Hydrogeochemical Study of Karst Formation and Drinking Water Quality in Kanger Valley and Adjoining Region, Bastar, Chhattisgarh, India

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Abstract

Karst topography is a unique topography created mainly by the dissolution of soluble materials including limestone dolomite, and gypsum, The hydrochemical processes that aid in the development and evolution of karst systems are examined in this study. Key physicochemical parameters, such as pH, electrical conductivity, total dissolved solids, and main ion concentrations (Ca^2, Mg^2, HCO, and SO^2), were determined by analyzing groundwater and surface water samples. The findings show that karst features including sinkholes, caverns, and subterranean drainage systems are primarily shaped by carbonate dissolution, which is driven by carbonic acid produced from atmospheric and soil $CO2$. The predominance of calcium-bicarbonate type water, which is indicative of active karstification, is revealed by hydrochemical facies study. All analyzed water samples fall within permissible limits for drinking purposes, indicating their suitability for human consumption. (Gupta, 2024).

Keyword: *Karstification, Hydrochemistry, Ground Water Quality, Water Portability, piper diagram*

I. Introduction

The source and transportation path of ground water determine its chemical composition. Groundwater comes from a variety of sources, including meteoric, hydrothermal, magmatic, metamorphic, and more. (Raghunath, 1987). Because water is a very potent and effective chemical agent linked to the weathering and disintegration of rocks, the composition of the rock formations that water flows through also has a big impact. Karst landscape formation is greatly influenced by the chemistry of water. Karst landscapes are formed from soluble rocks that dissolve in acidic water, such as gypsum, limestone, and dolomite. A few key elements of water's chemical behavior that aid in karst formation are Acidity, Dissolution, Chemical erosion, Speleogenesis, Karst denudation. For drinking water, geochemical examinations are equally important. (Dar et al. 2014). Following a thorough geochemical survey and characterization, future ground water resource development requires a well-defined strategy through appropriate planning. (Chen et al. 2024)

II. Study Area

Study area Kanger valley national park and adjoining area is located in the south part of the Jagdalpur city, Bastar district, Chhattisgarh occupying a total area of approximate 600 km². (Map -1). The region is hilly and extremely diversified, with elevations ranging from 338 to 781 meters above mean sea level. It is made up of plateaus, steep hills, deep valleys, and mostly karst formations. (Gupta et al 2021). The picturesque Tirathgarh Falls and several stream courses cut through the landscape, with the Kanger River acting as the main drainage system. The geological composition consists primarily of Indravati group rocks, featuring sandstone, limestone, shales, and dolostone and covers the toposheet no. 65F/13 and 65J/1. (Ramakrishnan,1987)

III. Methodology

Samples have been collected from several locations near the caves in order to examine the chemistry of the ground water in the area. The container was a 1-litre distilled water plastic container which was emptied and thoroughly washed from the sample water before taking the sample. The proper GPS locations of the sample sites were taken and these samples were immediately shifted to the laboratory facility. These samples were properly preserved and sent to the advanced laboratory for the required analysis. The analytical result acquired from this process has been subjected to critical examination, and an appropriate interpretation has been made. The following parameters were examined in detail during chemical analysis of water samples: pH, Electrical Conductivity (EC), TDS, Total Hardness, Bi-carbonate, Chloride, Calcium, Magnesium, Sodium, and

Potassium, magnesium, sulphate. The results of different assumptions represented in parts per million (ppm**)**. (Tiwari, 2023). The chemical analysis results are given in Table no.1.

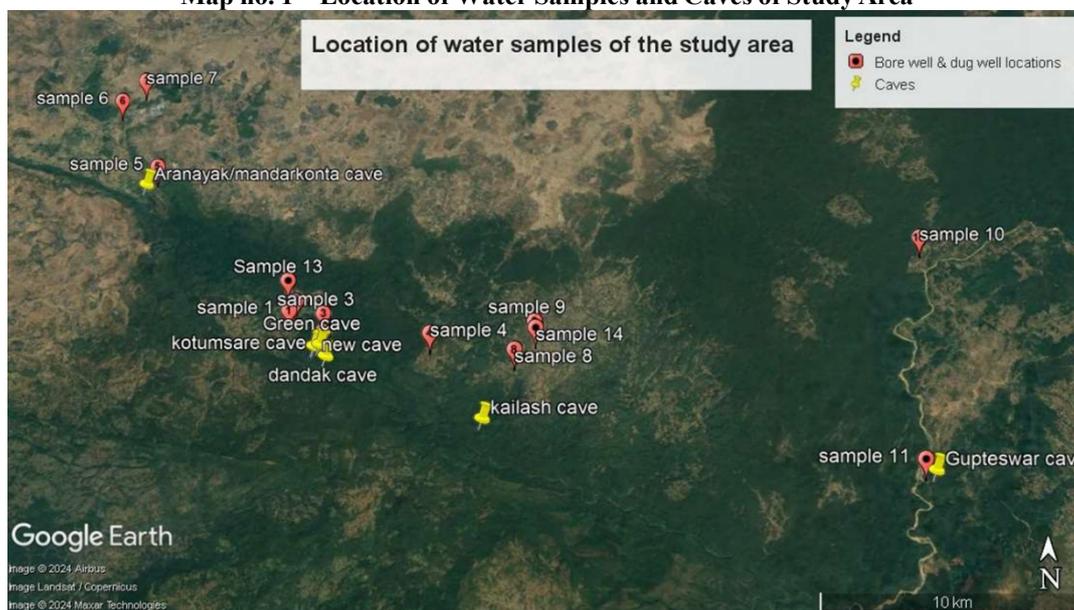**Map no. 1 – Location of Water Samples and Caves of Study Area**

Table No. 1 Geochemical Analysis of Ground Water of Study Area (after Gupta,2024)

Sample No.	Village	Latitude	Longitude	pH	EC	TDS	TH	Turbidity	Ca	Mg	Na	K	Hco₃	Co₃	Cl	So₄
1	Kotumsar	N18°52'44.58"	E81°55'24.3"	7.8	922.4	600	210	BDL (<0.5)	35.2	29.6	26.6	4.4	200	BDL	55.5	25.7
2	Kotumsar	N18°52'57.18"	E81°55'32.64"	7.8	952.7	620	222.2	BDL (<0.5)	36.8	31.6	27.4	4.8	185	BDL	56	26.4
3	Dear Park near Kotumsar cave	N18°52'39.36"	E81°56'13.38	8.04	968.8	640	246.4	BDL (<0.5)	40	35.5	28.8	5.2	150	BDL	57	26.7
4	Nagalsar	N18°52'12.18"	E81°58'43.86"	7.97	982.4	640	260.5	BDL (<0.5)	42.4	37.5	29	5.6	225	BDL	56.5	27.2
5	Mandarkonta	N18°56'16.44"	E81°51'53.04"	8.13	990	640	264.6	BDL (<0.5)	45.6	36.5	30.3	5.9	165	BDL	57.5	28.6
6	Kadma	N18°58'0.30"	E81°50'47.04"	7.84	996.5	620	274.7	BDL (<0.5)	47.2	38	31.9	6	175	BDL	58.5	29.5
7	Near Kadma cave	N18°58'33.18"	E81°51'18.66"	8.09	998.3	660	280.7	BDL (<0.5)	43.2	41.9	32	6.3	170	BDL	60	30
8	Netanar	N18°51'49.22"	E82°00'42.05"	7.8	950.2	625	261	BDL (<0.5)	42	38.2	28.5	5.8	224	BDL	57	27.1
9	Netanar	N18°52'28.13"	E82°01'09.77"	7.9	944	630	267	BDL (<0.5)	42.8	39.1	27.5	5.5	224	BDL	56.2	26.5
10	Tiriya	N18°54'28.38"	E82°10'24.85"	7	802	640	268	BDL (<0.5)	44.8	38.1	28.8	5.9	224	BDL	56.8	27.5
11	Gupteswar	N18°49'23.73"	E82°09'56.39"	7.2	757.3	639	248	BDL (<0.5)	42	35	32.6	5.4	210	BDL	55.6	29.8
12	Water sample collected inside the new Cave	N18°52'14.00"	E81°56'14.66	6.9	299.7	315	93	BDL (<0.5)	24	8	29	5	202	BDL	11	28
13	Dug well-Kotumsar	N18°53'27.08"	E81°55'19.25"	6.8	300	361	94	BDL	24.2	8.2	30	5.5	200	BDL	12.1	28.2
14	Dug well-Netanar	N18°52'19.22"	E82° 1'11.48"	6.8	302	345	99	BDL	25	9	29	5.8	204	BDL	13	29

IV. Physical Parameters

pH: The average pH of the collected water samples is 7.4, which is near the neutral range, with values ranging from 6.8 to 8.13. Nearly every sample has a pH that is safe to drink, according to the WHO. Minerals in karst terrain easily dissolve in acidic water with a pH of less than 7, which promotes karst formation. Samples of ground water were taken from the bored wells, and the results indicate a weakly basic character. On the other hand, one sample taken inside the dripping cave and two samples taken from the dug wells exhibit a mildly acidic pH of 6.8 to 6.9. It shows that when ground water travels from near the surface to modest depths, the values change. . The neutral to extremely weak acidic environment is further explained by this value. The optimal pH range for cave formation is between 6.5 and 7.5, which is slightly acidic to neutral and promotes the production of speleothem and allows for balanced precipitation and dissolution. Although neutral to slightly alkaline pH (7.5–8.5) is still beneficial for cave development, it may result in slower dissolution rates and more extensive speleothem growth. (Gupta, 2024, Drew et al. 2017)

Conductivity: The conductivity range is between 299.7 and 998.3 microseisms per centimeter, which is a respectable range. High EC (500-1000 μS/cm) may indicate high concentrations of dissolved minerals, which could lead to enhanced cave formation but also increase the probability of mineral precipitation and cave filling. (Gupta, 2024, Tiwari, 2023)

V. Chemical Parameters

Chemical parameters include Total Dissolved Solid, Total Hardness, several cations and anions examined from the collected samples.

Total Dissolved Solid (TDS): The total dissolved solids in the research area's collected samples range from 315 to 660 mg/l, with an average of 487.5. Since the WHO's maximum acceptable range for drinking water is 500 mg/l, nearly all of the samples fall into the freshwater category. and a higher TDS level (500–1000 mg/l) indicates a greater possibility of mineral breakdown and karst formation. (Chapman et al. 2024, Kalhor et al. 2019)

Total Hardness: The water samples' total hardness levels range from 210 to 280.7 mg/l, with an average of 245.35 mg/l. In contrast, the water samples from the drilled well and inside the dripping cave have TH values between 93 and 99 mg/l. Because it facilitates balanced processes for both precipitation and dissolution, moderate TH (150–300 mg/L) is beneficial for the formation of karst. Speleothem grows gradually and slowly. According to BIS, 300 mg/l is a desirable range while 600 mg/l is a permissible range for drinking water. Additionally, overall hardness fell into four categories: soft (<75 mg/l), moderately hard (75-150 mg/l), hard (150- 300 mg/l), and extremely hard (>300 mg/l). All of the samples fall within the desired range of drinking water. All of the water samples fall into the hard water category, according to analytical findings. (Tiwari, 2023, Liu et al. 2023).

Calcium: The primary element of rocks like gypsum, limestone, and dolomite is calcium. Calcium ions are necessary for the growth of speleothems, or cave structures like stalactites and stalagmites. Water samples from bore wells in the research region have a calcium range of 35.2–47.2 mg/l, while water samples from dug wells and inside the dripping cave (New Cave near Kotumsar Cave) have a calcium range of 24–25 mg/l. The WHO recommends a maximum allowable range of 200 mg/l and a recommended range of 75 mg/l for drinking water. One water sample that was taken inside the dripping cave (New Cave, close to Kotumsar Cave) has well joints. In comparison to other nearby caves in the area, the intensity and volume of water percolation inside this cave was remarkable. As a result, meteoric water may not have had much time to interact with the limestone of the surrounding areas, and the existence of this cave allowed water to percolate inside the cave in a comparatively large quantity. This could be the cause of the collected sample's low Ca and sharp decline. The rather high amount of iron (0.5 ppm) in the collected water may be caused by a thin layer of soil above the cave. The maximum acceptable iron range is 0.1 ppm. (Tiwari, 2023, Gao et al. 2023).

Magnesium: Additionally, magnesium plays a significant role in the creation of speleothems such as stalactite and stalagmites. The bored well sample's mg readings vary from 29.6 mg/l to 41.9 mg/l. which falls below the WHO's maximum recommended range for drinking water (30 mg/l). The magnesium content is extremely low, ranging from 8.2 mg/l to 9 mg/l in samples taken from the inside of the dripping cave and the well. (Gupta, 2024).

Sodium: The water samples' sodium concentrations range from 26.6 to 32 mg/l. When compared to other ions like as calcium, magnesium, and carbonate, sodium has little or no impact on the development of karst topography and the maximum acceptable and desired ranges of sodium for drinking water are 175 mg/l and 20 mg/l, respectively. (Gupta, 2024, Tiwari, 2023).

Potassium: The obtained water samples have potassium values ranging from 4.4 mg/l to 6.3 mg/l. Potassium has some implications on karst formation even if its influence on karst topography has been minimal. Potassium affects the pH, total dissolved solids (TDS), and overall aggressiveness of groundwater, all of which can have an impact on karst formation. and the maximum acceptable and ideal potassium ranges are 10 and 12 mg/l, respectively (WHO, 2011). (Gupta, 2024, Tiwari, 2023).

Bicarbonate: The range of bicarbonate levels in the research region is 150–224 mg/l. Bicarbonate (HCO_3^-) is important for karst topography, particularly for the formation and evolution of karst landforms. By interacting with calcium and magnesium ions to form soluble compounds that induce rock disintegration and the formation of karst, bicarbonate ions aid in the chemical weathering of carbonate rocks (limestone, dolomite). Bicarbonate-

rich water promotes karst processes such precipitation, dissolution, and speleogenesis which is how karst terrain is formed. Bicarbonate-enriched water helps form caves by dissolving rocks and transferring minerals that eventually deposit as speleothems (stalactites, stalagmites). Moderate bicarbonate concentrations: These ranges (100–300 mg/l) are regarded to be optimal for cave formation because they permit a balanced dissolving rate and promote the production of speleothems. (Gupta, 2024, Tiwari, 2023).

Chloride: The water sample from the bored well had a chloride content of between 55.5 and 60 mg/l. Because they accelerate karst denudation and speleogenesis, create caverns, and improve limestone dissolving, chloride ions have a significant impact on the morphology of karst ecosystems. Chloride ions in drinking water fall under the 200 mg/l acceptable range (WHO, 2011). (Tiwari, 2023).

Sulphate: Water samples have sulphate concentrations ranging from 25.7 mg/l to 30 mg/l. Sulphate ions play a significant role in karst topography, particularly in the formation of caves and other karst features: In addition to making calcium carbonate more soluble and encouraging the development of karst characteristics, sulphate ions can facilitate the dissolution of limestone. Sulphate-rich water may help build caverns and subterranean conduits by dissolving limestone and creating passages. Karst denudation, which can be expedited by sulphate ions, is the process by which the land surface is lowered as a result of erosion and dissolution, creating sinkholes, dolines, and other karst characteristics. All of the samples fall under the desired range of 200 mg/l for sulphate ions in drinking water. (Tiwari, 2023).

Table No. 2 - Drinking Water Standers

Constituents	WHO (2011)		BIS (2012)		Concentration In Study Area
	Max Desirable	Max Permissible	Max Desirable	Max Permissible	
pH	7.0 to 8	6.5 to 9.2	6.5 to 8.5	No relaxation	6.8 - 8.13
TDS mg/l	500	1500	500	2000	345 - 660
TH as CaCO3 mg/l	100	500	300	600	93 – 280.7
Ca mg/l	75	200	75	200	24 - 47.2
Mg mg/l	30	150	30	100	8 – 41.9
K mg/l	10	12	-	-	4.4 – 6.3
Na mg/l	20	175	-	200	26.6 – 32.6
HCO3 mg/l	-	-	300	600	165 – 225
SO4 mg/l	200	400	200	400	25.7 – 30
Cl mg/l	200	600	250	1000	11 - 60

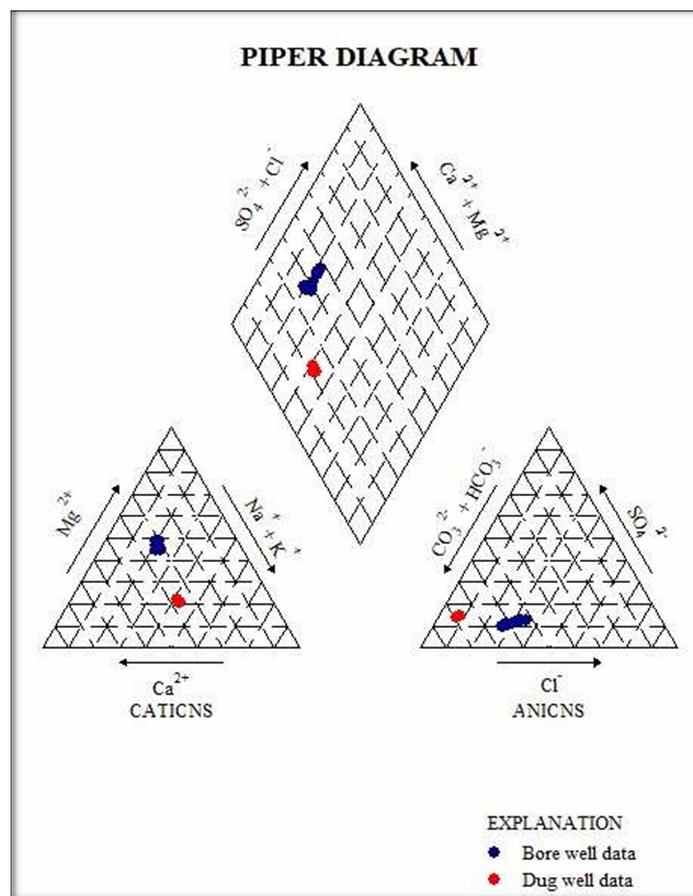**plate No. 1 – Water Sample Collection (Field Photographs)**

Fig. No. 1 – Piper Trilinear Diagram (after Gupta,2024)

Piper's (1953) more generally used technique, which displays the water's essential chemical character based on the relative concentration of its elements, is another attempt to assess natural waters. A graphical tool used in hydrogeology to visualize and classify water samples based on their chemical composition is the Piper Trilinear diagram. It's a useful tool for understanding the hydrochemical properties of groundwater and surface water. A trilinear plot known as a Piper diagram displays the concentration of the six major ions in a sample of water: sodium, potassium, calcium, magnesium, chloride, and sulphate. The figure consists of six fields, each of which stands for a different hydrochemical facies (or type of water). Plotting the ion concentrations on the Piper diagram allowed for the determination of the predominant type of water (such as freshwater, saltwater, or brine), the assessment of the degree of mineralization or salinization, the identification of possible sources of contamination, and the evaluation of the water's suitability for different uses (such as industrial, irrigation, or drinking). Piper diagrams are widely used in hydrogeological research, water resource management, and environmental monitoring to improve understanding of the complex relationships between geological processes and water chemistry. According to Piper's Trilinear diagram, the research area's water is linked to the Ca-Mg-HCO3, facies, and the groundwater plot includes fields 1, 3, and 5. Alkaline earths exceed alkalies, weak acids exceed strong acids, and the ions signifying carbonate hardness exceed 50%, according to fields 1, 3, and 5. The general hydrochemistry is dominated by weak acids and alkaline earths. The establishment of the chemical quality data in this investigation indicates that calcium bicarbonate is the primary component. Regarding karst development, areas 1, 3, and 5 of a Piper diagram show various phases of karst evolution: Area 1 (Ca-HCO$_3$) is a stage of early karst development that is characterized by the construction of cave channels and conduits, the dissolving of limestone, and the release of calcium and bicarbonate ions. 3 (Ca-SO$_4$) denotes the intermediate stage of karst development, where calcium and sulphate ions are released and subterranean passages and channels widen and unite. Area 5 (Ca, Mg, HCO, SO$_4$) shows: The karst landscape is mature, the cave systems are well-developed, and the mixed water type indicates a complex geochemical environment. (Gupta, 2024).

VI. Conclusion

Fourteen samples were collected from several handpumps and tubewells in order to analyze the chemistry of the ground water around the caverns using standard methods. pH, TDS, Total Hardness, Calcium, Magnesium, Sodium, Electrical Conductivity (EC), Bi-carbonate, Chloride, and Potassium, Magnesium,

Sulphate were all carefully analyzed during the chemical analysis of water samples. The results of many hypotheses in parts per million (ppm). Piper's Trilinear diagram indicates that the Ca-Mg-HCO facies is associated with the water in the research area. The groundwater plot includes fields 1, 3, and 5. These fields demonstrate that alkaline earths exceed alkalies, weak acids exceed strong acids, and alkaline earths and weak acids predominate in the overall hydrochemistry, with the ions displaying carbonate hardness above 50%, respectively. The investigation's chemical quality data shows that calcium bicarbonate is the main constituent. Areas 1, 3, and 5 of a Piper diagram illustrate different phases of karst evolution in terms of karst development: The first area (Ca-HCO) indicates an early stage of karst development marked by the formation of cave passages and conduits, the release of calcium and bicarbonate ions, and a prevalence of limestone breakdown. An intermediate stage of karst growth is shown by the third area (Ca-SO), where cavern passages and channels combine and sulphate and calcium ions are discharged. Area 5 (Ca, Mg, HCO, SO) demonstrates the maturity of the karst topography and the well-developed cave systems. A complicated geochemical environment is indicated by the presence of mixed water. In addition, the water samples' pH, conductivity, total dissolved solids, and total hardness levels indicate a greater probability of karst formation and mineral dissolution, and all of the samples fall within the acceptable range for drinking water.

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