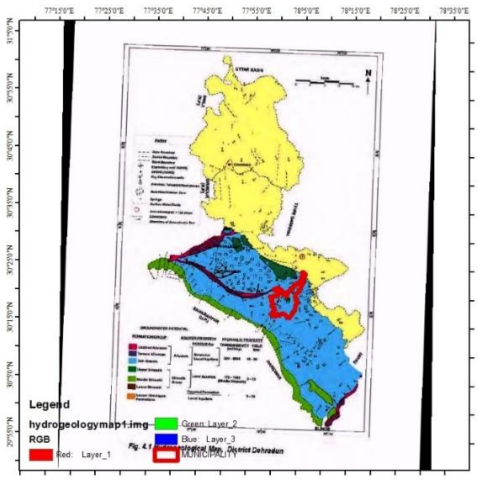

Figure 5-12: Geo referenced Hydrogeological map

5.3.1 Base map features:

After aligning all the data in the proper formats data capturing is started. Base map features include roads, river and railway line are all generated from the remote sensing data. Other features includes schools, colleges, institutions and hospitals are marked by searching the addresses given in the documents prepared by the Dehradun nagar nigam. These are validated and updated through field visits.

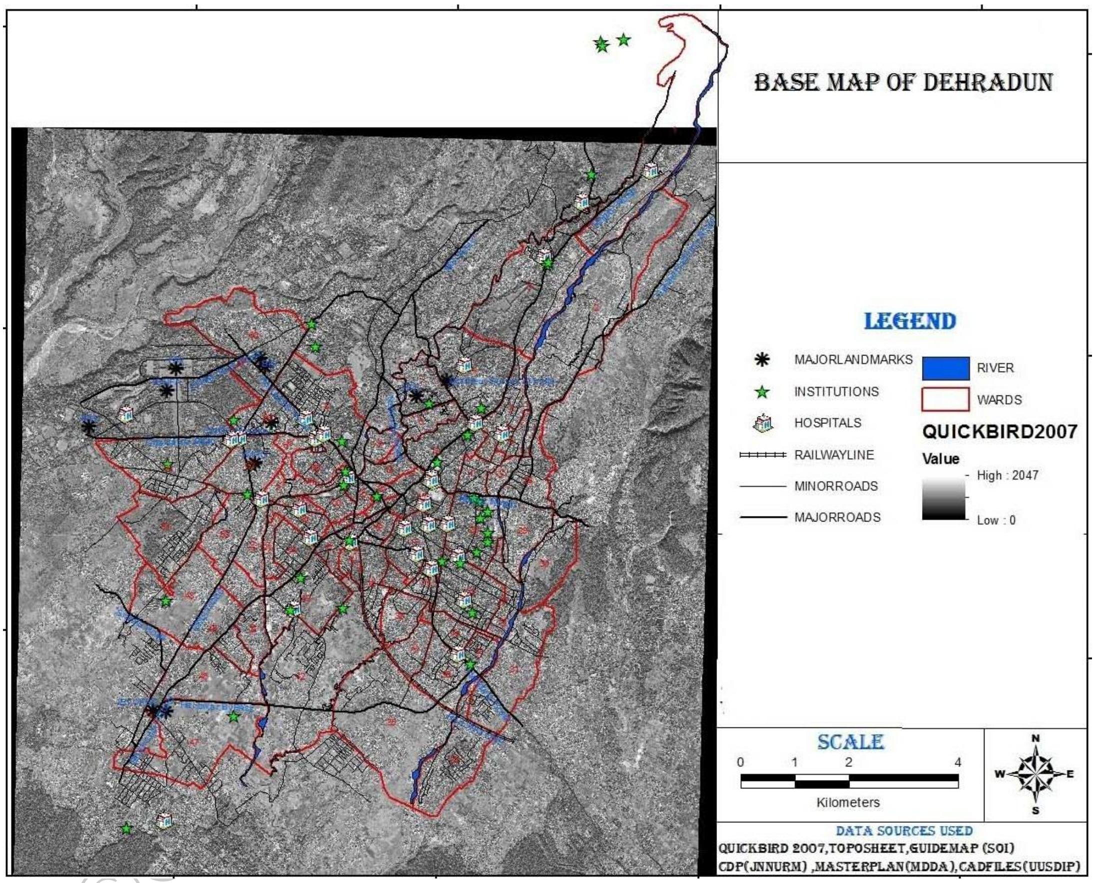

Figure 5-13: Base map of Dehradun

The municipal corporation of Dehradun reorganized the ward boundaries along the river and railway boundary and at present there are 60 wards. The ward boundary is created from Dehradun master plan given in the MDDA. Figure 5-13 shows the base map of Dehradun.

5.3.2 Water utility features

The Dehradun city is divided into 51 zones for ease of administration. In some parts of the town there are instances that one ward is divided into two water supply zones or one water supply zone is created by merging two wards or one water supply zone is created by taking the portion of two to three wards. The water supply zone map overlaid with ward map of the Dehradun is shown in the figure 5-14.

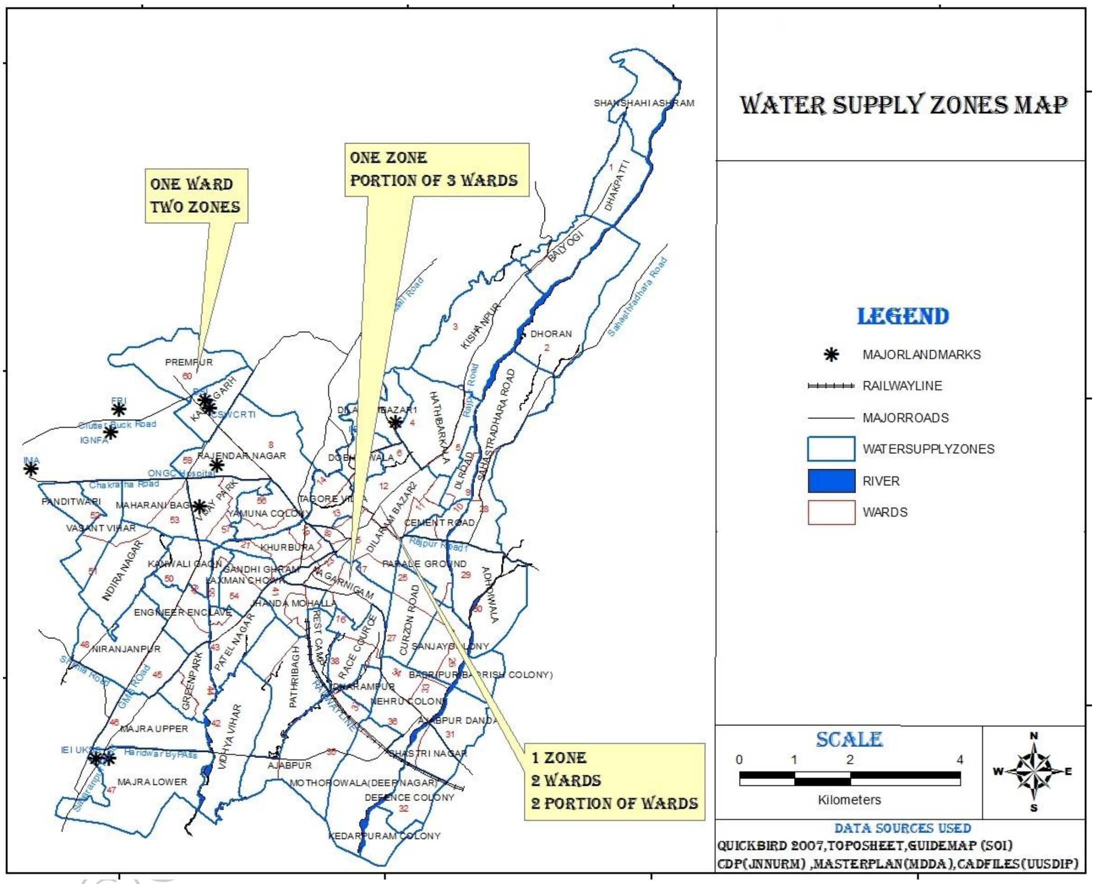

Figure 5-14: Water supply zone map

The assets of the water utility network consists of source, chamber, pipelines, water treatment plant, pump stations, valves, overhead tanks, tube wells and clear water reservoir. Remote sensing data can be very helpful in mapping some of the assets without any field work like OHTs and some with minimal field work like sources, water treatment plant etc. The following figures 5-15 and 5-16 shows that the overhead tanks are mapped through the visual interpretation which is based on the interpretation elements like shape, size, shadow, contrast, tone and texture. The attributes of overhead tanks are taken from UJS and they are attached to the overhead tanks shape file through manual entry by matching the address written in the records, Google search and location of OHT in the imagery. These attributes include height, capacity, and age. The age of the overhead tanks are decided from the temporal remote sensing data and other secondary sources like city development plan and documents obtained from UJS.

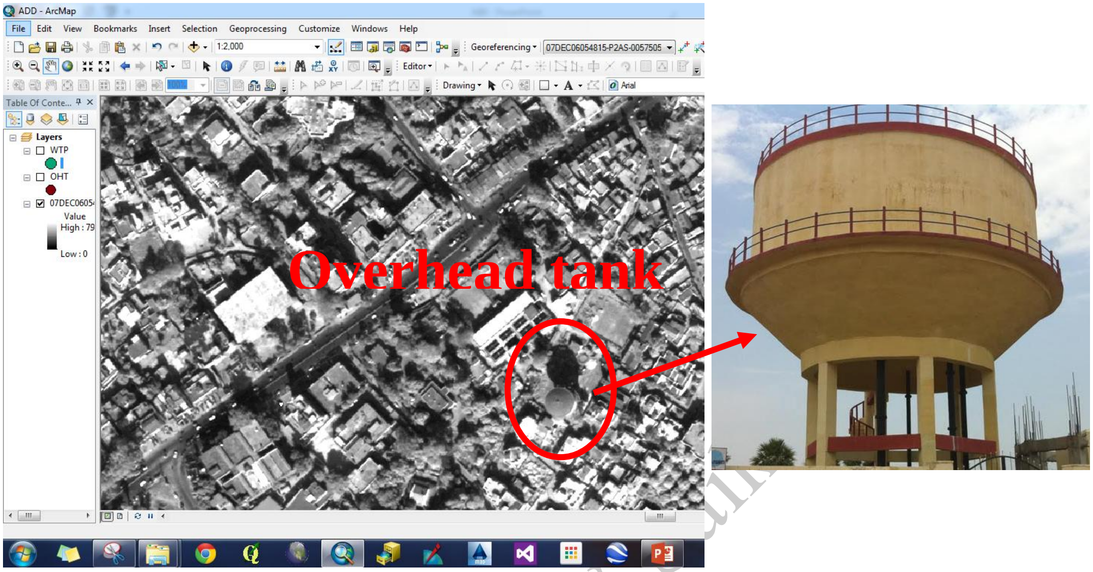

Figure 5-15: Overhead tank at Dilaram chowk

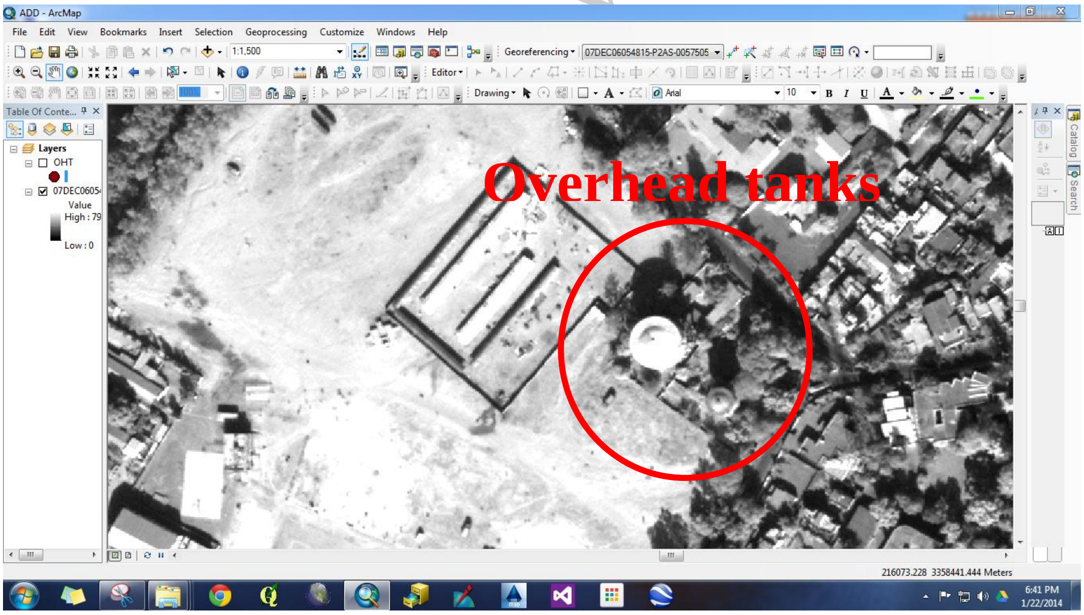

Figure 5-16: Overhead tanks at parade ground

The reflectance value is very high from the overhead tanks and it looks very bright in the image. So the visual interpretation is carried out. A fishnet is created on the top of the image and the interpretation is carried grid by grid. The overhead tanks are represented by a point shapefile, as the mapping is carried at the city level scale. Figure 5-17 and 5-18 shows the location of overhead tank utility in the Dehradun city. The new OHTs are mainly constructed in the highly populated area.

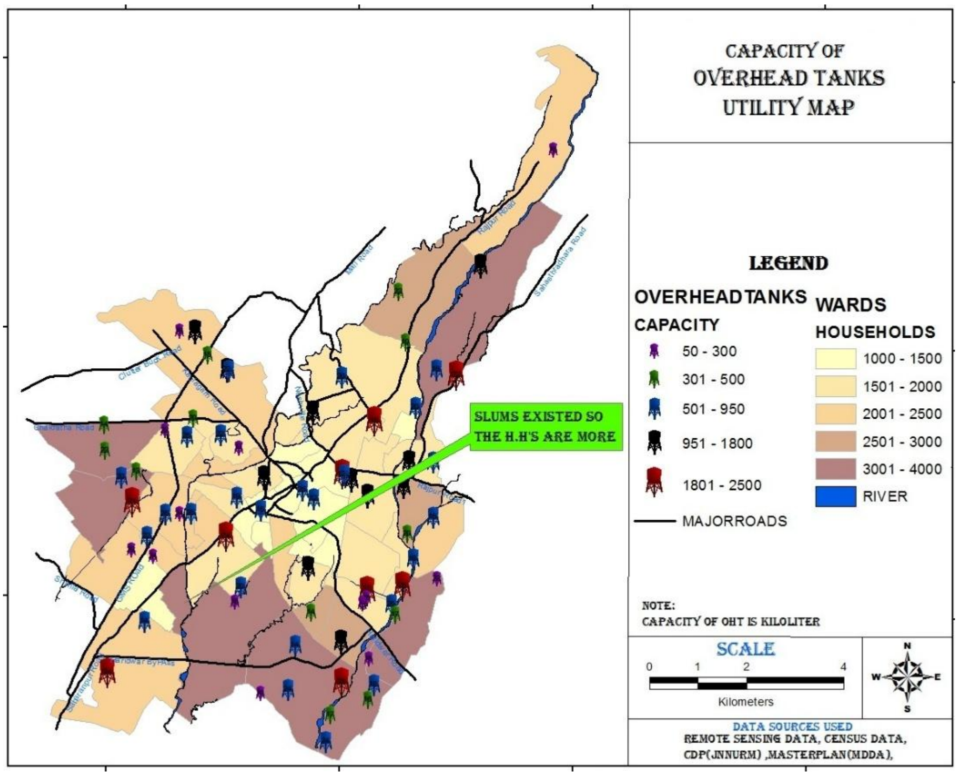

Figure 5-17: Capacity of overhead tanks

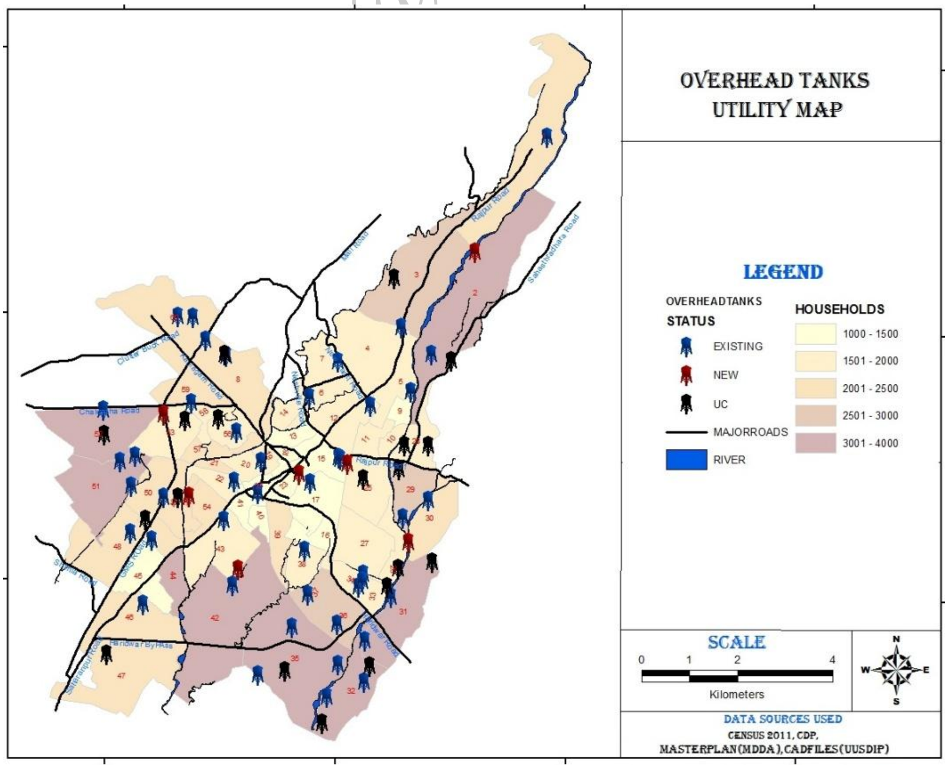

Figure 5-18: Age of overhead tanks

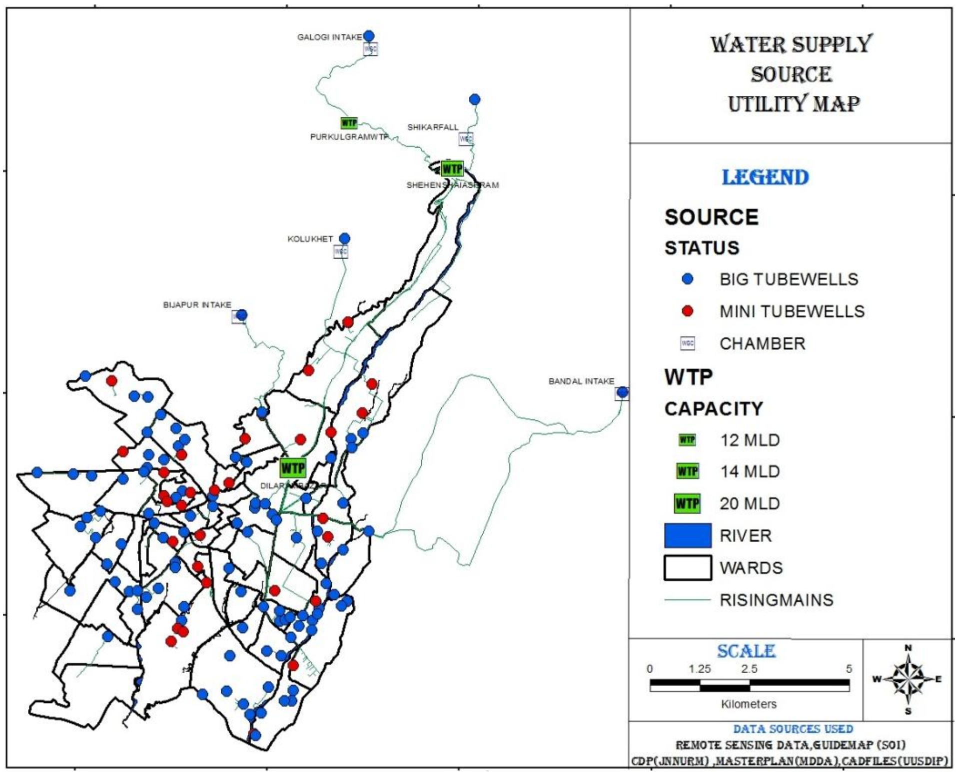

Figure 5-19: Water supply source asset status map

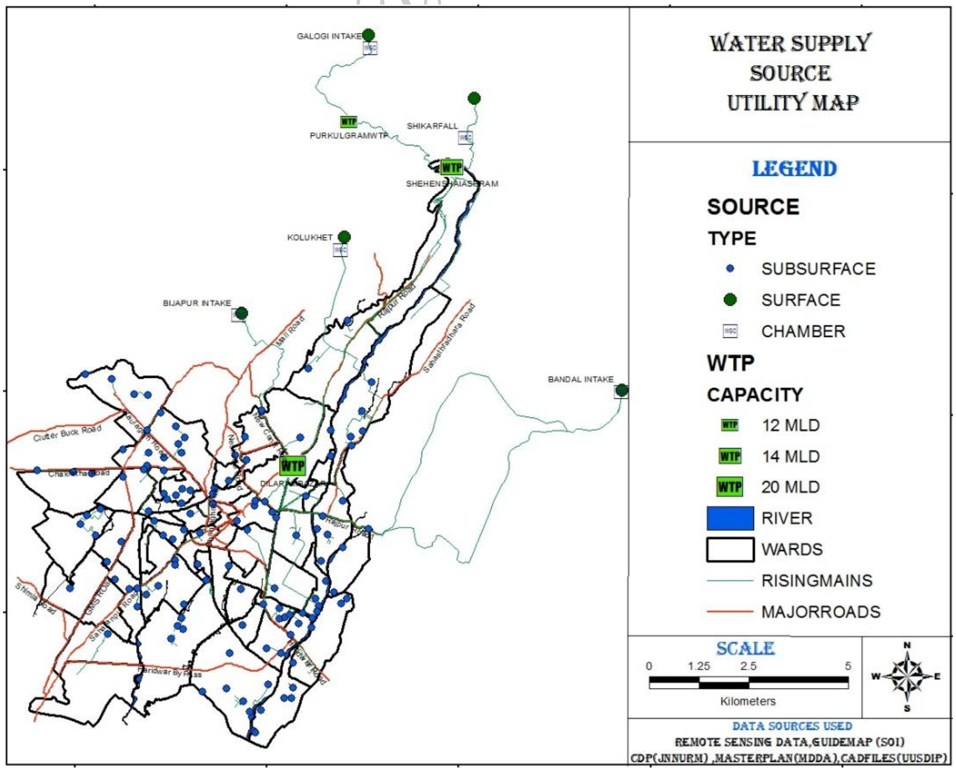

Figure 5-20: Surface and sub-surface source map

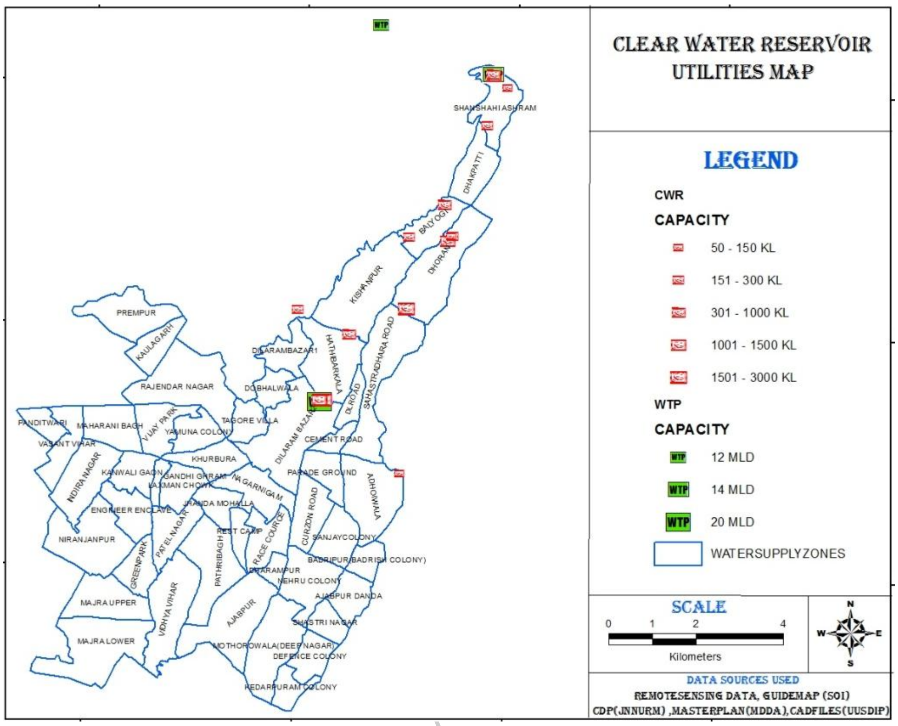

Figure 5-21: Capacities of CWR's

Figures 5-19 and 5-20 shows the location of tube well in the Dehradun city. Only the raw water from Kolukhet surface sources is not getting treated, the water from other surface sources are getting treated. Tube wells are categorized into two type's big tube wells and mini tube wells based on the yield. Mini tube wells are defined as, if the yield is less than 900lpm. The water extracted from the tube wells are pumped to the OHTs for distribution but in some cases the water is directly distributed to households through pumping. Figure 5-21 shows the capacities of clear water reservoirs and water treatment plants. The other assets present in the water treatment plants and CWR's are pump house and booster stations. Booster stations are used to boost the pressure in the water supply pipeline and the pump house contains pumps that are used to pump the water from one asset to another asset.

The assets like pipelines which can't be mapped through remote sensing data are created with the help of executive and junior engineers in UJS. The UJS doesn't have any detailed maps up to household water supply connections. They have only hand drawn maps of primary and secondary pipelines. These paper maps are converted to the geospatial databases. While creating the database, the idea behind mapping the pipelines is that they are mostly aligned along the roads. All pipes are connected properly from high diameter to low diameter. Water flow direction is from 600 to 550 to 500 diameter pipes etc. The major water feeder mains are made up of cast iron pipes which prevents it from rusting.

The accuracy of the database is better achieved by extensive field visits and the discussions with the line men's working in the water supply department. All the attributes include material, diameter of the pipe lines are added by manual entry**.** The following figures 5-22, 5-23 and 5-24, 5-25 shows the location of rising and distribution mains with their attributes.

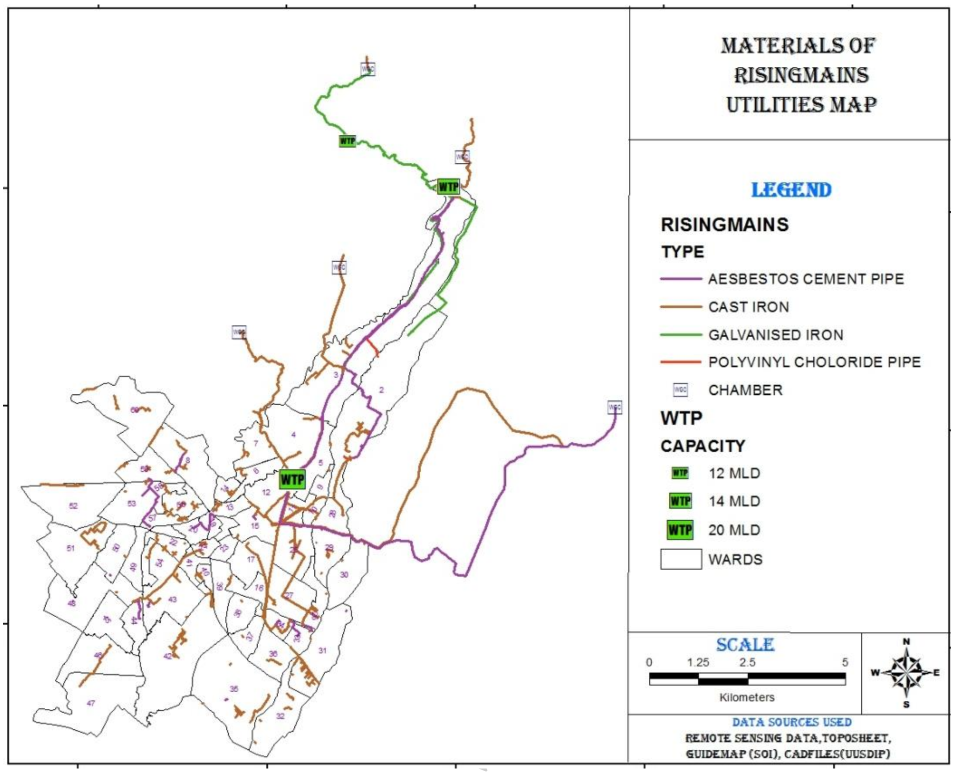

Figure 5-22: Material of rising mains

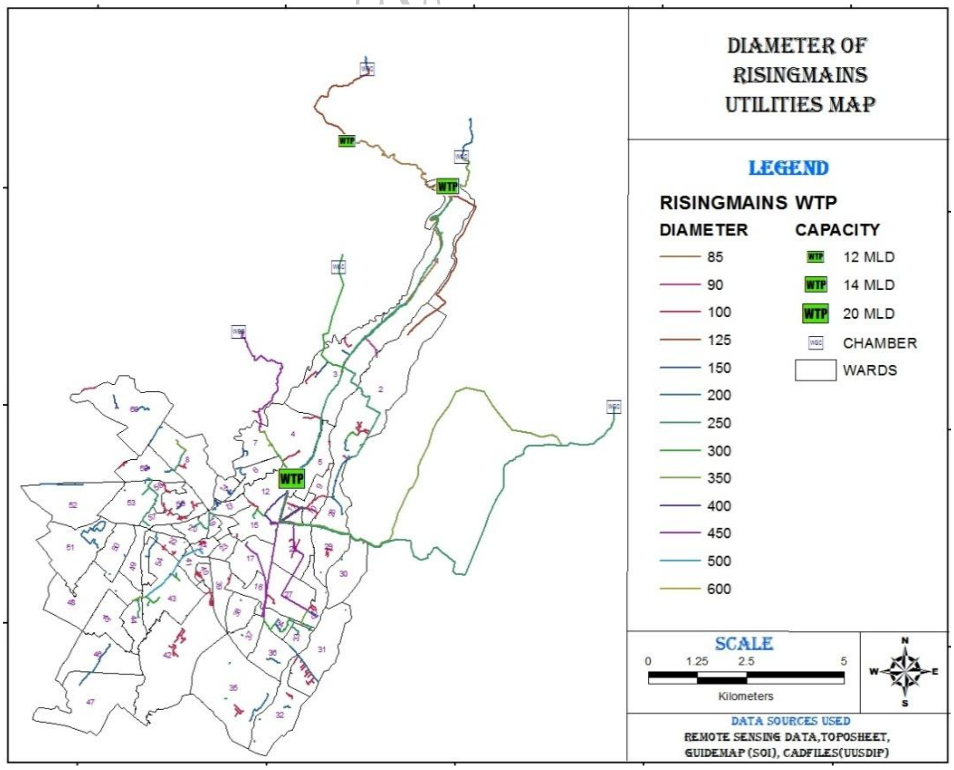

Figure 5-23: Diameter of rising mains

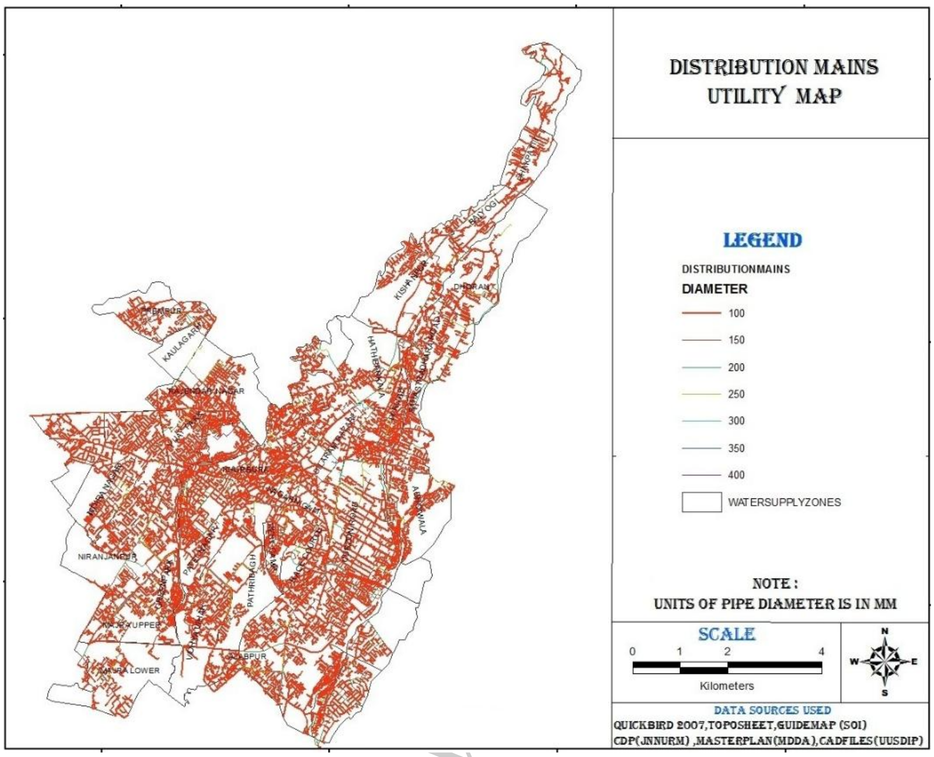

Figure 5-24: Diameter of distribution mains

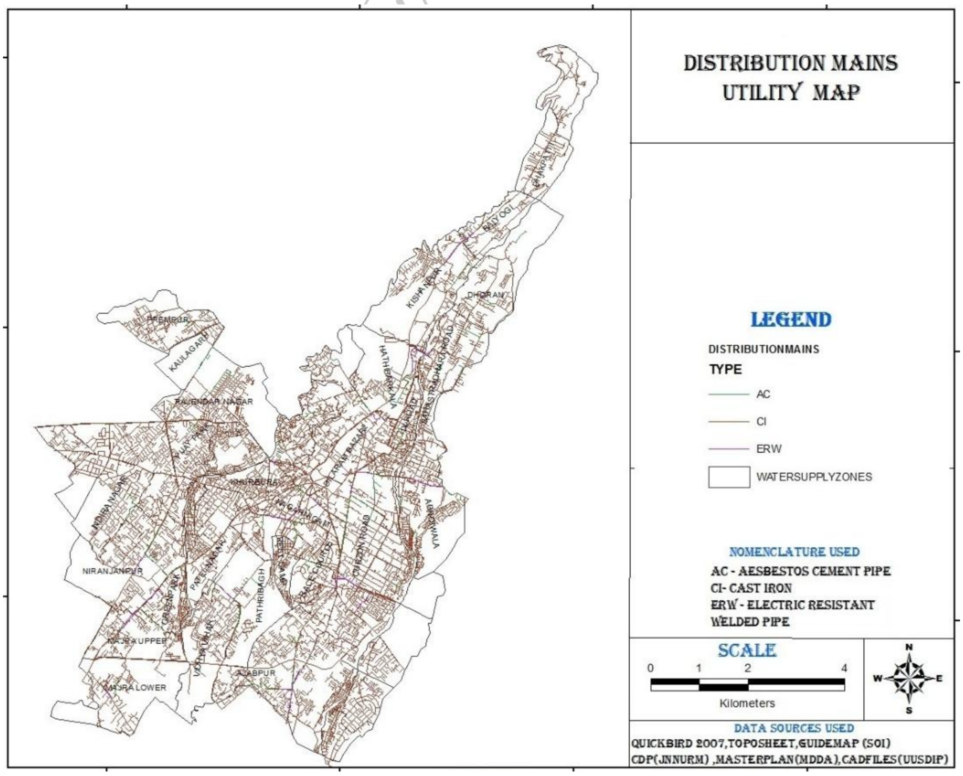

Figure 5-25: Material of distribution mains

5.3.3 Hydro geological mapping

The water level depth, Geomorphology maps are created from geo referenced JPEG maps obtained from central ground water board. The following figures 5-26, 5-27 and 5-28, 5-29 shows the water level depth in the months of May, November and geomorphology, iso-electrical conductivity maps respectively.

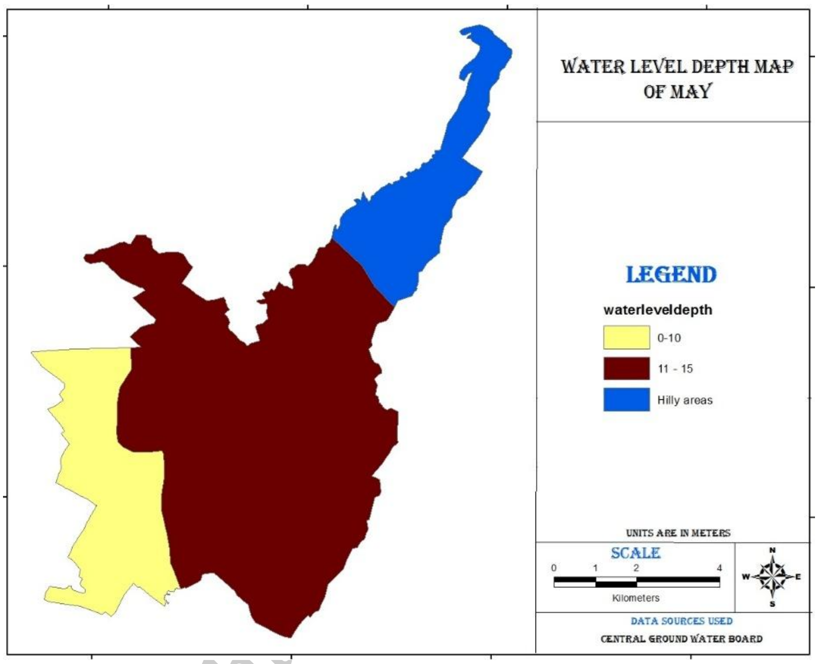

Figure 5-26: Water level depth map of May.

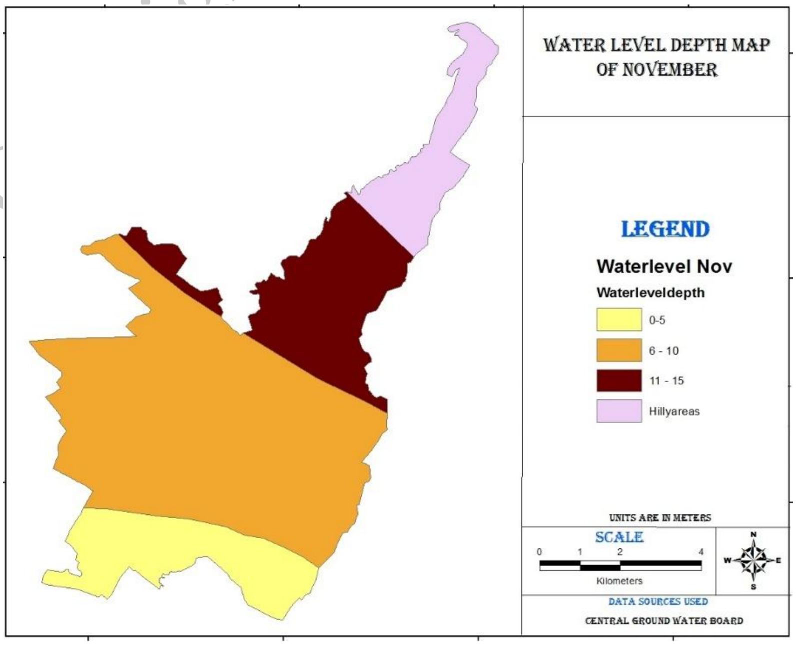

Figure 5-27: Water level depth map of November.

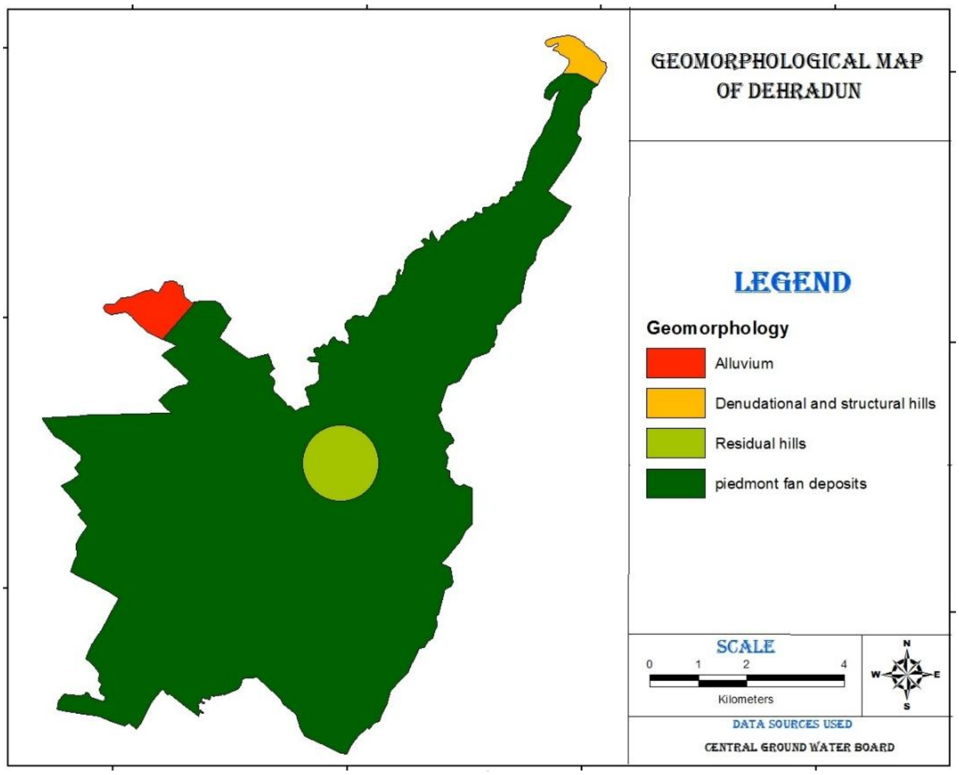

Figure 5-28: Geomorphological map of Dehradun

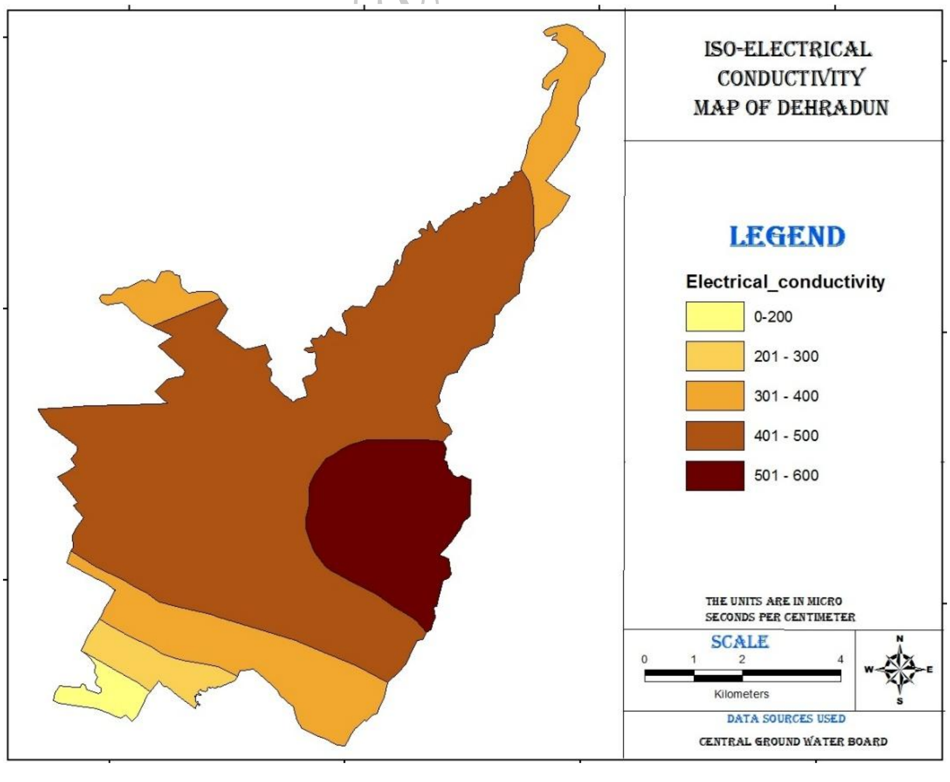

Figure 5-29: Iso-Electrical Conductivity map

From the studies conducted by central ground water board it is concluded that the ground water recharge is good in Dehradun. Water level depth is monitored by hydrographic stations established in the city by central ground water board. In summers the water level depth is going up to 15 meters through almost all the city except in western and south-western parts. Whereas in the winters the depth of water level is low and comparatively it is high in north-eastern, moderate in central and less in southern parts.
The classification adopted for geomorphology is taken from the classification given by the central ground water board.

5.3.4 Land use/Land cover mapping

The land use map is created from the Dehradun master plan 2025. The land uses classification is taken according to the classification given in the master plan. This is a broad level land use map and it won't give detailed classifications of the land uses. The following figure 5-30 shows the land use map of Dehradun. The percentage of residential land use dominates all other land uses in the city.

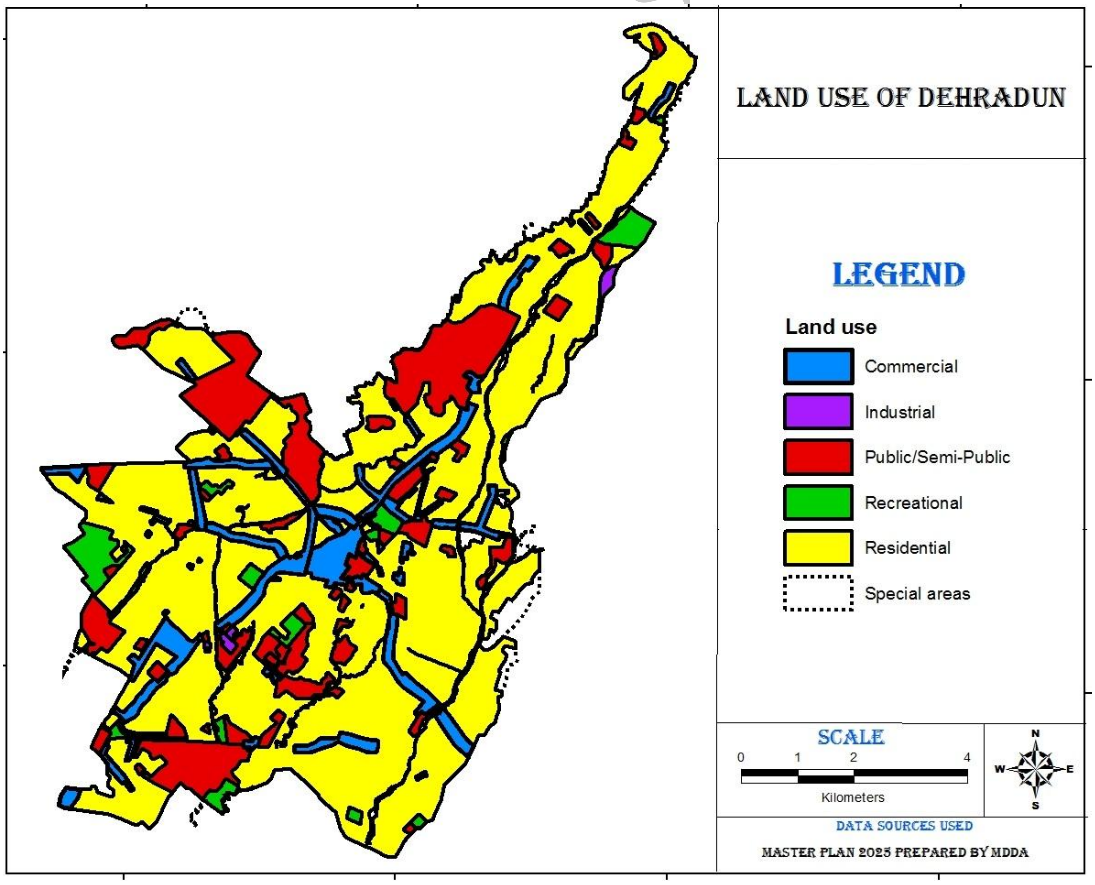

Figure 5-30: Land use map of Dehradun

5.3.5 DEM creation

A DEM is created by digitizing the contours lines obtained from the UUSDIP and the elevation points obtained from the DGPS survey. The following figure 5-31 shows the DEM of the city.

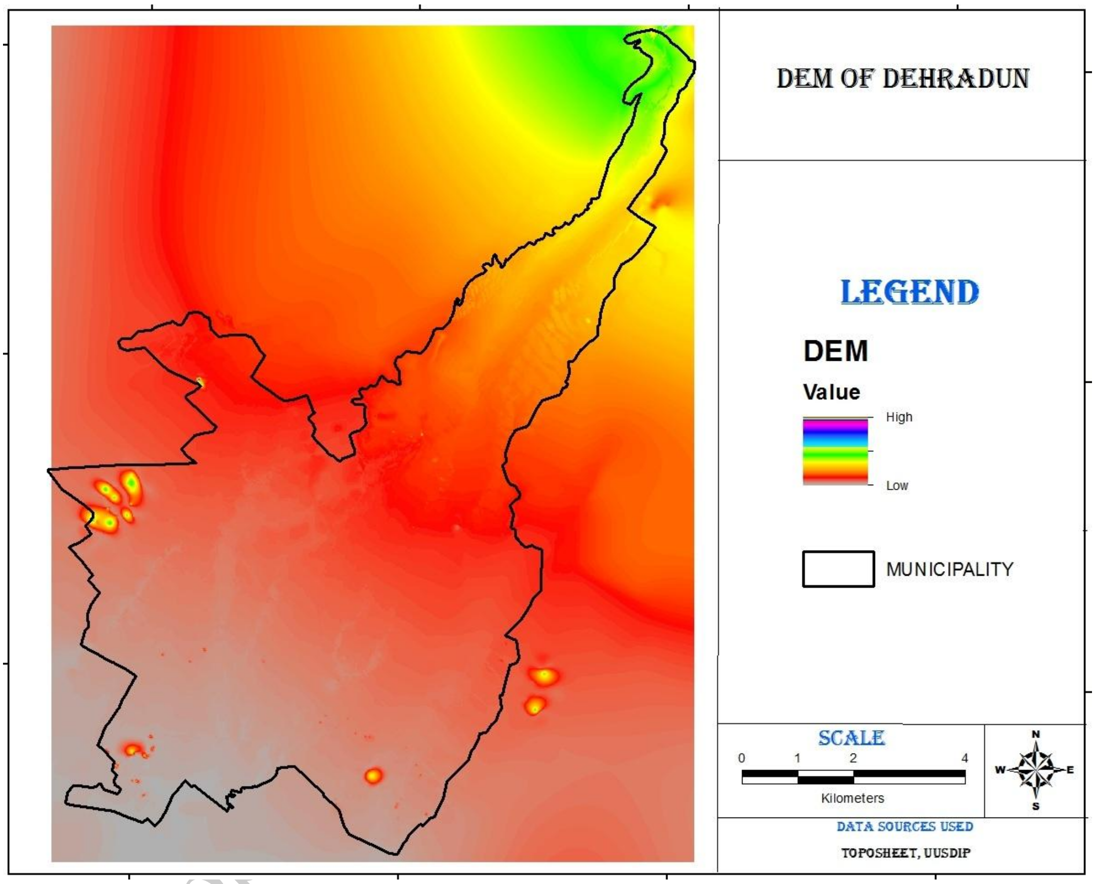

Figure 5-31: DEM of Dehradun

5.4 Multi criteria decision analysis for OHT risk factor calculation

Multi criteria decision analysis (MCDA) provides the framework for the decision makers for evaluating the criterias through a critical process and provides the values for in the crucial stage of decision making. Both Multi criteria decision analysis (MCDA) and Multi criteria decision making (MCDM) are used interchangeably (Jacek Malczewski, 1999), the main components of MCDM are: setting of goals, decision making process, set of criterias, set of alternatives, set of uncontrollable variables and set of outcomes. It is represented in the figure 5-32. The components of spatial multi criteria decision analysis are divided into three phases they are intelligence phase, design phase and choice phase. In each and every stage of spatial multi criteria analysis involves both MCDM and GIS methodologies are used. It is a process of combining and transforming the geographical data into a resultant decision output and it is represented in the figure 5-33.

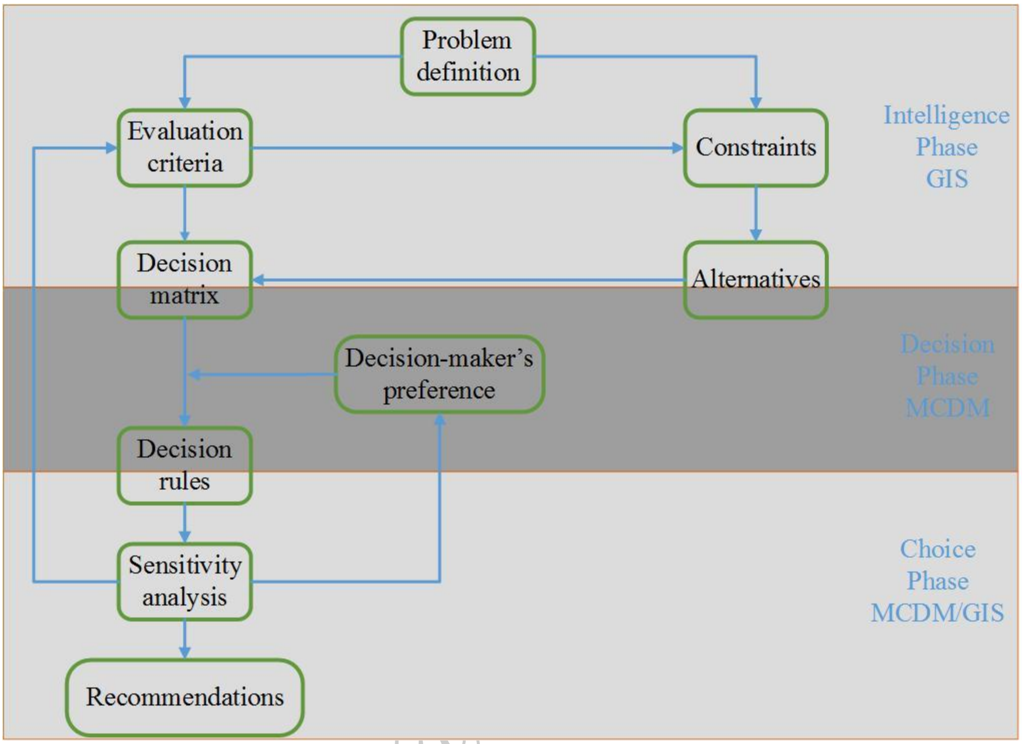

Figure 5-32: Framework of spatial multi criteria decision analysis

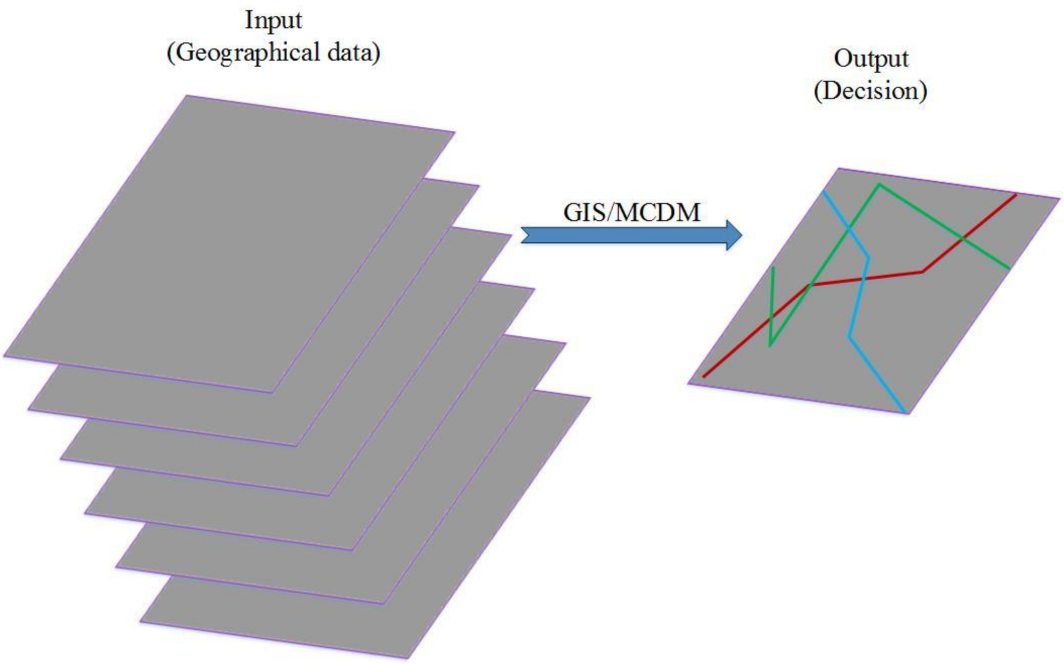

Figure 5-33: Spatial MCA input-output perspective

5.4.1 Analytical hierarchy process (AHP)

Spatial multi criteria analysis involves criterias having varying importance to decision makers. So by weighting the criteria it is possible to express its relative importance with other criterias. There are different weights assessment techniques for weighting the criterias. AHP is one of those techniques developed by Satty(Saaty, 2008). This technique involves three major steps: creation of pair wise comparison of criterias to create a ratio matrix, criterion weights computation and the consistency ratio estimation.

AHP based MCDM technique has been used in generating the priority vectors for all the spatial thematic layers like Land Use, roads, rivers, Iso-electrical conductivity, Geomorphology, Slope, zone type, water level depth, population, institution, and hospitals served. The weightages for non-spatial layers like age, height, capacity, source, pipeline type and diameter is also calculated. Each parameter is given certain weight and a ratio matrix is generated. The scale for pairwise comparison of weightages is shown below in the table 5-2 (Saaty, 1980)

Table 5-2: Scale for pairwise comparison

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate Importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong Importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Source: Saaty (1980)

A normalized pair wise comparison matrix is developed for computation of criterion weights. The consistency analysis is carried out by using the following formulas

- Consistency Measure = MMULT (product of pairwise judgment matrix and average of normalized values)
- Consistency Index = **(λmax – n) / (n-1)**
- Consistency Ratio = **Consistency Index / Random Index**

The consistency ratio is determined to check the level of consistency. If the CR<0.1 it indicates reasonable level of consistency and if CR $\geq$ 0.1 it indicates the inconsistency judgment (Saaty, 2003). The weightages of main criterias and sub-criterias are taken so that a CR<0.1 is achieved. The AHP process is criticized for the relative importance of evaluation criteria without reference to the scales on which the criterias are measured(Paul Goodwin and George Wright, 2014). The random index depends on the number of criterias being compared. The random inconsistency indices for n criterias are taken form the following table 5-3 given by Saaty.

Table 5-3: Random inconsistency indices for n criterias

n	RI	n	RI
1	0	9	1.45
2	0	10	1.49
3	0.58	11	1.51
4	0.9	12	1.48
5	1.12	13	1.56
6	1.24	14	1.57
7	1.32	15	1.59
8	1.41		

Source: Saaty

6 RESULTS AND DISCUSSIONS

6.1 Analysis of water supply system at city level

Table 6-1: Demand supply gap analysis at city level in 2011.

Year	2011
Population	569578
Floating Population	113916 (20%)
Total Population	683494
Per capita demand	210 lpcd
Total demand	143.53 MLD
Supply (surface + subsurface)	178 MLD
Losses(system losses+ friction losses)	106.8 MLD (60%)
Absolute supply	71.2 MLD
Demand supply gap	-72.33 MLD

Source: Census 2011, UUSDIP, Water supply engineering- Santosh kumar Garg.

As per the survey done by UUSDIP under the project Rehabilitation and Augmentation of Water Supply in Dehradun 2011 the total losses accounts for 60% due to the leakages in pipelines, utilities storage, poor maintenance, lack of water meters etc. The per capita demand is calculated by considering all the water demands include domestic, commercial, industrial, institutional, fire and public uses. Tables 6-1, 6-2 shows the Demand supply gap analysis.

Table 6-2: Demand supply gap analysis at city level in 2014

Year	2014
Total Population	709000
Per capita demand	240 lpcd
Total demand	170.16 MLD
Supply (surface + subsurface)	193.2 MLD
Losses (system losses+ friction losses)	68.5 MLD (35.5%)
Absolute supply	124.6 MLD
Demand supply gap	-45.56 MLD

Source: UJS, UUSDIP, Water supply engineering- Santosh kumar Garg.

There is a huge important in water supply system of Dehradun because of the project "Rehabilitation and Augmentation of Water Supply in Dehradun" which was funded by Asian development bank (ADB). The losses in the water supply system has come down to 35.5% in 2014 from 60%in 2011(Government of Uttarakhand, India, 2014).

6.2 Analysis of water supply system at ward level

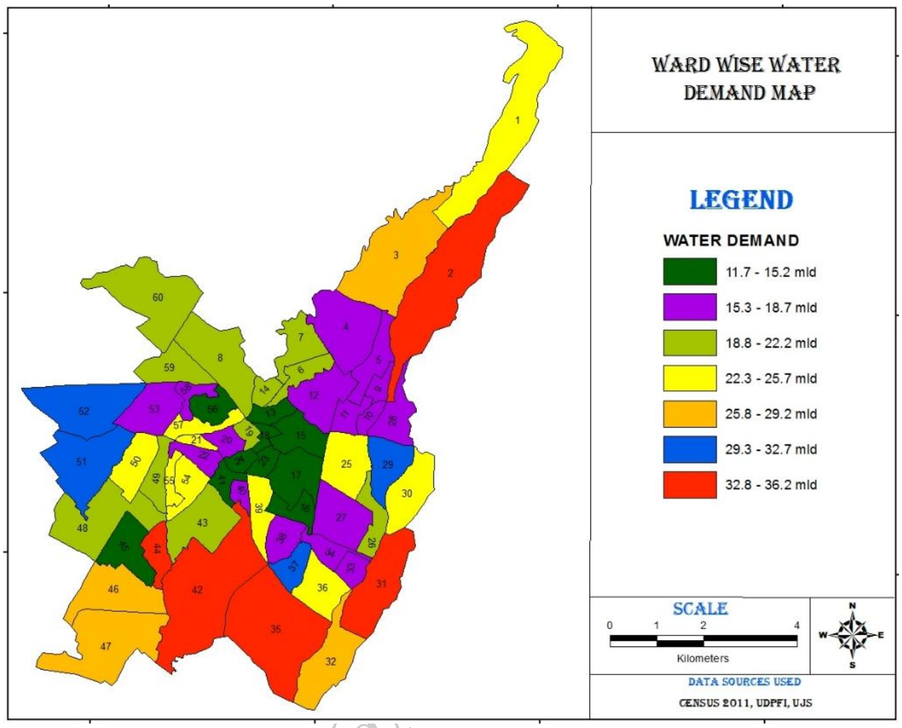

Figure 6-1: Ward wise water demand map in 2011

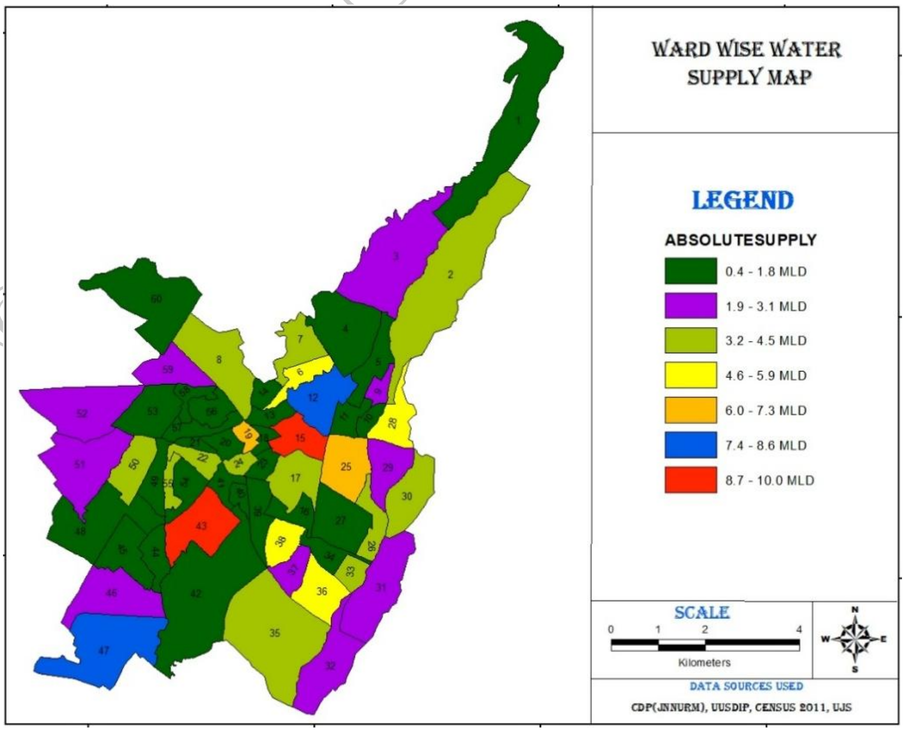

Figure 6-2: Ward wise water supply map in 2011

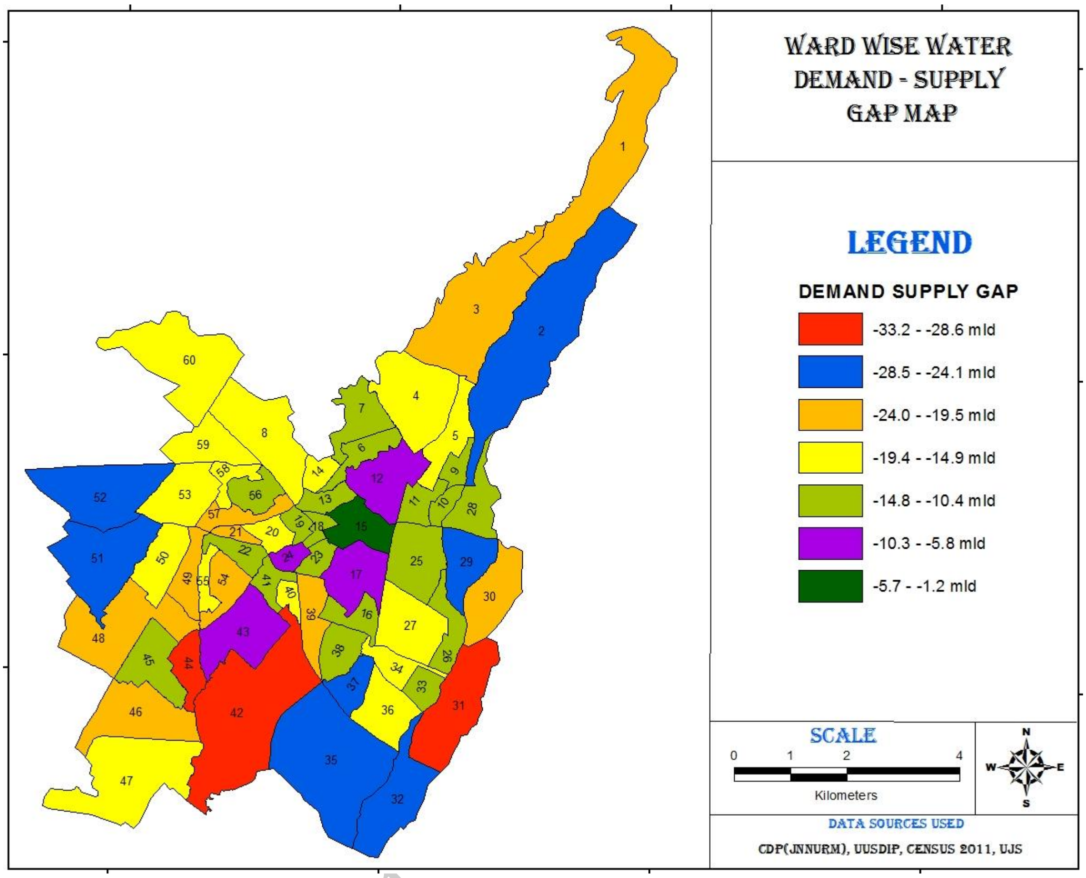

Figure 6-3: Ward wise water demand-supply gap map in 2011

A detailed ward level study is needed for construction/up gradation of assets of the water utility network and also for ward level planning. In each ward, the total population is obtained by summing the permanent population to the floating population. The floating population of each ward is obtained by taking the 5% of permanent population. The ward wise water demand map is created by multiplying the total population with 210 lpcd. The ward wise water supply map is created by summing the maximum capacities of the overhead tanks and maximum capacities of tube wells which are supplying water through direct pumping which are present in that respective wards. The ward wise water demand supply gap is generated by subtracting the ward wise water demand from ward wise water supply. The classification adopted for all the maps are equal interval method. The figures 6-1, 6-2 and 6-3 shows the ward wise demand, supply and demand-supply gap maps.

6.3 SWOT analysis of Water supply system

Table 6-3: SWOT analysis

Strengths	Weakness
• In gravity zone, operation cost will be very minimal. • Good quality of water is available from springs, tube wells so the treatment cost is less.	• The water supply pipelines are very old and they are in dilapidated condition. • Huge water losses due to leakages and illegal connections. • No water meters. • Water tariff is too low compared to cost of production. • Most of the assets of water utility network are old which needs to be replaced. • No stand by power supply.
Opportunities	**Threats**
• A reservoir is proposed for Song River, if it comes up it supply water under gravity.	• Tampering the width of pipe sizes sanctioned by the authority by the public.

6.4 Forecast of water supply system at city level

Population is the foremost important thing while analyzing the water supply system in terms of demand calculations. A sustainable water supply system is a system which can able to serve the water to the present population without compromising the future needs of the people. Firstly the population from 1951 to 2001(6 years) was taken to project the future population for next 30 years. Here the base year is 2011 and the ultimate year is 2041. The projection is done with all the four methods Arithmetic Growth Method (AGM), Geometric Growth Rate (GGR), Incremental Increase (II), Average of AGM, II, and GGR. From the census 2011, the population of Dehradun is 569578("Census of India Website : Office of the Registrar General & Census Commissioner, India," 2014). So among all the methods the projected value of population obtained from the Geometric Growth Rate (GGR) method is near to the real population of Dehradun city in the year 2011. So finally the Geometric Growth Rate (GGR) is considered for calculating the water demands for the upcoming years. Therefore the population from the year 1961 to 2011 was taken to project the future population for next 30 years. Here the base year is 2011 and the ultimate year is 2041. The following tables 6-4, 6-5 shows the population projections up to 2031 and 2041 using various methods.

Table 6-4: Population projection

2011 AS A BASE YEAR							
ARITHMETIC GROWTH METHOD				GEOMETRIC GROWTH RATE			
Year	Population	Decadal GR	Annual GR	Year	Population	Decadal GR	Annual GR
2011	488,728			2011	557,171		
2016	518,828	12.70%	1.20%	2016	636,700	30.58%	2.70%
2021	550,782	12.70%	1.20%	2021	727,580	30.58%	2.70%
2026	580,981	11.27%	1.07%	2026	831,432	30.58%	2.70%
2031	612,836	11.27%	1.07%	2031	950,108	30.58%	2.70%
INCREMENTAL INCREASE				AVERAGE OF AGM,II,GGR			
Year	Population	Decadal GR	Annual GR	Year	Population	Decadal GR	Annual GR
2011	525,268			2011	523,722		
2016	555,429	11.81%	1.12%	2016	570,701	18.75%	1.73%
2021	587,322	11.81%	1.12%	2021	621,895	18.75%	1.73%
2026	617,570	10.57%	1.01%	2026	677,207	18.58%	1.72%
2031	649,376	10.57%	1.01%	2031	737,440	18.58%	1.72%

Table 6-5: Population projection through geometric growth rate

GEOMETRIC GROWTH RATE			
Year	Population	Decadal GR	Annual GR
2021	771,646		
2026	898,153	35.48%	3.08%
2031	1,045,400	35.48%	3.08%
2036	1,216,788	35.48%	3.08%
2041	1,416,274	35.48%	3.08%

As Dehradun is tourist hub, the floating population is very high and there is no documentation with municipal authorities. So as per the guidelines the floating population is considered as the 20% of the permanent population. Water demand is calculated by multiplying the total population with the standard of consumption of water supply by a person per day as given in manual on water supply, CPHEEO(CPHEEO, Government of India, 2005)(Santosh Kumar Garg, 2010).

While forecasting the water demand the water losses in the system can be changed as per the actual. After five years the losses remain as same percent as before because the loss reduction take long time but after that the losses reduce by absolute 10%t ill it stabilizes at 15% minimum level.

The main problem in Dehradun’s water supply network is **“leakages in the pipelines, insufficient pressures in the pipelines, illegal water supply connections”.** So the total amount of potable water produced is not getting distributed to the public. Tables 6-6, 6-7 shows the forecasting of water demand and demand-supply gap analysis at city level.

Table 6-6: Forecasting of water demand at city level

Year	Population	Floating population	Total population	LPCD	Water demand (MLD)
2021	771,646	154329	925975	240	222
2026	898,153	179631	1077783	240	259
2031	1,045,400	209080	1254480	270	339
2036	1,216,788	243358	1460146	270	394
2041	1,416,274	283255	1699529	270	459

Table 6-7: Demand-supply gap at city level

Year	Water demand	Present Supply	Losses	Losses	Absolute supply	Deficit
	MLD	MLD	%	MLD	MLD	MLD
2021	222	193.2	35.5	68.6	124.6	-97.6
2026	259	193.2	35.5	68.6	124.6	-134.1
2031	339	193.2	26	50.2	143.0	-195.7
2036	394	193.2	16	30.9	162.3	-232.0
2041	459	193.2	15	29.0	164.2	-294.7

6.5 Risk factor analysis of OHTs at city level

The water utility data model is very useful in finding the deficiencies in the water supply system such as detection of leakages, illegal connections through water meters, locations of insufficient pressure in the system etc. Here an attempt is made to find the risk factor of overhead tanks. **Risk of the OHT is defined as who or what is affected if that asset fails.** The factor's which contributes to the risk associated with the overhead tank are classified as **spatial and non-spatial factors.** The criterias taken for both spatial factors and non-spatial factors are based on either **consequence/severity of failure of OHTs or chances of failure of OHTs or both.** The scoring is given to the assets based on its vulnerability to risk, the high vulnerability leads to high risk and low vulnerability leads to low risk. AHP based MCDA is used for giving the weightages to all main and sub-criterias which determines the risk factor of OHTs.

6.5.1 Spatial factors for overhead tanks risk assessment

All the possible spatial risk of failure parameters of OHTs are identified and a total of eleven criterias are taken for calculation of spatial risk factor of OHTs. Each and every criteria is again having sub-criterias. The eleven spatial criterias for risk factor calculation of OHTs are namely slope, roads, rivers, zone type, land use, population served, hospitals served, institutions served, water level depth, geomorphology and iso-electrical conductivity. A pair wise comparison of all the spatial factors that contributes to the risk of overhead tanks are compared with every other factor and a pair wise comparison matrix is generated. The weightages are given to the criterias by comparing how important each criteria is with respect to others and the scale of weights are taken according to the Saaty (Casini et al., 2007).

Table 6-8: Pair wise comparison of spatial criterias for risk factor calculation

Main Criterias	Slope	Roads	Rivers	Zone type	Land use	Population served	Hospitals served	Institutions served	Water level depth	Geomor phology	Iso-electrical conductivity
Slope	1.000	3.000	4	5.000	6.000	6	7	7	8	8	9
Roads	0.333	1.000	3.000	3	4.000	4.000	5.000	6.000	7.000	8.000	9.000
Rivers	0.250	0.333	1.000	3.000	3	4.000	4.000	5.000	7.000	8.000	9.000
Zone type	0.200	0.333	0.333	1.000	2.000	3	3.000	4.000	5.000	6.000	8.000
Land use	0.167	0.250	0.333	0.500	1.000	2.000	3	4.000	5.000	6.000	8.000
Population served	0.167	0.250	0.250	0.333	0.500	1.000	2.000	3	4.000	5.000	7.000
Hospitals served	0.143	0.200	0.250	0.333	0.333	0.500	1.000	2.000	3	4.000	7.000
Institutions served	0.143	0.167	0.200	0.250	0.250	0.333	0.500	1.000	3.000	5	6.000
Water level depth	0.125	0.143	0.143	0.200	0.200	0.250	0.333	0.333	1.000	4.000	6
Geomorphology	0.125	0.125	0.125	0.167	0.167	0.200	0.250	0.200	0.250	1.000	5.000
Iso-electrical conductivity	0.111	0.111	0.111	0.125	0.125	0.143	0.143	0.167	0.167	0.200	1.000

Table 6-9: Normalized ratio matrix of spatial criterias for risk factor calculation

Main Criterias	Slope	Roads	Rivers	Zone type	Land use	Population served	Hospitals served	Institutions served	Water level depth	Geomorphology	Iso-electrical conductivity
Slope	0.3619	0.5074	0.41044	0.3594967	0.34139	0.280031	0.266909	0.2140673	0.184261	0.144927536	0.12
Roads	0.1206	0.1691	0.30783	0.215698	0.2276	0.186687	0.190649	0.1834862	0.1612284	0.144927536	0.12
Rivers	0.0905	0.0564	0.10261	0.215698	0.1707	0.186687	0.152519	0.1529052	0.1612284	0.144927536	0.12
Zone type	0.0724	0.0564	0.0342	0.0718993	0.1138	0.140016	0.114389	0.1223242	0.1151631	0.108695652	0.10666667
Land use	0.0603	0.0423	0.0342	0.0359497	0.0569	0.093344	0.114389	0.1223242	0.1151631	0.108695652	0.10666667
Population served	0.0603	0.0423	0.02565	0.0239664	0.02845	0.046672	0.07626	0.0917431	0.0921305	0.09057971	0.09333333
Hospitals served	0.0517	0.0338	0.02565	0.0239664	0.01897	0.023336	0.03813	0.0611621	0.0690979	0.072463768	0.09333333
Institutions served	0.0517	0.0282	0.02052	0.0179748	0.01422	0.015557	0.019065	0.030581	0.0690979	0.09057971	0.08
Water level depth	0.0452	0.0242	0.01466	0.0143799	0.01138	0.011668	0.01271	0.0101937	0.0230326	0.072463768	0.08
Geomorphology	0.0452	0.0211	0.01283	0.0119832	0.00948	0.009334	0.009532	0.0061162	0.0057582	0.018115942	0.06666667
Iso-electrical conductivity	0.0402	0.0188	0.0114	0.0089874	0.00711	0.006667	0.005447	0.0050968	0.0038388	0.003623188	0.01333333

The pair wise comparison matrix is then normalized by dividing each element of the matrix with its column total and computed the average of elements in each row of the normalized matrix. A consistency analysis has been carried out for finding the consistency of weightages achieved. A consistency ratio of 0.054 which is less than 0.1 is achieved and is found satisfactory. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of the spatial factors are given in the following table 6-8, 6-9, 6-10.

Table 6-10: Consistency analysis of spatial criterias for risk factor calculation

Criterias	Priority vector/ Weights	Consistency measure	Priority/ Rank
Slope	0.290073111	13.22332319	9
Roads	0.184351097	13.53165262	11
Rivers	0.141283436	13.4320156	10
Zone type	0.095991561	13.12626717	8
Land use	0.080929973	12.91262931	7
Population served	0.061034684	12.60612284	6
Hospitals served	0.046511847	12.34661202	5
Institutions served	0.039771515	12.10529856	4
Water level depth	0.029080141	11.615861	2
Geomorphology	0.019653766	11.28321764	1
Iso-electrical conductivity	0.011318868	11.71635143	3
CI (consistency index)		0.081346813	
RI (random index)		1.51	
CR(consistency ratio)		0.053872	

Land use:

The land use of the Dehradun is classified into six classes' namely residential, commercial, industrial, public/semipublic, recreation and special areas as it is given in master plan. The risk of the OHT failure differs in various land uses because the activities in all the land uses has their own importance so risk is calculated based on consequences of failure of OHT. Also the number of people left without water supply will vary from one land use to another. The weightages for sub-criterias of land use has been taken by comparing the importance of each land use with respect to other land uses. The number of water supply connections are high for residential land use when compared to all other land uses, so the weight of the this land use is high with respect to others and accordingly the weights for all other land uses are taken.

Table 6-11: Pair wise comparison of Land use sub-criterias

Sub-Criterias	Residential	Commercial	Industrial	Public/semi public	Recreation	Special areas
Residential	1	2	3	5	7	9
Commercial	0.5	1	2	4	6	8
Industrial	0.3333333	0.5	1	3	5	7
Public/semi public	0.2	0.25	0.3333333	1	3	5
Recreation	0.1428571	0.16666667	0.2	0.333333333	1	3
Special areas	0.1111111	0.125	0.1428571	0.2	0.3333333	1

From the consistency analysis it is found that a CR of 0.044 is achieved so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of land use criteria are given in the tables 6-11, 6-12, 6-13.

Table 6-12: Normalized ratio matrix of Land use sub-criterias

Sub-Criterias	Residential	Commercial	Industrial	Public/semi public	Recreation	Special areas
Residential	0.4371964	0.49484536	0.4493581	0.369458128	0.3134328	0.272727273
Commercial	0.2185982	0.24742268	0.299572	0.295566502	0.2686567	0.242424242
Industrial	0.1457321	0.12371134	0.149786	0.221674877	0.2238806	0.212121212
Public/semi public	0.0874393	0.06185567	0.0499287	0.073891626	0.1343284	0.151515152
Recreation	0.0624566	0.04123711	0.0299572	0.024630542	0.0447761	0.090909091
Special areas	0.0485774	0.03092784	0.021398	0.014778325	0.0149254	0.03030303

Table 6-13: Consistency analysis of Land use sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
Residential	0.389503008	6.4239844	5
Commercial	0.262040063	6.475776006	6
Industrial	0.179484363	6.421275957	4
Public/semi public	0.093159793	6.198741768	3
Recreation	0.048994449	6.035707958	1
Special areas	0.026818324	6.094918887	2
CI (consistency index)		0.055013499	
RI (random index)		1.24	
CR(consistency ratio)		0.044365725	

Roads:

A Euclidian distance is created for the roads such that it covers the whole study area and it is reclassified into five classes. The units are in meters. This criteria is based on consequences of failure of OHTs. The OHTs which are located with very good accessibility to the roads can easily be repaired when it becomes failure than the inaccessible OHTs.

Table 6-14: Pair wise comparison of Roads buffer sub-criterias

Sub-Criterias	0-653	654-1703	1703-2986	2986-4409	4409-5949
0-653	1	0.33333333	0.2	0.14285714	0.11111111
654-1703	3	1	0.25	0.16666667	0.125
1703-2986	5	4	1	0.33333333	0.2
2986-4409	7	6	3	1	0.25
4409-5949	9	8	5	4	1

So the OHTs which are falling in the near buffer region are of less risk while compared to the OHTs falling in the far buffer zone. Therefore in the pair wise comparison matrix the weightages are given to these sub-criterias such that the near buffer are less importance than far buffer zones. From the consistency analysis it is found that a CR of 0.083379159 is achieved so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of roads criteria are given in the tables 6-14, 6-15 and 6-16.

Table 6-15: Normalized ratio matrix of Roads buffer sub-criterias

Sub-Criterias	0-653	654-1703	1703-2986	2986-4409	4409-5949
0-653	0.04	0.01724138	0.02116402	0.02531646	0.06589786
654-1703	0.12	0.05172414	0.02645503	0.02953586	0.07413509
1703-2986	0.2	0.20689655	0.10582011	0.05907173	0.11861614
2986-4409	0.28	0.31034483	0.31746032	0.17721519	0.14827018
4409-5949	0.36	0.4137931	0.52910053	0.70886076	0.59308072

Table 6-16: Consistency analysis of Roads buffer sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
0-653	0.033923943	5.152277339	2
654-1703	0.060370024	5.017268854	1
1703-2986	0.138080906	5.327264341	3
2986-4409	0.246658103	5.638697065	4
4409-5949	0.520967023	5.732185556	5
CI (consistency index)		0.093384658	
RI (random index)		1.12	
CR(consistency ratio)		0.083379159	

Rivers:

A Euclidian distance is created for the rivers and it is reclassified into five classes. The units are in meters. This criteria is based on consequences of failure of OHT and the risk factor is determined by who and what is affected if the OHT fails. The soil present near the rivers is not so stable and also during the flooding of rivers in urban areas the chances of water pollution is high because the pressures in the pipes when the water is either pumped to the OHTs or distributed to the customers is enormous, if there is any leakage in the pipelines the polluted water can easily get sucked by the pipelines.

Table 6-17: Pair wise comparison of Rivers buffer sub-criterias

Sub-Criterias	6201 - 8108	4389 - 6200	2704 - 4388	1177 - 2703	0 - 1176
6201 - 8108	1	0.5	0.25	0.14285714	0.11111111
4389 - 6200	2	1	0.5	0.25	0.16666667
2704 - 4388	4	2	1	0.33333333	0.2
1177 - 2703	7	4	3	1	0.33333333
0 - 1176	9	6	5	3	1

So the OHTs which are falling in the near buffer zones of river are at higher risk when compared to the OHTs falling in the far buffer zones. Therefore in the pair wise comparison matrix the weightages for the sub-criterias are given such that the near buffer is of high importance than far buffer zones. From the consistency analysis it is found that a CR of 0.027228517 is achieved so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of rivers criteria are given in the tables 6-17, 6-18 and 6-19.

Table 6-18: Normalized ratio matrix of Rivers buffer sub-criterias

Sub-Criterias	6201 - 8108	4389 - 6200	2704 - 4388	1177 - 2703	0 - 1176
6201 - 8108	0.043478261	0.037037037	0.025641026	0.0302267	0.06134969
4389 - 6200	0.086956522	0.074074074	0.051282051	0.05289673	0.09202454
2704 - 4388	0.173913043	0.148148148	0.102564103	0.07052897	0.11042945
1177 - 2703	0.304347826	0.296296296	0.307692308	0.2115869	0.18404908
0 - 1176	0.391304348	0.444444444	0.512820513	0.63476071	0.55214724

Table 6-19: Consistency analysis of Rivers buffer sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
6201 - 8108	0.039546543	5.035823524	1
4389 - 6200	0.071446782	5.050091223	3
2704 - 4388	0.121116742	5.040979927	2
1177 - 2703	0.260794482	5.198689199	4
0 - 1176	0.50709545	5.284334916	5
CI (consistency index)		0.030495939	
RI (random index)		1.12	
CR(consistency ratio)		0.027228517	

Slope:

The OHTs are usually located at higher elevation points and on flat surface in the city so that to achieve sufficient pressures in the pipelines. The land with higher slopes is not stable because the chances of landslides occurrences are high. So the selection of locations for constructing the OHTs are based on the slope and elevation, the site with higher elevation and low slopes are more suitable for construction of OHTs. Therefore the failure of OHT is high at higher slopes when compared to lower slopes. The slope of Dehradun if classified into five classes.

Table 6-20: Pair wise comparison of slope sub-criterias

Sub-Criterias	0-5	6-10	11-25	26-45	46-88
0-5	1	0.5	0.25	0.16666667	0.11111111
6-10	2	1	0.5	0.2	0.16666667
11-25	4	2	1	0.33333333	0.25
26-45	6	5	3	1	0.5
46-88	9	6	4	2	1

Table 6-21: Normalized ratio matrix of slope sub-criterias

Sub-Criterias	0-5	6-10	11-25	26-45	46-88
0-5	0.045455	0.034483	0.028571	0.04504505	0.05479452
6-10	0.090909	0.068966	0.057143	0.05405405	0.08219178
11-25	0.181818	0.137931	0.114286	0.09009009	0.12328767
26-45	0.272727	0.344828	0.342857	0.27027027	0.24657534
46-88	0.409091	0.413793	0.457143	0.54054054	0.49315068

Table 6-22: Consistency analysis of slope sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
0-5	0.04166966	5.040226011	3
6-10	0.07065266	5.023837594	1
11-25	0.129482538	5.032618691	2
26-45	0.295451523	5.139767738	5
46-88	0.462743619	5.122749656	4
CI (consistency index)		0.017959985	
RI (random index)		1.12	
CR(consistency ratio)		0.0160357	

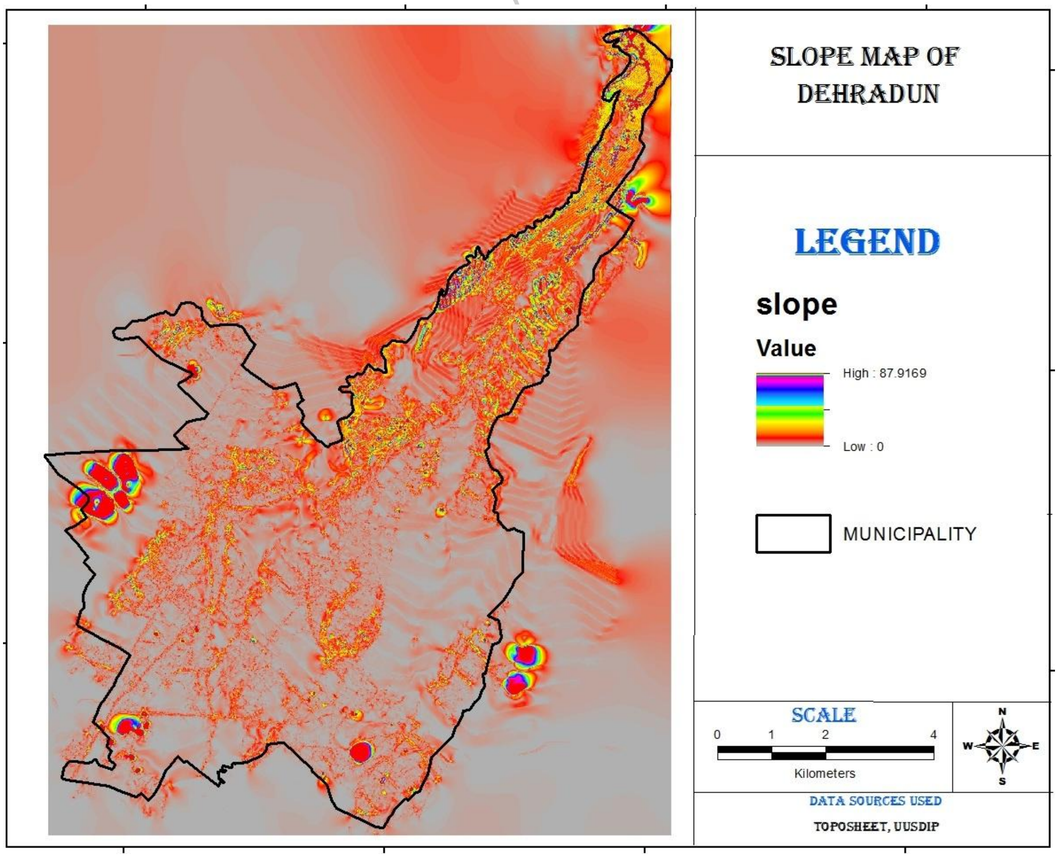

Figure 6-4: Slope map of Dehradun

This criteria is based on both consequences and chances of failure of OHTs. Hence in the pair wise comparison matrix, the weightages for the sub-criterias of slope are given such that the higher slopes are more important than lower slopes. From the consistency analysis it is found that a CR of 0.0160357 is achieved so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of slope criteria are given in the tables 6-20, 6-21 and 6-22. Also the slope map of Dehradun is shown in the figure 6-4.

Geomorphology:

Dehradun is classified into four classes of geomorphology according to CGWB namely Alluvium, Denudation & structural hills, Residual hills and Piedmont fan deposits (Ministry of Water Resources and Central Ground Water Board, 2011). Geomorphology plays a prominent role in the constructions activities. This criteria is based on chances of failure of OHTs. Different types of geomorphological areas are suitable for different type of activities such as cultivation, construction etc. The major area of Dehradun is occupied by piedmont fan deposits which is not suitable for construction activities. So the overhead tanks which are located in this region are at higher risks. Therefore in the pair wise comparison matrix the weightages for the sub-criterias of geomorphology are given such that each sub-criteria is compared with other according to their suitability of construction. The sub-criteria which is highly suitable for construction of OHTs when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a CR of 0.037563343 is achieved so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of geomorphology criteria are given in the following tables 6-23, 6-24 and 6-25.

Table 6-23: Pair wise comparison of Geomorphology sub-criterias

Sub-Criterias	Alluvium	Denudation & structural hills	Residual hills	Piedmont fan deposits
Alluvium	1	0.2	0.142857143	0.111111111
Denudation & structural hills	5	1	0.333333333	0.25
Residual hills	7	3	1	0.5
Piedmont fan deposits	9	4	2	1

Table 6-24: Normalized ratio matrix of Geomorphology sub-criterias

Sub-Criterias	Alluvium	Denudation & structural hills	Residual hills	Piedmont fan deposits
Alluvium	0.045455	0.024390244	0.04109589	0.059701493
Denudation & structural hills	0.227273	0.12195122	0.095890411	0.134328358
Residual hills	0.318182	0.365853659	0.287671233	0.268656716
Piedmont fan deposits	0.409091	0.487804878	0.575342466	0.537313433

Table 6-25: Consistency analysis of Geomorphology sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
Alluvium	0.042660543	4.026021247	1
Denudation & structural hills	0.144860679	4.053025277	2
Residual hills	0.310090857	4.174552808	4
Piedmont fan deposits	0.502387921	4.152084772	3
CI (consistency index)			0.033807009
RI (random index)			0.9
CR(consistency ratio)			0.037563343

Iso-electrical conductivity:

Iso-electrical conductivity is used to assess the purity of water. The permissible limit for electrical conductivity (EC) is 300 µs/cm (Chadetrik Rout and Arabinda Sharma, 2011). This criteria is based on consequences of failure of OHTs. Dehradun city is classified into five classes of Iso-electrical conductivity. So the areas with higher EC than the permissible limits are not suitable for drinking and the OHTs which are located in these regions are at higher risks. So in the pair wise comparison matrix of Iso-electrical conductivity criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to their suitability of drinking water.

Table 6-26: Pair wise comparison of Iso-electrical conductivity sub-criterias

Sub-Criterias	0-200 µs/cm	201-300 µs/cm	301-400 µs/cm	401-500 µs/cm	501-600 µs/cm
0-200 µs/cm	1	0.33333333	0.2	0.14285714	0.11111111
201-300 µs/cm	3	1	0.33333333	0.2	0.16666667
301-400 µs/cm	5	3	1	0.33333333	0.25
401-500 µs/cm	7	5	3	1	0.5
501-600 µs/cm	9	6	4	2	1

Table 6-27: Normalized ratio matrix of Iso-electrical conductivity sub-criterias

Sub-Criterias	0-200 µs/cm	201-300 µs/cm	301-400 µs/cm	401-500 µs/cm	501-600 µs/cm
0-200 µs/cm	0.04	0.02173913	0.0234375	0.0388601	0.05479452
201-300 µs/cm	0.12	0.06521739	0.0390625	0.05440415	0.08219178
301-400 µs/cm	0.2	0.19565217	0.1171875	0.09067358	0.12328767
401-500 µs/cm	0.28	0.32608696	0.3515625	0.27202073	0.24657534
501-600 µs/cm	0.36	0.39130435	0.46875	0.54404145	0.49315068

The sub-criteria which are having higher limits than the permissible when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a consistency ratio of 0.037462446 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of Iso-electrical conductivity criteria are given in the following tables 6-26, 6-27 and 6-28.

Table 6-28: Consistency analysis of Iso-electrical conductivity sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
0-200 µs/cm	0.035766251	5.067239294	2
201-300 µs/cm	0.072175163	5.018605626	1
301-400 µs/cm	0.145360184	5.173326013	3
401-500 µs/cm	0.295249105	5.311765059	5
501-600 µs/cm	0.451449297	5.268222808	4
CI (consistency index)			0.04195794
RI (random index)			1.12
CR(consistency ratio)			0.037462446

Water level depth:

The water level depth varies from season to season. In summers the depth of water will go down than in winters because the water demand increases in summer as the usage of water is high. This criteria is based on chances of failure of OHTs. So the chances of failure of OHT to serve the people with water supply is high in summer comparing to winters. Hence the risk of the overhead tanks is highly associated with the water level depth, if the water level depth is high the risk of OHT is high and vice versa. Dehradun city is classified into three classes of water level depth according to central ground water board (Ministry of Water Resources and Central Ground Water Board, 2011). Therefore in the pair wise comparison matrix of water level depth criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with respect to others according to their depth of water availability. The sub-criteria with higher depths of water availability are given high weightages when compared to other sub-criterias and vice versa. From the consistency analysis it is found that a consistency ratio of 0.032055926 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of water level depth criteria are given in the following tables 6-29, 6-30 and 6-31.

Table 6-29: Pair wise comparison of water level depth sub-criterias

Sub-Criterias	0-5 m	6-10 m	11-15 m
0-5 m	1	0.25	0.11111111
6-10 m	4	1	0.25
11-15 m	9	4	1

Table 6-30: Normalized ratio matrix of water level depth sub-criterias

Sub-Criterias	0-5 m	6-10 m	11-15 m
0-5 m	0.071429	0.047619	0.08163265
6-10 m	0.285714	0.190476	0.18367347
11-15 m	0.642857	0.761905	0.73469388

Table 6-31: Consistency analysis of water level depth sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
0-5 m	0.066893424	3.006591337	1
6-10 m	0.219954649	3.027061856	2
11-15 m	0.713151927	3.077901431	3
CI (consistency index)		0.018592437	
RI (random index)		0.58	
CR(consistency ratio)		0.032055926	

Zone type:

The distribution system is of three type's i.e. gravity zone, mixed zone and pumping zone ("City Development Plan of Dehradun," 2007). This criteria is based on chances of failure of OHTs. The OHTs which are present in gravity zone can easily be filled with water without much pumping. In the gravity zone the operation and maintenance cost is also very less when compared to the OHT present in the mixed and pumping zones. So the OHT which are located in gravity zones are at lower risk compared to other zones. Therefore in the pair wise comparison matrix of zone type criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to their zone types.

Table 6-32: Pair wise comparison of zone type sub-criterias

Sub-Criterias	Gravity	Mixed	Pumping
Gravity	1	0.25	0.11111111
Mixed	4	1	0.25
Pumping	9	4	1

Table 6-33: Normalized ratio matrix of zone type sub-criterias

Sub-Criterias	Gravity	Mixed	Pumping
Gravity	0.071429	0.047619	0.08163265
Mixed	0.285714	0.190476	0.18367347
Pumping	0.642857	0.761905	0.73469388

Table 6-34: Consistency analysis of zone type sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
Gravity	0.066893424	3.006591337	1
Mixed	0.219954649	3.027061856	2
Pumping	0.713151927	3.077901431	3
CI (consistency index)		0.018592437	
RI (random index)		0.58	
CR(consistency ratio)		0.032055926	

The sub-criteria with higher operation and maintenance costs and high pumping requirements when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a consistency ratio of 0.032055926 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of zone type criteria are given in the tables 6-31, 6-32 and 6-33.

Population served:

The population data of Dehradun has taken from census 2011 (“Census of India Website : Office of the Registrar General & Census Commissioner, India,” 2014) and the population of Dehradun is divided into six classes. The overhead tanks are spatially distributed throughout the city and each of it are having different number of water supply connections. This criteria has a high correlation with the overhead tanks risk because it is the measurement of number of people left without water supply when the OHT becomes failure. This criteria is based on consequences of failure of OHTs. So the risk factor of overhead tanks for this criteria is based on its location in various classes of populated areas. The wards with higher population are having more number of water supply connections and they are at higher risk and vice versa. Therefore in the pair wise comparison matrix of population served criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to their location in the type of populated areas. The equal interval classification method is used for creating the population distribution map.

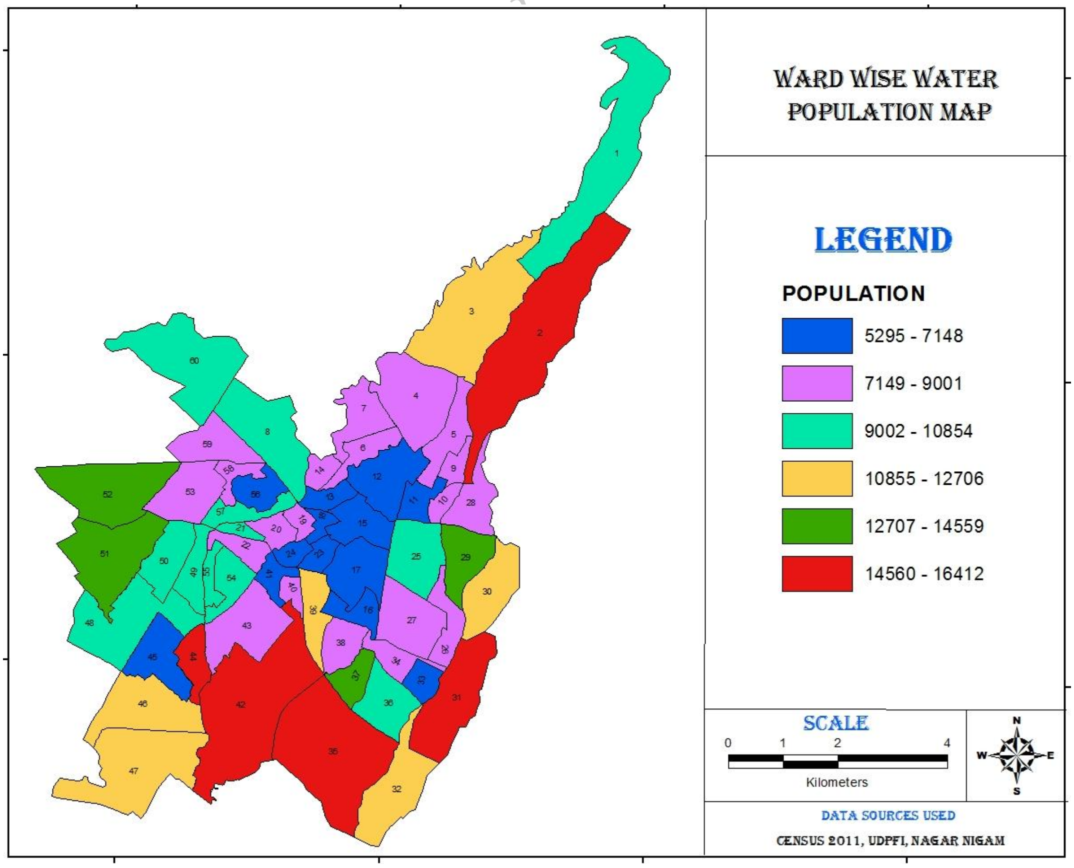

Figure 6-5: Ward wise population map

From the consistency analysis it is found that a consistency ratio of 0.026703275 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of zone type criteria are given in the following tables 6-35, 6-36 and 6-37 and the ward wise population map is shown in the figure 6-5.

Table 6-35: Pair wise comparison of Population served sub-criterias

Sub-Criterias	5295-7148	7149-9001	9002-10854	10855-12706	12707-14559	14560-16412
5295-7148	1	0.5	0.333333	0.2	0.142857	0.111111
7149-9001	2	1	0.5	0.25	0.166667	0.142857
9002-10854	3	2	1	0.5	0.2	0.166667
10855-12706	5	4	2	1	0.333333	0.25
12707-14559	7	6	5	3	1	0.5
14560-16412	9	7	6	4	2	1

Table 6-36: Normalized ratio matrix of Population served sub-criterias

Sub-Criterias	5295-7148	7149-9001	9002-10854	10855-12706	12707-14559	14560-16412
5295-7148	0.037037	0.02439	0.022472	0.022346	0.037175	0.051188
7149-9001	0.074074	0.04878	0.033708	0.027933	0.043371	0.065814
9002-10854	0.111111	0.097561	0.067416	0.055866	0.052045	0.076782
10855-12706	0.185185	0.195122	0.134831	0.111732	0.086741	0.115174
12707-14559	0.259259	0.292683	0.337079	0.335196	0.260223	0.230347
14560-16412	0.333333	0.341463	0.404494	0.446927	0.520446	0.460695

Table 6-37: Consistency analysis of Population served sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
5295-7148	0.032434763	6.08587725	2
7149-9001	0.048946571	6.008167756	1
9002-10854	0.0767968	6.092286257	3
10855-12706	0.138130855	6.149413822	4
12707-14559	0.285797794	6.346598089	6
14560-16412	0.417893217	6.311018667	5
CI (consistency index)		0.033112061	
RI (random index)		1.24	
CR(consistency ratio)		0.026703275	

Hospital served:

The land use is considered as one of the spatial criteria for risk factor calculation, even though the hospitals served criteria is separately considered because the land use map is prepared at a very broad level where some classes are aggregated with each other and also the infrastructure services are not represented clearly.

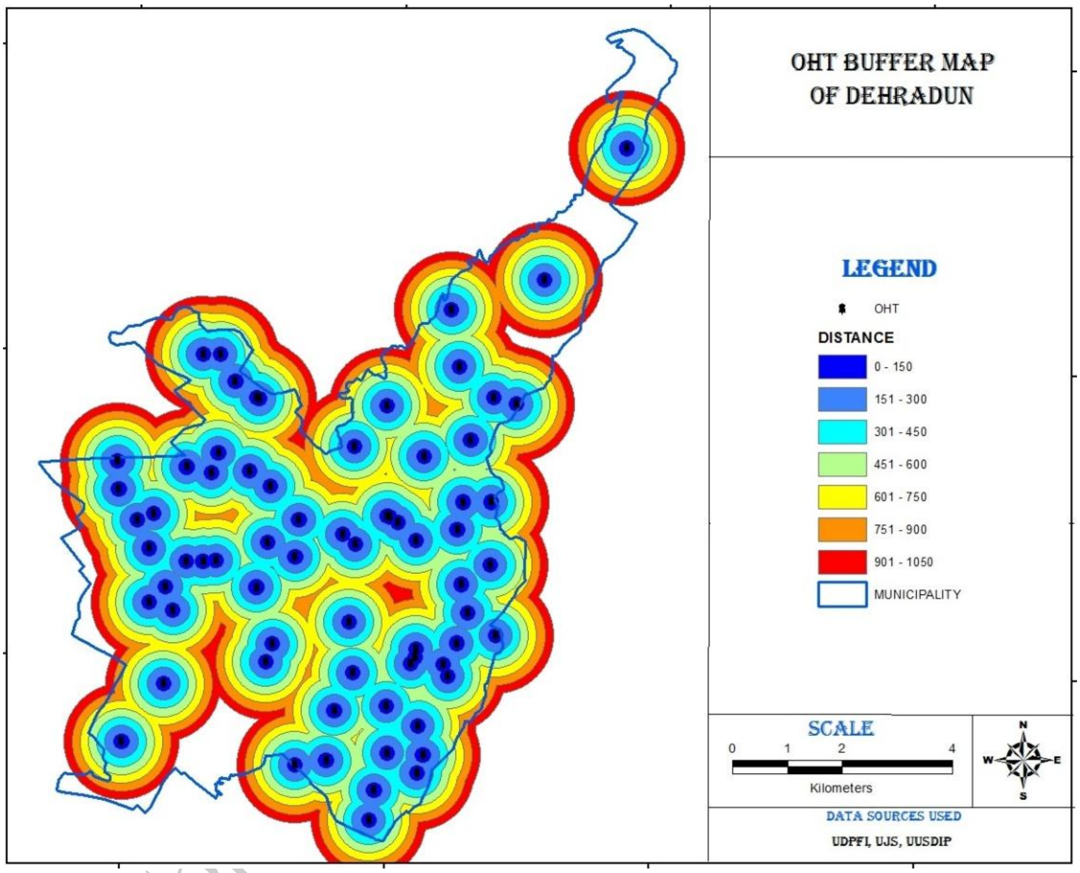

Figure 6-6: OHTS buffer map

This criteria is based on consequences of failure of OHTs. A zone of influence of overhead tanks is created to find the number of hospitals served by each overhead tanks. A multiple buffer rings are created to OHTs, and based on the number of hospitals coming in these buffer zones, the risk factor of OHTs is calculated. The distances taken for the buffer zones of the OHT are 25, 50, 75,100, 200 and 400 meters. Therefore in the pair wise comparison matrix of hospitals served criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with others according to the number of hospitals present in each buffer zones. The sub-criteria with more number of hospitals present in buffer zones when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a consistency ratio of 0.007436339 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of hospitals served criteria are given in the following tables 6-38, 6-39 and 6-40.

Table 6-38: Pair wise comparison of Hospital served sub-criterias

No.of hospitals	1	2	3	6	8
1	1	0.5	0.25	0.16666667	0.11111111
2	2	1	0.5	0.25	0.16666667
3	4	2	1	0.5	0.25
6	6	4	2	1	0.5
8	9	6	4	2	1

Table 6-39: Normalized ratio matrix of Hospital served sub-criterias

No.of hospitals	1	2	3	6	8
1	0.045455	0.037037	0.032258	0.04255319	0.05479452
2	0.090909	0.074074	0.064516	0.06382979	0.08219178
3	0.181818	0.148148	0.129032	0.12765957	0.12328767
6	0.272727	0.296296	0.258065	0.25531915	0.24657534
8	0.409091	0.444444	0.516129	0.5106383	0.49315068

Table 6-40: Consistency analysis of Hospital served sub-criterias

No.of hospitals	Priority vector/ Weight	Consistency measure	Priority/ Rank
1	0.042419472	5.009767167	1
2	0.075104172	5.013062902	2
3	0.141989167	5.024653227	3
6	0.265796515	5.049177205	4
8	0.474690674	5.069913494	5
CI (consistency index)		0.0083287	
RI (random index)		1.12	
CR(consistency ratio)		0.007436339	

Institutions served:

Table 6-41: Pair wise comparison of institutions served sub-criterias

No.of institutions	1	3	4	5	6	9
1	1	0.5	0.333333333	0.2	0.142857143	0.111111
3	2	1	0.5	0.333333333	0.166666667	0.142857
4	3	2	1	0.5	0.25	0.2
5	5	3	2	1	0.5	0.333333
6	7	6	4	2	1	0.5
9	9	7	5	3	2	1

This criteria is similar to hospitals served criteria, so in the pair wise comparison matrix of institutions served criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with others according to the number of institutions present in each buffer zones. The sub-criteria with more number of institutions present in buffer zones when compared to other sub-criterias are given high weightages and vice versa.

Table 6-42: Normalized ratio matrix of institutions served sub-criterias

No.of institutions	1	3	4	5	6	9
1	0.037037037	0.02564103	0.025974026	0.028436019	0.035190616	0.048577
3	0.074074074	0.05128205	0.038961039	0.047393365	0.041055718	0.062457
4	0.111111111	0.1025641	0.077922078	0.071090047	0.061583578	0.087439
5	0.185185185	0.15384615	0.155844156	0.142180095	0.123167155	0.145732
6	0.259259259	0.30769231	0.311688312	0.28436019	0.246334311	0.218598
9	0.333333333	0.35897436	0.38961039	0.426540284	0.492668622	0.437196

Table 6-43: Consistency analysis of institutions served sub-criterias

No.of institutions	Priority vector/ Weight	Consistency measure	Priority/ Rank
1	0.033476017	6.042710142	2
3	0.052537146	6.009808579	1
4	0.085285032	6.043165709	3
5	0.150992479	6.077637295	4
6	0.271322096	6.144710723	5
9	0.40638723	6.145562678	6
CI (consistency index)		0.015453171	
RI (random index)		1.24	
CR(consistency ratio)		0.012462235	

From the consistency analysis it is found that a consistency ratio of 0.012462235 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of hospitals served criteria are given in the following tables 6-41, 6-42 and 6-43.

Weighted sum analysis:

A weighted sum analysis is performed on all the spatial criterias to get the overall spatial risk factor for all the overhead tanks. The overall spatial risk map is represented in the figure 6-7. The OHTs are assigned with the values of the pixels on which it is overlapped with the overall spatial risk map. The scale of values ranges from 0 to 1. A model builder is used to performing all these geo processing tasks which helps in saving time and it is shown in the figure 6-8.

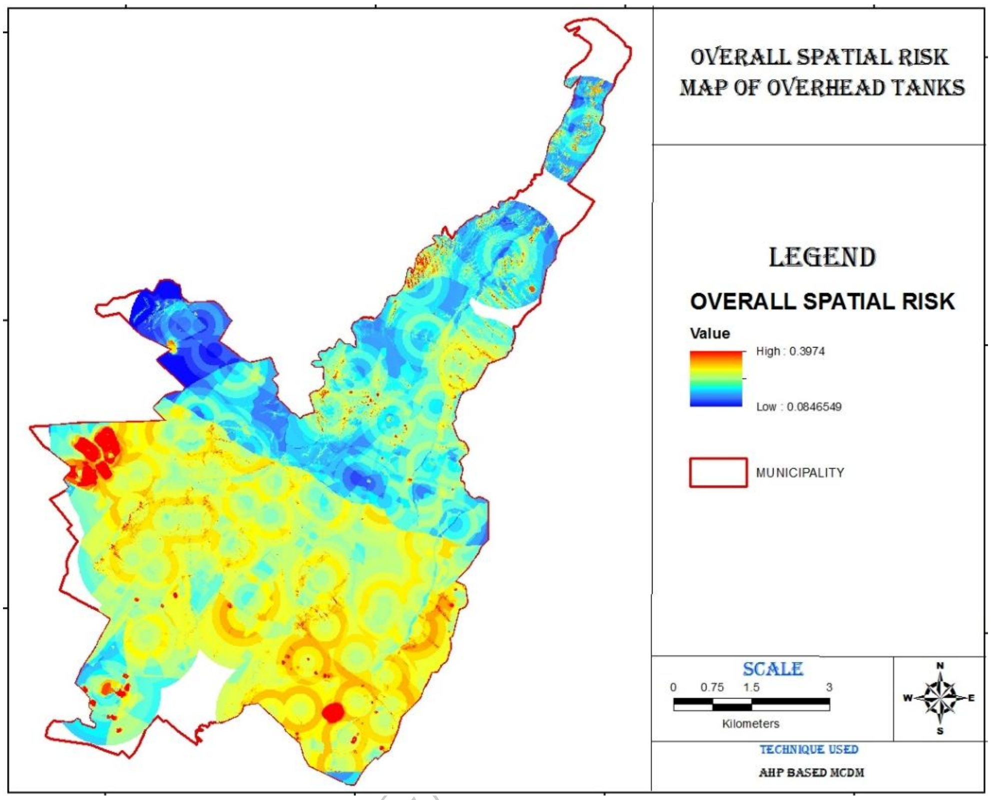

Figure 6-7: overall spatial risk map of OHTs

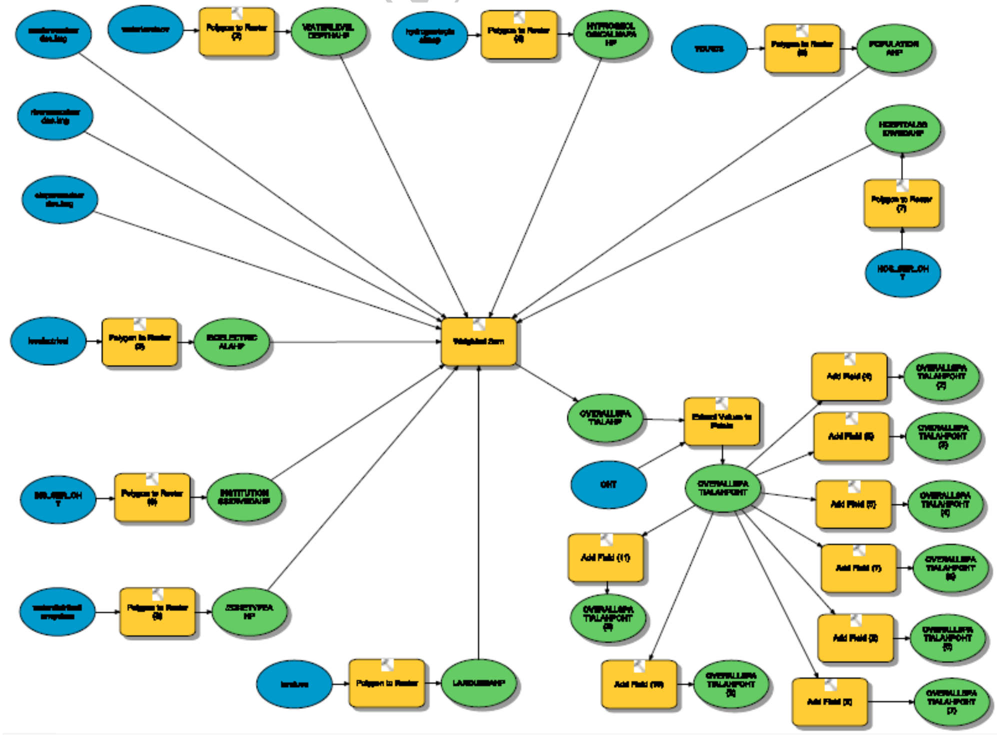

Figure 6-8: Overall spatial risk factor model

6.5.2 Non-Spatial factors for overhead tanks risk assessment

The non-spatial factors include source of water supply, height, age, capacity of the overhead tanks, source of water supply and type, diameter of pipelines connected to it. A pair wise comparison of all the main non-spatial factors which contributes to the risk of overhead tanks are compared with every other factor and a pair wise comparison matrix is generated.

Table 6-44: Pair wise comparison of non-spatial criterias

Non-spatial criterias	Capacity	Age	Source	Height	Diameter of pipelines	Type of pipelines
Capacity	1.000	2.000	3	5.000	7.000	9
Age	0.500	1.000	2.000	4	6.000	8.000
Source	0.333	0.500	1.000	3.000	5	7.000
Height	0.200	0.250	0.333	1.000	4.000	6
Diameter of pipelines	0.143	0.167	0.200	0.250	1.000	5.000
Type of pipelines	0.111	0.125	0.143	0.167	0.200	1.000

Table 6-45: Normalized ratio matrix of non-spatial criterias

Non-spatial criterias	Capacity	Age	Source	Height	Diameter of pipelines	Type of pipelines
Capacity	0.437196	0.494845	0.449358	0.372671	0.301724138	0.25
Age	0.218598	0.247423	0.299572	0.298137	0.25862069	0.222222222
Source	0.145732	0.123711	0.149786	0.223602	0.215517241	0.194444444
Height	0.087439	0.061856	0.049929	0.074534	0.172413793	0.166666667
Diameter of pipelines	0.062457	0.041237	0.029957	0.018634	0.043103448	0.138888889
Type of pipelines	0.048577	0.030928	0.021398	0.012422	0.00862069	0.027777778

Table 6-46: Consistency analysis of non-spatial criterias

Non-spatial criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
Capacity	0.384299126	6.63760987	4
Age	0.257428746	6.770717202	5
Source	0.17546561	6.793017049	6
Height	0.102139707	6.602921935	3
Diameter of pipelines	0.055712804	6.083261502	1
Type of pipelines	0.024954007	6.133879171	2
CI (consistency index)		0.100713558	
RI (random index)		1.24	
CR(consistency ratio)		0.081220611	

The weightages of all the non-spatial criterias are taken by comparing their importance with respect to other non-spatial criterias. This matrix is then normalized by dividing each element of the matrix with its column total and computed the average of elements in each row of the normalized matrix. A consistency analysis has been carried out for finding the consistency of weightages achieved. A consistency ratio of 0.081220611 which is less than 0.1 is achieved and is found satisfactory. The pair wise comparison matrix, normalized ratio matrix and consistency analysis are given in the tables 6-44, 6-45, 6-46.

Capacity:

This criteria is based on consequences of failure of OHTs. The overhead tanks present in the city are of varying capacities. The capacities of overhead tanks are taken from the UJS in form of scan document hard copy and this data is entered manually to all the OHTs and the units are in KL. The capacities of OHTs are classified into five classes. The risk associated with the OHTs is dependent on the capacity of OHTs. During the construction of OHT the capacity is decided based on demand in that area and number of water connections needed. The OHTs with higher capacities when fails will left more number of people without water supply.

Table 6-47: Pair wise comparison of capacity sub-criterias

Sub-Criterias	50-500	501-700	701-950	951-1800	1801-2500
50-500	1	0.5	0.33333333	0.2	0.142857143
501-700	2	1	0.5	0.25	0.166666667
701-950	3	2	1	0.333333333	0.2
951-1800	5	4	3	1	0.25
1801-2500	7	6	5	4	1

Table 6-48: Normalized ratio matrix of capacity sub-criterias

Sub-Criterias	50-500	501-700	701-950	951-1800	1801-2500
50-500	0.05555556	0.037037037	0.03389831	0.034582133	0.081190798
501-700	0.11111111	0.074074074	0.05084746	0.043227666	0.094722598
701-950	0.16666667	0.148148148	0.10169492	0.057636888	0.113667118
951-1800	0.27777778	0.296296296	0.30508475	0.172910663	0.142083897
1801-2500	0.38888889	0.444444444	0.50847458	0.691642651	0.568335589

Table 6-49: Consistency analysis of capacity sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
50-500	0.048452766	5.10066902	3
501-700	0.074796581	5.039232457	1
701-950	0.117562747	5.07129931	2
951-1800	0.238830676	5.288509834	4
1801-2500	0.52035723	5.479778801	5
CI (consistency index)		0.048974471	
RI (random index)		1.12	
CR(consistency ratio)		0.043727206	

Therefore in the pair wise comparison matrix of capacity criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to their storage capacity of drinking water. The sub-criterias which are having storage capacities when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a CI of 0.043727206 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of capacity criteria are given in the tables 6-47, 6-48, 6-49.

Age:

This criteria is based on chances of failure of OHTs. According to the guidelines given by CPHEEO the maximum life of an OHT is 20 years. From the temporal remote sensing data, the field visits and discussions with the officials in UJS the age of the overhead tanks is classified as very old, old, new and newest. The chances of OHTs failure is more for the older OHTs than the newer OHTs because of deterioration of the structure. So in the pair wise comparison matrix of age criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to their age and condition of the structure. The sub-criterias which are very old and at higher deterioration conditions when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a consistency ratio of 0.068321636 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of age criteria are given in the tables 6-50, 6-51, 6-52.

Table 6-50: Pair wise comparison of age sub-criterias

Sub-Criterias	Very old	Old	Newer	Newest
Very old	1	4	7	9
Old	0.25	1	4	6
Newer	0.142857143	0.25	1	3
Newest	0.111111111	0.166666667	0.33333333	1

Table 6-51: Normalized ratio matrix of age sub-criterias

Sub-Criterias	Very old	Old	Newer	Newest
Very old	0.664907652	0.738461538	0.56756757	0.473684
Old	0.166226913	0.184615385	0.32432432	0.315789
Newer	0.094986807	0.046153846	0.08108108	0.157895
Newest	0.073878628	0.030769231	0.02702703	0.052632

Table 6-52: Consistency analysis of age sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
Very old	0.611155242	4.388418071	4
Old	0.247739024	4.26700641	3
Newer	0.095029118	4.025099072	1
Newest	0.046076616	4.057350119	2
CI (consistency index)		0.061489473	
RI (random index)		0.9	
CR(consistency ratio)		0.068321636	

Height:

This criteria is based on consequences of failure of OHTs. The height of overhead tanks are taken from the UJS in form of hard copy and this data is entered manually to all the OHTs. All the heights of OHTs are classified into five classes and the units of height are in meters. While constructing the OHT the height is decided based on the pressure required at that particular place, so that all the households should get sufficient amount of water supply. The water stored at certain height can possess potential energy which is directly proportional to the height. So the height of the OHT from the ground level has a direct impact on the risk of overhead tank. The OHTs constructed with higher height from the ground level are at more risk because if there are any leakages the water will come out with higher pressure and create problem to the normal living of public life and also more number of houses are left without water supply. Therefore in the pair wise comparison matrix of height criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to height of the structure from the ground level.

Table 6-53: Pair wise comparison of Height sub-criterias

Sub-Criterias	10-13	14-16	17-19	20-24	25-28
10-13	1	0.33333333	0.2	0.14285714	0.11111111
14-16	3	1	0.25	0.16666667	0.125
17-19	5	4	1	0.5	0.25
20-24	7	6	2	1	0.33333333
25-28	9	8	4	3	1

Table 6-54: Normalized ratio matrix of Height sub-criterias

Sub-Criterias	10-13	14-16	17-19	20-24	25-28
10-13	0.04	0.01724138	0.026846	0.02970297	0.0610687
14-16	0.12	0.05172414	0.033557	0.03465347	0.06870229
17-19	0.2	0.20689655	0.134228	0.1039604	0.13740458
20-24	0.28	0.31034483	0.268456	0.20792079	0.18320611
25-28	0.36	0.4137931	0.536913	0.62376238	0.54961832

Table 6-55: Consistency analysis of Height sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
10-13	0.034971738	5.082998104	2
14-16	0.061727388	5.014524851	1
17-19	0.156497943	5.287375067	3
20-24	0.24998562	5.375324261	4
25-28	0.49681731	5.39701543	5
CI (consistency index)		0.057861886	
RI (random index)		1.12	
CR(consistency ratio)		0.051662398	

The sub-criterias at higher heights when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a consistency ratio of 0.051662398 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of height criteria are given in the tables 6-53, 6-54, 6-55.

Type of pipelines connected to OHTs:

This criteria is based on consequences of failure of OHTs. The water which is stored in the overhead tank can be transmitted through different types of pipelines. The material used for the pipelines are cast iron (CI), galvanized iron (GI), poly vinyl chloride(PVC), asbestos cement(AC), electric resistance welding(ERW). These pipelines are having different physical and chemical properties. So various type of pipelines are used for laying the primary, secondary and tertiary pipe lines which are of different usages. The pipe lines that are made up of asbestos are of more durable and chances of rusting is very less when compared to others. Therefore in the pair wise comparison matrix of types of pipelines criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with others according to their life span and rustiness. The sub-criterias that are non-rusty and gives long life span, when compared to other sub-criterias are given less weightages and vice versa. From the consistency analysis it is found that a consistency ratio of 0.074956387 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of height criteria are given in the tables 6-56, 6-57, 6-58.

Table 6-56: Pair wise comparison of type of pipeline sub-criterias

Sub-Criterias	AC	CI	ERW
AC	1	0.33333333	0.2
CI	3	1	0.25
ERW	5	4	1

Table 6-57: Normalized ratio matrix of type of pipeline sub-criterias

Sub-Criterias	AC	CI	ERW
AC	0.111111	0.0625	0.137931
CI	0.333333	0.1875	0.172414
ERW	0.555556	0.75	0.689655

Table 6-58: Consistency analysis of type of pipeline sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
AC	0.103847382	3.022598002	1
CI	0.231082375	3.067702936	2
ERW	0.665070243	3.170547288	3
CI (consistency index)		0.043474704	
RI (random index)		0.98	
CR(consistency ratio)		0.074956387	

Diameter of pipelines connected to OHTs:

This criteria is based on consequences of failure of OHTs. The OHTs are connected with various diameters of pipelines that are used for distribution of drinking water. The pipelines that are connected to OHTs are of seven diameters and the units are in mm. The pipes with higher diameter when leaked will cause more wastage of water, ultimately left the OHT with no water as well as it creates traffic jams, water logging problems in the city.

Table 6-59: Pair wise comparison of diameter of pipeline sub-criterias

Sub-Criterias	100	150	200	250	300	350	400
100	1.000	0.5	0.333333	0.25	0.2	0.142857	0.111111
150	2	1.000	0.333333	0.25	0.2	0.142857	0.125
200	3	3	1.000	0.5	0.333333	0.2	0.143
250	4	4	2	1.000	0.5	0.25	0.167
300	5	5	3	2	1.000	0.333333	0.2
350	7	7	5	4	3	1.000	0.333
400	9.000	8.000	7.000	6.000	5.000	3.000	1.000

Table 6-60: Normalized ratio matrix of diameter of pipeline sub-criterias

Sub-Criterias	100	150	200	250	300	350	400
100	0.032258	0.017544	0.017857	0.017857	0.019544	0.028182	0.053445
150	0.064516	0.035088	0.017857	0.017857	0.019544	0.028182	0.060126
200	0.096774	0.105263	0.053571	0.035714	0.032573	0.039455	0.068715
250	0.129032	0.140351	0.107143	0.071429	0.04886	0.049319	0.080168
300	0.16129	0.175439	0.160714	0.142857	0.09772	0.065759	0.096202
350	0.225806	0.245614	0.267857	0.285714	0.29316	0.197276	0.160336
400	0.290323	0.280702	0.375	0.428571	0.488599	0.591827	0.481008

Table 6-61: Consistency analysis of diameter of pipeline sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
100	0.026669678	7.255360818	3
150	0.034738619	7.005534064	1
200	0.061723843	7.150213924	2
250	0.089471628	7.293831423	4
300	0.128568622	7.493350207	5
350	0.23939474	7.774921723	6
400	0.41943287	7.789787495	7
CI (consistency index)		0.131631249	
RI (random index)		1.32	
CR(consistency ratio)		0.099720643	

So in the pair wise comparison matrix of diameter of pipelines criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to the diameter of pipelines. The sub-criterias that are of higher diameters when compared to other sub-criterias are given high weightages and vice versa. From the consistency analysis it is found that a consistency ratio of 0.099720643 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of height criteria are given in the tables 6-59, 6-60, 6-61.

Source of supply to OHTs

This criteria is based on consequences of failure of OHTs. The OHTs are getting water from both the surface and sub-surface source. The water from the sub-surface are taken and directly pumped to OHT without treatment or minimal treatment, and the water from the surface source are properly treated and sent to the OHTs for distribution. So the OHTs which receives water from sub-surface source are having ill effects on the health of the people. From the geometric network of geo spatial water utility database it is found that some OHT are getting water from both surface and sub-surface sources. Therefore in the pair wise comparison matrix of source criteria the weightages for the sub-criterias are given such that each sub-criteria is compared with other according to the source of water supply. The sub-criterias that are serving untreated water when compared to other sub-criterias are given high weightages and vice versa.

Table 6-62: Pair wise comparison of source sub-criterias

Sub-Criterias	Surface	Mixed	Subsurface
Surface	1	0.25	0.16666667
Mixed	4	1	0.25
Subsurface	6	4	1

Table 6-63: Normalized ratio matrix of source sub-criterias

Sub-Criterias	Surface	Mixed	Subsurface
Surface	0.090909	0.047619	0.11764706
Mixed	0.363636	0.1904762	0.17647059
Subsurface	0.545455	0.7619048	0.70588235

Table 6-64: Consistency analysis of source sub-criterias

Sub-Criterias	Priority vector/ Weight	Consistency measure	Priority/ Rank
Surface	0.085391732	3.022779987	1
Mixed	0.243527714	3.091495295	2
Subsurface	0.671080553	3.215026562	3
CI (consistency index)		0.054883641	
RI (random index)		0.58	
CR(consistency ratio)		0.094626966	

From the consistency analysis it is found that a consistency ratio of 0.094626966 is achieved, so the weights taken for this criteria are consistent. The pair wise comparison matrix, normalized ratio matrix and consistency analysis of source criteria are given in the tables 6-62, 6-63, 6-64. An overall non-spatial risk factor is calculated by doing vector analysis of all the criterias and then the non-spatial risk value are obtained for all the OHTs.

6.5.3 Overall risk factor determination of overhead tanks

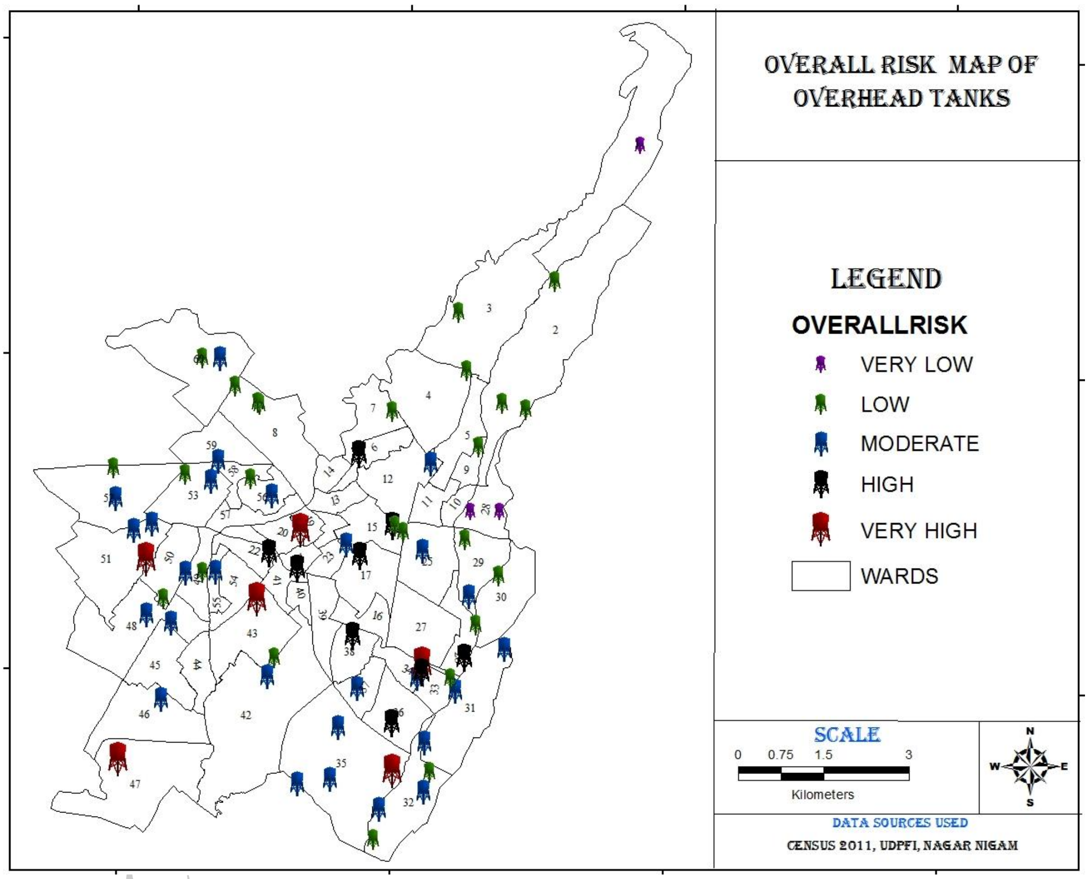

Figure 6-9: Overall risk factor of overhead tanks

The overall spatial and non-spatial risk factors are multiplied each other and normalized to get final risk factor of overhead tanks. This risk factor is again classified into four classes' namely **very low, low, high and very high**. Figure 6-9 shows the overall risk map of OHTs. The number of OHTs which are coming under high and very high risk categories contributes to 12.9 and 8.5% each. It is shown in the following table 6-65.

Table 6-65: Number of OHTs at different risk levels

Risk level	Number of OHTs	Percentage
Very low	3	4.3
Low	25	35.7
Moderate	27	38.6
High	9	12.9
Very high	6	8.5

The OHTs which are at high very high risk are mostly concentrated on core area and south-eastern part of the city. The 3D view of the overhead tanks with various risk factors that were overlaid on DEM is shown in the following figure 6-66.

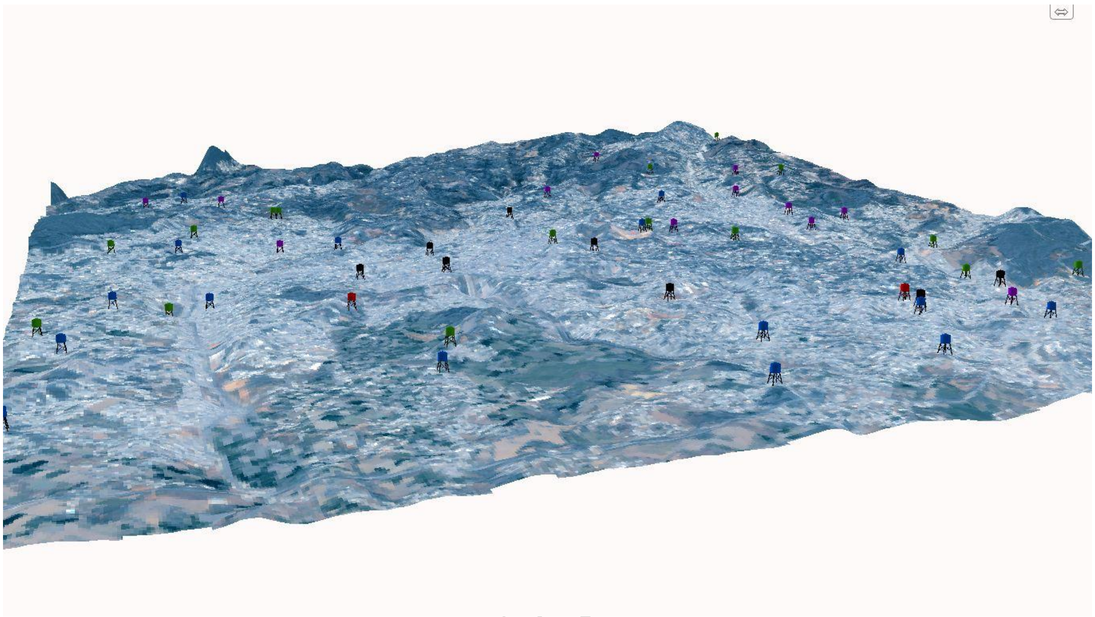

Table 6-66: 3D view of Overall risk factor of overhead tanks

6.6 Validation of risk factor of OHTs

The results obtained from the risk analysis were validated by taking a sample of OHTs. A ground verification was done by taking all the characteristics that are considered for risk analysis. Two OHTs for each class of OHTs risk classification was taken as a sample, so a total of 10 OHTs out of 70 OHTs was selected for validation purpose that are spatially distributed through the city. The following figure 6-10 shows the OHTs selected for validation and the photographs taken in the field.

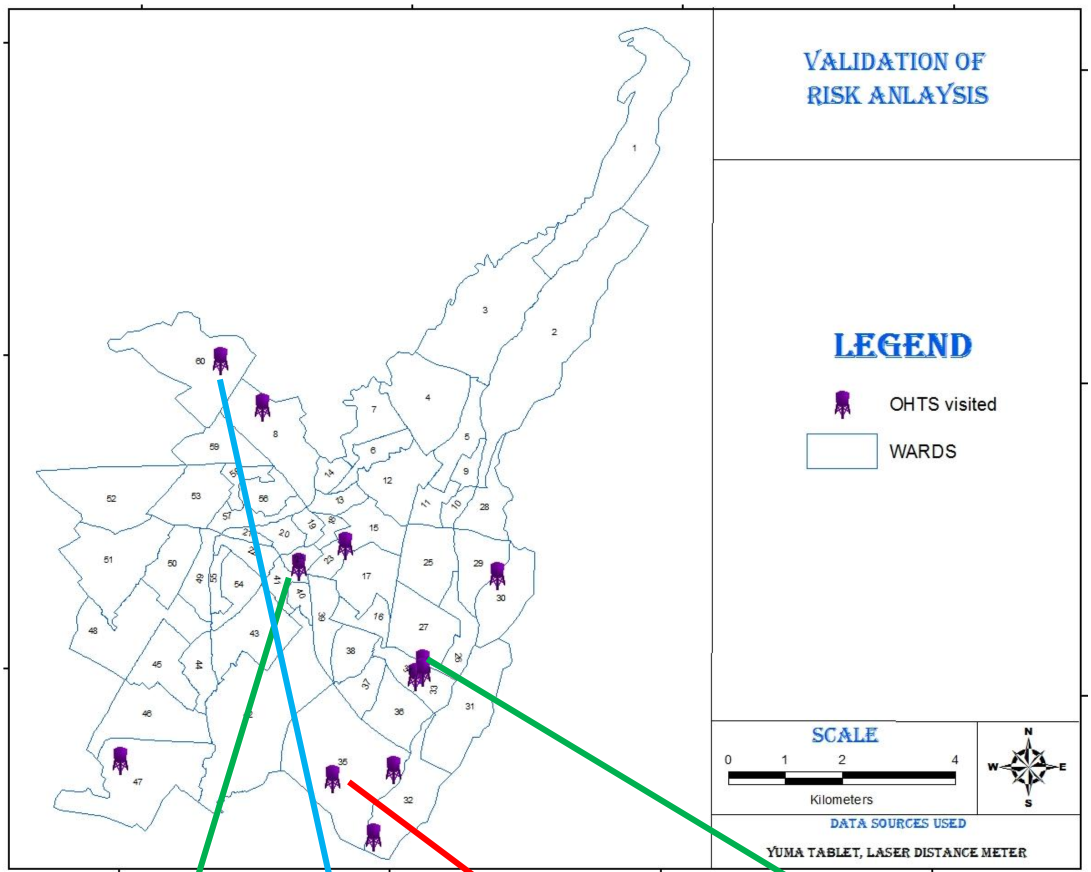

Figure 6-10: OHTs selected for validation

Table 6-67: OHTs characteristics captured from ground data

S.no	Location	Height	Age	Capacity	X	Y	Z
1	Deep nagar	28	5-10 yrs.	1900kl	216259.08	3354108.34	582.74
2	Raipur road, sarswativihar	Around 15mts	6-10 yrs.	800 kl	218093.43	3357550.03	630.89
3	Near ONGC	22	5-10 yrs.	900 kl	213931.01	3360538.09	645.79
4	Kaulagrah	23	8-10 yrs.	1500	213188.36	3361367.45	652.62
5	Gandhi road	25	4 yrs.	800 kl	215395.25	3358081.44	627.89
6	ISBT	24	3-4 yrs.	2000 kl	211405.86	3354273.53	573.12
7	Mothorwala road	24	3 yrs.	1000 kl	215170.43	3353946.65	577.63
8	MDDA colony	24	3-4 yrs.	850 kl	215901.98	3352916.51	575.44
9	Nehru colony 1	15	20-25 yrs.	2500 kl	216766.65	3355998.43	610.99
10	Nehru colony 2	18	10-15 yrs.	150 kl	216650.44	3355751.65	608.86
11	Nehru colony 3	Around 15mts	33 yrs.	225 kl	216767.11	3355841.95	615.51
12	Saharanpur chowk	Around 20mts	25-30 yrs.	900 kl	214577.11	3357706.99	602.26

Table 6-68: OHTs characteristics captured from geo spatial database

S.no	Zone name	Zone no	Height	Age	Capacity(kl)
1	Mothorowala	38(2)	28	old	1900
2	Adhoiwala	41(1)	15	old	700
3	Rajendar nagar	11(3)	18	old	900
4	Prempur	9(1)	23	old	1500
5	Dilaram bazar	4b(2)	25	newer	800
6	Majra lower	30(1)	24	newest	2000
7	Ajabpur	37(2)	24	newest	800
8	Kedarpuram colony	46(2)	24	newest	850
9	Nehru colony	35(1)	15	very old	2500
10	Nehru colony	35(2)	16	very old	225
11	Nehru colony	35(3)	18	old	150
12	Nagar nigam	8(1)	15	very old	900

Apart from these ten OHTs two more OHTs in Nehru colony are also verified. The reason for this is the three OHTs in the Nehru colony taken for validation purpose are spatially located nearly but the risk factors are different. The tables 6-67, 6-68 shows the OHTs verified on the ground and their characteristics that are captured both from the ground and the geo spatial database respectively. The spatial factors which are possible for verification process from the ground are also verified. From the observations it is found that very minor differences were observed among the ground data and data captured in the geo spatial database. Among the observations taken at various places the height of the overhead tanks deviated at two places namely Saraswati vihar and Saharanpur chowk, the age of the overhead tanks deviated at four places namely Deep nagar, Saraswati vihar, near ONGC and Kaulagrah and the height of the overhead tanks deviated at two places namely Deep nagar, Mothorwala road. The following figure 6-11 shows the deviations in the data captured from the ground and secondary sources. In the figure the +1 the deviation is positive and -1 indicates negative deviation and o indicates no deviation.

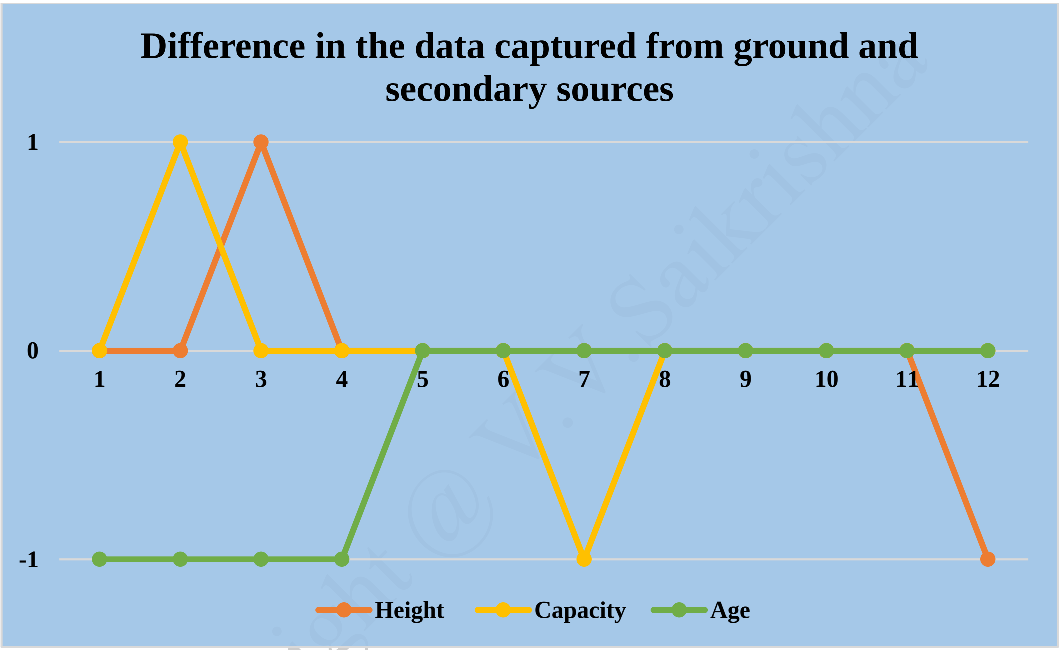

Figure 6-11: Difference in the data captured from ground and secondary sources

6.7 Strengthening of Institutional framework

As per 74th constitutional amendment act, the powers were given to the local bodies (municipalities) for preparation of plans for economic development and social justice and for implementation of the schemes including those listed in the Twelfth Schedule to the Constitution. So the responsibilities of the municipality is to provide all the necessary infrastructure to the public. The following figure 6-12 shows the basic functions of municipalities.

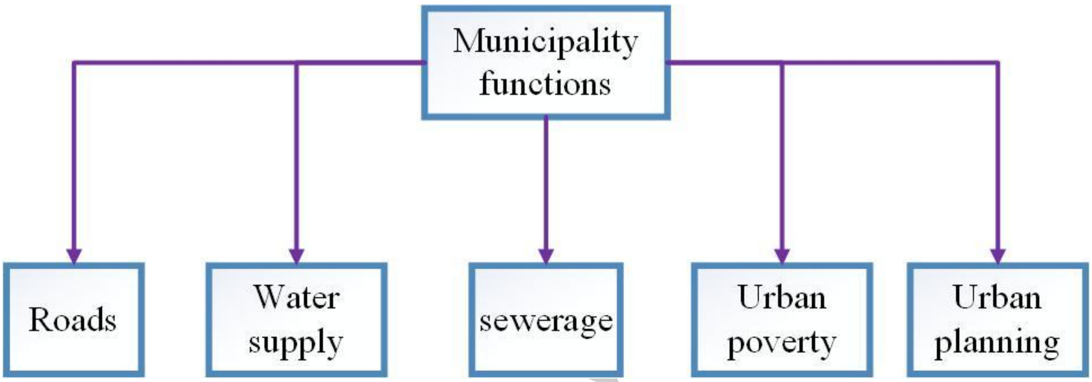

Figure 6-12: Role and Responsibilities of the ULB under the 74th CAA

The responsibilities of the municipalities are as follows

- Planning and designing of the infrastructure/services
- Execution of the infrastructure/services as envisaged
- Operation and maintenance of the infrastructure/services

But the existing situation of the Dehradun municipality is as follows

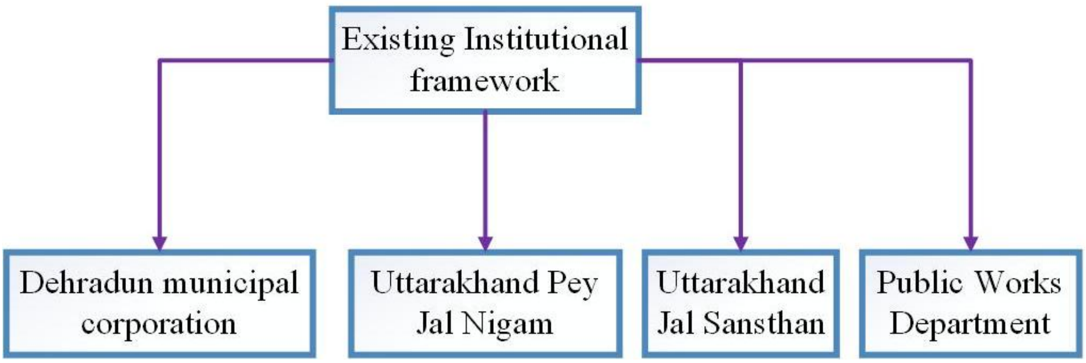

Figure 6-13: Existing institutional framework of Dehradun

So there is a need to change the institutional framework of Dehradun nagar nigam so that all the municipal functions for providing the infrastructure facilities should be under its control for a planned growth and a sustainable development of a city.

6.8 Detailed ward level analysis of water supply system for study area - II

A detailed ward level study is carried out for analyzing the water supply system at micro level. The area chosen for the study area part – II covers a part of Dobhalwala ward of Dehradun city which covers an area of 25.749741 hectares and is located between 78° 2' 27" west, 78° 2' 59"east longitudes and 30° 20' 27” north, 30° 20' 8" south latitudes. The study area part – II is shown in the following figure 6-14.

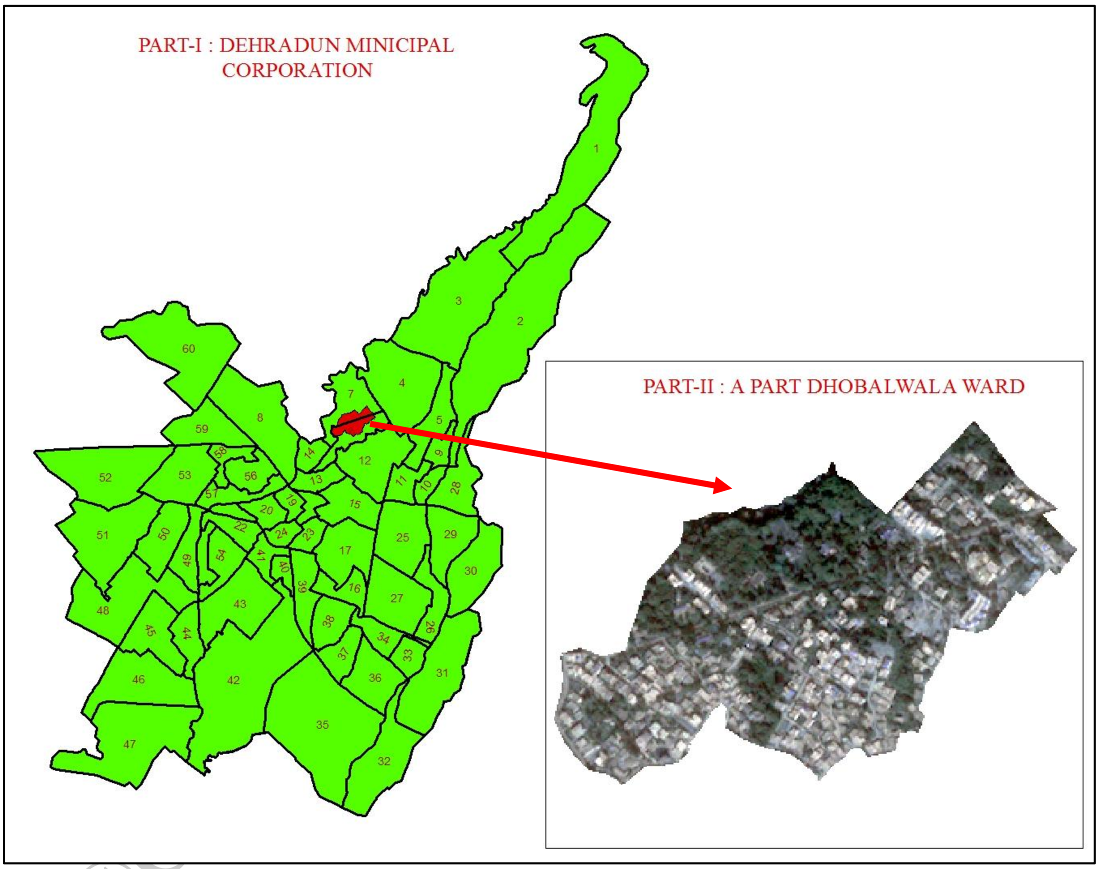

Figure 6-14: Study area part - II

6.8.1 Methodology of the study area part - II

The methodology for the study area part – II consists of following major steps:

- Preparation of land use maps.
- Creation of detailed geospatial water utility database.
- Visualization of water utility network in 3D and water demand supply gap calculations.

First a base map was prepared from the remote sensing data and then it was updated with the help of land use surveys. Land use classification was adopted from the UDPFI guidelines. A utility survey was done to map the surface assets of water utility infrastructure in the study area with the help of Yuma tablet. Laser distance meter is useful in finding the height of assets of utilities(“Applications for laser distance meters,” 2014). The methodology adopted for the study area part – II is shown in the following figure 6-15.

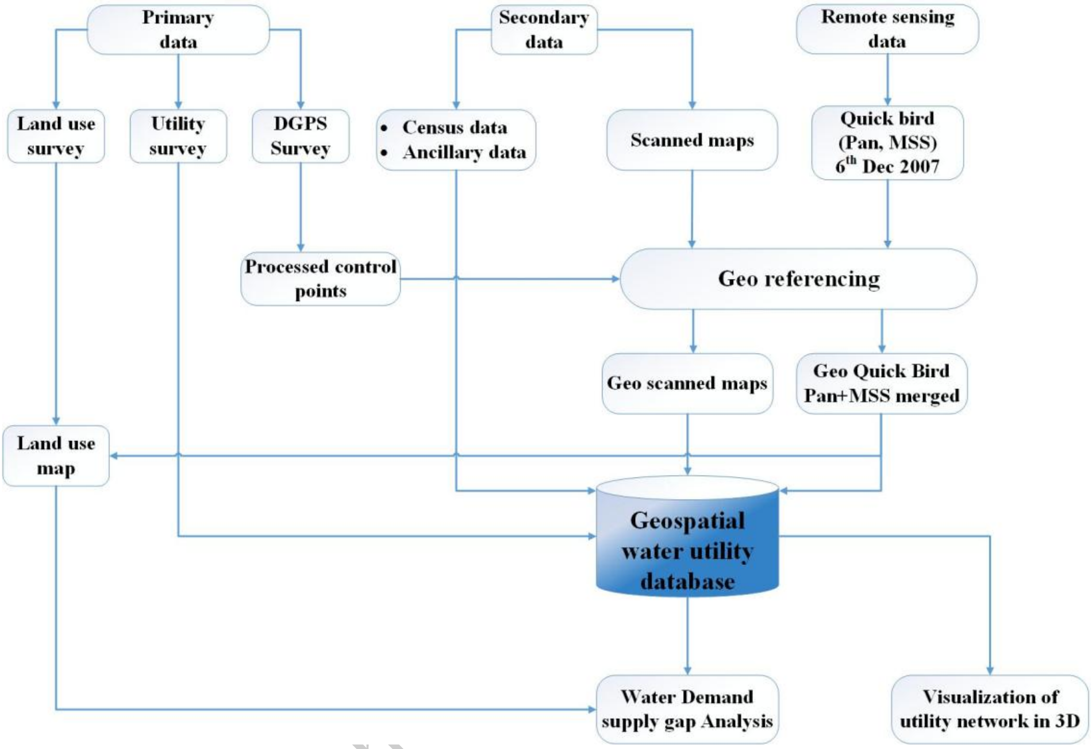

Figure 6-15 : Methodology adopted for the study area part – II

6.8.2 Geodatabase design and creation of study area part – II

A Geodatabase was designed with the feature datasets of base map and water supply network and it is represented in the following figure 6-16. Infrastructure editing tools bars having tools like point at end of line, point along a line, add a connection and lateral etc. are extensively used to create the utility database. The initial schema of the water utility database is in the following table 6-69.

Table 6-69: schema of the water utility database for study area part - II

S.no	Feature classes	Attributes			
1	Distribution mains	Length	Diameter	Type	Depth
2	Overhead tanks	Zone name	Height	Capacity	Status
3	Rising mains	Length	Diameter	Type	Depth
4	Tube well	Depth			
5	Valve	Depth			
6	Water chamber	Depth			

The database was designed in such a way that it can be further extended to include the water flow direction or the parameters that helps in modelling the interdependencies of either one utility on another or different assets of one utility or different assets of different utilities.

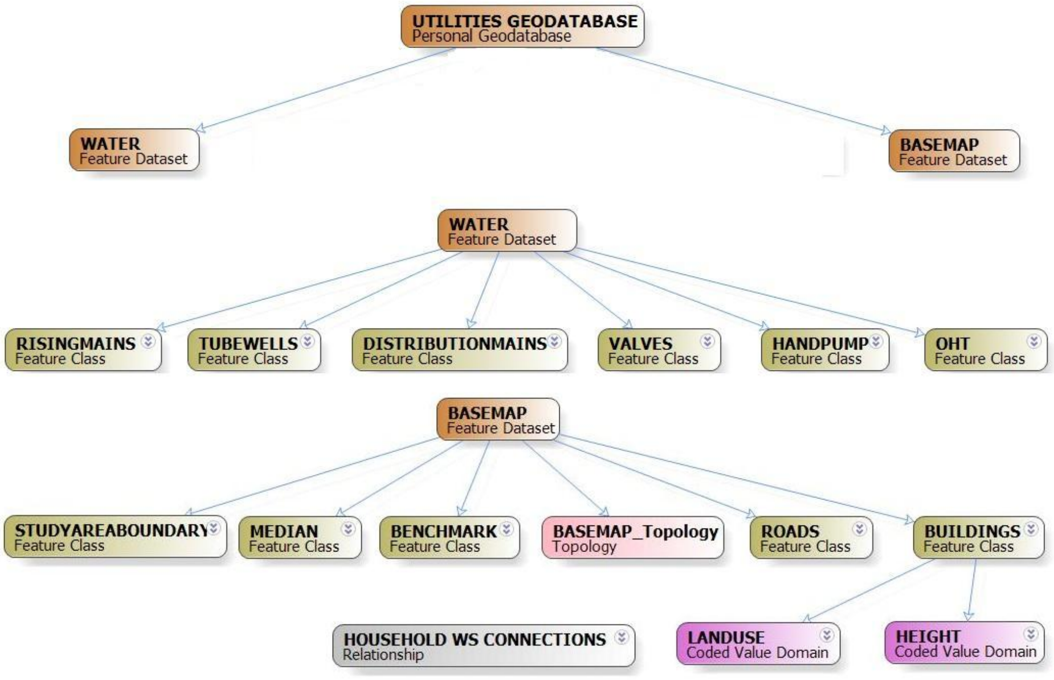

Figure 6-16: Water utility geo spatial database of study area part - II

6.8.3 Results of study area part – II

Land is one of the most important natural resources which should be used very effectively and it is utmost important for urban planning. The land use classes include residential, commercial, manufacturing, public and semipublic, open spaces, green spaces, drainage, and roads at a broader level. The main land use classes are again subdivided. Residential includes primary, mixed residential zones, commercial includes retail shopping zone, wholesale, Godowns, ware housing, manufacturing includes service, light industry. Public and semipublic includes Govt/semi Govt, education &research, social cultural & religious and utilities & services. The analysis reveals that the study area is dominated by green spaces with 66.4% and primary residential area is of 20 % of total area. Land use map, percentage of land use distribution of the study area part – II is represented in the following figure 6-17.

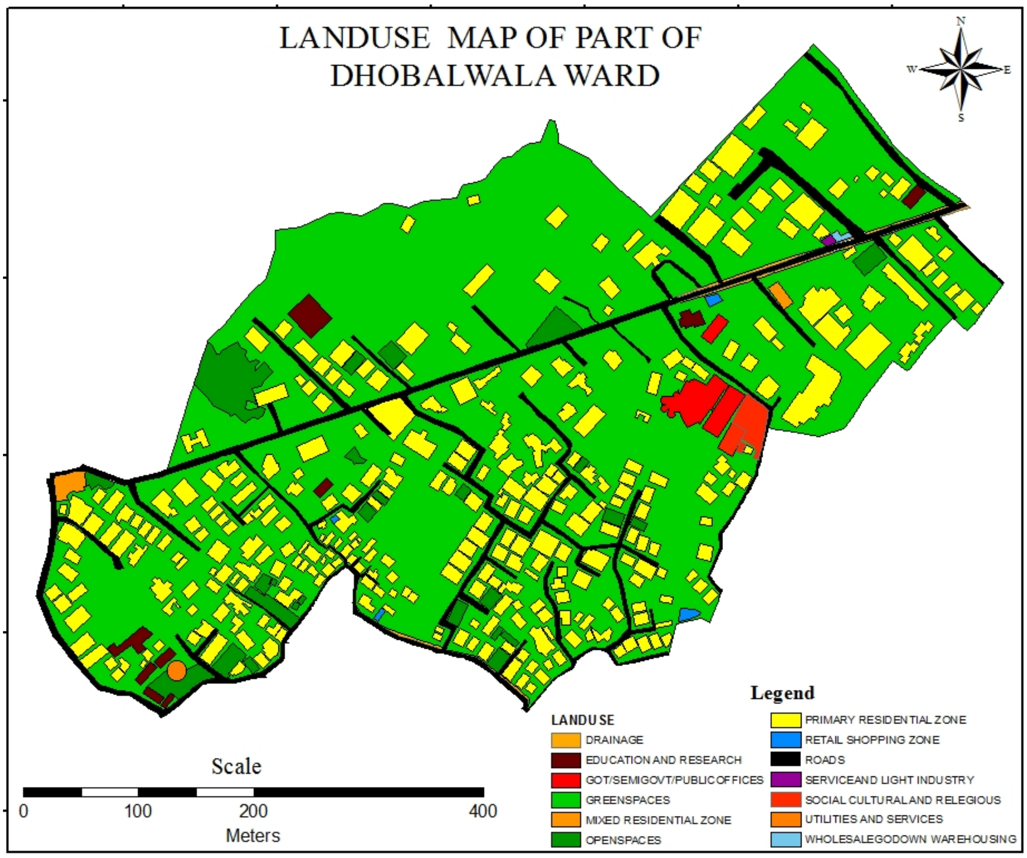

Figure 6-17: Land use map of study area part – II

The assets of water utility network present in the study area part – II includes tube wells, valves, water chamber, overhead tanks, rising mains and distribution mains and there are two sources of water supply. They are surface source which includes the water coming from the water treatment plant located at the Dilaram chowk, Dehradun, and the subsurface includes the tube wells. The type of water supply system present in the study area is intermittent system. A water valve is used to divert the flow of water(Ozger and Mays, 2004) and the water chamber is used to change the sizes of pipes when the pressure is not sufficient to meet the water demand. The water pipelines are mapped by taking the help from linemen's working in the UJS and by field visit. The total length of distribution mains in the study area accounts to 5281.03 meters and the rising accounts to 18.6 meters. There are two tube wells in the study area, the water from one tube well is lifted through the rising mains to the overhead tank and then it is distributed to the consumers through the distribution mains. The water from the other tube well is lifted through the rising mains and then connected to the distribution mains directly. Every day the tube wells are operated for 16 hours and it is monitored through the SCADA (Supervisory Control and Data Acquisition) system. The water utilities are represented in the figure 6-18. The 2D information and the mapping of surface water utilities are taken with the help of Yuma tablet. The 3D information of surface water utilities are taken with the help of laser distance meter and subsurface information are taken form officials of

Uttarakhand Jal Sansthan. 3D information was used to extrude the assets of utilities both on the surface and sub-surface and it shown in the following figure 6-19. The analysis reveals that all the buildings are having good access to water infrastructure facilities.

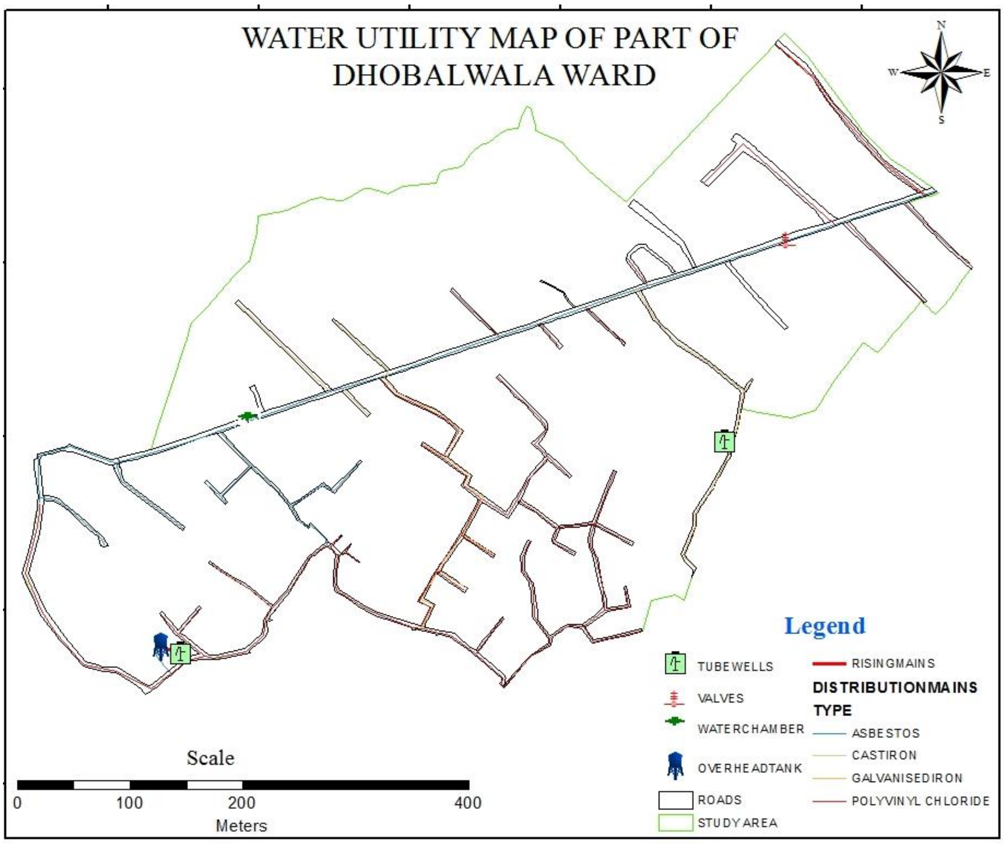

Figure 6-18: Water utility map of study area part - II

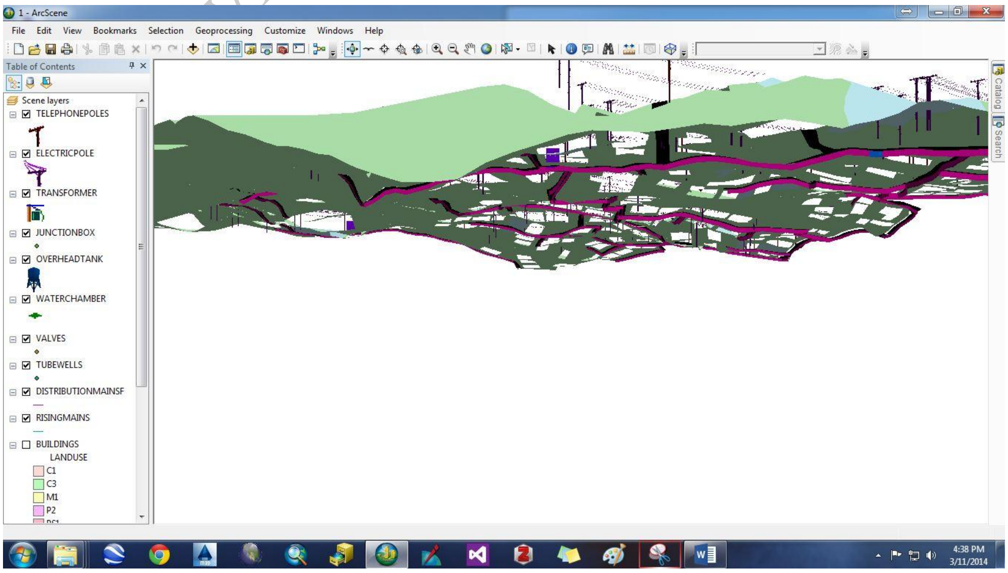

Figure 6-19: 3-D model of sub-surface utilities

6.8.4 Water demand supply calculation of study area part – II

The water demand for the study area part – II was calculated by adding the water demand of all the land uses. Therefore the absolute water demand for the study area part – II is 2 MLD. It is shown in the following table 6-70.

Table 6-70: Water demand for study area part – II

Land use	Water demand(kl)
Residential	659707.4
Commercial	569657.4
Manufacturing	200.0
Public and semi public	625297.4
Green spaces	221644.0
Absolute demand	2076506.2

The water supply of the study area part – II is calculated by adding the maximum capacity of the OHT and the yield of the tube well that is supplying water through direct distribution. Therefore the absolute supply of the study area part – II is 1.55 MLD and it is shown in the following table 6-71.

Table 6-71: Water supply for study area part – II

OHT capacity	1250 kl	1.25 MLD
Tube well yield	1800 Lpm	1.728 MLD
	Total supply	2. 789 MLD
	Losses	1.042 MLD (35.5%)
	Absolute supply	1.936 MLD

Therefore the demand supply gap of the study area part – II is -64 Kl and the area is in deficit.

6.9 Web portal creation of water utility network

6.9.1 Design and development of water utility information system

A web portal is created by using free and open source software (**FOSS**) which facilitates the users for visualizing the water utility network of Dehradun city. The design of web portal is mainly of three stages.

- To design all the web pages which are best suited for the user requirements.
- Combining all these web pages with C#.net.
- To integrate the database which is created in Geoserver with the web pages for fetching results of user queries.

The system architectural gives a clear view of the connection between various layers in the WIS portal. A three-tier architecture is created which gives a clear separation of various layers is shown in the following figure 6-20. The various layers present in the portal are internet layer, application layer and database layer.

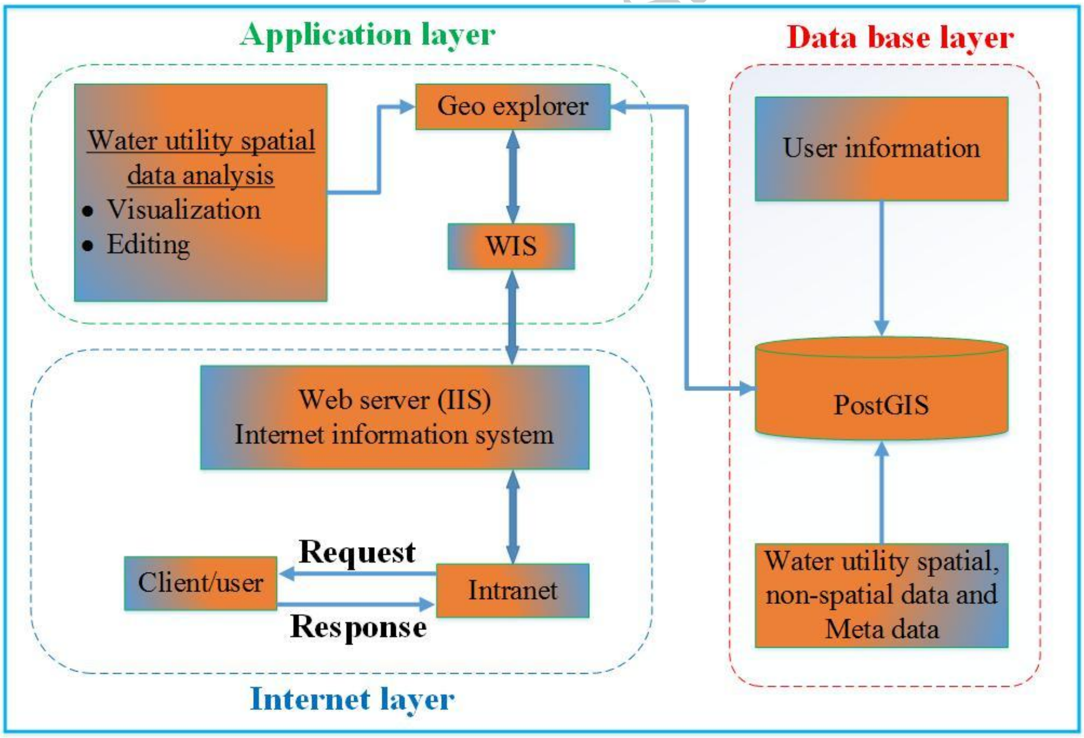

Figure 6-20: System architecture of WIS

The web pages created in this web portal are home, city level login, zonal level login, city level statistic and zonal level statistics pages. Home page describes the overview of water supply system of Dehradun. City level and zonal level login pages are used to visualize the data at various levels and it is described below. Both the city level statistics and zonal level statistics gives the statistics of water utility assets at city level and zonal level. The following figure 6-21 shows the home page of WIS.

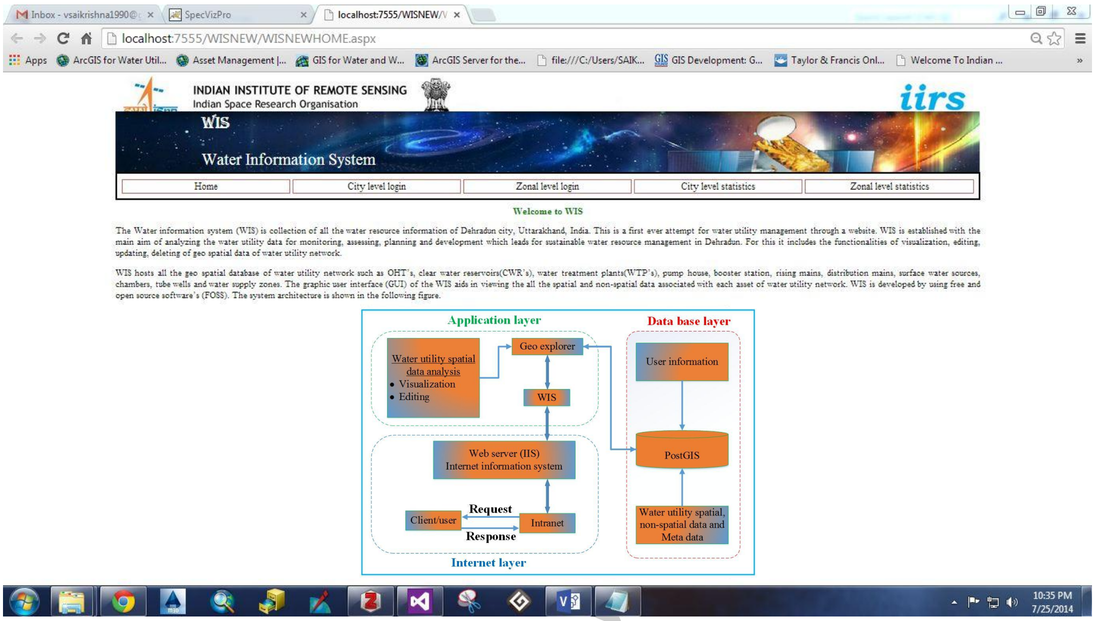

Figure 6-21: Home page of WIS

6.9.2 City level login in WIS

The users should use their credentials such as username, password for logging into the WIS web portal. If the user is new to the web portal, a new registration should be taken by using new registration link.

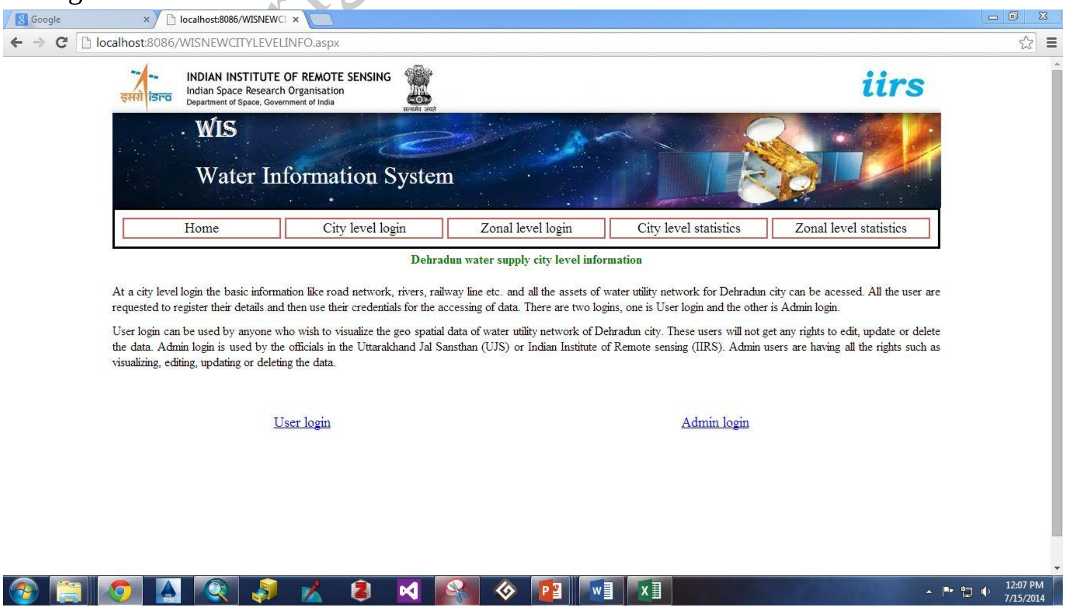

Figure 6-22: City level login page

The users after successful registration can use their credentials for logging into WIS. There are two logins namely admin and user logins. Both the login pages are redirected to another page where all the water utility network data at city level can be accessed. The user who are logging in with User login link are permitted only for visualization, and will not get any rights such as visualization and editing (WFS service) of water utility network data. The user who are logging in with Admin login link are permitted for visualization and editing (WFS service) of water utility network data. The following figures 6-22, 6-23, 6-24, 6-25 shows the city level login page, user login, WIS geo portal accessed from user login and admin login respectively.

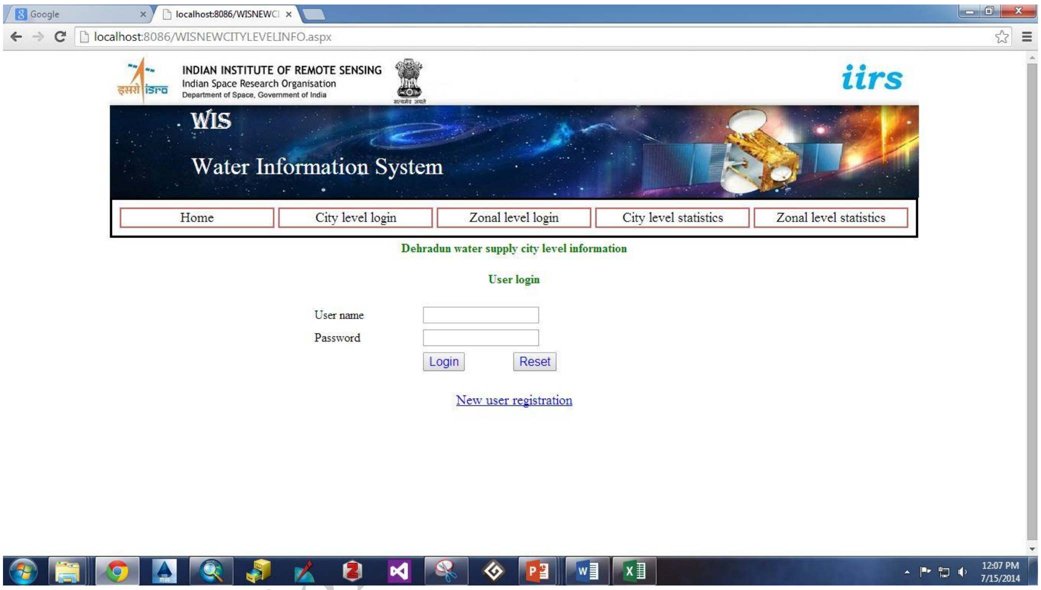

Figure 6-23: New user registration page

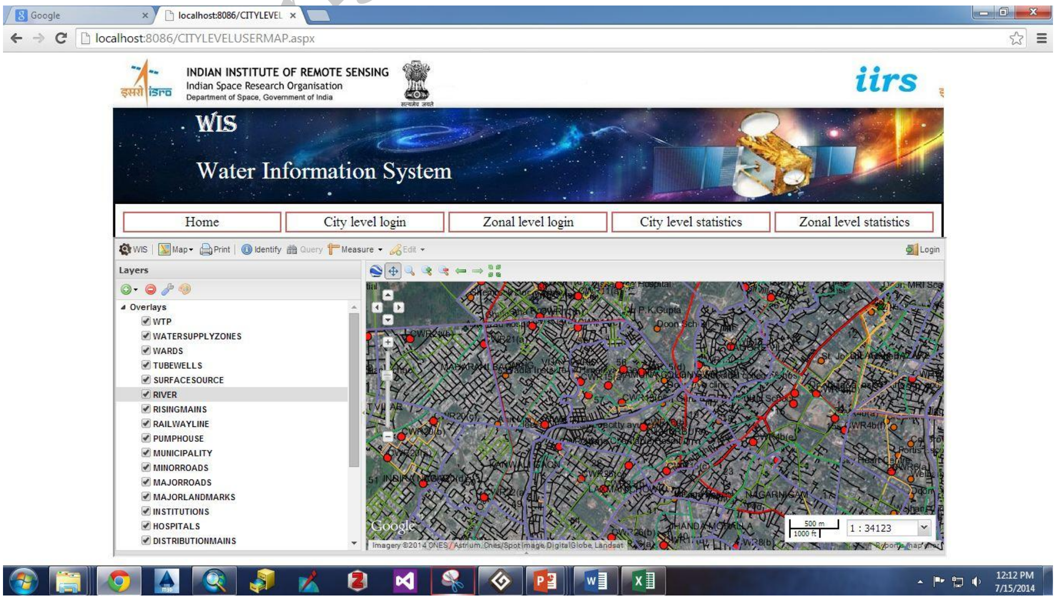

Figure 6-24: WIS geo portal from city level User login

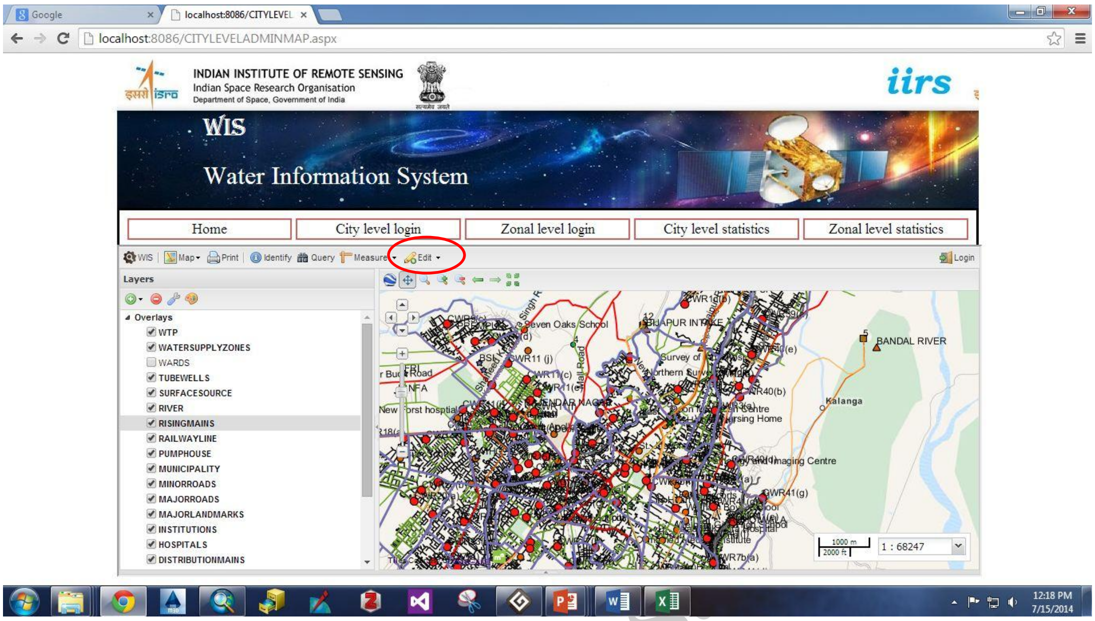

Figure 6-25: WIS geo portal from city level Admin login

6.9.3 Zonal level login in WIS

The working functionality of this page is similar to city level login page. Here the user when they log in with their user name and password, it will be redirected to another page which facilitates the user to select the division, sub-division and zone number after that it redirects to the final WIS portal. It is shown in the following figures 6-2, 6-27.

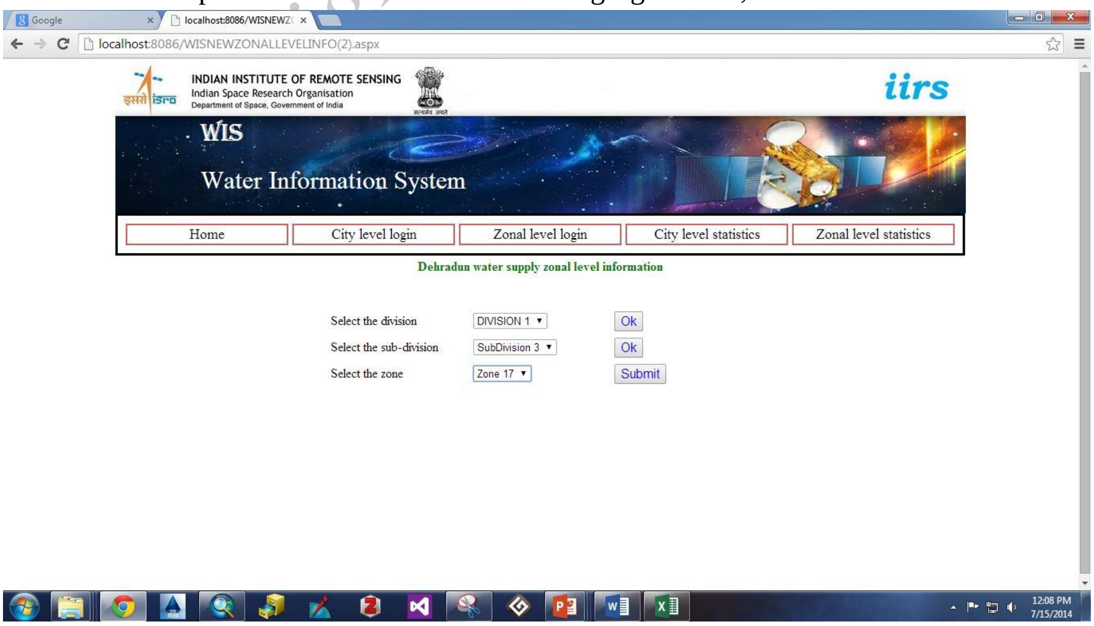

Figure 6-26: Zone selection page

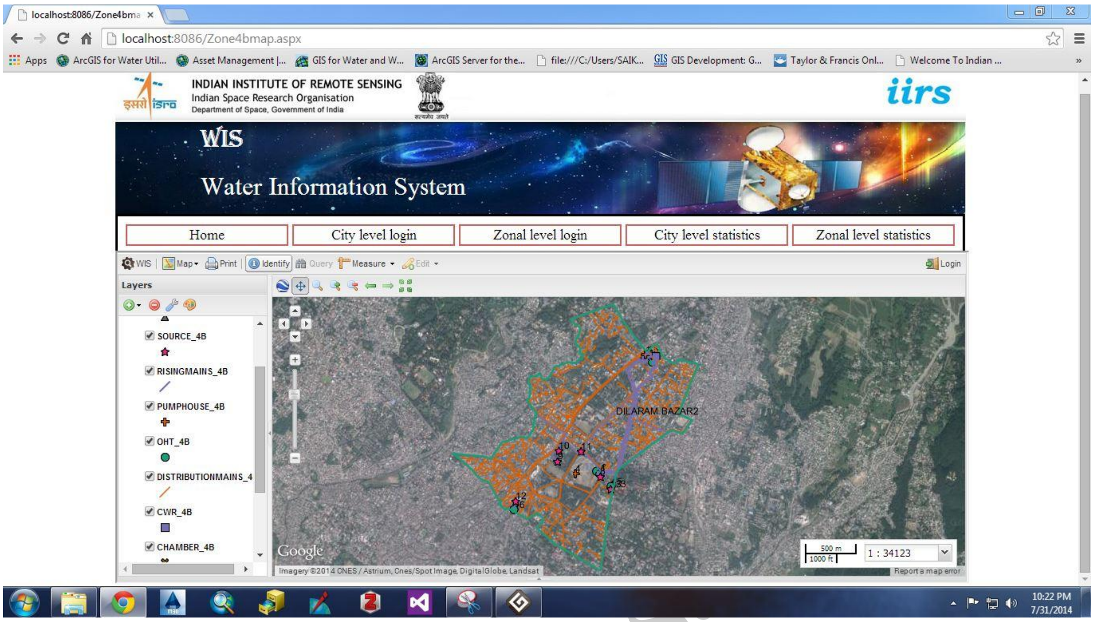

Figure 6-27: WIS geo portal from zonal level User login

There are two logins namely admin and user logins. Both the login pages are redirected to another page where all the water utility network data at zonal level can be accessed. The user who are logging in with User login link are permitted only for visualization, and will not get any rights such as editing (WFS service) of water utility network data. The user who are logging in with Admin login link are permitted for visualization and editing (WFS service) of water utility network data at zonal level. The reason for giving these rights is, water supply zone is the last part in the hierarchy of urban water supply system in Dehradun, any kind of **updating, and deleting** operations of water utility network data should be carried out from micro level planning.

The technologies used in developing the web portal are, C# .NET, Asp.NET, PostGIS, internet information service (IIS), GeoServer and GeoExplorer. The C# .NET command language, Asp.NET server side scripting languages are used for designing the web portal. IIS is used as a web server and PostGIS is used to store the geospatial data in Geoserver. GeoExplorer is used to compose the maps.

6.10 Discussions

In this section, the research questions posed to achieve the objectives are discussed. It cover the highlights and the drawback encountered during the execution of the research project.

1. What are the issues in creating a geospatial database from different sources?

The main challenge in the geospatial database creation from different sources is the availability of data in different formats of varying scales and in poor condition. This is has been addressed by bringing all the datasets in one common platform by using various transformation techniques of spatial adjustment like similarity, projective and rubber sheeting. The CAD files could not be adjusted properly even after the spatial adjustment transformations due to the varying scale and absence of any projections system then a grid wise adjustment was carried out with the help of the control point collected from the DGPS survey. The pipelines are mapped in consultation with the line men working in water supply department and by extensive field visits.

2. What are issues in analysis of water supply system and the possible methods to find out the risk of failure parameters for an overhead tank asset in the water supply utility network?

The main issues in demand supply gap analysis of water supply system are that, there is no detailed land use map, no authenticated information about floating population, no detailed maps of household supply connections, no proper maps or documentation about the relationships of each asset with the other. Somehow these issues are answered by taking the floating population as a percent of permanent population by considering the past trend of the population growth, historic and tourism importance of the city. The land use was addressed by taking broad level land use map from the master plan 2025 whereas the other issues were addressed by one small study area along with extensive field data collection using latest technology. As far as the last issue finding out of risk of failure parameters for an overhead tank is considered it has been addressed by taking into account who will suffer and what will suffer.

3. What are the issues in creating web application by using the open source software with respect to spatial data and analysis?

The issues in the use of open source software for the development of online WIS portal for water utility spatial data visualization and analysis are the size and format of the data. These issues have been addressed by converting all the data into the open formats. The interoperability standards approved by open geo spatial consortium(OGC) have been utilized for the data sharing, which includes web mapping, feature, process, coverage services.(WMS, WFS, WPS and WCS). To address various operations of WIS like mapping, editing, and querying in the web environment, the open library viz. OpenLayers API and development environment of OpenGeo Suite have been used.

7 CONCLUSIONS AND RECOMMENDATIONS

This research has concluded that geospatial technologies like remote sensing, DGPS, mobile mapping are very useful in the creation of assets of geo spatial water utility database and GIS is helpful in various stages of water utility network management especially in asset management, identifying the risk of assets and sub-surface 3D modelling of the utility networks. It is proved that the high resolution satellite data has a great potential in identifying the assets of water utility network data. The new insight in this research is that it brought out a better understanding of spatial influences of a particular overhead tank. It also highlights the process of conversion of CAD data in to GIS data which gave better results and the storing, managing, analyzing of the utilities data is very simple, fast and accurate in GIS than AutoCAD. The study also highlights all the possible risk of failure parameters for an overhead tank asset and given the priorities for investigating the overhead tanks physical/mechanical condition so as to minimize the chances or consequences of failure. The water information system (WIS) that is created by using open source software will be very useful for easy access of geo spatial water utility database for either the visualization or editing(WFS service) or both purposes from anywhere with any type of devices like Pc's, laptops, mobile phones etc. and in complex decision making process. So this web portal can be used while updating the asset information from the field. WIS is also helpful for find the exact location of assets when workers are going to repair or replacing the pipelines or any asset of the utility network.

7.1 Practical application the research

This can be taken as an example for the other municipalities to create their own geospatial databases of water utility network with the available data formats and for the creation of water information system. The municipalities can easily prioritize the repairing or replacement of asset when the life expectancy of assets is coming to an end. Preparation of water supply plans at both micro, macro level is very simple, cost effective, time and labor efficient with the help of the water information system (WIS). During the urban expansion when there is a need to expand the existing water utility network a least cost path for laying the pipelines, alternate surface source of water supply and cost-benefit analysis can be easily carried out.

7.2 Future scope of the research

The research can be further improved by strengthening the water utility geospatial database like mapping the household water supply connections which helps in finding the illegal connections, leakages in the system, demand supply gap etc. As it is mentioned earlier each asset can house other assets also, so by mapping all these assets the interdependency of one utility on the other utility can be revealed which forms the basis of asset risk factor calculation. Also the sub-surface 3-D modelling of water utility network can be done for analyzing the data in three dimensions with the help of latest technologies like mapping with ground penetrating radars etc.

7.3 Recommendations

Taking into account the results obtained from this research, following recommendations are made considering the future prospects:

- All the works carried by UJS can be in geospatial domain i.e. all the maps, data pertaining to assets of water utility network should be created, stored in digital format with the help of GIS.
- Based on the master plan and the risk factor of OHTs the future sites for establishing the new OHTs are shown in the following figure 7-1.

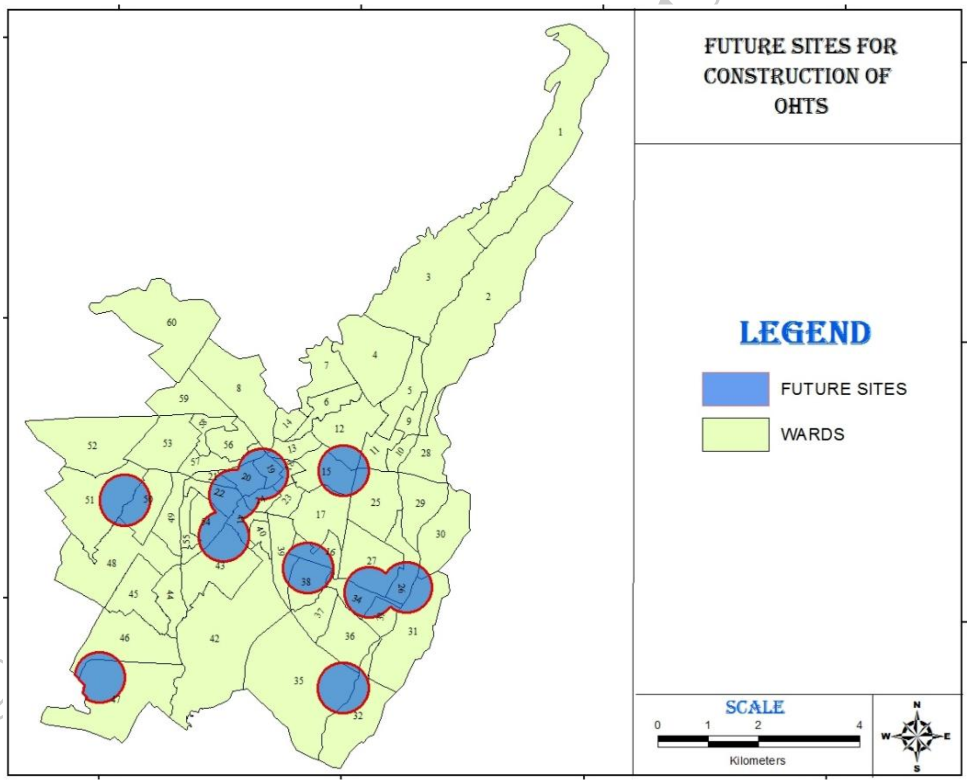

Figure 7-1: Future sites for establishing new OHTs based on master plan

- They can also use GPR, handheld GPS devices like Trimble's Yuma tablet for mapping the utilities with high accuracy.
- The connectivity of all the assets should be in such a way that even if any asset fails in the network, the population dependent on it should not suffer. There should be some alternative assets to serve that necessary service to the people.
- Also the connectivity of each and every assets in each and every utility like the water utility, electric utility network should be very strong for a sustainable water supply management.

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9 ANNEXURES

9.1 Baseline processing reports

Project Information		Coordinate System	
Name:	D:\dgpsprojects\27.vce	Name:	UTM
Size:	139 KB	Datum:	WGS 1984
Modified:	1/6/2014 10:12:59 PM	Zone:	44 North
Reference number:		Geoid:	
Description:		Vertical datum:	

Baseline Processing Report

Session Details

mnbldgbs72hr - jakan (3:30:00 PM-4:19:15 PM) (S1)

Baseline Observation:	mnbldgbs72hr --- jakan (B1)
Processed:	1/6/2014 10:12:28 PM
Solution Type:	Fixed
Frequency used:	Multiple Frequencies
Horizontal Precision:	0.007 m
Vertical Precision:	0.011 m
RMS:	0.016 m
Ratio:	3.126
Ephemeris used:	Broadcast
Antenna Model:	Trimble Calibration
Processing Start Time:	12/27/2013 3:30:00 PM (Local: UTC0hr)
Processing Stop Time:	12/27/2013 4:19:15 PM (Local: UTC0hr)
Processing Duration:	00:49:15

Vector Components (Mark to Mark)

From:	mnbldgbs72hr				
Grid		**Local**		**Global**	
Easting	215841.852 m	**Latitude**	N30°20'26.47065"	**Latitude**	N30°20'26.47065"
Northing	3360241.629 m	**Longitude**	E78°02'39.31844"	**Longitude**	E78°02'39.31844"

Elevation	662.542 m	**Height**	662.542 m	**Height**	662.542 m

To:	jakan				
Grid		**Local**		**Global**	
Easting	217848.308 m	**Latitude**	N30°21'46.62269"	**Latitude**	N30°21'46.62269"
Northing	3362659.949 m	**Longitude**	E78°03'52.02586"	**Longitude**	E78°03'52.02586"
Elevation	725.641 m	**Height**	725.641 m	**Height**	725.641 m

Vector:					
DEasting	2006.456 m	**NS Fwd Azimuth**	38°11'15"	**DX**	-2146.840 m
DNorthing	2418.320 m	**Ellipsoid Dist.**	3140.464	**DY**	-765.096 m
DElevation	63.099 m	**DHeight**	63.099	**DZ**	2162.025 m

Standard Errors

Vector Errors:					
s DEasting	0.002 m	**s NS Fwd Azimuth**	0°00'00"	**s DX**	0.003 m
s DNorthing	0.003 m	**s Ellipsoid Dist.**	0.003 m	**s DY**	0.005 m
s DElevation	0.005 m	**s DHeight**	0.005 m	**s DZ**	0.003 m

Aposteriori Covariance Matrix (Meter^2)

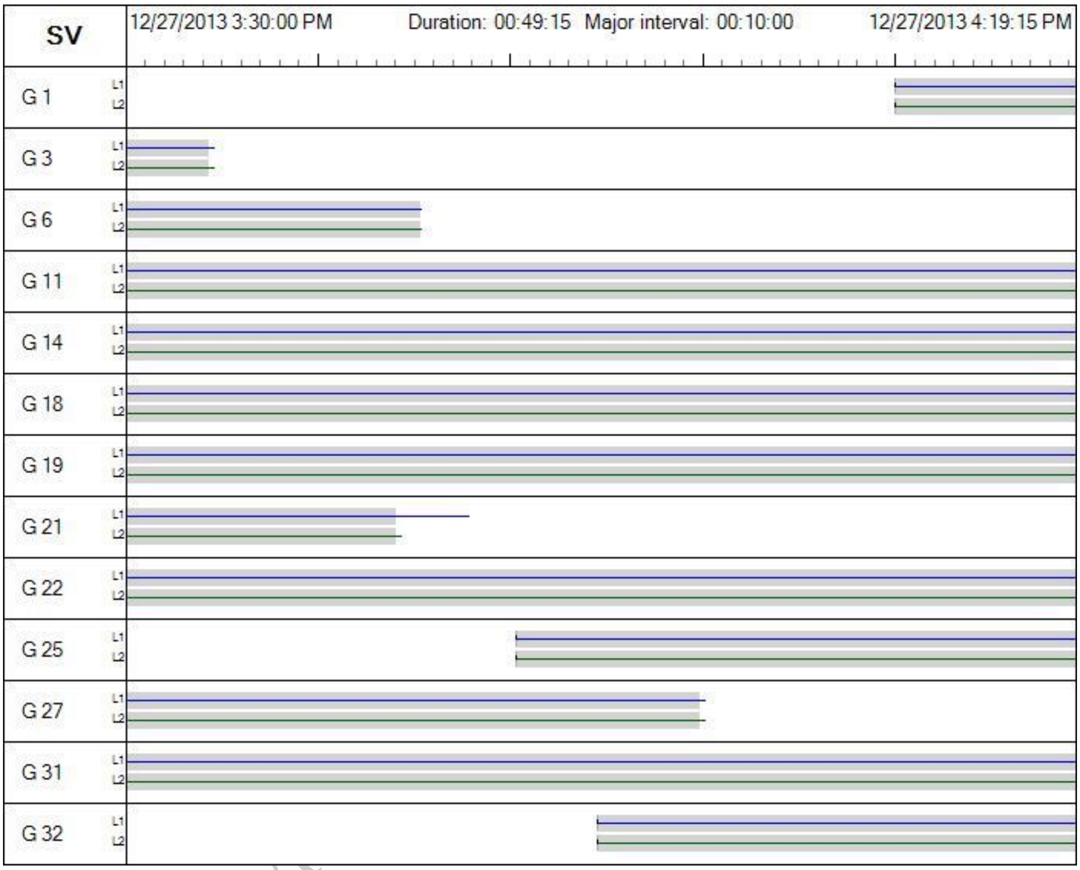
	X	**Y**	**Z**
X	0.0000082999		
Y	0.0000086188	0.0000266937	
Z	0.0000022099	0.0000056794	0.0000070589

Occupations

	From	**To**
Point ID:	mnbldgbs72hr	jakan
Data File:	D:\dgpsprojects\27\41603570.DAT	D:\dgpsprojects\27\29643611.DAT
Receiver Type:	R7 GNSS	R7 GNSS
Receiver Serial Number:	4906K34160	4836K32964
Antenna Type:	Zephyr Geodetic 2	Zephyr Geodetic 2
Antenna Serial Number:	06k34160	--------
Antenna Height (Measured):	1.300 m	1.780 m

Antenna Method:	Bottom of notch	Bottom of notch

Tracking Summary



Processing Style

Elevation Mask:	10.0 deg
Auto Start Processing:	Yes
Start Automatic ID Numbering:	AUTO0001
Continuous Vectors:	No
Generate Residuals:	Yes
Antenna Model:	Automatic
Ephemeris Type:	Automatic
Frequency:	Multiple Frequencies
Force Float:	No

Acceptance Criteria

Vector Component	**Flag**	**Fail**
Horizontal Precision >	0.050 m + 1.000 ppm	0.100 m + 1.000 ppm
Vertical Precision >	0.100 m + 1.000 ppm	0.200 m + 1.000 ppm

Date: 1/7/2014 10:40:47 AM	Project: D:\dgpsprojects\27.vce	Trimble Business Center

9.2 List of overhead tanks with their spatial and non-spatial factors

Table 9-1: List of overhead tanks with their spatial and non-spatial factors

OHT Asset id	Zone Number	Zone Name	Overall Spatial	Overall Non-spatial	Overall risk factor
1	2	Hathibarkala	0.2002	0.2018	40.3986
2	3	Dl road	0.1843	0.1684	31.0327
3	4b	Dilaram bazar ww	0.1393	0.4355	60.6633
4	4b	Dilaram bazar ww	0.1393	0.2561	35.6808
5	4b	Dilaram bazar ww	0.1843	0.2777	51.1778
6	8	Nagar nigam	0.2039	0.3312	67.5255
7	9	Prempur	0.1534	0.2137	32.7794
8	9	Prempur	0.1550	0.3280	50.8480
9	11	Rajendar nagar	0.1898	0.2338	44.3728
10	11	Rajendar nagar	0.1310	0.2140	28.0444
11	11	Rajendar nagar	0.1951	0.2333	45.4997
12	12	Dobhalwala	0.1860	0.3534	65.7346
13	15	Yamuna colony	0.2174	0.2234	48.5565
14	16	Khurbura	0.2191	0.4120	90.2515
15	8	Nagar nigam	0.2070	0.3174	65.7118
16	19	Vasant vihar	0.1971	0.2140	42.1822
17	20	Indira nagar	0.2318	0.2114	49.0107
18	20	Indira nagar	0.2402	0.4146	99.5978
19	20	Indira nagar	0.2318	0.2450	56.7971
20	25	Laxman chowk	0.2087	0.3436	71.7172
21	26	Patel nagar	0.2191	0.5297	116.0442
22	23	Engineer enclave	0.2228	0.2333	51.9715
23	27	Niranjanpur	0.2228	0.2334	51.9995
24	29	Majra upper	0.2212	0.2357	52.1227
25	32	Vidhya vihar	0.2295	0.2137	49.0556
26	34	Race cource	0.2174	0.3534	76.8111
27	35	Nehru colony	0.2208	0.2421	53.4500
28	35	Nehru colony	0.2292	0.5105	116.9997
29	35	Nehru colony	0.2208	0.3076	67.9094
30	36	Dharampur	0.2318	0.2157	49.9927
31	37	Ajabpur	0.2399	0.2357	56.5333
32	37	Ajabpur	0.2338	0.2129	49.7787
33	38	Mothorowala(deep nagar)	0.2228	0.2814	62.6923

34	38	Mothorowala(deep nagar)	0.2338	0.3432	80.2255
35	40	Sahastradhara	0.2323	0.1488	34.5673
36	41	Adhoiwala	0.2335	0.2494	58.2526
37	41	Adhoiwala	0.1772	0.2258	40.0037
38	43	Ajabpur danda	0.2416	0.2461	59.4473
39	44	Shastri nagar	0.2399	0.2172	52.1013
40	45	Defence colony	0.2257	0.2137	48.2391
41	46	Kedarpuram colony	0.2257	0.2237	50.4972
42	1b	Dhakpatti	0.1631	0.1109	18.0920
43	4a	Dilaram bazar ww	0.1860	0.1422	26.4601
44	22	Kanwali gaon	0.2228	0.2686	59.8444
45	4b	Dilaram bazar ww	0.1429	0.1918	27.3994
46	4b	Dilaram bazar ww	0.2022	0.2293	46.3582
47	39	Dhoran	0.1989	0.1892	37.6296
48	31	Pathribagh	0.1951	0.2256	44.0114
49	24	Gandhighram	0.2228	0.2293	51.0854
50	21	Maharani bagh	0.2087	0.1939	40.4845
51	7b	Sanjay colony	0.2208	0.1945	42.9470
52	6	Parade ground	0.1772	0.2542	45.0357
53	22	Kanwali gaon	0.2228	0.1810	40.3325
54	40	Sahastradhara	0.1860	0.1326	24.6612
55	45	Defence colony	0.2318	0.1934	44.8438
56	15	Yamuna colony	0.1700	0.1911	32.4983
57	19	Vasant vihar	0.3054	0.1867	57.0193
58	14	Vijay park	0.2191	0.2329	51.0121
59	35	Nehru colony	0.2191	0.1386	30.3671
60	1d	Kishanpur	0.3062	0.1060	32.4555
61	40	Sahastradhara	0.2068	0.1792	37.0556
62	7b	Sanjay colony	0.2208	0.3291	72.6534
63	30	Majra lower	0.3033	0.3843	116.5435
64	42	Badripur	0.2416	0.1918	46.3491
65	46	Kedarpuram colony	0.2257	0.1915	43.2195
66	37	Ajabpur	0.2338	0.1946	45.5046
67	23	Engineer enclave	0.2228	0.1915	42.6604
68	41	Adhoiwala	0.1568	0.2111	33.0989
69	40	Sahastradhara	0.1860	0.1085	20.1904
70	11	Rajendar nagar	0.1658	0.2241	37.1443

9.3 List of documents given by UUSDIP

List of Existing Storage Reservoirs

ZONE NO.	ZONE NAME	OVER HEAD TANK: Location	Existing Cap(KL)	Existing Stg(m)	New OHT Cap(KL)	New OHT Stg(m)	Under Construction Cap(KL)	Under Construction Stg(m)	CLEAR WATER RESERVOIR: location	Existing Capacity(KL)	Under Constn. Capacity(KL)
1a	SHANSHAHI ASHRAM								Near WTP	340	1100
									Old Bazar Chowk	50	
									Massouri Old Road	200	
1b	DHAKPATTI	Tehri House	100	15							
1c	BALYOGI								Rajpur road	350	
									Ramkrishna ashram	240	
1d	KISHANPUR	Green Valley					500	22			
2	HATHIBARKALA	Survey of India	450	10					Survey of India	350	
3	DL ROAD	Ambedkar Nagar	650	20							
4a	DILARAM BAZAR WW (PART)										
4b	DILARAM BAZAR WW (PART)	Dilaram Bazar WW & Tehsil Campus	1890	15			800	25	Dilaram Bazar WW	730	
		Parade Ground	2500	15					Dilaram Bazar WW	730	
		Parade Ground	900	12					Dilaram Bazar WW	1248	
									Dilaram Bazar WW	2850	
		ITI Womens Training Centre					1700	22			
5	CEMENT ROAD										
6	PARADE GROUND										
7a	CURZON ROAD										
7b	SANJAY COLONY (INDER ROAD)	Inder Road & Balbir road			800.00	18	2200	25			
8	NAGAR NIGAM	Jhanda Mohalla	900	15							

ZONE NO.	ZONE NAME	OVER HEAD TANK: Location	Existing Cap(KL)	Existing Stg(m)	New OHT Cap(KL)	New OHT Stg(m)	Under Construction Cap(KL)	Under Construction Stg(m)	CLEAR WATER RESERVOIR: location	Existing Capacity(KL)	Under Constn. Capacity(KL)
		Nagar Nigam	900	12							
9	PREMPUR	Nimbuwalla	1500	23							
		Shanti vihar	300	16							
10	KAULAGARH										
11	RAJENDAR NAGAR	Kaulagarh Canal	450	15							
		Kamala Nagar									
		Rajendranagar Street No 8	900	18			1450	22			
12	DOBHALWALA	Govt School Premises	1250	20							
13	TAGORE VILLA										
14	VIJAY PARK	In nagar Nigam Park (Behind Wadia Institute)	500	20			700	25			
15	YAMUNA COLONY	Yamuna Colony					800	25			
16	KHURBURA	Govt Primary School premises	1800	17							
17	JHANDA MOHALLA										
18	PANDITWARI	Near Police station Compound					350	18			
19	BASANT VIHAR	Pandit wari	450	14							
							400	22			
20	INDIRA NAGAR	Near Indira Market	750	20							
		AE Jal santhan office	450	13							
		Dom International School	2200	21							
21	MAHARANI BAGH	Near Ballupur Chowk			250	22					
22	KANWALI GAON	Vivek Gupta School near GMS road					900	25			
							300	24			
23	ENGINEER ENCLAVE	Engineer Enclave					650	22			
		MDDA Colony GMS road	500	24							
24	GANDHI GRAM	Near Radha shyam Mandir, Gandhigram			800	25					

Design Supervision Consultants (DSC-1)
Uttarakhand Urban Sector Development investment Program (UUSDIP)

Water Supply Master Plan - Dehradun

ZONE NO.	ZONE NAME	Location	OVER HEAD TANK: Existing Cap(KL)	Existing Stg(m)	New OHT Cap(KL)	New OHT Stg(m)	Under Construction Cap(KL)	Under Construction Stg(m)	CLEAR WATER RESERVOIR: location	Existing Capacity(KL)	Under Constn. Capacity(KL)
25	LAXMAN CHOWK	Near Jatia Mohalla ,kawali road	900	19							
26	PATEL NAGAR	Near Lakkar Mandi, Saharpur road	2500	24							
27	NIRANJANPUR	Engineer Enclave	150	22							
28	GREEN PARK										
29	MAJRA UPPER	Shakti Vihar	700	14							
30	MAJRA LOWER	Behind ISBT Complex					2000	24			
31	PATHRIBAGH	Patri bagh			950	20					
32	VIDHYA VIHAR	Dehrakhas	200	15							
34	RACE COURCE	Bannu School	1250	20							
35	NEHRU COLONY	Nehru colony I block	2500	15							
		Nehru colony C block	225	16							
		Income tax office,Nehru Office	150	18							
		Near Police station, Nehru Colony					750	25			
36	DHARAMPUR	Mata Mandir	500	14							
37	AJABPUR	Saraswathi vihar & Bengali Koti	900	14			800	24			
		Banjarawala	75	10							
38	MOTHOROWALA (DEEP NAGAR)	Shiv Mandir Ajabpur	1250	23							
		Deep nagar	1900	28							
39	DHORAN								Dhoran	200	
									Dhoran	60	
40	SAHASTRADHARA ROAD	Kondoli & Bharmawala khala near Gururam rai public school	800	15			1900	22	Chirowali	2100	
		Keval Vihar					700	18			
41	ADHOIWALA	Vani Vihar Raipur road	700	15					Shiv lok raipur road	120	
		Dhalan wala MDDA colony	450	20							
		Chunnabhatta Azad Nagar					1300	20			

Existing Storage Reservior
Annexure - 9

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Design Supervision Consultants (DSC-1)
Uttarakhand Urban Sector Development investment Program (UUSDIP)

Water Supply Master Plan - Dehradun

ZONE NO.	ZONE NAME	Location	OVER HEAD TANK: Existing Cap(KL)	Existing Stg(m)	New OHT Cap(KL)	New OHT Stg(m)	Under Construction Cap(KL)	Under Construction Stg(m)	CLEAR WATER RESERVOIR: location	Existing Capacity(KL)	Under Constn. Capacity(KL)
							1300	25			
42	BADRIPUR (BADRISH COLONY)	Badrish colony					250	22			
							1700	25			
43	AJABPUR	Rajiv nagar Dhanda & Opposite to gurudwara , Badrish colony	500	17.5			1700	26			
44	SHASTRI NAGAR	Vidhan sabha road - Sector 1	150	15							
45	DEFENCE COLONY	Defence colony	500	16			700	25			
46	KEDARPURAM COLONY	MDDA colony Kedarpuram & Kedarpuram VS marg	500	17			850	24			
		Total	37140		2820		21500			9568	1100

41 4 24 14

Existing Storage Reservior
Annexure - 9

Page 4 of 4

No.of water supply connections in the city: 131007 (upto Jan 2014)

– No.of water supply connections zone wise:

Total population (present): 789900

Population covered: 95% Coverage.

No.of tube wells: 122

Percent of non-revenue water: 25

Yearly revenue assessment: 32 crore [2012-13]

Yearly revenue received: 28.91 Crore [2012-13]

— Yearly O&M expenditure:

No.of employees : 429

Road length:

Distribution laid: 2816 km

Pumping hours: 16-20 hrs. | Distribution hrs → 4-6 hrs.

Cwr's at present no: 81

Cwr's capacity at present: 72108 KL

~~Distribution reservoirs at present no:~~

~~Distribution reservoirs capacity at present~~

Required capacity of ~~ohsr's~~ CWR's 22882 KL (additional).

~~Required capacity of cwrs:~~

Avgohsr's capacity:

No.of working pumps for RWPS: 6

No.of working pumps for CWPS: 23

– Stand bye pumps : –

Energy charges per kilowatt: 3.5 /-

– Interest rate

– Roughness coefficient for modified Hazen William:

+ Proposed reduction in existing source per 5 years: 10%

friction loss – 7.5%.

OHT's → no → 68
capacity → 13150 KL
Additional Require →

81
– 13 – 9L
68

95 Rajpur
H. K. Pandey.
Madhuban
water works.

Age of the OHT's: — Before 2008 and After 2008

Condition of OHT's: All are working Condition

Structure of OHT'S: R.C.C

No.of hospitals served by OHT'S:

No.of institutions served by OHT'S:

Age of the pipelines: — More than 20 yrs.

9.4 Field photographs

Figure 9-1: Water tapping from Shikar fall

Figure 9-2: New pipelines are planning to be laid through ongoing project

Figure 9-3: Ongoing project under UUSDIP for augmentation of water supply in Dehradun