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Full Length Research Paper

Groundwater quality mapping using geographic information system (GIS): A case study of Gulbarga City, Karnataka, India

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Spatial variations in ground water quality in the corporation area of Gulbarga City located in the northern part of Karnataka State, India, have been studied using geographic information system (GIS) technique. GIS, a tool which is used for storing, analyzing and displaying spatial data is also used for investigating ground water quality information. For this study, water samples were collected from 76 of the bore wells and open wells representing the entire corporation area. The water samples were analyzed for physico-chemical parameters like TDS, TH, Cl^- and NO_3^-, using standard techniques in the laboratory and compared with the standards. The ground water quality information maps of the entire study area have been prepared using GIS spatial interpolation technique for all the above parameters. The results obtained in this study and the spatial database established in GIS will be helpful for monitoring and managing ground water pollution in the study area. Mapping was coded for potable zones, in the absence of better alternate source and non-potable zones in the study area, in terms of water quality.

Key words: Groundwater pollution, drinking-water, physico-chemical parameters, spatial interpolation.

INTRODUCTION

Groundwater is one of earth's most vital renewable and widely distributed resources as well as an important source of water supply throughout the world. The quality of water is a vital concern for mankind since it is directly linked with human welfare. In India, most of the population is dependent on groundwater as the only source of drinking water supply (NIUA, 2005; Mahmood and Kundu, 2005; Phansalkar et al., 2005). The groundwater is believed to be comparatively much clean and free from pollution than surface water. Groundwater can become contaminated naturally or because of numerous types of human activities; residential, municipal, commercial, industrial, and agricultural activities can all affect groundwater quality (U.S. EPA, 1993; Jalali, 2005a; Rivers et al., 1996; Kim et al., 2004; Srinivasamoorthy et al., 2009; Goulding, 2000; Pacheco and Cabrera, 1997). Contamination of groundwater can result in poor drinking water quality, loss of water supply, high clean-up costs, high costs for alternative water supplies, and/or potential health problems. A wide variety of materials have been identified as contaminants found in groundwater. These include synthetic organic chemicals, hydrocarbons, inorganic cations, inorganic anions, pathogens, and radionuclides (Fetter, 1999). The importance of water quality in human health has recently attracted a great deal of interest. In developing countries like India around 80% of all diseases are directly related to poor drinking water quality and unhygienic conditions (Olajire and Imeokparia, 2001; Prasad, 1984).

Groundwater is a valuable natural resource that is essential for human health, socio-economic development, and functioning of ecosystems (Zektser, 2000; Humphreys, 2009; Steube et al., 2009). In India severe water scarcity is becoming common in several parts of the country, especially in arid and semi-arid regions. The

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overdependence on groundwater to meet ever-increasing demands of domestic, agriculture, and industry sectors has resulted in overexploitation of groundwater resources in several states such as Gujarat, Rajasthan, Punjab, Haryana, Uttar Pradesh, Tamil Nadu, among others (CGWB 2006; Garg and Hassan, 2007; Rodell et al., 2009). Geographic information system (GIS) has emerged as a powerful tool for storing, analyzing, and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields (Stafford, 1991; Goodchild, 1993; Burrough and McDonnell, 1998; Lo and Yeung, 2003).

Groundwater can be optimally used and sustained only when the quantity and quality is properly assessed (Kharad et al., 1999). GIS has been used in the map classification of groundwater quality, based on correlating total dissolved solids (TDS) values with some aquifer characteristics (Butler et al., 2002) or land use and land cover (Asadi et al., 2007). Other studies have used GIS as a database system in order to prepare maps of water quality according to concentration values of different chemical constituents (Skubon, 2005; Yammani, 2007). In such studies, GIS is utilized to locate groundwater quality zones suitable for different usages such as irrigation and domestic (Yammani, 2007). A similar approach was adopted by Rangzan et al. (2008) where GIS was used to prepare layers of maps to locate promising well sites based on water quality and availability. Babiker et al. (2007) proposed a GIS-based groundwater quality index method which synthesizes different available water quality data (for example, Cl, Na, Ca) by indexing them numerically relative to the WHO standards.

Water quality assessment involves evaluation of the physical, chemical, and biological nature of water in relation to natural quality, human effects, and intended uses, particularly uses which may affect human health and the health of the aquatic system itself (UNESCO/WHO/UNEP, 1996). The use of GIS technology has greatly simplified the assessment of natural resources and environmental concerns, including groundwater. In groundwater studies, GIS is commonly used for site suitability analyses, managing site inventory data, estimation of groundwater vulnerability to contamination, groundwater flow modeling, modeling solute transport and leaching, and integrating groundwater quality assessment models with spatial data to create spatial decision support systems (Engel and Navulur, 1999). A GIS-based study was carried out by Barber et al. (1996) to determine the impact of urbanization on groundwater quality in relation to land-use changes. Nas and Berktay (2010) have mapped urban groundwater quality in Koyna, Turkey, using GIS. Ahn and Chon (1999) studied groundwater contamination and spatial relationships among groundwater quality, topography, geology, landuse, and pollution sources using GIS in Seoul. GIS has been useful in establishing the spatial relationship between pollution level and its source in this study. ArcView GIS was used to map, query, and analyze the spatial patterns of groundwater in north-central Texas that includes large percentages of both urban and agricultural land uses (Hudak and Sanmanee, 2003). Ducci (1999) produced groundwater contamination risk and quality maps by using GIS in Southern Italy. It was suggested that the use of GIS techniques is vital in testing and improving the groundwater contamination risk assessment methods. For any city, a ground water quality map is important to evaluate the water safeness for drinking and irrigation purposes and also as a precautionary indication of potential environmental health problems. Singh and Lawrence (2007) prepared a groundwater quality map in GIS successfully for Chennai city, Tamilnadu, India but a groundwater quality assessment in Dhanbad district, Jharkhand, India was much more difficult due to the spatial variability of multiple contaminants and wide range of indicators that could be measured.

Considering the above aspects of groundwater contamination and use of GIS in groundwater quality mapping, the present study was undertaken to map the groundwater quality in Gulbarga city, Karnataka, India. The literature survey indicates that several researchers have made studies on groundwater quality of both bore wells and open wells in the city. Some have studied only physico-chemical parameters, while some have observed the parameters in a combined state; while a few have studied the bacteriological status of these waters. Further there are reports only on the detection of hydro-chemical factors. From the literature survey one is unable to detect spatial variation of the groundwater quality. Moreover such a study has not been carried in the Gulbarga city. This study aims to visualize the spatial variation of certain physico-chemical parameters through GIS.

The main objective of the research work is to make a groundwater quality assessment using GIS, based on the available physico-chemical data from 76 locations in Gulbarga city. The purposes of this assessment are (1) to provide an overview of present groundwater quality, (2) to determine spatial distribution of groundwater quality parameters such as Hardness, TDS, NO_3^-, and Cl^-, and (3) to generate groundwater quality zone map for the Gulbarga city.

MATERIALS AND METHODS

Study area

Gulbarga is a fast developing city in northern Karnataka state of India. The City is situated at Latitude of 17°17' to 17° 22' and Longitude of 76° 47' to 76° 52', at the mean sea level of 454 m and referred in topographic sheet No. 56 C/SE (Figure 1). It spreads to an area of 54.13 sq km, and has a population of 430,000. Average annual rainfall is about 750 mm and the mean daily temperatures for the same period range from 19°C in winter to over 40°C in summer. The study area is identified as chronically drought prone

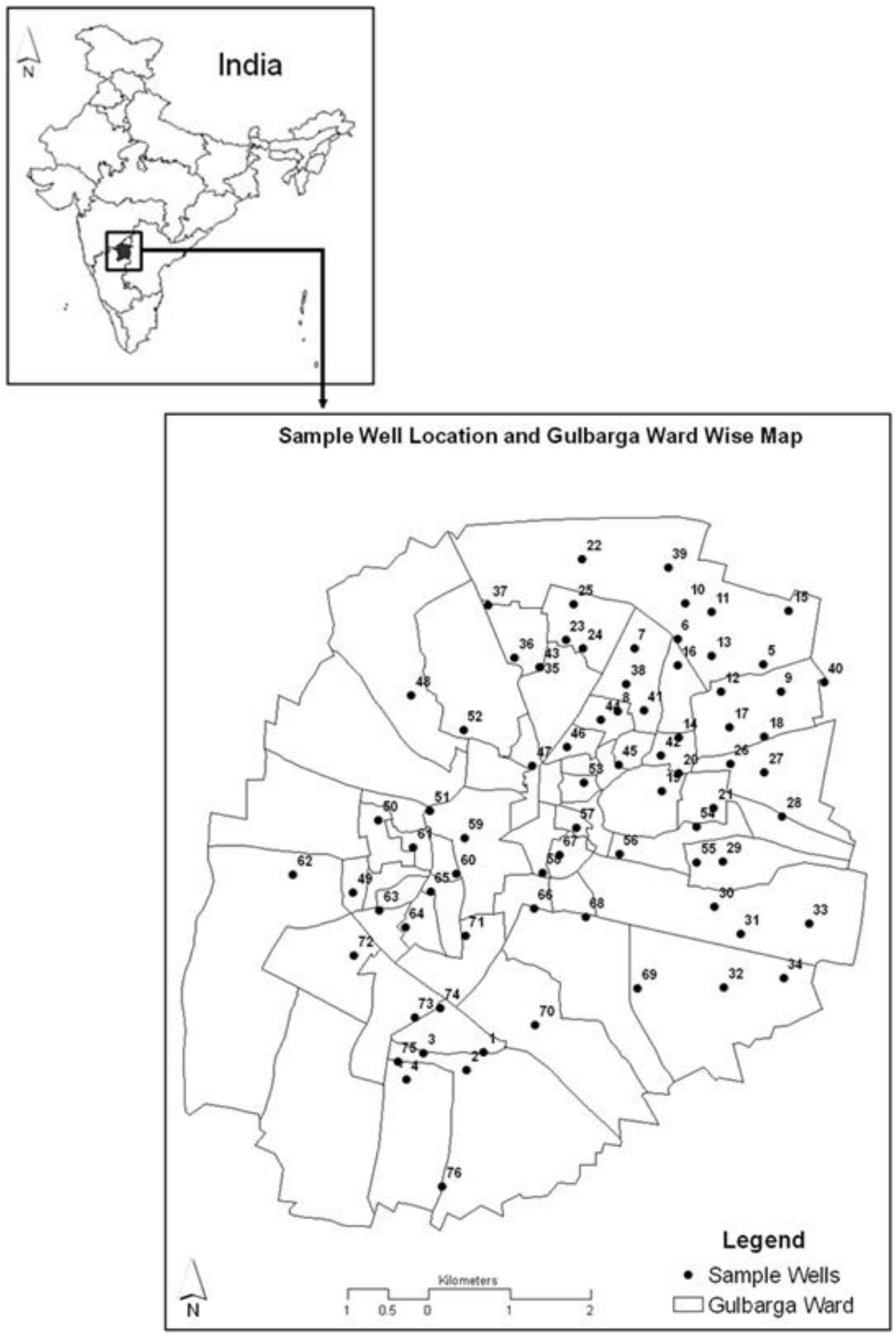

Figure 1. Study area Location Map.

district of the Karnataka state, due to less and variable occurrence of annual rainfall which puts onus on exploitation and management of the sub surface water (Gulbargacity, 2010).

The City is served by piped potable water supply derived from Bennithora and Bhima rivers and Bhosga reservoir located 10 to 25 km away from the treatment plant. Water supply is augmented through more than 1852 bore wells installed and maintained by City Corporation, out of which about 1260 bore wells are fitted with hand pumps, and about 300 each operated through single phase motors and power pumps as on 20th March 2010 (Gulbargacity, 2010). There is no record of the number of private bore wells in the city. Based on physical observation it may be safely quoted that almost every third house has one bore well and the total number of bore wells in the city may exceed 20,000, which means more than 300 bore wells per sq km area. The municipal supply of groundwater through the bore wells is without any treatment. As of now there is no effort by municipal authorities to supply treated groundwater or at least to inform which of the bore wells have water fit for drinking purpose as per WHO standards. There is no record of the number of private bore wells in the city. Dependency on groundwater is currently very high and it is preferred for drinking purpose by large number of the population. Because of the inadequacy and concern

Table 1. Drinking water: Parameters and recommended permissible limits.

Parameter	WHO (mg/L)	ISI (mg/L)
Total dissolved solids (TDS)	500	500
Hardness (TH)	500	600
Chloride (Cl^-)	200	250
Nitrate(NO_3^-)	40	45

over quality of tap water, ground water will continue to be a significant source of domestic water supply for this city (Saleem et al., 2008).

It is reported that the incidence of water related diseases is high in the city, due to inadequate water supply, poor sanitation and inefficient solid waste collection and disposal system. In a random survey conducted in 2003, 120 households were questioned on occurrence of water related diseases. 78% of households reported positive and the diseases included cholera, jaundice, typhoid and more frequently diarrhea (Degaonkar, 2003). Groundwater quality study with samples taken from 25 sampling wells spread across the city, conducted during 1999 to 2001 showed excess nitrates in all samples with values ranging from 99 to 342 mg/L, along with higher values and alarming level of Coliforms in most of the samples (Majagi et al., 2008). Another report shows nitrates and fluoride beyond permissible limits for drinking water from some groundwater samples in Gulbarga district (GWIBGDK, 2008).

Groundwater sample collection and analysis

As part of the study, groundwater samples are collected from 76 bore wells, representing one from each zone/ward of the city. The samples taken during March 2009 were analyzed for various physico-chemical parameters. Bottles used for water sample collection are first thoroughly washed with the water being sampled and then were filled. After collection of the samples, the samples are preserved and shifted to the laboratory for analysis. Physico-chemical analysis was carried out to determine TDS, TH, Cl^-, and NO_3^-, and compared with standard values recommended by World Health Organization (WHO, 1993) and Indian Standards Institution (ISI, 1991) (Table 1).

As groundwater in Gulbarga city is extensively used for drinking purpose and, previous studies report that pollution is mainly due to sewage, (Majagi et al., 2008), the water quality testing in present study is restricted to measurement of hardness/salinity (TDS, TH) and determination of potential contamination by sewage. The major indicators of sewage contamination, Cl^- and NO_3^- , are considered for the analysis. One of the sources of nitrate is on-site disposal systems such as septic tanks. The disturbance of soil during house building can also lead to an amount of nitrate leaching similar to the one observed when grassland is ploughed for agricultural purposes (Wakida and Lerner, 2006).

Preparation of well location point feature

The flow chart in Figure 2 was followed to develop a groundwater quality classification map from thematic maps based on the WHO (1993) and ISI (1991) standards for drinking water. We obtained the location of 76 wells all over the study area by using a handheld GPS instrument GARMIN GPS-60 receiver. GPS technology proved to be very useful for enhancing the spatial accuracy of the data integrated in the GIS. We utilized ArcGIS software in our study. Based on the location data we obtained, we prepared point feature showing the position of 76 wells (Figure 1). From these wells, we collected and analyzed groundwater samples for the study area. The water quality data thus obtained forms the non-spatial database. It is stored in excel format and linked with the spatial data by join option in ArcMap. The spatial and the non-spatial database formed are integrated for the generation of spatial distribution maps of the water quality parameters. For spatial interpolation Inverse Distance Weighted (IDW) approach in GIS has been used in the present study to delineate the locational distribution of groundwater pollutants. Other spatial interpolation techniques include Kriging, Cokriging, Spline etc.

Kriging is based on the presence of a spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation) (Robinson and Metternicht, 2006; Goovaerts, 1999). In this method the experimental variogram measures the average degree of dissimilarity between unsampled values and a nearby data value (Deutsch and Journel, 1998) and thus can depict autocorrelation at various distances. From analysis of the experimental variogram, a suitable model (for example spherical and exponential) is derived by using weighted least squares and the parameters (for example range nugget and sill). Some advantages of this method are the incorporation of variable interdependence and the available error surface output. A disadvantage is that it requires substantially more computing and modeling time and KRIGING requires more input from the user.

In co-kriging, the “co-regionalization” (expressed as correlation) between two variables, that is, the variable of interest, groundwater quality in this case and another easily obtained and inexpensive variable, can be exploited to advantage for estimation purposes. A crosssemivariogram is used to quantify cross-spatial auto-covariance between the original variable and the covariate (Stefanoni and Hernandez, 2006). This method appears to be more appropriate for handling when the sampling points are many.

The SPLINE method can be thought of as fitting a rubber-sheeted surface through the known points using a mathematical function. In ArcGIS, the spline interpolation is a Radial Basis Function (RBF). These functions allow analysts to decide between smooth curves or tight straight edges between measured points. Advantages of splining functions are that they can generate sufficiently accurate surfaces from only a few sampled points and they retain small features. A disadvantage is that they may have different minimum and maximum values than the data set and the functions are sensitive to outliers due to the inclusion of the original data values at the sample points.

Inverse distance weighting (IDW)

In interpolation with IDW method, a weight is attributed to the point to be measured. The amount of this weight is dependent on the distance of the point to another unknown point. These weights are controlled on the bases of power of ten. With increase of power of ten, the effect of the points that are farther diminishes. Lesser power distributes the weights more uniformly between neighboring points. In this method the distance between the points count, so the

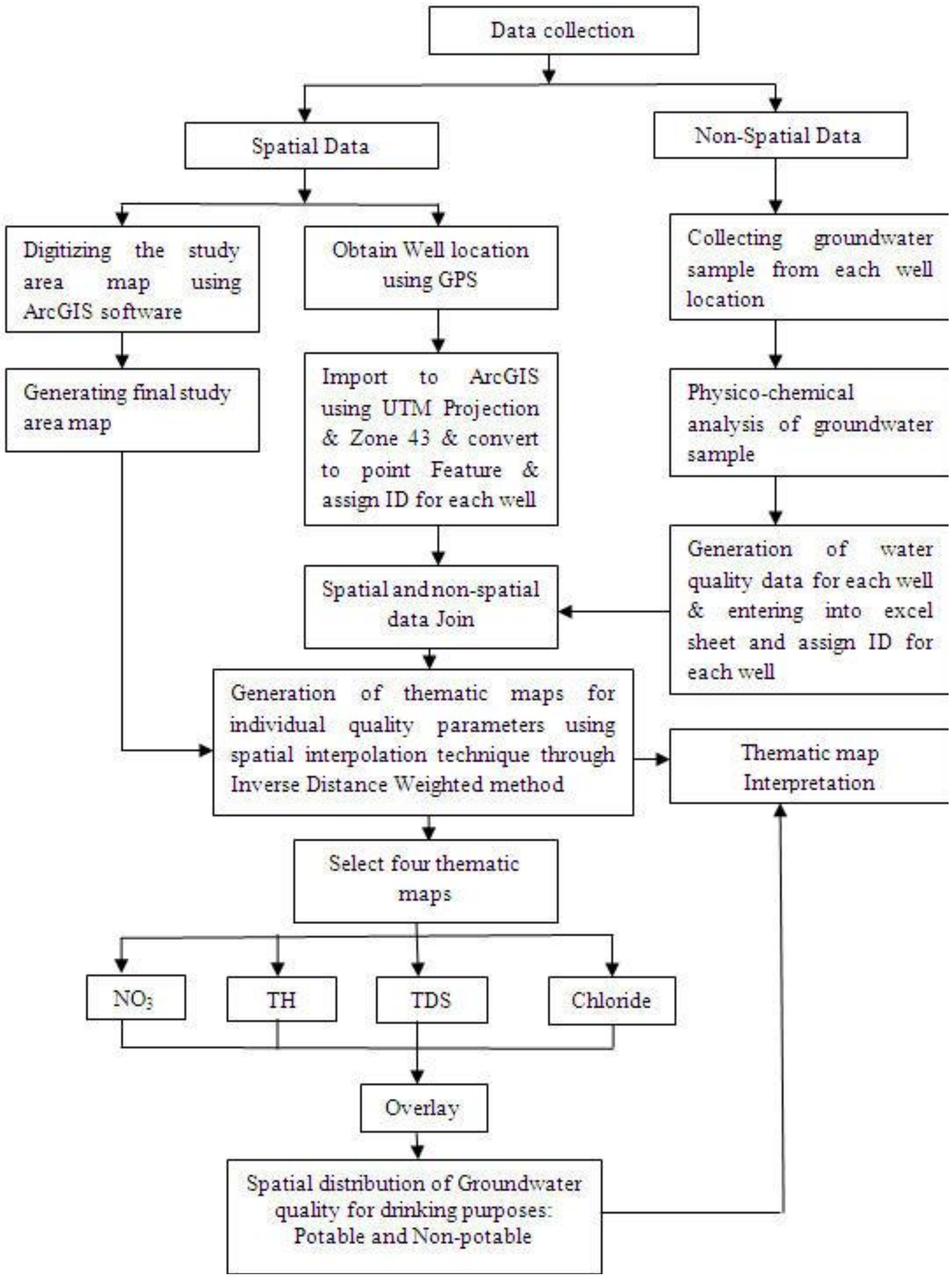

Figure 2. Flow chart of the method adopted.

points of equal distance have equal weights (Burrough and McDonnell, 1998). The weight factor is calculated with the use of the following formula:

$$\lambda_i = \frac{D_i^{-\alpha}}{\sum_{i=1}^{n} D_i^{-\alpha}}$$

λi = the weight of point, Di = the distance between point i and the unknown point, α = the power ten of weight.

The advantage of IDW is that it is intuitive and efficient. This interpolation works best with evenly distributed points. Similar to the SPLINE functions, IDW is sensitive to outliers. Furthermore, unevenly distributed data clusters result in introduced errors.

Criteria for acceptability and rejection in water quality

In this stage, the criteria for suitability and non-suitability of the water samples were elucidated for analysis. This was performed based on the water quality standards stipulated by the WHO, and ISI. Ranks were assigned for each parameter depending on the

Table 2. Criteria for acceptability and rejection in water quality.

S/No.	Parameter	Rank	Criteria	Remarks
1	TDS	1	< 500	Desired
		2	500 - 1000	Acceptable
		3	> 1000	Not Acceptable
2	TH	1	< 500	Desired
		2	500 - 1000	Acceptable
		3	> 1000	Not Acceptable
3	Cl^-	1	< 250	Desired
		2	250 - 1000	Acceptable
		3	> 1000	Not Acceptable
4	NO_3^-	1	< 45	Desired
		2	45 - 100	Acceptable
		3	> 100	Not Acceptable

respective tested values, as given in the Table 2.

Groundwater quality mapping

Various physico-chemical parameters like chloride, nitrate, TDS, and hardness were analyzed in the groundwater samples used for drinking purposes and their levels in different locations of the study area are shown in Table 3a and b. The rapid growth of urban population in Gulbarga city led to unplanned settlements where the access to sewerage is limited and pit latrines or septic tanks are the only options available for sewage disposal. The main sources of nitrate and other pollutants of urban groundwater is sewage and nitrate can reach the aquifer by sewer leakage and, on-site disposal systems such as septic tanks which is a common practice in Gulbarga city. Urban sources of nitrate may have a high impact on groundwater quality because of the high concentration of potential sources in a smaller area than agricultural land (Wakida and Lerner, 2005).

Table 1 shows a number of major drinking-water quality parameters and their corresponding permissible limits as recommended by WHO (1993) and ISI (1991). Some groundwater samples were found to have chloride, hardness, nitrate and total dissolved solids (TDS) values above desirable limits. We plotted the values for various sample locations and interpolated surfaces. We generated water quality thematic maps for chloride, nitrate, TDS, and hardness within the study area, showing locations that fell within the potable, potable in the absence of better alternate source and non-potable zones.

Generating the drinking – water groundwater quality map

Four thematic maps for the parameters of chloride concentration, nitrate, TDS and hardness were integrated using the addition function available in the ArcGIS software. We created a final drinking-water groundwater quality map by overlaying these four thematic maps which are produced as a result of inverse distance weighted (IDW) interpolations. The spatial integration for final groundwater quality zone mapping was carried out using ArcGIS Spatial Analyst extension. We then delineated three areas within the study area based on the quality of the groundwater for drinking purposes: potable, potable in the absence of better alternate source and non-potable zone.

RESULTS AND DISCUSSION

Groundwater quality maps are useful in assessing the usability of the water for different purposes. Figures 3, 4, 5 and 6 show the spatial distribution of chloride, total hardness, total dissolved solids distribution and nitrate concentrations in study area, respectively. A groundwater quality map is created for each parameter following the classification shown in Table 2.

Chloride (Cl^-)

Chloride is minor constituent of the earth's crust. Rain water contains less than 1 ppm Chloride. Chloride in drinking water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt, and saline intrusion (WHO, 1993). Its concentration in natural water is commonly less than 100mg/L unless the water is brackish or saline (Fetter, 1999). High concentration of chloride gives a salty taste to water and beverages and may cause physiological damages.

Water with high chloride content usually has an unpleasant taste and may be objectionable for some agricultural purposes. The level of chloride taste perception is variable from person to person, but is generally of the order of 250 mg/L. Animals usually can drink water with much more concentration than humans can tolerate (300 to 400 mg/L). Cholride is also relatively free from effects of exchange adsorption and biological activity. Once taken into solution it is difficult to remove it through natural process. Shanthi et al. (2002) reported

Table 3a. Showing values of various physico-chemical parameters.

Well no	Well location	Easting	Northing	Cl^- (mg/L)	NO_3^- (mg/L)	TH (mg/L)	TDS (mg/L)
1	Sharanappa Doddamani	694597.54	1915217.42	120	150	396	750
2	Devendra Tengli	694387.03	1914994.05	256	680	1184	1910
3	Nr.Railway Compound/Boundry	693853.38	1915210.35	190	350	532	1150
4	Shoukat Ali Patel	693643.90	1914876.32	202	229	612	1000
5	Mohd.Basheed Saheb	698059.63	1920010.22	140	141	208	690
6	Opp.Mosque	696993.56	1920331.96	255	84	528	482
7	Near School	696463.21	1920216.15	258	66	532	830
8	Behind Masjid Rahmania	696258.09	1919439.37	364	71	624	1120
9	Infront of KBN Engg. College	698275.43	1919680.25	300	190	528	1250
10	MRF RETRADING I.A	697095.57	1920775.69	165	49	380	520
11	Shakeel Ahmed M.N	697415.48	1920668.10	184	44	280	900
12	Masjid Bulund Parwaz	697531.41	1919673.03	160	62	312	650
13	Masjid infront of Peer	697420.84	1920114.71	90	40	220	470
14	Khaja Colony Masjid	697005.32	1919114.51	375	128	308	1350
15	Masjid Ifsahim Behind KBN	698372.03	1920677.38	314	212	592	1250
16	Public Borewell	696996.77	1919999.92	428	88	504	1320
17	Public Borewell infont of KES	697641.99	1919231.35	232	22	404	820
18	Public Borewell Syed Galli	698068.22	1919124.80	185	62	252	850
19	Public B/W	696799.14	1918448.40	129	18	220	520
20	Majid Hussain Ali	697009.59	1918671.80	70	47	204	450
21	Public B/W	697439.04	1918233.20	294	97	276	980
22	Public B/W, Ramnagar	695814.88	1921316.78	235	66	200	880
23	Public B/W, Shivajinagar	695611.88	1920318.66	202	124	404	730
24	Public B/W, Bharat Colony	695825.50	1920210.02	185	31	404	750
25	Public B/W, Bhavaninagar	695713.91	1920762.38	398	133	644	1280
26	Opp. Kanwar Meusum	697646.28	1918788.65	154	53	248	650
27	Public B/W	698072.52	1918682.09	227	71	192	810
28	Dr. SA Chand Pasha	698290.48	1918130.77	414	26	328	1120
29	LM Hospital	697551.76	1917570.17	134	9	52	590
30	Chetan Clinic	697450.81	1917015.76	129	88	164	550
31	Sri.Sangameshwar Krupa	697772.93	1916686.81	185	22	384	570
32	Vinayak House	697566.74	1916020.69	207	71	328	790
33	Taradevi	698622.28	1916805.74	165	40	256	580
34	Public Well, Bhagy Nagar	698309.81	1916138.58	358	62	468	900
35	P B/W infront of Cattle	695296.20	1919983.57	104	26	204	460
36	B/W infront of Temple	694976.29	1920091.20	218	53	348	810
37	Kanchani Mahal Mosque	694651.10	1920752.21	784	53	1024	1800
38	House of Amtusalcha	696361.19	1919772.42	627	66	960	1510
39	Khaja mohala darga	696878.73	1921216.34	238	62	660	830
40	Malgati Road school	698805.79	1919796.10	148	97	504	660
41	KBN Colleage	696576.96	1919442.44	157	66	492	870
42	Roza police station	696794.87	1918891.11	342	80	664	1440
43	Open land	695296.20	1919983.57	370	133	960	1300
44	Adarsh Englih med. School	696046.58	1919326.65	199	75	416	840
45	Gunj Road Temple	696264.48	1918775.31	283	102	484	1120
46	Nehru Gunj	695624.61	1918990.54	274	44	828	1050
47	Bhavani Nager Gunj Road	695201.56	1918765.12	246	89	580	1040
48	Aland Road	693705.09	1919636.35	179	40	504	920
49	MSK.Mills	692984.10	1917194.45	378	128	616	1320
50	Hanuman Mandir	693294.62	1918082.87	204	35	272	650
51	Chowdeshwar school	693931.33	1918199.59	210	57	396	930

Table 3b. contd.

52	Lal Hanuman Chowdeshwar Temple	694347.02	1919199.71	87	35	232	590
53	Khari Bawali	695841.44	1918549.88	238	155	476	1090
54	Shive mandir	697228.59	1918009.80	395	150	568	1630
55	Adarsh nager Hauman Mandir	697232.86	1917567.09	255	111	708	960
56	Gubbi colony GT TC College	696275.12	1917668.55	476	49	844	1410
57	Maktampur Gadge Mata	695740.45	1917995.48	456	150	808	1480
58	Gazipur Jagat Road	695320.56	1917438.03	199	66	492	860
59	Sharannagar	694359.66	1917871.61	272	22	588	970
60	Kumbar Galli	694257.58	1917427.89	266	146	588	1170
61	Brahampur Ragvendra Mat	693722.94	1917754.87	98	18	320	520
62	Husain Garden iii rd cross	692237.93	1917408.79	249	97	556	920
63	shanti nager	693305.09	1916976.12	168	49	496	650
64	Regional resource Centre	693626.09	1916757.79	174	40	500	740
65	MahantNager jai bhavani stores	693940.79	1917203.51	308	133	616	1510
66	Anapurna Hospitals	695218.49	1916994.31	414	230	612	1510
67	Karnataka Primary Stores	695531.04	1917661.41	190	57	424	810
68	Sunder Nager(Medical College)	695857.35	1916889.74	224	40	496	780
69	Rajapur Petrol Pump	696503.67	1916010.45	199	53	420	710
70	Alwin ShahMSI College	695232.23	1915555.53	272	49	580	840
71	Khoba Plot Khoba Kalyan Mantapa	694371.25	1916654.18	213	53	548	820
72	CIB colonySangeet Ladies Tailors	692991.42	1916419.73	305	111	624	1190
73	Venkatesh Colony Raj Laxmi Hostel	693742.88	1915652.05	238	155	520	1040
74	Mohan Bar Station Area	694060.75	1915765.75	202	40	436	750
75	Kotnoor	693535.50	1915096.66	302	252	640	1180
76	GDA Layout	694081.74	1913552.25	232	35	508	780

that the higher concentration of Chloride is considered to be an indicator of pollution due to higher animal waste. Shivakumar et al. (2000) and Hari Haran (2002) reported that concentration up to 250 mg/L are not harmful but is an indication of organic pollution. This could be due to sewage mixing and increased temperature and evapo-transpiration of water.

The maximum contaminant level (MCL) for chloride in drinking water is given as 250 mg/L by the WHO standards. In the present study chloride concentration has complied with a value of 250 mg/L for 46 (60.53%) out of 76 wells. There were 30 (39.47%) wells in which chloride concentration exceeds the MCL given in WHO Standards. As indicated by Figure 3, chloride concentration is high in north to center and southwest of the city. In a wide area around the south and west part of the city, less than 250 mg/L chloride concentration occurs. There is 59% of the study area having desired, and 41% of the area acceptable levels of chloride acceding to WHO standards. On an overall consideration, the chloride distributions in the study areas are below the prescribed limits and are potable.

Nitrate (NO_3^-)

The main source of nitrate in water is from atmosphere, legumes, plant debris and animal excreta (WHO, 1993). During recent years, the problem of groundwater contamination by nitrates has been studied thoroughly all over the world (Hudak, 1999, 2000; Vinten and Dunn, 2001; Levallois et al., 1998; Nas and Berktay, 2006; Fytianos and Christophoridis, 2004). The concentration in natural water is less than 10 mg/L. Water containing more than 100 mg/L is bitter to taste and causes physiological distress. Water in shallow wells containing more than 45 mg/L causes methemoglobinemia the so-called blue baby syndrome in humans (Durfer and Baker, 1964). Several studies document adverse effects of higher nitrate levels, most notably methemoglobinemia (Hudak, 1999, 2000; Levallois et al., 1998; WHO, 1985, 1993). Nitrogen is an essential constituent of protein in all living organisms. Nitrate compounds are highly soluble and nitrate is taken out of natural water only by the activity of organisms or through evaporation and eventually reaches the groundwater. Nitrate in groundwater generally originates from sewage effluents, septic tanks and natural drains carrying municipal wastes. NH^{4+} from organic sources is converted to NO_3^- by oxidation. Concentrations of NO_3^- commonly reported for groundwater are not limited by solubility constraints. Because of this and because of its anionic form NO_3^- is very mobile in groundwater.

The MCL of nitrate is given as 45 mg/L by the WHO for

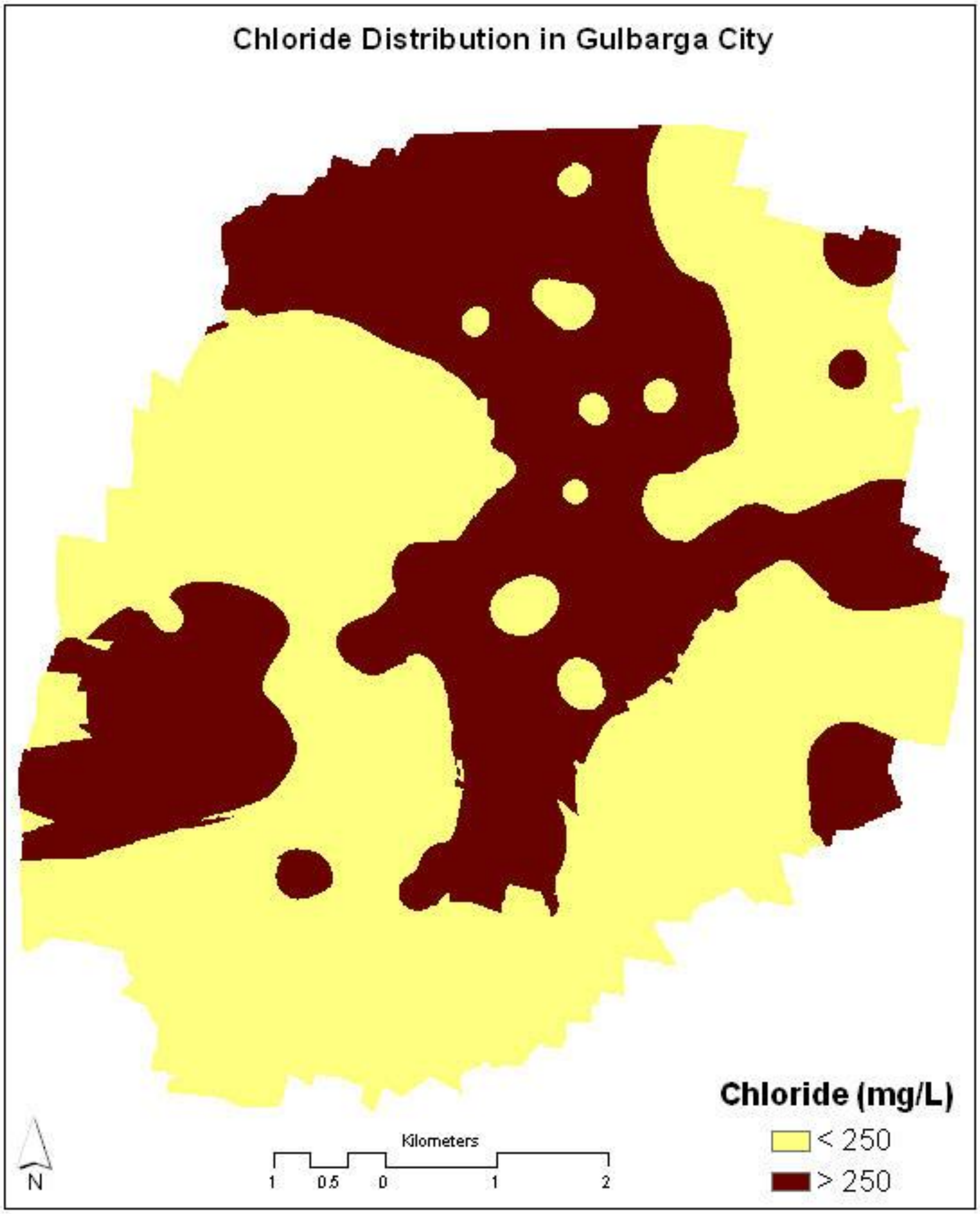

Figure 3. Chloride spatial distribution in Gulbarga City.

drinking water. Spatial distributions of nitrate concentrations for the study area are shown in Figure 4. The nitrate concentration has complied with a value of 45 mg/L for 20 (26.32%) out of 76 wells. There were 56 (73.68%) wells in which the nitrate concentration exceeds the MCL given in WHO Standards. Some samples of the south, center and north east part of the study area have high amount of nitrate. In a small packet of area around the study area, less than 45 mg/L nitrate concentration occurs. 40% of the study area has desired and 62% of the area acceptable levels of nitrate acceding to WHO standards. We can say empirically that the nitrate distributions in the study areas are above the prescribed limits and are not potable and require to be processed before supply.

Total dissolved solids (TDS)

The mineral constituents dissolved in water constitute dissolved solids. The concentration of dissolved solids in natural water is usually less than 500 mg/L, while water

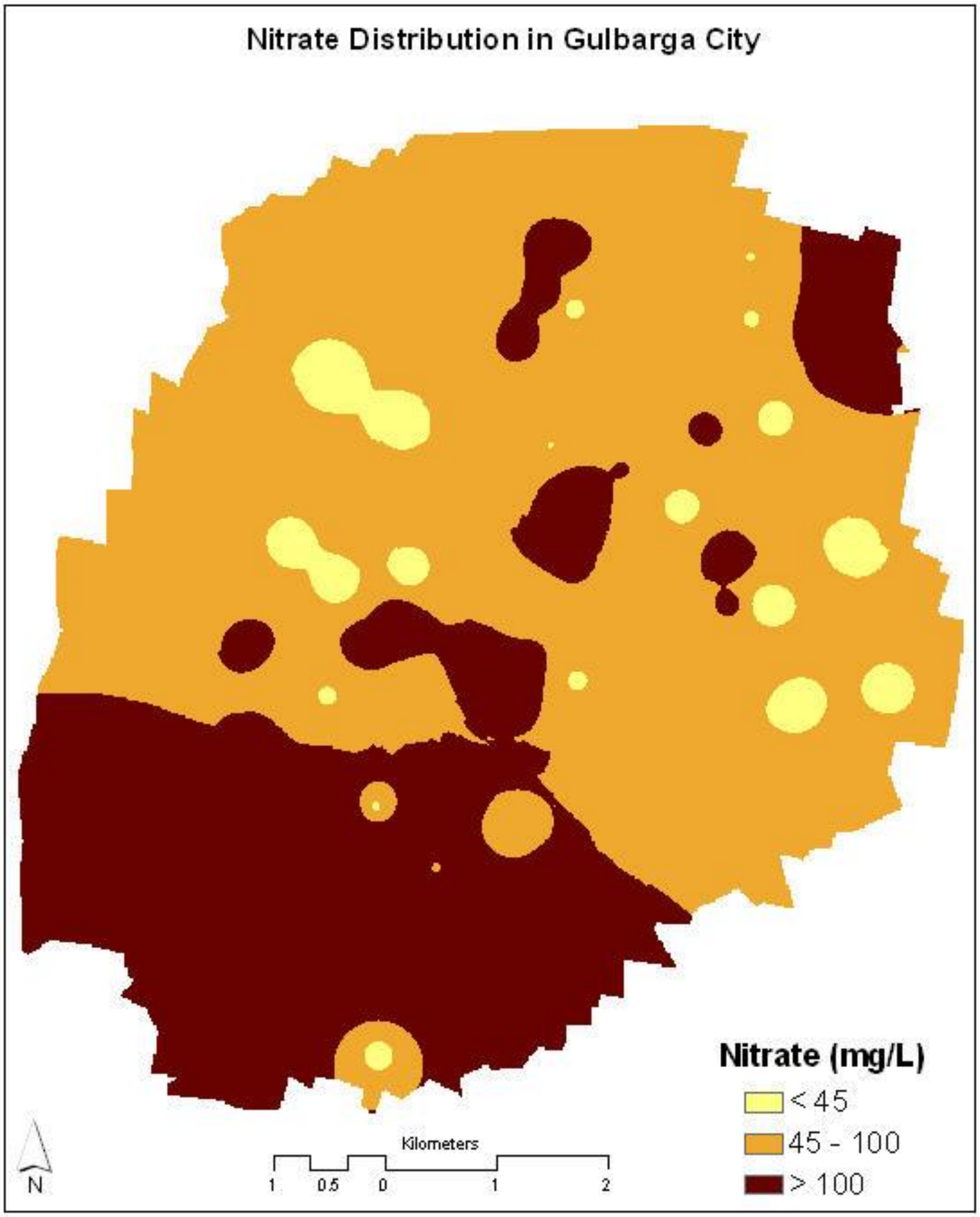

Figure 4. Nitrate spatial distribution in Gulbarga City.

with more than 500 mg/L is undesirable for drinking and many industrial uses. Water with TDS less than 300 mg/L is desirable for dyeing of cloths and the manufacture of plastics, pulp paper, etc. (Durfer and Baker, 1964). The total concentration of dissolved minerals in water is a general indication of the over-all suitability of water for many types of uses. Water with high dissolved solid content would therefore be expected to pose problems like taste, laxative and other associated problems with the individual minerals. Such waters are usually corrosive to well screens and other parts of the well structure. If the water contains less than 500 mg/L of dissolved solids, it is generally satisfactory for domestic use and for many industrial purposes. Water with more than 1000mg/L of dissolved solids usually gives disagreeable taste or makes the water unsuitable in other respects.

Subba Rao et al. (1998) and Deepali et al. (2001) reported that TDS concentration was high due to the presence of bicarbonates, carbonates, sulphates, chlo- rides and calcium. TDS can be removed by reverse osmosis, electrodialysis, exchange and solar distillation process. It was reported that TDS value of 500 mg/L is the desirable

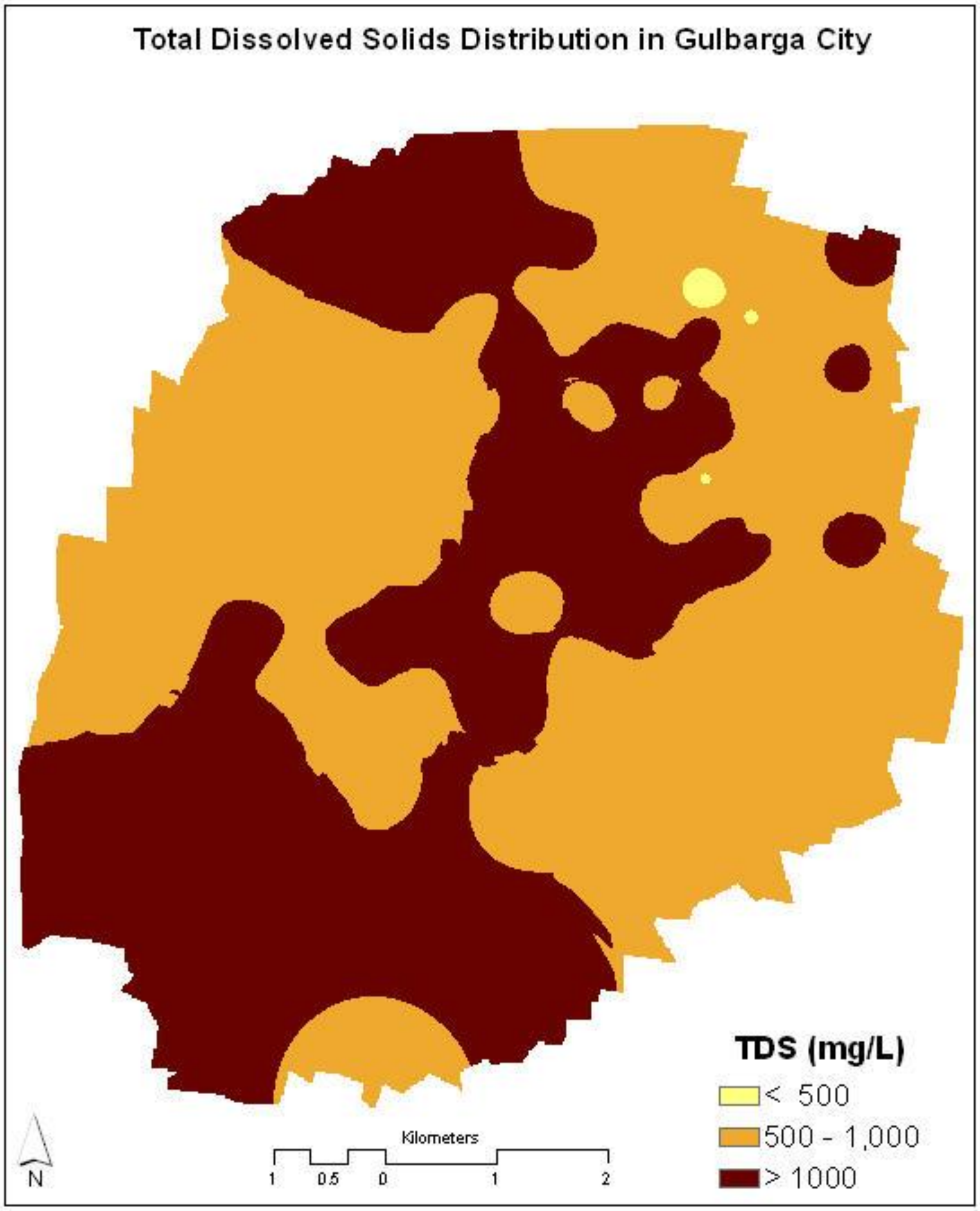

Figure 5. TDS spatial distribution in Gulbarga City.

limit and 2000 mg/L is the maximum permissible limit and that water containing more than 500 mg/L of TDS causes gastrointestinal irritation (Jain et al., 2003). High value of TDS influences the taste, hardness, and corrosive property of the water (Ranjana et al., 2001; Joseph and Jaiprakash, 2000; Hari Haran, 2002; Subhdra Devi et al., 2003). To determine the suitability of groundwater for any purpose, it is important to classify the groundwater depending upon their hydro chemical properties based on their TDS values (Davis and DeWiest, 1966), which are represented in Table 4 and displayed spatially in Figure 5 respectively. The groundwater of the present study area is fresh water type for 63.16% of the sample locations and the rest represent brackish water.

As per David and DeWiest (1966) classification method, only 5.26% of the samples have below 500 mg/L of TDS which can be used for drinking without any risk. Considering the TDS in the water samples almost all the samples need treatment before use as they are found to have TDS values more than the prescribed standards.

Total hardness (TH)

Calcium and magnesium mostly cause the hardness of water. The total hardness of water may be divided in to 2 types, carbonate or temporary and bi-carbonate or permanent hardness. The hardness produced by the

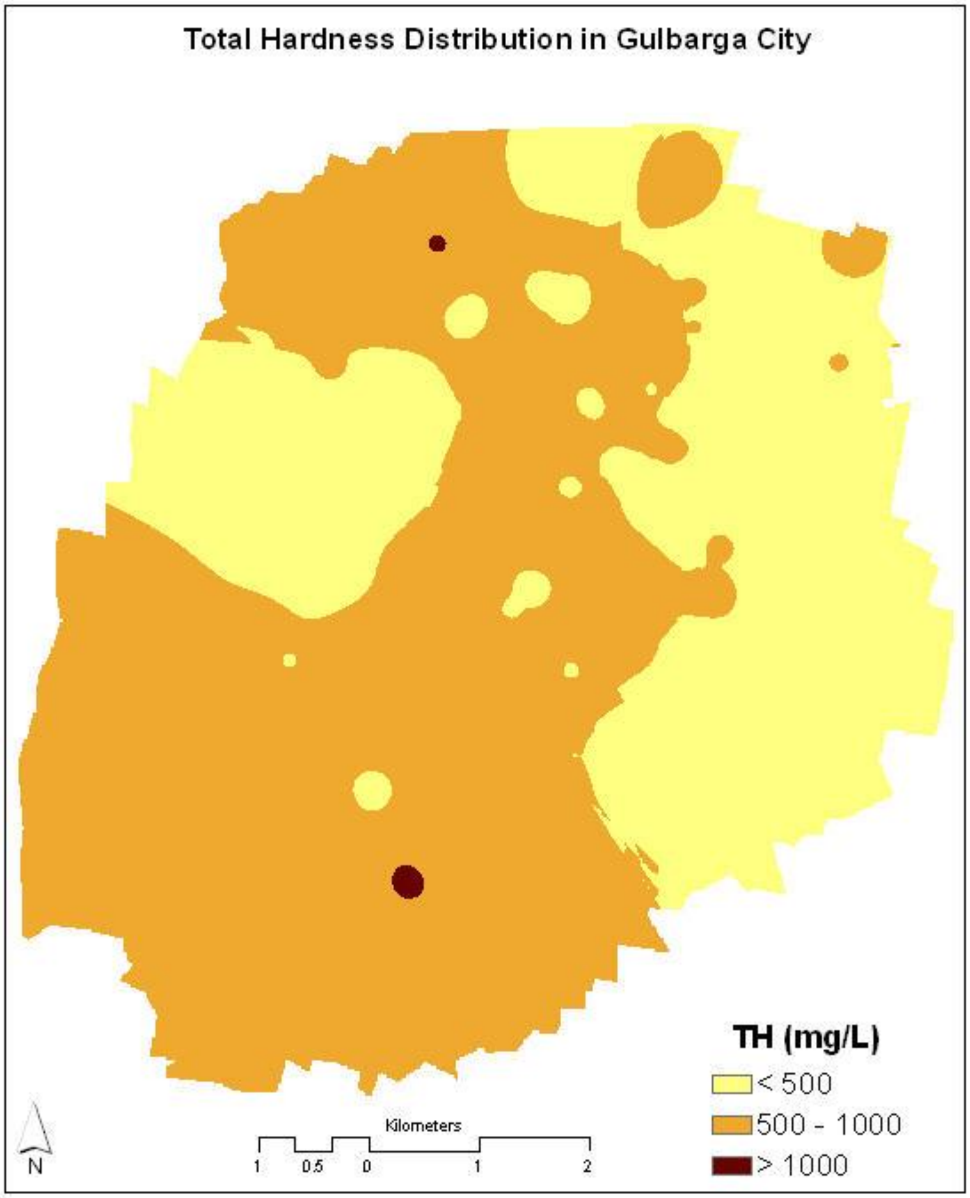

Figure 6. TH Spatial distribution in Gulbarga City.

bi-carbonates of calcium and magnesium can be virtually removed by boiling the water and is called temporary hardness. The hardness caused mainly by the sulphates and chlorates of calcium and magnesium cannot be removed by boiling and is called permanent hardness. Total hardness is the sum of the temporary and permanent hardness. Water that has a hardness of less than 75 mg/L is considered soft. A hardness of 75 to 150 mg/L is not objectionable for most purposes. Water having more than 150 mg/L hardness, is unsafe. The removal of temporary hardness by heat causes the deposition of calcium and magnesium carbonates as a hard scale in kettles, cooking utensils, heating coils, and boiler tubes resulting in a waste of fuel.

The classification of groundwater in the study area based on total hardness as given in Table 5 shows that a majority of the samples fall in very hard water category. The hardness values range from 52 to 1184 mg/L. The maximum allowable limit of TH for drinking purpose is 500 mg/L and the most desirable limit is 100 mg/L as per the WHO international standard. For total hardness, the most desirable limit is 80 to 100 mg/L (Freeze and Cherry, 1979). Groundwater exceeding the limit of 300 mg/L is considered to be very hard (Sawyer and McCarty, 1967). Around 78.94% of groundwater samples out of 76 collected exceed the maximum allowable limit of 500 mg/L. All the groundwater of the present study area is rated as hard to very hard and requires processing before

Table 4. Classification of water based on TDS after Davis and DeWiest (1966).

TDS (mg/L)	Classification	Number of samples	Percentage of samples
< 500	Desirable for drinking	4	5.26
500 – 1,000	Permissible for drinking	45	59.21
1,000 – 3,000	Useful of irrigation	27	35.53
> 3,000	Unfit for drinking and irrigation	0	0.00

Table 5. Classification of water based on TH after Sawyer and McCarty (1967).

TH (mg/L)	Classification	Number of samples	Percentage of samples
0 – 75	Soft	1	1.32
75- 150	Moderately hard	0	0
150 – 300	Hard	15	19.74
> 300	Very hard	61	78.94

use. Figure 6 shows the spatial distribution and concentration of TH in the city of Gulbarga.

Drinking- groundwater quality map

Figure 7 shows the final drinking water quality map that was produced by integrating four thematic grid maps for chloride, TDS, total hardness and NO_3^- The spatial integration for groundwater quality mapping was carried out using ArcGIS Spatial Analyst extension. It can be seen in the final drinking water quality map that a large area on the east, west and north east parts of the study area has water potable in the absence of better alternate source. Non-potable water quality is seen in the north, south and city center. The city of Gulbarga thus has potable water quality only in 0.02% (about 0.01 km^2) of the total area. 49.22% (26.04 km^2) of the rest of the study area has water classified as medium and 50.76% (27.47 km^2) has water with poor quality levels. Therefore most of the groundwater in this city requires processing before use.

Conclusion

After the overlay of critical parameters for potable and non-potable zones in Gulbarga city, the final Ground-water Quality Map (Figure 7) derived shows only a small region in the north-eastern part of the city where the groundwater is potable. As can be seen from the map many regions have groundwater that is potable only after proper treatment. However in much of the southern and central parts and some area in the northern region of the city the water is non-potable. In this non-potable zone the four parameters that are studied are above maximum permissible limits for majority of the sample wells. The Cl^- concentration for most of the samples is above 250 mg/L and the minimum value and the maximum values observed are 120 and 784 mg/L respectively. The maximum permissible level for chloride is 200 mg/L according to WHO standards. NO_3^- levels are more than 40 mg/L in many wells in this zone with a maximum value of 680 mg/L and a minimum of 26 mg/L. Only one sample has shown less than 40 mg/L which is the maximum permissible level as per WHO standards. The TH is observed to be well above 500 mg/L for majority of the sample wells in this zone. The maximum and minimum levels observed are 1184 and 204 mg/L respectively. The maximum permissible level for this parameter is 500 mg/L in WHO standards. There are alarming levels of TDS in this non-potable zone of Gulbarga city with almost all the wells showing well above 1000 mg/L and only one well with a TDS of 460 mg/L whereas 500 mg/L is the maximum permissible level for TDS as per WHO stipulations.

The spatial distribution analysis of groundwater quality in the study area indicated that many of the samples collected are not satisfying the drinking water quality standards prescribed by the WHO and ISI with almost half of the city having non-potable ground water. The results obtained gave the necessity of making the public, local administrator and the government to be aware on the crisis of poor groundwater quality prevailing in the area. The government needs to make a scientific and feasible planning for identifying an effective groundwater quality management system and for its implementation. For this, public awareness on the present quality crisis and their involvement and cooperation in the actions of local administrators are very important. Since, in future the groundwater will have the major share of water supply schemes, plans for the protection of groundwater quality is needed. Present status of groundwater necessitates for the continuous monitoring and necessary groundwater quality improvement methodologies imple-mentation.

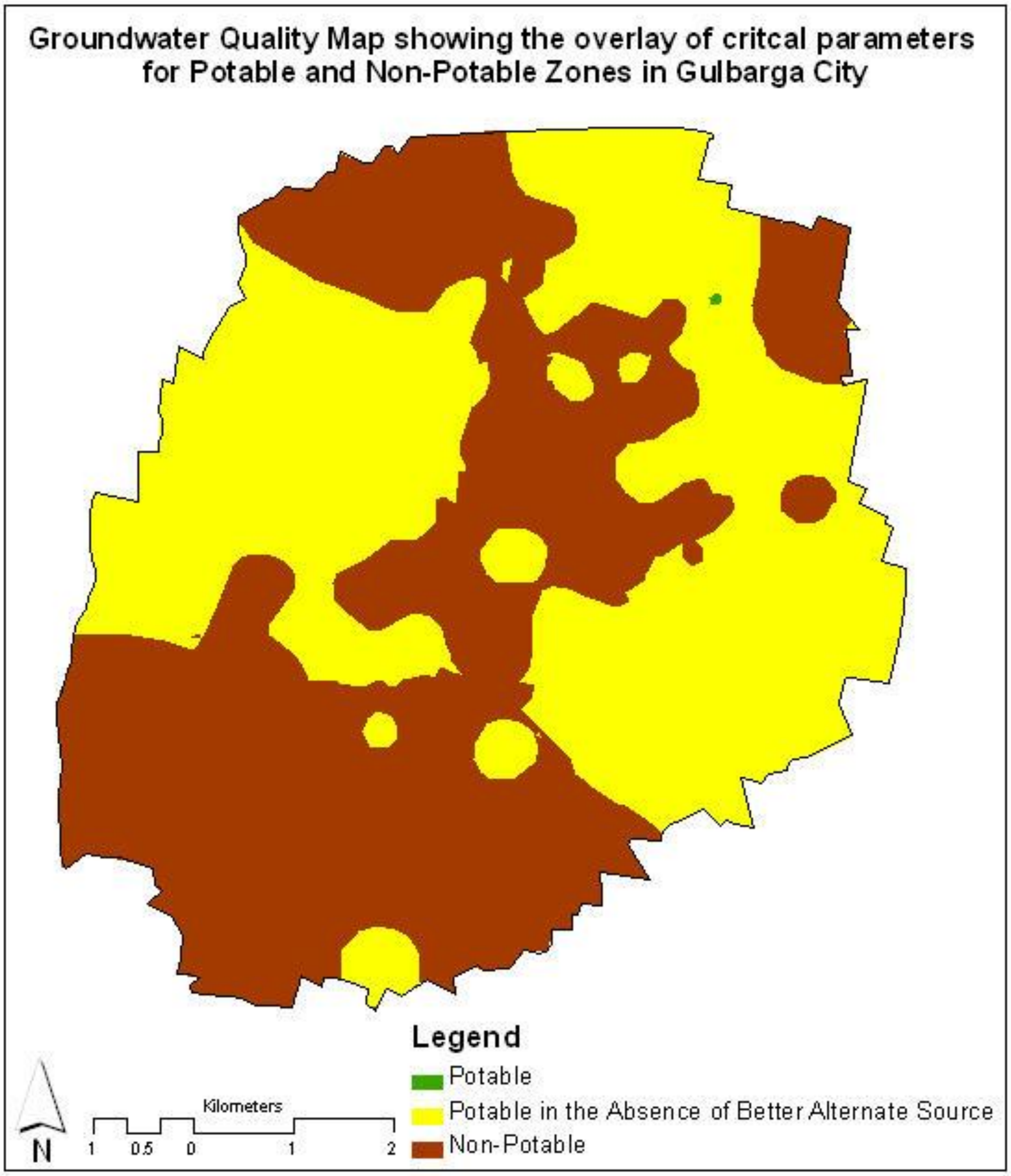

Figure 7. Drinking- groundwater quality zone map.

Following are the recommendations for preventing further groundwater quality deterioration and strategy for protecting the same in future.

(i) Quantifying the domestic sewage that enters into the different water bodies located in the city, will help in planning for effective sewage treatment plant and minimizing groundwater pollution by sewage.
(ii) Identification of groundwater recharging locations and structures. For this purpose, Geographical Information System (GIS) with the required spatial and non-spatial data can be used very well as the tool. Designing recharging structures is to be done.
(iii) Groundwater recharging structures are to be formed at different parts of the city. Formation of storm water drains leading to groundwater recharging structures, to increase their recharging potentials.
(iv) Continuous monitoring of groundwater table level along with quality study will minimize the chances of further deterioration.
(v) Structural engineers, consultants, contractors and general public are to be addressed about the groundwater quality not satisfying the water quality requirements as per IS 456 to 2000 (Bureau of Indian Standards, 2000) and advising them for avoiding the use of untreated groundwater.

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