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Assessment of Groundwater Quality using Water Quality Index (WQI) in Kulpahar watershed, District Mahoba, Uttar Pradesh, India

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Abstract: **The continuous stress on groundwater due to its overexploitation and rampant use which is indispensable to the quality of life on the earth. The study area is occupied by Precambrian basement comprised of Bundelkhand massif unconformably overlain by Quaternary sediments consisting of alluvium, clay, silt, sand and gravel. The present study deals with the various geochemical characteristic of groundwater and henceforth assess the water quality index (WQI) which is an important criterion for the determination of drinking water quality of the area. The WQI is significant unique digital rating expression to decipher the overall quality of groundwater viz. excellent, good, poor, etc. that is helpful for selecting appropriate and economically feasible treatment process to cope up with the concerned quality issues. It is one of the most relevant and effective tool for educating the people residing in the area concerned and policy-makers about water quality.**

An attempt has been made to understand the suitability of groundwater for human consumption in hard rock terrain of Bundelkhand region particularly in Kulpahar watershed, district Mahoba, Uttar Pradesh using WQI. The WQI has been calculated considering twenty parameters of twenty-two groundwater samples of different locations of the study area. These parameters pH, EC, TDS, alkalinity, total hardness, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, F^{-}, NO_3^{-}, Ag, Cu, Fe, Mn, Ni, Zn. The WQI in the study area ranges from 4.75 to 115.93. The extreme southern part of the Kulpahar watershed, district Mahoba of Bundelkhand region is dominant with poor groundwater quality. The higher value of WQI indicative of poor quality has been observed which is mainly due to the higher values of EC, fluoride, nitrate, manganese, and nickel in the groundwater. The study suggests that groundwater quality in Panwari Block mainly belongs to excellent and good categories. A remarkable portion in the southern part of Jaitpur block is affected by poor to unsuitable category and needs sincere effort for a detailed zonation at micro-level to understand properly and provide accurate information to the residents as well as policy makers.

Keywords: **Groundwater, Watershed, WQI, GIS, Bundelkhand massif.**

I. INTRODUCTION

There has been tremendous increase in the demand of groundwater due to geometric growth of population, rapid pace of industrialization and urbanization in India (Yisa and Jimoh, 2010). The availability and quality of groundwater is badly affected due to its overexploitation and unmonitored waste disposal. The anthropogenic activities are mainly responsible for infusing industrial, domestic and agricultural waste gradually into groundwater reservoirs at a galloping rate (Panda and Sinha, 1991). As a result, human health is being endangered by the exiting agricultural practices particularly with respect to excessive use of chemicals and fertilizers. Disposal of industrial effluent and sewage into groundwater cause groundwater pollution and unsanitary conditions (Panigrahi et al., 2012). The quality of groundwater is deciphered using various physical, chemical and biological characteristics of water (Diersing and Nancy, 2009). It is a measure of health and hygiene of groundwater with respect to the need and purpose of human beings (Johnson et al., 1997). The amount of water that percolates into the ground varies widely from place to place due to different type of lithology and geomorphology. The groundwater quality varies with depth of water table, periodic monsoonal changes, leached dissolved salts and sub-surface environment (Gebrehiwot et al., 2011). It is essential to monitor the quality of groundwater regularly and to device ways and means to prevent it from further contamination as it becomes very difficult to ensure its proper quality and restoration once it is contaminated. In this study, the physicochemical properties of representative groundwater samples collected from wells and hand pumps of different locations from the study area have been determined and compared with recommended guidelines of World Health Organization (WHO, 2017) and BIS (2012, 2015) specification for drinking, domestic and other uses based on Water Quality Index (WQI).

Horton (1965), for the first time developed the concept of WQI based on weighted arithmetical calculation. In the past fifty years or so, several researchers (Brown et al., 1972; GEMS UNEP, 2007; Kavitha and Elangovan, 2010; Alobaidy et al., 2010) have developed different types of WQI models on the basis of weightage and rating of different water quality parameters derived by weighted arithmetic method. The WQI is a dimensionless number with values ranging between 0 and 100. It is a unique digital expression which reflects the overall water quality at a specified space with time on the basis of various water quality parameters. It has become an important tool to compare the quality of groundwater in a particular region. Such indices are very important and effective means to communicate the information related to groundwater quality and their management (Jagadeeswari and Ramesh, 2012). In fact, it is a water quality categorization viz: excellent, good, poor, very poor and unsuitable; and express overall water quality at a certain location and time reflecting the composite influence of different water quality parameters. It depicts and discusses the unified impact of various water quality parameters and communicates water quality information to the residence in the concerned area and legislative policy makers to design strong policy and implement the water quality programs (Kalavathy et al., 2011) by the government. In order to keep the health of an aquifer system at an optimal level, certain water quality indicators or parameters needs to be regularly monitored and controlled. Therefore, the objective of the study is to calculate the WQI of groundwater in the study area in order to assess its suitability for human consumption, agricultural practices and other land use practices.

II. STUDY AREA

The study area Jaitpur and Panwari blocks of Kulpahar tehsil, district Mahoba, Uttar Pradesh extends between longitudes 79º10′E and 79º40′E to latitudes 24º50′N and 25º30′N having an area of 1240 km² (Fig. 1). The typical subtropical climate punctuated by long and intense summer, with distinct seasons characterizes the study area. The average annual precipitation of 864 mm is catered by the south-west monsoon. January is usually the coolest month with an average temperature 8.3ºC while May is the warmest with temperature shooting upto 47.5ºC. The rivers Virma, Arjun and Chandrawal mainly drain the area under investigation.

The study area is consisting mainly of hard rock formation of Bundelkhand massif. The Jaitpur block is characterized by rugged topography with a very thin soil cover as overburden while Panwari Block is covered by a thick overburden consisting of clay, silt and fine grained sand. The prominent rock formations viz. granite, granitic-gneiss are having secondary porosity due to its highly fractured and jointed nature. These may be responsible for the occurrence of groundwater mostly in the upper weathered zone and under secondary porosity in deeper fractured zone. The rainfall generally does not percolate subsurface since the rocks are of massive and compact in nature. However, secondary porosity in the form of cracks, fractures, joints and fissures allow some surface water to percolate underneath.

Geological Set-up:

The study area is mainly characterized by granite, particularly leucogranite, older and younger alluvium consisting of clay, silt, sand and gravel. The most dominant lithology is leucogranite which covers mainly central and eastern part while recent alluvium occurs in northern part of the study area (Fig. 2). There are few patches of pink granite which appears enclosed in leucogranite or adjacent to its outcrop.

Stratigraphically, the quaternary sediments of recent to sub-recent age comprising alluvium, sand, gravel, silt and clay lies unconformably over the Precambrian rocks comprising Bundelkhand massif, granite, gneiss, schist, dolerite and quartz reef

III. MATERIALS & METHOD

The groundwater samples were collected from twenty-two different locations in the study area following the standard procedures of American Public Health Association (APHA, 2017). The sterilized bottles (1 litre capacity each) under aseptic condition were used for collecting the samples to avoid unpredictable contamination leading to any changes in the characteristics of groundwater samples. The sample locations have been marked using global positioning system (GPS) as indicated in the Figure 1. In the present study, twenty groundwater quality parameters of twenty-two samples have been analysed in the laboratory except unstable parameters viz. pH, EC and TDS were determined in situ by portable device (pH-meter, EC-meter and TDS-meter). The studied parameters are alkalinity, total hardness (TH), calcium($Ca2+$), magnesium ($Mg2+$), sodium ($Na+$), potassium ($K+$), bicarbonate (HCO^{3-}), sulfate (SO_42^-), chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), silver (Ag), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni) and zinc (Zn). The accuracy of the chemical analysis has been validated by charge balance errors and samples with < 5 % error. The correlation matrix and statistical analysis of the analyzed groundwater quality parameters have been laid down as shown in Table 2 and Table 3 respectively.

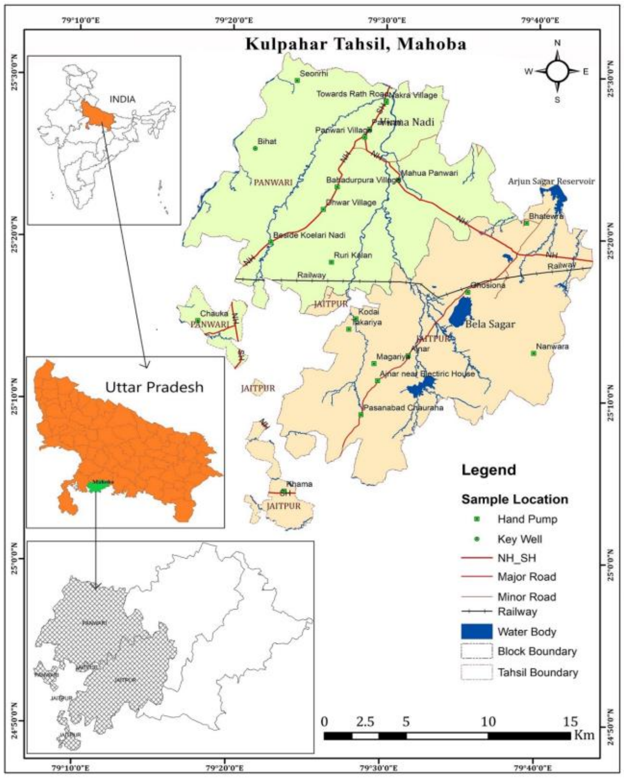

Figure 1: Map of the Study area

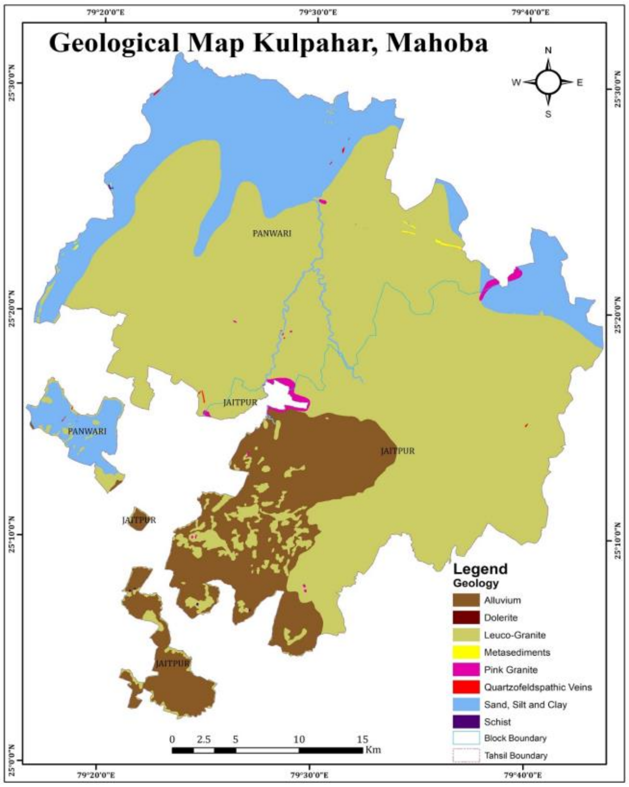

Figure 2: Geological Map of Study area

Water Quality Index (WQI): The WQI has been determined with the help of drinking water quality standards as recommended by the World Health Organization (WHO, 2017). It has been calculated by using weighted arithmetic water quality index as has been originally proposed by Horton (1965) and modified by Brown et al., (1972). The weighted arithmetic WQI is represented in the following way:

$$WQI = \sum_{i=1}^{n} \frac{W_i Q_i}{\sum_{i=1}^{n} W_i} \qquad (1)$$

where,
n = number of variables or parameters,
$\mathbf{W_i}$ = unit weight for the ith parameter,
$\mathbf{Q_i}$ = quality rating (sub index) of the ith water quality parameter.

The unit weight (W_i) of the various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters.

$$\mathbf{W_i = K/S_n} \qquad (2)$$

where,
$\mathbf{W_i}$ = unit weight for the ith parameter,
$\mathbf{S_n}$ = standard value for ith parameters,
K = proportional constant,

The value of **K** has been considered **'1'** here and is calculated using the following equation:

$$\mathbf{K=1/\Sigma\ (1/\ S_n)} \qquad (3)$$

According to Brown et al., (1972), the value of quality rating or sub-index ($\mathbf{Q_i}$) is calculated using the following equation:

$$\mathbf{Q_i = 100[(V_o - V_i) / (S_n - V_i)]} \qquad (4)$$

where,

$\mathbf{V_o}$ = observed value of ith parameter at a given sampling site,
$\mathbf{V_i}$ = ideal value of ith parameter in pure water,
$\mathbf{S_n}$ = standard permissible value of ith parameter.

All the ideal values (V_i) have been taken as zero for potable water except pH and dissolved oxygen (Tripathy and Sahu, 2005). The ideal value of pH is 7.0 for natural or pure water while the permissible value is 8.5. Similarly, the ideal value of dissolved oxygen is 14.6 mg/l while the standard permissible value for potable water is 5 mg/l. Hence, the quality rating for pH and Dissolved Oxygen are calculated respectively from the following equations:

$$\mathbf{Q_{pH} = 100\ [(V_{pH} - 7.0) / (8.5 - 7.0)]} \qquad (5)$$

$$\mathbf{Q_{do} = 100\ [(V_{do}\ 14.6) / (5.0 - 14.6)]} \qquad (6)$$

where,
V_{pH} = observed value of pH
V_{do} = observed value of dissolved oxygen
Q_i = 0 indicates complete absence of contaminants, while $0 < Q_i < 100$ indicates that the contaminants are within the prescribed standard. Further, Q_i >100 indicates that the contaminants are above the prescribed standards.

In this study, the water quality index (WQI) proposed by Brown et al. (1972) and Chatterji and Raziuddin (2002) have been considered for the classification of water quality as given in Table 1.

TABLE 1
Classification of water quality and status based on weighted arithmetic WQI Method

WQI	Rating Class
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
> 100	Unsuitable

Source: Brown et al. (1972), Chatterji and Raziuddin (2002)

IV. RESULT AND DISCUSSION

(i) Statistical analysis, Correlation Matrix and Relative Weightage: The correlation matrix, statistical analysis and relative weightage of groundwater quality parameters are tabulated in Table 2, 3 and 4 respectively. The correlation matrix of twenty groundwater quality parameters including six heavy metals has been created and analysed (Table 2). Out of these, eight parameters viz. EC, Alkalinity, TH, Ca^{2+}, Mg^{2+}, Na^{+} and Cu are significantly correlated to each other reflecting more than 0.50 correlation values. Further, EC vs TDS, Alkalinity vs Na^{+} and HCO_3^{-}, TH as $CaCO_3$ vs Mg^{2+} and SO_4^{2-}, Ca^{2+} vs Ni, and Cu vs Fe indicates most relevant correlation having a significant impetus on the overall assessment of quality of groundwater than any other major radicals and physical parameters. However, the majority of quality parameters are positively correlated with each other. A critical analysis of the correlation matrix for the heavy metals, indicates that Ag is positively correlated with AK, TH, Ca2+, Mg2+, K+, SO_4^{2-}, Cl^{-} and NO_3^{-}. Similarly, Cu is positively correlated with EC, TDS, AK, Na+, K+, F^{-} and NO_3^{-}. While, Fe is positively correlated with TDS, Mg2+, Na+, K+, HCO_3^{-}, SO_4^{2-}, NO_3^{-}, Ag and Cu. Further, Mn is positively correlated with pH, EC, TDS, NO_3^{-} and Ag. Similarly, Ni is positively correlated with pH, EC, TDS, Ca2+, K+, NO_3^{-} and Cu.

The higher concentration of Ni, Fe and Cu may trigger the presence of other heavy metals viz. Pb, Cd and Cr which are very sensitive and significant heavy metal and needs to be observed carefully in future for groundwater quality in the study area. The presence of Fe, SO_4^{2-} and NO_3^{-} may trigger the presence of Cd (Chaurasia et al., 2018).

(ii) Groundwater Quality Parameters and Spatial Distribution Pattern: In the present study, the spatial distribution pattern of the contour for different groundwater quality parameters have been generated using the Arc GIS 10.4 software as represented in Fig. 3A, 3B, 3C, 3D, 3E, 3F, 3G, 3H, 3I, 3J, 3K, 3L, 3M, 3N, 3O, 3P, 3Q, 3R, 3S and 3T. The Bureau of Indian Standard (BIS, 2012, 2015) and World Health Organization (WHO, 2017) of drinking water standards have been considered as a reference in this study.

Hydrogen ion concentration (pH): It is an important indicator for assessing the quality and pollution of any aquifer system as it is closely related to other chemical constituents of water. The ideal range of pH for human consumption needs to be in the range of 6.5–8.5. In the study area the pH varies between 6.81 (minimum) to 8.32 (maximum) which suggest that it is well within the acceptable limit (6.5 - 8.5) with an average of 7.95 suggesting the alkaline nature of groundwater.

The spatial distribution pattern of the pH indicates that mainly the eastern part and some patches in western part of the study area is affected by the presence of alkaline groundwater (Fig. 3A).

Electrical conductivity (EC): It is a measure of ability of a substance or solution to conduct electrical current through the water due to the presence of dissolved salts in it and is directly proportional to the dissolved salts. The desirable limit of EC for drinking purpose is 750 µS/cm. In the study area the EC varies between 286 and 1162 µS/cm. In the vicinity of dense urban areas presence of high EC suggests that open sewer/drain carrying domestic waste is triggering the contamination of groundwater .EC is mainly higher (> 750 mg/l) in the eastern part (Fig. 3B).

Total Dissolved Solids (TDS): It is defined by the presence of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride and sulfate. The potable water contains less than 500 mg/l TDS as per BIS recommendation. In the study area it ranges between 285 to 879 mg/l. The existing agricultural patterns, anthropogenic wastes and leaching of top soil causing contamination may be the primary sources for enhancing the TDS (Boyd, 2000).

The eastern portion of the study area is having high TDS (> 500 mg/l) in groundwater (Fig. 3C). The sympathetic relationship between TDS and EC as evinced from the correlation matrix of the quality parameters (Table 2).

Alkalinity (AK): The presence of carbonate, bicarbonate and hydroxide ions in water defines its alkalinity. Its desirable limit in drinking water is 200 mg/l, above which the taste of water become unpleasant. In this study, the alkalinity ranges between 50 to 452 mg/l which is within the permissible limit (600 mg/l).

The alkalinity map clearly indicates that it is higher in NE part (Fig. 3D). The quality of groundwater in a significant portion of the study area is alkaline in nature which may be due to presence of dissolved carbonates in the form of bicarbonates (Adams et al., 2001). A positive correlation exits between alkalinity of groundwater and fluoride content (Table 2) affecting fluoride in the groundwater. This fact validates the leaching of fluoride from alkali granite.

TABLE 2

Correlation matrix of analysed groundwater quality parameters

Parameters	pH	EC	TDS	AK	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	F^-	NO_3^-	Ag	Cu	Fe	Mn	Ni	Zn
pH	1.000																			
EC	-0.048	1.000																		
TDS	-0.218	0.886	1.000																	
AK	0.033	0.364	0.350	1.000																
TH	-0.193	-0.050	0.150	-0.248	1.000															
Ca^{2+}	-0.015	-0.335	-0.357	-0.086	-0.033	1.000														
Mg^{2+}	-0.175	-0.180	-0.024	-0.072	0.664	-0.150	1.000													
Na^+	0.021	0.366	0.382	0.811	-0.414	-0.280	-0.059	1.000												
K^+	-0.063	0.077	0.285	0.026	0.233	-0.158	0.297	0.115	1.000											
HCO_3^-	-0.027	0.245	0.327	0.779	-0.008	-0.098	0.118	0.754	0.375	1.000										
SO_4^{2-}	-0.502	-0.050	0.190	-0.425	0.663	-0.309	0.557	-0.366	0.334	-0.143	1.000									
Cl^-	-0.005	0.122	0.236	-0.094	0.453	-0.265	0.357	0.058	-0.174	-0.211	0.236	1.000								
F^-	0.319	0.308	0.167	0.270	-0.053	-0.322	-0.058	0.243	-0.035	0.143	-0.212	0.265	1.000							
NO_3^-	-0.155	0.241	0.232	0.019	0.137	0.027	0.095	-0.065	-0.039	-0.262	0.067	0.217	-0.342	1.000						
Ag	-0.128	-0.363	-0.156	0.044	0.233	0.146	0.361	-0.077	0.093	-0.029	0.029	0.134	-0.328	0.163	1.000					
Cu	-0.406	0.413	0.457	0.080	-0.223	-0.006	-0.195	0.132	0.094	-0.013	-0.061	-0.096	0.058	0.127	-0.148	1.000				
Fe	-0.325	-0.117	0.061	-0.045	-0.021	-0.312	0.325	0.103	0.357	0.050	0.219	-0.098	-0.258	0.020	0.383	0.506	1.000			
Mn	0.095	0.231	0.186	-0.155	-0.123	-0.008	-0.154	-0.168	-0.365	-0.231	-0.043	-0.152	-0.082	0.124	0.068	-0.005	-0.165	1.000		
Ni	0.100	0.074	0.091	-0.268	-0.017	0.515	-0.253	-0.257	0.352	-0.030	-0.010	-0.345	-0.279	0.007	-0.361	0.134	-0.235	-0.044	1.000	
Zn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

[Unit of each groundwater quality parameter is in mg/l except EC (µS/cm) and pH (on scale); The highlighted value indicates significant correlation (> 0.5); AK denotes Alkalinity and TH denotes Total Hardness as $CaCO_3$.]

TABLE 3

BIS, WHO specifications & statistical analysis of groundwater quality parameters

Parameters	BIS (2012, 2015) *	WHO (2017)	Min.	Max.	Mean	SD (σ)
pH (On Scale)	6.5-8.5	7 - 8	6.81	8.32	7.95	0.44
EC (µS/cm)	300	-	286.00	1162.00	616.73	251.98
TDS (mg/l)	500-2000	600-1000	285.00	879.00	482.00	177.73
Alkalinity (mg/l)	200-600	-	50.00	452.00	172.73	112.25
TH as $CaCO_3$ (mg/l)	200-600	200	139.00	536.00	284.00	100.53
Ca^{2+} (mg/l)	75-200	100-300	12.00	112.00	63.52	30.67
Mg^{2+} (mg/l)	30-100	-	6.80	64.80	30.15	15.05
Na^+ (mg/l)	-	50-200	48.71	233.50	129.49	55.94
K^+ (mg/l)	-	-	0.96	2.41	1.71	0.48
HCO^- (mg/l)	300-600	-	36.61	536.95	226.76	132.42
SO^{2-} (mg/l)	200-400	250	3.47	73.04	17.80	15.92
Cl^- (mg/l)	250-1000	250	70.92	241.13	156.30	44.84
F^- (mg/l)	1-1.5	1.5	0.11	3.34	1.18	0.83
NO^- (mg/l)	45	50	86.95	210.40	156.96	35.41
Ag (mg/l)	0.1	0.1	0.00	0.02	0.01	0.01
Cu (mg/l)	0.05-1.5	2	0.00	0.01	0.00	0.00
Fe (mg/l)	1	0.3	0.10	0.38	0.23	0.08
Mn (mg/l)	0.1-0.3	0.1-0.4	0.01	0.22	0.05	0.04
Ni (mg/l)	0.02	0.07	0.00	0.04	0.01	0.01
Zn (mg/l)	5.0-15	3 - 5	0.01	0.01	0.01	0.00

* The lower value denotes acceptable/desirable limit and the higher value denotes the permissible limit in absence of alternate source (Bureau of Indian Standards, 2012, 2015).

Calcium (Ca^{2+}): In the study area the calcium concentration ranges between 12 to 112 mg/l and is within permissible limit (200 mg/l). The higher concentration of calcium in groundwater is in northern and south eastern part of the study area (Fig.3F)

Magnesium (Mg^{2+}): The presence of magnesium is equally responsible for the hardness of water. Its concentration ranges between 6.8 to 64.8 mg/l in the study area and is within permissible limit (100 mg/l). Spatial distribution reveals that the magnesium concentration in groundwater is higher in northern part of the study area (Fig. 3G).

Total Hardness (TH): The presence of calcium and magnesium in the water determines the total hardness. In general, hard water originates in areas where the top soil is thick and limestone formations are present (Arumugam, 2010). The naturally occurring minerals are dissolved and carried down by the water while moving through soil and rock into the groundwater as water is a great solvent for calcium and magnesium. In the study area it ranges between 139 to 536 mg/l which is within the permissible limits (600 mg/l).

The spatial distribution map of Ca^{2+} indicates presence of varying concentration within permissible limit thought out the area concerned (Fig. 3F). Similarly, Mg^{2+} is also unevenly distributed within permissible limit except in NE part of the study area (Fig. 3G). Further, in coherence with the presence of Ca^{2+} and Mg^{2+} and in consequence the spatial distribution pattern of total hardness in the study reflects that the groundwater is moderately hard (Fig. 3E). Higher concentration of TH in groundwater may cause heart disease and kidney stone in human beings. The correlation matrix clearly marks a significant positive correlation between Mg^{2+} and total hardness as well as Na^+ and alkalinity (Table 2).

Sodium (Na^+): It is one of the highly reactive alkali metal. It is commonly present in the groundwater. The rock forming minerals and soils contain sodium compounds which are easily dissolved and liberate sodium in groundwater. The weathering of rock forming minerals i.e., particularly silicate minerals cause the higher concentration of Na^+ in groundwater (Stallard and Edmond 1983). The higher concentration of Na^+ in groundwater may be due to the mechanism of cation exchange (Kangjoo Kim and Seong-Taekyun, 2005). In the study area it ranges between 48.71 to 233.5 mg/l. Na^+ is highest in the NE part which is in conformity with the alkalinity and TDS (Fig. 3C, 3D & 3H).

Potassium (K^+): Many rocks and minerals contain potassium which are released in the groundwater due to relatively soluble nature of these minerals and rocks. In this study it varies between 0.96 to 2.41 mg/l.

Although, K^+ is insignificant present and it's lower concentration is covering major portion of the study area. Its distribution pattern is more or less conformable with the TDS and Na^+ (Fig. 3C, 3H & 3I).

Bicarbonate (HCO_3^-): HCO_3^- is another important quality parameter. It is produced by the carbonate rocks viz. limestone and dolomite through its reaction with carbon dioxide and water. Also, the carbon-dioxide present in the soil reacts with the rock forming minerals to produced bicarbonate, resulting an alkaline environment in the groundwater. It varies between 36.61 to 536.95 mg/l in the study area and is within the permissible limit of 600 mg/l.

It is showing a significant positive correlation (> 0.50) with alkalinity and Na^+ (Table 2) which is also reflected in the spatial distribution pattern of these parameters (Fig. 3D, 3H & 3J).

Sulfate (SO_4^{2-}): The dissolution of rocks containing gypsum, iron sulfides, and other sulfur bearing compounds cause their leaching and releases sulfates. It ranges between the 3.47 to 73.04 mg/l in the study area which is well within the acceptable limit i.e.200 mg/l. Although, sulfate (SO_4^{2-}) is an important quality parameter, it is insignificantly distributed in the study area (Fig. 3K).

Chloride (Cl^-): It is also a significant component in quality analysis. It ranges between 70.92 to 241.13 mg/l in the study area which is within the desirable limit (250 mg/l) as revealed from the spatial distribution map of chloride (Fig. 3L).

Fluoride (F^-): It is an important and sensitive/vulnerable quality parameter. In groundwater, fluoride is geogenic in nature. It usually occurs either in trace amounts or as a major ion with high concentration in groundwater (Gaciri and Davies, 1993; Apambire et al., 1997; Fantong et al., 2010). The fluoride-bearing minerals release fluoride into groundwater mainly due to groundwater-host rock interaction. The granite, granitic gneiss etc. predominantly present in the study area is commonly found to contain fluorite (CaF_2) as an accessory mineral (Ozsvath, 2006; Saxena and Ahmed, 2003) which plays a significant role in controlling the geochemistry of fluoride (Deshmukh et al. 1995). Besides fluorite mineral, it is also abundant in other rock-forming minerals like apatite, micas, amphiboles, and clay minerals (Karro and Uppin, 2013; Narsimha and Sudarshan, 2013; Naseem et al., 2010; Jha et al., 2010; Rafique et al., 2009; Carrillo-Rivera et al., 2002). Its concentration ranges between 0.11 to 3.34 mg/l in the study area. The concentration of fluoride exceeds the permissible limit (1.5 mg/l) in about 22% of the groundwater samples. In acidic water, fluoride is adsorbed on clay surface, while in alkaline water, fluoride is absorbed from solid phases; therefore, alkaline pH is more favorable for fluoride dissolution, (Keshavarzi et al., 2010; Rafique et al., 2009; Saxena and Ahmed 2003; Rao, 2009; Ravindra and Garg, 2007; Vikas et al., 2009).

F^- is present noticeably in NE portion of the study area where it is beyond permissible limit (3.34 mg/l) (Fig. 3M). The high concentration (>3.0 mg/l) of fluoride may lead to skeletal fluorosis (Raju et al, 2009). Several factors viz. temperature, pH, presence or absence of complexing or precipitating ions and colloids, solubility of fluorine bearing minerals, anion exchange capacity of aquifer materials (i.e. OH^- with F^-), size and type of geological formations traversed by groundwater and the contact time period during which water remains in contact with a particular formation are responsible for fluoride concentration in groundwater (Apambire et al., 1997). The secondary porosity developed due to presence of cracks, joints and fractures contain more fluoride bearing minerals in comparision to massive rocks (Pandey et al., 2016).

Nitrate (NO_3^-): Nitrate and Nitrite are naturally occurring ions and are significant component in nitrogen cycle. Groundwater mainly contains anthropogenic nitrate which could be due to leaching from waste disposal, sanitary landfills, over application of inorganic nitrate fertilizer or improper manure management (Chapman, 1996).

In the study area its concentration ranges between 86.95 to 210.4 mg/l and is in excess of the permissible limits (45 mg/l) with varying degree of concentration (Fig. 3N). This may be hazardous to health. The higher values of nitrate in potable water increases the chances of gastric ulcer/cancer and other health hazards to pregnant women and infants less than 6 months of age causing Methaemoglobinaemia, birth malformations and hypertension (Majumdar and Gupta, 2000; Egereonu and Nwachukwu, 2005; Rao, 2006; Kumar et al., 2012; Kumar et al., 2014). The high values of nitrate in groundwater samples may be due to unlined septic tanks and unplanned sewerage system that contaminates to phreatic aquifer. Hence, proper monitoring and regulated effort are consistently required to get the desired impact.

Silver (Ag): It is a naturally occurring metal which usually occurs in the form of insoluble and immobile oxides, sulfides and some salts. It is rarely present at concentrations above 5µg/litre (WHO, 2017) in groundwater and surface water under natural condition. In the present study, silver does not show any remarkable presence in groundwater (Fig. 3O) and it ranges between 0.000 to 0.021 mg/l which is within the permissible limit (0.1 mg/l).

Copper (Cu): This metal naturally occurs in rock, soil, plants, animals, and groundwater in very less concentration. The quarrying and mining activities, farming practices, manufacturing operations and municipal or industrial waste released enrich the concentration of Cu into groundwater. Cu enters into drinking water either by contamination of well water or corrosion of copper pipes in case of water is acidic. It is negligibly present between 0 to 0.0078 mg/l in the study area (Fig. 3P) which is well within permissible limit (1.5 mg/l).

Iron (Fe): The mafic minerals especially the iron bearing minerals and rocks are the most common sources of iron in groundwater. In the aquifer system the iron occurs naturally in the reduced Fe^{2+} state but its concentration in groundwater increases gradually by its dissolution and has no ill effect on human health. The study area is having secondary porosity and groundwater containing iron in ferrous state (Fe^{2+}) usually occurs below the water table. This Fe^{2+} state is oxidised to Fe^{3+} state when it comes in contact with atmospheric oxygen or by the action of iron related bacteria. It forms insoluble hydroxides which precipitates in groundwater and causes health hazards. So, by raising the water table through recharging, the ill impacts can be reduced and the affected area can be mitigated. In fact, concentration of iron in groundwater is often higher than those measured in surface water. In the study area it ranges between 0.102 to 0.381 mg/l (Fig. 3Q) which is well within the permissible limit (1.0 mg/l, BIS, 2015).

Manganese (Mn): It occurs naturally in groundwater, especially in anaerobic environment. The rainfall chemistry, aquifer lithology, geochemical environment, groundwater flow paths and residence time, etc. are responsible for the concentration of Mn in groundwater which may vary significantly in space and time. It may be released by the leaching of the overlying soils and minerals in underlying rocks as well as from the minerals of the aquifer itself in groundwater. In the study area it ranges between 0.005 to 0.221 mg/l (Fig. 3R) which is well within the permissible limit (0.3 mg/l).

Nickel (Ni): The nickel ore bearing rocks and minerals are the primary source of nickel in groundwater. The nickel which occurs in drinking water is usually derived through the leaching from metals present in water supply pipes and fittings. It ranges between 0 to 0.0408 mg/l in the study area and it crosses the permissible limit (0.02 mg/l). It shows its remarkable presence in smaller patches (Fig. 3S) and possibly it does not reflect any hazard to human health.

Zinc (Zn): Groundwater rarely contains zinc above 0.1 mg/l though it occurs in significant quantities in rocks and minerals. In the study area the groundwater shows insignificant concentration of Zn (0.0136 mg/l) which is well within the acceptable limit (5 mg/l) (Fig. 3T).

(iii) Water Quality Index: The water quality index (WQI) map of the study area has been prepared using the twenty analysed parameters for twenty-two locations (Fig. 4) following the standard procedure. It has become a significant digital tool to categorize the samples depicting their quality for various specific uses. The samples of the study area have been classified into five different classes ranging from excellent to unsuitable (Table 5) on the basis of WQI.

The WQI Map of the study area indicates that its major portion is having excellent (0-25 mg/l) and good (25-50) quality of groundwater while very poor (75-100 mg/l) to unsuitable (> 100 mg/l) quality is prevailing only in small pockets in southern part (Fig. 4). The WQI map has been generated based on the selective quality parameters to decipher the various groundwater quality classes viz. excellent, good, poor, very poor and unsuitable for different types of uses at each location (Table 5 & Fig. 4).

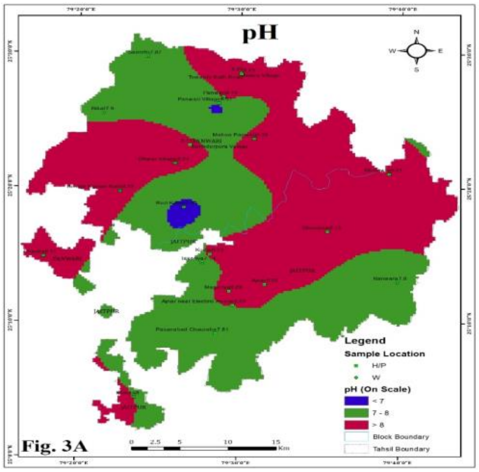

Figure 4A spatial distribution map of pH

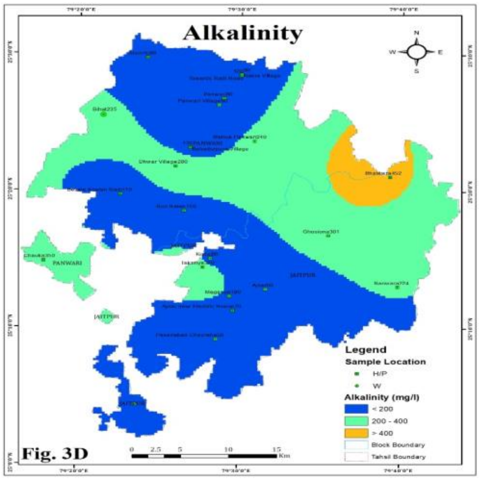

Figure 4D spatial distribution map of Alkalinity

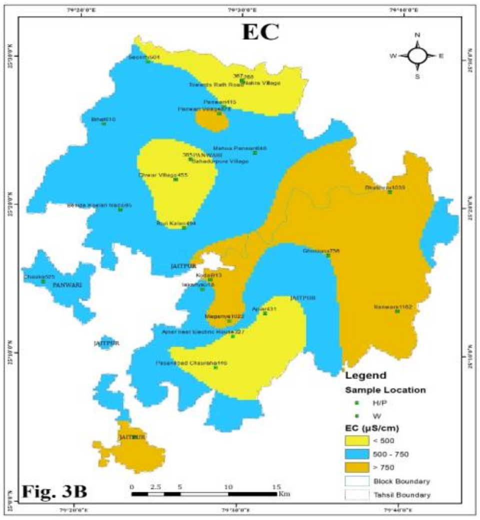

Figure 4B spatial distribution map of EC

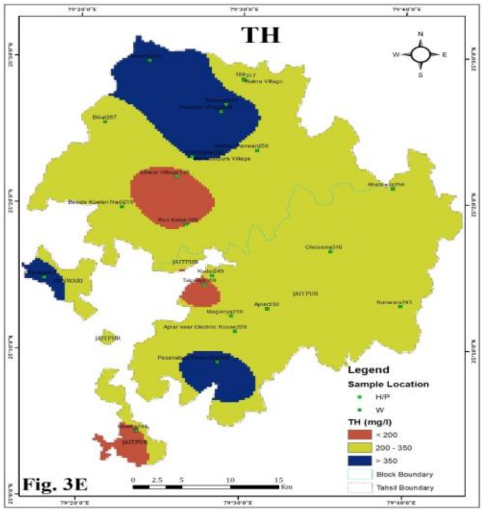

Figure 4E spatial distribution map of Total Harddness

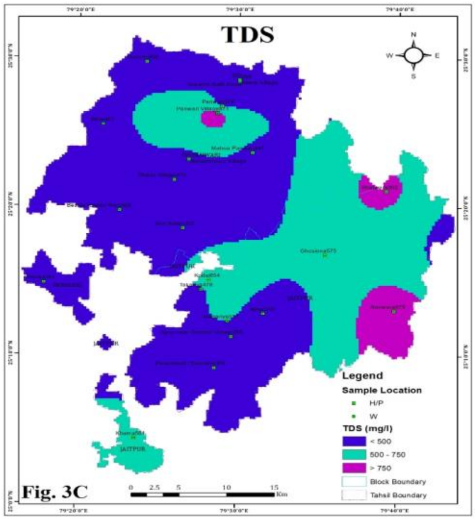

Figure 4C spatial distribution map of TDS

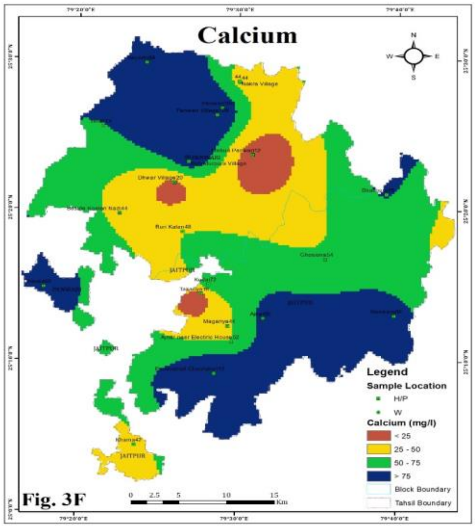

Figure 4F spatial distribution map of Ca

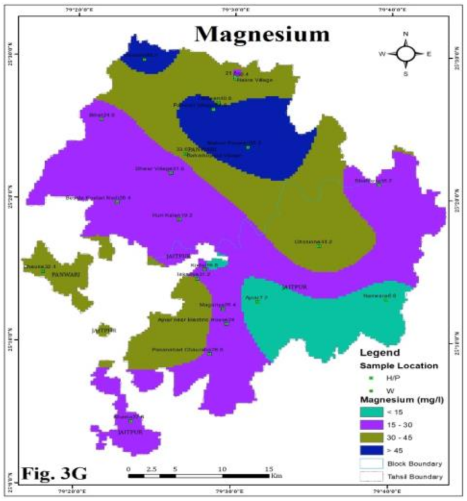

Figure 4G spatial distribution map of Mg

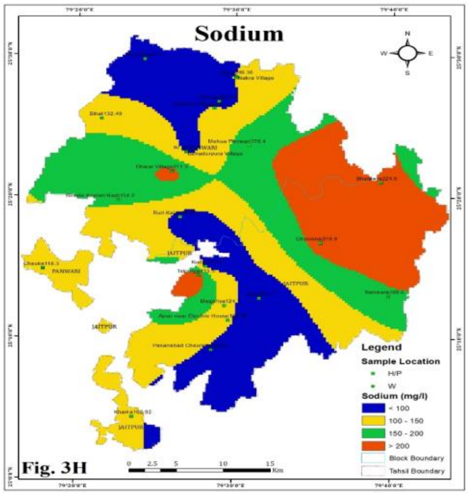

Figure 4H spatial distribution map of Na

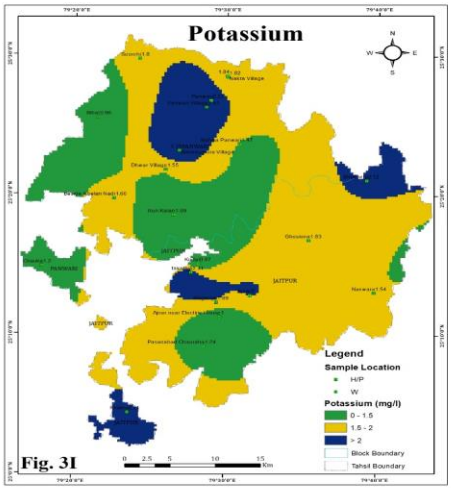

Figure 4I spatial distribution map of K

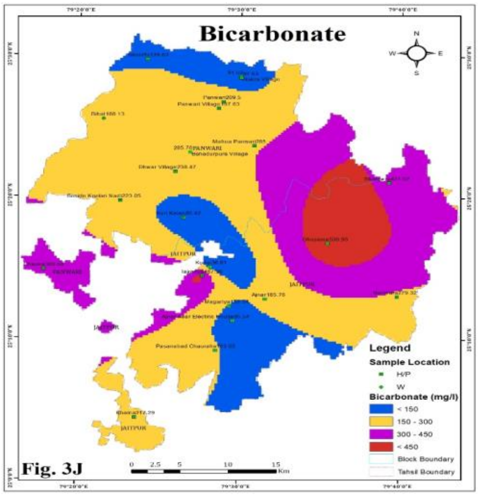

Figure 4J spatial distribution map of HCO3

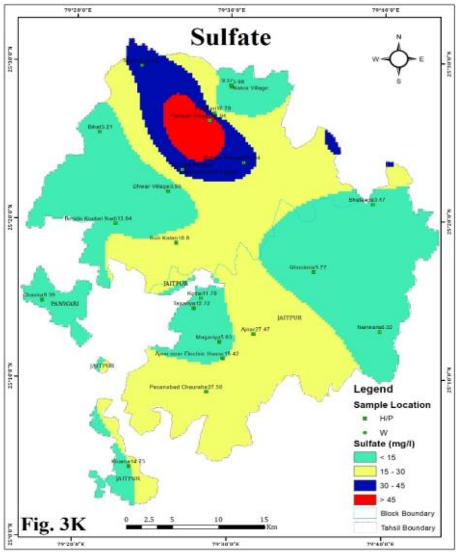

Figure 4K spatial distribution map of SO4

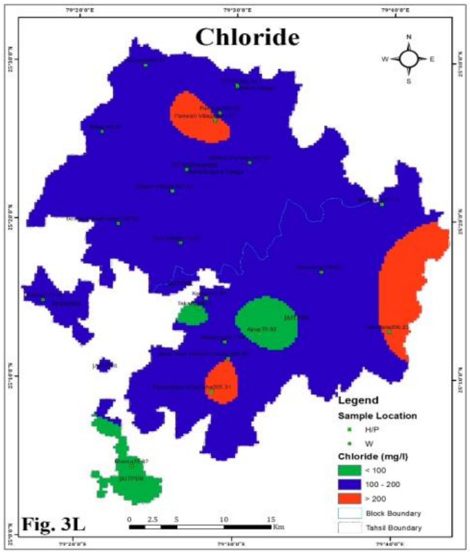

Figure 4L spatial distribution map of Cl

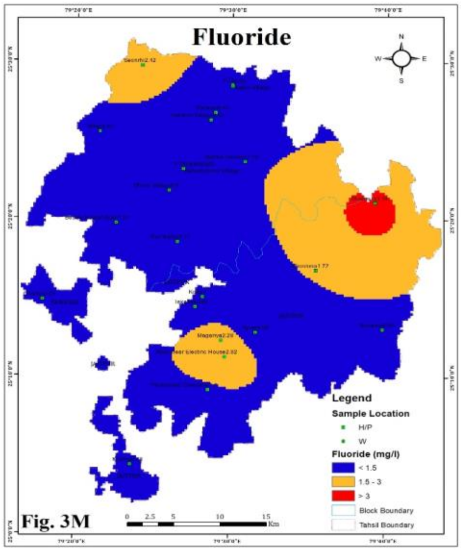

Figure 4M spatial distribution map of F

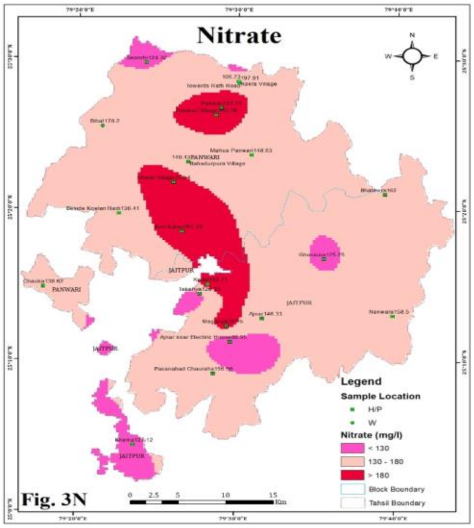

Figure 4N spatial distribution map of NO3

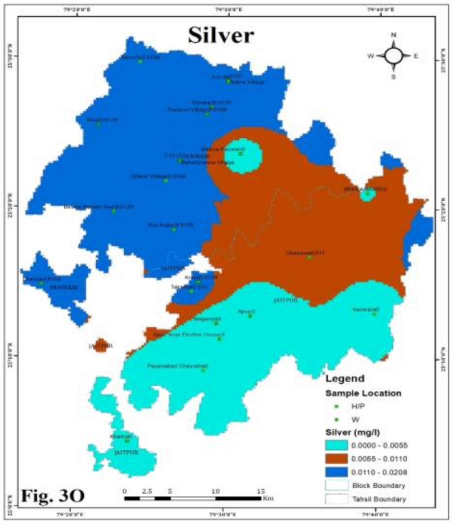

Figure 4O spatial distribution map of Ag

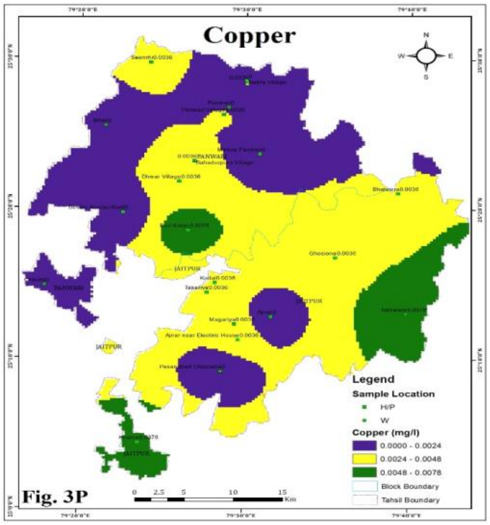

Figure 4P spatial distribution map of Cu

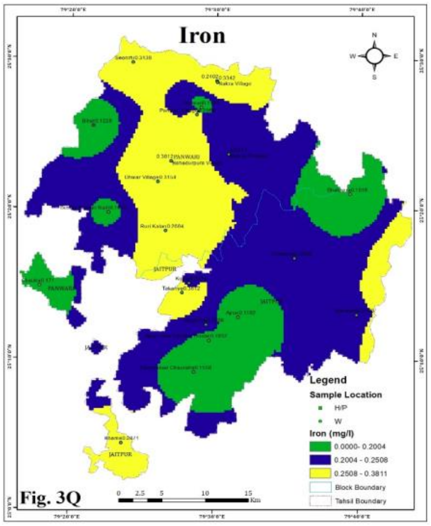

Figure 4Q spatial distribution map of Fe

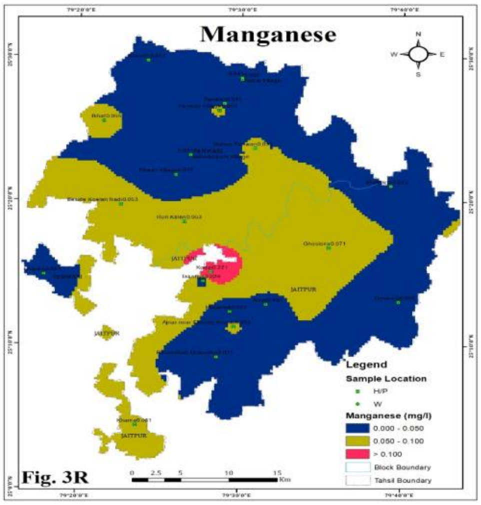

Figure 4R spatial distribution map of Mn

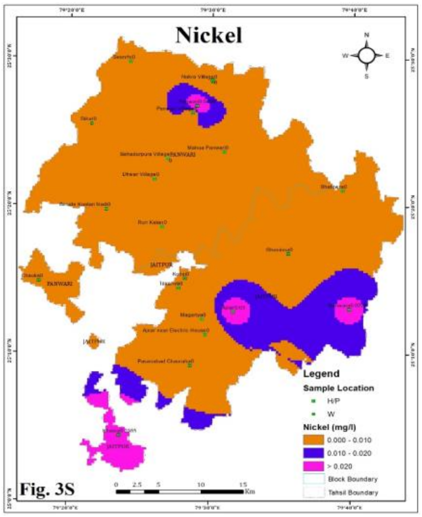

Figure 4S spatial distribution map of Ni

Figure 4T spatial distribution map of Zn

The map clearly indicates that groundwater quality in Panwari Block mainly belongs to excellent and good categories and is suitable for drinking as well as for other domestic uses. In the Jaitpur block there is a noticeable variation in the quality class. A remarkable portion in the SW part is affected by poor-very poor-unsuitable categories while SE part is covered by good-poor-very poor category and needs sincere effort for a detailed zonation at micro-level to understand properly and provide accurate information to the residents as well as policy makers.

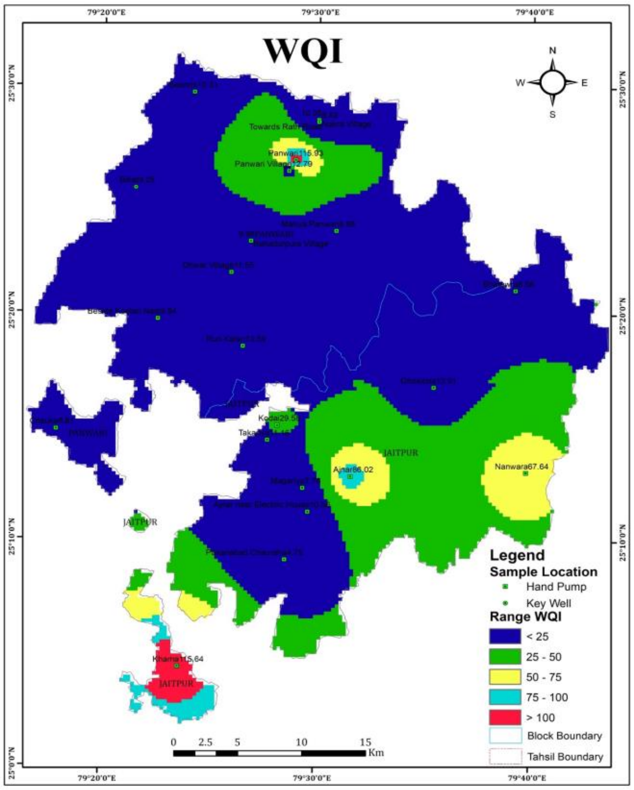

Fig. 4 Water Quality Index map of the study area, Kulpahar Watershed, Mahoba

TABLE 4

Weight (w_i), Relative Weight (W_{ir}) & Unit Weight (W_i) of each groundwater quality parameter

Parameters	BIS Standard	Weightage (wi)	Relative Weightage (Wir)	Wi= K/Sn
Ph (On Scale)	6.5-8.5	1	0.0333	0.0016
EC (µS/cm)	300	2	0.0667	0.0000
TDS (mg/l)	500-2000	1	0.0333	0.0000
AK (mg/l)	200-600	1	0.0333	0.0001
TH (mg/l)	200-600	1	0.0333	0.0001
Ca^{2+} (mg/l)	75-200	1	0.0333	0.0001
Mg^{2+} (mg/l)	30-100	1	0.0333	0.0004
Na^{+} (mg/l)	-	2	0.0667	0.0002
K^{+} (mg/l)	-	1	0.0333	0.0011
HCO_3^{-} (mg/l)	300-600	1	0.0333	0.0000
SO_4^{2-} (mg/l)	200-400	1	0.0333	0.0001
Cl^{-} (mg/l)	250-1000	1	0.0333	0.0000
F^{-} (mg/l)	1-1.5	2	0.0667	0.0105
NO_3^{-} (mg/l)	45	3	0.1000	0.0002
Ag (mg/l)	0.1	2	0.0667	0.1054
Cu (mg/l)	0.05-1.5	2	0.0667	0.2107
Fe (mg/l)	1	2	0.0667	0.0351
Mn	0.1-0.3	2	0.0667	0.1054

(mg/l)				
Ni (mg/l)	0.02	2	0.0667	0.5268
Zn (mg/l)	5 - 15	1	0.0333	0.0021
		Σw_i=30	$\Sigma \mathbf{W}_{ir}$=1.0	ΣW_i=1.0

TABLE 5

Water Quality Index and its groundwater quality class for each hydro-station in study area, Kulpahar Watershed, Mahoba

Sam. No	Hydro-station	Abstraction Structures	WQI Values	Rating Class
S-1	Ajnar	Hand Pump	86.02	Very Poor
S-2	Panwari	Hand Pump	115.93	Unsuitable
S-3	Pasanabad Chauraha	Hand Pump	4.75	Excellent
S-4	Ajnar near Electiric House	Hand Pump	10.56	Excellent
S-5	Beside Koelari Nadi	Hand Pump	9.94	Excellent
S-6	Magariya	Hand Pump	7.78	Excellent
S-7	Mahua Panwari	Hand Pump	8.98	Excellent
S-8	Towards Rath Road	Hand Pump	10.35	Excellent
S-9	Kodai	Hand Pump	29.58	Good
S-10	Ruri Kalan	Hand Pump	13.59	Excellent
S-11	Panwari Village	Hand Pump	12.79	Excellent
S-12	Dhwar Village	Hand Pump	11.55	Excellent
S-13	Nakra Village	Hand Pump	8.52	Excellent
S-14	Bahadurpura Village	Hand Pump	9.98	Excellent
S-15	Takariya	Hand Pump	11.16	Excellent
S-16	Khama	Hand Pump	115.64	Unsuitable
S-17	Chauka	Hand Pump	8.81	Excellent
S-18	Bihat	Key Well	9.25	Excellent
S-19	Seonrhi	Hand Pump	10.31	Excellent
S-20	Bhatewra	Hand Pump	8.56	Excellent
S-21	Ghosiona	Hand Pump	13.91	Excellent
S-22	Nanwara	Hand Pump	67.64	Poor

V. CONCLUSION

The observations of the groundwater quality class of the area under investigation reflects that the extreme southern part of the Kulpahar watershed, district Mahoba of Bundelkhand region is dominant with poor water quality index (WQI) due the occurrence of granite massif with isolated patches of Alkali granite and Syenite.

The prolonged interactions between water and country rock has resulted the enriched fluoride concentration in groundwater. The presence of higher TDS and total hardness in certain patches may be corroborated with the occurrence of syenite and alkali granite. The poor fluxing of groundwater is responsible to deteriorate the groundwater quality in the study area. The unlined septic tanks, unplanned sewerage system and other anthropogenic activities have triggered the nitrate concentration in groundwater particularly in central and northern part of the study area. The remaining area is quite safe and bears excellent to good quality of groundwater suitable for human consumption.

VI. ACKNOWLEDGEMENT

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