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Prediction of water demand and water storage capacity of municipal system by using geospatial techniques

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Abstract: The uneven growth of urban population leads to the failure in the sustainable development of basic amenities such as water, due to increase in demand. There is an urgent need for providing adequate storage capacity to meet the need of water for growing population. In this research work, the remote sensing satellite image of LISS-4 and Cartosat-1 along with the GIS and Differential Global Positioning System (DGPS) technique is used for the precise estimation of water storage capacity. The investigations were done based on the population density and existing storage capacity. The water requirement as well as the existing storage is analyzed using analytical methods for Bhopal area. It was found that the density of population in zone 4 is increasing by 528 p/ha and storage requirement is insufficient due to increase in population

Keywords: Remote sensing, GIS, DGPS, Population, Population density

1. Introduction

The increasing population and rapid urbanization in the developing countries like India have put a lot of pressure on the natural resources. Proper conservation of water is essential for the sustainable development of mankind. Given the constantly increasing population, cities may face a great problem of securing sufficient quantity of water and proper amount of storage capacity such as over head tank (OHT), sump well and ground water reservoirs. Because of these problems it is essential to have optimum, judicious use and distribution of water supply (Shamsi, 2005).

Proper management of water resources, water demand prediction and storage capacity estimation should be based on the consumption parameters such as fire demand as well as daily and peak consumption pattern. Increase in population density within city areas has created problems for management of municipal water distribution system (MWDS) which adopted conventional population based approach for the water demand and storage capacity estimation (Larry, 1999). In this method, elements concerned in the population growth such as growth rate, historical population trends etc. are also analyzed for the calculation of water demand and storage requirement of the areas (Laura et al., 2007). The growth of population is random and water resources are designed for limited users only. The increase or decrease in population density within particular areas may create imbalance of resources provided over there. So there is urgent need to analyse spatial and non-spatial data in systematic manner to calculate water demand for present and future use.

Only proper land-use planning may reduce the problem of random sprawling of population. Government uses the land-use planning to manage the development of land within their jurisdictions. In doing so, the governmental unit can plan for the needs of the community while safeguarding natural resources. The systematic assessment of various parameters like land and water potential, alternatives for land use, economic and social conditions are required in order to select and adopt the best land-use options (Wikipedia, 2012).

Many of these problems can only be resolved with high quality field research and analysis performed using geospatial techniques viz. Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS). Geospatial techniques provide ample scope towards this initiative for proper management of natural resources. The planning and management task is hampered due to insufficient information on rates of Land Use/Land Cover (LULC) change. The LULC changes occur naturally in a progressive and gradual way, however sometimes it may be rapid and abrupt due to anthropogenic activities. RS data at different time interval help in analyzing the rate of change as well as in identifying causal factors or drivers of changes. Hence it is having a significant role in regional planning at different spatial and temporal scales (Ramachandra and Uttam, 2004). Investigations were carried out using RS image namely CARTOSAT-1 (Anon. 2008) and LISS-4 (Paul et al., 2006).

Impact of mining industry on LULC using Cartosat-1 images was studied by Chitade and Katiyar (2010). Fusion of Cartosat-1 and LISS-4 was used for generating multi-tier database on resources inventory for condition assessment, conservation management planning and monitoring of infrastructure development (Eduardo and Evans, 2002).

Spatial data contribute to track patterns of water requirement and for this reason it is necessary to evaluate the water demand and storage capacity of MWDS (Harry, 2008). Various spatial data can be used to model the efficient use of water resources and also to perform different simulations. Laura et al.

(2007) have used three basic types of models of water demand projection based on population information, land-use information and customer billing records. LULC change information has a vital role to play at local and regional as well as at macro level planning of natural resources. The analysis of each spatial individual component should be evaluated as a whole, integrated system to understand the adequacy and reliability of the complete water supply delivery system should be deveoped on land use based method (Shamsi, 2005). Land use based allocation of water demand was suggested by using polygon based overlaying techniques. In this research work, classification of the different LULC categories such as commercial, industrial and public were overlaid on demographic data and used for calculation of water demand (Alan, 1999). Jinsheng et al. (2006) adopted a land use based approach to prepare a long-range forecast of water demand for the city of Cape Coral in Southwest Florida. They made comparison of population based method and landuse based method and concluded that land use based method was more accurate and improved the coordination of the water supply and effective planning in local government. A methodology of planning and design of new pipelines for water and sewer network based on land use for floating population was suggested by Venkatarao (2010). Ufoegbune et al. (2011) carried out a study on municipal water supply planning based on land based approach for Oyo metropolis. This approach prepares a long range forecast of water supply demand with the aim of providing effective planning, development and operation of water supply and distribution networks which is one of the most essential components of urban infrastructure.

Slobodanka et al. (2010) suggested use of GPS devices for collection of data regarding the location of wells, their attributes and discussed the further analysis of them using GIS. The urban expansion can be summarised to be either vertical or horizontal depending on the geographic factors and among which the vertical expansion is preferred with regard to water management (Pedrag 2012; Donald 2008).

2. Objectives of study

The main objective of the study was to illustrate use of fine resolution satellite data along with GIS and DGPS surveys in planning of water distribution in a city. The sub-objectives were:

(i) To determine water demand and water storage capacity held by MWDS using population density map of different years and to identify of area which have high density and no horizontal development;

(ii) To classify satellite image for finding the LULC categories and to calculate the water demand and storage capacity based on land use map;

(iii) To analyse the storage capacity by these two methods and perform comparative analysis; and

(iv) To assess its impact on MWDS and compare with other zones.

3. Study area and data resources

Bhopal is located at heart of India and north of the upper limit of the Vindhya mountain ranges located on the Malwa plateau. It is higher than north Indian plains and the land rises towards the Vindhya range to the south. The city has uneven elevation and has small hills within its boundaries. The major hills in Bhopal comprise of Idgah hills and Shyamala hills in the northern region and Arera hills in the central region. The Bhopal Municipality Corporation (BMC) covers 235 sq. km of area under its jurisdiction. The city is divided into 70 wards and these are superimposed on Google image as shown in fig. 1. The city has two very beautiful big lakes, collectively known as the Bhoj wetland. These lakes are the upper lake (built by king Bhoj) and the lower lake. Locally these are known as the Bada Talab and Chota Talab, respectively. The population of the city has increased from 14 lakh in 2001 and about 18 lakh in 2010 (BMC).

Satellite data, instrument and software used are listed in Table 1.

3.1 Brief description of water supply system

Water supply was first introduced in this town in 1947 and then many times its reorganization augmentation has been done. Number of zones to water supply, raw water is abstracted from the surface and groundwater source (Tube well/Infiltration well/Open well) are also shown in Fig.1. Main components of the water distribution system are listed in Table 2.

4. Methodology

A schematic representation of the methodology is given in fig. 2 and a detailed explanation of each block is described here:

- Primary data is referred to easily available data such remotely sense data (satellite imagery, Ariel Photography)

Secondary data is referred to spatial and non-spatial features location in terms (Latitude/ Longitude) collected from the ground using DGPS

4.1 Base Map Preparation

Bhopal toposheet (SOI) at 1:50,000 scale, layout of water supply network of Bhopal (BMC) at 1:12,000 scale and Cartosat-1 image of 2006 were used for base map preparation and Google maps were used for ground truth. A GIS base map was prepared by using above data, after earth curvature correction is made and DGPS is used for taking ground control point (GCPs). Twenty GCPs were taken in the area. The city is divided into 14 zones for supply water. These sectors and zones were made with the help of the base map as shown in fig.1.

Figure 1: Ward boundary, zones and uncovered area of BMC overlaid on Google image

4.2 Geo database preparation

Geo database of existing water distribution system was created as shown in fig. 3 and storage capacity based on population and land use was estimated.

4.2.1 Population based criteria for calculation of storage requirement

For projection of population it is necessary to determine birth rate, death rate, rate of urban sprawling and increase due to annexation. All these four factors affect the change in population and, consequently, its water demand requirement. For forecasting of population and calculation of water demand, the following standard calculations were made.

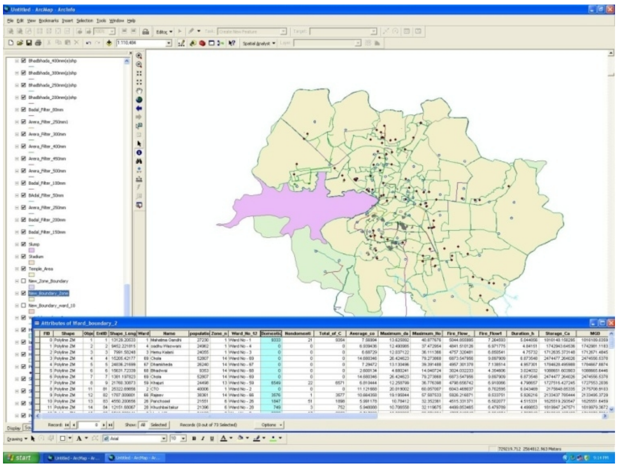


Figure 3: Geo-data base of existing water distribution system of Bhopal

a. Average daily water demand (ADWD): It can be estimated using population density map given in fig 4 (a - b) and then the average daily water demand (ADWD) is sized to the community using the following equation:

Average community daily water demand (ACDWD) = ADWD × Number of people

b. Maximum Water Demand: Maximum daily water demand is calculated as:

Maximum daily water demand = 1.8 × ACDWD

Maximum hourly water demand takes into account the daily cycles of water. It is calculated as follows:

Maximum hourly water demand = 3 × ACDWD

c. Fire Flow: The fire flow for a region can be calculated in a variety of ways. Most methods require knowledge of the size and type of buildings within the distribution system. We used a method which is based on the population of the community. The fire flow is calculated as follows:

$$Fire\ Flow = 1020\sqrt{P}(1 - 0.01\sqrt{P})$$

(Equation from the National Board of Fire Underwriters for communities with less than 200,000 people)

where,

P is the population in 1,000's of people.
Fire flow is in gallons per minute (gpm)

4.2.2 Storage based on land use

For calculation of water demand at present and future from land use information, it was necessary to track patterns of land use and its water use record. LULC map prepared by supervised classification of multispectral image (fusion of LISS-4 and Cartosat-1) is shown in fig.5. Besides the estimated acreage for each land use type and average water demand coefficient were fixed as shown in Table 3.

*Average Water Demand = Avg. water demand coefficient. (gpm/Acre)*Landuse(Area (acre))*
*Maximum Day Demand=2.2*Average Day Demand*
*Peak Hour Demand=3.4*Average Day Demand*
Operation storage =25% of Maximum Day Demand
Fire Storage=0.63 MG per acre
Emergency Storage=Underground (provided emergency pumping methods are available for supplying 25% Maximum Day Demand)

4.3 Drawing of population density maps using Spatial Analyst Tool:

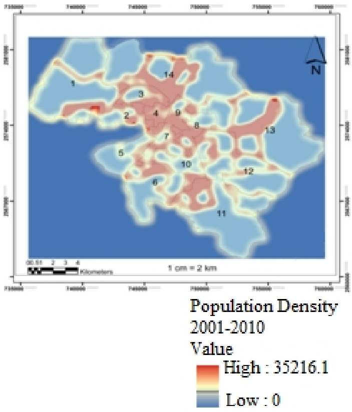
Fig. 4 (a - b) shows the different wards based population density maps . Where in these maps red line shows the wards boundaries and numbers shows the different zones of water supply.

5. Result, analysis and discussion

We prepared the digital maps of water distribution system of each zone as shown in fig. 2.

The overhead tank (OHT) or ground storage reservoir/sump are the main sources of distribution of water in Bhopal city. OHT capacity should be sufficient to meet the requirement of fire as well as growing population demand of particular location. In order to reduce the response time in case of fire, there should be continuous check on water required for fire, water demand and supply from the sources. Water demand and supply should be saved in the form of data base in GIS in order to fix the storage requirement of area. Storage capacity of OHT for Bhopal was analysed with respect to increase in population density from 2001-2010 to 2011 as shown in fig. 4(a - b). The density of population in zone 4 has increased by 528 per ha.

(a)



(b)

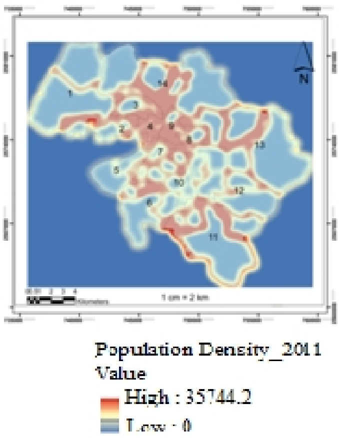


Figure 4: Wards based Population Density Map Based on Census Data (a) 2001-2002 and (b) 2011

Vertical development is feasible when compared to horizontal development and will reduce the burden on infrastructure. Layout information is required for monitoring horizontal and vertical development, for this classification of the fused multi spectral imagery of LISS-4 and Cartosat-1 were carried out and is given in fig. 5.

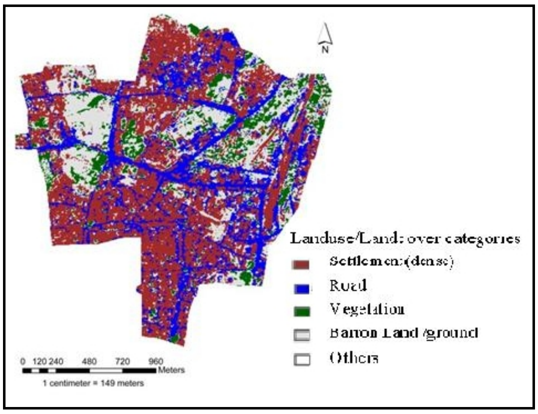


Figure 5: Classified Multispectral (fusion and supervised classification of LISS-4 and Cartosat-1) image

The following are the storage capacity calculation based on LULC categories by performing supervised classification of multispectral (fusion of LISS-4 and Cartosat-1) image as shown in fig. 5 and the storage calculation is summarized in Table 3.

The observations revealed that the development of population at random basis in the study area. Water demand considering 135 liter/day as per Indian standard, water demand in 2010 was 13607595 liter/day, but water demand in 2011 is 14857695 liter/day. Water demand has increased by 1250100 liter/day (120095gpm). Table 4 shows the storage capacity requirement based on population census data provided by BMC.

The graphical representation of above said scenario well depicted in the fig. 6. Shows the zones and Storage capacity provide in city.

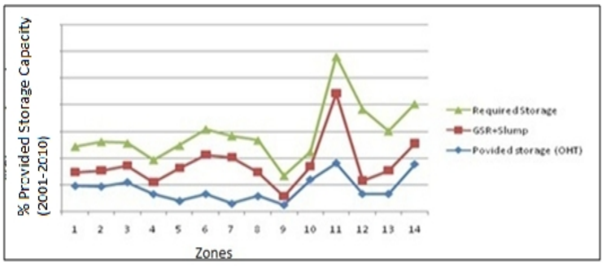


Figure6: Storage capacity in various zones of Bhopal

Comparative analysis of the storage capacity is shown in Table 5 and the zonal distribution of water demand is depicted graphically as shown in fig.6. There is shortage of storage capacity of OHT storage. The OHT storage should be in such a manner, that growing requirement of population and sustainable development of infrastructure should be fulfilled. In case any mishap like fire and other demand is to be fulfilled by OHT storage capacity in the area, than GSR and sump are just an additional storage.

The Table 5 reveals the storage capacity variation in 2011, 2001-2010, and 2006 where the land use based approach was used in 2006 due to the unavailability of census data but was found to be effective estimation. With available data between the year (2001-2010) and 2011 there is shortage of storage of 1.49 lakh gallon capacity of OHT in zone-4. Zone 8 and Zone 10 shows a negative growth in population from 2001-2010 to 2011. There is mass migration of people from Mandi Tank, Subhash Nagar,Padmanam Nagar, Ashok Vihar, Shanshal Garden, M.P.Nagar, Char Imli, Arera Colony and Bagheera of Bhopal to the higher density areas such as zone 4. This may lead to failure of the basic amenities in these areas. This in turn is putting pressure on existing water pipeline system which has grown older, so there is an immediate need to rehabilitate the existing older system as reported by report based on Jawaharlal Nehru National Urban Renewal Mission – JnNURM number of Leaks/km is highest as compared to zone 3,10 and 12 , Number of leaks repaired in 2009-10 is 14,620.Network Length in meter is 60,569. Leak/km is highest 241 Leak/km. Other incident as reported in news paper the Dailypioneer (2012), taken place in the highly dense population area on Friday broke out at the Bharat Sanchar Nigam Limited (BSNL) office-cum-exchange situated at Royal Market area. It results in disrupting the telephone and mobile services in the city on April 13, 2012. If proper stress would have given for monitoring of storage capacity, it could have acting as first-aid to reduce the major loss of infrastructure.

Table 5: Comparatively analysis the storage capacity

S.no	Storage capacity of OHT in lakh gallon		
	Population Census (2001-2010)	Population Census 2011	Land use based (2006)
1	6.55	8.04	8.03

6. Conclusions

Analysis for required water demand and storage capacity of water in OHT is done for wards having the highest population density and no horizontal development of area using geospatial techniques. The outcome of the analysis is that the required estimated water demand and storage capacity is higher than that currently present. Population density of study area increase 528 p/ha, water demand increases from 2001-2011 by 120095 (gpm) and storage capacity requirement OHT is increased by 1.49 lakh gallon. The analysis may be useful for planning for future demand estimation, estimation of growing storage requirement of urban regions and also to keep check on the uneven population growth in the urban area. Satellite images (Cartosat-1 and LISS-4) and Google views can also be used for monitoring the population density, estimating water demand and storage capacity based on landuse. The Geospatial technique helps to provide input data to monitor the infrastructure development.

References

Alan, W. M. (1999). Population and demand allocation using polygon overlay Techniques. Proceeding of ESRI, pp.552, available: http://proceedings.esri.com/library/userconf/proc99/proceed/papers/pap552/p552.htm

Anonymous (2008). Introduction to Cartosat-1 Available: http://cartosat-us.blogspot.in/ December 3, 2008

Chitade, A.Z. and S.K. Katiyar (2010). Impact Analysis Of Open Cast Coal Mines On Land Use/ Land Cover Using Remote Sensing And GIS Technique: A Case Study, International Journal of Engineering Science and Technology, 2 (12), 7171-7176.

Dailypioneer (2012).BSNL Exchange on Fire, Online availability Available: http://www.dailypioneer.com /state-editions/bhopal/57556-bsnl-exchange-on-fire.html, 05-June 12

Donald, T. (2008). Horizontal or vertical expansion, which is best for you? http://www.irazoo.com/ViewSite.aspx?q=vertical+expansion&Page=&irp=&Site=http://secondwindconsultants.com/blog/2008/02/04/horizontal-or-vertical-expansiond-which-or-neither/, Feb. 4, 2008.

Eduardo, F.C. and A.N. Evans (2002). Image fusion. Project Report for the Degree of Meng. In Electrical and Electronic Engineering Signal and Geospatial Application Papers. Department Electronic and Electrical Engineering.

Harry, E.H. (2008). Water supply system and evaluation methods: Volume II. US Fire Administration, FEMA.

Jinsheng, H., A. Mittl, G. Reilly and R. Sosnowski (2006). Application of GIS to plan long-range water supply facilities by linking land use and water billing data of city of Cape Coral in Southwest Florida. Water Environment foundation WEFTEC, pp 1319-1327.

Larry, W. M. (1999). Hydraulic design handbook. McGraw Hill Publication, New York.

Laura B., V. Hart and S. Darkwah (2007). Effect of GIS-based demand allocation on water distribution system modelling. Florida Water Resources Journal, December, 15-19.

Paul, S., H. Dave, C. Dewan, P. Kumar, S.S. Sansowa, A. Dave, B.N. Sharma and A. Verma

(2006). LISS-4 camera for Resourcesat. Proceedings of the SPIE, Volume 6405, pp. 640-510. DOI: 10.1117/12.693964

Pedrag, M. (2012). Vertical or horizontal city? available: http://www.illywords.com/archive-magazine/19-aequopolis/vertical-or-horizontal-city/ April 16, 2012.

Ramachandra, T. V. and K. Uttam (2004). Geographic resources decision support system for land use, land cover dynamics analysis. Proceedings of the FOSS/GRASS Users Conference - Bangkok, Thailand, Vol. 8, pp. 12-14.

Shamsi, U.M. (2005). GIS applications for water, waste water and storm water systems. Taylor and Francis, Published by C.T.C Press.

Slobodanka, K., E. Hadzic and D. Bijedic (2010). Application of GPS and GIS methods in the process of water management. Balwois 2010-Ohrid, Republic of Macedonia, 25-29 May.

Ufoegbune G. C., O. C. Oparinde and A. O. Eruola (2011). Municipal water supply planning in Oyo Metropolis, Oyo State, South Western Nigeria. Journal of Geography and Regional Planning, Vol. 4(7), 392-400.

Venkatarao, K. (2010). Sewerage and water supply systems design for a city with large floating population (Haridwar, India) using GIS. Map Asia 2005.

Water Demand, available: http://water.me.vccs.edu/math/waterdemand2.html April 16, 2012.

Wikipedia, (2012). Land-use planning Available: http://en.wikipedia.org/wiki/Landuse_planning, April 16, 2012.ld

Table 1: Satellite data, instrument and software used

S.No	Satellite image	Sensor	Resolution	Swath(m)	Altitude(km)	Orbit Repent	Date
1	Catosat-1	PAN	2.5	30	617.99	116	March-2006
2	LISS-4	IRS-P6	5.8	23	817	5	April-2006
Software and Instrument used							
3	DGPS	Single frequency			Promark-3 Magellan		
4	Erdas 2011	Image Processing software			ERDAS geospatial product team		
5.	ArcGIS 9.3	GIS			ESRI		

Table 2: Total components of the water distribution system of Bhopal (BMC)

S.No	**Component**	**Quantity**
1	Number of sectors	70
2	Number of zones	14
3	Number of Tube wells	1104
4	Number of existing ground level services	200
5	Number of Clear water reservoir	6
6	Number of Over head Tanks	100
7	Total length of pipe line	137.130 km
8	Diameter of pipe varying from	50mm to 750mm
9	Total Production Capacity of upper lake (catchment area = 361km^2)	106.69 MLD
10	Total Production Capacity of Kolar	154.36 MLD
11	Total Production Capacity of ground water	49.94 MLD
12	Total discharge from Upper Lake	10.89%
13	Total discharge from Kolar Dam	67%
14	Total discharge from Open wells	20%

Table 3: Water Demand based on Land use by classification satellite image

S. No	LULC categories	Area (*10000 sq.m)	Area (acre)	Avg. water demand coeff. gpm/Acre	Avg. Water Demand based on landuse (gpm)	Max. day water demand (gpm)	Peak Hour demand (gpm)	Fire flow (gpm)	Emergency storage
1	Settlement (dense)	135.82	335.48	1	335.487	738.07	1140.6	15.12	184.5
2	Vegetation	29.6	73.12	0.1	7.31181	16.085	24.86	-	4.021
3	Road	60.0	148.36	-	-	-	-	-	-
4	Barron Land /ground	75.72	187.03	-	-	-	-	-	-
5	Others	238.2	588.4	0.1	58.84	129.46	200.1		32.36
	Total	301.2	743.9			883.62	1365.9	15.12	220.9
Total storage= Operation storage +Fire Storage + Emergency Storage= 8.03lakh gallon									

Table 4: Total storage capacity calculation based on census data 2001-2010 and 2011

Zone	Population		Existing storage (OHT) lakh gallons survey (2001-2010)	GSR+Sump (lakh. gallon)	Total Storage Provided	Required Storage(OHT) (lakh gallon)(2011)
	2000-2010	2011				
1	116253	118949	9.64	5	14.64	9.79
2	128963	134346	9.4	5.98	15.38	10.86
3	99696	100693	11	6.3	17.3	8.41
4	**100797**	**110057**	**6.55**	**4.5**	**11.05**	**8.04**
5	101970	103642	4	12.3	16.3	8.50
6	115024	119050	6.6	14.64	21.24	9.69
7	95606	96967	3	17.35	20.35	8.06
8	141935	131903	5.8	9	14.8	11.94
9	91127	132393	2.5	3.25	5.75	7.69
10	82670	67710	12	5.025	17.025	5.28
11	164621	174809	18.1	26.21	44.31	13.84
12	134426	185328	6.65	5	11.65	26.73
13	176015	185328	6.65	8.75	15.4	14.80
14	177129	179786	17.7	7.8	25.5	14.89

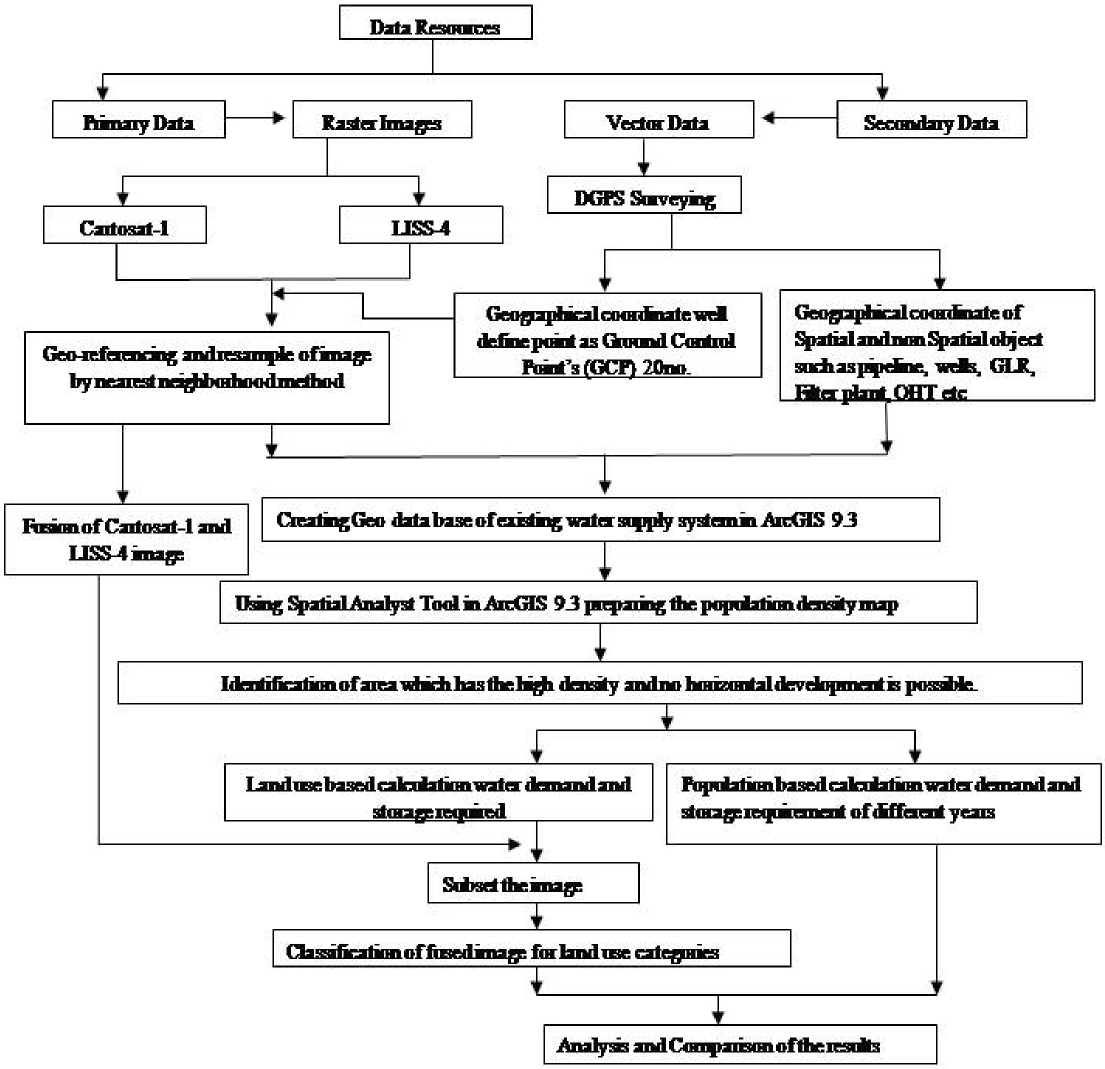


Figure 2: Flow diagram of methodology adopted