COMPARATIVE ASSESSMENT OF GROUNDWATER QUANTITY USING GIS FOR CHENNAI METRO RAIL CORRIDOR, TAMIL NADU, INDIA

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Abstract. This paper aims to compare the water quantity availability before and after the construction of the Chennai metro rail corridor in Tamil Nadu, India. Data relating to water levels from eight observation wells were collected for a period of 20 years, i.e., from 1995 to 2014. The construction of metro rail started in the year 2008 and the data were divided into two phases, namely 1995-2007 and 2008-2014 i.e., before and after the construction of metro rail. The volume of water was calculated for each phase using Geographical Information System (GIS). Rasterizied data such as specific yield of the various soil types covering the study area, water table levels and the shape area of the study were used. For calculation, the calculated values of water quantity for each and every year were mapped, the mean values for 1995-2007 and 2008-2014 were found and the mapping was used to compare the existing water quantity scenario in the metro rail corridor.
Keywords: *water quantity, GIS, specific yield, spatial distribution, rasterization, groundwater*

Introduction

Urbanization in any form will have both positive and negative impacts in equal measures. The prevalent water problems like quantity shortage, environment pollution and ecological damage restrict urban sustainable development (Cui et al., 2009). In India pollution and over extraction are important components of the groundwater problem (Rajamanickam et al., 2010) Historically, a distinct separation in the consideration of water quantity and water quality concerns has been in existence, with most of the attention being given to the provision of required quantities.(Jat et al., 2005). In urban areas, available surface water resources are generally inadequate to satisfy the entire water requirements. So the reliance on ground water has increased over the years. In most of the states in India, withdrawal of groundwater for both agricultural and industrial use has been more than what can be recharged (Yoo et al., 2007).

Metro rail construction is a massive contribution towards urbanization which involves tunneling for underground construction. The tunneling assignment of the Chennai metro in Tamil Nadu, India is considered as one of the most complicated jobs due to the complex soil structure. The water table in Chennai too is very high. During the rainy season it reaches almost ground level. Hence, tunneling becomes a highly complicated job. All these factors lead to changes in the water table.

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Tunneling results in ground water drawdown and impacts the ground settlements. Tunneling beneath the ground water table causes a state of stress and pore water pressure distribution (Han et al., 2005). Hence the assessment of water levels becomes the subject matter for this study.

Geographic Information System (GIS)

Geographical Information System (GIS) based groundwater studies were focused on the preparation of hydrogeomorphological maps, interpretation of lineaments and integrated terrain analysis (Goodchild et al., 1993) Data is the core and emphasis of geographical information system (GIS) (Wei et al., 2003). Remote Sensing, GIS and other assessment techniques have been in use for a long time now to study groundwater in terms of its movement, quantity, and quality (Wang et al., 2011). GIS is a comprehensive system of figure data management, attribute data management and spatial data analysis based on computer. It is a new research area that synthesizes computer science, management science, information science, spatial science, geology, environment science and others (Ravikumar et al., 2005). Introduction of GIS techniques for ground water research followed by analysis of the features and regulations for ground water field through informational and visual modeling is a new trend (Cui et al., 2009).

Literature Review

Shukla (2014) derived the groundwater potential zones for the entire basin of river tons in Allahabad district, Uttar pradesh, India, using GIS and remote sensing techniques. Various thematic layers such as base map, drainage map, counter map, geology map have been prepared using Arc GIS 9.3 software. These thematic layers have been integrated on GIS environment through assigning proper weight to various factors controlling occurrence of groundwater. As a result, groundwater potential zones map obtained, classifies the study area into zones such as very good, good, moderate, poor and very poor.

Jasmin et al. (2015) developed groundwater potential index (GWPI) map of the Araniar river basin, India, through an overlay analysis of climatic, geologic, geomorphic, soil and land use/land cover features of the basin using Landsat 5 Thematic Mapper (TM) data and ArcGIS 9.2. Correlation analysis was carried out for rainfall, geology, soil, slope, geomorphology and land use/land cover maps being overlaid with standardized weights of 0.49, 0.20, 0.17, 0.05, 0.05, and 0.04 and maximum correlation coefficient of 0.922 was obtained. The GWPI map showed groundwater potential zones as “excellent”, “very good”, “good”, “moderate” and “poor” with yield values in the ranges 293–361, 210–292, 126–209, 43–125, and 15–42 lpm, respectively.

Riad et al. (2011) were interested in finding the locations for artificial recharge of groundwater. The technique was applied on Sadat Industrial City which is located in a semi arid area in the western desert fringes of the Nile delta in the north west of Egypt. Thematic layers for number of parameters were prepared from some maps and satellite images and they were classified, weighted and integrated in ArcGIS environment. By means of the overlay weighted model in ArcGIS a suitability map which was classified into a number of priority zones was obtained and it could be compared with the obtained true-false map of boolean logic. This study recommended Boolean logic as a

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first estimator for locating the best locations as it is easier and not time consuming, while the overlay weighted model for more accurate results.

Navarro-Solís et al. (2016) proposed an integrated methodology to define the flow patterns governing the movement of groundwater in a semiarid region of Mexico. The methodology incorporated hydrogeochemical characterization with the application of flow systems theory, the behaviour of arsenic and fluoride as indicators of the quality for human consumption and a correlation matrix to identify potential areas of recharge-discharge; these variables were grouped in GIS. The results explained the movement of groundwater influenced by the dissolution of silicates with the geochemical evolution of arsenic under two natural conditions, whereas fluoride exhibited two situations, one natural and the other anthropogenic.

Bonansea et al. (2016) classified land use and land cover (LULC) in the Natural forest of Rio Tercero watershed (Argentina).The relationship was related to nutrient loading in the watershed with the land use and land cover map. Statistical analyses were carried out to identify relationships between water quality and LULC. Results suggested that urban and agricultural activities were the primary driving forces behind the variations in nutrient loads measured in tributaries. Sub-watershed most affected by human activities displayed the highest values of nutrient loads.

Ravikumar et al. (2005) developed a model in lumped approach with limited data for a better understanding of ground water potentia. This study was carried out in Ambur sub-watershed of Upper Palar basin in Vellore district in Tamil Nadu, India. GIS software was used to create a spatial database and to analyze the data using overlaying techniques. The conclusion was that this method could be used effectively for speeder estimation of ground water quantity with reasonable accuracy.

Jat et al. (2009) made estimates of quantitative and qualitative impacts of groundwater resulting from urbanization in Ajmeer, a major city of Rajasthan. Groundwater recharge was computed using the water level fluctuation method. Database related to urbanization and groundwater was created in GIS and the temporal and spatial variations in groundwater quality and quantity were correlated with urban growth, using overlay analysis GIS. Watershed approach was used for the estimation of the groundwater recharge and delineated using GIS. Average recharge from the area was found to be 3.06%.

Marufur Rahman et al. (2012) made computation of changes in groundwater level with expansion of irrigation in Bangladesh. Secondary data was mainly used for this study. Hydrograph analysis, groundwater level mapping, groundwater depletion rate calculation were done from groundwater level observation well data found to be provided by Bangladesh Water Development Board (BWDB) and Barind Multipurpose Development Authority (BMDA). Mapping software ArcGIS 9.3.1 was used for mapping. As a result, the difference between the maximum and the minimum water levels in one season was found to be 2.67 ft. The average value of yearly maximum rate of depletion and minimum rate of depletion was seen as 1.04 feet / year.

Study Area

Chennai (formerly Madras), is the fourth largest metropolitan city in India. There has been a steep increase in population in recent years, with enhanced reliable and safe transportation needs.Chennai district enjoys a tropical climate with mean annual temperature of 24.3 to 32.9 °C. The temperature is usually in the range 13.9-45 °C.

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The metro rail corridors have been digitized along with metro stations and river sources like Adyar and Coovam rivers. The observational well points are located in the study area using GIS shown in *Figure 1*.

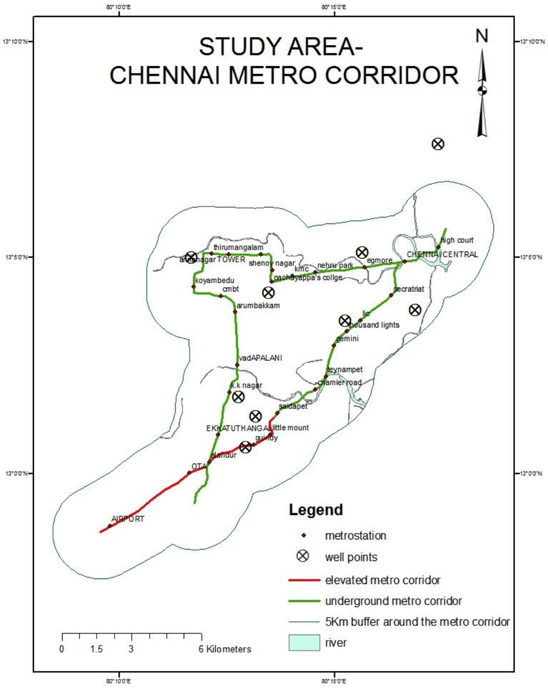

***Figure 1.** Study area with observation well of Chennai metro rail corridor, Tamil Nadu, India*

Results

Slope map for study area

Chennai district forms part of coastal plains of Tamil Nadu. A major part of the district has a flat topography with a very gentle slope towards east. The altitudes of land surface vary from 10 m above MSL in the west to sea level in the east. Fluvial, marine and erosion landforms are noticed in the district. The statement is proved by mapping the elevation levels of the selected locations of the area and it is shown in *Figure 2* and the elevation values are tabulated in *Table 1.*

***Table 1.** Locations with elevation*

Serial Number	Location	Elevation
1	Tandiarpet	12
2	Vepery	12
3	Chepauk	13
4	Lights	13
5	Saidapet	15
6	Guindy	15
7	Aminjikarai	15
8	Tirumangalam	15
9	Vadapalani	18.5
10	K.K.Nagar	16
11	Airport	15

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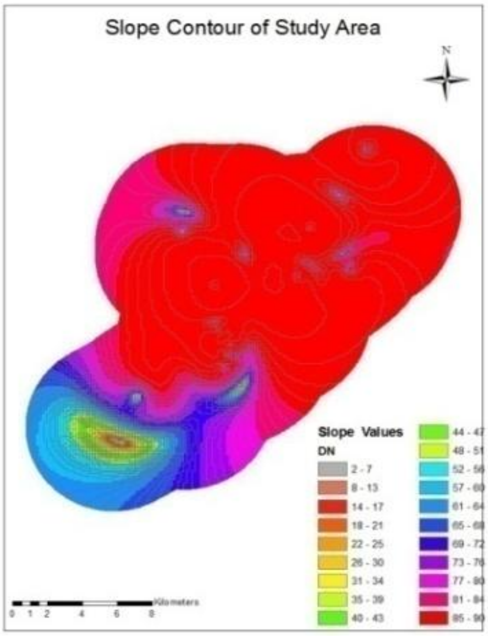
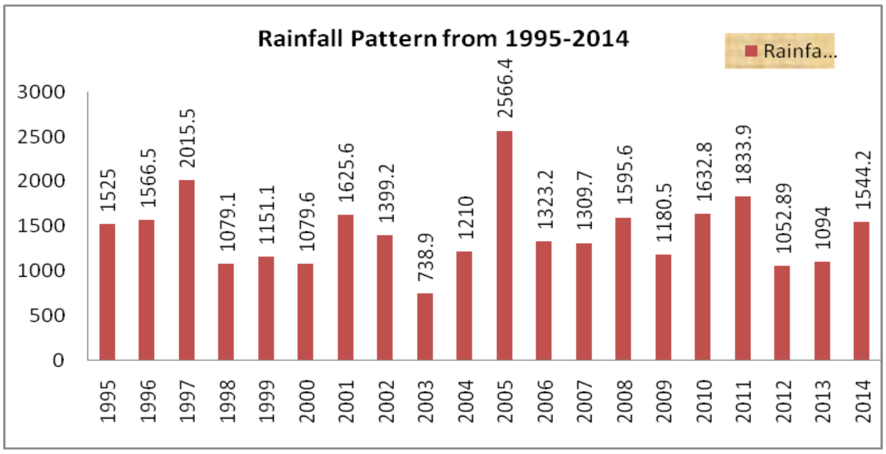


Figure 2. *Slope contour of study area*

The contour map shows that the values are higher in the North and gradually reduce towards to the East. Hence, the study area has a gentle slope from North to East.

Rainfall pattern

Rainfall data were collected for a study of the rainfall pattern in the study area. The water table levels before and after the construction were analyzed along with the rainfall data. The analysis helped to determine the tunneling effect on water table levels. The rainfall data are plotted and shown in the *Graph 1*.



Graph 1. *Rainfall data from 1995 to 2014*

The mean rainfall for the period 1995-2007 was found to be 1429.98 mm and 1419.13 mm for 2008-2014. The rainfall distribution variation between the two periods

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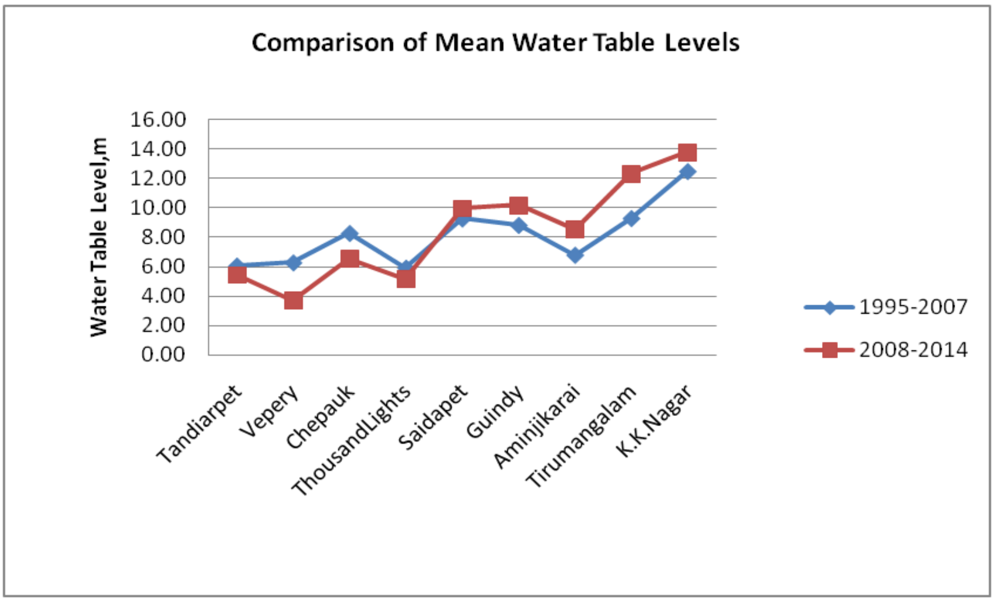
is very small, and shows that reduction in ground water level is not due to decreased rainfall. It was rather the underground work that caused a change in the ground water volume.

Water table levels

Data were collected for the period 1995-2014 from Centre Ground Water Board and the Institute of Water Studies, Chennai, and the data were separated into 1995-2007 and 2008-2014, that is, before and after the construction of metro rail corridor. The mean values of the water levels were calculated for 1995-2007 and 2008-2014. These values are tabulated in the Excel spread sheet with the location of observation wells in and around the metro rail corridor and shown in *Tables 2, 3*, and *4*.

The comparison of mean water table levels for the observation wells for the periods 1995-2007 and 2008-2014 was plotted and is shown in *Graph 2*.The graph clearly shows that in Tondiarpet, Vepery, Chepauk, and Thousand Lights the water table level has gone down after the construction. In Saidapet,Guindy, Amnijikarai, Tirumangalam and K. K. Nagar the water table level shows increase in underground.This scenario of rise and fall of the ground water table is purely due to the underground work undertaken for metro rail.



Graph 2. *Comparison of mean water table values*

Soil map

The soil map of the Chennai was collected and it was georeferenced and digitized for the study area. Within the study area, eight polygons were digitized for different types of soils present in the study area. The digitized soil map of the study area with types of soil available in the study area is shown in *Figure 3.*

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Table 2. *Mean water table levels (1995-2001)*

	Latitude	Longitude	Elevation	1995	1996	1997	1998	1999	2000	2001
Tandiarpet	13^0 07'38"N	$80^0$17'24"E	9.98	6.54	6.39	6.80	6.76	5.36	5.70	5.48
Vepery	13^0 05'07"N	$80^0$15'38"E	10.13	9.17	7.48	6.09	5.87	7.49	5.54	4.05
Chepauk	13^0 03'48"N	$80^0$16'52"E	10.43	8.39	8.60	8.47	8.36	8.33	8.19	8.12
Thousand Lights	13^0 03' 32"N	$80^0$15'05"E	11.52	6.77	5.37	6.79	7.11	5.39	5.70	5.44
Saidapet	$13^0$01 '20"N	$80^0$13'10"E	13.11	10.35	9.90	9.35	9.82	9.36	8.24	9.50
Guindy	13^0 0' 37"N	$80^0$12'56"E	13.1	10.15	9.35	9.00	9.12	8.99	8.15	9.22
Aminjikarai	13^0 04'12"N	$80^0$13'28"E	14.12	7.96	6.40	7.12	6.68	7.08	5.29	14.12
Tiruman galam	13^0 05'00"N	$80^0$11'40"E	13.78	9.74	9.23	10.05	11.15	11.43	8.42	8.16
K. K. Nagar	13^0 01'47"N	$80^0$12'47"E	16	13.75	12.84	13.20	13.30	13.33	12.46	10.46

Table 3. *Mean water table levels (2002-2007)*

Location	Latitude	Longitude	Elevation	2002	2003	2004	2005	2006	2007	Mean
Tandiarpet	13^0 07'38"N	$80^0$17'24"E	9.98	5.90	5.26	5.98	3.96	7.37	6.94	6.03
Vepery	13^0 05'07"N	$80^0$15'38"E	10.13	6.60	7.23	5.04	4.96	5.92	5.75	6.24
Chepauk	13^0 03'48"N	$80^0$16'52"E	10.43	8.56	7.68	8.41	8.48	8.37	7.33	8.25
Thousand Lights	13^0 03' 32"N	$80^0$15'05"E	11.52	6.40	5.20	5.51	5.65	5.60	5.62	5.89
Saidapet	$13^0$01 '20"N	$80^0$13'10"E	13.11	11.30	11.99	8.74	6.71	6.75	8.12	9.24
Guindy	13^0 0' 37"N	$80^0$12'56"E	13.1	10.95	11.12	8.25	6.13	5.96	8.05	8.80
Aminjikarai	13^0 04'12"N	$80^0$13'28"E	14.12	7.73	4.83	4.12	2.45	7.08	7.14	6.77
Tiruman galam	13^0 05'00"N	$80^0$11'40"E	13.78	9.20	8.51	6.11	7.67	9.77	11.13	9.28
K. K. Nagar	13^0 01'47"N	$80^0$12'47"E	16	13.07	11.76	8.97	10.67	14.22	14.29	12.49

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Table 4. *Mean water table levels (2008-2014)*

Location	Latitude	Longitude	Elevation	2008	2009	2010	2011	2012	2013	2014	Mean
Tandiarpet	13^0 07'38"N	$80^0$17'24"E	9.98	7.03	6.05	5.12	5.47	5.01	5.46	3.78	5.42
Vepery	13^0 05'07"N	$80^0$15'38"E	10.13	4.19	3.71	3.63	4.15	3.18	3.46	3.41	3.68
Chepauk	13^0 03'48"N	$80^0$16'52"E	10.43	6.67	6.45	7.08	7.09	6.44	6.26	5.80	6.54
ThousandLights	13^0 03' 32"N	$80^0$15'05"E	11.52	5.98	4.98	5.05	5.00	4.97	5.11	4.86	5.14
Saidapet	$13^0$01 '20"N	$80^0$13'10"E	13.11	14.62	8.16	8.97	8.33	9.86	9.92	9.85	9.96
Guindy	13^0 0' 37"N	$80^0$12'56"E	13.1	8.76	10.05	11.27	11.50	9.96	8.60	10.92	10.15
Aminjikarai	13^0 04'12"N	$80^0$13'28"E	14.12	8.07	7.37	7.96	8.65	7.25	6.25	14.12	8.52
Tirumangalam	13^0 05'00"N	$80^0$11'40"E	13.78	11.84	11.70	12.94	12.96	12.38	10.49	13.82	12.30
K. K .Nagar	13^0 01'47"N	$80^0$12'47"E	16	13.36	12.54	13.70	14.77	13.85	13.54	14.75	13.79

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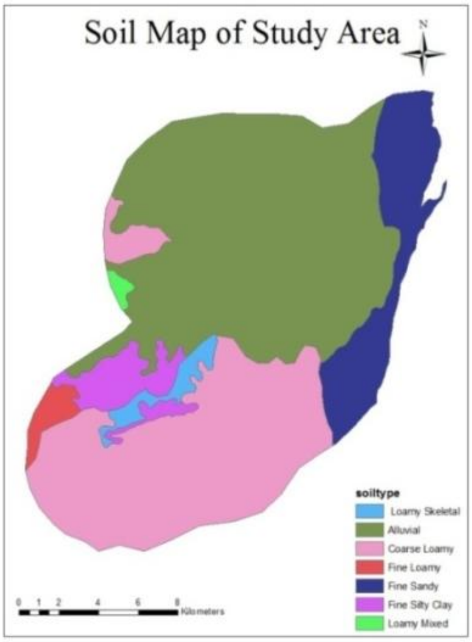

Figure 3. *Soil map of study area*

Specific yield

Specific yield is defined as the ratio of the volume of water that a saturated rock or soil yields due to gravity to the total volume of the rock or soil. Specific yield is usually expressed as a percentage. The value is not definitive, because the quantity of water that drains by gravity depends on variables such as duration of drainage, temperature, mineral composition of the water, and various physical characteristics of the rock or soil under consideration. Specific yield values for the various types of soils were identified and assigned to the respective polygons. *Table 5* lists the types of soil and their specific yield values.

Table 5. *Soil type and its specific yield*

Serial Number	Soil type	Specific yield (%)
1	Coarse loamy	22%
2	Alluvial	26%
3	Fine Sandy	21%
4	Loamy mixed	19.6%
5	Fine loamy	16.4%
6	Fine Silty Clay	18%
7	Loamy skeletal	11.2%

Quantification of water

Rasterisation (or rasterization) is the task of taking up an image described in a vector graphics format (shapes) and converting it into a raster image (pixels or dots) for output on a video display or printer, or for storage in a bitmap file format. Soil map contains the specific yield values converted into raster data. Ground water volume is calculated by using the formula:

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$$\text{Change in ground Water Volume} = S_y \times h \times A \qquad \text{(Eq.1)}$$

where S_y is the Specific yield (%) that varies for different types of soils
h = Water table fluctuation ,m
A = Shape area of the study map

In the spatial analyst tool, raster calculator was used for calculating the volume of water. Weights were assigned on the basis of importance of the parameters. Since the water level is considered to be the predominant one to quantify, it is allotted with the weightage 70%, 20% for specific yield, 10% for the shape area.

Spatial distribution and the quantity of water were calculated for the mean values of each year and are tabulated in *Table 6.* The samples for the first phase (1995-2007) are shown in *Figure 4* and *Figure 5*. Samples of spatial distribution for the second phase (2008-2014) are shown in *Figure 6* and *Figure 7.*

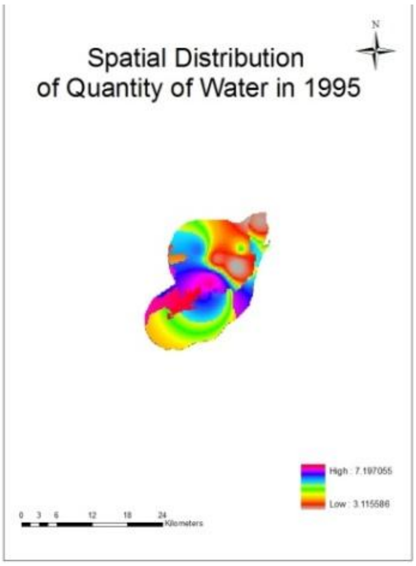

Figure 4. *Spatial distribution of quantity of water in 1995*

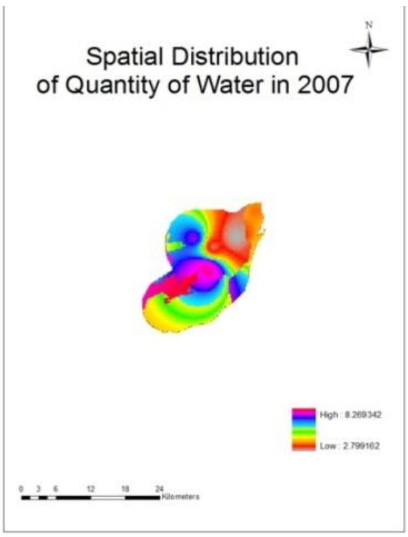

Figure 5. *Spatial distribution of quantity of water in 2007*

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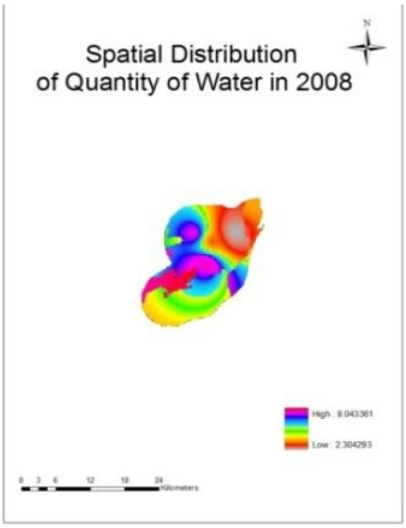

Figure 6. *Spatial distributon of quantity of water in 2008*

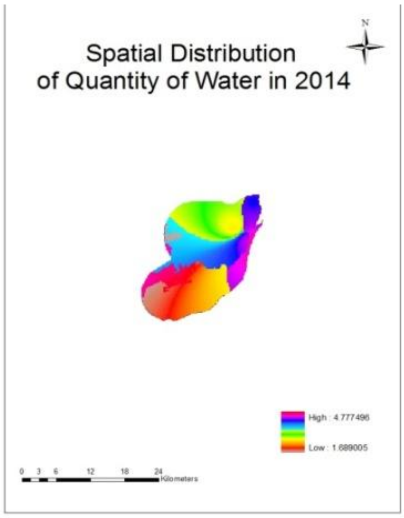

Figure 7. *Spatial distributon of quantity of water in 2014*

Table 6. *Calculated water quantity range from 1995-2014*

Serial Number	Year	Water Quantity Range
1	1995	3.12 - 7.20
2	1996	2.66 - 7.46
3	1997	2.94 - 7.51
4	1998	2.85 - 7.60
5	1999	2.66 - 7.56
6	2000	2.62 - 7.14
7	2001	2.12 - 6.98
8	2002	3.05 - 7.69
9	2003	2.44 - 7.39
10	2004	2.15 - 6.34
11	2005	1.48 - 6.49
12	2006	2.87 - 8.23
13	2007	2.80 - 8.27

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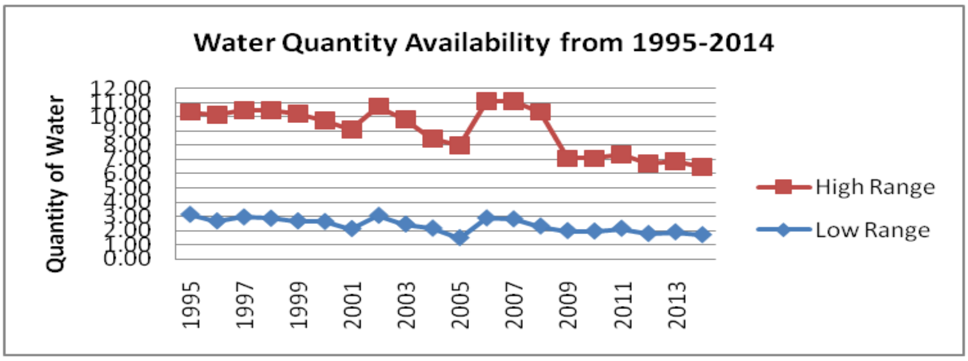
14	2008	2.30 - 8.04
15	2009	1.98 - 5.11
16	2010	1.95 - 5.12
17	2011	2.14 - 5.23
18	2012	1.77 - 4.94
19	2013	1.89 - 4.99
20	2014	1.69 - 4.78

The water quantity range calculated using the raster calculator from 1995-2014 was plotted as *Graph 3*. The graph clearly shows that both the low range and high range values after 2008, i.e., after the commencement of construction for the metro rail corridor.The quantity of water got reduced and the same scenario continued upto 2014 and the mean spatial distribution from 1995-2007 and 2008-2014 also confirms the same status and it is shown in *Figure 8* and *Figure 9.*

Spatial distribution of the mean ground water volume calculated for the period 1995-2007 was found to be 2.98-7.37 for the study area. Similarly, the ground water volume got reduced to 1.98-5.44 during the period 2008-2014, i.e., after the construction of metro rail.



Graph 3. *Water quantity availability from 1995-2014*

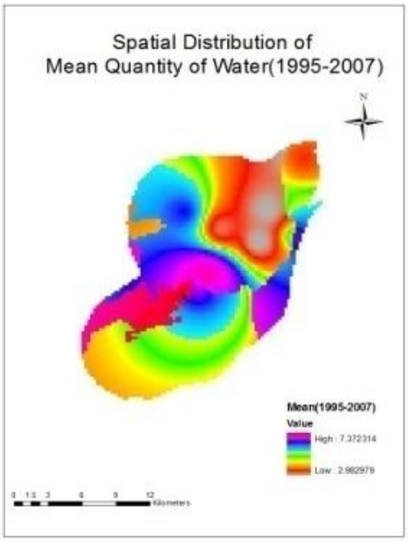


Figure 8. *Spatial distribution of quantity of water in 1995-2007*

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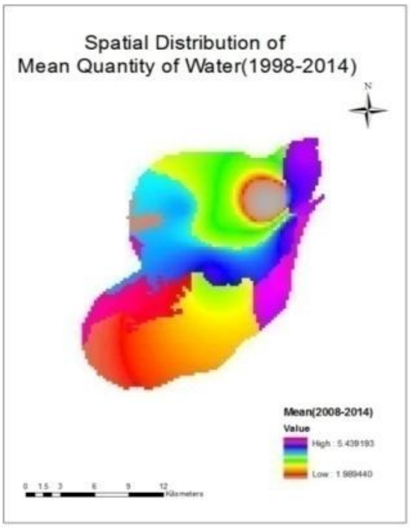

Figure 9. *Spatial Distribution of Quantity of Water in 2008-2014*

Conclusion

Reduction in ground water volume was due to the underground development around the metro rail corridors. This was clearly shown from the calculation of ground water volume using raster calculator in GIS. The mean water table levels were found to be decreased in Tondiarpet, Vepery, Chepauk, whereas increased water table levels were found in Guindy, Saidapet, Aminjikarai, Tirumangalam and K. K. Nagar. This may be due to the slope disturbance created by the underground development. The plotted graphs clearly show that the Rainfall cannot be seen as the parameter which changes the water table levels and the massive underground construction seems to be the major cause for the reduction in water levels.

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