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Appraisal of Hydrochemical Quality of Groundwater in Bamanghaty Subdivision of Mayurbhanj District, Odisha, India Using Geospatial Technology

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Abstract

Geochemical attributes of groundwater were investigated in the Bamanghaty Subdivision of Mayurbhanj District, Odisha, India using geospatial technology. The assessment was undertaken to depict the suitability of water for drinking and irrigation use. Geospatial technology is reliable and cost-effective to measure the quality of groundwater in Precambrian hard rock terrain. Around 14 groundwater samples were collected arbitrarily from various sources such as hand pumps, tube wells and bore wells. Major ions were analysed to understand the influence of geochemical processes on groundwater quality in the Bamanghaty subdivision. Samples were tested for pH, Electrical Conductivity, Carbonate, Bicarbonate, Chloride, Sulfate, Nitrate, Calcium, Magnesium, Sodium, Potassium and absolute hardness. Based on the results of the chemical analysis of water samples, various graphical representations were made, *viz.* Ionic concentration diagram, Stiffs' diagram, Permeability index diagram, Salinity hazard diagram and Piper's trilinear diagram. The chemical properties of groundwater were analysed to decipher its suitability for drinking and irrigation use. Investigation demonstrates that most of the groundwater is chemically suitable for drinking and agricultural uses.

Keywords: Groundwater; Chemical Analysis; Geospatial Technology; Permeability Index; Salinity Hazard Index; Piper Diagram.

Introduction

Adequate pure drinking water is needed for sustenance of life, and it should be sufficiently available for all categories of people (Mosaferi *et al*., 2014). In India, a huge quantity of groundwater is required as the country's economy is dependent on agricultural growth (Girish, 2003; Basavarajappa and Manjunatha, 2015). Excessive use of fertilizers, agrochemicals, industrial and urban sewage, mining effluent are serious threats to groundwater quality (Rajmohan *et al*., 2002; Hejabi and Basavarajappa, 2009; Basavarajappa and Manjunatha, 2015). Over the last few decades, the quality and quantity of groundwater have sharply declined in the urban region due to over-exploitation of water, haphazard urbanisation, uncontrolled industrialisation and mining of ores and minerals (Appelo and Postma, 2005). Types of dissolved minerals present in the water determine the suitability of groundwater (Mirrabasi *et al*., 2008; Mohan and Krishnakumar, 2021). The quality of groundwater is dynamic in nature and depends on seasonal, spatial and climatic variations, *etc.* (Ackah *et al*., 2011). As rainwater contains chemically active fluid and gaseous substances, it interacts with various biological and chemical components while infiltrating through the soil (Hejabi and Basavarajappa, 2010; Bundschuh *et al*., 2012; Basavarajappa and Manjunatha, 2015; Deshmukh and Taksande, 2021). The cations and anions available in the groundwater comprise calcium, manganese, chromium, cadmium, copper, cobalt, zinc, lithium, sodium, potassium, nitrate, sulfate, bicarbonate and chloride. These parameters determine the nature of groundwater as far as cations and anions are concerned (Shyam and Kalwania, 2011; Tharun *et al.,* 2021). Both anthropogenic and geogenic factors influence the groundwater of the assessment zone in many areas (Kanmani and Gandhimathi, 2013; Agbaire and Obi, 2009; Nandi *et al.,* 2017).

Water samples were collected from 14 localities of the Bamanghaty Subdivision, Mayurbhanj, Odisha. Geographical coordinates of individual locations were recorded with the help of handheld GPS. The spatial distribution of various parameters has been observed and digitized using ArcGIS v10.2.2. The samples collected were analysed in the laboratory. The Bamanghaty Subdivision experiences subtropical monsoon rainfall with moderate hot and cold climate. The present work is an attempt to determine the spatial variability and assessment of different hydro-

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geochemical parameters and understanding of groundwater potential in the Bamanghaty Subdivision applying Kriging supplement tools of ArcGIS.

Location of the Study Area

The Bamanghaty Subdivision is situated in the northwest part of the Mayurbhanj District of Odisha (Fig. 1). It is a marginal part of the Chhatonagpur Plateau. The subdivision lies between 85°55'E to 86°30'E longitude and 22°0'N to 22°35'N latitude. It is surrounded by the Singhbhum region of Jharkhand in the north and west, the Panchpir Subdivision in the south and the Baripada Subdivision in the east. The subdivisional headquarter is Rairangpur, located 83km away from the district headquarter in Baripada. The subdivision exhibits rugged topography with a maximum elevation of 248m above MSL. The dominant forests cover of this subdivision is tropical deciduous monsoon type.

Methodology

The methodology adopted for the groundwater quality evaluation of the Bamanghaty Subdivision has been carried out following standard analytical procedures (Trivedi and Goel, 1984; Saxena, 1995; Gupta, 2004; Jaiswal, 2004; Gray, 2005; APHA, 2005; Fig. 2). pH and electrical conductivity of the water samples were measured by digital pH meter- Model 335 and conductivity meter – Model-304 of Systronics Make, respectively. Flouride is analysed by Flouride meter (Spectro quant move-Model-100). Na and K were measured by Flame photometer- Model 128 Systronics Make. Different types of parameters namely TDS, EC, TH, Ca_2, Na, Mg_2, K, Cl, SO_4 have been analysed to investigate the changes in groundwater quality (Table 1). Throughout the analysis, instruments were initially standardized and calibrated with known concentration of the standard. After that the value of the various parameters were estimated with unknown samples as per method described by APHA (2005). Others parameters were analysed by volumetric method following the standard procedures (Trivedi and Goel, 1984; Saxena, 1995; Gupta, 2004; Jaiswal, 2004; APHA, 2005). The ionic balance error (IBE) was computed for the cations (Ca_2, Mg_2, Na and K) and anions

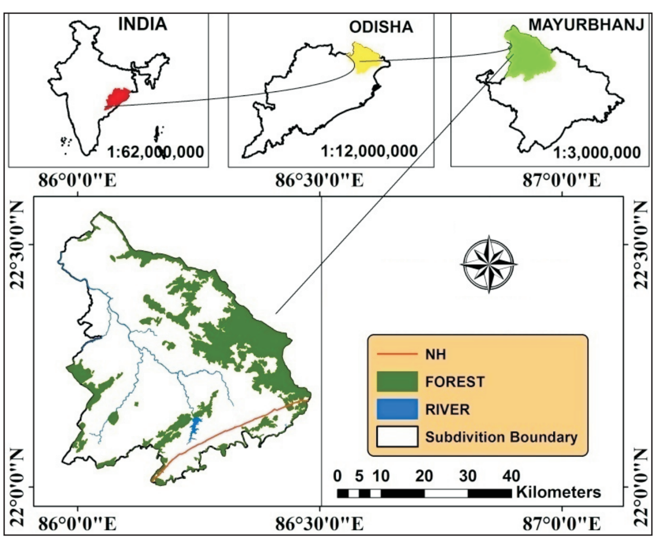

Fig. 1. Location map of Bamanghaty Subdivision, Mayurbhanj, Odisha.

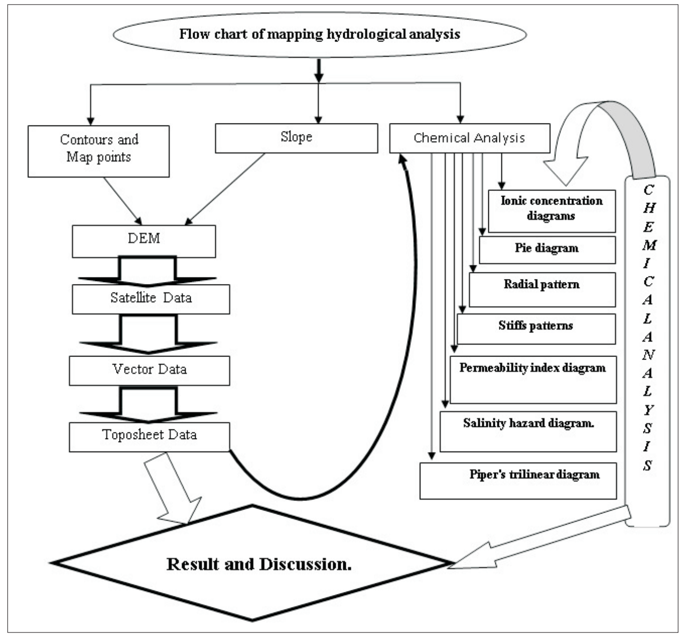

Fig. 2. Flow chart of ground water analysis.

(HCO_3^-, Cl^-, SO_4^{2-}, NO_3^- and F^-) to verify the accuracy of a complete chemical analysis of each groundwater sample. All the diagrams were created by using the Diagrammes and GW chart software. Finally, the maps were created by ArcGIS 10.2 software.

Results and Discussion

Geology of the Subdivision

Geological fieldwork has been carried out using GPS to study the lithological units and topography of the area, which controls the occurrence and movement of groundwater (Shankar *et al*., 2011). The major rock types are Banded Hematite Quartzite (BHQ), Banded Magnetite Quartzite (BMQ), shale, lava, gabbro, and calc-alkaline, ultra-basic rocks, granite and gneissic complex, schist, phyllites and calc-gneiss rocks. The diverse mineralogical composition can significantly influence groundwater movement and distribution (Krishnamurthy and Srinivas, 2010). Geographically, the study area is the southernmost part of the Chhatonagpur Super Group. The general slope in the study area is moderate to high towards the east and low to medium in the western parts (Fig. 3a). The Singhbhum Granite of the Archean age covers the north and western part of the study region.

Lineaments of the Subdivision

Linear and curvilinear features such as joint, fractures, fold, fault, shear zone and lithological contacts are considered lineaments. These are secondary features developed due to structural disturbances, which control the storage and movement of groundwater in hard rock terrain (Basavarajappa *et al*., 2008, 2012; Ramasamy *et al*., 2005; Rao, 2006; Basavarajappa and Manjunatha, 2015; AlSuhaimi *et al*., 2019; Kundu and Nag, 2016; Varade *et al*., 2019). Lithology is also another factor that controls the amount and nature of groundwater in a given zone (Bhuvaneswaran *et al*., 2015, Mirabbasi *et al*., 2008). The occurrence and movement of groundwater rely upon the secondary porosity such as lithological

Table 1: Chemical constituents of groundwater of Bamanghaty Subdivision

Village	Constituent's value (in mg/l), EC (in mhos/cm), PI (in %)												
	Ca	Mg	Na	HCO_3	CO_3	SO_4	Cl	K	TDS	TH	pH	EC	PI %
Tiring	31	15.81	2.36	163	0	2.81	10.622	1.83	145	143	8.13	292	48.61
Jaonirdiha	35	19.45	21.1	173	0	2.92	49.67	5.91	221	167	7.85	431	61.52
Ambadiha	15	7.33	8.21	87	0	3.21	10.631	5.45	97	64	7.91	239	92.63
Bhatachhata	77	81.52	63.72	192	0	29.33	326.13	3.67	671	521	7.81	1365	34.32
Bisoi	22	7.33	9.70	87	0	7.02	11.718	6.35	113	83	7.93	203	78.73
Manda	16	3.65	14.43	63	0	6.85	17.79	4.73	95	52	7.84	174	102
Bademtola	34	9.75	14.27	142	0	7.72	17.72	4.56	152	121	8.07	242	70.41
Bahalda	43	23.17	25.25	167	0	10.3	70.93	2.52	254	208	7.91	551	19.72
Bahalda- (R)	42	24.34	25.72	169	0	11.41	70.97	2.57	253	203	8.06	531	53.94
Jamda	39	6.15	36.53	137	0	7.33	53.176	7.25	218	121	7.93	402	76.62
Moranda	43	10.94	61.48	153	0	6.85	92.175	4.08	292	152	8.05	603	75.43
Khema	19	2.46	18.92	64	0	6.47	28.32	3.87	104	58	7.85	203	94.74
Naujara	28	18.25	14.27	173	15	7.35	24.835	4.56	182	143	8.02	351	67.18
Champrai	16	6.12	0.79	69	0	8.24	17.73	2.58	95	64	8.06	162	90.32

contact and topographical structures like unconformities, folds, bedding fields, break, joints, shear zones, *etc*. Lineaments are analysed by visual interpretation method on IRS-1D, PAN+LISS-III satellite image through Erdas Imagine and SRTM DEM data. The remotely gathered information offers a concise view of the vast area, which helps in better understanding and mapping the lineaments both on a local and regional scale. The lineament study of the terrain from remotely detected information gives imperative data on subsurface cracks that may control groundwater occurrence. The spare lineament density is located in the northern and eastern parts of the subdivision, which is revealed in Fig. 3b. Basically, these areas have better prospects for groundwater.

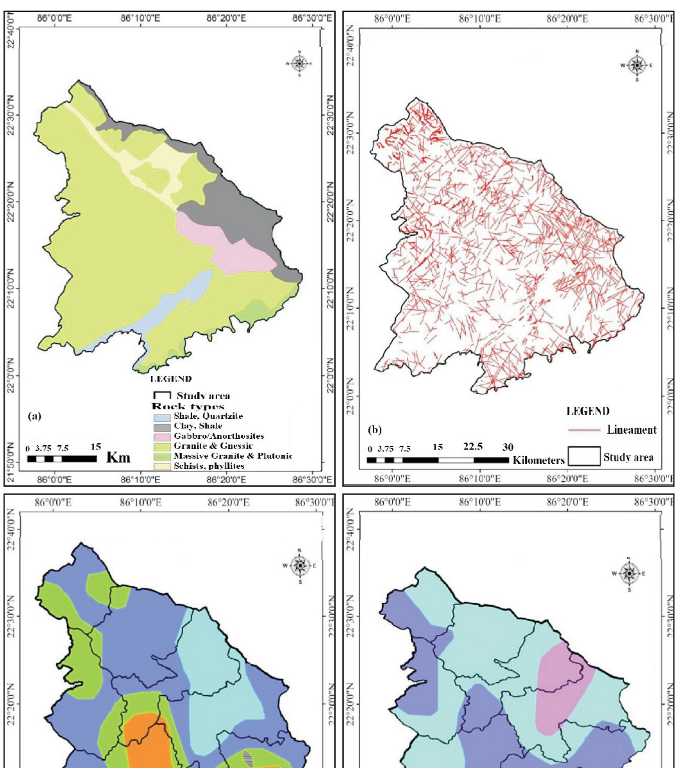

Fig. 3 a. Geological map, b. Lineament map, c. Depth of groundwater level in pre-monsoon period, d. Depth of groundwater level in post monsoon period of Bamanghaty subdivision.

Chemical Quality of Groundwater (Pre-monsoon and Post-monsoon)

The study area is dominated by monsoon rainfall. Pre-monsoon precipitation takes place from March to May in the form of *Kalbaishaki*. The groundwater potential of the subdivision during the pre-monsoon period is poor. Pre-monsoonal map (Fig. 3c) shows clearly that the water level depth significantly goes down. During the pre-rainstorm period, the groundwater level goes down in the southern part of the Bisoi block and the eastern part of the Kusumi Block. Post monsoonal map depicted the depth of groundwater in the study area (Fig. 3d). The water level rises remarkably in the eastern part of the Rairangpur and Bijatola. The shallow water table is observed in the southwest region of the Bisoi Block. The water level of Bahalda road is shallow in the years 2014 (November), 2015 (April), 2015 (November). The decreasing trend of water level is observed in the entire subdivision. The result of the chemical analysis is presented in Table 1.

Water Quality Plots

The water quality index (WQI) was determined for assessing the impact of anthropogenic activities based on a few critical parameters of groundwater. To outline the WQI, the weightage has been assigned for the physicochemical parameters. The allotted weightage ranges from 1 to 5. The highest load of 5 has been given for nitrate and TDS, 4 for pH, EC, SO_4, 3 for HCO_3, Cl, 2 for Ca, Na, K and weight 1 allotted for magnesium (Vasanthavigar *et al*., 2010).

Stiff's Diagram

Stiff"s system uses four parallel horizontal axes and one vertical axis. Four cations are plotted on one side and four anions on the other side of the vertical axis. The axis of the polygon is connected to give the shape and characteristics of the water samples (Ragunath, 1987). Table 2 demonstrates that the Cl, HCO_3, SO_4 of the groundwater of Jamda Block is high. Usually, the Jamda Block is covered with granitic rocks. The water and soils are acidic in nature (Chandra *et al.*, 2010). Fig. 4a demonstrates that the Na, K cations are the most elevated among the cations. The most

Table 2: Chemical composition of rock types of Bamanghaty Subdivision

Sl. No.	Block	Rocks	Na	K	F	Cl	Ca	HCO_3	Mg	SO_4
			Chemical Data (Ions epm) Mg/l							
A1	Tiring	Granite, plutonic, clay	2.35	1.9	0.09	10.632	32	153	15.81	2.81
A2	Bahalda	Granite	25.27	2.52	0.225	70.91	43	162	23.13	10.3
A3	Rairangpur	Granite, plutonic,schist	10.73	2.57	0.153	17.72	17	68	6.12	8.22
A4	Bisoi	Shale, granite, massive granite	9.75	6.34	0.133	11.723	19	87	7.33	7.2
A5	Jamda	Granite	36.55	7.25	0.134	53.172	34	132	6.13	7.35
A6	Bijatola	Gabbro, clay, Granite		4.52	0.156	17.71	31	143	9.72	7.71
A7	Kusumi	Shale, granite	14.28	4.55	1.75	24.812	24	172	18.25	7.35

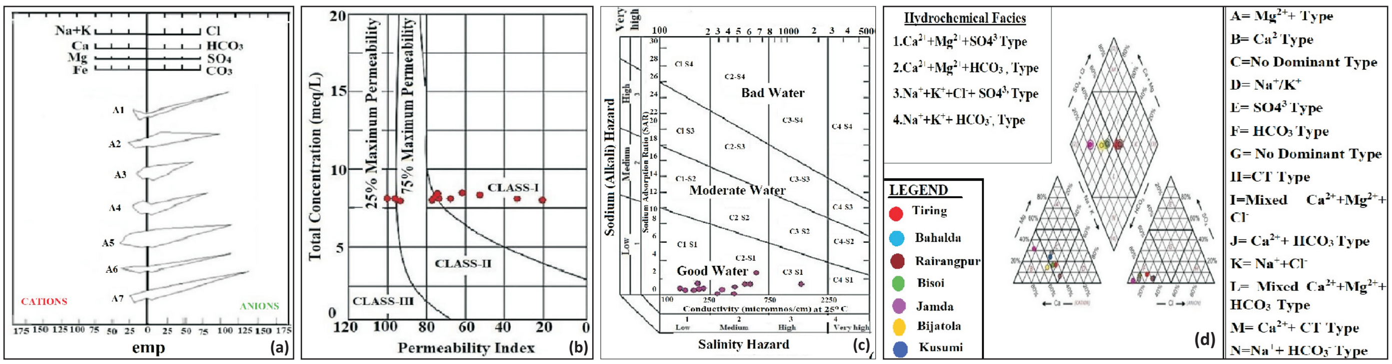

Fig. 4 a. Graph showing Stiffs pattern of chemical data, b. Graph showing permeability index of chemical data, c. Salinity hazard diagram, d. Piper's Triliner diagram pattern of chemical data of Bamanghaty Subdivision.

transcendent water type in study zones is the Na-Cl water type (Salehi and Hosseinifard, 2012).

Permeability Index

PI is calculated using the following formula (Ragunath, 1987). The chemical data of the permeability index is presented in Table 3.

$PI= [(Na^{+} + HCO_3) [(Ca_2^{+} + Mg^{2+} + Na^{+}]100$

Where all values are in meq/l. The PI values computed for the area ranged from 24.1 to 254.3 with a mean of 93% and 44% of the samples fall under class II of the Doneen (1962) chart. The maximum permeability is located in the Bisoi and Kusumi Blocks of Mayurbhanj District of Odisha. It also demonstrates all the PI values of the survey area (Fig. 4b).

Salinity Hazard Analysis

The salinity hazard diagram is made by plotting EC and SAR value on the US salinity laboratory's diagrams (Fig. 4c). Salinity hazard categorization for the Bamanghaty Subdivision was calculated. The majority of water samples fall under the C1-S1, C2-S1 groups. C1-S1 is the low saline group and low to intermediate alkaline groups of the hazard diagram. C2-S1 is moderate saline to low alkaline. Low-salinity water can be used for irrigation. The total concentration of soluble salts in irrigation water can be expressed as low (EC = <250 µS/cm), medium (250-750 µS/cm), high (750-2,250 µS/cm), and very high (>2,250 µS/cm); and classified as C1, C2, C3 and C4 salinity zones, respectively (Singh *et al*., 2011). EC, TDS, SAR, PI of all the sampling sites are presented in Table 4.

Table 3: Permeability index of groundwater of Bamanghaty Subdivision

Block	Site	EC µ mhos/cm	PH	TH	NCH	TDS	Na %	SAR	RC	PI %
			Mg/l					Mg/l		
Tiring	Tiring	292	8.13	143	40.00	145	2.36	0.072	-8.00	48.61
Bisoi	Jaonirdiha	431	7.85	167	24.50	221	21.1	0.73	-0.49	61.52
Bisoi	Ambadiha	239	7.91	64	-5.50	97	8.21	0.45	0.10	92.63
Bisoi	Bhatachhata	1365	7.81	521	364.5	671	63.72	1.23	-7.29	34.32
Bisoi	Bisoi	203	7.93	83	10.50	113	9.70	0.48	-2.1	78.73
Bisoi	Manda	174	7.84	52	0	95	14.43	0.85	0	102
Bijatola	Bademtolia	242	8.07	121	5.50	152	14.27	0.57	-0.11	70.41
Bahalda	Bahalda	551	7.91	208	64.50	254	25.25	0.76	-1.29	19.72
Bahalda	Bahalda road	531	8.06	203	64.50	253	25.72	0.75	-1.29	53.94
Jamda	Jamda	402	7.93	121	10.50	218	36.53	1.42	-0.21	76.62
Jamda	Manada	603	8.05	152	20	292	61.48	2.15	-0.40	75.43
Kusumi	Kherna	203	7.85	58	5	104	18.92	1.13	-0.10	94.74
Kusumi	Naujara	351	8.02	143	-24.50	182	14.27	0.512	0.51	67.18
Rairangpur	Chanprai	162	8.06	64	5.50	95	0.79	0.58	-0.11	90.32

Table 4: Calculated parameters of groundwater of the study area

Blocks	Site	EC µ mhos/cm	TDS	SAR	PI %
			Mg/l		
Tiring	Tiring	292	145	0.072	48.61
Bisoi	Jaonirdiha	431	221	0.73	61.52
Bisoi	Ambadiha	239	97	0.45	92.63
Bisoi	Bhatachhata	1365	671	1.23	34.32
Bisoi	Bisoi	203	113	0.48	78.73
Bisoi	Manda	174	95	0.85	102
Bijatola	Bademtolia	242	152	0.57	70.41
Bahalda	Bahalda	551	254	0.76	19.72
Bahalda	Bahalda road	531	253	0.75	53.94
Jamda	Jamda	402	218	1.42	76.62
Jamda	Manada	603	292	2.15	75.43
Kusumi	Kherna	203	104	1.13	94.74
Kusumi	Naujara	351	182	0.512	67.18
Rairangpur	Chanprai	162	95	0.58	90.32

Piper's Trilinear Analysis

A Piper's Triliner diagram (Piper, 1944, 1953) is a graphical demonstration of the chemical and physical properties of water (Fig. 4d ; Table 5). The cations and anions are shown by separate ternary plots. Water samples shown on the piper diagram can be grouped into different hydro-chemical facies (Chebotarev, 1955). It depicts that Ca Mg, HCO_3, types and Na, K, Cl, SO_4 types of hydro-chemical facies have been found in this region. The saline character is maximum in the Kusumi Block, and the groundwater of Bahalda is acidic in nature.

Conclusions

The study has clearly revealed that the integrated approach of satellite remote sensing and GIS is the most valuable and modern scientific tool for hydrogeological and geomorphological studies. It provides crucial clues about the spatial distribution of lithology, geomorphology, land use/land cover and structural features that directly control groundwater occurrence and movement. Different thematic maps like slope, drainage density and network, lithology, lineaments and topography and groundwater prospect zones have been prepared in the GIS software. These factors directly control the storage and movement of groundwater. The demarcation of groundwater potential zones was done by overlapping the various thematic layers using the GIS technique. After integrating all the layers, four categories of groundwater potential zone such as very good, good, moderate and low have been identified in the study area. The area with a gentle slope or near horizontal with dense lineament and where precipitated water percolated more is considered as very good to good category, while the mountainous and steep slope regions where there is more surface runoff is deemed to be moderate to low potential groundwater zone. The study concluded that about 30% of the area has good to very good groundwater potential. The physicochemical results revealed that the water of Bamanghaty is suitable for irrigation and drinking purposes.

Authors' Contributions

Tanmoy Chatterjee: Data Collection, Investigation, Analysis, Writing Original Draft. **Duryadhan Behera**: Conceptualization, Data Analysis, Investigation, Writing Original Draft, Reviewing and Editing. **Shreerup Goswami**: Writing Original Draft, Reviewing and Editing. **Prashanta Kumar Patra**: Data Collection, Investigation, Analysis. **Surjit Munshi**: Data Collection, Investigation, Analysis.

Conflict of Interest

The authors do not have any conflict of interest.

Table 5: Chemical composition of groundwater plotted in piper's Trilinear diagram

Sl.No.	Block	Cation	Value	Percentage value of Cation (%)	Anions	Value	Percentage value of Anion	Combination	Value	Percentage value of the Combination
A1	Tiring	Mg	15.83	32	CO_3+HCO_3	154	92	SO_4+Cl	13.42	23
		Na+K	4.12	08	SO_4	2.78	02	Ca+Mg	45.82	77
		Ca	30.001	60	Cl+NO_3	10.61	06			
A2	Bahalda	Mg	24	25	CO_3+HCO_3	160	67	SO_4+Cl	80.7	56
		Na+K	27.79	30	SO_4	10.1	4	Ca+Mg	64.13	44
		Ca	41.1	45	Cl+NO_3	70.5	29			
A3	Rairangpur	Mg	6.11	18	CO_3+HCO_3	69	72	SO_4+Cl	25.91	55
		Na+K	13.25	40	SO_4	8.23	9	Ca+Mg	20.12	45
		Ca	15	42	Cl+NO_3	17.5	19			
A4	Bisoi	Mg	7.33	17	CO_3+HCO_3	89	82	SO_4+Cl	18.71	41
		Na+K	16.07	37	SO_4	7.8	7	Ca+Mg	27.35	59
		Ca	21	46	Cl+NO_3	11.17	11			
A5	Jamda	Mg	6.13	7	CO_3+HCO_3	139	69	SO_4+Cl	60.45	58
		Na+K	43.72	50	SO_4	7.38	4	Ca+Mg	44.15	42
		Ca	38.3	43	Cl+NO_3	53.12	27			
A6	Bijatola	Mg	9.78	16	CO_3+HCO_3	144	84	SO_4+Cl	25.46	38
		Na+K	18.75	31	SO_4	7.72	5	Ca+Mg	41.72	62
		Ca	32.3	53	Cl+NO_3	17.75	11			
A7	Kusumi	Mg	18.25	29	CO_3+HCO_3	169	84	SO_4+Cl	32.15	42
		Na+K	18.76	30	SO_4	7.31	4	Ca+Mg	44.24	58
		Ca	26.8	41	Cl+NO_3	24.78	12			

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