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Major Ion Chemistry and Assessment of Groundwater Quality around Gangapur Village, Nagpur District, Maharashtra, India

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Abstract

Groundwater quality results of 37 representative groundwater samples around Gangapur village are discussed here. The pH values of the groundwater reveal that it is in general alkaline in nature. The electrical conductivity varies from 565 to 1687 µS/cm; the TDS content from the area shows that the 63% of groundwater samples from the study area have drinking utility, while its spatial variation is attributed to variations in lithology and hydrological processes. The cation chemistry is dominated by Ca^{2+} and Mg^{2+} while anion chemistry is dominated by Cl^- and HCO_3^-. There are two dominant hydrogeochemical facies, which are Mg-Ca-HCO_3 and Ca-Mg-SO_4-HCO_3 where in alkaline earths (Ca^{++} + Mg^{++}) dominates over the alkalies (Na^+ + K^+). The US Salinity classification indicates that water of the study area belongs to C2–S1, and C3 – S1classes. In general, the groundwater from the study area is suitable for drinking, domestic as well as irrigation purpose without any hazards.

Keywords: Groundwater Quality, Major Ions, Groundwater Suitability, Gangapur, Nagpur District, Maharashtra, India

Introduction

Water has vital importance for sustaining life and being a natural resource it is the chief component of environment. The enormous increase in uncontrolled utilization of water resources trapped beneath the surface has led to very pathetic condition of lowering of water table as well as lowering of its quality. The highly mineralized areas, wherein natural resources are being mined out are also dealing with important issues of change in water quality (Duraiswami *et al.*, 2018). The mineralized water from mine areas varies greatly in terms of concentrations of various chemical constituents and hence discarded many a times; the closely related another issue is of decline of groundwater table in many parts of the World (Choubey, 1991; Allen *et al.*, 1996; Tiwari, 2001; Khan *et al.*, 2005; Soni, 2007; Khond *et al.*, 2015). Thus, the fresh water resources are extremely limited, even at global level. The ascending graph of utilization of water is resulting in the descending levels of ground water; hence the depletion of the groundwater has created a big mess in human life. The living beings are directly affected by the quantity as well as quality of water also (Rawat and Viswanathan, 1990; Taranekar, 1993; Mohabey *et al.*, 1996; Gupta, 1996; Singh *et al.*, 2010). The high concentrations of elements like fluorine, arsenic, nitrate, and other toxic entities, than the safe limit, pollute the groundwater, making it unsafe for drinking and domestic utilities. Many times water is not sufficiently safe for irrigation purpose. Many parts of India experience the acute shortage of water for different purposes and such problems of water crises are likely to become more severe and serious and will continue and escalate in the 21st century (Biswas, 1991). The present attempt has been made to understand the hydrogeochemical behaviour of groundwater around Gangapur village, Nagpur District, Maharashtra, India (Fig.1).

Study Area

Location, Climate, Physiography and Drainage

The study area (Lat. 20º50'00"- 20º52'50" N and Long. 79º16'00" - 79º18'30" E) lies in southeast at 42 km from Nagpur City, Nagpur District (M.S.), Central India. The area experiences tropical dry sub humid climate. The summer months are very hot (max. temp. ~ 44ºC) while, winter is cool (min. temp. ~ 15.1ºC). The area receives the rainfall of 1084.17 mm by south-west monsoon (June to September) with relative humidity of 71 % during monsoon season. The area exhibits moderately dissected topography with a few isolated hills. It forms a part of the Pranhita-Godavari Graben (PGG)

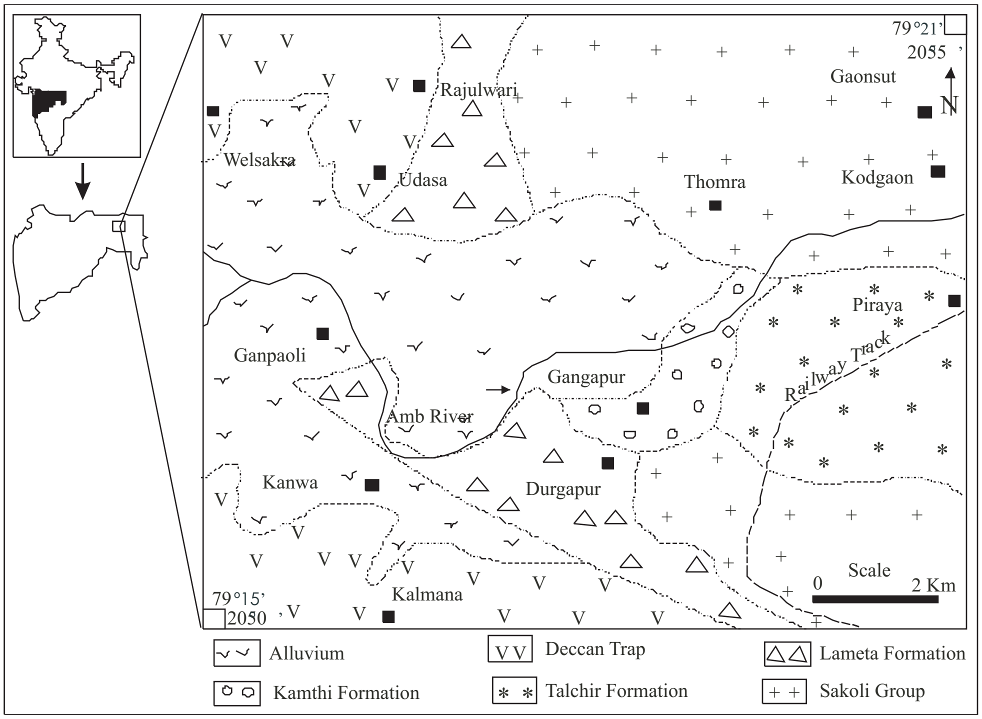


Fig. 1. Location and Geological map of the study area

(Raja Rao, 1982; GSI, 2008) with general slope towards east and southeast directions. The Amb River and its tributaries drain the area in east. The drainage network is dendritic to sub dendritic with ephemeral drainages.

Geology and Hydrogeology

The study area is a semi-elliptical basin with sedimentary rocks dipping from 5º to 10º towards south. The northern boundary of the basin is an erosional unconformity, whereas the southern boundary is bounded by an east-west trending fault (Raja Rao, 1982). The geological setup of the area is presented in Table 1. The quartz-mica schist and phyllites of Sakoli Group (Archaean) forms the basement of the overlying sediments of the Gondwana Supergroup. The Talchir Formation rests unconformably over the metamorphic rocks and attains 30 m in thickness, as noticed from borehole data. The Talchir Formation exhibits conformable relationship with the succeeding Barakar Formation. The Kamthi Formation rests on the Barakar beds with distinct angular unconformity (Raja Rao, 1982). The Kamthi Formation is unconformably overlain by isolated and patchy outcrops of the Lameta Formation. The migratory black soil, derived from the Deccan Traps and local alluvial sediments, cover the area in patches.

In the study area the occurrence of groundwater from quartz-mica schist and phyllites of the Sakoli Group is mainly controlled by the degree of weathering, joints and fractures. The dugwells penetrating rocks of the Sakoli Group range in depth between 8 to 15 mbgl. The diameters of the dugwells range between 3 to 5 m. The dugwells penetrating Gondwana rocks range in depth between 5 to 15 mbgl. The diameters of the dugwells range between 3 to 6 m. The wells piercing these have the discharge of 50 to 300 m^3/ day (GSDA, 2005, 2009). In the study area, the Lameta rocks do not act as prolific aquifers. The Basaltic lava flows are vesicular in nature and possess deep weathering as well as joints. The average depth of dugwells varies from 9 to 15 mbgl and the yield ranges from 75 to 100 m^3/ day. The borewells penetrating deeper aquifers have good yields ranging from 150 to 250 m^3/ day. The wells piercing aquifers in alluvial areas have discharge in between 100 to 300 m^3/ day, though in a few cases higher yields are observed (GSDA, 2009).

Table 1: Geological succession of Umrer coalfield (*after* Raja Rao, 1982).

Age	Group\Formation	Lithology
Recent Cretaceous	--	Black soil, migratory and derived from Deccan Trap
	Lameta	Limestones and sandstones
~~ Unconformity~~~~~~~~~~~~~~~~~~~~~		
Up.Permian -Lr.Triassic	Kamthi	Reddish brown sandstones, yellowish and brown shale
~~ Unconformity~~~~~~~~~~~~~~~~~~~~~		
Lr.Permian	Barakar	Coarse grained sandstones, carbonaceous shale and coal seams
Up.Carbo-niferous Lr.Permian	Talchir	Greenish shale with occasional bands of sandstones
~~ Unconformity~~~~~~~~~~~~~~~~~~~~~		
Archaean	Metamorphics	Schists and phyllites

Materials and Methods

The hydrogeochemical survey for systematic sampling in the study area was carried out during pre-monsoon season of 2018 and 37 groundwater samples was collected in one liter polyethylene bottles. These samples bottles were washed in laboratory with dilute hydrochloric acid and then rinsed twice with double distilled water. The chemical parameters were analyzed using the standard hydrochemical analytical techniques (APHA, 1995) (Table 2). The results were evaluated in accordance with the World Health Organization guidelines (WHO, 1997), and standard specifications of Bureau of Indian standards (BIS, 2002). The determination of hydrochemical facies was carried out as per the Piper trilinear diagram (1953) using Aquachem 4.0 software. Presentation of geochemical data in the form of graphical chart was performed by US salinity diagram (1954).

Results and Discussion

Physical and Hydrogeochemical Characters

The temperature of the groundwater samples collected during the fieldwork ranged from 24.7 ºC to 28.2 ºC. The pH

Table 2: Analytical data of water samples collected from study area

Sr. No.	Village	pH	EC	TDS	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	NO_3^-	HCO_3^-	SO_4^{--}	Cl^-	F^-	Gibbs (Na+K)/(Na+K+Ca)	Gibbs (Cl/(Cl+HCO_3))
			(µS/cm)	(mg/L)											Meq/l	Meq/l
1	Gangapur 1	7.7	1665	1066	296	108.1	6.4	57.3	48.5	14.4	88	57.3	65.1	0.8	0.5	0.4
2	Gangapur 2	7.7	1687	1080	313	110.3	9.2	61.6	53.2	9.3	76	67.6	89.4	0.7	0.5	0.5
3	Gangapur 3	7.8	1679	1075	289	105.7	6.1	52.8	49.3	7.6	74	66.1	91.5	0.8	0.5	0.6
4	Gangapur 4	7.7	1683	1077	303	107.2	8.5	56.7	51.7	8.5	82	67.7	78.8	0.6	0.5	0.5
5	Gangapur 5	7.6	1681	1076	298	106.3	7.8	55.3	50.9	8.3	83	66.5	78.1	0.5	0.5	0.5
6	Kanvwa 1	7.7	1062	680	641	123.1	81.3	62.4	4.9	98.8	112	6.8	67.2	0.7	0.4	0.4
7	Kanvwa 2	7.8	856	548	411	65.5	60.3	38.9	4.8	62.4	111	8.3	63.6	0.4	0.4	0.4
8	Kanvwa 3	7.7	851	545	402	62.4	59.9	36.1	3.3	58.3	109	9.0	64.3	0.6	0.4	0.4
9	Kanvwa 4	7.7	856	548	418	71.5	58.3	38.7	4.2	61.5	102	8.6	61.1	0.5	0.4	0.4
10	Kanvwa 5	7.6	854	547	414	71.9	57.1	37.4	4.4	61.2	103	8.7	60.8	0.4	0.4	0.4
11	Udasa 1	8.4	833	533	1166	78.8	236.3	24.6	5.1	86.7	267	33.2	36.8	0.4	0.3	0.1
12	Udasa 2	8.5	821	525	1162	79.2	235.2	24.4	6.2	91.8	271	35.0	38.7	0.5	0.3	0.1
13	Udasa 3	8.2	824	527	1161	81.3	233.6	25.9	7.5	89.3	273	36.4	33.4	0.4	0.3	0.1
14	Udasa 4	8.3	829	531	1169	77.8	237.7	22.3	4.8	88.2	265	32.1	34.2	0.4	0.3	0.1
15	Udasa 5	8.2	831	532	1158	82.8	231.9	25.4	3.5	91.4	272	29.9	31.9	0.3	0.3	0.1
18	Welsakra 1	8.3	821	525	1183	72.4	244.4	20.2	2.7	86.7	261	35.7	36.4	0.3	0.2	0.1
19	Welsakra 2	8.4	824	527	1199	86.7	239.6	18.6	3.1	88.9	257	34.2	37.6	0.4	0.2	0.1
20	Welsakra 3	8.4	826	529	1212	88.3	241.7	16.4	3.4	91.4	255	33.4	35.3	0.3	0.2	0.1
21	Welsakra 4	8.3	827	529	1208	88.2	240.8	15.8	3.6	91.7	256	32.6	36.4	0.4	0.2	0.1
22	Kalmana 1	7.7	567	363	554	66.5	94.5	4.5	26.2	58.2	210	8.9	4.2	0.6	0.3	0.0
23	Kalmana 2	7.4	565	362	574	69.3	97.8	5.1	23.5	54.6	214	6.3	4.1	0.5	0.3	0.0
24	Kalmana 3	7.6	571	365	581	66.2	101.4	3.2	26.7	57.2	212	9.1	3.8	0.4	0.3	0.0
25	Kalmana 4	7.4	565	362	571	69.8	96.8	4.1	23.3	52.4	216	7.5	5.3	0.5	0.3	0.0
26	Kalmana 5	7.5	568	364	556	71.1	92.2	5.3	22.8	55.7	213	5.6	5.2	0.4	0.3	0.0
28	Pirava 1	8.2	862	552	359	91.7	31.7	92.3	2.1	8.2	178	34.3	40.5	0.4	0.5	0.2
29	Pirava 2	8.4	875	560	400	95.3	39.5	96.7	3.4	10.4	175	32.7	43.2	0.6	0.5	0.2
30	Pirava 3	8.1	881	564	433	103.0	42.8	101.2	6.4	14.5	187	47.1	28.4	0.4	0.5	0.1
31	Pirava 4	8.4	878	562	386	98.5	34.1	97.6	4.1	12.3	179	36.6	33.6	0.6	0.5	0.2
32	Pirava 5	8.2	875	560	390	99.7	34.3	97.2	4.3	12.9	181	36.8	32.5	0.5	0.5	0.2
33	Gaonsut 1	7.6	1634	1046	1005	278.4	75.4	33.6	56.6	134.3	213	56.3	126.5	0.4	0.2	0.4
34	Gaonsut 2	7.8	1672	1070	1007	283.6	72.6	37.3	59.7	131.6	217	49.8	121.6	0.3	0.3	0.4
35	Gaonsut 3	8.1	1579	1011	1048	291.1	78.1	42.5	61.3	133.3	223	52.4	126.2	0.4	0.3	0.4
36	Gaonsut 4	7.7	1674	1071	1008	281.4	74.3	39.6	58.4	129.2	219	48.3	124.9	0.3	0.3	0.4
37	Gaonsut 5	7.9	1668	1068	1013	282.8	74.7	39.9	59.6	131.4	221	49.5	125.7	0.4	0.3	0.4
38	Min	7.4	565.0	361.6	289.3	62.4	6.1	3.2	2.1	7.6	74.0	5.6	3.8	0.3	0.2	0.0
39	Max	8.5	1687.0	1079.7	1211.7	291.1	244.4	101.2	61.3	134.3	273.0	67.7	126.5	0.8	0.5	0.6
40	Average	7.9	1051.3	672.8	714.4	115.2	104.0	40.9	22.2	64.5	187.5	33.8	54.9	0.5	0.3	0.2
41	STDEV	0.3	414.9	265.6	359.6	72.6	86.0	29.0	22.7	42.4	67.7	20.2	37.6	0.1	0.1	0.2

values grading from 7.4 to 8.5 reveals dominantly alkaline nature. The conductivity in groundwater directly corresponds to the concentration of ions present in it. The TDS content from the area grades from 361.6 to 1079.7 mg/l. According to Davis and De Wiest (1966) if the TDS value ranges up to 500 mg/l then groundwater is desirable for drinking; however water is permissible for drinking if it grades from 500-1000 mg/l and if TDS exceeds then water is only utilizable for agriculture purpose. According to this classification 63% of groundwater samples from the study area have drinking utility. The spatial variation in TDS values may be attributed to variations in lithology and hydrological processes (Singh *et al.*, 2010). Dufor and Becker (1964), based on TH values have categorized the water as 0-60: soft, 61-120: moderately hard, 121-180: hard and >180: very hard water. As per this classification the groundwater of the study area is very hard (Av. 714.4 mg/l).

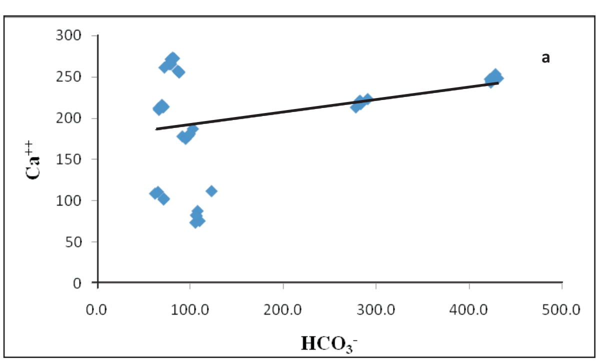
Ca^{++} is the major constituent in the groundwater of the study area and it ranges from 62.4 to 291.1 mg/l. The concentration of Mg^{++} ranges from 6.1 to 244.4 mg/l. The principal sources of Mg^{++} in the natural waters are the magnesium bearing minerals present in the rocks. The domestic and industrial wastes also higher up the Mg^{++} concentration. The Na^+ and K^+ contents range between 3.2 to 101.2 mg/l and 2.1 to 61.3 mg/l, respectively. The Na^+ and K^+ in groundwater is related to weathered rock forming minerals like sodium plagioclase, potassium plagioclase as well as anthropogenic sources like domestic and animal waste. Handa (1975) and Jacks *et al.* (2005) have reported increased Na^+ content with decreasing Ca^{++} concentration in alkaline water conditions as also noted in the present study.

The major anions from groundwater samples from the study area are HCO_3^- and SO_4^{--} and the minor constituents are NO_3^-, Cl^- and F^-. The HCO_3^- content from the study area grades from 74 to 273 mg/l. The strong positive correlation is noted between Ca^{++} and HCO_3^- and Mg^{++} and HCO_3^-. The dissolution of CO_2 gas through anoxic biodegradation of organic matter derived from industrial and domestic waste in shallow aquifers is the source of HCO_3^- in groundwater (Canter, 1997; Jeong, 2001). The SO_4^{--} concentration grades from 5.6 to 67.7 mg/l, pointing out that the groundwater from the study area has SO_4^{--} concentration within the potable limit (BIS, 2002). NO_3^- content varies between 7.6 to 134.3 mg/l indicating that the 48% of groundwater samples have concentration of NO_3^- more than desirable limit (BIS, 2002). The Cl^- and F- contents in dugwells range between 3.8 to 126.5 mg/l and 0.3 to 0.8 mg/l, respectively.

Rock-water Interaction

The Ca^{++} and HCO_3^- (Fig.2a) as well as Mg^{++} and HCO_3^- (Fig.2b) show positive correlation between these ions because these cations have common tendency to combine with HCO_3^- (Todd, 1982). The Na^+/ Cl^- molar ratios in most of the groundwater samples are more than 1, which indicates that silicate weathering reactions may be the sources for Na^+ in the study area (Meyback, 1987). In addition, Ca^{++} and Mg^{++} exchange Na^+ at the ion exchangeable sites of the clay minerals, resulting in decrease of Ca^{++} and Mg^{++} and the increase of Na^+ in groundwater (Marghade *et al.*, 2010).

The negative correlation of both Ca^{++} with Na^+ as well as Mg^{++} with Na^+ clearly corroborate that Ca^{++} and Mg^{++} exchange Na^+ at the ion exchangeable sites (Murkute 2011; Table 3). The feldspars, pyroxenes and amphiboles are the sources of Ca^{++} in groundwater samples from Deccan Trap while the feldspars, calcite and clay minerals are the probable sources of Ca^{++} from the gneiss and sedimentary rock (Hem, 1970; Todd, 1982; Murkute and Badhan, 2011). The principal sources of Mg^{++} in natural water are the magnesium-bearing minerals like pyroxenes, olivine and amphiboles (Singh *et al.*, 2010; Marghade *et al.*, 2010) while the feldspars, and clay minerals are the probable sources for Na^+ and K^+. SO_4^{--} is generally derived from the oxidative weathering of sulphate bearing minerals like pyrite (FeS_2), which is very common secondary mineral in the Gondwana coals and associated sediments (Singh *et al.*, 2010). The F^- concentration in groundwater depends upon the degree of weathering and leaching of fluoride bearing minerals from the rocks and soils (Ramesam and Rajagopalan, 1985; Murkute and Badhan, 2011; Murkute *et al.*, 2019). Besides, the source of F^- is also expected to be the amphibolites and biotite.



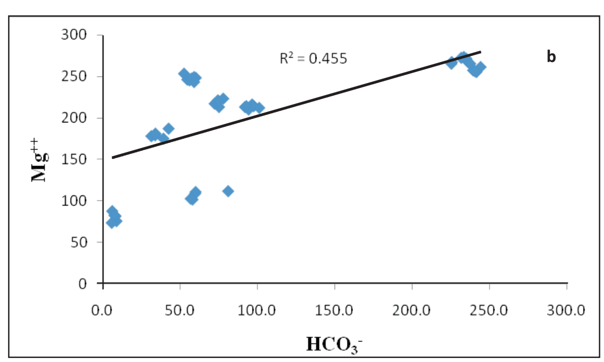


Fig. 2. Relationship of cations and anions. a) HCO_3^- vs Ca^{++} and b) HCO_3^- vs Mg^{++}

Table 3: Correlation matrix of physic-chemical parameters of groundwater samples from study area.

	pH	EC	TDS	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	NO_3^{-}	HCO_3^{-}	SO_4^{--}	Cl^{-}	F^{-}
pH	1.00												
EC	-0.54	1.00											
TDS	-0.54	1.00	1.00										
TH	-0.37	0.68	0.69	1.00									
Ca^{++}	-0.36	0.75	0.74	0.96	1.00								
Mg^{++}	-0.36	0.31	0.31	0.74	0.71	1.00							
Na^{+}	-0.16	-0.02	-0.04	-0.27	-0.32	-0.23	1.00						
K^{+}	-0.31	0.67	0.71	0.12	0.22	-0.31	0.21	1.00					
NO_3^{-}	0.17	-0.19	-0.31	-0.15	-0.18	0.22	-0.31	-0.04	1.00				
HCO_3^{-}	0.52	-0.28	-0.28	0.18	0.13	0.28	-0.61	-0.48	0.33	1.00			
SO_4^{--}	-0.37	0.72	0.79	0.96	0.98	0.56	-0.32	0.19	-0.29	0.18	1.00		
Cl^{-}	-0.44	0.43	0.45	0.15	0.09	0.13	0.36	0.73	0.47	-0.51	0.00	1.00	
F^{-}	-0.19	0.21	0.19	-0.29	-0.19	-0.39	0.44	0.35	-0.34	-0.58	-0.19	0.13	1.00

The Piper's trilinear diagram (Piper, 1953), constructed to understand the behavior of major cations-anions shows that groundwater samples fall in regions 1, 3 and 4, indicating the dominance of alkaline earths (Ca^{++}+Mg^{++}) over the alkalies (Na^{+}+K^{+}). The weak acid (HCO_3^{-}) exceeds strong acids (SO_4^{--} +Cl^{-}) and plotted points fall in regions 1 and 3 (Fig. 3).

Gibbs (1970) has well established the mechanism of controlling chemical composition of water and propounded the close relationship of chemical composition of water with aquifer lithology. In the present study the Gibbs plots are constructed by plotting ratio against the TDS by dominant anions [(Na+K) / (Na+K+Ca)] (Fig.4a), and dominant cations [(Cl/Cl+HCO3)] (Fig.4b). These plots suggest that the major ion chemistry of the water seems to be controlled by chemical weathering of rock forming minerals and anthropogenic activities (Gibbs, 1970; Ravikumar *et al.*, 2010).

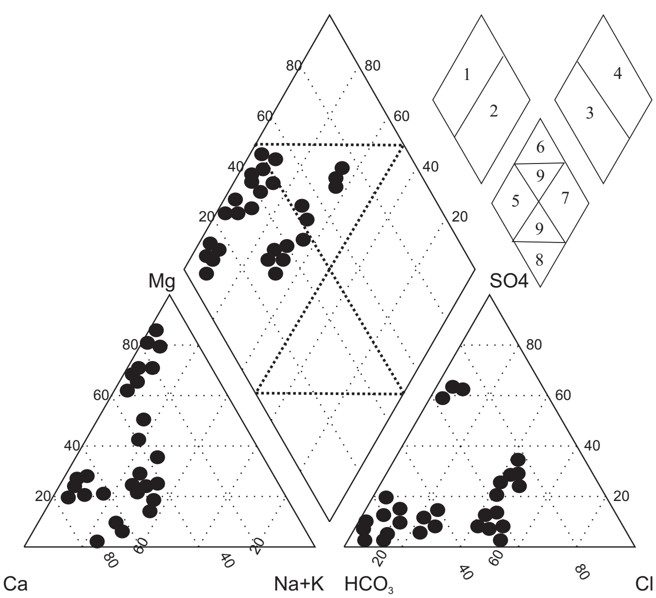


Fig. 3. Chemical facies of water samples from study area in Piper Trilinear Diagram (*after* Piper, 1953)

Groundwater Suitability

The suitability of groundwater from the study area has been checked for drinking and domestic as well as irrigation purposes.

Drinking and Domestic Use

The suitability for drinking and public health purposes has been checked using the prescribed limits of WHO (1997) and Indian drinking water standards (BIS, 2002; Table 4). The major objectionable physico-chemical parameters are EC, TDS, and total hardness (TH).

Electrical conductivity (EC) is a measure of salinity hazard as it reflects the total dissolved solids in groundwater (Ravikumar *et al.,* 2010). The 63% groundwater samples from the study area have EC values less than the permissible limit of 1500 mg/l as prescribed by WHO (1997), confirming their suitability for drinking purpose. Carrol (1962) has propounded the relationship of TDS and salinity as 0-1000 (mg/l), fresh water; 1000-10000 (mg/l), brackish water; 10000- 100000 (mg/l), saline water and > 100000 (mg/l) it is brine. According to this classification scheme the 63% groundwater samples are of fresh water type and suitable for drinking purpose (WHO, 1997; BIS, 2002). However, remaining 37% of groundwater samples are brackish water and such high salinity is attributed to the concentration of soluble salts within the geological formation (Todd, 1980). According to Murkute (2011) and Tiwari (2014) the higher concentration of TDS in inland area is the sole result of interaction of groundwater with subsurface minerals. Sawyer and McCarty (1967) on the basis of TH, have categorized the water as soft (< 75 mg/l) moderately hard (75-150mg/l), hard (150-300 mg/l) and very hard water (>300 mg/l). The analyzed data indicate that only 5% groundwater samples have TH values lesser than 300 mg/l, which is the desirable limit as per BIS (BIS, 2002), and remaining 95% are of very hard type. The SO_4^{--} concentration in the study area

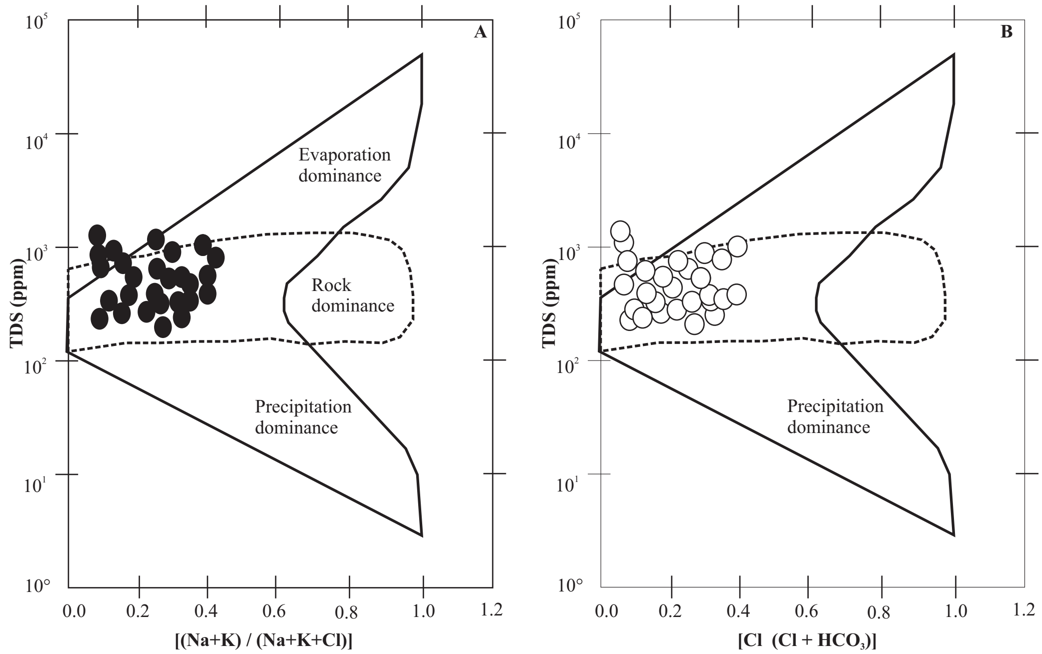


Fig. 4. Mechanism controlling groundwater chemistry of the study area (Gibbs, 1970)

does not exceed the value of 67.7 mg/l which is less than permissible limit of 400 mg/l (BIS, 2002).

Irrigation Use

In the present study, the suitability of groundwater has been checked for irrigation purpose using US Salinity Laboratory diagram (1954) in relationship with the Sodium Absorption Ratio (SAR = $Na^+/\sqrt{[(Ca^{++}+Mg^{++})/2)}$ (Fig.5). Besides, the Percent Sodium (%Na = Na + K/ (Ca + Mg + Na + K) x 100), Residual Sodium Carbonate (RSC = (HCO_3^- + CO_3^-) – (Ca^{++} + Mg^{++})), Residual Sodium Bicarbonate (RSBC = HCO_3^- – Ca^{++}), Soluble Sodium Percentage (SSP = [(Na^++K^+)/ (Ca^{++}+Mg^{++}+Na^++K^+)] x100), Mg Ratio (MR = (Mg^{++} x 100)/ (Ca^{++} + Mg^{++})), Corrosively Ratio (CR = [(Cl^- / 35.5) + 2 (SO_4^{--} /96)] / 2 (HCO_3 - + CO_3 $^{2-}$ /100)), Kelley's Ratio (KR = Na^+/ (Ca^{++}+Mg^{++})) and permeability Index (PI = [(Na^++$\sqrt{HCO_3^-}$)/ (Ca^{++}+Mg^{++}+Na^+)] x 100) have been also evaluated which decides its suitability for irrigation purpose (Table 5).

Table 4: Geochemical parameters of the study area in comparison to WHO (1997) and BIS (2002)

Major Ions	Alluvium			WHO (1997)		BIS (2002) IS: 10500	
	Min	Max	Mean	Desira-ble	Permi-ssible	Desira-ble	Permi-ssible
pH	7.4	8.5	7.9	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2
EC	565.0	1687.0	1051.3	750	1500	-	-
TDS	361.6	1079.7	672.8	500	1500	500	2000
TH	289.3	1211.7	714.4	100	500	300	600
Ca^{++}	62.4	291.1	115.2	75	200	75	200
Mg^{++}	6.1	244.4	104.0	30	150	30	100
Na^+	3.2	101.2	40.9	50	200	-	-
K^+	2.1	61.3	22.2	100	200	-	-
NO_3^-	7.6	134.3	64.5	-	50	45	100
HCO_3^-	74.0	273.0	187.5	200	600	200	600
SO_4^{--}	5.6	67.7	33.8	200	600	200	400
Cl^-	3.8	126.5	54.9	250	600	250	1000
F^-	0.3	0.8	0.5	0.6-0.9	1.5	1	1.5

Water with SAR value ≤ 10 is considered as of excellent quality, 10 to 18 is good, between 18 to 26 is fair and above 26 is said to be unsuitable for irrigation. The SAR values calculated in the study area range from 0.1 to 2.8 meq/l. The plots of the groundwater samples falling in C_2- S_1 and C_3-S_1 category indicate the water of medium to high salinity–low sodium type and thus can be utilized for irrigation with very little danger of exchangeable sodium (Fig. 5).

The % Na is widely used for evaluating the suitability of water quality for irrigation (Wilcox, 1955). The % Na, < 60 represents safe water while it is unsafe if > 60 (Eaton, 1950). The % Na in the study area ranges from 3.0 to 39.4 meq/l. High % Na in irrigation water causes exchange of sodium in water, and exchange of calcium and magnesium contents in soil having poor internal drainage. As per this criterion the water from study area is safe for irrigation purpose.

The maximum RSC value of water in the study area is 1.8 meq/l. The RSC values < 1.25 meq/l are considered as suitable for the irrigation and hence groundwater samples collected from study area are suitable for irrigation.

The values of RSBC < 5 epm is satisfactory; between, 5-10 epm is marginal and > 10 epm is unsatisfactory (Gupta, 1983). In the study area, 24% samples are completely suitable; while 36% samples have RSBC <10 epm, hence marginally suitable for irrigation.

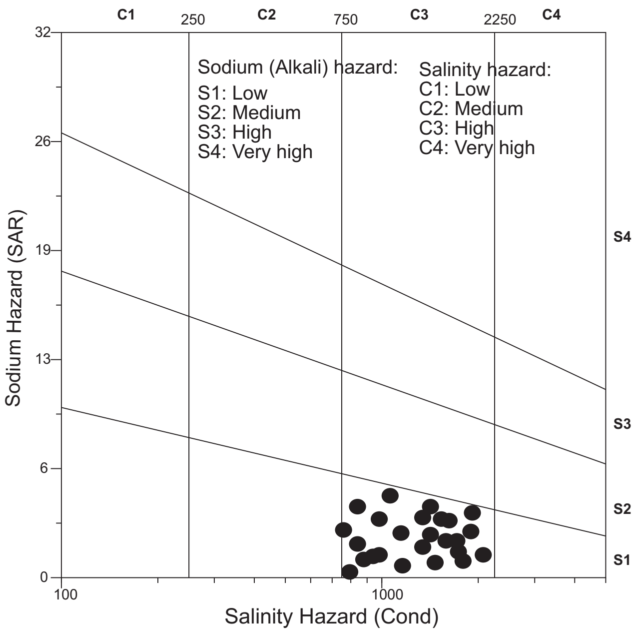


Fig. 5. US salinity diagram for irrigation water classification

The groundwater having SSP values ≤ 50 is categorized as good quality whereas values >50 are unsuitable for irrigation. All the groundwater samples of the study area have SSP <50, and hence are suitable for irrigation. The sodium in irrigation waters indicates quantitatively the adverse effect of sodium content involving the process of Base Exchange that replaces calcium in the soil, which in turns lowers soil permeability.

The MR values < 50 are suitable for the irrigation and MR values > 50 are unsuitable. Excess amount of magnesium can affect the quality of soil and reduces the yield of crops. About 46% samples are not suitable for irrigation while 54 % samples are suitable for irrigation.

The CR values ≤ 1 is considered as good and > 1 indicates corrosive nature of water, hence, water should not be transported through the metal pipes (Raman, 1985). In the study area, all the samples have CR values ≤1, which indicates that groundwater is good for irrigation.

It is the ratio of sodium ion to calcium and magnesium ions is expressed as Kelley's Ratio (KR) (Kelley's 1963). The

Table 5: Irrigation quality results of groundwater samples from the study area

Sr.No	Village	SAR	% Na	RSC	RSBC	SSP	MR	CR	KR	PI
1	Gangapur 1	1.9	38.8	-1.52	-1.01	38.77	8.65	0.04	0.39	53.47
3	Gangapur 3	1.8	38.3	-2.07	-1.59	38.35	8.45	0.05	0.37	51.18
5	Gangapur 5	1.8	38.6	-1.79	-1.17	38.63	10.51	0.05	0.37	52.13
4	Gangapur 4	1.8	38.7	-1.94	-1.26	38.74	11.26	0.05	0.38	51.67
2	Gangapur 2	2.0	39.4	-2.45	-1.72	39.38	11.77	0.05	0.39	50.64
6	Kanwa 1	1.4	17.3	-7.06	-0.56	17.27	51.38	0.03	0.20	32.08
7	Kanwa 2	1.1	17.3	-2.55	2.28	17.35	59.56	0.03	0.19	40.52
8	Kanwa 3	1.0	16.3	-2.46	2.33	16.32	60.57	0.03	0.18	40.39
9	Kanwa 4	1.1	16.9	-3.14	1.53	16.89	56.61	0.03	0.19	38.89
10	Kanwa 5	1.0	16.6	-3.01	1.56	16.63	55.96	0.03	0.18	38.98
11	Udasa 1	0.4	4.7	-9.49	9.41	4.74	82.75	0.02	0.04	19.46
12	Udasa 2	0.4	4.9	-9.23	9.59	4.85	82.61	0.02	0.04	19.61
13	Udasa 3	0.4	5.3	-9.10	9.59	5.25	82.13	0.02	0.05	19.89
14	Udasa 4	0.4	4.3	-9.66	9.36	4.33	83.02	0.02	0.04	19.04
15	Udasa 5	0.4	4.7	-9.09	9.46	4.71	81.76	0.02	0.04	19.84
18	Welsakra 1	0.3	3.7	-10.12	9.43	3.69	84.38	0.02	0.03	18.43
19	Welsakra 2	0.3	3.4	-10.65	8.52	3.44	81.56	0.02	0.03	17.85
20	Welsakra 3	0.3	3.1	-11.00	8.34	3.09	81.41	0.02	0.03	17.32
21	Welsakra 4	0.3	3.0	-10.87	8.39	3.03	81.37	0.02	0.03	17.32
22	Kalmana 1	0.1	8.2	-0.39	7.18	8.15	69.45	0.00	0.02	30.91
23	Kalmana 2	0.1	7.5	-0.59	7.24	7.45	69.31	0.00	0.02	30.24
24	Kalmana 3	0.1	7.5	-0.82	7.29	7.52	71.02	0.00	0.01	29.30
25	Kalmana 4	0.1	7.1	-0.43	7.31	7.13	68.93	0.00	0.01	30.27
26	Kalmana 5	0.1	7.6	-0.28	7.10	7.58	67.48	0.00	0.02	31.19
28	Pirava 1	2.8	34.5	1.78	4.32	34.53	35.61	0.02	0.52	61.73
29	Pirava 2	2.7	33.4	0.83	3.99	33.38	39.87	0.03	0.49	57.88
30	Pirava 3	2.8	33.1	0.78	4.20	33.09	39.93	0.02	0.47	56.30
31	Pirava 4	2.8	34.5	1.30	4.03	34.48	35.65	0.02	0.51	59.67
32	Pirava 5	2.8	34.2	1.32	4.07	34.20	35.50	0.02	0.50	59.36
33	Gaonsut 1	0.6	13.2	-9.30	-3.27	13.23	30.23	0.07	0.07	21.64
34	Gaonsut 2	0.7	14.1	-9.14	-3.33	14.11	29.06	0.06	0.07	22.28
35	Gaonsut 3	0.7	14.5	-9.65	-3.41	14.54	30.03	0.06	0.08	22.39
36	Gaonsut 4	0.7	14.3	-9.06	-3.12	14.29	29.70	0.06	0.08	22.66
37	Gaonsut 5	0.7	14.4	-9.07	-3.09	14.40	29.71	0.06	0.08	22.66

groundwater having KR < 1 is considered to be good quality for irrigation whereas KR > 1 is considered to be unsuitable for irrigation and causes alkali hazard (Karanth, 1987). The Kellay's ratio (KR) for the groundwater of the study area ranges up to 0.5 suggesting all the samples are of good quality for irrigation.

It is represented by class I, class II and class III depending upon total concentration and PI values. According to Doneen (1964), soil permeability is affected by long term use of irrigation water and depends mainly upon soil characteristics, sodium content, bicarbonate content, *etc*. In the study area, PI values ranging from 17.3 to 61.7 falls in class I of Doneen (1964), which indicate good quality for irrigation.

Conclusions

The groundwater around Gangapur village is alkaline in nature. The greater variation in EC values from the study area points out ion exchange and solubilization process within the aquifer also suggesting anthropogenic activity and geochemical processes through rock-water interaction. Ca^{++} is the major constituent in the groundwater of the study area; the principal sources of Mg^{++} in water are the magnesium bearing minerals present in the rocks. The weathered rock forming minerals like sodium plagioclase, potassium plagioclase as well as anthropogenic sources like domestic and animal waste is the sources for Na^{+} and K^{+} in groundwater. The plot of the chemical data on Piper's trilinear diagram shows that groundwater samples indicate the dominance of alkaline earths (Ca^{++} + Mg^{++}) over the alkalies (Na^{+} + K^{+}). The US Salinity classification shows that water of the study area belongs to C2–S1, and C3 – S1classes. Most of the water from the study area is suitable for drinking, domestic as well as irrigation purpose without any hazards.

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