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GIS Application for Groundwater Management and Quality Mapping in Rural Areas of District Agra, India

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Abstract: With the advent of powerful personal computers and the advances in space technology, efficient techniques for land and water management have evolved of which RS (remote sensing) and GIS (geographic information system) are of great significance. These techniques have fundamentally changed our thoughts and ways to manage natural resources in general and water resources in particular. Spatial variations in groundwater quality of Agra rural areas have been studied using Geographic Information System (GIS) technique. For this study, water samples were collected from various bore wells. The objectives of this investigation were (1) to provide an overview of present groundwater quality, (2) to determine spatial distribution of groundwater quality parameters such as TDS, Total Hardness, Iron and Fluoride concentrations and (3) to map groundwater quality in the study area by using GIS. The ground water quality information maps of the entire study area have been prepared using Inverse Distance Weighted (IDW) interpolation technique approach in GIS for all the above parameters. The results obtained in this study and the spatial database established in GIS would 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: Spatial Variation · IDW · Groundwater · GIS and Agra

INTRODUCTION

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. The groundwater resources play a very significant role in meeting the ever increasing demands of the agriculture, industry and domestic sectors [1]. Because of its several inherent qualities (e.g., consistent temperature, widespread and continuous availability, excellent natural quality, limited vulnerability, low development cost, drought reliability, etc.), it has become an immensely important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries [2]. Over exploitation and unabated pollution of this vital resource is threatening the ecosystems and even the life of future generation. In recent years, it has been recognized that the quality of ground water is of nearly equal importance to quantity. Unfortunately, the excessive use and continued mismanagement of water resources to supply ever-increasing water demands to profligate users have led to water shortages, increasing pollution of freshwater resources and degraded ecosystems worldwide [3, 4, 5, 6]. The required quality of ground water supply depends upon its purpose; thus, the needs for drinking water, industrial water and irrigation water vary widely. In recent years, the use of the Geographic Information System (GIS) has grown rapidly in groundwater management and research. GIS is now widely used to create digital geographic databases, to manipulate and prepare data as input for various model parameters and to display model output.

Water quality monitoring has one of the eminent priorities in environmental protection policy [7]. Understanding the quality of groundwater with its temporal and seasonal variation is important because it is the factor that determines the suitability for drinking, domestic, agricultural and industrial purposes [8].

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In the present study, groundwater samples have been collected and analyzed for various parameters such as, TDS, Total Hardness, Iron and Fluoride. The obtained results were exported into the GIS environment. Further, it is observed that the concentration of major ions in groundwater of the area is high in many locations leading to the unsuitability of groundwater for drinking. Thus, a GIS based study has been attempted to understand the spatial variation of ground water quality parameters over the rural areas of Agra district.

MATERIALS AND METHODS

Study Area: The metropolitan city of Agra is one of the important industrial towns of north central India. It is situated about 200 km southeast of Delhi. The metropolitan city of Agra occupies an area of about 140 km^2 and lies between 27°8' to 27°14' N latitude and 77°57' to 78°04' E longitude. The area is bounded by Thar Desert at its southwest, west and northwest peripheries. It lies 169 m above sea level in the plains of Uttar Pradesh and has population of 1.5 million approximately. It is the 22nd largest town in India (population wise) and the 3rd largest town in Uttar Pradesh after Kanpur and Lucknow. The climate is semi-arid characterized by hot summers, cold winters and sufficient rains in the monsoon. The maximum temperature is attained up to 47°C in summer months (May to June) and minimum temperature as low as 3°C in winter. The average rainfall in the region is 685 mm.

Analysis of Water Samples: As part of the study, the groundwater samples from bore wells of 200 rural locations which are extensively used for drinking and also irrigation purposes were collected during the year 2012. The maps of the locations of groundwater sampling points are shown in Fig. 1. Collected samples were brought to the laboratory and then analyzed according to the standard procedures prescribed by American Public Health Association (APHA, 1995) [9], TDS was measured using LDO probe (HACH), Total hardness was measured using EDTA Titrimetric method, Iron and Fluoride were measured using Spectrophotometer (DR 5000- HACH). The results were compared with standard values recommended by Indian Standard Specification for drinking water: IS: 10500-1991, [10] (Table 1).

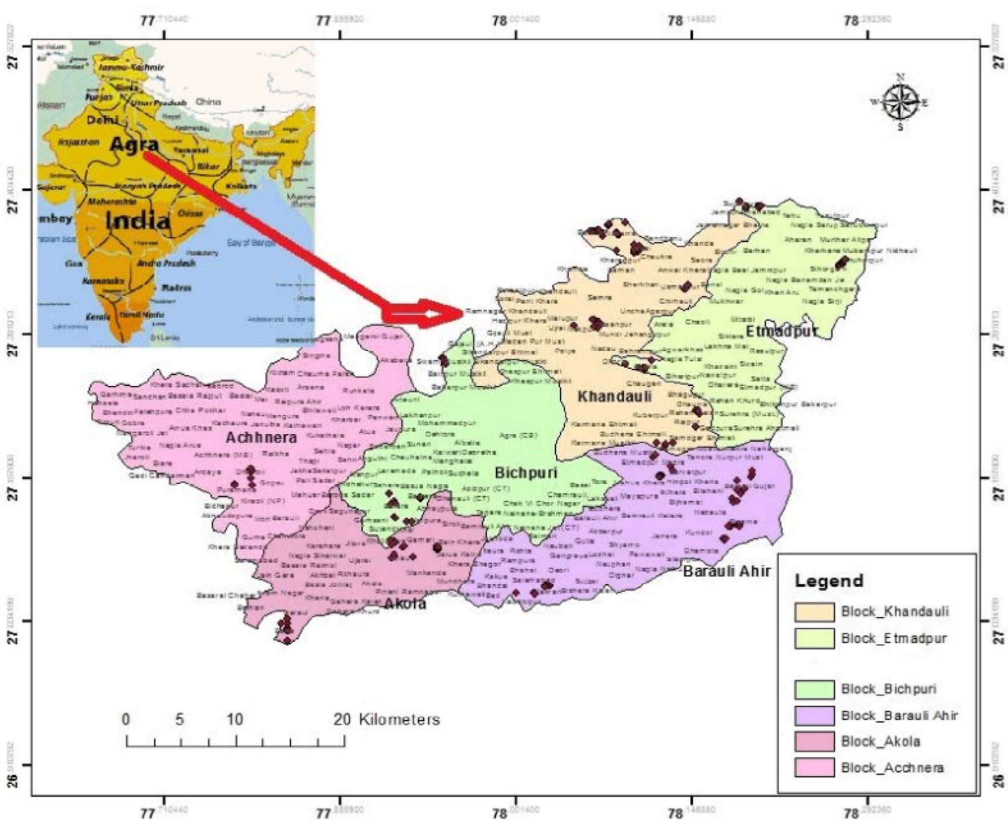

Fig. 1: Map representing the studied Agra rural areas.

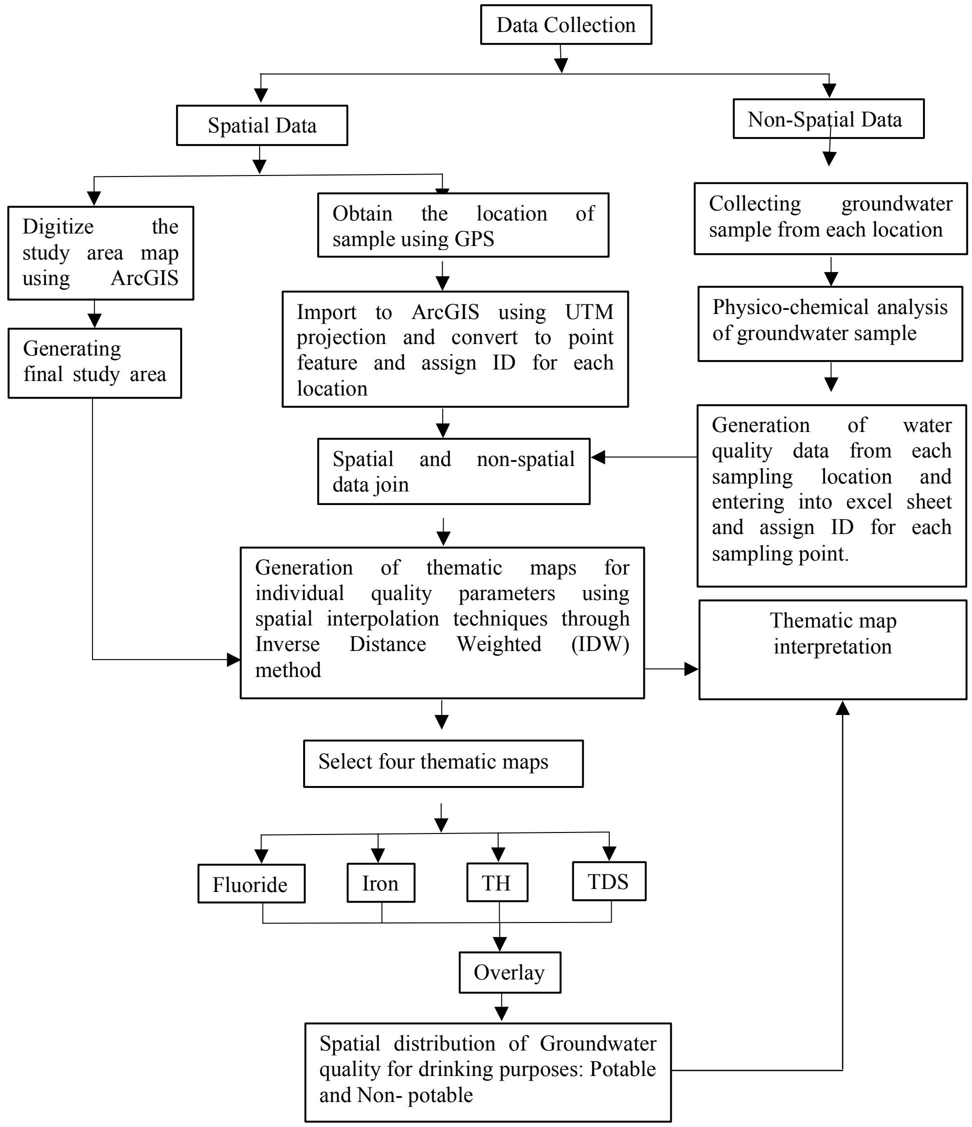

Fig. 2: Flow chart of the method adopted.

The flow chart (Fig. 2) was followed to develop a groundwater quality classification map from the thematic maps based on the ISI (1991) and WHO (1993) standards for drinking water [10, 11]. The locations of 200 wells all over the study area were geographically determined by using a handheld GPS instrument GARMIN GPS-60 receiver. ArcGIS software was employed in current study. From these wells, samples were collected and analyzed. The obtained water quality data were, consequently, in non-spatial database form. Therefore, they were 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 to generate spatial distribution maps of the water quality parameters. For spatial interpolation Inverse Distance Weighted (IDW) approach in GIS has been used to delineate the areal distribution of groundwater pollutants.

Inverse Distance Weighting (IDW) Interpolation: 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 points of equal distance have equal weights [12]. The weight factor is calculated with the use of the following formula:

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

λ_i = the weight of point,
D_i = the distance between point i and the unknown point,
α = the power ten of weight.

RESULTS AND DISCUSSION

A hard copy of the city development plan is digitized and geo referenced. Latitude and longitude of sampled wells are recorded and converted to UTM coordinates, using Geographic Calculator [13]. Water quality attributes for each sampling wells are transferred in Arc GIS desktop version 9.3.1 and maps showing concentration of TDS, TH, Iron and Fluoride in groundwater across the rural areas of Agra.

Total Hardness (TH): The Bureau of Indian Standards has recommended 300 mg/l as the permissible limit and 600 mg/l as the maximum permissible limit for Total Hardness in drinking water [14]. The Total hardness was classified in to three ranges (0-300 mg/l, 300-600 mg/l and >600 mg/l) and based on these ranges the spatial variation map for total hardness has been obtained and presented in Fig 3. From the map it was observed that for Achhnera, Akola and some part of Bichpuri block, the total hardness value is in the poor range (>600 mg/l) and area of Barauli Ahir and Bichpuri are in medium range (300-600 mg/l). Etmadpur and Khandauli represent the desirable range (<300 mg/l).

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. For total hardness, groundwater exceeding the limit of 300 mg/L is considered to be hard [15]. Except Khandauli and Etmadpur block areas, most of the groundwater of the present study area is rated as hard to very hard and requires processing before use.

Total Dissolved Solids (TDS): The Bureau of Indian Standards has recommended 500 mg/l as the desirable limit and 2000 mg/l as the maximum permissible limit for TDS in drinking water [14]. The spatial variation map for TDS was prepared based on these three ranges (0-500 mg/l, 500-2000 mg/l and >2000 mg/l) and presented in Fig 4. From the spatial variation map it was observed that in most of the areas, the TDS value is in the medium range (500-1000 mg/l). For the whole Achhnera block and a portion of Bichpuri as well, the TDS value is in the poor range (>2000 mg/l) and the smaller portion of the study area has TDS under the good range (0-500 mg/l).

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 with more than 500 mg/L is undesirable for drinking and many industrial uses.

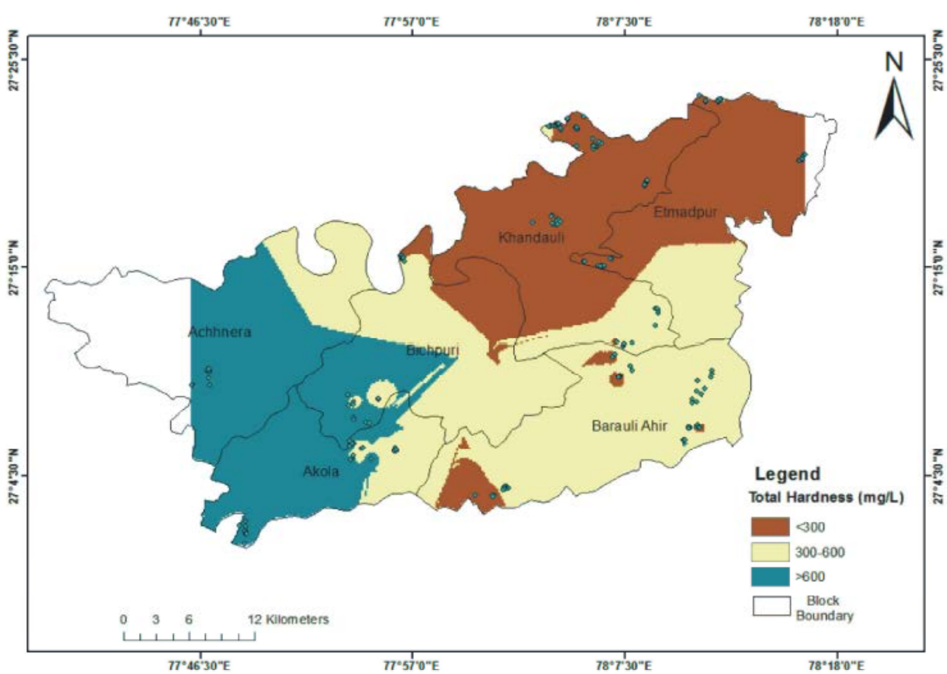

Fig. 3: Spatial distribution of Total Hardness in blocks of rural Agra

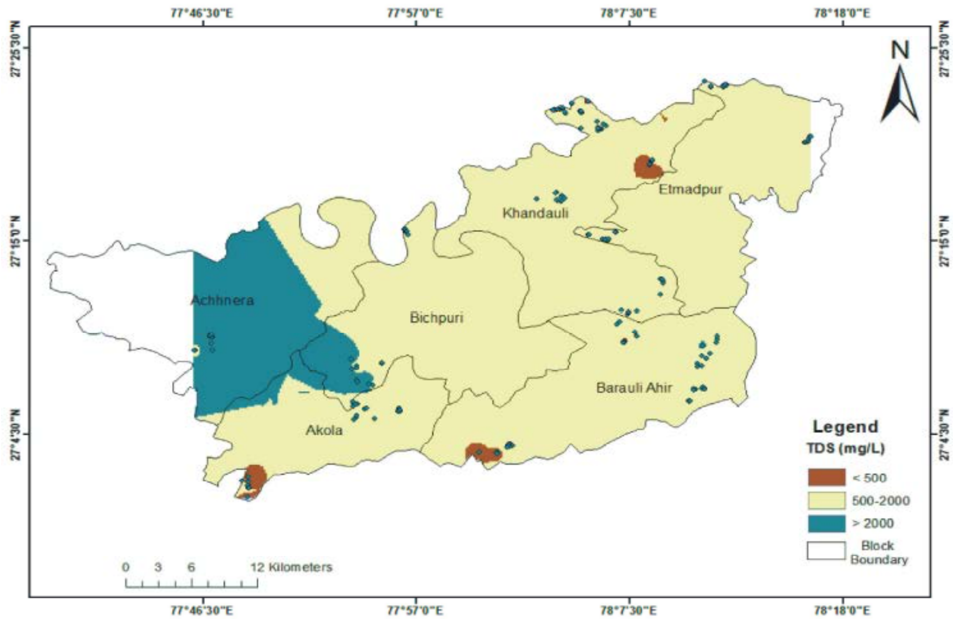

Fig. 4: Spatial distribution of Total Dissolved Solids in blocks of rural Agra

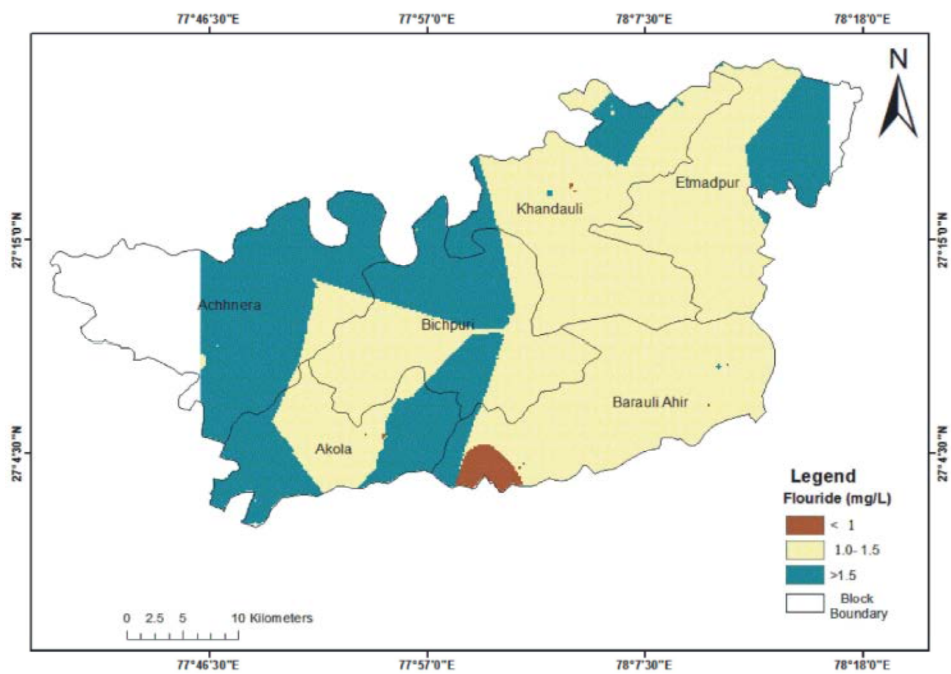

Fig. 5: Spatial distribution of Fluoride in blocks of rural Agra

It was reported that water containing more than 500 mg/L of TDS causes gastrointestinal irritation [16]. High value of TDS influences the taste, hardness and corrosive property of the water [17, 18, 19, 20]. It is important to classify the groundwater depending upon their hydro chemical properties based on their TDS values [21]. 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,

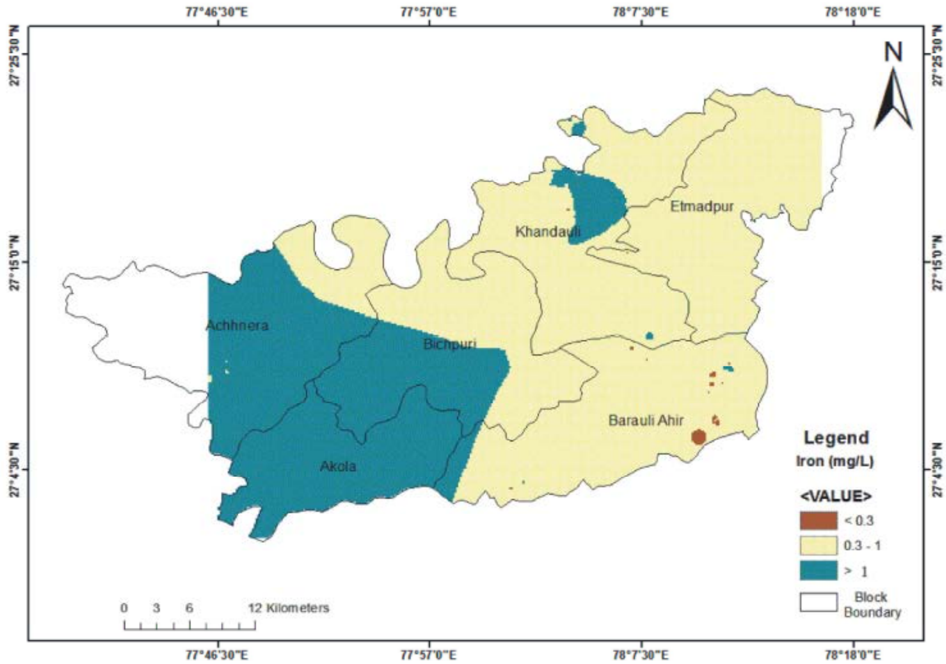

Fig. 6: Spatial distribution of Iron in blocks of rural Agra.

it is generally satisfactory for domestic use and for many industrial purposes. Water with more than 2000mg/L of dissolved solids usually gives disagreeable taste or makes the water unsuitable in other respects. SubbaRao, et al. (1998) and Deepali, et al. (2001) reported that TDS concentration was high due to the presence of bicarbonates, carbonates, sulphates, chlorides and calcium [22, 23]. TDS can be removed by reverse osmosis, electro dialysis, exchange and solar distillation process.

Fluoride: Fluoride is one of the main trace elements in groundwater, which generally occurs as a natural constituent. The Bureau of Indian Standards has recommended 1.0 mg/l as the desirable limit and 1.5 mg/L as the maximum permissible limit for Fluoride in drinking water [14]. The excess fluoride (>1.5mg/L) in drinking water causes Dental and Skeletal Fluorosis, which is a crippling disease. The spatial variation map for Fluoride was prepared based on these ranges and presented in Fig 5. From the spatial variation map it was observed that in most of the areas the Fluoride value is in the medium range (1.0-1.5 mg/l). For a major portion of Achhnera, Bichpuri, Akola block, a certain portion of Etmadpur and Khandauli as well, the Fluoride value is in the poor range (>1.5 mg/l) and the blocks Barauli Ahir, Etmadpur and Khandauli of the study area have Fluoride under the desirable range (1.0-1.5 mg/l).

Bedrock containing fluoride minerals is generally responsible for high concentration of this ion in groundwater [24, 25 and 26]. The presence of fluoride in groundwater may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, amphiboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks especially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may contribute due to man's activities. The fluoride containing insecticides and herbicides may contribute through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in groundwater.

Iron: The Bureau of Indian Standards has recommended 0.3 mg/l as the desirable limit and 1 mg/l as the maximum permissible limit for iron in drinking water [14]. The spatial variation map for Iron was prepared based on these ranges and presented in Fig 6. From the spatial variation map it was observed that in most of the areas the Iron value is in the medium range (0.3-1.0 mg/l).

Table 1: Criteria for acceptability and rejection in groundwater quality.

Parameters	Rank	Limits *	Remarks
Total Hardness	A	<300	Desired
	B	300-600	Acceptable
	C	>600	Not- Acceptable
Total Dissolved Solids	A	<500	Desired
	B	500-2000	Acceptable
	C	>2000	Not- Acceptable
Fluoride	A	<1.0	Un-Desirable
	B	1.0-1.5	Desirable
	C	>1.5	Not Acceptable
Iron	A	<0.3	Un-Desirable
	B	0.3-1.0	Desirable
	C	>1.0	Not Acceptable

*all concentrations in mg/l

Table 2: Classification of groundwater samples based on Total Hardness, after Sawyer and McCarty, 1967 [15].

TH (mg/l)	Classification	Number of samples	Percentage of samples
<300	Soft	98	49
300-600	Hard	68	34
>600	Very hard	34	17

Table 3: Classification of groundwater samples based on TDS after Davis and DeWiest, 1966 [21].

TDS (mg/L)	Classification	Number of samples	Percentage of samples
<500	Desirable for drinking	36	18
500-2000	Permissible for drinking and irrigation	144	72
>2000	Unfit for drinking and irrigation	20	10

Table 4: Classification of groundwater samples based on Fluoride according to Bureau of Indian Standards [14].

Fluoride (mg/L)	Classification	Number of samples	Percentage of samples
<1.0	Un-Desirable	13	6.5
1.0-1.5	Desirable	142	71
>1.5	Not Acceptable	45	22.5

Table 5: Classification of groundwater samples based on Iron according to Bureau of Indian Standards [14].

Iron (mg/L)	Classification	Number of samples	Percentage of samples
<0.3	Desirable	35	17.5
0.3-1	Acceptable	112	56
>1	Not Acceptable	53	26.5

For Akola block and a major portion of Achhnera, Bichpuri block and a certain portion of Khandauli as well, the Iron value is in the poor range (>1.0 mg/l) and the blocks Barauli Ahir, Etmadpur and Khandauli of the study area have Iron under the acceptable range (0.3-1.0 mg/l).

High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odour sand red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

CONCLUSION AND RECOMMENDATIONS

The spatial analysis and interpretations of the groundwater quality of the study area successfully demonstrate that the applied GIS methodology is a powerful tool in evaluation and describing the spatial analysis and mapping of the groundwater characteristics. The estimated water quality indices demonstrates that groundwater quality in the study area is quite unsatisfactory for drinking purposes and the corresponding suitable area have been delineated by producing different spatial extent maps. This study can offer the requisite information for the authority to pursue the sustainable approaches on groundwater management and contamination prevention.

The spatial distribution analysis of groundwater quality in rural blocks of Agra indicated that many of the samples collected are not satisfying the drinking water quality standards; almost half of the rural areas are having non-potable groundwater. The results obtained gave the necessity of making the public, local administrator and the government to be aware of the crisis of poor groundwater quality prevailing in these rural areas. The government needs to make a scientific and feasible planning such as providing centralized water supply scheme. For this, public awareness of the present quality crisis and their involvement and cooperation in the actions of local administrators are very important. Since, in the 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 implementation.

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