Journal of Geointerface, Vol. 4, No. 1, July 2025, pp. 135–141 e-ISSN: 2583-6900

Assessment of Post-Monsoon Groundwater Quality and its Suitability for Drinking and Domestic use in Sukinda Valley, Odisha, India

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ABSTRACT

Sukinda Valley in Odisha is famous worldwide for rich occurrence of chromite ore. The present study on the groundwater quality of Sukinda area was done in the post-monsoon period, 2023 in order to access its suitability for drinking and domestic use keeping in view the large- scale mining and industrial activities in the region. To draw a reasonable conclusion, ground water samples were collected from 64 locations and analyzed for key physicochemical parameters such as pH, Electrical conductivity (EC), Total dissolved solids (TDS), Total hardness (TH), major and trace elements such as Ca, Mg, Na, K, Fe, CO_3^{2-}, HCO_3^-, Cl^-, F^-, SO_4^{2-} and Cr (Total). The analytical results indicate that the groundwater in this region is slightly alkaline and hard in nature which needs softening treatment for domestic use. Further, the groundwater is not suitable for drinking purpose in a few places, mostly mining areas, due to chromium concentration exceeding the permissible limit specified by the BIS (2012) drinking water standards. However, in most of the locations, groundwater can be made suitable for drinking after removal of excess iron. The Piper diagram reveals that the dominant hydro geochemical facies in the study area is Ca–Mg–HCO_3 followed by Ca–Mg–SO_4–Cl. The study highlights the necessity for regular monitoring of water quality and appropriate treatment measures to minimize health risks.

ARTICLE HISTORY

Received: 27 May 2025
Revised: 22 June 2025
Accepted: 26 June 2025

https://doi.org/10.5281/zenodo.15747324

KEYWORDS

Post-monsoon
Groundwater quality
Sukinda valley
Drinking water standards

1. Introduction

Groundwater is a crucial source of potable and domestic water supply, especially in regions where surface water availability is either limited or contaminated. The quality of groundwater is impacted by both natural geochemical processes and anthropogenic activities. This can lead to contamination and pose serious health hazards. In industrial and mining regions, groundwater pollution is often a major concern due to the leaching of heavy metals and other toxic substances into aquifers (CGWB, 2021). Sukinda valley, located in the Jajpur district of Odisha is one of the world's richest chromite mining regions, which contribute significantly to the country's chromite production. Grave concern has been raised for the extensive mining activities and associated industrial processes in Sukinda valley region with resultant groundwater contamination, particularly with heavy metals like chromium. The monsoon plays a significant role in altering groundwater quality by facilitating the leaching and transport of contaminants from mine tailings, industrial effluents and surface runoff into the aquifer system. Thus,

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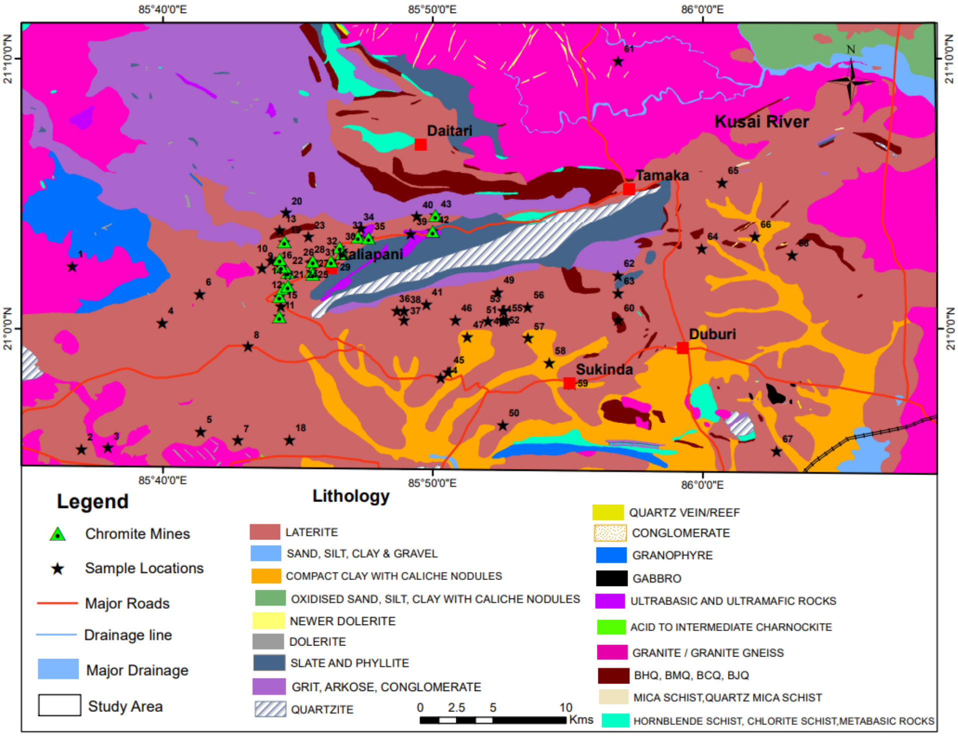

Fig. 1. Geological map of the study area with sample locations.

post-monsoon assessment of groundwater quality is crucial for understanding of the extent of pollution and its implications for drinking and domestic water use. This study aims to access the post-monsoon groundwater quality of Sukinda Valley region with special emphasis on its suitability for drinking and domestic use and identify potential health hazards.

2. Study area

Sukinda valley, well-known for rich chromite deposits, is surrounded by Daitari hill range (maximum altitude 200 amsl) in north and the Mahagiri hill range (maximum altitude 300 amsl) in the southern part trending E–W and NE–SW respectively. The study area (Fig. 1) lies between latitude 20°53' and 21°05' N and longitude 85°40' and 85°53' E and is a part of famous Sukinda Valley, Jajpur district, Odisha. The entire region falls in the south–western quadrant of topo-sheet nos. 73G/12 and 73G/16. Drainage in the area flow towards NW, which finally join Damasal Nala. Damasal Nala is perennial in nature as most of the mine seepage is discharged into it. The region witnesses a tropical monsoon climate, with hot and humid summers, a rainy monsoon season from June to September followed by mild winters. The average annual rainfall is approximately 1,500 mm; the largest contributors are the monsoon months. The seasonal fluctuation of groundwater occurs due to recharge from rainfall during monsoon and a fall during the dry months of summer.

3. Geology

The Sukinda Chromite Belt (Fig. 1) is an important mining belt of Odisha, with mining activities dating back to the early 20th century. This belt of Odisha occupies the first position in reserve and production in the entire nation giving 97% of all India output. The Sukinda valley presents a synformal fold plunging towards WSW at a low angle 10°–15°. (Banerjee, 1971). The main geological feature of the area is the presence of ultramafic rocks accompanied by chromite ore bodies. The ultramafics appear to have intruded into the quartzite and this layered laccolith complex is composed of alternate bands of chromite, dunite, peridotite and orthopyroxene repeated in a rhythmic fashion. These ultramafics are extensively serpentinised, lateritized and limonitised. Pyroxenite intrudes into the early formed chromiferous ultramafic rocks. Numerous chert bands are also found within the ultramafics which are often completely weathered to a mass of talc-limonite. The Sukinda chromite belt lies in seven alternate subpar-

Table 1. Comparison of post monsoon ground water samples of the study area with BIS (2012) drinking water quality standards.

Parameters	Unit	Min.	Max.	Mean	SD	BIS(2012) standards		No. of samples below permissible limit	No. of samples above permissible limit
						Acceptable Limit	Permissible limit		
pH		6.23	8.16	7.4	0.43	6.5	8.5	64	-
EC	µS/cm	59	651	296.8	150	-	-	-	-
TDS	mg/l	37.4	416.6	190	96.2	500	2000	64	NIL
Cl^-	mg/l	8	55	20.7	9.5	250	1000	64	NIL
$HCO^{2-}{}_3$	mg/l	16	324	131	76.9	200	600	64	NIL
$SO^{2-}{}_4$	mg/l	0.1	63.6	3.9	9.57	200	400	64	NIL
Na^+	mg/l	0.83	28.8	6.39	5.17	-	-	-	-
K^+	mg/l	0.15	5.58	1.46	1.04	-	-	-	-
Mg^{2+}	mg/l	0.97	22.36	8.37	5.15	30	-	-	-
Ca^{2+}	mg/l	6.41	120.24	39.4	24.9	75	200	64	NIL
TH	mg/l	1.8	304	124	71.4	200	600	64	NIL
F^-	mg/l	0.04	0.71	0.17	0.12	1	1.5	64	NIL
Fe	mg/l	0.05	8.7	2.3	2.6	0.3	0.3	28	36
Cr (Total)	µg/l	1	322.8	41.9	1.05	50	50	56	8

allel stratigraphic levels which is thick in the southern side and becomes thinner towards the northern side. The ore bodies vary from 200 m to as much as 7 km in length and have variable thickness from 0.3 to 50 m. These seams dip at very steep angles (65°–75°). The important mining centers in the belt are Bhimtanagar, Kaliapani, Sukurangi, Saruabil, Kumardah, Kalarangi, Talangi, Gurujang and Ostapal.

4. Materials and methods

Water samples from 64 tube wells and dug wells were collected in polyethylene bottles from different parts of study area during post-monsoon period (October–December). The bottle was completely filled with water taking care that no air bubble was trapped within the water sample. To prevent evaporation, double plastic caps bottles were used. The samples were stored at a temperature below 4°C prior to analysis in the laboratory. Electrical conductivity (EC) and pH of the water samples were measured by EC meter and pH meter respectively. Total dissolved solids (TDS) were calculated by multiplying EC with 0.64.

Major cations (Ca^{2+}, Mg^{2+}, Na^+, K^+ and Fe) and anions (CO^{2-}, HCO^{3-}, CI^-, F and SO^{2-}) including total hardness (TH) and total alkalinity (TA) of the water samples were determined following standard analytical procedure of APHA (2005). Ca^{2+}, CO^{2-}, HCO^3 and CI^- were determined by volumetric titrations. Fe was determined by AAS. Na^+, Ca^{2+} and K^+ were estimated by flame photometer after calibrating the instrument with known standard and $SO_4{}^{2-}$ was estimated by spectrophotometer. F^- was determined by ion selective electrode method. Mg^{2+} was calculated from TH and Ca^{2+} by employing standard equations. Chloride analysis is carried out by volumetric titration by using $AgNO_3$ and $K_2CR_2O_7$ solution, while bicarbonate is determined by HCl and methyl orange indicator solution by titration method. Chromium (Total) was measured by ICP-AES at CSIR-IMMT laboratory, Bhubaneswar. The analytical results are summarized in Table 2.

Table 2. Hardness classification of post monsoon ground water of study area after Sawyer and Mc Carty (1967).

Hardness (mg/l) as CaCO3)	Water Class	No of Samples
0–75	Soft	12
75–150	Moderately hard	21
150–300	Hard	30
>300	Very hard	1

5. Results and discussion

In ground water management, quality is as significant as the quantity of water. Understanding the quality of groundwater is important because it is the main factor which decides its suitability for domestic and drinking purpose. In this study, the drinking water standard of BIS (2012) forms the basis for the evaluation of groundwater for drinking purpose. Summary of analysis of key parameters along with the limits prescribed by BIS (2012) is given in Table 1.

pH is the potential of hydrogen ion concentration which measures acidity and alkalinity of water. Water samples having pH value of 7 are neutral in nature, the values greater than 7 are alkaline in nature and values less than 7 are acidic in nature. The pH value of the study area ranges from 6.23 to 8.16 with an average of 7.42 which indicates most of the water samples are alkaline in nature.

EC stands for electrical conductivity which measures the ability of water to conduct the electrical current. EC values confirm how much solids are dissolved in a solution. The EC value of the ground

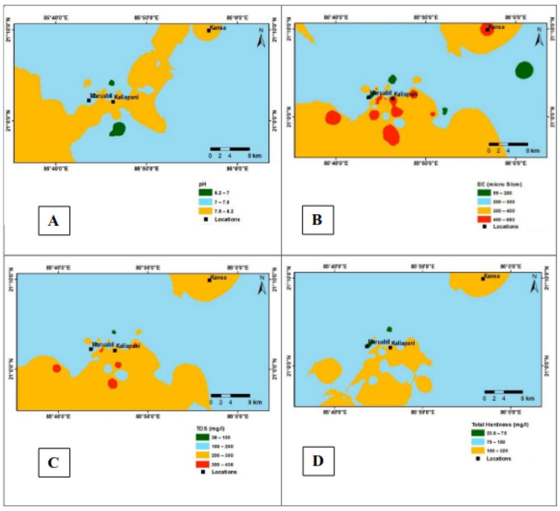

Fig. 2. (A–D). Isoconcentration map of pH, EC, TDS and TH in ground water of study area.

water samples of Sukinda area ranges from 59 to 682 µs/cm with an average of 302.8µs/cm.

TDS is the measurement of dissolved organic and inorganic constituents in the water samples which ranges from 38 to 436 mg/l with an average value of 94 mg/l in the study area. Total hardness is the sum of the carbonate hardness and non-carbonate hardness present in the sample (Todd, 1980). TH of the area varies from 24 to 349 mg/l with an average of 131 mg/l.

Principal cations present in the water samples of the study area are Na^+, K^+, Ca^{2+}, Mg^{2+} and Fe. Salts of Sodium and Potassium are basically dissolved in water from rocks and sediments. Sodium concentration in water ranges from 0.83 to 22 mg/l with an average of 6.07 mg/l and that of Potassium ranges from 0.15 to 5.58 mg/l with an average of 1.44 mg/l. Calcium and Magnesium occur in groundwater mainly in form of carbonate, bicarbonate and sulphate. Carbonate and bicarbonate create temporary hardness in water while sulphate, Chloride and Nitrate give permanent hardness (Akhauri and Akhauri, 2015). Calcium ranges from 6.41 to 120.24 mg/l with an average of 39.01 mg/l and Magnesium lies between 0.97 and 22.36 mg/l with an average of 8.27 mg/l. The iron content owes its presence due to leaching of iron in water from iron bearing minerals present in host rocks which ranges from 0.05 to 8.7 mg/l with an average value of 2.4 mg/l.

Dominant anions in the water samples of the study area are HCO_3^-, Cl^-, F^- and SO_4^{2-}. Bicarbonate ranges from 16 to 324 mg/l with an average of 128.8 mg/l. Chloride is one of the major anionic constituents of groundwater. Industrial and mining activities in the area contribute to the chloride content. The chloride is between 8 to 55 mg/l with an average of 20.68 mg/l. Fluoride in groundwater is derived mainly from fluorite, apatite and mica. Fluoride ranges from 0.04 to 0.71 mg/l with an average of 0.514 mg/l. Sulphate is obtained from minerals like gypsum and anhydrite in groundwater. Sulphate concentration ranges from 0.1 to 63.6 mg/l with an average of 3.9 mg /l. Chromium enters into groundwater mainly due to chemical weathering of ultramafic rocks and chromite ore. The chromium content in the groundwater in Sukinda area ranges from 1 to 322.8 µg/l with an average of 41.9 µg/l.

The spatial distribution of important physico-chemical parameters in the groundwater of study area are illustrated in the isoconcentration maps (Fig. 2 to Fig. 4). From the figures it is clearly understood that all the parameters except iron are within the safe limit standards. Almost the entire study area shows high iron concentration except a few places in the central part. Some places in the southeastern part i.e., Pimpudia, Rankia, Ambpal, Muturibandh, Sadhuamunda, Sendhasara, Mangalpur and Katapal show very high iron concentration. These hotspots correspond to areas with intense mining activities, suggesting a strong anthropogenic influence on water chemistry (Dhakate et al., 2008). High iron levels in these zones may be attributed to the oxidation of iron-bearing minerals in overburden material and subsequent leaching into surrounding water bodies, especially during the monsoon season when water infiltration increases.

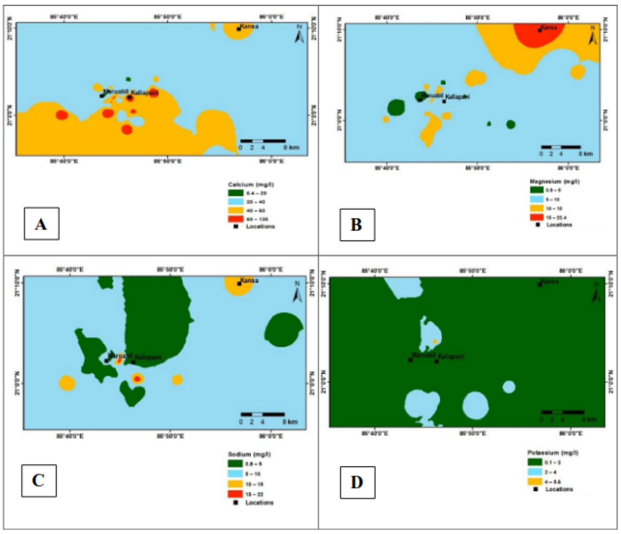

Fig. 3. (A–D). Isoconcentration Map of Ca, Mg, Na and K in ground water of study area.

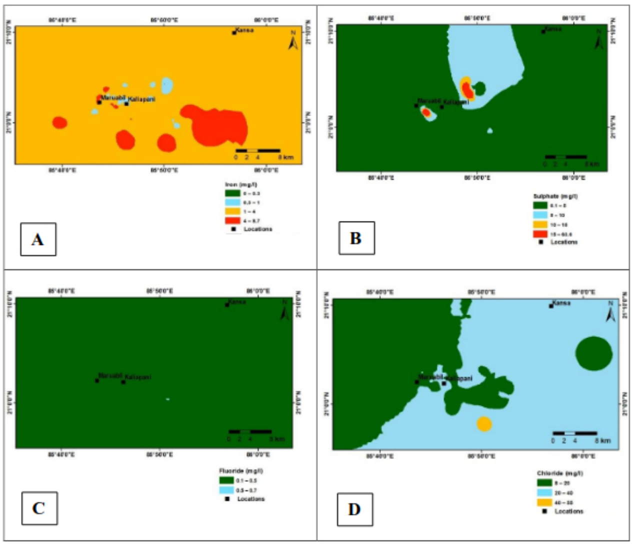

Fig. 4. (A–D). Isoconcentration Map of Fe, SO_4, F and Cl in ground water of study area.

5.1. Drinking and domestic use

Drinking and domestic consumptions are the important fields of water use. Drinking water standards in India is set by the Bureau of Indian Standards (BIS, 2012) following the recommendations of World Health Organization (WHO, 2004). On comparison of the groundwater of the study area with drinking water quality standards of BIS (2012), it is found that thirty-six Nos. (56%) and eight Nos. (12%) of the samples respectively contain iron and chromium above the permissible limit (Table 1) but other parameters are within the permissible limit for drinking purpose. Chromium compounds can be highly soluble, carcinogenic (Mancuso, 1951; Mancuso and Heuper, 1951; Ono, 1988; Waterhouse, 1975; Yassi and Nieboer, 1988), and teratogenic (Abbasi and Soni, 1984). The high chromium content in these areas causes serious health problems like lung cancer, skin ulcer, respiratory and digestive issues (Tiwary et al., 2018). Thus, water is unsuitable for drinking in eight locations, namely Gurujang canal, Talangi mines,

South Kaliapani mines, Ostapal mines, Damsal Nala, Ostia, Dhabahali and Kendupura. However, in majority of locations (thirty six out of sixty four), water can be used for drinking after removal of excess iron. Chronic exposure to elevated iron levels in drinking water can lead to organ damage, discoloration, and unpleasant taste and can interfere with the absorption of other essential nutrients. Multivariate analysis carried out by Naz et al. (2016) showed

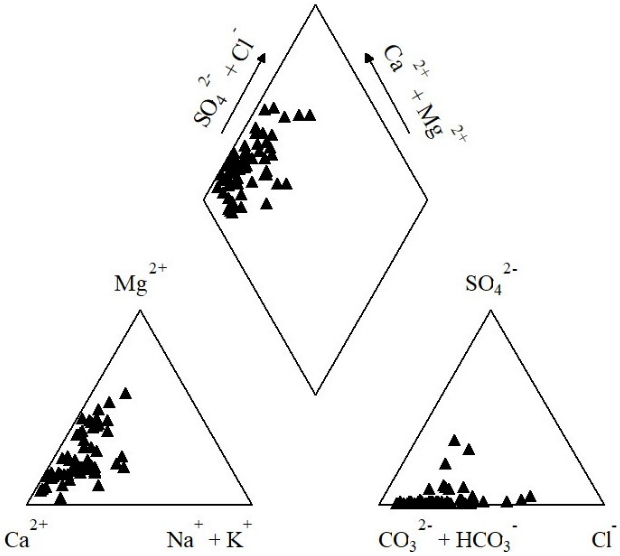

Fig. 5. Piper trilinear diagram of water samples of study area.

that the chromium pollution was due to mining activities, whereas iron has a geogenic origin in case of surface water.

The pH values indicate that water is commonly neutral to slightly alkaline in nature. Based on TDS value, ground water of study area is classified as fresh (TDS<1000 ppm). As 80% of the samples come under moderately hard to very hard category (Table 2), softening treatment of water is required for domestic use.

5.2. Hydro chemical classification of groundwater

5.2.1. Piper trilinear diagram

Piper (1944) proposed a graphical means to plot the water quality data to identify the sources of dissolved ions in water which we term as piper trilinear diagram. This diagram consists of two triangles represented by cations and anions in the left and right corners respectively along with a diamond shaped field in the Centre. The apexes of the left triangle comprise of calcium, magnesium and sodium plus potassium cations. The apexes of the right triangle comprise of sulphate, chloride and carbonate plus bicarbonate anions.

The Piper diagram (Fig. 5) shows that the water samples of Sukinda area classify mainly into two types, i.e., Ca–Mg–HCO_3 and Ca–Mg–Cl. The general predominance of cations is in the order of Ca>Mg>Na>K and that of anions is in the order of HCO_3>Cl>SO_4.Thus alkaline earth dominates over alkalis and weak acids dominate over strong acids in the water samples.

6. Conclusion

In view of increasing importance of groundwater as a reliable and sustainable source for drinking and domestic use, a comprehensive study of post monsoon groundwater quality of Sukinda chromite valley has been undertaken. The analytical results show that the groundwater of the study area is slightly alkaline and hard in nature and requires softening treatment for domestic use. As per BIS drinking water quality standards, it is found that all chemical parameters of groundwater except iron and chromium are within permissible limit. In majority of places, water can be used for drinking after removal of excess iron. The chromium concentration, however, is above the permissible limit in a few locations, mostly mining areas and groundwater in these places must not be used for drinking. The piper trilinear diagram indicates that Ca–Mg–HCO_3 and Ca–Mg–SO_4–Cl are the dominant hydro chemical facies in the region.

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