

Spatial Analysis Of Ground Water Quality Using Geographical Information System And Water Quality Index

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Abstract

Ground water quality of an area can be assessed in respect of various physical, chemical and biological parameters. Of these, some parameters may have permissible values and others may not. Also, the relative significance of each of these parameters may give a varied idea about its nature. The overall nature of groundwater can be determined by combining the effect of each parameter by giving relative weights and integration. Then, spatial analysis of these integrated indexes will give an effective insight about the water quality distribution of the area. This study aims to estimate the Water Quality Index (WQI), indicating an useful representation of overall quality of water. The parameters of pH, EC, Total Hardness, Ca, Mg, Na, Cl, SO₄, CO₃, HCO₃, F, TDS and NO₂+NO₃ from 26 wells were considered from Chennai City, India, to determine the WQI. Inverse Distance Weighted (IDW) interpolation method in ArcGIS has been used to generate the spatial distribution of the ground water physico-chemical parameters and water quality index map. The WQI ranges from 48 to 380. Based on the analysis, the study area is found to contain 47% good and 24% excellent ground water quality.

Keywords: Ground water, Geographical Information System, Water Quality Index

Introduction:

Water, a prime natural resource and precious national asset, forms the chief constituent of ecosystem. Groundwater is an essential renewable resource and

dynamic in nature. Over exploitation of groundwater is of primary concern due to its pronounced an irrational use in the recent decades. Hence, monitoring and conserving this important resource is essential. The quality of groundwater depends on a large number of individual hydrological, physical, chemical and biological factors. Industries, residential, agricultural and commercial activities adversely affect the quality of groundwater. Due to the rapid growth of industries and urban settlements, there is an increasing pressure on land, water and environment, particularly in the metropolitan cities. Inadequate management of water resources as directly or indirectly resulted in the degradation of hydrological environment. Therefore, a continuous periodical monitoring of water quality is necessary so that appropriate steps may be taken for water resource management practices. Spatial distribution mapping for various water quality parameters utilizing Geographical Information System (GIS) technology and the resulted information on the quality of water could be useful for policy makers to take remedial measures such as increasing the water treatment levels and proper management for water supply. Inverse distance weighted (IDW) interpolation technique in ArcGIS is used for spatial distribution of the various parameters listed as Hardness, pH, TDS, HCO₃, SO₄, NO₃, Ca, Mg, Cl and F. Water Quality Index (WQI) can provide simple indicator of water quality, gives a general idea about the quality of water in a particular region. The main objective is to make a groundwater quality assessment using GIS, based on the available physico-chemical data in the study area.

Spatial Analysis Of Groundwater Quality:

The spatial variation in ground water quality of a particular region can be obtained by many methods. The literature review has been carried out on these aspects (i) Analysis of Groundwater quality, (ii) Spatial mapping techniques and (iii) Based on Water Quality Index.

Analysis of Groundwater quality:

Assessments of groundwater quality for different places were presented by Ramesh & Elamvaluthi, (2012), Chadetrik Rout & Arbinda Sharma, (2011), Patil. PN et al (2012) Groundwater quality can be evaluated systematically from the physical, chemical and biological characteristics. The samples collected from the open wells were tested and the results were compared with the standards prescribed by World Health Organization (WHO) and Bureau of Indian Standard (BIS). Contaminated area were identified and recommended for treatment of groundwater before the domestic supply.

Spatial mapping techniques:

GIS, a powerful tool used for assessing the water quality and also to develop solutions for water resource problems on a local or regional scale. The various researches are reviewed below.

Thematic maps for various water quality parameters are created using GIS. The final integrated map is prepared from the priority classes as High, Medium, and Low or from the desirable limits of WHO or BIS water quality standards. This technique is demonstrated by Karthikeyan et al (2013), Selvam et al (2013), Kumaravel et al (2014). But Ishaku et al (2011) created spatial distribution maps based on the chemical indices for the Jada area, Nigeria. Basem shomar (2010) integrated the Environmental hotspots in groundwater quality map it helped to refine information on land use, soil types, depth to groundwater table, environmental “hot spots”, and contaminant concentrations of the Gaza Strip Palestine.

The physico-chemical parameters of groundwater have been integrated with Spatial Interpolation technique, IDW to generate various thematic maps in ArcGIS. The results obtained with the spatial database established in GIS will be helpful for monitoring and managing ground water quality and its pollution in the study area. Suvarna Tikle et al (2012), Mahalingam et al (2014), Shivayogimath et al (2014),

The groundwater quality has been assessed using Geostatistical techniques in ArcGIS by Amadi et al (2012) and Jagdish Kumar et al (2013) and the results obtained will be used to monitor effectively and periodically to assess the quality and vital parameters of ground water and also to draw the attention of civic authorities for suitable action. Gorai & Subash Kumar (2013) created final groundwater quality map using Geostatistical (Kriging) approach, overlay and index ratio in ArcGIS.

Water Quality Index:

Water quality index (WQI) is a valuable tool used to assess the overall water quality status in a single term. Reported work on assessment of ground water quality index is summarized below.

The physic-chemical analyses were carried out for the samples collected in the study area for both the pre & post monsoon seasons. Ambiga & AnnaDurai (2013) and Ganeshkumar & Jaideep (2011) and WQI has been calculated for the various parameters. Cristina Rosu et.al (2013) examined the ground water quality in Tureni Village ,Cluj County, from the samples collected weekly for three months. Water Quality Index reveals the entire village was identified as medium & strongly mineralized. From the final water quality index, Sirajudee et al (2013) and Neeraj & Patel (2010) concluded that the groundwater needs treatment before consumption.

Thakor et al (2011) assessed the impact of industries, agriculture and human activities on groundwater during rainy, winter and summer seasons. The result showed except Total alkalinities and magnesium all the parameters are within the permissible limits.

WQI for the various physico-chemical parameters are calculated and it is interlinked with the GIS thematic maps and the final water quality map of an area can be obtained in ArcGIS. which can be used for better understanding of the present water quality scenario of the study area. Sundara Kumar et al (2010), and Swarna Latha & Nageswara Rao (2010). The Hierarchical Cluster analysis was applied on the groundwater quality data in GIS and integrated with WQI to obtain the final contaminated area by Abulhakeem et al (2011).

Study Area:

The study area is located between latitudes $13^{\circ}14'12''\text{N}$ to $12^{\circ}56'32''\text{N}$ and longitudes $80^{\circ}19'46''\text{E}$ to $80^{\circ}15'38''\text{E}$ and covers an area of 260.58 sq.km, as shown in Figure 1. The study area falls in two districts, Chennai and Thiruvallur. The mercury rises to 40°C during the summer months but the average temperature in the winters revolves around 24°C . People of Chennai enjoy monsoon rains and it gets 1,300 mm of rainfall annually. The study area is encompassed with mixed land use activities such as high concentration of urban activities, Commercial and IT Industries in the South and other Industrial activities and Thermal Power stations in the North of Chennai.

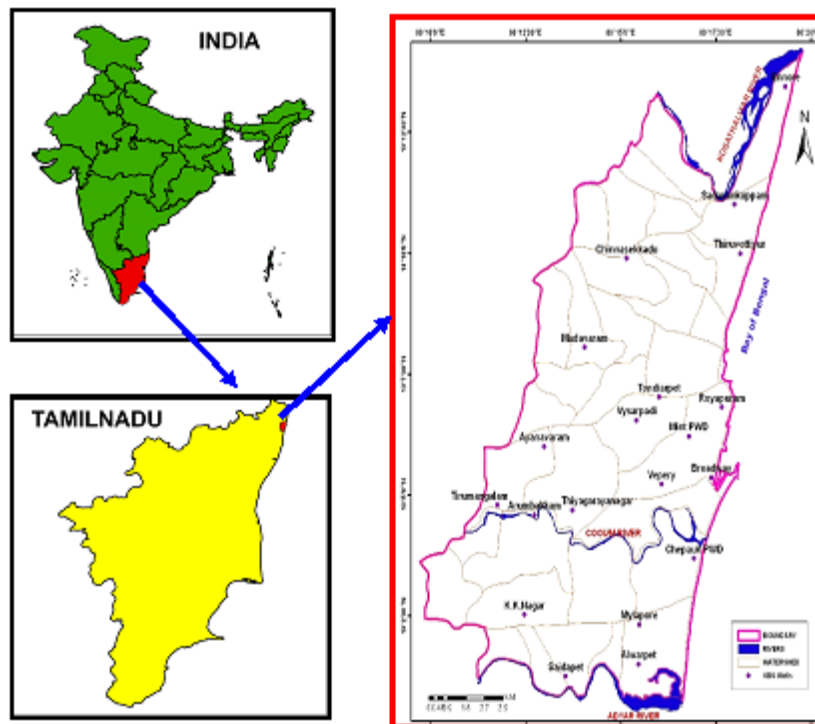


Figure 1: Index map

Methodology:

The overall methodology to obtain the water quality map of the study area is as given below. The study is carried out in three steps, (i) To create a Database for all the physic-chemical properties of groundwater for all the wells in the study area. (ii) Creating thematic maps in GIS for various water quality parameters. (iii) Computing Water Quality Index.

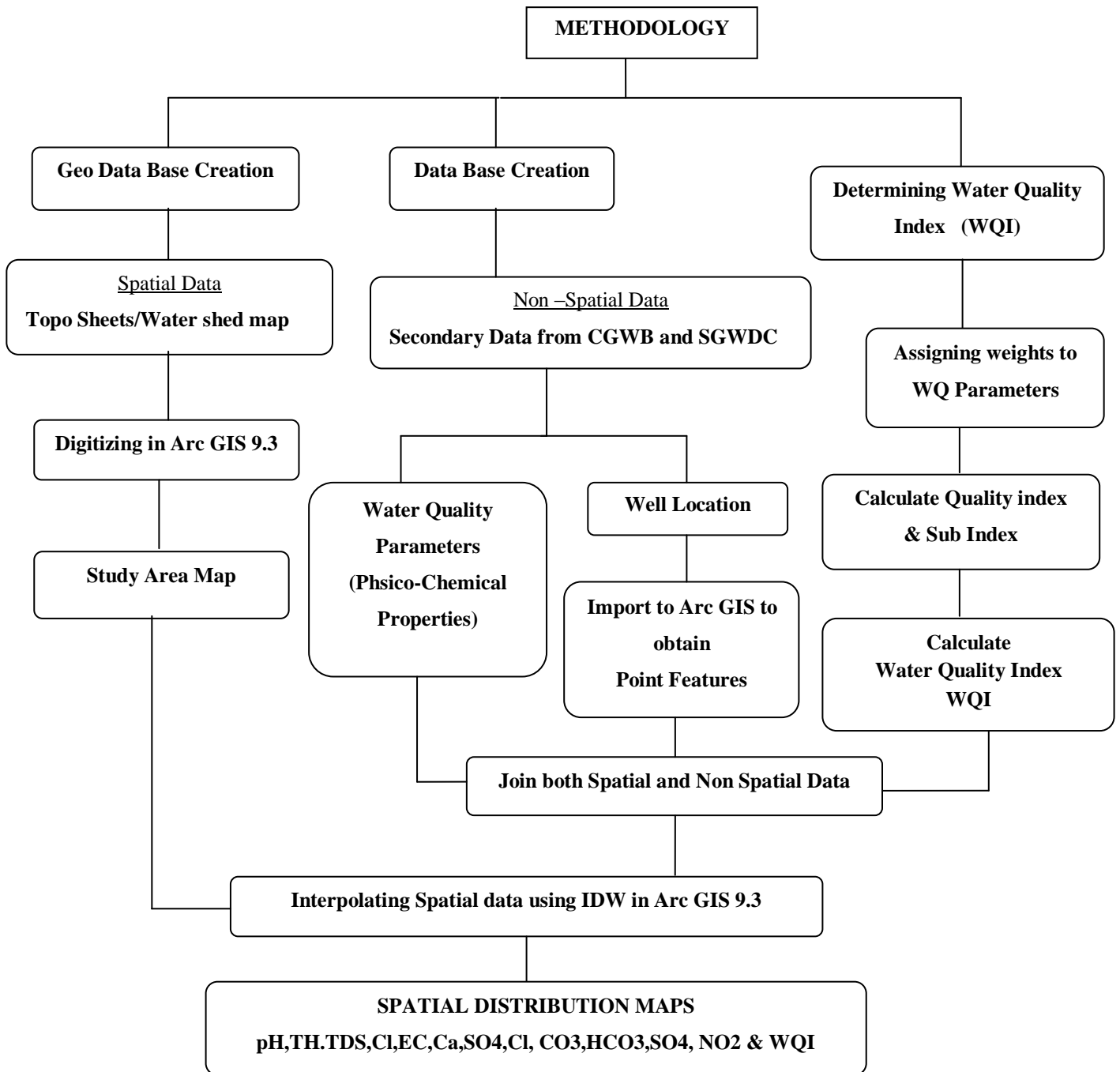


Figure 2: Flowchart showing methodology

All the required non spatial data are collected from Central GroundWater Board, Chennai, and the database is created to interlink with the spatial data. The Base map is created from the Topo sheets and watershed map of the study area. Both spatial and non spatial data are interlinked in Arc GIS to carry out the interpolation

technique. The overall Water quality map of the study area is acquired from the computation of Water Quality Index, a single value by assigning weights to the physical & chemical properties of water based on their importance in the quality criteria.

Database:

The secondary data for the groundwater level and groundwater quality are collected from the Data Center, Central Government Water Board, Chennai and State Ground and Surface Water Resources Data Centre, Chennai. The data for the year 2011 has been utilized for the study. The wells location is identified and the corresponding water quality parameters are arranged.

Geo Database:

Geographic Information System (GIS), a high performance computer based tool is playing a critical role in water resource management and pollution study. GIS represents a technological advancement in terms of interpolation techniques. Thematic maps for various water quality parameters and an integrated Water Quality Index map are created in GIS which is very much helpful to understand the present status of water quality in the study area.

The study area is delineated from the Topo sheets 66C4, 66C8 and 66D1&5 imported in to ARCGIS 9.2 and geo referenced. The base map is digitized from the geo referenced image.

The boundary of the study area has been fixed based on the watershed map and the final map is as shown in figure 1. Observation well locations have been imported in ArcGIS through a point layer. A unique code has given to each observation well and stored in the attribute table. Data for the selected water quality parameters are linked to the well point layer.

Inverse Distance Weighed (IDW) raster interpolation technique has been used to estimate the spatial distribution of the water quality parameters. This method is an algorithm for spatially interpolating values which are estimated between measurements. In IDW, every value is a weighted average of surrounding points. Weights are computed by taking the inverse of the distance from observations location to the location of the point being estimated.

Water Quality Index:

The Water quality index (WQI) which was first developed by Horton in 1965 which provides a single number that expresses the overall water quality at a certain location and time based on several water quality parameters. After Horton, a number of workers all over the world developed WQI based on rating of different water quality parameters. The arithmetic weighted water quality index is followed in this study.

The following steps are followed to determine the Water Quality Index (WQI)

Water quality parameters are assigned with a weight (**wi**) according to its relative importance in the overall quality of water for drinking purposes. The weights are assigned based on the previous studies by the researchers. The maximum weight of 5 has been assigned to the parameters TDS, Cl, SO₄, NO₂, F due to its major importance in water quality assessment. Similarly weight 4 has been assigned to pH, weight 3 assigned to Ca, Mg, weight 2 to CO₃ & Tot Hard and weight 1 to EC and HCO₃.

Relative weight (**Wi**) is computed from the following equation,

$$\mathbf{Wi} = \mathbf{wi} / \Sigma \mathbf{wi}$$

A quality rating scale (**qi**) for each parameter is calculated by using the equation

$$\mathbf{qi} = (\mathbf{Ci} / \mathbf{Si}) \times 100$$

Ci is the concentration of each parameter in the water sample in mg/L

Si is the Standards of each chemical parameter prescribed by BIS10500-2012 in mg/L

Sub Index **SIi** is to be determined for each chemical parameter

$$\mathbf{SIi} = \mathbf{Wi} \times \mathbf{qi}$$

Water Quality Index is then determined

$$\mathbf{WQI} = \Sigma \mathbf{SIi}$$

The WQI values are classified into five types as given in Table1.

Table 1: Classification of Water Quality

WQI Value	Water Quality
<50	Excellent
50-100	Good
100-200	Poor
200-300	Very Poor
>300	Unsuitable

The final WQI values are linked to the attribute table of the observation wells point layer.

Results and Discussion:

Spatial Distribution Maps:

The maps generated using IDW technique in GIS of various ground water quality parameters are shown in figures 3 to 11.

pH values ranges from 7.05 to 8.90. It is very high in Mylapore, Adyar & Arumbakkam. Nearly 10 wells show more pH value than the allowable limit.

Electrical conductivity (EC) ranges from 450.00 $\mu\text{S}/\text{cm}$ to 4950 $\mu\text{S}/\text{cm}$. **Total Hardness (TH)** ranges from 150.00 mg/l to 1820.00 mg/l **Chlorine** values ranges from 39.00 mg/L to 1134 mg/L. Higher values are in Sadayankuppam and Vepery

Calcium ranges from 20 mg/L to 114.00 mg/L and **Magnesium** ranges from 10 mg/L to 379 mg/L. in the study area. The maximum value is in Sadayankuppam.

Sulphate In study area sulfate concentration ranges from 28mg/L to 758 mg/L, and **Fluoride** concentrations are found to be in the range of 0.03 to 1.27 mg/l. K.K.Nagar shows the maximum fluoride value.

Total Dissolved Solids (TDS) It is found that the TDS in the water samples ranges from 258.00 mg/l to 3037.00 mg/l. TDS values in Vepery and Sadayankuppam are 2752 and 3037 respectively.

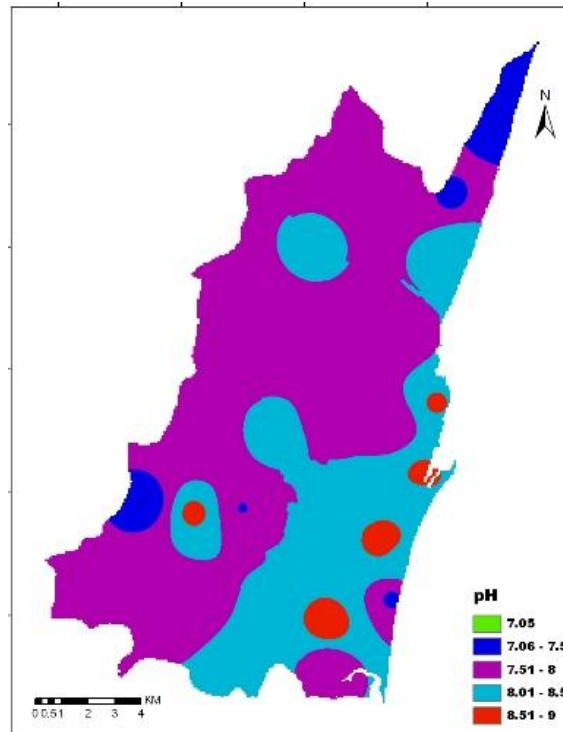


Figure 3: pH Distribution

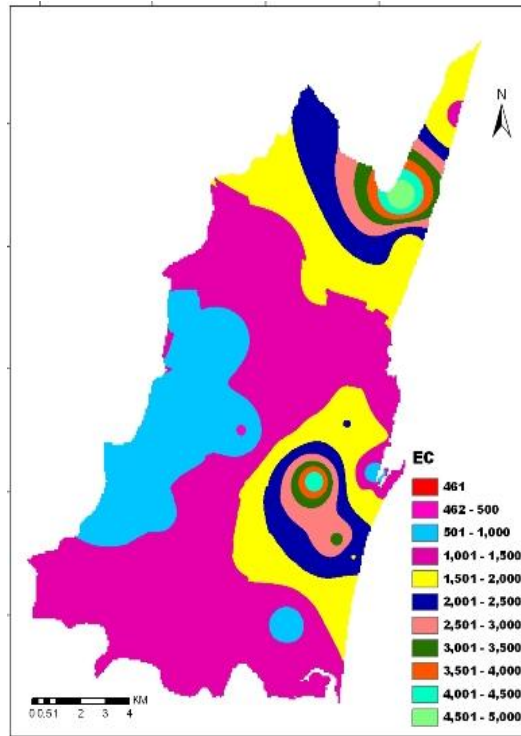


Figure 4: EC Distribution

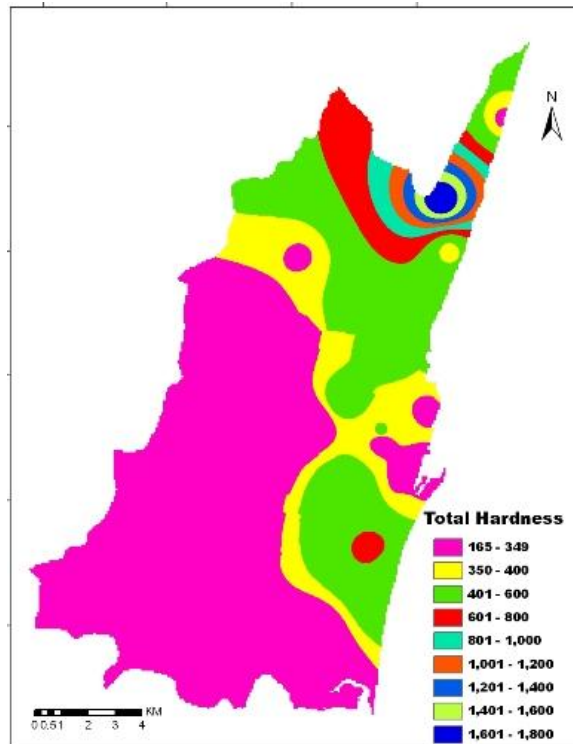


Figure 5: Total Hardness Distribution

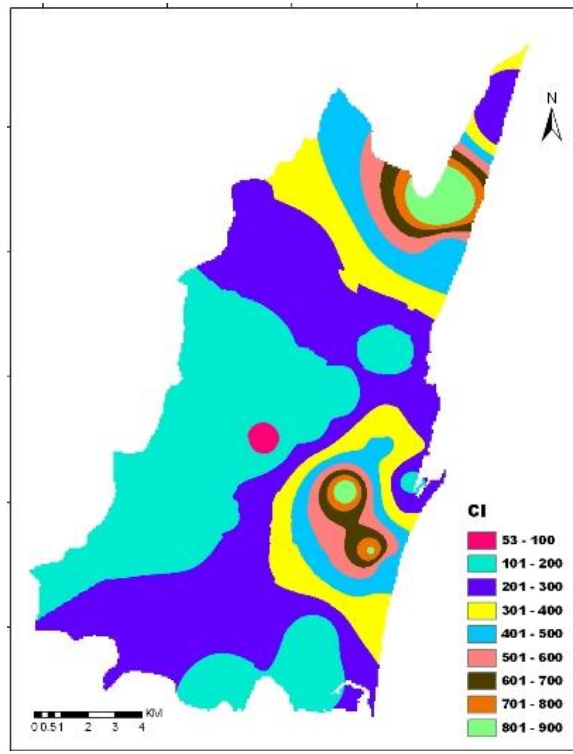


Figure 6: Chlorine Distribution

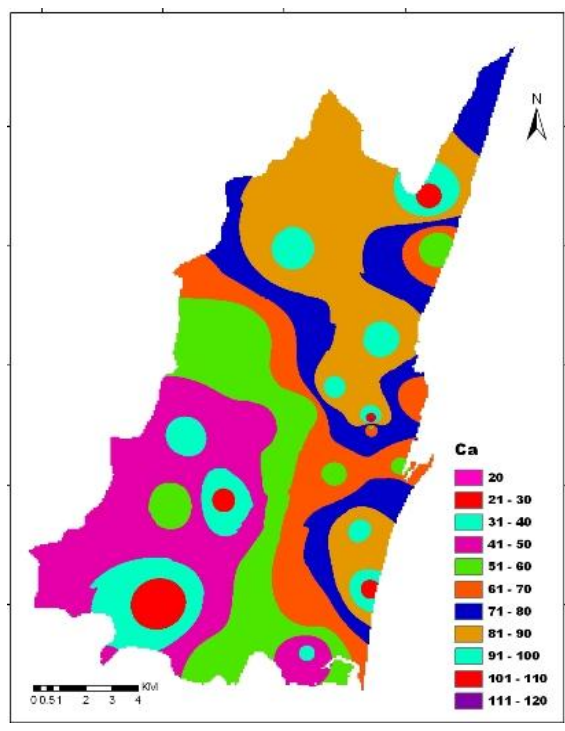


Figure 7: Calcium Distribution

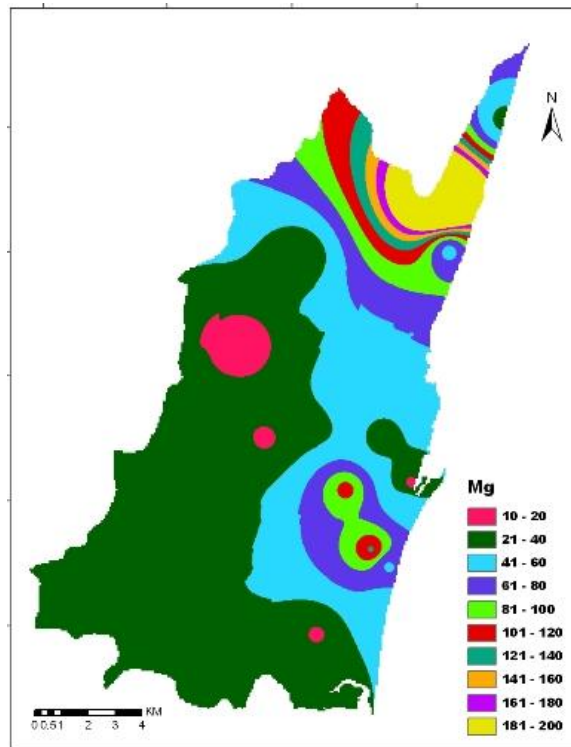


Figure 8: Magnesium Distribution

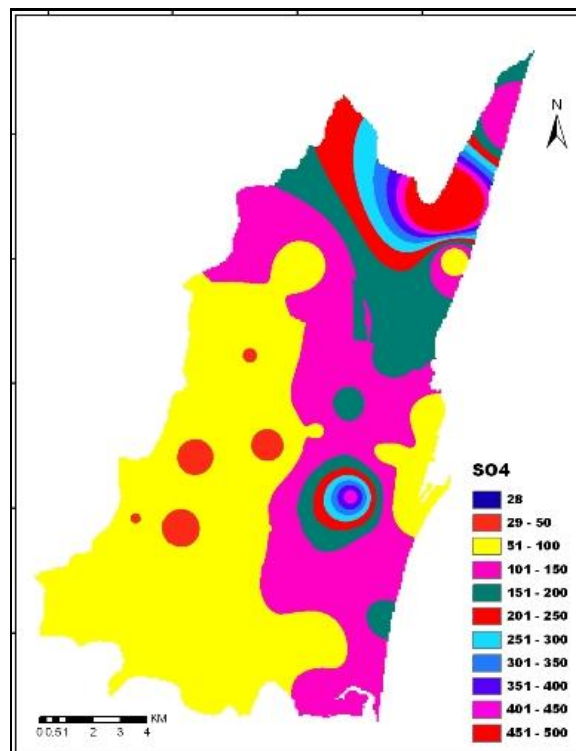


Figure 9: Sulphate Distribution

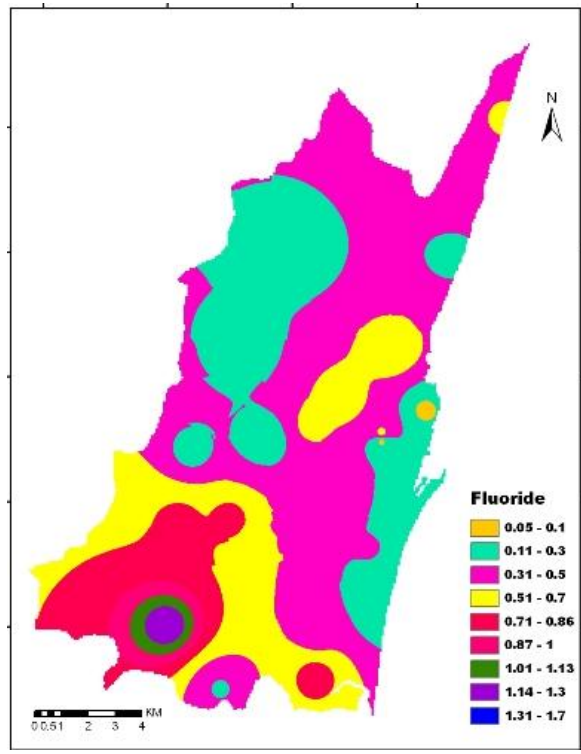


Figure 10: Fluoride Distribution

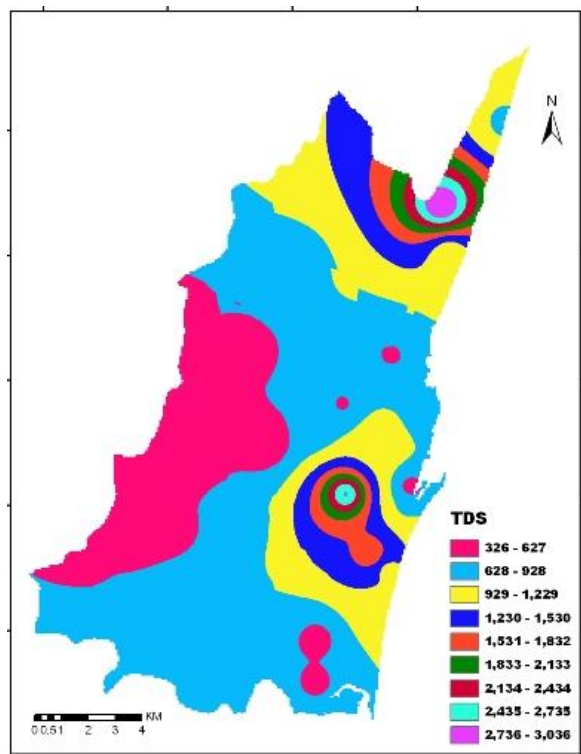


Figure 11: TDS Distribution

Water Quality Index (WQI) MAP

WQI will give a single value to the water quality of a source along with reducing higher number of parameters into a simple expression resulting into easy interpretation of water quality monitoring data. The water quality index of the study area has been calculated as per the procedure given above.

The relative weight (**rwi**) of the parameter is calculated for each sample well by assigning individual weights to the water quality parameters. The quality rating scale (**qi**) is calculated, it is the ratio of concentration of each sample to the water quality standards prescribed by BIS. The Sub Index (**S_{li}**) is calculated and the sum of all the sub index gives the Water Quality Index value. A sample calculation for Water Quality Index (WQI) of an observation well in Alwarpet area is shown in table 2 and the index is 98.32 i.e. the quality of groundwater in the surrounding area is Good.

Table 2: Calculation of WQI

	Ci	wi	Si	rwi	qi	S _{li}
pH	7.6	4	6.5	1	116.9	10.39
EC	1100	1	600	0.25	183.33	4.07
Total Hard	200	2	300	0.5	66.67	2.96
Ca	38	3	75	0.75	50.67	3.38
Mg	25.52	3	30	0.75	85.06	5.67
Na	133	4	50	1	266	23.64
Cl	145.35	5	250	1.25	58.14	6.46
SO ₄	105.6	5	200	1.25	52.8	2.07
CO ₃	14	2	75	0.5	18.67	0.83
HCO ₃	225.7	1	30	0.25	752.5	16.72
F	0.81	5	1	1.25	80.96	9
TDS	590	5	500	1.25	118	13.11
NO ₂ + NO ₃	0.5	5	45	1.25	0	0
WQI						98.32

WQI values for all the sample wells at various locations in the study area have been calculated and the nature of water quality is arrived. The Water Quality Index of the entire study area has been obtained as shown in the table 3, is interlinked with the base map attributes and the final WQI map is generated by applying IDW technique in ArcGIS 9.2.

Table 3: Water Quality Index for the study area

Sl.No	Place name	WQI	Nature of Water Quality
1	Alwarpet	98.32	Good
2	Arumbakkam	99.02	Good
3	Ayanavaram	64.92	Good
4	Broadway	83.92	Good
5	Chepauk PWD	160	Poor
6	Chinnasekkadu	112.8	Poor
7	Ennore	129.7	Poor
8	Government Estate	242.8	Very Poor
9	K.K.Nagar	142.3	Poor
10	Lady Wellington School	146	Poor
11	Madavaram	80.42	Good
12	Mint PWD	149	poor
13	Mylapore	90.47	Good
14	Perambur	48.12	Excellent
15	Royapuram	102.3	Poor
16	Sadayankuppam	372.6	Unsuitable
17	Saidapet	105.6	Poor
18	Secretariate	136.7	Poor
19	Tandiarpet	112.7	Poor
20	Thiruvottiyur	150.3	Poor
21	Thiyagarayanagar	115.1	Poor
22	Tirumangalam	75.13	Good
23	Tondiarpet	111.5	Poor
24	Vallalar Nagar	156	Poor
25	Vepery	379.7	Unsuitable
26	Vysarpadi	118.9	Poor

The final interpolated WQI map is as shown in Figure12. The Percentage area of water quality in the study area arrives as 25% -Excellent, 47% -Good, 18%-Poor, 7% Very Poor and 3% is Unsuitable.

Conclusions:

The study has demonstrated the utility of GIS technology combined with Water Quality Index (WQI) in evaluating groundwater quality and mapping of an urban region. The ground water quality in the Sadayankuppam & Vepery is affected very much. The application of the Geographical Information System using Inverse Distance Weighted (IDW) method proved a useful tool in delineating areas of different groundwater quality status based on selected parameters. The spatial

distribution maps generated for various physicochemical parameters using GIS techniques could be useful for initiating groundwater quality development in the area. The analysis reveals that the groundwater of the area needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination.

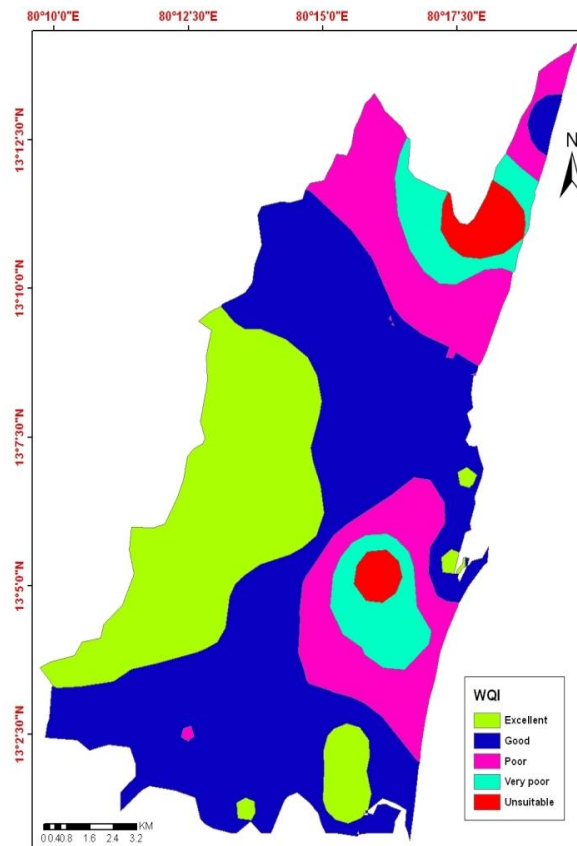


Figure 12: Final Water Quality map

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