Groundwater Quality in Mineral Rich Areas: A Case Study of Jharkhand

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Abstract: *Mineral rich areas are known for contaminated ground and surface water. In order to resolve this problem, it is imperative to gauge the extent of contamination. This paper is a sincere effort in that direction. To know the suitability of water for drinking purposes and irrigation, chemical parameters like pH, electrical conductivity, concentration of ions are analysed. Various chemical indices such as Sodium Absorption Ratio, Sodium Percentage, Permeability Index, Kelly's Ratio were calculated by adopting the standard procedures of water analysis. The study brings out the local and regional variations in groundwater composition across four districts of Jharkhand.*

Keywords: *Ground water, Minerals, Water Quality, Sodium Absorption Rate, Permeability Index*

I. INTRODUCTION

India is abundantly endowed with mineral wealth. Mineral resources before being harnessed, have to pass through different stages of exploration, mining, and processing. Anthropogenic activities like mining and smelting of metal ores have increased the occurrence of heavy metal on the Earth's surface, which leads to contamination of both soil and water.

Mining waste is commonly disposed on the land surface, the tailings left behind is a serious cause of pollution. Mine waste can augment the mineral content and acidity levels in soil and water. Most mine waste sites are not protected from oxidation and metal release; these sites therefore represent a source of serious contamination to groundwater and aquatic systems for a considerably long period of time.

It is known that the natural chemistry of the groundwater is largely controlled by the dissolution of the geologic materials through which the water flows.

The present study is an effort to characterize the extent and nature of contamination in groundwater, as it relates to mining and processing. Surprisingly little attention has been given to this issue until recently.

II. LITERATURE SURVEY

A number of studies on groundwater quality with respect to drinking and irrigation purposes have been carried out in the different parts of the country .(e.g., Niranjan Babu *et al.*, 1997; Majumdar and Gupta, 2000; Khurshid *et al.*, 2002; Sreedevi, 2004; Subba Rao and John Devadas, 2005; Kumar *et al.*, 2007; Raju, 2007).

Mishra *et al.* (2003) have described the assessment of the quality of water in the mining area of the Keonjhar District of Orissa for drinking and agricultural purposes.

A study by Singh.et.al., focuses on the chemical characteristics of surface, groundwater and mine water of the upper catchment of the Damodar River basin to evaluate the major ion chemistry, geochemical processes controlling water composition and suitability of water for domestic, industrial and irrigation uses.

The study concluded that water chemistry of the area reflected continental weathering, aided by mining and other anthropogenic impacts.

A study by Avishek, Kirti, et.al., assessed the water quality with special reference to fluoride in Majhiaon block of Garwa district in Jharkhand. The study found that over 50% of the samples had high Fluorine content. Iron and Nitrate content also exceeded permissible limit in most samples.

Reddy, K.S. assessed groundwater quality for its suitability for irrigation in semi-arid region of Nalgonda district.

Since most of the area in this region is occupied by hardrock terrains, limited availability of groundwater has resulted in growing number of over-exploited blocks/mandals/taluks (Chatterjee and Purohit, 2009). In these rocks, the groundwater occurs in shallow unconfined aquifers in the weathered residuum and under semi-confined conditions in deeper fracture and joints. The presence of unsaturated fractures has been detected down to 285 m depth but the unsaturated fractures are either non-productive or completely dry (Dev Burman and Das, 1990).

Thus the presence of groundwater is subject to availability of secondary porosity i.e. joints, fractures, fissures and weathered residuum.

As per the report of CGWB (2006), many districts are facing falling levels of groundwater in Jharkhand (Dhanbad, Dumka, Lohardaga, East-Singhbhum, West-Singhbhum, Giridih, Palamu, Hazaribagh and Ranchi).The quality of water is deteriorating as well.

Study Area

The state is underlain by diverse rock types of different geological ages ranging from, Archaean to Recent. The major rock type is Igneous & Metamorphic Rocks covering nearly 85 percent of the geographical area of the state.

Four districts have been chosen for the purpose of study. The basis of selection is predominance of mining, smelting and industrial activity in these districts. However for the purpose of comparison, one district (Ranchi) has been chosen such that it has relatively less mining activity in contrast to the other three which are mining hubs in the state (East Singbhum, West Singbhum and Dhanbad).

Dhanbad

Major rock groups are sandstone shale, limestone and gneisses, coal, fireclay and china clay.

Precambrian basement metamorphic rocks (Granite, granite-gneisses, quartzites, mica schists and amphibolites) are overlain by Talchir Formation (Greenish shale and fine-grained sandstones).

The Damodar Basin is a storehouse of Indian coal. Other than coal, fire clay, bauxite, mica, limestones are associated with the geological formation of the basin.

Besides domestic effluents, these reservoirs receive the pollution load from the various sources like coal washeries, coal mining effluent, mining dumps, coke industries, thermal power plants, mining machineries and vehicular sources. These point and non-point sources of pollution severely affected the quality of the water and sediments

Ranchi

The district is underlain by Pre-cambrian metamorphic rocks viz. Chhotanagpur granites, gneisses and schists. The district has variety of soils, such as red, yellow and sandy soils, while red gravelly and older alluvium occurs occasionally.

The district has 16 big industrial estates of which Heavy Engineering Corporation, Cement Company Ltd., Electric Equipment Factory, High Tension Insulator Factory and Auxiliary Factories comprising of thousands of small scale and cottage industries are important.

East Singbhum

The East Singbhum district is one of the most industrially developed districts of Jharkhand. The major group of industries include metallurgical, automobile, chemical wires and cable units. They are mostly concentrated in Tatanagar and Ghatsila. In addition to large scale industries, there are many other small scale industries such as, khadi and village industries and cement based industries.

The geological formation of the district consists largely of metamorphosed basic igneous rocks of Archaean age. The significant formation i.e. the series of basic lavas flows of Dalma hills, north of Jamshedpur (Tatanagar). Other rocks are schists, mica, quartzite, pegmatite and conglomerate.

West Singhbhum

The district forms part of the southern fringe of the Chhotanagpur plateau and is highly mountainous tract, high hills alternating steep valleys. The district occupies an important place in the industrial map of Jharkhand due to its mineral wealth. Iron ore mines are located in Noamundi, Manoharpur blocks. Other minerals those are available in the district include limestone, china clay, Manganese, soapstones etc.

The geological features of the district are composed of granites and gneisses of Archaean age intrusive into the oldest sedimentary rocks now highly metamorphosed. Iron ore series are originated from igneous rocks and equivalent to a larger part of Dharwar system.

The predominant industrial activity in these districts is as follows-

Sl No.	District	Predominant Activity
1.	Dhanbad(Jharia)	Coal Mining
2.	Ranchi(Muri)	Metal Smelting and processing industry
3.	East Singbhum (Tatanagar, Jadugoda, Rakha, Ghatsila, Musabani	Metal Processing industry- Uranium, Copper
4.	West Singbhum (Noamundi)	Metal Smelting industry -Iron

Two important river basins in the area are :

III. METHODOLOGY

To know the suitability of water for drinking purposes and irrigation, chemical parameters like pH, electrical conductivity (EC), concentration of ions like Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, F^{-}, NO_3^{-}, PO_4^{2-}, SO_4^{2-}, various chemical indices such as Sodium Absorption Ratio (SAR), Sodium Percentage (SP), Permeability Index (PI), Kelly's Ratio (KR) were calculated by adopting the standard procedures of water analysis.

This paper is divided into two sections, where the first part is dedicated to assessment of water for drinking purpose and the second determines suitability of water for irrigation purposes.

Indices used:

- **Sodium percentage**
  This was calculated employing the equation (Todd, 1995) as:
  $$Na\,\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$
- **Sodium Absorption Ratio** (Richard, 1954)
  $$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$$
- **Permeability Index** $=[(Na^{+} + \sqrt{HCO_3^{-}})/(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}) * 100]$ (Raghunath 1987)
- **Kelly's Ratio** $= (Na^{+}/Ca^{2+}+Mg^{2+})$ (Kelley, 1951)

All values expressed in milli equivalents/ litre.

Finally, water is categorized based on classification criteria given by Reddy, K.Srinivasa, 2013, in "Assessment of Ground water quality for irrigation, Nalgonda, India", International Journal of Water Resource and Engineering

A) Suitability for Drinking

Suitability for drinking is assessed by measuring various parameters of water quality against those established by World Health Organisation (WHO) and Bureau of Indian Standards (BIS).

BIS

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 1986 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country. This standard was originally published in 1983. A report prepared by the World Health Organization in cooperation with the World Bank showed that in 1975, some 1230 million people were without safe water supplies. These appalling facts were central to the United Nations decision to declare an International Drinking Water Supply and Sanitation decade, beginning in 1981.

Further, the VI Five-Year Plan of India had made a special provision for availability of safe drinking water for the masses. Therefore, the standard was formulated with the objective of assessing the quality of water resources, and to check the effectiveness of water treatment and supply by the concerned authorities.

If figures are anything to go by, there are about 2.17 lakh quality affected habitations in the country with more than half affected with excess iron, followed by fluoride, salinity, nitrate and arsenic in that order.

Further, approximately, 10 million cases of diarrhoea, more than 7.2 lakh typhoid cases and 1.5 lakh viral hepatitis cases occur every year a majority of which are contributed by unclean water supply and poor sanitation.

WHO (Guidelines for Drinking Water Quality 3rd Edition Vol. 1 Recommendations, 2008)

This standard specifies the acceptable limits and the permissible limits in the absence of alternate source.

IV. RESULT AND DISCUSSION

Seasonal trends

General

- Comparatively lower pH values, in general, is observed in summer.
- An **enrichment of many minor and trace elements** is observed.
- Except Cu and Zn, all the elements analysed exceed drinking water quality standards provided by WHO (2004) and BIS (2003)
- Except PO_4^{2-} and Cl^{-} all ions exceed permissible limits in at least one season.
- Generally, the highest concentrations of major cations are recorded in summer season. This can be explained due to evaporation in the shallow aquifers, aided by elevated temperature in the region.
- Major anions show a wide range of variations.
- The $HC0_3$- is largely contributed by natural mineralization and derives mainly from the elevated soil zone $C0_2$ produced from the decay of organic matter and root respiration which in turn, reacts with rainwater (H_2O) to form HCO_3- at the time of weathering of minerals of the parent rocks. High HC03- concentrations is a typical feature of the region, and this can be attributed to the dissolution of carbonate via biodegradation of organic matter under local reducing condition and reaction of silicates with carbonic acid. The reported high concentration of HC03- is an indication of intense chemical weathering occurring in the drainage basins.
- There is a distinct seasonal variation in TDS concentration with increased values in winter and summer as compared to monsoon season.
- The increase in concentration of conservative Cr^{2+} ion in the groundwater from summer (pre-monsoon) to winter (post-monsoon), supports the leaching of salts stored in the soil weathered zone.

- Studies have shown a high degree of correlation between $N0_3^-$ and Cr^{2+} (*r* =0.75) suggesting their similar sources of origin and their elevated levels indicate that agricultural activities considerably affect groundwater quality.
- The presence of $N0_3^-$, Cr^{2+} is a direct indicator of anthropogenic contaminants from agricultural land uses (irrigation return-flows and chemical fertilizers)
- Higher concentration on NO_3^- ion indicates high concentration of nitrate in infiltrating rain water (agricultural run-off).
- Sulphate concentration is highest in summer and least in monsoon. This can be partly attributed to pyrite oxidation which releases Iron and Sulphate ions. This is also the cause of lowering of pH of water.SO_4^{2-} is contributed by multiple sources, such as atmospheric deposition, agricultural activities and pyrite oxidation. Other sources of Sulphate and chromium are dissolution of halites supplied from saline/alkaline soil, and discharge from groundwater in addition to anthropogenic inputs.
- Sulphate dissolved in groundwater is derived mainly from agricultural activities and decomposition of organic matter in weathered soil.
- Thus the higher concentrations of Cr, SO_4^{2-} and NO_3^- in the groundwater is largely a consequence of anthropogenic activities.
- Both, Calcium and Magnesium ions exist in bicarbonates. The elevated concentrations of Ca^{2+} and Mg^{2+} in summer season may be attributed to the dissolution of carbonate minerals in the case of low or non-existence of groundwater recharge. This explains the low concentration of HCO_3^- during summer season.

Spatial Trends

If districts are ranked on the basis of water quality, Ranchi will perform the best followed by west Singhbhum while East Singhbhum has the worst water quality and Dhanbad is only marginally better.

1. **Dhanbad**

13 out of 18 parameters exceed the permissible limit prescribed by WHO/BIS (whichever is greater). Potassium levels are very high during summer season (13 times the permissible limit).

Concentration of potassium in drinking water is even higher as a consequence of the use of potassium permanganate as an oxidant in water treatment.

Potassium Chloride is also used for water softening in place of, or mixed with, sodium chloride, so potassium ions would exchange with calcium and magnesium ions. Potassium salts are also used for conditioning desalinated water by replacing sodium salts with potassium salts.

It is established that increased exposure to potassium could result in significant health effects in people with kidney disease or other conditions, such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia, (WHO, 2009, “Potassium in Drinking Water”, Background document for development of WHO Guidelines for Drinking-water Quality).

Other cations like Ca^{2+} and Mg^{2+} also show fluctuation across seasons. Nitrate concentration is highest in the monsoon season (twice the permissible limit). Chromium levels are highest in the monsoon season (eight times the permissible limit). Lead and Cadmium show modest fluctuation. Arsenic levels reach values up to eight times the permissible limit.

2. **Ranchi**

It is the best performing district among all four in terms of groundwater quality. Chromium, Cadmium and Arsenic are the three elements that remain high in concentration across seasons. Cations like Ca^{2+} and Mg^{2+} show little fluctuation from permissible standard.

3. **East Singbhum**

It is worst performing district among all four in terms of groundwater quality. Incidentally, it is also the most urbanized and industrialized district. 15 out of 21 parameters exceed the permissible limit and 8 out these 15 parameters show a high degree of variation across seasons. TDS is highest in monsoon (4 times the permissible limit). Water is extremely hard (goes up to 21 times the permissible limit in summer season). Several epidemiological investigations have demonstrated the relation between risk for cardiovascular disease, growth retardation, reproductive failure, and other health problems and hardness of drinking water. Except Fluorine all ions exceed permissible limit.

4. **West Singbhum**

10 out of 21 parameters exceed the permissible limit. However, when compared to other districts, the degree of variation in these parameters across seasons is relatively less. Nitrate content in water goes up to four times the permissible limit. Chromium, lead , arsenic and cadmium are problematic elements in this district.

According to WHO, groundwater seldom contains **high levels of cadmium** unless it is contaminated by mining or industrial wastewater, or seepage from hazardous waste sites.

Thus high level of cadmium is typically a phenomenon of mining areas.

Cadmium in high concentration is potentially lethal. With chronic oral exposure, the kidney is the most sensitive organ to cadmium.

Problems pertinent to mining region

1. **Heavy Metals**

Heavy metals and metalloid contamination of stream systems can occur in response to many catchment sources, including the weathering of naturally mineralized rocks, from mining activities, urban and industrial wastes and effluents. In addition, agriculture also has been identified as a source of heavy metals via fertilizers. Due to their high toxicity and tendency to bio-accumulate, heavy metals are considered as one of the most serious pollutants in the environment.

Elements like Cu, Zn, Fe, Mn, and Co, which are required for normal biochemical functions, could become toxic when present in anomalous concentrations and, according to Bowen may result in poisoning of enzyme. Iron exceeds the permissible limit in Dhanbad, Ranchi and East Singbhum, while Manganese occurs in higher proportion only in Dhanbad.

Heavy metals are of high ecological significance since they are not removed from water as a result of self-purification, but accumulate in reservoirs and enter the food chain (Loska and Wiechula, 2003).

Higher concentration of trace metals may have far reaching implications directly to the biota and the food chain.

2. **Fluoride**

While in a moderate concentration range between 0.7- 1.2 mg F^- prevents dental caries; higher concentrations are responsible for dental and skeletal fluorosis.

Elevated concentration in some of the groundwater samples could be attributed to the weathering of F-bearing minerals such as micas and amphiboles in the rocks.

The fluoride problem in the area is mainly geogenic, however other factors like pH, climatic conditions also play a major role. Fluoride endemic areas have high concentration of fluoride in vegetable and foods like sorghum, Ragi, Bajra which aggravate the condition. The cause of presence of high fluoride in groundwater is the aridity of climate, dissolution of fluoride bearing minerals and rocks such as fluorspar, cryolite, fluorite, fluorapatite, and hydroxyapatite , ion exchange , velocity of flowing water , temperature, pH, concentration of calcium and bicarbonate ions in water and evaporative concentration can locally account for high fluoride concentration in groundwater.

The observed excess of Na^+ over K^+ is because of the greater resistance of K+ to chemical weathering and its adsorption on clay minerals restricting its mobility. Although K^+ is the least dominant cation in the groundwater of the study area, its concentration is modest.

Evaporation is likely to be responsible for many of the higher concentrations.

The fluoride problem is acute in Dhanbad followed by East Singbhum. In Dhanbad Fluoride level reaches up to 2.2mg/l. However, during monsoon, the concentration of Fluorine declines drastically.

3. **Total Hardness**

When water passes through or over deposits such as limestone, the levels of Ca^{2+}, Mg^{2+}, and HCO_3^- ions present in the water can greatly increase and cause the water to be classified as hard water. This term results from the fact that calcium and magnesium ions in water combine with soap molecules, making it “hard” to get suds. Total hardness is defined as the sum of calcium and magnesium hardness, in mg/L as $CaCO_3$.

The CGWB (2013) data shows highest total hardness for Dhanbad (361.8 mg/l) and least value for Ranchi (138.71 mg/l). The WHO has accepted 100 mg/l to be the permissible limit for TH. In contrast, BIS is more liberal by keeping the permissible limit at 300 mg/l. Seasonal trends show that Total Hardness is highest in the Pre-monsoon season and least during the monsoon season, while during the post monsoon season it attains intermediate values. The decreased values in monsoon imply dilution and flushing.

East Singbhum has the highest range for total Hardness, varying from 7713mg/l (summer) to 1465 mg/l (monsoon). Ranchi is the only district among all four in which TH remains under permissible limit (BIS) across the year. However, it does exceed the WHO standards. Both Dhanbad and West Singbhum have high Total Hardness of water (reaching values up to twice the permissible limit).

Total hardness in freshwater is usually in the range of 15 to 375 mg/L as $CaCO_3$. Calcium hardness in freshwater is in the range of 10 to 250 mg/l, often double that of magnesium hardness (5 to 125 mg/L). Typical seawater has calcium hardness of 1000 mg/L, magnesium hardness of 5630 mg/L, and total hardness of 6630 mg/L as $CaCO_3$.

The classification of groundwater based on total hardness ((Sawyer and Mc Cartly, 1967) shows that the groundwater in the study area is hard to very hard in nature.

Total Hardness is highest in the summer season and least in the winter season.

B) **Suitability for Irrigation**

Suitability for irrigation is assessed by analysing the Electrical Conductivity of water and studying various indices like Sodium Absorption Rate (SAR), Kelly’s Ratio (KR), Sodium Percentage (SP) and Permeability Index (PI).

Electrical conductivity (EC) and Na^+ ion concentration play a vital role in determining the suitability of water for irrigation.

Higher EC in water is a characteristic of saline soil. It is known that higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Osmotic pressure is the minimum pressure which needs to be applied to a solution to prevent the inward flow of water across a semipermeable membrane. It is also defined as the measure of the tendency of a solution to take in water by osmosis).

The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability and aeration, which indirectly affect plant growth.

Electrical conductivity is least in Ranchi (360 µs/cm) and maximum in East Singbhum (956µs/cm), which is clear indication of higher salt content in water.

Usually Electrical Conductivity is least in monsoon and high in other seasons.

Electrical Conductivity is a measurement of all soluble salts in samples, it is also the most significant water quality standard on crop productivity which was the water salinity hazard.

The primary effect of high EC water on crop productivity was the failure of the plant to compete with ions in the soil solution for water. The higher the EC, the lesser the water available to plants, even though the soil may show wet, because plants can only transpire "pure" water; useable plant water in the soil solution decreases significantly as EC increases. The amount of water transpired through a crop was directly related to yield; therefore, irrigation water with high EC reduces yield potential.

1. **Alkalinity hazard**

The sodium/alkali hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. Sodium hazard of irrigation water can be well understood by knowing SAR. The SAR value for each district was calculated by using following equation:

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$$

(All Concentrations are expressed in milli-equivalents /litre)

The likelihood that sodium present in irrigation water will cause permeability problems can be evaluated by computing sodium adsorption ratio.

As a rule, water that has an SAR below 3 is safe for irrigating turf and other ornamental landscape plants. Water that has an SAR greater than 9, on the other hand, can cause severe permeability problems when applied to fine-textured soils (for example, a silty clay loam) and should be avoided.

On an average SAR is least in the summer season and highest in winter season.

All the districts considered in this case have SAR value less than 3. It is observed that SAR is lowest in summer season and highest in winter season.

The calculated SAR values, for four districts range from 0.5 -2.1. The SAR value is least for Ranchi and maximum for East Singbhum.

Excess exchangeable sodium can have an adverse effect on the physical and nutritional properties of the soil, with consequent reduction in crop growth, significantly or entirely. The soils contain appreciable quantities of salts capable of alkaline hydrolysis, e.g. sodium carbonate.

However, high SAR values are not as problematic for coarse textured soil sandy soil as it is for fine textured soil.

There is a close relationship between SAR values in irrigation water and the extent to which Na+ is adsorbed by soils. If water used for irrigation is high in Na^+ and low in Ca^{2+}, the ion-exchange complex may become saturated with Na+, which destroys soil structure, because of dispersion of clay particles. As a result, the soils can be very difficult to cultivate (Subba Rao, 2006).

The relatively “good waters” can be used for irrigation with little danger of harmful levels of exchangeable Na+. The “moderate waters” can be used to irrigate salt tolerant and semi-tolerant crops under favourable drainage conditions. The bad waters are generally undesirable for irrigation and should not be used on clayey soils of low permeability. Bad waters, however, can be used to irrigate plants of high salt tolerance, when grown on previously salty soils to protect against further decline of fertile lands (Subba Rao, 2006).

2. **Kelly’s Ratio**

Richards 1954). Kelly (1940) and Wilcox (1958) have also determined the hazardous effect of sodium on water quality for irrigation usage in terms of Kelly’s ratio (KR).

$$\text{Kelly's Ratio} = \{ Na^+/(Ca^{2+}+ Mg^{2+})\}$$

A Kelly’s ratio of more than one indicates excessive sodium in water. Therefore, water with a Kelly’s ratio less than one are suitable for irrigation, while those with a ratio more than one are unsuitable.

In all districts and in all seasons the value of Kelly’s ratio remains below 1 (ranges from 0.36 - 0.55). Across seasons, it ranges from 0.18 to 0.55. No clear pattern can be identified, due to the variable concentration of these metal ions across the year.

3. Percentage Sodium (%Na)

Percentage of Na+ is also widely utilized for evaluating the suitability of water quality for irrigation. The %Na $^{+}$is computed with respect to relative proportions of cations present in water.

When the concentration of Na+ is high in irrigation water, it tends to be absorbed by clay particles, displacing Ca $^{2+}$ and Mg $^{2+}$ ions. This exchange process of Na+ in water for Ca $^{2+}$ and Mg $^{2+}$ in soil reduces the permeability and eventually results in soil with poor internal drainage.

Na percentage is highest for East Singbhum (38 %) and least for Ranchi (27%).If we compare across seasons, the Na % is least in monsoon and high in other seasons.

High concentrations of sodium can cause soil dispersion, ion toxicity and nutrient competition, weakening the turf so it is vulnerable to pathogen attacks. Decreases in water infiltration and distribution as well as reduced oxygen levels in the root zones are also common problems resulting from high sodium concentrations.

4. Permeability index (PI)

The soil permeability is influenced by long-term irrigation which in turn is affected by Na^{+}, Ca^{2+}, Mg^{2+} and $HC0_{3}^{-}$contents of the soil. The PI values indicate the suitability of groundwater for irrigation.

Permeability Index = (Na^{+} + $HC0_3^{-}$ / Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}) *100

The Permeability ranges from (The soil permeability is affected by long term use of irrigation water. A criterion for assessing the suitability of water for irrigation was based on PI water and can be classified as class I, Class II and Class III orders. Class I and Class II water was categorized as good for irrigation with 75% or more and 25-75 % maximum permeability. Class III water was unsuitable with 25% of maximum permeability.

Overall Permeability index is quite high, ranging from 50% (Dhanbad) to 65% (Ranchi).

In summer the permeability index varies from 15% to 53 %, in monsoon from 20 % to 45 % and in winter season from 22 % to 36 %.

A criterion for assessing the suitability of water for irrigation based on the permeability index (WHO, 1989) indicates that a majority of groundwater samples come under class II (P.I. ranges from 25 to 75%) category.

V. CONCLUSION

The study brought out the local and regional variations in groundwater composition.

The observed higher EC implies intensive mineralization in groundwater. Ca^{2+} and Mg^{2+} dominate the cation chemistry of groundwater in the study area except in West Singhbhum district where Na+ dominates over Ca^{2+} in summer season which indicates that weathering and cation exchange processes normally control the levels of these cations in groundwater in the region.

Elevated K+ concentration seems to be derived from domestic effluents or increased K-rich fertiliser used for the agriculture as its natural occurrence in higher concentrations is rare.

$HC0_3^{-}$ and NO $_{3}$ - are the dominant ions controlling anion chemistry in groundwater. The N0 $_{3}$ - concentration was detected as high. The observed higher concentrations of N03- reflect man-made pollution, apparently due to application of fertilizers targeted for higher crop yields.

Many of the minor and trace elements were found to be high. Except Cu and Zn, all the elements analysed exceeded drinking water standards provided by WHO (2004) and BIS (2003).

The hydrochemical analysis, in order to examine suitability of groundwater for irrigation reveals that groundwater of the study area is generally good for irrigation purposes except for few locations. But high TH (total hardness) values in groundwater render the groundwater unsuitable for drinking purpose.

Both TH and TDS concentrations in groundwater of Jharkhand point toward its unsuitability for drinking purpose.

The elevated concentrations of dissolved metals at some stations could be attributed to increased industrialization including mining and smelting processes, and agricultural activities in the region.

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Appendices

Irrigation water Quality based on Ec		
EC(µs/cm)	Class	District
0-250	Low	
251-750	Medium	Ranchi
751-2250	High	W. Singbhum, Dhanbad, E.Singbhum
2251-6000	V High	
Classification of water based on SP values		
SP (%)	Class	District
<20	Excellent	
20-40	Good	Dhanbad, Ranchi, East Singbhum,West singbhum
40-60	Permissible	
60-80	Doubtful	
>80	Unsuitable	

Classification of Water based on SAR values		
<10	Excellent	ALL
10--18	Good	
18-26	Fair	
>26	Poor	
Classification of water based on KR values		
KR	Class	District
<1	Safe	ALL
>1	Unsuitabl	NIL
Classification of water based on permeability Index		
PI (%)	Class	District
>75	Excellent	
50-75	Good	All
25-50	Fair	
<25	Unsitable	
Source : Groundwater Information Booklet, Jharkhand State, CGWB, Ministry of Water Resource (GoI), September 2013		
Classification Criteria:		
Reddy, K.Srinivasa,2013, "Assessment of Ground waterquality for irrigation, Nalgonda, India", International Journal of Water Resource and Engineering		

Parameters of Ground Water													
District	Ranchi												
Sl No.	Block	E.C.	pH	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F	Ca^{2+}	Mg^{2+}	TH	Na+	K^+
		µs/cm		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
	WHO/BIS		6.5-8.5	200	250	200	45	1	75	30	100	200	2.5
1	Ormanjhi	472	6.5	118	67	20	45	1.5	60	19	226	14	2.9
2	Ranchi	325	8.1	79	40	25	20	0.3	33	6	108	25	1.5
3	Mandar	340	7.4	46	63	3.9	50	0.3	23	11	103	29	11
4	Bero	191	8.2	106	6		5.9	0.6	23	6	82	7	1.9
5	Silli	620	6.9	343	27	13	0.1	2.2	74	13	236	48	4.1
6	Tamar	235	8.2	132	8	2.2	4.1	0.7	27	11	113	8	0.9
7	Chuttupalu	325	8.1	165	17	4.8		2.6	27	9	103	33	2.4
	Average	358.29	7.63	141.29	32.57			1.17	38.14	10.71	138.71	23.43	3.53
	Source: Groundwater Information Booklet, Ranchi District, Jharkhand State, CGWB, Ministry of Water Resource(GOI), September 2013												

Parameters of Ground Water										
District	West Singbhum									
Sl No.	Block	E.C.	pH	HCO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	TH	Na+	K^+
		µs/cm		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
	WHO/BIS		6.5-8.5	200	250	75	30	100/300	200	2.5
1	Chakradharpur	1118	8.28	311	163	92	47	425	58	2.1
2	Chaibasa	727	8.56	299	67	56	29	260	44	5.5
3	Khuntpani	811	8.53	390	50	36	56	320	34	1.2
4	Kereikala	587	8.11	129	95.7	38	25.5	200	37	2.2
5	Bandgaon	1634	8.26	104	394	72	58	420	147	19
6	Kokcho	356	8.68	98	39	34	11	130	14	0.4
7	Pandrasalai	694	8.42	209	95.7	24	25.5	165	76	1.8
8	Hesadih	269	8.5	152	14	24	13	115	12	1.1
	Average	774.50	8.42	211.50	114.80	47.00	33.13	254.38	52.75	4.16

Source: Groundwater Information Booklet West Singbhum District , Jharkhand State , CGWB, Ministry of Water Resource(GoI), September 2013

Parameters of Ground Water										
District	East Singbhum									
Sl No.	Block	E.C.	pH	HCO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	TH	Na+	K^+
		µs/cm		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
	WHO/BIS		6.5-8.5	200	250	75	30	100/300	200	2.5
1	Ghatshila	945	8.26	396	92	80	29	320	56	2.5
2	Jamshedpur	533	8.32	148	89	36	20	170	38	2.6
3	Dalbhumgarh	286	8.39	67	50	24	7.3	90	21	2.2
4	Musabani	896	8.51	244	99	74	32	315	52	15
5	Potka	582	8.56	293	39	38	36	245	27	0
6	Galudih	424	8.39	110	64	40	12	150	30	10
7	Kalikapur	2400	8.46	457	394	126	49	515	195	26
8	Hata	1588	8.13	543	213	126	25	420	145	1.2
	Average	956.75	8.38	282.25	130	68	26.29	278.13	70.5	7.44

Source : Groundwater Information Booklet, East Singbhum District , Jharkhand State, CGWB, Ministry of Water Resource (GoI), September 2013

Parameters of Ground Water									
District	Dhanbad								
Sl No.	Block	E.C.	HCO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	TH	Na+	K^+
	WHO/BIS		200	200	75	30	100/300	200	2.5
1	Jharia	577	160	49.6	24	28	175	37	12.1
2	Tundi	605	98	67.4	56	17	210	33	2.2
3	Nirsa	1172	98	124.1	74	29	305	111	3.2
4	Topchancl	1970	268	259	160	78	720	43	3.2
5	Mahuda	973	289	67.4	26	68	345	52	8.8
6	Govindpu	588	277	14.2	34	15	145	48	5.3
7	Rajganj	1690	390	195	86	60	460	143	1.2
8	Katras	1750	196	241.1	28	86	670	68	4.8
9	Sindri	1138	329	89	75	28	275	108	1.4
10	Dhanbad	1384	234	184.3	19	75	455	62	17.5
11	Baghmara	677	111	70.9	19	19	220	39	1.9
	Average	1138.5	222.7	123.8	54.6	45.7	361.8	67.6	5.6

Source:Groundwater Information Booklet, Dhanbad District, Jharkhand State, CGWB, Ministry of Water Resources, GoI, September 2013.

Parameters of Ground Water									
District	Dhanbad								
Sl No.	Block	E.C.	HCO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	TH	Na+	K^+
	WHO/BIS		200	200	75	30	100/300	200	2.5
1	Jharia	577	160	49.6	24	28	175	37	12.1
2	Tundi	605	98	67.4	56	17	210	33	2.2
3	Nirsa	1172	98	124.1	74	29	305	111	3.2
4	Topchancl	1970	268	259	160	78	720	43	3.2
5	Mahuda	973	289	67.4	26	68	345	52	8.8
6	Govindpu	588	277	14.2	34	15	145	48	5.3
7	Rajganj	1690	390	195	86	60	460	143	1.2
8	Katras	1750	196	241.1	28	86	670	68	4.8
9	Sindri	1138	329	89	75	28	275	108	1.4
10	Dhanbad	1384	234	184.3	19	75	455	62	17.5
11	Baghmara	677	111	70.9	19	19	220	39	1.9
	Average	1138.5	222.7	123.8	54.6	45.7	361.8	67.6	5.6

Source:Groundwater Information Booklet, Dhanbad District, Jharkhand State, CGWB, Ministry of Water Resources, GoI, September 2013.

Sl. No.	Parameters	Units	Dhanbad	Ranchi	East Singbhum	West Singbhum
6	K^+	mg/l	5.6	3.53	7.44	4.16
6	Ca^{2+}	mg/l	54.6	38.14	68	47
7	Mg^{2+}	mg/l	45.7	10.71	26.29	33.13
8	Na+	mg/l	67.6	23.43	70.5	52.75
9	HCO_3^-	mg/l	222.7	141.29	282.25	211.56

Sl. No.	Parameters	Units	Dhanbad	Ranchi	East Singbhum	West Singbhum
6	K^+	meq/l	0.14	0.09	0.19	0.16
6	Ca^{2+}	meq/l	2.73	1.9	3.4	2.35
7	Mg^{2+}	meq/l	3.76	0.88	2.16	2.72
8	Na+	meq/l	2.94	1.01	3.06	2.29
9	HCO_3^-	meq/l	3.65	2.31	4.62	3.46
	Kelly's Ratio		0.45	0.36	0.55	0.45
	Na+ percentage		32.18	28.35	36.89	32.58
	PI		50.68	65.20	59.13	55.19
	SAR		1.63	0.86	1.84	1.44

mg/l is converted into meq/l using the formula:
meq=(weight in mg *valance)/atomic weight of element

Parameters of Groundwater, Dhanbad

Sl. No.	Parameters	Units	Atomic weight	Valance	Summer	Monsoon	Winter
9	Na+	meq/l	23	2	1.56	3.37	3.72
7	Ca^{2+}	meq/l	40	2	4.26	5.49	1.31
8	Mg^{2+}	meq/l	24.3	1	4.41	2.91	6.13
6	K^{+}	meq/l	39	1	0.82	0.2	0.12
10	HCO_3^-	meq/l	61	1	2.5	3.83	4.35
	SAR				0.75	1.64	1.93
	KR				0.18	0.40	0.50
	Na +(%)				21.54	29.82	34.04
	PI				15.87	19.72	22.21

Parameters of Groundwater, Ranchi

Sl. No.	Parameters	Units	Atomic weight	Valance	Summer	Monsoon	Winter
9	Na+	meq/l	23	2	1	1.03	1.67
7	Ca^{2+}	meq/l	40	2	2.88	1.75	2.21
8	Mg^{2+}	meq/l	24.3	1	2.77	0.86	0.85
10	HCO_3^-	meq/l	61	1	2.5	2.57	2.6
6	K^{+}	meq/l	39	1	0.22	0.05	0.04
	SAR				0.59	0.90	1.35
	KR				0.18	0.39	0.55
	Na+(%)				17.76	29.27	35.85
	PI				24.02	44.48	35.47

mg/l is converted into meq/l using the formula:
meq=(weight in mg *valance)/atomic weight of element

Parameters of Groundwater, Dhanbad

Sl. No.	Parameters	Units	Atomic weight	Valance	Summer	Monsoon	Winter
9	Na+	meq/l	23	2	1.56	3.37	3.72
7	Ca^{2+}	meq/l	40	2	4.26	5.49	1.31
8	Mg^{2+}	meq/l	24.3	1	4.41	2.91	6.13
6	K^{+}	meq/l	39	1	0.82	0.2	0.12
10	HCO_3^-	meq/l	61	1	2.5	3.83	4.35
	SAR				0.75	1.64	1.93
	KR				0.18	0.40	0.50
	Na +(%)				21.54	29.82	34.04
	PI				15.87	19.72	22.21

Parameters of Groundwater, Ranchi

Sl. No.	Parameters	Units	Atomic weight	Valance	Summer	Monsoon	Winter
9	Na+	meq/l	23	2	1	1.03	1.67
7	Ca^{2+}	meq/l	40	2	2.88	1.75	2.21
8	Mg^{2+}	meq/l	24.3	1	2.77	0.86	0.85
10	HCO_3^-	meq/l	61	1	2.5	2.57	2.6
6	K^{+}	meq/l	39	1	0.22	0.05	0.04
	SAR				0.59	0.90	1.35
	KR				0.18	0.39	0.55
	Na+(%)				17.76	29.27	35.85
	PI				24.02	44.48	35.47

Acknowledgement

Missing Data corroborated from: Sharma, K.S. (2010), "Study of Groundwater Quality with Special Reference to arsenic Contamination in Bihar and Jharkhand, India", School of Environmental Sciences, Jawaharlal Nehru University