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GIS-Based Evaluation of Water Quality Index of Groundwater Resources in West Bokaro coalfield, India

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ABSTRACT

Water Quality Index (WQI), a technique of rating water quality, is an effective tool to assess quality and ensure sustainable safe use of water for drinking. The present work is aimed to assess the groundwater quality of West Bokaro coalfield region for knowing the suitability of drinking purpose by calculating the WQI and using Geographical Information System (GIS) techniques. Thirty three groundwater samples were collected from dug wells during post-monsoon, 2012 for comprehensive physico-chemical analysis. Ten parameters were considered for calculating the WQI such as: pH, fluoride (F^-), chloride (Cl^-), nitrate (NO_3^-), sulphate(SO_4^{2-}), bicarbonate (HCO_3^-) calcium(Ca^{2+}), magnesium (Mg^{2+}), total hardness (TH) and total dissolved solid (TDS). The spatial distribution maps of the above mentioned parameters were prepared by using GIS, software. The computed WQI value ranges from 21 to 131 with an overall average of WQI value 73. More than half of the locations fall in Excellent to Good category indicating the groundwater in the study area is suitable for drinking purposes.

Key words: Water quality index**,** Groundwater, West Bokaro coalfield, GIS.

INTRODUCTION

Groundwater is the major source for drinking and domestic purposes in both rural and urban areas. Besides, it is an important source for both agriculture and industrial sectors.In the last few decades, there has been a tremendous increase in the demand for fresh water due to the rapid growth of population and the accelerated pace of industrialization. Rapid urbanization, especially in developing countries like India, has affected the availability and quality of groundwater due to its overexploitation and improper waste disposal, especially in urban areas (Ramakrishnalah *et al*. 2009) .Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source therefore it becomes very important to regularly monitor the quality of groundwater and to device ways and means to protect it (Mufid al-hadithi 2012). Water pollution not only affects water quality, but also threats human health, economic development, and social prosperity (Milovanovic2007). Access to drinking water in India has increased over the past few decades with the tremendous adverse impact of unsafe water for health (Singh *et al.* 2013). According to World Health Organization (WHO), about 80% of all the diseases in human beings are caused by water. It is estimated that about 21 % of the communicable diseases in India are water borne (Bradon and Homman1995). Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of West Bengal, Jharkahnd, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab (Tiwari & Singh 2014).

Water Quality Indexis an important way to assess the quality of groundwater in the recent years. WQI is an a superior way to the understanding of water quality issues by integrating complex data and generating a score, which ultimately describes the water quality status(Tiwari *et al.* 1985; Singh,D. F. 1992; Rao, S.N; 1997; Mishra *et al.*2001).GIS is a computer system for capturing, storing, querying, analyzing and displaying all types of geographical data. GIS allowsviewing, understanding, questioning, interpreting, and visualizing data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts.GIS is an effective tool not only for collection, storage, management and retrieval of a multitude of spatial and non-spatial data, but also for spatial analysis and integration of these data to derive useful outputs and modeling (Gupta and Srivastava *et al*. 2010). It can be a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment and managing water resources on a local or regional scale (Tjandra *et al*. 2003). GIS is widely used for collecting diverse spatial data and for overlay analysis in spatial register domain to represent spatially variable phenomena (Bonham-Carter1996;Babikeretal.2004; Guptaand Srivastava2010). GIS-based, simple, and robust WQI is an essential tool for rapid transfer of information to water resources managers and the public. GIS can be useful for taking quick decisions as graphical representation would be easy to take a policy decision by the makers (Singh *et al*. 2013).

Nowadays, groundwater pollution has become a major problem in the world and need a regular monitoring of water bodies with required number of parameters for the welfare of the society. WQI is one of the most effective expressions which reflect a composite influence of contributing factors on the quality of water of any water system (Tiwari *et al*. 1986).The major objective of the present study to assess the suitability of groundwater quality for drinking purpose and generated water quality mapsusing GIS based on the available parameters from 33 locations in West Bokaro coalfield. This study will be usefull in current water resource planning and provide some basic data for the rational exploitation and use of water resources in the future.

Study area

The West Bokaro coalfield lies between 23° 41' to 23° 52' N latitude and 85° 24' to 85° 41' E longitude (Fig.1) comprising an area of 207 Sq. Km. It is geographically separated from the East Bokaro coalfield by conspicuous Lugu Hill (987 m). The entire coalfield falls in the Ramgarh District of Jhrakhand.It is a major storehouse of medium coking coal.The coalfield is drained by Bokaro River passing through the central part of coalfield with easterly flows. Chutua River is the main tributaries of the Bokaro River which drains the northern hilly terrain of the coalfield. Chotha River is also the tributaries of Bokaro River which drains the Southern region of the coalfield. The West Bokaro coalfield is fourth from east among the Damodar Valley coalfield.

The West Bokaro coalfield forms a broad syncline with its trending E-W and exhibits a complete sequence of lower Gondwana formation which rest unconformably a basement rocks (Fig. 1). The Barakar Formation covers the major part of the coalfield and comprises of coarse to fine grained sand stone , pebbly conglomerates, gritty sandstones , grey shales , carbonaceous shales , fire clays and coal seams. The total of 29 correlates coal seams in Barker formation with 13 major seams (seam XIII to me and Karharbari formation contain only one seam (seam 0). The coals from West Bokaro- coalfield range from non-coking to almost prime coking type.The upper coal seams in the south western part are generally non – coking whereas the coal seams occurring in the northern part of the coalfield are more mature and medium coking to almost prime coking. In general improvement in the rank of coal from east to west and alsowith depthis observed.

The West Bokaro coalfield area experiences tropical climate and is characterized by very hot pre-monsoon and cold post- monsoon season. The month of May and mid June is the peak of the pre - monsoon season with an average maximum temperature of 44°C, while December and January are the coldest months. The average annual rainfall of the district is 1418 mm and more than 85% of annual rainfall occurs during the four monsoon months (June to September).

MATERIALS AND METHODS

For the assessment of groundwater quality of the West Bokaro coalfields, systematic samplings were carried out duringpost-monsoon, 2012. Thirty three groundwater samples were collected from dug wells of the West Bokaro coalfield area (Fig. 1). The groundwater samples were collected in one liter narrow mouth pre-washed polyethylene bottles. Electrical conductivity (EC) and pH values were measured in the field using a portable conductivity and pH meter (Consort C831).In the laboratory, the water samples were filtered through 0.45 ìm Millipore membrane filters to separate suspended particles. Acid titration and were used to determine the concentration of bicarbonate (HCO_3^-) in water (APHA 1998). Major anions (F^-, Cl^-, SO_4^{2-} and NO_3^-) were analysed onion chromatograph (Dionex Dx-120) using anions AS12A/AG12 columns coupled to an anion self-regenerating suppressor (ASRS) in recycle mode. Major cations (Ca^{2+}, Mg^{2+}, and Na^+) were measured by Atomic Absorption Spectrophotometer (Varian 680FS) in flame mode after calibrating the instrument with known standards.Three replicates were run for each sample for cation analysis and the instrument recalibrated after every 15 samples. An overall precision, expressed as percent relative standard deviation (RSD), was obtained below 10% for the entire samples.

Water Quality Index

WQI is defined as a rating reflecting the composite influence of different water quality parameters, which is calculated from the point of view of the suitability of groundwater for human consumption.The concept of WQI was firstly used by Horton (1965), and then developed by Brown et.al. (1970) and further improved by Deininger (Scottish Development Department, 1975).WQI a well known method as well as one of the most effective tools to express water quality that offers a simple, stable, reproducible unit of measure and communicate information about water quality to the policy makers and concerned citizens (Singh *et al.* 2013). It thus, becomes an important parameter for the assessment and management of ground water (Venkata and Reddy, 1995).WQI summarizes large amounts of water quality data into simple terms (e.g., excellent, good, bad, etc.) for reporting to management and the public in a consistent manner.The WQI can also be used for estimating water quality on-line, but the accuracy of the model depends upon the judicious selection of parameters.

Various researchers have considered the spatial groundwater quality index and the procedure of weighing is widely used to identify the quality of the water (Ckakraborthy *et al.*, 2007; Bhaskar and

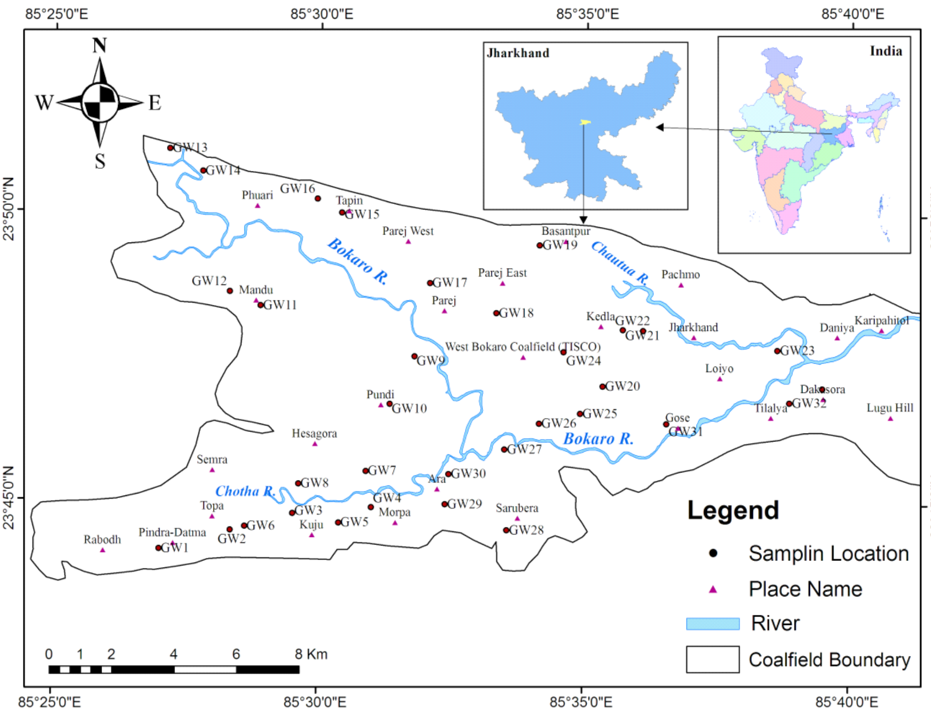

Fig. 1: Sampling location map of the West Bokaro coalfield

Nagendrappa 2008; Ramakrishnalah *et al.* 2009, Sathish, 2011, Mufid al-hadithi 2012; Reddy and Patode 2013).

GIS analysis

Generated spatial distribution maps for the nitrate, sulphate, total hardness and total dissolved solid have been created for West Bokaro coalfield. Developed groundwater quality classification map from different thematic layers (Fig. 2a–c) based on Indian (ISI 2003) Standards for Drinking Water by using the ARC GIS 9.3 software. The classification of water quality is essential to an assessment of the suitability of water for domestic purposes.

Table 1: Relative weight of chemical parameters

Chemical parameters	Standards (BIS)	Weight (*Wi*)	Relative weight (*Wi*)
pH	8.5	4	0.11
Total dissolved solids	500	5	0.13
Fluoride	1	5	0.13
Chloride	250	5	0.13
Nitrate	45	5	0.13
Sulphate	200	5	0.13
Bicarbonate	200	1	0.03
Calcium	75	3	0.08
Magnesium	30	3	0.08
Total Hardness	300	2	0.05
		ΣWi=38	ΣWi =1.00

All concentration in mg/l, accept pH.

Table. 2: Classification of WOI range and category of water

WQI Range	Category of water
<50	Excellent water
50-100	Good water
100-200	Poor water
200-300	Very Poor water
>300	Unfit for drinking purpose

RESULTS AND DISCUSSION

The pH of groundwater samples in the study area was found to be slightly acidic to slightly alkaline in nature. The F^- and Cl^- concentration measured in study area were below in the desirable limit while the NO^-_3 (Fig. 2a) and SO^{2-}_4 (Fig. 2b) ion concentration is within both desirable and max. Permissible limits. The classification maps of TDS (Fig. 2c), Ca^{2+} and

Table. 3: Water Quality Index for Groundwater of West Bokaro coalfield

S. No.	Sample Code	Sample Descripation	WQI	Description
1	GW1	Datma	94	Good
2	GW2	Topa	66	Good
3	GW3	Orla	38	Excellent
4	GW4	Murpa	101	Poor
5	GW5	Kuju	69	Good
6	GW6	Nayamore	50	Good
7	GW7	Hesagara	92	Good
8	GW8	Hesagara	53	Good
9	GW9	Pundi	56	Good
10	GW10	Pundi	61	Good
11	GW11	Mandu	101	Poor
12	GW12	Mandu	114	Poor
13	GW13	Charhi	75	Good
14	GW14	Charhi	78	Good
15	GW15	Tapin North	38	Excellent
16	GW16	Tapin	131	Poor
17	GW17	Parej East	21	Excellent
18	GW18	Parej	44	Excellent
19	GW19	Basantpur	131	Poor
20	GW20	Kedla	83	Good
21	GW21	Kedla	93	Good
22	GW22	Jharkahnd	91	Good
23	GW23	Laiyo	54	Good
24	GW24	Bhalghara	43	Excellent
25	GW25	Lahatungri	122	Poor
26	GW26	Mukund Beda	63	Good
27	GW27	Butbera	49	Excellent
28	GW28	Saruber	54	Good
29	GW29	Ara	38	Excellent
30	GW30	Ara	129	Poor
31	GW31	Chainpur	53	Good
32	GW32	Badgon	87	Good
33	GW33	Jageshvar Bihar	51	Good

Mg^{2+} vary between the desirable and permissible limit. The concentration of total hardness varies from soft to very hard categories.

Estimation of WQI

Water quality index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water (Singh *et al.* 2013). WQI is a mathematical equation used to transform a large number of water quality data into a single number (Stambuk-Giljanovic 1999). It is simple and easy to understandable for decision makers about quality and possible uses of any water body (Bordalo *et al.* 2001). For assessing the suitability of drinking water, the water quality data of the analyzed samples were compared with the prescribed drinking water standard of BIS 2003 (IS:10500) have been considered for the calculation of WQI. The Indian Standards as per ISI for the drinking water together with its corresponding status categories of WQI (Rao1997). In computing WQI three steps are followed. In the first step, each of the 10 parameters (pH, TDS, F^-,Cl^-, NO_3^-, SO_4^{2-} HCO_3^-, Ca^{2+}, Mg^{2+} ,TH) has been assigned a weight (*w i*) according to its relative importance in the overall quality of water for drinking purposes (Table1)

The maximum weight of 5 has been assigned to the parameters like TDS, F^-,Cl^-, NO_3^-, and SO_4^{2-} due to their major importance in water quality assessment (Vasanthavigar *et al.* 2010). HCO_3^- is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment.

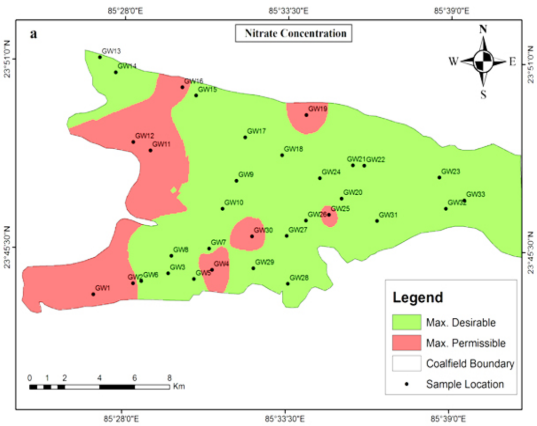

Fig. 2(A): Distribution of nitrate concentration in West Bokaro coalfield area

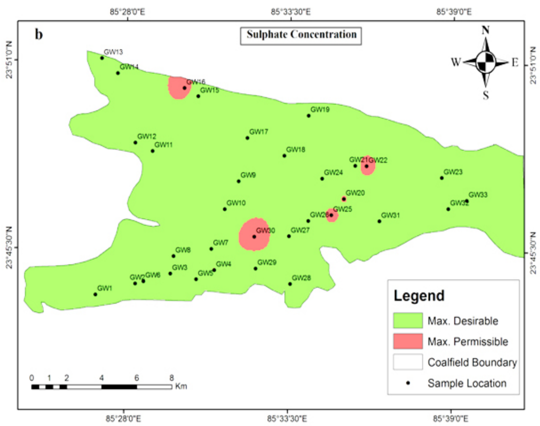

Fig. 2(B): Distribution of sulphate concentration in West Bokaro coalfield area

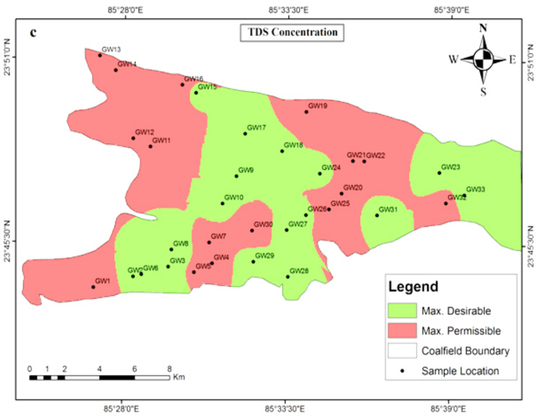

Fig. 2(C): Distribution of TDS concentration in West Bokaro coalfield area

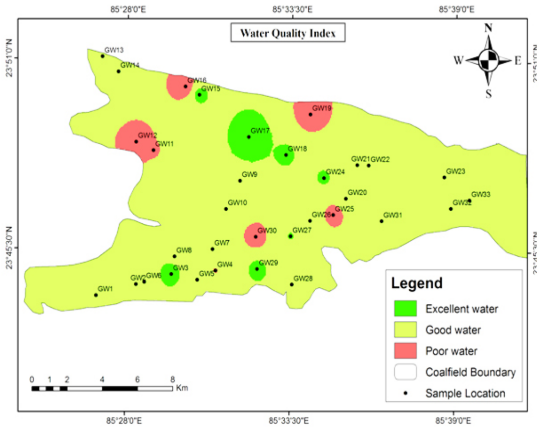

Fig. 3: Water quality index map of the West Bokaro coalfield area

Other parameters like Ca^{2+}, Mg^{2+} Na^{+}, and TH were assigned a weight (*w i*) between 1 and 5 depending on their importance in water quality determination. In the second step, the relative weight (*W i*) is computed from the following equation:

$$W_i = w_i / \sum_{i=1}^{n} w_i$$

Where, the W_i is the relative weight, *W i* is the weight of each parameter and n is the number of parameters.

Calculated relative weight (*W i*) values of each parameter are given in (Table1).

In the third step, a quality rating scale (*q i*) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS 10500 (2003) and the result is multiplied by 100:

$$q_i=(C_i/S_i)\times 100$$

Where, the *qi* is the quality rating, *Ci* is the concentration of each chemical parameter in each water sample in mg L^{-1} and *Si* is the BIS standard for each chemical parameter in mg L^{-1} according to the guidelines of the BIS 10500 (2003).

For computing the WQI, the *SI* is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$SI_i = W_i \times q_i$$

$$\mathrm{WQI} = \sum SI_i$$

Where, the *SIi* is the sub-index of ith parameter, *qi* is the rating based on concentration of ith parameter and n is the number of parameters

Water quality category, were determined on the basis of WQI. The computed WQI values range from 21 to 131 and average 73 respectively. WQI range and category of water can be classified (Table2). The highest WQI were calculated from the samples collected from the Murpa, Mandu, Tapin, Basntpur, Lahatungi and Ara sampling locations (Table3).The reason for high WOI in the study area may be due to the natural and anthropogenic sources (mining activity, agriculture wastes, domestic sewage disposals etc.) Among all the of the groundwater samples, the percentage (%) of WQI categories Excellent (21%), Good (58%) and Poor (21 %) were observed. More than half the location falls in Excellent to Good category (fig. 3).

CONCLUSIONS

The above study indicates that the groundwater of variable quality exists in the West Bokaro coalfield area. However, despite the coal mining and industry, an analysis of the chemistry of 33 dug wells sample indicates it is generally suitable for drinking purposes, except some locations. The WQI shows that 79% of groundwater samples were found as Excellent to Good category and can be used for direct consumption while 21% of water samples are the Poor category,samples show that the water is not suitable for direct consumption and requires treatment before its utilization.Suitable water treatment process such as water softening, ion exchange and reverse osmosis should be used to reduce the concentrations of contaminants in the study area.

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