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An integrated approach for evaluation of groundwater quality in Korba district, Chhattisgarh using Geomatic techniques

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Abstract

Aim: The objective of the study was to evaluate and assess present groundwater quality scenario by developing groundwater quality index map for Korba district in Chhattisgarh.

Methodology: For the study, well wise water quality data was collected for 719 villages over the period of six years from 2009 to 2015. The relative weights, quality rating scale and accordingly weighted values were calculated to estimate the overall groundwater quality index (GQI) and calculation of GQI was carried out for 10 parameters such as pH, turbidity, total hardness, chloride, calcium, nitrate, iron, magnesium, sulphate and fluoride. GQI map was developed by creating spatial reference to point locations for which the quality of groundwater is known using GIS software.

Results: The concentration of the parameters in the study area was found in the following order: Turbidity > Iron > pH > Fluoride > Nitrate > Magnesium > Calcium > Chloride > Total Hardness > Sulphate. Groundwater quality index map show decrease in water quality from north to east in the study area. According to the classification of GQI, 8.86% of water sampling locations were found having GQI less than 100 means bearing good quality water and 91.14% having GQI greater than 100 indicating non potable water.

Interpretation: Application of GQI in the present work communicates comparative information on groundwater quality of Korba district. Presence of low water quality in the study area may be attributed due to mining activities and overexploitation of groundwater. Analysis suggests that groundwater in the study area needs specific treatment before supply to the public as potable water.

Introduction

Earth is known as "The Blue Planet" because of its massive oceans and other water bodies, which is unique in universe for its quality of living organisms and water is essential for existence of living organisms. Water pollution simultaneously affects the water quality and threatens the economic development and social prosperity of human health (Al-Rajab and Hakami, 2014). On earth, water is available as surface water and groundwater. Major part of the population from urban and rural areas depends on subsurface water. Subsurface water is one of the essential and valuable natural resource, which not only supports the life on the earth but governs the agricultural, industrial, economical and social growth of human beings, however due to population growth, urbanization and industrialization, the demand for groundwater is potentially increasing day by day, which imposes pressure on groundwater resources and leads to higher concentration of elements.

Groundwater quality deterioration of a specific area depends on a large number of individual hydrological, physical, geochemical and biological factors (Ilavarasan *et al.*, 2016). Generally higher proportions of dissolved constituents are found in groundwater compared to surface water because of greater interaction of groundwater with various materials in geologic strata. In addition, inferior water quality may also be observed in a region due to continuous abstraction of shallow fresh groundwater (Islam *et al.*, 2014). This may be due to percolation of chemicals from land surface, confining aquifers or adjacent aquifers that contain polluted or saline water. A wide range of measured variables associated with contamination sources is among the factors contributing to the complexity of groundwater quality assessment and monitoring (Srivastava *et al.*, 2009).

In order to integrate water quality variables, water quality index have been developed which transform large quantity of water quality data into a single number and express as a single term (Shiji *et al.*, 2016). By determining of Water Quality Index (WQI), suitability of groundwater and surface water samples for the purpose of human consumption can be assessed (Ravikumar *et al.*, 2013).

In developing countries like India around 80% of water borne diseases can be attributed to poor drinking water quality and unhygienic conditions (Balakrishnan *et al.*, 2011). Scientific efforts has been taken to address the problem of water quality in India led by Rajiv Gandhi National Drinking Water Mission (RGNDWM) with external agencies like United Nations Children's Fund (UNICEF). As assessment of groundwater quality was not given due importance, water borne diseases have become common now a days. In environmental quality management related to potable water, paramount importance is given to water quality (Sundara Kumar *et al.*, 2010). In India, various groundwater research works of similar nature have been carried

out to identify potential sites for groundwater assessment and management (Remesan and Panda, 2007). GIS mainly handles the layer wise existing geographical features, capable to analyze and represents the computational multimap integrations (Subramani *et al.*, 2012). GIS plays a vital role in assessing the water quality status as well as the solutions towards water quality related issues (Shankar *et al.*, 2010). Several aspects which contribute the drinking water crisis are rapidly increasing trend of population, industrial needs, unnecessary over exploitation of groundwater, change of land use pattern, environmental hot-spot etc (Shomar *et al.*, 2010).

The focused research was an attempt to map the quality of groundwater of Korba district in Chhattisgarh by creating spatial reference to point locations for which the quality of groundwater is known using GIS. The study also aimed to calculate GQI and develop GQI map for better understanding of the groundwater quality scenario in the study area.

Materials and Methods

Study area: Korba district was selected as the study area, which is one of the well known districts for the major coal production areas in Chhattisgarh, as well as in Central India. The total area of open cast coal mines is about 530 sq. km within the district. In most of the open cast mines, coal excavation is carried out more than hundred meters below from the ground surface, resulting in huge groundwater deterioration in the area. The study area is shown in Fig. 1a, which is located in the east-central part of Chhattisgarh. It comprises of total 719 villages under five blocks namely Korba, Katghora, Kartala, Pali and Podi-Upraro are shown in Fig. 1a. River Hasdeo flows north to south throughout its length in the district and eventually joins the Mahanadi River (Fig.1a). Geologically, Korba district is underlain mainly by three distinct geological formations ranging in age from Achaean to Recent. The geology map of the study area is shown in Fig. 1b. From geological point of view, Korba district can be categorized into three groups such as Chhota Nagpur Gneissic Complex, Chhattisgarh Super Group of rocks, Gondwana Super Group of rocks with various formations. According to the formations, study area is divided into 22 parts (Fig.1b). The granite and granitic gneiss rocks of Chhota Nagpur Group, occupy western and south-western parts of the study area (Fig.1b). Phyllite and quartzite has limited occurrence towards the southern part and western, south-western part of the district, respectively (Fig.1b). The rocks of Chhattisgarh Super Group overlying the basement crystalline are represented by the sandstone, limestone and shale sequence occupying small area at the southern part of the region (Fig.1b). The rocks of Gondwana Super Group constitute the major part of the district and is represented by sandstone, shale and coal seams with various combinations (Fig.1b). Ferruginous sandstone with carbonaceous shale and very thin coal seams of Kamthi formation forms prominent ridges in the eastern part of the district (Fig.1b). The basalts occur as narrow

Fig. 1(a) : Location map of study area

Fig. 1 (b) : Geology map of study area (source CGCOST, Raipur)

linear ridges in the northern part of the district (Fig.1b). Few laterite capings with small lenses of bauxite occur in the east-central and west-central part of the area over Barakar and Kamthi sandstone (Fig.1b). The pre-monsoon groundwater level varies from 3.18 to 13.47 meter below ground level (mbgl) with average water level of 8.3 mbgl and the post-monsoon water level varies from 0.81 to 10.21 mbgl with average water level of 4.5 mbgl according to Central Groundwater Board (CGWB). The yield in granitic rocks varies from 0.5 to 3.5 lps. The yield in sedimentary formation varies from 0.28 to 7.1 lps (Source: Groundwater Brochure of Korba District, Chhattisgarh, 2012).

Data source and processing : In the present study, topographical maps (64J 05,06,07,10,11,14,15 &16) of Survey of India (SOI) on 1:50,000 scale, IRS LISS III digital data Path 102, 103 Row 56 was used. GIS software was used for database creation and generation of thematic layers for various parameters. Groundwater quality data was collected for 719 villages from CGCOST, Raipur over a period of 6 years from 2009 to 2015. Attribute database for the present study was prepared in GIS by taking the mean value of each parameter. Ten groundwater quality parameters namely pH, turbidity, total hardness, calcium, magnesium, sulphate, iron, fluoride, nitrate, chloride were selected for determining of GQI. Weighted Arithmetic index method was used for determining of GQI (Cude, 2001).

Data interpolation : For obtaining the spatial distribution of above mentioned groundwater quality parameters, Inverse Distance Weighting (IDW) method was used to interpolate data points. Using these techniques, element wise groundwater quality thematic maps of Korba district was predicted for unknown locations for each parameter. The entire element wise groundwater parameter layers (pH, turbidity, total hardness, calcium, magnesium, sulphate, iron, fluoride, nitrate, chloride) were integrated using GIS software. As a result of integration a combined groundwater quality layer (GQI map) was generated.

Results and Discussion

Chemical contaminants may provoke various health issues such as trouble in breathing, dermatitis, methemoglobinemia, etc. (WHO, 2015). Table 1 shows the summary of physico-chemical parameters with their ranges as per BIS standards and total area contaminated or not contaminated. The pH value is less than 6.5 which covers an area of 159.56 sq. km and pH value more than 6.5 which covers an area of 6985.88 sq. km (Table 1) of the study area. Low pH concentration was observed in the study area may be due to acid mine drainage (AMD) or spill of acidic materials from the industries. AMD is a waste product of the mining as well as mineral industries which carries highly polluted water because of low pH, dissolved heavy metals and sulphate (Kumari *et al.*, 2010). pH of potable water is not a health related issue; however, since low acidic nature of

water can leach metals from plumbing systems can cause health problems (Rahmanian *et al.*, 2015).

Turbidity value was less than 5 NTU which covers 1380.08 sq. km and major part of the area 5765.36 sq. km (Table 1) having turbid water (more than 5 NTU). Higher concentration of turbidity observed may be due to anthropogenic impact on groundwater. Armah *et al.* (2010) highlighted the issue of contamination of groundwater in Tarkwa gold mining area at Ghana, due to anthropogenic activities and the need to mitigate the risks associated with humans drinking it. Turbidity of water less than 5 NTU is acceptable for human consumption (WHO, 2012). Highly turbid water (greater than 5 NTU) may indicate the presence of pathogens (Rahmanian *et al.*, 2015).

Major part of the study area showed total hardness concentration to be within the desirable limit as per BIS guidelines (IS: 10500:1991). An area of 7141.55 sq. km was found to have total hardness concentration less than 300 mg l⁻¹ and 3.89 sq. km (Table 1) having more than 300 mg l⁻¹, respectively. Calcium and magnesium contents are responsible for the hardness of water (Prasanth *et al.*, 2012). Calcium concentration values less than 75 mg l⁻¹ covered 192.48 sq. km (Table 1), whereas an area of 6940.67 sq. km (Table 1) was found to have calcium concentration ranging between 75-200 mg l⁻¹ (within the permissible limit) and 12.29 sq. km (Table 1) area having calcium concentration more than 200 mg l⁻¹ (above the permissible limit). Similarly magnesium

Table 1 : Summary of physico-chemical parameters and areal extent of contamination

Parameter	Range	Area cover (in sq.km)
pH	< 6.5	159.56
	> 6.5	6985.88
Turbidity	< 5	1380.08
	> 5	5765.36
Total hardness	< 300	7141.55
	> 300	3.89
Calcium	< 75	192.48
	75-200	6940.67
	> 200	12.29
Magnesium	< 30	13.97
	30-100	7118.10
	> 100	13.37
Sulphate	< 200	7145.44
Iron	< 0.3	471.79
	0.3-1.0	4410.96
	> 1.0	2262.69
Fluoride	< 1.0	6889.77
	1.0-1.5	172.76
	> 1.5	82.91
Nitrate	< 45	7118.63
	> 45	26.81
Chloride	< 250	7133.51
	> 250	11.93

Table 2 : The percentage of areal extent of GQI

Status	Scores	Area cover (in sq. km)	Percentage (%) of area covered
Excellent	0 – 50	3.91	0.06
Good	51 – 100	629.45	8.80
Poor	101 – 200	3133.15	43.85
Very Poor	201 – 300	1793.63	25.10
Unfit for Drinking	> 301	1585.30	22.19

concentration less than 30 mg l⁻¹ was observed in an area of 13.97 sq. km (Table 1), an area of 7118.10 sq. km (Table 1) was found to be within the permissible limit (30-100 mg l⁻¹) where as 13.37 sq. km (Table 1) area showed magnesium concentration above permissible limit (more than 100 mg l⁻¹). Prasanth *et al.* (2012) reported that the higher calcium content may cause abdominal ailments and is not suitable for domestic purposes as it causes scaling and encrustation. Similarly intake of low calcium content increases risks of osteoporosis, nephrolithiasis, colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity (WHO, 2009). Moderate to high concentration of magnesium (10-100 mg l⁻¹) in drinking water potentially prevents 4.5 million heart disease and stroke deaths yearly, worldwide (Rosanoff, 2013). Deficiency or inadequate intake of magnesium increases risk of developing pathological problems to humans such as vasoconstrictions, hypertension, cardiac arrhythmia, atherosclerotic vascular disease, acute myocardial infarction, and eclampsia in pregnant women, possibly diabetes mellitus of type II and osteoporosis (Saris *et al.*, 2000). Sulphate content in the entire study area (7145.44 sq. km) was observed within the desirable limit *i.e.* less than 200 mg l⁻¹ (Table 1).

The study area was mostly influenced by iron concentration. An area of 471.79 sq. km (Table 1) was observed having iron concentration less than 0.3 mg l⁻¹ (within desirable limit), 4410.96 sq. km (Table 1) area comes within the permissible limit of 0.3-1.0 mg l⁻¹, where 2262.69 sq. km (Table 1) area was highly affected by iron concentration with more than 1.0 mg l⁻¹ (above permissible limit). Presence of high iron concentration in the study area may be due to iron rich minerals in formation, AMD or corroded water distribution pipes. Ezeigbo and Ezeanyim (1993) reported that high iron content in groundwater was generally found due to the presence of large amount of pyrites in ground strata. Prasad *et al.* (2014) reported that the common forms of iron in nature are iron oxides which promote growth of "Iron bacteria" within iron pipes of water distribution systems. Grazuleviciene *et al.* (2009) reported presence of iron content in high doses in drinking water may cause neurological effects and long term iron toxicity may lead to progressive dysfunction and damage DNA.

One of the major influencing parameter in drinking water is fluoride concentration. An area of 6889.77 sq. km (Table 1) comes

under potable water (less than 1.0 mg l⁻¹), 172.76 sq. km (Table 1) area come within the permissible limit of 1.0-1.5 mg l⁻¹, whereas 82.91 sq. km (Table 1) area was exposed to fluoride concentration higher than 1.5 mg l⁻¹ (above permissible limit). The fluoride concentration observed in the study area may be due to the presence of fluoride rich minerals in the formations and anthropogenic activities. Fordyce *et al.* (2007) reported that high fluoride concentration in the environment might be due to various man made activities such as coal and aluminum industries, use of fertilizer and manufacturing process. Mondal *et al.* (2016) reported fluoride concentration above 1.5 mg l⁻¹ carry an increasing risk of dental and skeletal fluorosis, as well as osteoporosis disease in women.

Nitrate concentration with less than 45 mg l⁻¹ covered an area of 7118.63 sq. km (Table 1), where as nitrate concentration with values greater than 45 mg l⁻¹ extended over an area of 26.81 sq. km (Table 1) in the study area. Elevated nitrate levels in the study area might be due to agricultural activities, inadequate manure management practices and open dump sites of solid wastes. Nitrate consumption may lead to methemoglobinemia in infants popularly called as "Blue Baby" syndrome (Min *et al.*, 2002).

Chloride concentration with less than 250 mg l⁻¹ *i.e.* within desirable limit extended over an area of 7133.51 sq. km (Table 1), where as 11.93 sq. km (Table 1) was observed having chloride concentration more than 250 mg l⁻¹ in the study area. High chloride content may be due to disposal of wastes from industries and leaching of saline residues in the soil. The elevated levels of chloride content in groundwater is marked as an index of contamination and considered as tracer for groundwater pollution (Prasanth *et al.*, 2012).

The concentration of the parameters in the study area was found in the following descending order: Turbidity > Iron > pH > Fluoride > Nitrate > Magnesium > Calcium > Chloride > Total Hardness > Sulphate.

Ten parameters viz., pH, turbidity, total hardness, calcium, magnesium, sulphate, iron, fluoride, nitrate and chloride were considered for the calculation of GQI. Application of GQI in the present work communicates comparative information on groundwater quality of Korba district. The percentage of areal extent of GQI is given in Table 2. Very few locations were having

Fig. 2 (a) : Groundwater Quality Index (GQI) Map

Fig. 2 (b) : GQI values for different wells

excellent (0-50) quality of water (3.91 sq. km i.e. 0.06 %) (Table 2) in the study area. Locations having good (51-100) quality of water covered 629.45 sq. km (8.80%) (Table 2) area, while poor (101-200) and very poor (201-300) quality of water covered an area of 3133.15 sq. km (43.85%) and 1793.63 sq. km (25.10%) (Table 2), respectively. Total area of 1585.30 sq. km (22.19%) (Table 2) comes under unfit for drinking (> 301) category. Armah *et al.* (2010) reported the groundwater samples from all sampling stations had WQI >100 in Tarkwa gold mining area, Ghana and can therefore be considered as unsuitable for human consumption without prior treatment which can be comparable to the present study i.e. GQI > 100 (91.14%) (Table 2). The GQI map of the study area is shown in Fig. 2a. It is divided into five classes such as Excellent, Good, Poor, Very poor, and Unfit for drinking (Fig. 2a). The Groundwater Quality Index map (Fig. 2a) show a decrease in water quality from north to east in the study area. From GIS overlay analysis, it is inferred that quality of groundwater predominantly is of good quality, except in eastern locations (Fig. 2a). Heavy mining activities and agricultural practices in this region may be responsible for the contamination of groundwater. The major contaminated area of the study area belongs to Ferruginous Sandstone with shale and coal seams from Kamthi formation and Sandstone with intercalation of shale and coal seam from Barakar formation of Gondwana Super Group (source: Groundwater Brochure of Korba District, Chhattisgarh, 2012).

The well wise GQI values of the study area is shown in Fig. 2b. The GQI values assigned ranged from 0-50, 51-100, 101-200, 201-300 and greater than 301 (> 301) (Fig. 2b), respectively. For most of the locations, the GQI values were above 100 (Fig. 2b) indicating non potable water. The permissible drinking water limit considered for the study is 100 (Sunil Kumar and Ravindranath, 1998). Ramakrishnaiah *et al.* (2009) recorded WQI of almost 700 in a mining area in Tumkur, India which were significantly high than that reported in the present study. The higher GQI values in the study area may be attributed due to the continuous discharge of industrial effluent, acid mine drainage from mining activities and agricultural practices.

It may be concluded that mining activities, agricultural practices and industrial effluents discharged in the study area contributes for low water quality, hence necessary steps may be taken to improve the water quality in the study area. Stringent rules should be imposed on mining activities and concern regulating authorities should monitor and prevent acid mine discharge to contaminate the valuable surface and groundwater resources.

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