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Assessment of Chemical and Microbial Contaminations of Water in Mangrove Region of East Godavari District of India

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The mangroves region in East Godavari region of India has its significance and existing as an ecosystem. Anthropogenic activities in the surrounding areas influence the quality of surface as well as ground waters in this region as such there will be a threat to the environment. The present study is focused in characterizing the surface and ground waters to assess the influence of surface waters on ground water quality. Surface and ground water samples were collected from Chollangi mangrove region and characterized for physico-chemical parameters *viz*., pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), calcium and magnesium, sodium, potassium, chloride, sulphate, nitrate and phosphate. The metal ion concentrations were also analyzed by ICP-MS technique. The irrigation parameters like percent sodium (% Na), sodium adsorption ratio (SAR), Kelly's ratio (KR) and magnesium hazard (MH) were determined. The results revealed that the higher value of all the parameters are due to the hectic interactions of surface waters with ground waters, which are a significant cause for contamination of ground waters in the study area. Lower concentrations of metal ions indicate the absence of metal toxicity in waters. However, higher level of magnesium hazard can deplete the soil quality. The presence of bacteria like *Pseudomonas* spp, *E. coli* and *Bacillus* spps can also cause severe health hazards.

Keywords: Water quality, Ground Water, Surface Water, Mangrove, East Godavari region.

INTRODUCTION

Ground water is a valuable resource and contributes to the health and integrity of our aquatic ecosystems and accounts for half of the drinking water [1]. This resource is susceptible to contamination from many sources which include septic system, infiltration of industrial run off, landfills and irrigation return flows and among which agriculture is a major source of pollution. The chemical characteristics of groundwater play an important role in assessing the water quality. At present, world groundwater aquifers provide approximately 23 % of the water used throughout the world [2]. Subsurface or groundwater quality also affected by several factors like discharge of agricultural, domestic and industrial wastes, land use patterns, geological formation, rainfall pattern and infiltration rate in an area [3]. It has long been known that groundwater and surface waters are intrinsically linked systems. The areas around coastal environments, like estuaries, represent zones of interaction and transition between groundwater and the estuary where dissolved constituents such as pollutants, nutrients, *etc*. can be diluted, exchanged, transformed and destroyed. Groundwater and surface water interaction in estuarine environments are influenced by a number of processes which leads to the forming complex spatially and temporally variable systems. Tidal activity often induces a fluctuating water table as well as an infiltration of surface water into the coastal sediments, forming a mixing zone with groundwater discharging from the adjacent aquifer and the term groundwater-surface water interface is commonly used [4-7].

The composition of surface and groundwaters is dependent on geological, topological meteorological, hydrological and biological factors and varies with seasonal differences in runoff volumes, weather conditions and water levels. Water quality is affected by a wide range of natural and human influences. The most important natural influences include geological, hydrological and climatic factors, since these affect the quantity and the quality of water available and their influence is generally very high. At the same time, understanding of the discharge regime of a river is extremely important to the interpretation of water quality measurements, especially those including suspended sediment or intended to determine the flux of sediment of contaminants. The discharge of a river is related to the nature of its catchment, particularly the geological, geographical and climatological influences.

In general, however, erosion can be said to vary according to the following influences like amount and pattern of rainfall and resultant river regime, slope of the land extent of destruction of vegetation. Keeping in view the hectic anthropogenic activities which can contaminate the groundwaters near mangrove region, it is proposed to carryout research investigations by characterizing the groundwaters for physico-chemical parameters to assess the chemical toxicity and further to carryout microbial analysis to identify the bacterial species which can cause water borne diseases and also to suggest the remedies to protect the quality of water in the mangrove region of East Godavari region of South East India.

EXPERIMENTAL

Study area: The present study area Chollangi is located in East Godavari District of South East India between the latitude 82º 14′ E and longitude 16º 52′ N. Ground water samples were collected in the mangrove region of Chollangi and the details of sampling code, source and location are presented in Table-1.

The water samples were analyzed for physico-chemical parameters *viz*., pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), calcium and magnesium, sodium, potassium, chloride, sulphate and phosphate as per standard procedures. The analytical data is presented in Table-2.

TABLE-1
SAMPLE CODE, LOCATION, SOURCE TYPE, LONGITUDE (82°14'E) AND LATITUDE (16°52'N)

Sampling code	Sampling location (Chollangi)	Type of source
SW-1	Near Bridge	Surface water
SW-2	Near Forest Bridge	Surface water
SW-3	Near Mangrove Forest	Surface water
GW-1	Near Rice Mill	Open well
GW-2	Near TulasiBhavan	Open well
GW-3	Near Hospital	Bore well
GW-4	Near Market	Open well
GW-5	Near Temple	Bore well
GW-6	Chollangi Village	Bore well

Irrigation parameters: The irrigation parameters like percent sodium (% Na), sodium adsorption ratio (SAR), Kelly's ratio (KR) and magnesium hazard (MH) were determined (Table-3) by using the following relationship:

$$\%\,\text{Na (me/L)} = \frac{\text{Na}^+ \times 100}{\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+} + \text{Mg}^{2+}}$$

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

$$\text{Kelly's ratio (KR)} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}}$$

TABLE-2
PHYSICO-CHEMICAL CHARACTERISTICS OF WATERS

Sample code	pH		EC (μmhos/cm)		TDS (mg/L)		TH (mg/L)		TA (mg/L)		F^- (mg/L)		Cl^- (mg/L)	
	Monsoon		Monsoon		Monsoon		Monsoon		Monsoon		Monsoon		Monsoon	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SW-1	7.9	7.6	3350	25400	2144	16256	3800	27000	720	600	0.81	0.7	10954.1	8118.1
SW-2	7.0	7.7	3080	9240	1971	5914	4900	48000	680	600	0.79	0.76	13435.6	8118.1
SW-3	7.7	7.7	3420	13200	2189	8448	4000	42000	880	600	0.81	0.65	12017.6	8118.1
Average	7.53	7.67	3283	15946	2101	10205	4233	39000	760	600	0.80	0.70	12135.7	8118.1
GW-1	7.7	7.6	9090	2900	5818	1856	3800	4700	2560	900	0.76	0.66	3509.6	496.3
GW-2	8.9	7.6	1060	1250	678	800	1900	5000	1540	900	0.82	0.87	195.0	70.9
GW-3	8.5	7.8	2910	1040	1862	666	1300	6700	1960	700	0.83	0.85	372.2	70.9
GW-4	8.6	7.7	2340	8380	1498	5363	1400	4700	1330	700	0.79	0.83	336.8	70.9
GW-5	8.6	7.5	3670	6940	2349	4442	1500	5800	1840	1500	0.81	0.84	638.1	496.3
GW-6	8.5	7.7	7160	5090	4582	3258	1600	6000	2860	1200	0.9	0.92	2091.6	496.3
Average	8.47	7.65	4371	4266	2797	2730	1917	5483	2015	983	0.82	0.83	1190.5	283.6

Sample code	SO_4^{2-} (mg/L)		NO_3^- (mg/L)		PO_4^{3-} (mg/L)		Na^+ (mg/L)		K^+ (mg/L)		Ca^{2+} (mg/L)		Mg^{2+} (mg/L)	
	Monsoon		Monsoon		Monsoon		Monsoon		Monsoon		Monsoon		Monsoon	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SW-1	239.4	263.5	56.4	52.6	6.4	5.2	719.0	744.4	55.9	39.7	400	120	683.2	6514.8
SW-2	190.0	214.0	54.8	50.8	5.2	3.5	717.4	18.7	53.0	0.9	240	160	1049.2	11614.4
SW-3	239.4	229.0	58.2	51.2	6.1	52.0	947.4	34.4	71.3	1.7	280	160	805.2	10150.4
Average	222.9	235.5	56.5	51.5	5.9	20.2	794.6	265.8	60.1	14.1	306.7	146.7	845.9	9426.5
GW-1	105.0	190.8	57.6	54.8	4.5	BDL	338.7	12.4	35.5	0.6	120	160	854.0	1049.2
GW-2	43.7	24.7	41.3	45.2	6.2	BDL	22.2	5.3	1.3	0.3	100	120	402.6	1146.8
GW-3	21.0	9.7	55.6	57.6	5.7	BDL	50.0	4.2	3.0	0.3	80	80	268.4	1586.0
GW-4	105.3	8.1	51.7	58.2	4.3	BDL	30.0	2.8	16.7	0.8	120	80	268.4	1098.0
GW-5	214.0	241.9	56.8	59.6	4.8	BDL	43.2	27.0	22.7	2.8	140	120	280.6	1342.0
GW-6	219.3	200.0	61.5	63.5	5.4	6.1	45.0	19.8	2.2	1.6	80	120	341.6	1390.8
Average	118.1	112.5	54.1	56.5	5.2	1.0	88.2	11.9	13.6	1.1	106.7	113.3	402.6	1268.8

TABLE-3
IRRIGATION PARAMETERS OF WATERS

Sample code	% Na (me/L)		SAR (me/L)		Kelly's ratio (KR)		MH	
	Monsoon		Monsoon		Monsoon		Monsoon	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SW-1	29.12	5.77	5.12	1.99	0.42	0.06	73.21	98.86
SW-2	24.28	0.09	4.50	0.04	0.33	BDL	87.49	99.15
SW-3	37.64	0.18	7.15	0.07	0.62	BDL	96.99	99.02
Average	30.35	2.01	5.59	0.70	0.45	0.02	85.90	99.01
GW-1	16.37	0.58	2.42	0.08	0.20	0.01	91.93	91.30
GW-2	2.53	0.23	0.22	0.03	0.03	BDL	86.56	93.86
GW-3	7.84	0.14	0.61	0.02	0.09	BDL	84.30	96.94
GW-4	4.46	0.13	0.35	0.02	0.05	BDL	78.16	95.64
GW-5	5.88	1.03	0.49	0.16	0.06	0.01	76.23	94.71
GW-6	5.87	0.73	0.49	0.11	0.06	0.01	87.23	94.88
Average	7.16	0.47	0.76	0.07	0.08	0.01	84.07	94.56

$$\text{Magnesium hazard (MH)} = \frac{Mg^{+} \times 100}{Ca^{2+} + Mg^{2+}}$$

Metal ions: The water samples collected during premonsoon (SW-1, SW-2, SW-3) were coded as BVK-1 and for post monsoon (SW-1, SW-2, SW-3) as BVK-2 respectively. Similarly, the combined premonsoon samples (GW-1, GW-2, GW-3) were coded as BVK-3 and for postmonsoon samples (GW-1, GW-2, GW-3) as BVK-4. The premonsoon samples (GW-4, GW-5, GW-6) are combined and coded as BVK-5 and for postmonsoon samples (GW-4 GW-5 and GW-6) are coded as BVK-6 (Table-4).

Bacterial analysis: The most probable number (MPN) technique has been employed for the enumeration for the coliform count which involves the presumptive test using lactose broth and nutrient agar confirmatory test using Eosin methylene blue (EBM) agar, pure colonies of the isolated were subjected to grams stain, motility, indole, methyl red, voges proskar test, citrate utilization test, urease test, catalase and oxidase test. The cultural characteristics and the details of biochemical characterization for identification of bacteria are presented in Table-5.

Correlation matrix: Correlation matrix has been drawn for the physico-chemical parameters to verify the reason for the enhancement of certain parametric values, which can contaminate water quality. The correlation matrix of physico-chemical parameters of groundwaters in pre and post monsoon periods are presented in Tables 6 and 7, respectively.

RESULTS AND DISCUSSION

pH: The average pH of surface waters during pre and post monsoon seasons are 7.53 and 7.67, while pH of groundwaters during pre and post monsoon seasons are 8.47 and 7.65. The values are within the range of permissible limit of drinking waters [5]. The pH of surface waters of pre monsoon is lower

TABLE-4
CONCENTRATION OF METAL IONS (ppm) IN SURFACE AND GROUND WATERS

Metal	Premonsoon			Postmonsoon		
	BVK-1	BVK-3	BVK-5	BVK-2	BVK-4	BVK-6
Li	0.2112	0.0898	0.0128	0.0129	0.0933	0.0093
Be	BDL	BDL	BDL	0.0003	BDL	0.0002
Al	0.0155	0.0411	0.0100	11.8295	0.0196	0.2224
V	0.0103	0.0066	0.0101	0.0324	0.0069	0.0401
Cr	0.0036	0.0046	0.0006	0.0272	0.0026	0.0008
Mn	BDL	0.0023	BDL	0.0238	BDL	0.0006
Fe	BDL	0.0676	0.0044	10.7388	0.0070	0.2399
Co	0.0001	BDL	BDL	0.0026	BDL	BDL
Ni	BDL	0.0003	0.0003	0.0132	BDL	BDL
Cu	0.0014	0.0019	0.0013	0.0266	0.0007	0.0019
Zn	0.0032	0.0066	0.0021	0.0425	0.0049	0.0094
Ga	0.0123	0.0089	0.0016	0.0935	0.0081	0.0040
As	0.0029	0.0013	0.0009	0.0017	0.0015	0.0059
Se	0.0096	0.0066	0.0010	0.0026	0.0081	0.0016
Rb	0.0622	0.0323	0.0024	0.0127	0.0319	0.0066
Sr	5.0906	2.5392	0.2135	0.0226	2.4800	0.1813
Ag	0.0001	0.0010	0.0002	0.0054	0.0026	0.0005
Cd	BDL	BDL	BDL	BDL	BDL	BDL
Cs	0.0002	0.0001	BDL	0.0007	0.0001	BDL
Ba	0.0949	0.0607	0.0093	0.4740	0.0561	0.0221
Tb	BDL	BDL	BDL	0.0001	BDL	BDL
Ti	BDL	BDL	BDL	BDL	BDL	BDL
Pb	0.0008	0.0016	0.0012	0.0039	0.0010	0.0009
U	0.0032	0.0020	0.0037	0.0001	0.0019	0.0007

TABLE-5
CULTURAL, MORPHOLOGICAL AND BIOCHEMICAL CHARACTERISTICS AND IDENTIFIED *Bacterial Spps* IN WATERS

Sample No.	MPN count/ 100 mL	No. of biochemical colonies	Gram staining	Motility	Biochemical tests – IMViC tests				Catalase	*Bacterial spp* identified
					Indole	MR	VP	Citrate		
1	0	0	–ve	Motile	+ve	+ve	–ve	–ve	+ve	*E. coli*
2	0	1	–ve	Motile	–ve	–ve	–ve	–ve	–ve	*Pseudomonas spps*
3	0	1	+ve	Non-motile	–ve	+ve	–ve	–ve	–ve	*Bacillus*

TABLE-6
CORRELATION MATRIX OF PHYSICO-CHEMICAL PARAMETERS OF GROUND WATERS DURING PREMONSOON SEASON

	pH	EC*	mg/L											
			TDS	TH	TA	F^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	Na^+	K^+	Ca^{2+}	Mg^{2+}
pH	1													
EC*	-0.259	1												
TDS (mg/L)	-0.260	1.000	1											
TH (mg/L)	-0.939	0.179	0.179	1										
TA (mg/L)	0.437	0.691	0.691	-0.527	1									
F^- (mg/L)	0.437	0.039	0.039	-0.480	0.398	1								
Cl^- (mg/L)	-0.872	-0.037	-0.037	0.908	-0.692	-0.231	1							
SO_4^{2-} (mg/L)	-0.431	0.204	0.204	0.440	-0.277	0.185	0.627	1						
NO_3^- (mg/L)	-0.398	0.659	0.659	0.204	0.269	0.229	0.298	0.608	1					
PO_4^{3-} (mg/L)	0.003	-0.400	-0.400	0.194	-0.388	0.363	0.382	0.137	-0.197	1				
Na^+ (mg/L)	-0.831	-0.003	-0.003	0.900	-0.670	-0.318	0.967	0.587	0.300	0.400	1			
K^+ (mg/L)	-0.810	0.032	0.032	0.868	-0.668	-0.469	0.908	0.639	0.336	0.208	0.960	1		
Ca^{2+} (mg/L)	-0.587	-0.191	-0.191	0.707	-0.767	-0.254	0.849	0.645	0.191	0.489	0.855	0.855	1	
Mg^{2+} (mg/L)	-0.944	0.248	0.248	0.987	-0.432	-0.493	0.850	0.360	0.191	0.113	0.840	0.803	0.587	1

*µmhos/cm

TABLE-7
CORRELATION MATRIX OF PHYSICOCHEMICAL PARAMETERS OF GROUND WATERS DURING POSTMONSOON SEASON

	pH	EC*	mg/L											
			TDS	TH	TA	F^-	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	Na^+	K^+	Ca^{2+}	Mg^{2+}
pH	1													
EC*	-0.182	1												
TDS (mg/L)	-0.182	1.000	1											
TH (mg/L)	0.201	0.558	0.559	1										
TA (mg/L)	-0.579	-0.383	-0.383	-0.577	1									
F^- (mg/L)	0.126	-0.512	-0.512	-0.566	0.514	1								
Cl^- (mg/L)	0.071	0.772	0.772	0.950	-0.584	-0.648	1							
SO_4^{2-} (mg/L)	-0.450	0.583	0.583	0.513	0.191	-0.496	0.613	1						
NO_3^- (mg/L)	0.132	-0.137	-0.137	-0.438	0.521	0.401	-0.427	0.087	1					
PO_4^{3-} (mg/L)	0.205	0.328	0.328	0.595	-0.317	-0.518	0.570	0.346	-0.217	1				
Na^+ (mg/L)	-0.248	0.867	0.867	0.244	-0.296	-0.349	0.523	0.422	-0.148	-0.018	1			
K^+ (mg/L)	-0.267	0.867	0.867	0.226	-0.266	-0.331	0.507	0.427	-0.124	-0.031	0.999	1		
Ca^{2+} (mg/L)	-0.282	0.163	0.163	0.605	-0.080	-0.649	0.558	0.692	-0.400	0.455	-0.025	-0.041	1	
Mg^{2+} (mg/L)	0.203	0.559	0.559	1.000	-0.578	-0.565	0.950	0.511	-0.437	0.594	0.245	0.227	0.602	1

*µmhos/cm

than pH of groundwater indicating the absence of interaction between surface water and groundwater while the pH of surface water and groundwater during post monsoon season are hereby equal indicating equilibrium between surface water and groundwater.

Electrical conductivity (EC): Electrical conductivity of surface waters of pre and post monsoon season are 3283 and 15946 µmhos/cm, while the electrical conductivity of groundwaters of pre and post monsoon seasons are 4371 and 4266 µmhos/cm. The levels are higher and indicate the saline nature of waters. The electrical conductivity of surface water during pre monsoon season is lower than electrical conductivity of groundwater indicating the absence of surface water interaction with groundwater, while the electrical conductivity of surface water during post monsoon season is extraordinarily high compare to groundwater indicating interaction of surface water with groundwater.

Total dissolved solids (TDS): Total dissolved solids of surface waters of pre and post monsoon season are 2101 and 10205 mg/L, while TDS of groundwater is 2797 and 2730 mg/L. The levels exceeded the permissible limit of drinking water standards [5]. The higher values indicate the presence of soluble solid matter in waters. Higher levels of TDS indicate that the waters can cause encrustation on water supply systems and hence the waters are unsuitable for domestic purposes. Total dissolved solids of surface water during pre monsoon season is less than TDS of groundwater indicating the absence of surface water interaction with groundwater while TDS of surface water during post monsoon season is higher than TDS of groundwater indicating the interaction of surface water with groundwater.

Total hardness (TH): Total hardness of surface waters of pre and post monsoon season is 4233 and 39000 mg/L, while total hardness of groundwater is 1917 and 5483 mg/L. The levels are higher than the permissible limit of drinking water standards [5]. Total hardness of surface water during pre and post monsoon season is higher than total hardness of groundwater of both the seasons. This indicates the hectic interactions of surface water with groundwater in the study area.

Total alkalinity (TA): Total alkalinity of surface waters of pre and post monsoon season are 760 and 600 mg/L. Total alkalinity of groundwater of pre and post monsoon waters is 2015 and 983 mg/L. The values exceeded the permissible limit of drinking water standards [5]. Higher values can cause unpleasant taste and smell. Total alkalinity of surface water during pre and post monsoon season is lower than total alkalinity of groundwater during both the seasons indicating the absence of interaction of surface water with groundwater.

Fluoride: Fluoride ion concentration of surface waters of pre and post monsoon season is 0.80 and 0.70 mg/L and the concentration of fluoride ion in the groundwaters of pre and post monsoon season is 0.82 and 0.83 mg/L. The levels are within the permissible limit of drinking water standards [5]. Fluoride ion concentration of surface water during pre monsoon is almost equal to fluoride concentration in groundwater indicating the equilibrium between surface water and groundwater, while the fluoride concentration in surface water during post monsoon season is lower than groundwater indicating the absence of surface water interaction with groundwater.

Chloride: Chloride ion concentration in surface waters of pre and post monsoon season is 12135.7 and 8118.1 mg/L, while chloride ion concentration in groundwater of pre and post monsoon season is 1190.5 and 283.6, respectively. The levels exceeded the permissible limit of drinking water standards [5]. Chloride ion concentration in surface water during pre and post monsoon season is extraordinarily higher than chloride ion concentration in groundwater during both the seasons indicating hectic interaction of surface water with groundwater. It indicates the sea water intrusion into fresh waters.

Sulphate: Sulphate ion concentration in surface waters of both pre and post monsoon season is 222.9 and 235.5 mg/L, while sulphate levels in groundwaters of pre and post monsoon are 118.1 and 112.5 mg/L. Sulphate ion concentration in surface water during pre and post monsoon season is higher than in groundwater of both the seasons indicating the surface water interaction with groundwater however the sulphate values are within the permissible limit of drinking waters [5] and indicate the non-discharge of industrial effluents into surface as well as into groundwater in the study area.

Nitrate: Nitrate ion concentration in surface waters of both pre and post monsoon season is 56.5 and 51.5 mg/L and in groundwaters of pre and post monsoon season is 54.1 and 56.5 mg/L. Nitrate ion concentration in surface water during pre monsoon and post monsoon are very nearer to the levels of nitrate in groundwater during both the seasons indicating the equilibrium in concentrations, however, the levels crossed the permissible limit of drinking water standards [5] and indicate the possible discharge of agricultural runoff into the water bodies in the study area.

Phosphate: Phosphate ion concentration in surface waters of both pre and post monsoon season is 5.9 and 20.2 mg/L and the levels are higher than the permissible limit [5] indicating the discharge of agricultural runoff into the surface waters. Phosphate ion concentration in groundwaters of pre monsoon season is 5.2 mg/L and indicates the occasional discharge of agricultural runoff into the groundwater, while phosphate level in groundwater during post monsoon season was observed as BDL in all samples except in samples GW-6. In GW-6 sample, phosphate ion concentration is observed as 6.1 mg/L indicating the discharge of agricultural runoff into groundwater. Phosphate ion concentration in surface water during pre monsoon season is slightly higher than in groundwater indicating moderate interaction between surface water and groundwater, while phosphate level in surface water of post monsoon season is higher than in groundwater indicating the absence of interaction of surface water with groundwater in the study area.

Sodium and potassium: Sodium ion concentration in surface waters of both pre and post monsoon season is 794.6 and 265.8 mg/L. The values exceeded the WHO standards. Sodium ion concentration in groundwater during pre monsoon season is 88.2 while it is 11.9 mg/L in post monsoon season. Both values are within the WHO standards. Potassium ion concentration in surface waters during pre and post monsoon season is 60.1 and 14.1 mg/L and exceeded the permissible limit of WHO standards and in groundwater the level in pre post monsoon season is 13.6 and 1.1 mg/L which is within the permissible limit of WHO standards. Sodium ion concentrations in surface water during pre and post monsoon seasons exceeded the permissible limit. Potassium level in surface water during pre and post monsoon period are comparatively higher than in groundwater indicating the absence of surface water interaction with groundwater.

Calcium: Calcium ion concentration in surface waters of pre and post monsoon season is 306.7 and 146.7 mg/L, while its concentration in groundwaters of pre and post monsoon season is 106.7 and 113.3 mg/L. The levels crossed the permissible limit of drinking water standards. Calcium ion concentration in surface water during pre and post monsoon season is higher than in groundwater indicating the absence of interaction of surface water with groundwater. However the higher levels of calcium ion concentration indicate that the waters can cause encrustation [8].

Magnesium: Magnesium ion concentration in surface waters of both pre and post monsoon season is 845.9 and 9426.5 mg/L, while its concentration in groundwaters of pre and post monsoon is 402.6 and 1268.8 mg/L. Magnesium ion concentration in surface of pre and post monsoon season is higher than in groundwater of both the season indicating the moderate interaction of surface water with groundwater, however, the levels crossed the permissible limit of drinking water standards [5].

Percent sodium (% Na): Percent sodium of surface waters of pre and post monsoon season is 30.35 and 2.01 meq/L, while its value in groundwaters of both pre and post monsoon season is 7.16 and 0.47 meq/L. The levels are within the permissible limit of irrigation standards.

Sodium adsorption ratio (SAR): Sodium adsorption ratio of surface waters of pre and post monsoon season is 5.59 and

0.70 meq/L, while its value in groundwater of both pre and post monsoon season is 0.76 and 0.07 meq/L. The levels are within the permissible limits of irrigation standards [9].

Kelly′s ratio (KR): Kelley′s ratio of surface waters of both pre and post monsoon season is 0.45 and 0.02, while Kelley′s ratio of groundwaters of pre and post monsoon season is 0.08 and 0.01. The Kelley′s ratio is within the permissible limit of irrigation standards [9].

Magnesium hazard (MH): Magnesium hazard of surface waters of both pre and post monsoon season is 85.90 and 99.01. The magnesium hazard of groundwaters of pre and post monsoon season is 84.07 and 94.56. The values exceeded the permissible limit of irrigation standards [9] and hence can cause magnesium hazardness to the waters.

Metal ions: The concentration of metal ions *viz*., Li, Be, Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Ar, Se, Rb, Sr, Ag, Cd, Cs, Ba, Ti, Pb and U in representative samples of surface and groundwaters collected during pre and post monsoon seasons are found to be within the permissible limit of drinking water standards [5].

Correlation data

During pre-monsoon season: From the data generated by correlation matrix, it is observed that electrical conductivity is strongly correlated to TDS and moderately correlated with total alkalinity and nitrate. Total hardness is strongly correlated with Cl^- , Na^+, K^+ and Mg^{2+} and moderately correlated with Ca^{2+}. The chloride ion is strongly correlated with Na^+, K^+, Ca^{2+} and Mg^{2+} and moderately correlated with SO_4^{2-}. The sulphate ion is moderately correlated with nitrate, Na^+, K^+ and Ca^{2+}. While Na^+ is strongly correlated with K^+, Ca^{2+} and Mg^{2+}. However, K^+ is strongly correlated with Ca^{2+} and Mg^{2+} while Ca^{2+} is moderately correlated with Mg^{2+}. Higher electrical conductivity is indicated by its interdependence on TDS which will have relationship with cations like Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^2, PO_4^{3-} ions. Total hardness is strongly correlated with Cl^- and Mg^{2+} which indicates the hardness of water due to the presence of $MgCl_2$ and $CaCl_2$. Strong correlation of chloride with Na^+ and K^+ indicate the saline nature of waters which is confirm by high electrical conductivity and shows correlation of chloride with Ca^{2+} and Mg^{2+} confirmed the hardness of water. Moderate correlation sulphate with calcium also confirmed the hardness of waters. Strong correlation of Na^+ ion with K^+, Ca^{2+} and Mg^{2+} ions indicated the interdependence among these ions which in turn can indicate the saline nature of waters due to their presence hence higher electrical conductivity values.

Post-monsoon season: Electrical conductivity is strongly correlated with TDS, Na^+, K^+ but moderately correlated with total hardness, Cl^-, SO_4^{2-} and Mg^{2+}. TDS is strongly correlated with Na^+ , K^+ and moderately correlated with total hardness, Cl^-, SO_4^{2-}, Na^+, K^+ and Mg^{2+}. Total hardness is strongly correlated with Cl^- and Mg^{2+}. Total alkalinity is moderately correlated with F^- and NO_3^- while Cl^- is strongly correlated with Mg^{2+} and moderately correlated with SO_4^{2-}, PO_4^{3-} and Na^+, K^+ and Ca^{2+}. The sulphate ion is moderately correlated with Ca^{2+} and Mg^{2+} while phosphate ion is moderately correlated with Mg^{2+}. The sodium ion is strongly correlated with K^+ but Ca^{2+} ion is moderately correlated with Mg^{2+}.

Electrical conductivity is strongly correlated with TDS which is dependent on cations like Na^+, K^+ and also moderately correlated with Cl^-, SO_4^{2-} and Mg^{2+} ions. This relationship is responsible for higher EC values. Strong correlation of TDS with Na^+, K^+ and moderately correlation with total hardness, Cl^-, SO_4^{2-}, Na^+, K^+ and Mg^{2+} confirmed the presence of soluble matter in waters. Strong correlation of total hardness with Cl^- and Mg^{2+} indicated the hardness which is due to the presence of $MgCl_2$ in waters. Strong correlation of chloride with Mg^{2+} and its moderate correlation with SO_4^{2-} and Ca^{2+} also indicate the higher values of hardness. Correlation of chloride with ions Na^+ and K^+ confirmed the saline nature of waters and hence increase in electrical conductivity values. Moderate correlation of SO_4^{2-} with Ca^{2+} and Mg^{2+} also confirmed the hardness of waters.

Conclusion

The data generated from the correlation matrix for water samples collected during pre and post monsoon periods confirmed higher values for electrical conductivity, total dissolved solids and total hardness due to which the waters are unsuitable for drinking purposes but fit for the irrigation purposes. Higher values of magnesium hazard (MH) can deplete the soil quality and there by reduce the crop yield in the study area. The concentration of metal ions is within the permissible limit of the drinking water standards indicating the absence of metal toxicity in waters but presence of bacteria like *Pseudomonas*, *E. coli* and *Bacillus* spp. are unsuitable for drinking and domestic purposes.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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