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Major Ion Chemistry of Groundwater and Surface Water in Parts of Mulugu-Venkatapur Mandal, Warangal District, Telangana State, India

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Abstract

Fifty water samples including Surface water, Dug well, Hand pump and Bore well during pre-monsoon (May-June) and post-monsoon season (November) in parts of Mulugu-Venkatapur mandals, Warangal District to an extent of 453 Km² and falls under Top sheet No. 56 N/15 and 56 N/16 of Survey of India were collected. The samples were analysed for major ion chemistry to study the groundwater characteristics and its suitability for drinking as well as irrigation purposes. The pH ranges from 6.7-8 indicating water is slighly acidic to alkaline in nature. TDS ranges from 201-3612 mg/l and 154-3457 mg/l during pre and post monsoon season. Total Hardness (TH) ranges from 100-1000 mg/l and 38.8-2148 mg/l; Chloride ranges from 7.81-1667 mg/l and 7.6-1089 mg/l; sulphate ranges from 2-1533 mg/l and 5.2-1200 mg/l during pre and post season respectively. Majority of the samples are suitable for domestic purposes due to low to medium hardness, however few samples described very hard and unsuitable for domestic, drinking and irrigation purposes. Various indices like Salinity Index, Sodium Absorption Ratio (SAR), Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP), Permeability Index (PI) and Water Quality Index (WQI) are used to classify groundwater and surface water for drinking as well as irrigation purposes. Besides this, Piper trilinear diagram, Wilcox diagram, Doneen's classification and Gibb's plot were studied for geochemical controls, and hydrogeochemistry of groundwater and surface water.

Keywords: Sodium absorption ratio (SAR); Kelly's ratio (KR); Residual sodium carbonate (RSC); Soluble sodium percentage (SSP); Permeability index (PI); Water quality index (WQI); Mulugu-Venkatapur mandal

Introduction

Water scarcity in many areas worldwide is due to population growth and fast growing big cities often located in unfavorable places is a major concern now-a-days [1]. The drastic increases in population, modern land use applications (agricultural and industrial), and ever increasing demands for water supply resulted in deterioration of water quality and quantity. Even though urban aquifers are the only natural resource for drinking water supply, they are often perceived as of lesser relevance for the drinking water supply, leading toward crisis in terms of drinking water scarcity, becoming increasingly polluted thereby decreasing their portability [2]. Once contamination of groundwater in aquifers occurs by means of agricultural and industrial activities and urban development, it persists for several of years because due to slow movement in the aquifer regime [3] and prompts investigations on their quality [4]. The groundwater quality is of major concern in densely populated and thickly industrialized areas which depend on shallow groundwater tube wells [5].

Geochemical studies of groundwater provide better understanding of possible changes in quality as development progresses. The suitability of groundwater for domestic and irrigation purposes is determined by its geochemistry. Stream and tank water are designated as surface water. They occur in the form of natural as well as artificial water bodies in the area. The water supplies to these tanks and streams are mainly dependant on rainfall. A number of studies on groundwater and surface water quality with respect to drinking and irrigation purposes have been carried out in different parts of India and around the world with reference to major ion chemistry, trace element chemistry and through multivariate statistical techniques [6-13].

Generally, shallow aquifers are calcium-bicarbonate type and calcium-magnesium-bicarbonate type, while the deeper aquifers are mostly calcium-magnesium-bicarbonate type, calcium-magnesium-sodium-bicarbonate type and sodium-calcium-bicarbonate type [13]. Water level fluctuations in hard rock terrain are very erratic. Water level in open wells usually rises in the post-monsoon season and the water table fluctuates between 5 and 10 m below ground level (bgl). Water levels usually decline and the water table fluctuates between 10 and 25 m during the pre-monsoon season. The hydrogeochemical characters of the water and soils have been dealt with comprehensively to pursue the quality of water and soils for irrigation and drinking purposes.

Groundwater occurs in fracture zones and weathering formations of granitic terrain. The maximum depth of the weathered formation is about 10-30 m, but the majority of the wells that are encountered fall in the depth range of 20-30 m. The topography characteristics are found to have extensive influence on the groundwater regime. It is found that the deeper wells are capable of sustaining daily pumping for about 7-8 hrs. The position of water tables is not only influenced by the rainfall, but also controlled by topography, geology, structures and hydrogeological conditions. The groundwater resources can be replenished and improve water quality through drainage pattern, construction of percolation tanks, judicious land management and crop pattern [14-21]. Desirable results of water/soil analysis may further indicate the quality of water.

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The objective of the study is to assess the groundwater and surface water quality from parts of Mulugu and Venkatapur mandals of Warangal district, Telangana State for safe drinking and irrigation purposes. A better understanding of water chemistry in the study area is important for evaluating the contamination process more precisely. This study uses a multifarious approach to understand the mechanism responsible for the spatial and temporal distribution of groundwater and surface water throughout the watershed composed of different geological units (granitic/gneiss and sedimentary rock).

Study area

Mulugu and Venkatapur mandals of Warangal district is situated about 50 km North-east of Warangal City. The study area covers a part of Mulugu and Venkatapur mandals of Warangal District. The present study area falls under Toposheet No. 56 N/15 and 56 N/16 of Survey of India covering an extent of 453 km^2 (Figure 1). The study area is gently sloping from north-western to south-eastern side and north-eastern to south-eastern.

The area under investigation falls in the semi-arid zone. The area is generally hot in summer and cool in winter. The temperature gradually rises from the month of February and reaches a maximum in the month of May. It gradually decreases form June to December. May is the hottest month with a temperature range from 30°C to 38°C, and it varies from 8 to 10°C during winter. Rainfall occurs between June and October during the onset of the southwest monsoon. The normal annual rainfall of the district is 994 mm. The rainfall increases from southwest to northeast part varying from 924 to 1061 mm. The southwest monsoon contributes about 80% of the annual rainfall. The highest precipitation occurs during the southwest monsoon. The intensity and amount of rainfall are unpredictable during the northeast monsoon period.

Geology and hydrology of the study area

The drainage of the study area is of dendritic and rectangular pattern controlled by undulatory topography. The investigated area falls under part of the stable Southern Indian shield consisting of Peninsular Gneissic Complex (PGC), Pakal group, Mulugu subgroup. Mulugu subgroup occupies a major part of the study area and comprises of Arkose, shale with dolomite quartzite, shale, quartzite, Limestone, sandstone, gneisses, granite and dolorite dykes. In the study area Archaean peninsular gneissic complex are unconformably overlain by sedimentary rocks of Middle Proterozoic age, consisting the Pakal group of rocks (Figure 2).

Groundwater occurs in the soil of weathered granite, semi-weathered, fractured hard and in weathered sedimentary formations under the water table in semi-confined conditions. The average depth of groundwater is about 8 m to 10 m. The granites rocks possess negligible primary porosity but in sedimentary rock the secondary porosity exits by deep fracturing and weathering, they are rendered with a porosity and permeability, which locally form potential aquifers in study area [22,23].

Materials and Methods

The methods of collection of samples play an important role in maintaining a high degree of accuracy of analytical data and its application to hydrochemical studies. Groundwater and surface water samples were collected in pre-cleaned polyethylene bottles from the tanks (surface water), dug wells, hand pump and bore wells in the pre and post-monsoon periods as per the standard procedures [24]. The location of these samples is shown in Figure 3. The water samples were analyzed at Centre for Materials for Electronics Technology (C-MET) Laboratory, Hyderabad. Samples of pre and post-monsoon were studied for various physic-chemical parameters which include pH, EC, TDS, TH, cations such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and anions Cl^{-}, SO_4^{2-}, F^{-}, NO_3^{-}, CO_3^{2-} and HCO_3^{2-}. The pH was measured using the digital pH meter of Elico; EC was estimated by the EC analyzer CM 183 model of ELICO; classical methods of analysis were applied for the estimation of Ca^{2+}, Mg^{2+}, CO_3^{2-} and Cl^{-}. Na^{+} and K^{+} were analyzed by flame photometry using CL-345 flame photometer of ELICO. Sulfate was estimated by the turbidity method using the Digital Nephelo-Turbidity meter 132 model of Systronics. Nitrate was analyzed applying the UV-V is screen method using UV-visible spectrophotometer UV-1201 model of Shimadzu. Fluoride was analyzed by the ion selective electrode method using Orion 290A+ model of Thermo-electron Corporation. The TDS were estimated by the summation of cations and anions (epm) method [25]. The charge balance is calculated between cations and anions and are within acceptable limits confirming the reliability of analytical results [26,27] with precision of ± 5% for all the samples. Standard titration method [28] was used for carbonates and bicarbonates. The analytical data of groundwater and surface water samples are presented in Table 1.

Results and Discussion

Drinking water purposes

The quality of groundwater and surface water of the study area was assessed as per standard specification given by BIS [28] and World Health Organization [29].

Hydrogen ion concentration (pH): The pH of the water samples in the study area varies from 6.7-8.1 and 6.8-8.0 with a mean values of 7.23 and 7.2 during pre and post-monsoon seasons respectively (Table 1). The pH is slightly acidic to alkaline in nature. The desirable range of pH in drinking water is 6.5-8.5 [28] (Table 2). The spatial distribution of pH of water samples in the area does not show any significant variation during pre and post-monsoon periods. The pH shows a little variation from the south-western to the north-western part of the area. The pH of samples considerably high in the southern part compared to the northern part of the study area (Figures 4a and 4b).

Total Dissolved Solids (TDS): In natural water, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. The suitability of groundwater for domestic and irrigation purposes depends upon hydrochemical properties that are categorized with respect to TDS [30]. Based on the classification given by BIS [28], the groundwater samples of the study area fall in three classes as: (1) desirable for drinking, (2) permissible for drinking, (3) useful for agriculture. The majority of samples are found suitable for drinking and irrigation (Table 3). The general formula adopted to calculate the TDS is q=KA where q is the total dissolved salts, K is the conductance in μS/cm and the conversion factors for the value of A is taken as 0.64 [31]; then the TDS in mg/l=0.64 × EC (μS/cm). The groundwater of pre-monsoon has high TDS values (from 201 to 3612 versus 154 to 3,457 mg/l) than in post-monsoon. The average TDS of pre-monsoon samples is 1248 mg/l, while it is 1265 mg/l for post-monsoon samples (Table 1). The spatial distribution of TDS of groundwater samples is displayed in concentration maps (Figures 5a and 5b) for the pre and post-monsoon periods respectively.

Magnesium (Mg^{2+}): Sources of Magnesium in the groundwater is mainly derived from the process of ion exchange of minerals in rocks and soils by water [32]. The concentration of Mg^{2+} in groundwater

S No	Sample No.	Name of the village	Pre-monsoon				Post-monsoon			
			pH	EC	TDS	TH	pH	EC	TDS	TH
1	SW-2	Mallampally	7.7	522	334	169	7.7	716	458	161
2	SW-5	Katrapally	7.4	397	254	128	7.4	283	181	69
3	SW-30	Jakaram	7.3	314	201	128	7.3	328	210	150
4	SW-37	Ramappa lake	7.2	2448	1567	600	7.1	241	154	92
5	SW-43	Kottapally cheruvu	7.1	341	218	146	7.0	320	205	49
6	DW-6	Sadanpally	7.5	2084	1334	552	7.5	2078	1330	553
7	DW-9	Ganginenigudem	7.7	1030	659	188	7.7	1198	767	480
8	DW-10	Nizampet	7.4	1719	1100	505	7.4	1922	1230	582
9	DW-12	Koppula	7.8	1033	661	317	7.8	1688	1080	530
10	DW-15	Jakaram	7.3	870	557	359	7.3	897	574	396
11	DW-18	Abbapur	7.3	1131	724	466	7.3	664	425	506
12	DW-19	Konarao pet	7.4	1595	1021	318	7.4	1694	1084	508
13	DW-21	Sulthanpur	7.6	681	436	257	6.9	1355	867	477
14	DW-22	Jaggayyapet	7.7	1141	730	277	7.4	1109	710	354
15	DW-27	Ramakrishna puram	7.0	1025	656	435	7.0	1013	648	425
16	DW-31	Mulugu	7.4	1556	996	457	7.1	1920	1229	532
17	DW-33	Jangalpally	7.4	4369	2796	796	7.2	4336	2775	941
18	DW-34	Encherla	7.6	1194	764	220	7.2	1475	944	319
19	DW-40	Chataraj pally	7.3	4536	2903	716	7.4	4469	2860	838
20	DW-41	Keshapur	7.2	3423	2191	863	7.2	4328	2770	1142
21	DW-48	Madanpally	7.2	4197	2686	861	7.2	4711	3015	1150
22	HP-1	Mallampally	8.1	1395	893	441	8.0	1770	1133	616
23	HP-4	Rajapally village	7.6	2528	1618	558	7.3	2984	1910	632
24	HP-7	Katrapally	7.1	3594	2300	827	7.1	3363	2152	860
25	HP-8	Suryanaik thanda	7.0	2189	1401	573	7.0	2870	1837	265
26	HP-11	Kottapallygori	6.9	5316	3402	1001	6.9	5402	3457	2148
27	HP-13	Chinnakodapaka	7.4	2864	1833	704	7.0	3181	2036	924
28	HP-14	Balayyapally	7.2	1488	952	500	7.2	1505	963	538
29	HP-16	Sriramulapally	7.2	1405	899	532	7.0	1470	941	599
30	HP-17	Abbapur	7.5	584	374	258	7.5	361	231	256
31	HP-20	Venkateshwarapally	7.4	3730	2387	464	7.0	4250	2720	522
32	HP-23	Narsimhareddy pally	7.1	992	635	363	7.7	998	639	398
33	HP-25	Pandikunta x road	7.0	661	423	313	7.1	664	425	322
34	HP-32	Jangalpally	7.5	1886	1207	420	7.3	1902	1217	396
35	HP-35	Barugana palli	7.3	2356	1508	611	7.4	2283	1461	563
36	HP-36	Palampet	6.8	5644	3612	912	7.6	3755	2403	696
37	HP-38	Dubbapalli	7.4	877	561	346	6.8	528	338	333
38	HP-39	Ramanjapur	7.2	1058	677	350	7.2	927	593	341
39	HP-42	Narsapur	7.3	2038	1304	625	7.3	3127	2001	921
40	HP-44	Jublinagar	6.8	1773	1135	672	7.0	1797	1150	730
41	HP-45	Papayya pally	7.2	1183	757	372	7.0	1052	673	366
42	HP-46	Bandaru pally	6.8	5186	3319	927	7.1	5352	3425	1007
43	HP-49	Mulugu Urban Area	6.7	5261	3367	986	6.8	4722	3022	1045
44	HP-50	Gattampally	7.2	1194	764	426	7.1	886	567	273
45	BW-3	Manchinilla pally	7.5	1783	1141	348	7.5	1820	1165	341
46	BW-24	Mallampally	7.2	698	447	343	7.4	720	461	298
47	BW-26	Pandikunta village	7.1	969	620	401	7.2	944	604	384
48	BW-28	Pandikunta (Bhupalpally)	7.3	878	562	346	7.1	961	615	364
49	BW-29	Jakaram	7.1	1314	841	449	7.0	1475	944	442
50	BW-47	Mulugu	7.5	1013	648	371	6.8	1050	672	347
		Min	6.7	314	201	128	6.8	241	154	49
		Max	8.1	5644	3612	1001	8.0	5402	3457	2148
		Avg	7.3	1949	1248	484	7.2	1977	1265	544
Standards		BIS 1991	6.5-8.5	-	2000	600	6.5-8.5		2000	600

NOTE: SW=Surface Water; DW=Dug Well; HP=Hand Pump and BW=Bore Well

Table 1: Physical parameters of groundwater samples from both pre and post-monsoon.

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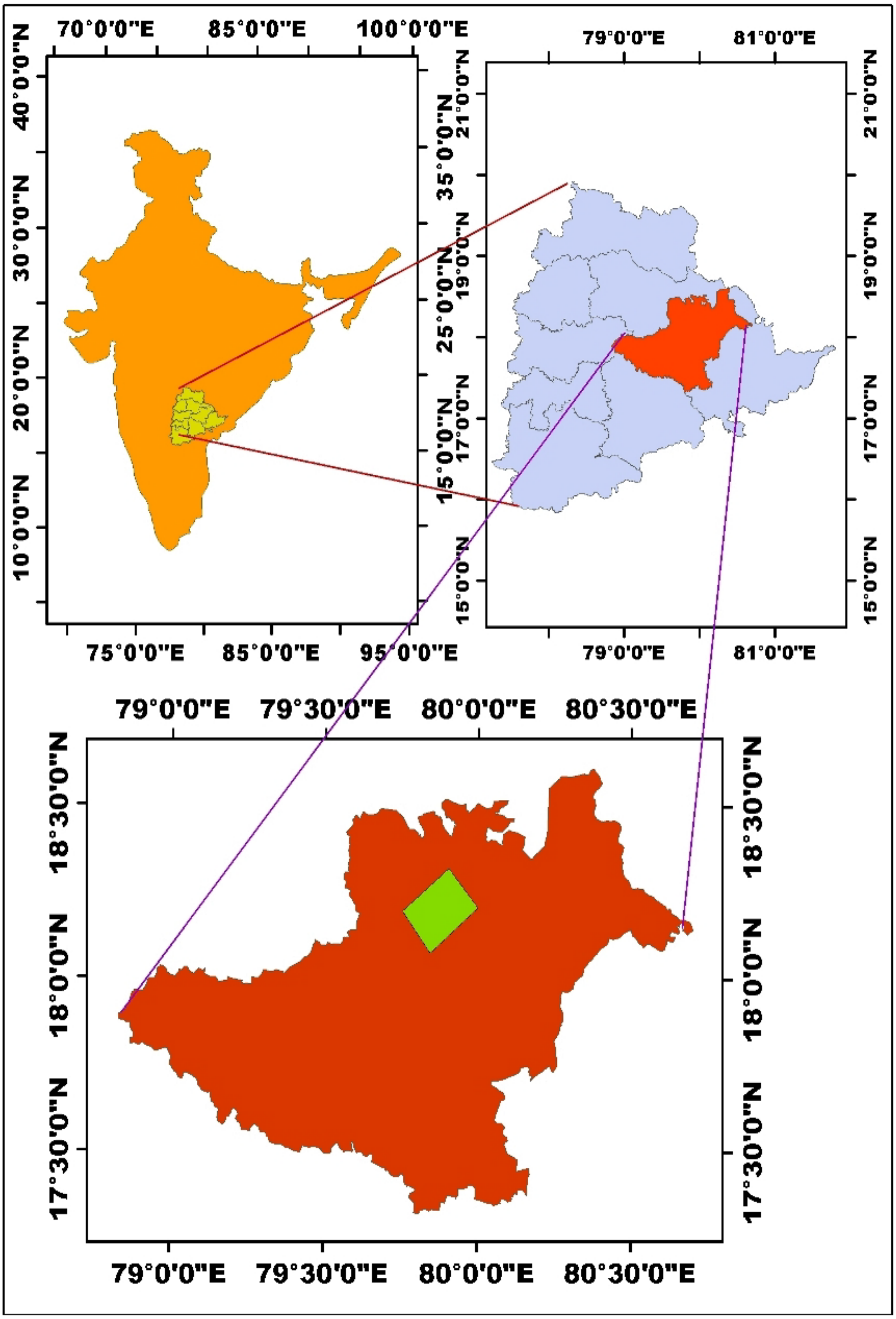

Figure 1: Location map of the study area.

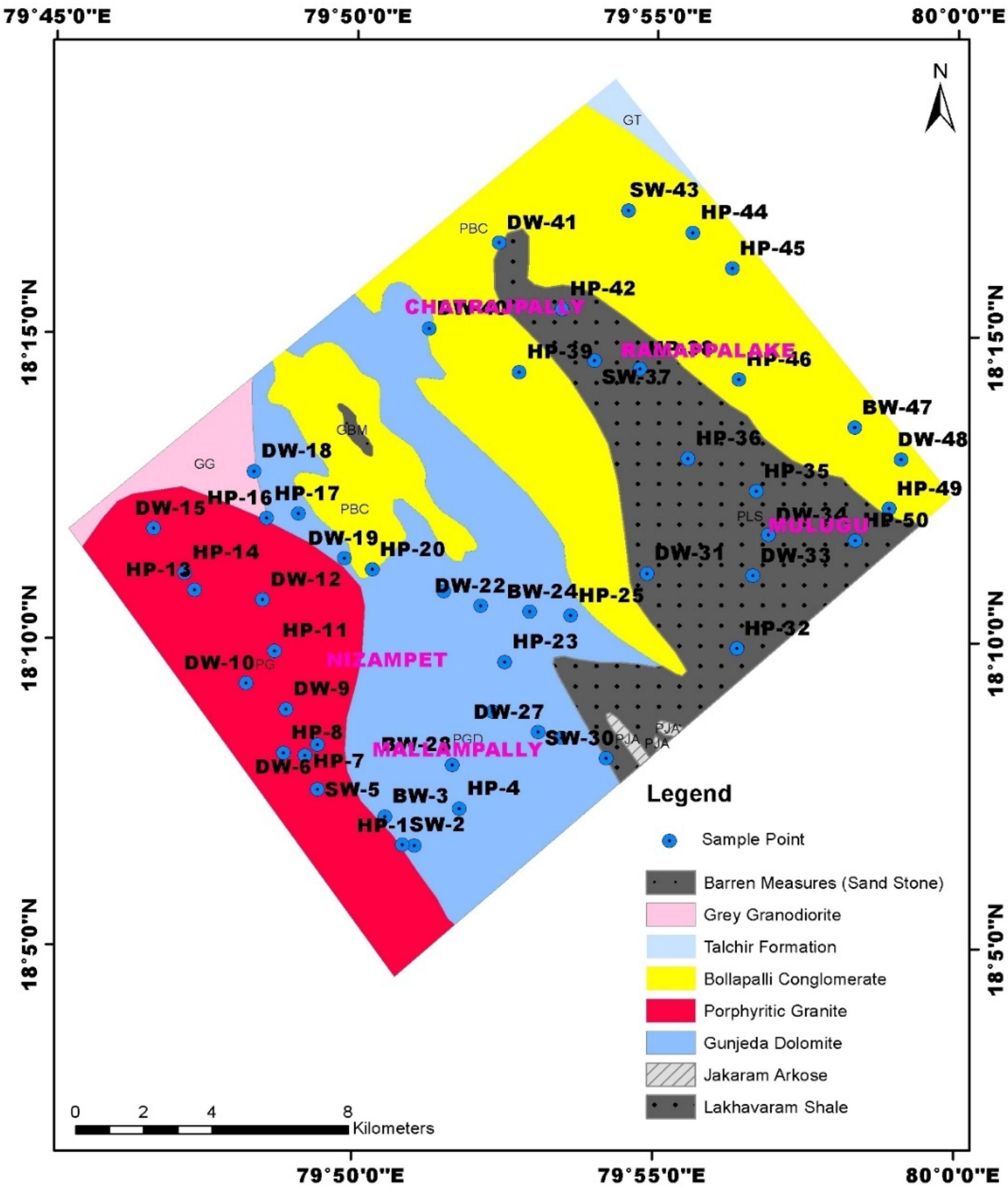

Figure 2: Map showing the Geology of the study area.

Parameters	Maximum Permissible limits (WHO)	Samples category					
		Pre-monsoon (n=50)			Post-monsoon (n=50)		
		No. of Samples (%)		Range of estimated values	No. of Samples (%)		Range of estimated values
pH	6.5-8.5	0	Nil	6.7-8.0	0	Nil	6.7-8.0
TDS	1000	21	42	201-3612	23	46	154-3457
TH	500	16	32	100-1000	23	46	38.8-2148
Mg	150	0	Nil	7.4-127.4	2	4	7.62-193.8
Ca	200	1	2	28-204	4	8	3-541.4
Cl	250	18	36	7.81-1667	16	32	7.6-1089.2
SO_4	400	6	12	2-1533	4	8	5.2-1200

Table 2: Quality of groundwater samples from Mulugu and Venkatapur mandals for drinking purpose after WHO [29].

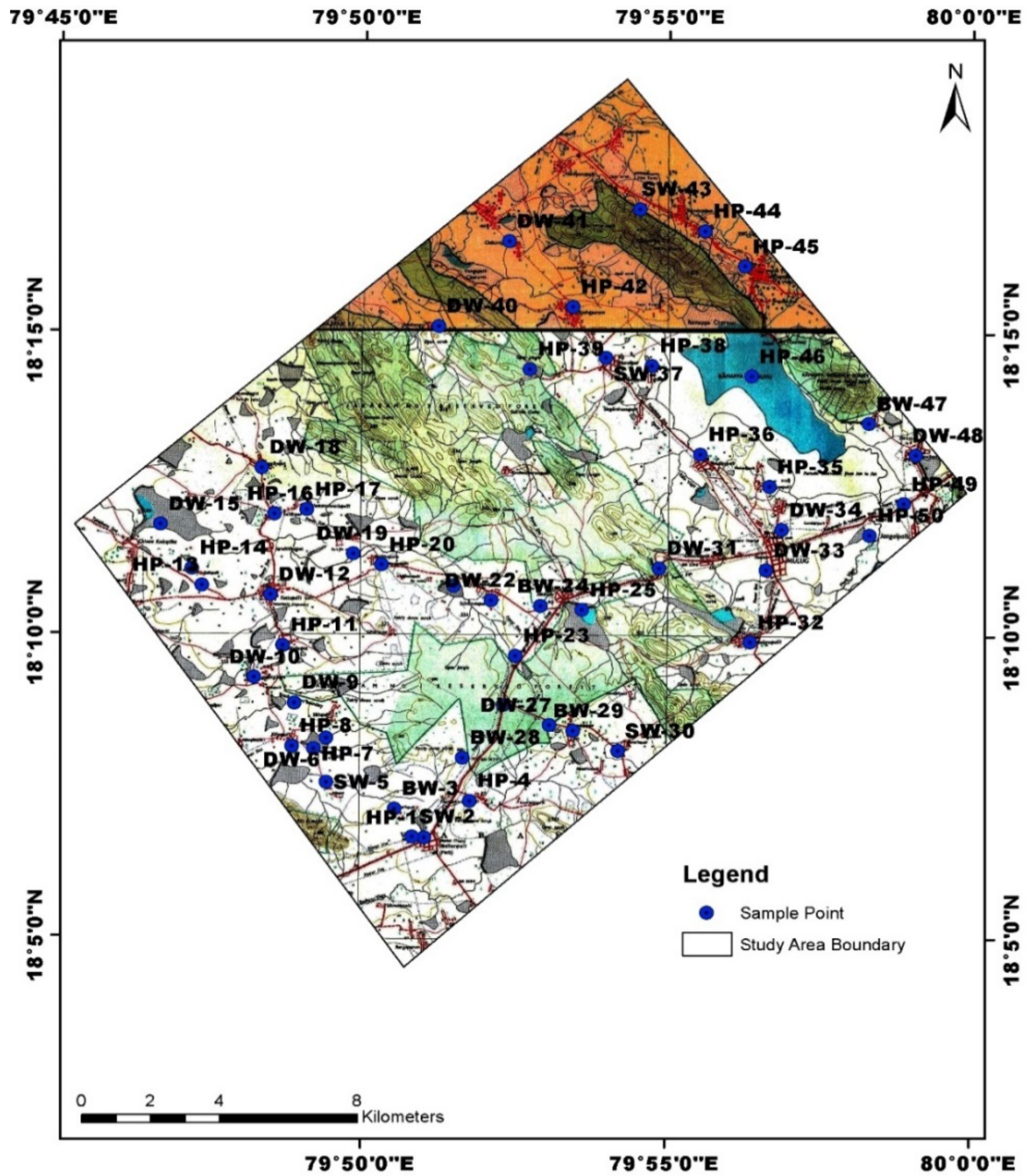

Figure 3: Map showing the samples location of groundwater and surface water in the study area.

TDS (mg/l)	Class	Pre-monsoon (Nos. of samples)	Pre-monsoon (Nos. of samples)
Up to 500	Desirable for drinking	8	12
500-1,000	Permissible for drinking	20	19
1,000-3,000	Useful for agriculture (slightly saline)	22	19

Table 3: TDS classification of groundwater samples after WHO [29].

ranges from 7.4 to 127.4 mg/l with an average of 57 mg/l during the pre-monsoon and from 7.6 to 193.8 mg/l with an average of 69.6 mg/l in the post-monsoon period. This hydrochemical feature again a precipitate or seasonal control. Like Ca^{2+} and K^{+}, Mg^{2+} in Kottapallygori has higher concentration as compared to other wells. These hydrochemical characteristics may be influenced by rock weathering in nearby places around Kottapallygori village. All the analyzed water samples are suitable for drinking purposes, since the values of Mg^{2+} are within the permissible limits (<150 mg/l) as per the standards [29]. The Mg^{2+} values of all the samples for pre and post-monsoon are shown in distribution maps (Figures 6a and 6b).

Calcium (Ca^{2+}): In northeast and west parts of the study area consists of relatively high concentration of calcium because of the presence of gnessic rock containing feldspars, pyroxene and amphiboles, accessory minerals such as apatite, wollastonite and fluorite. Ca^{2+} shows considerable variation in water samples from the pre to post-monsoon period in 1 well (pre-monsoon) and 4 wells

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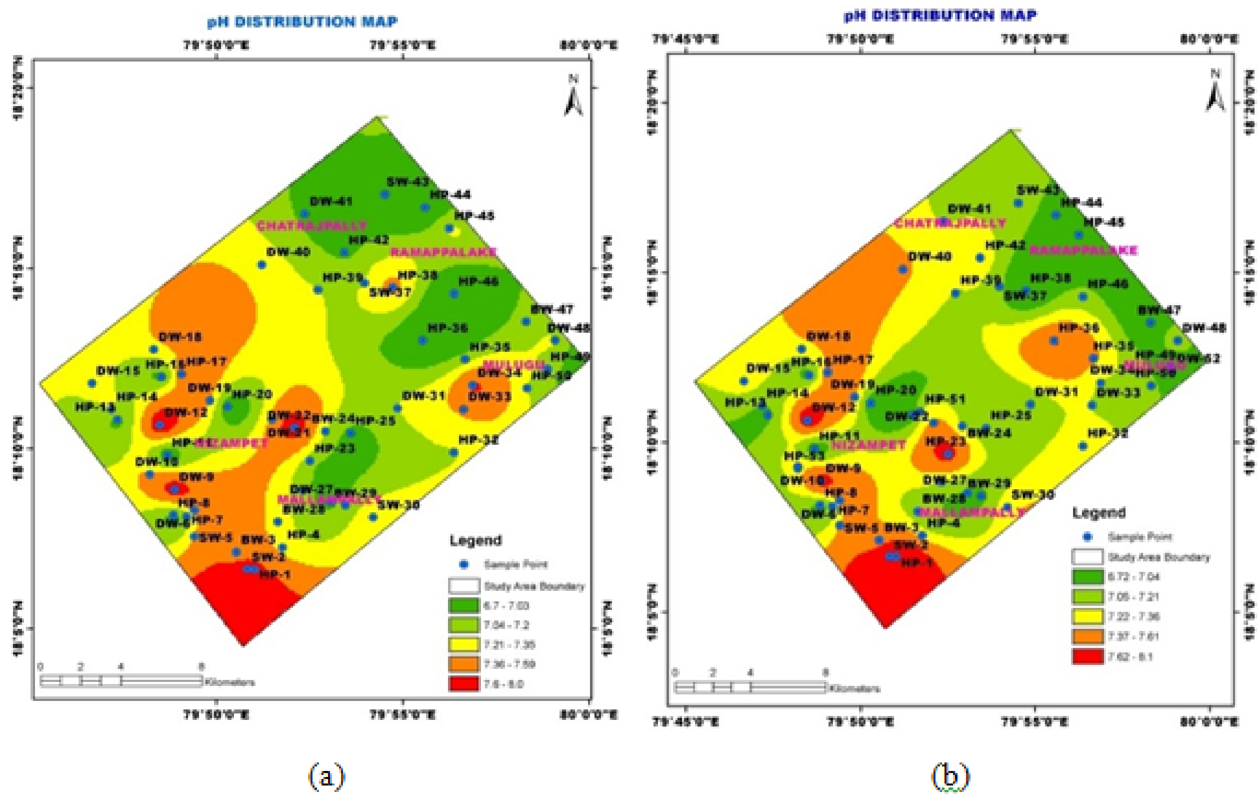


Figure 4: Spatial distribution map of pH in groundwater and surface water samples during (a) Pre-monsoon and (b) Post-monsoon.

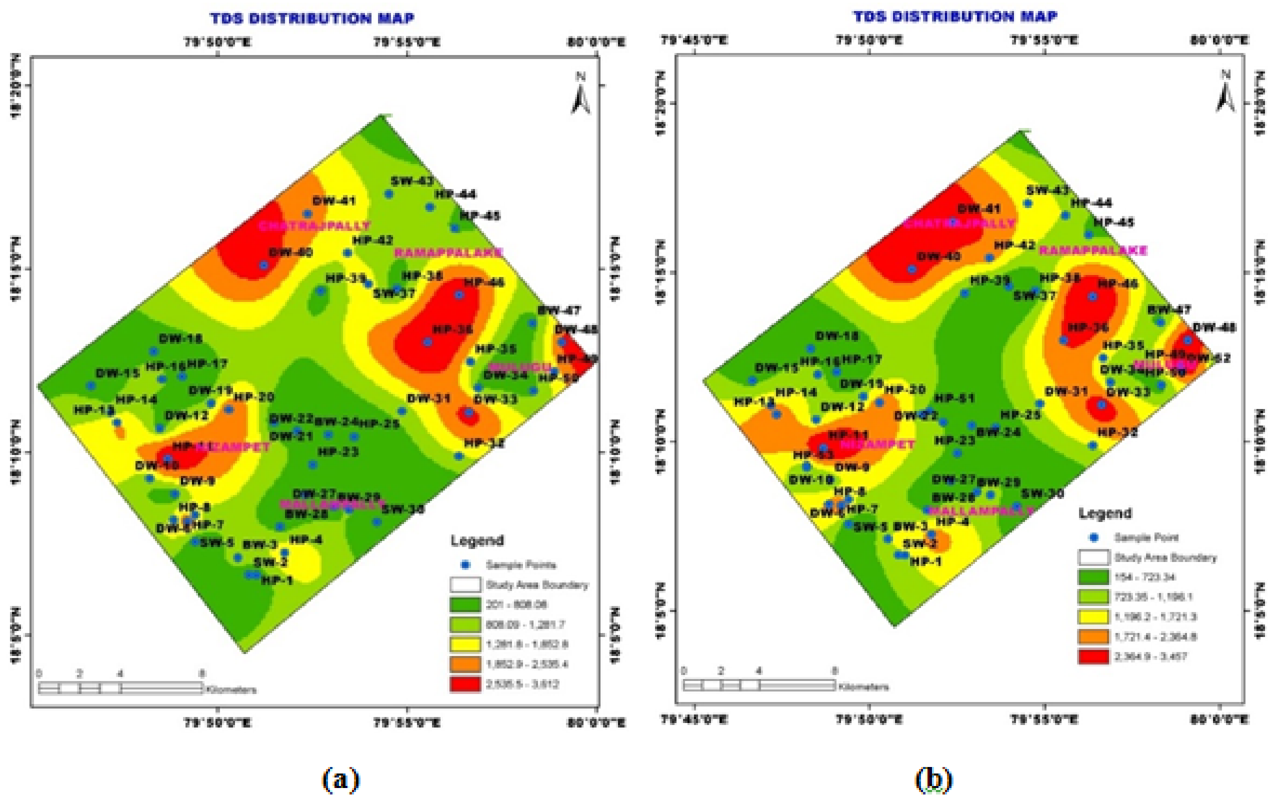


Figure 5: Spatial distribution map of TDS mg/l in groundwater and surface water samples during (a) Pre-monsoon and (b) Post-monsoon.

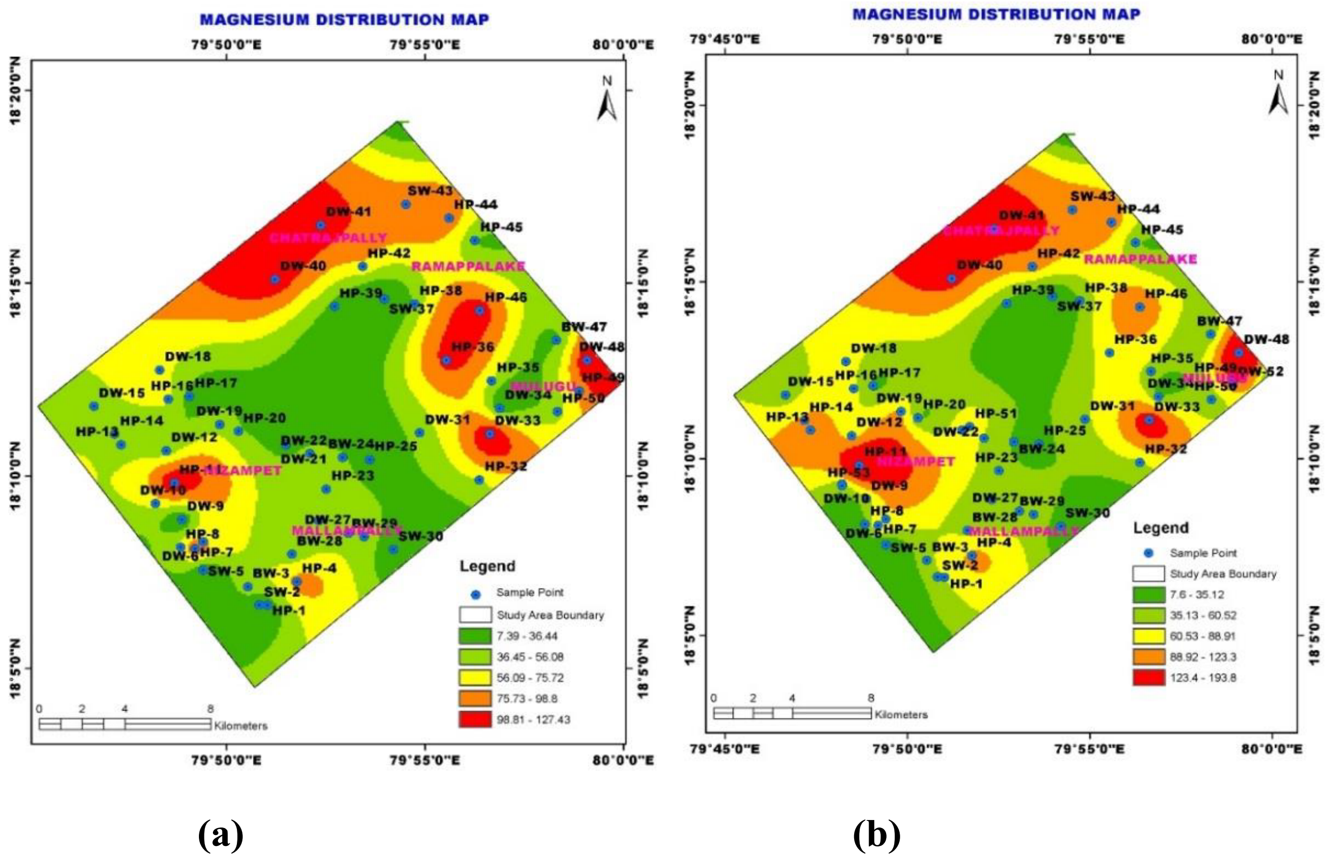
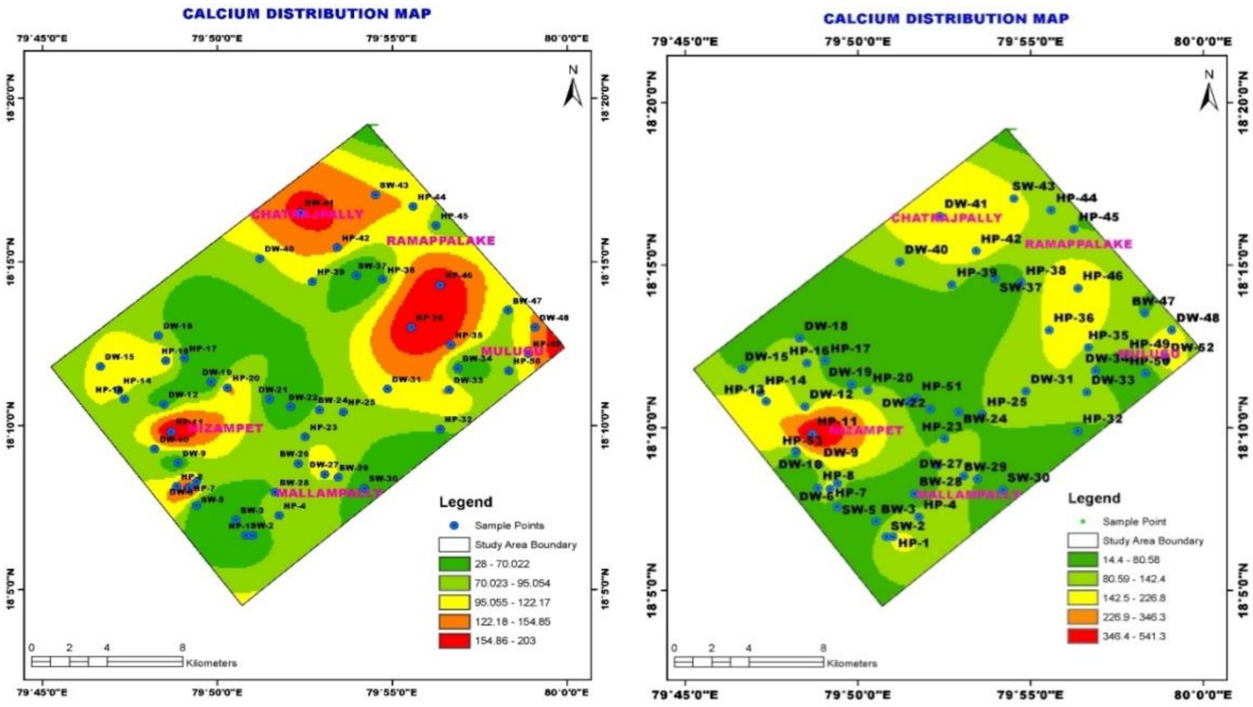


Figure 6: Spatial distribution map of mg mg/l in groundwater samples during the (a) pre-monsoon and (b) post-monsoon.

(post-monsoon). All the groundwater samples have lower Ca^{2+} than permissible limits of >200 mg/l as per standards [28]. The open well at Ramappa Lake has the lowest concentration of Ca^{2+} among all bore and open wells in the area. Ca^{2+} in groundwater for pre and post-monsoon periods varies from 28 to 204 mg/l and 3.0 to 541.35 mg/l, respectively. The average amount of calcium present in water samples of the pre-monsoon season is 95 mg/l and in post-monsoon season, 105 mg/l. It seems that the average values of Ca^{2+} are within the permissible limits as per WHO [29] standard value of 200 mg/l. The spatial distribution of Ca^{2+} in the area (Figures 7a and 7b) shows higher concentration at Kottapallygori village.

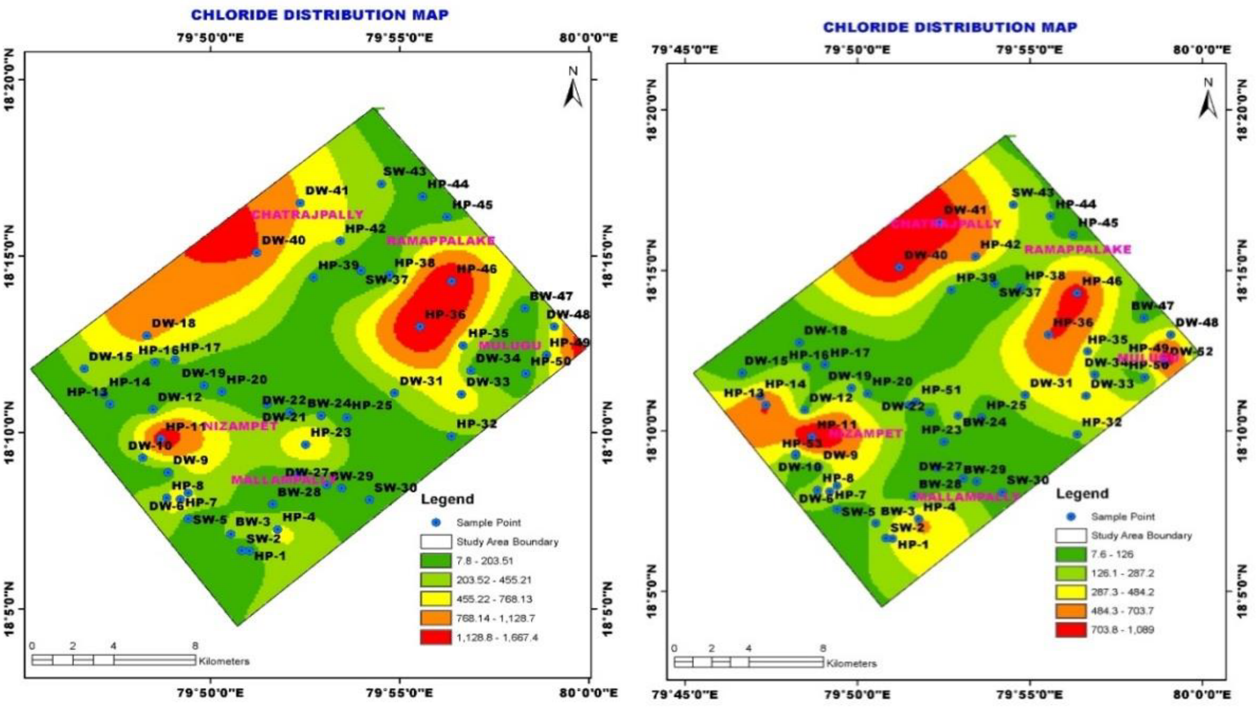
Chloride (Cl^-)**:** Chloride in groundwater originates from both natural and anthropogenic sources. Chloride content in groundwater samples was much higher than the permissible limits. High chloride content indicates heavy pollution. It can be due to the uses of inorganic fertilizer, landfills leachates, septic tank effluents and industrial and irrigation drainage. Chloride concentrations in the study area have a wide range from 7.81 to 1667 mg/l and 7.6 to 1089.2 mg/l in the groundwater samples during the pre and post-monsoon periods. The lowest (7.8 mg/l) concentration of Cl^- is noticed in Jakaram village surface water, while the highest (1667 mg/l) is at Parapet village bore well during the pre-monsoon period. In the post-monsoon period, the Cl^- levels are lower in Jakaram surface water (7.6 mg/l) and higher at Palampet bore well (1089 mg/l). The Cl- ions are compatible with Na^+ cation in most of the groundwater samples collected from wells due to geochemical coherence between Cl- and Na^+. Both ions are controlled by extensive and intensive weathering of granite and gneisses that contain a lot of plagioclase, alkali amphiboles, micas apatite and fluorite minerals. The spatial distribution maps (Figures 8a and 8b) of Cl^- exhibit lower concentration at Jakaram and higher concentration at Palampet, Kottapallygori, Chatarajpally, Bandarupally, Mulugu urban area in the pre and post- monsoon periods. The Cl^- concentration in majority of wells was under permissible limits [29], devoid of excess salinity in the groundwater. Few wells have Cl^- concentration exceeding the desirable limits (250 mg/l) as per WHO [29] rendering unsuitable for drinking, but can be used for irrigation and domestic purposes. The chloride content in the groundwater during the pre-monsoon season varies from 7.81 to 1667 mg/l with a mean of 355 mg/l and in the post-monsoon season from 7.3 to 1089.20 mg/l with a mean of 263.61 mg/l. The mean values of chloride from both seasons show that there is little seasonal fluctuation of chloride. The lowering of Cl^- values during post-monsoon season was due to the dissolution processes play an important role in the watershed.

Sulfate (SO_4^{2-}**):** SO_4^{2-} concentration is possibly contributed by the type of precipitation and excess use of fertilizers in paddy cultivation. The sulfate in the groundwater during the pre- monsoon season varies from 2 to 1533 mg/l with a mean of 162 mg/l and in the post-monsoon season from 5 to 1200 mg/l with a mean of 153 mg/l. The maximum permissible limit SO_4^{2-} was 250 mg/l. The lowest (2 mg/l) value is at Jaggayyapet Bore well and highest (1533 mg/l) at Jangalpally Dug well for the pre-monsoon period. This chemical variation is comparable with that of all major cations and anions. The mean value of sulfate shows that there is seasonal fluctuation in the area. Spatial distribution maps (Figures 8a and 8b) of SO_4^{2-} concentrations show distinct variations



(a) (b)

Figure 7: Spatial distribution map of Ca mg/l in groundwater samples during the pre-monsoon and (b) post-monsoon.



(a) (b)

Figure 8: Spatial distribution map of Cl mg/l in groundwater samples during the (a) pre-monsoon and (b) post-monsoon.

from the northern to the southern part of the study area. The northern part has shown no variation in SO_4^{2-} concentration compared to the southeastern part of the study area (Figures 9a and 9b).

Water quality criteria for irrigation

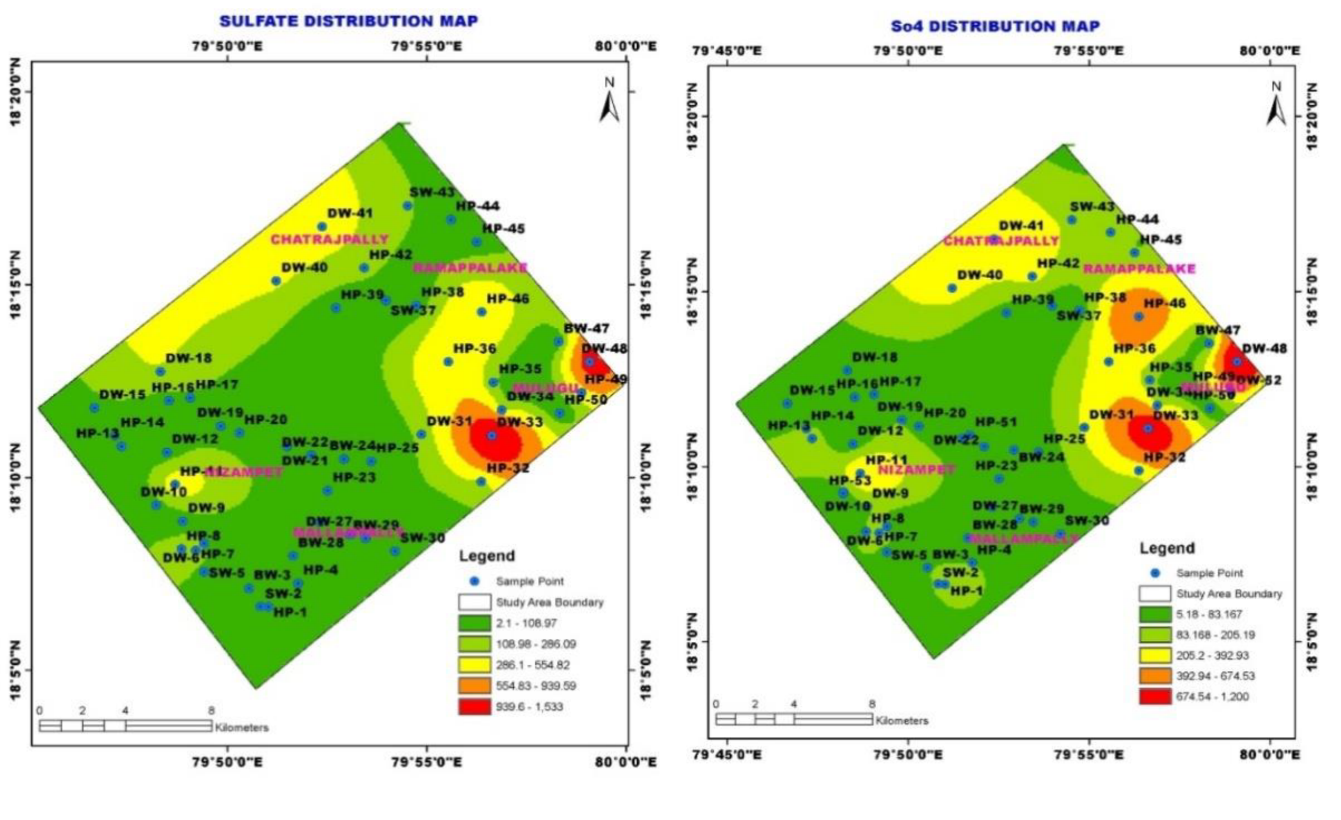
Water quality for irrigation refers to its suitability for agricultural use. The estimation of concentration and composition of dissolved constituents in water plays important role in ascertaining its quality for irrigation. Quality of water is an important consideration in any appraisal of salinity or alkalinity conditions in an irrigated area. The suitability of groundwater for irrigation is evaluated by Salinity index (EC), Sodium Absorption Ratio (SAR), Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP), Permeability Index (PI) and Water Quality Index (WQI).

Classification of salinity (EC) in groundwater: EC is an assessment of all soluble salts in samples. The most influential water quality guideline on crop productivity is the water salinity hazard, which is a measure of electrical conductivity (EC). The higher the EC, the less suitable is water available to plants, because plants can only transpire "pure" water and usable plant water in the soil solution decreases dramatically as EC increases. The amount of water transpired through a crop is directly related to yield; therefore, irrigation water with high EC reduces yield potential. The electrical conductivity (EC) of the groundwater in the study area varies from 314.1 to 5643.8 µS/cm and 240-5401.6 µS/cm in pre and post-monsoon, respectively (Table 4). Based on the EC, the groundwater of study area has been classified into four classes [33], (Table 4). Accordingly these classes 1, 8, 25 and 16 samples in pre-monsoon and 1, 7, 25 and 17 smples in post-monsoon seasons show low, medium, high and very high salinity classes. The majority of groundwater samples from both pre and post-monsoon periods have low sodium to high salinity and hence the groundwater is not good for irrigation.

Kelly's Ratio (KR): Water can be categorized on basis of Kelly' ratio. The concentration of Na^+ measured against Ca^{2+} and Mg^{2+} is known as Kelly's ratio, based on which irrigation water can be rated [34-36]. The concentration of Na^+ is considered to be one of the prime concern in making the water unsuitable if Kelly's ratio is >1. As per the Kelly's ratio water from the study area are categorized into suitable if KR is <1, marginal, when KR is 1-2 and unsuitable if KR is >2 (Table 5). The majority of groundwater samples were suitable (82% from pre-monsoon, 86% from post-monsoon) for irrigation (Table 5), whereas the majority of water samples were marginal (18% from post-monsoon, 14% from post-monsoon) for irrigation (Table 5). Accordingly Kelly Ratio's 41 and 9 samples for pre-monsoon and 43 and 7 sample for post-monsoon season indicates suitable and marginal suitable for irrigation purposes. Na^+ increases from groundwater in the area due to water-rock interaction due to oxidizing condition and evapotranspiration processes.

Sodium Absorption Ratio (SAR): SAR for the groundwater from the study area was estimated by the formula:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \tag{1}$$



(a) (b)

Figure 9: Spatial distribution map of So4 mg/l in groundwater samples during the (a) pre-monsoon and (b) post-monsoon.

Electrical conductivity (EC)	Salinity Class	Sample falling in different categories	
		Pre-monsoon (n=50) No. of samples %	Pre-monsoon (n=50) No. of samples %
0-250	Low	1 2	1 2
251-750	Medium	8 16	7 14
751-2,250	High	25 50	25 50
2,251	Very high	16 32	17 34

Table 4: Classification of groundwater based on EC after Handa [33].

Range of Kelly's ratio	Category	No. of samples % Pre-monsoon (N=50)	No. of samples % Post-monsoon (N=50)
<1	Suitable	41 82	43 86
1-2	Marginal	9 18	7 14
>2	Unsuitable	Nil -	Nil -

Table 5: Classification of groundwater [34].

Water having SAR values <10 is considered excellent, 10-18 is good, 18-26 is fair and above 26 is unsuitable for irrigation use [37]. In the present study area all the sample are excellent category in pre and post-monsoon period. The SAR values calculated are presented in Table 6.

Residual Sodium Carbonate (RSC): Residual Sodium Carbonate (RSC) has been used to determine the harmful effect of carbonate and bicarbonate on the quality of water for agricultural purpose and is estimated by the formula.

$$RSC = (CO_3 + HCO_3 - (Ca + Mg)) \tag{2}$$

Where all ionic concentrations are expressed in meq/L.

According to the RSC classification for irrigation purposes, the water with more than 2.5 meq/l (Table 6) is unsuitable for irrigation [37]. Groundwater of the study area is classified on the basis of RSC and is presented in (Table 6). The RSC values varies from 2.84 to 3.02 and -14.36 to 0.32 meq/l during pre and post-monsoon periods respectively. It is observed that 98% and 100% samples during pre and post-monsoon samples are fall in the safe class for irrigation, except one sample NO. HP32 is range 3.02 meq/l in unsuitable for irrigation. This is clearly established by the field studies of the occurrence of alkaline white patches and of the low permeability of the soil. Hence, continued usage of high residual sodium carbonate waters affects and yields of crop.

Soluble Sodium Percentage (SSP): Wilcox has proposed a classification for rating irrigation waters on the basis of Soluble Sodium Percentage (SSP). The SSP was computed using following formula [37]:

$$SSP = \frac{Nax100}{Ca + Mg + Na} \tag{3}$$

Where the concentrations of ions are expressed in meq/l. The values of SSP <50 indicate good quality of water, and higher values (i.e., >50) show that the water is unsafe for irrigation [38]. It is observed from Table 6 that 91% and 93% groundwater samples show <50 SSP values indicating good quality for irrigation in each pre and post-monsoon period. SSP values >50 found in 9% and 7% samples are in unsafe for irrigation in each pre and post monsoon period.

Permeability Index (PI): Long term use of irrigation water affects soil permeability. It depends on various factors like total soluble salt, sodium, calcium, magnesium and bicarbonate content of the water. Doneen classified irrigation waters into three classes based on the Permeability Index (PI) [39]. The PI has been computed and plotted on Doneen Chart (Table 6) and is formulated as

$$PI = \frac{(Na + K) + \sqrt{HCO_3}}{Ca + Mg + Na + K} \times 100 \tag{4}$$

All the ions are represented in meq/l. As per the PI of groundwater samples in the study area, the majority of the samples fall in the field of class I and are described as having excellent permeability (Figure 10) in both pre and post-monsoon.

Water Quality Index (WQI)

Water Quality Index (WQI) is important because it arises first from the need to share and communicate with the public in a consistent manner of monitoring ambient water. Second, it is associated with the need to provide a general means of comparing and ranking various bodies of water throughout the region. The index strives to reduce an analysis of many factors into a simple statement. The WQI is founded on three issues involving the measurement of the attainment of water quality objectives. These factors are (1) number of objectives that are not met, (2) frequency with which objectives are not met and (3) the amount by which objectives are not met. The WQI was calculated for groundwater and surface water samples for pre and post-monsoon period taking into consideration six parameters, namely pH, electrical conductivity, total dissolved solids, nitrates, sulfates and total hardness. The weighted arithmetic water quality index was calculated as follows and given in Table 6.

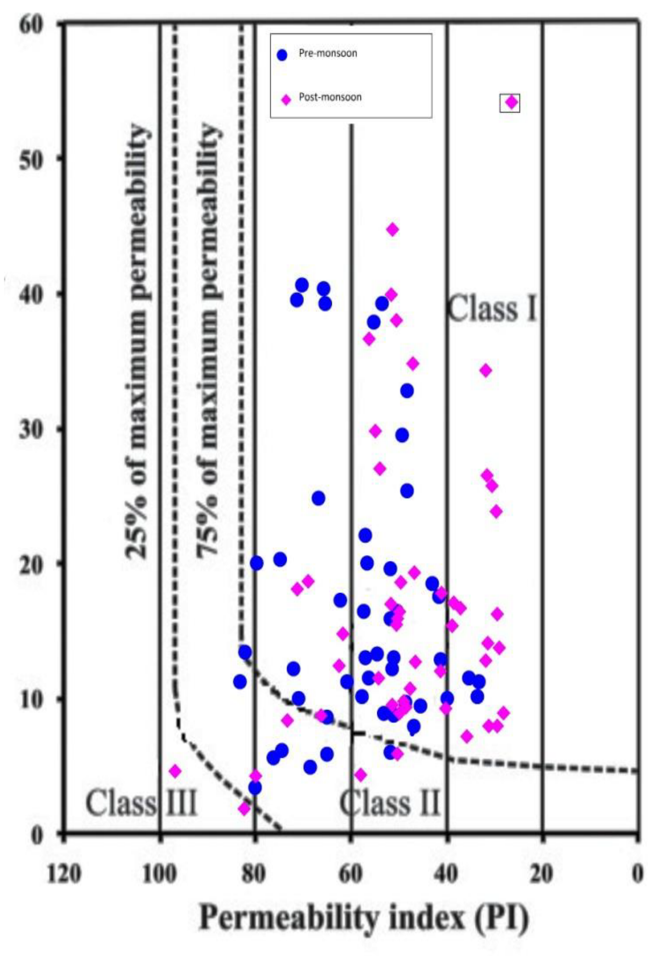


Figure 10: Doneen classification of irrigation for groundwater based on the permeability index [39].

Sample ID	Pre-monsoon samples						Post-monsoon samples					
	SAR (meq/l)	KR (meq/l)	RSC (meq/l)	SSP (meq/l)	PI (meq/l)	WQI	SAR (meq/l)	KR (meq/l)	RSC (meq/l)	SSP (meq/l)	PI (meq/l)	WQI
SW-2	1.83	0.70	-1.39	41.23	67.06	35	1.73	1.63	-1.26	44.62	69.37	43
SW-5	1.83	0.81	-0.99	44.66	72.40	28	1.18	2.16	0.02	46.56	92.50	21
SW-30	0.61	0.27	-1.24	21.30	58.00	18	0.23	3.43	-0.86	10.45	50.05	19
SW-37	3.88	0.79	-6.70	44.20	55.13	101	0.47	7.46	-0.62	23.97	70.68	16
SW-43	0.80	0.33	-1.52	24.71	57.05	20	1.16	1.25	0.83	47.28	118.26	16
DW-6	3.93	0.83	-5.48	45.45	57.26	169	2.91	0.61	-7.29	41.95	52.46	160
DW-9	3.99	1.45	-0.56	59.20	78.66	153	2.29	0.76	-6.80	40.08	50.38	155
DW-10	2.44	0.54	-4.84	35.15	50.18	132	1.68	0.52	-7.54	29.86	42.29	135
DW-12	2.73	0.76	-2.88	43.26	60.28	115	1.72	0.62	-9.59	30.80	37.80	283
DW-15	0.37	0.10	-0.99	8.89	42.78	43	0.17	0.67	-3.00	5.07	33.13	67
DW-18	0.65	0.15	-5.19	12.99	32.20	86	0.48	1.26	-7.96	11.41	22.05	59
DW-19	2.91	0.81	1.86	44.85	69.78	69	2.58	0.46	-5.29	39.11	51.66	121
DW-21	1.72	0.54	-3.31	34.88	53.59	56	1.22	0.71	-3.96	24.64	44.42	77
DW-22	2.47	0.74	1.94	42.52	70.89	51	1.76	0.36	-1.79	35.01	55.89	85
DW-27	1.79	0.43	-6.59	29.96	42.97	56	0.29	0.05	-4.73	8.20	31.06	79
DW-31	2.33	0.54	-5.15	35.24	51.23	73	3.19	0.11	-7.84	46.43	55.61	88
DW-33	4.76	0.84	-8.96	45.67	57.41	208	5.49	0.03	-17.74	51.01	55.60	216
DW-34	3.93	1.32	-1.01	56.92	77.56	60	2.80	0.18	-3.46	49.74	65.33	77
DW-40	8.66	1.61	-5.28	61.69	69.88	254	6.03	0.39	-11.43	54.41	60.84	232
DW-41	3.34	0.57	-11.24	36.14	45.94	201	2.64	0.31	-16.93	32.11	39.79	253
DW-48	5.35	0.91	-11.93	47.56	55.47	266	5.29	0.14	-21.39	47.39	50.83	301
HP-1	2.63	0.62	-4.08	38.43	53.89	103	1.94	0.31	-8.83	33.05	43.30	121
HP-4	5.79	1.22	-5.87	54.97	64.34	213	4.62	0.13	-7.89	51.95	60.32	226
HP-7	2.66	0.46	-9.86	31.54	43.55	228	1.61	0.18	-14.49	23.72	34.19	203
HP-8	2.19	0.46	-5.29	31.34	46.54	134	1.89	0.03	-5.39	34.79	48.91	160
HP-11	3.95	0.62	-12.84	38.35	47.06	466	1.95	0.01	-41.99	21.14	23.25	403
HP-13	2.94	0.55	-6.85	35.58	48.17	135	1.82	0.04	-14.39	26.86	35.11	170
HP-14	1.41	0.31	-5.36	23.94	40.72	113	0.88	0.19	-9.96	19.15	26.23	167
HP-16	0.70	0.15	-4.87	13.21	33.16	120	0.38	0.28	-8.21	8.79	23.89	114
HP-17	0.60	0.19	-4.18	15.65	32.50	69	0.25	0.07	-3.08	8.78	31.96	27
HP-20	7.45	1.72	-0.29	63.28	75.19	197	2.67	0.47	-0.11	42.85	60.66	235
HP-23	1.14	0.30	-5.45	22.97	37.56	88	0.65	1.27	-2.89	16.76	40.48	69
HP-25	0.42	0.12	-2.58	10.63	38.76	38	0.13	3.04	-2.34	4.55	35.18	36
HP-32	5.06	1.23	-1.57	55.14	69.14	107	4.29	0.80	-3.34	56.00	67.95	128
HP-35	2.63	0.53	-6.73	34.64	47.52	156	2.01	0.54	-10.30	35.08	41.34	142
HP-36	7.32	1.21	-9.62	54.70	62.58	272	4.27	1.01	-12.61	50.26	57.25	176
HP-38	1.42	0.38	-2.10	27.60	50.85	52	0.71	0.09	-4.22	19.53	37.59	37
HP-39	1.90	0.51	-2.27	33.63	54.72	55	0.99	0.24	-2.22	25.76	49.60	57
HP-42	1.98	0.40	-8.48	28.34	40.42	121	1.52	0.13	-17.70	23.70	27.68	161
HP-44	1.27	0.24	-7.15	19.58	37.44	117	0.86	1.37	-9.18	15.84	31.43	126
HP-45	2.25	0.58	-3.17	36.81	54.60	84	1.28	1.47	-4.05	29.46	47.22	80
HP-46	4.95	0.81	-10.86	44.74	55.89	213	4.18	0.28	-14.34	44.92	54.78	227
HP-49	5.88	0.93	-12.45	48.28	55.68	270	3.86	0.01	-14.90	42.29	49.29	218
HP-50	1.85	0.45	-3.20	30.90	50.52	57	2.35	0.50	-1.47	44.94	63.81	53
BW-3	6.60	1.76	-3.57	63.81	73.46	126	4.74	0.45	-0.26	60.10	75.16	122
BW-24	0.51	0.14	-5.40	12.08	28.10	86	0.45	3.31	-3.07	14.92	38.74	90
BW-26	0.52	0.13	-4.47	11.47	32.52	76	0.23	0.38	-3.38	6.81	31.59	82
BW-28	1.63	0.44	-2.56	30.44	51.91	47	0.89	2.84	-1.38	21.77	48.04	75
BW-29	1.52	0.36	-3.44	26.36	46.52	89	1.33	1.73	-6.39	27.56	41.08	138
BW-47	1.50	0.39	-2.70	27.91	49.33	55	1.27	0.64	-1.69	29.83	53.31	82

Table 6: Calculation of SAR, KR, RSC, SSP, PI and WQI for groundwater samples are in pre and post-monsoon periods.

$$WQI = \left[\sum (qi.wi) \div \sum wi \right] \quad (5)$$

Further, water quality status based on WQI was classified as excellent (WQI <50), good (WQI=50-100), poor (WQI=100-200), very poor (WQI=200-300) and water unsuitable for drinking and irrigation (WQI >300). Most of the groundwater samples of the study area fall in the category of excellent and good water, while the few were unsuitable for drinking and irrigation use (Table 8) [40-42].

Hydrochemical facies: To evaluate hydrogeochemistry of water the cations and anions are plotted on Piper diagram [43]. This diagram reveals similarities and dissimilarities among groundwater samples because those with similar qualities will tend to plot together as groups

[44]. This diagram is very useful in bringing out chemical relationships among groundwater in more definite terms [45]. The Piper plot, which has been divided into five subcategories, viz. I-(Na-Mg-HCO_3-Cl type), II-(Ca-Mg-HCO_3 type), III-(Mixed Ca-Mg-Na-HCO_3), IV-(Mixed Na-Mg-SO_4-Cl type) and V-(Mixed Mg-Ca-HCO_3) type. As per the Piper Trilinear classification Class II and Class V are increased in Pre-monsoon and decreased in Post-monsoon, Class I and Class III are decreased in Pre-monsoon and increased in Post-monsoon and class IV is same in pre and post monsoon (Figures 11a and 11b).

Wilcox Model: The total concentration of soluble salts in irrigation water termed 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 C-1, C-2, C-3 and C-4 salinity zones, respectively [46,47]. A high salt concentration (high EC) in water leads to formation of saline soil and a high sodium concentration leads to development of an alkaline soil. Salinization is one of the most adverse environmental impacts associated with irrigation. Saline condition severely limits the choice of crop, adversely affect crop germination and yields and can make soils difficult to work on. Excessive solutes in irrigation water are a common problem in semi-arid areas where water loss through evaporation is maximum. Salinity problems encountered in irrigated areas is mostly due to poor drainage system. This allows the water table to rise close to the root zone of plants, causing the accumulation of sodium salts in the soil solution through capillary rise following surface evaporation of water.

The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of sodium adsorption ratio (SAR). Irrigation water is classified into four categories on the basis of sodium adsorption ratio (SAR) as: S-1 (<10), S-2 (10-18), S-3 (18-26) and S-4 (>26). There is a significant relationship between SAR values of irrigation water and the extent to which sodium is adsorbed by the soil. High sodium and low calcium in water raises the cation exchange between water and soil and is responsible for saturated sodium in an irrigated area. This can destroy the soil structure due to dispersion of Na in the clay particles. The calculated values of SAR for groundwater range from 0.30 to 7.55 in the pre-monsoon and from 0.13 to 6.0 in the post-monsoon periods. The EC ranges for groundwater from 314 to 5,644 mg/l in the pre-monsoon and from 241 to 5,402 mg/l in the post-monsoon periods (Table 7). In Wilcox diagram (Figures 12a and 12b), EC is taken as salinity hazard and SAR as alkalinity hazard. It shows low alkalinity hazard (S1) and high salinity hazard (C3) for the majority of groundwater samples for both the seasons, there is a gradual increase in both alkalinity and salinity characters of the groundwater samples during pre to post-monsoon periods, due to long-term precipitation and water-rock interaction in space and time.

Gibbs Plots: Gibbs plots are indicated by the variation diagrams of TDS against the ratios (Na^++K^+)/Na^++K^++Ca^{+2}) and TDS against Cl^-/(Cl^- + HCO_3^-) for both cations and anions groups. These plots provide very good genetic information about the composition, origin and distribution of the dissolved constituents in surface water and groundwater. The major natural mechanisms controlling surface and groundwater chemistry are (i) atmospheric precipitation, (ii) rock weathering, (iii) evaporation and fractional crystallization [48]. The groundwater samples of the area are plotted on Gibbs diagrams (Figures 12a and 12b). For better understanding controlling mechanisms, according to Gibbs classification the majority of groundwater samples are fall under rock dominance province. Alkali (Na^+ + K^+) content is higher in many samples collected during pre and post-monsoon periods at a given amount of TDS (400-1,100 mg/l).

The groundwater samples of the area on the plot TDS versus {Cl^-/ Cl^- +HCO_3^-} show similar variation with that of earlier cation diagram (Figures 13a and 13b). However, the samples are shifted from right to left fields due to less Cl^- content and high concentration of HCO_3^-. The rock-water interaction may play a major role in the groundwater chemistry of the area [49].

Conclusions

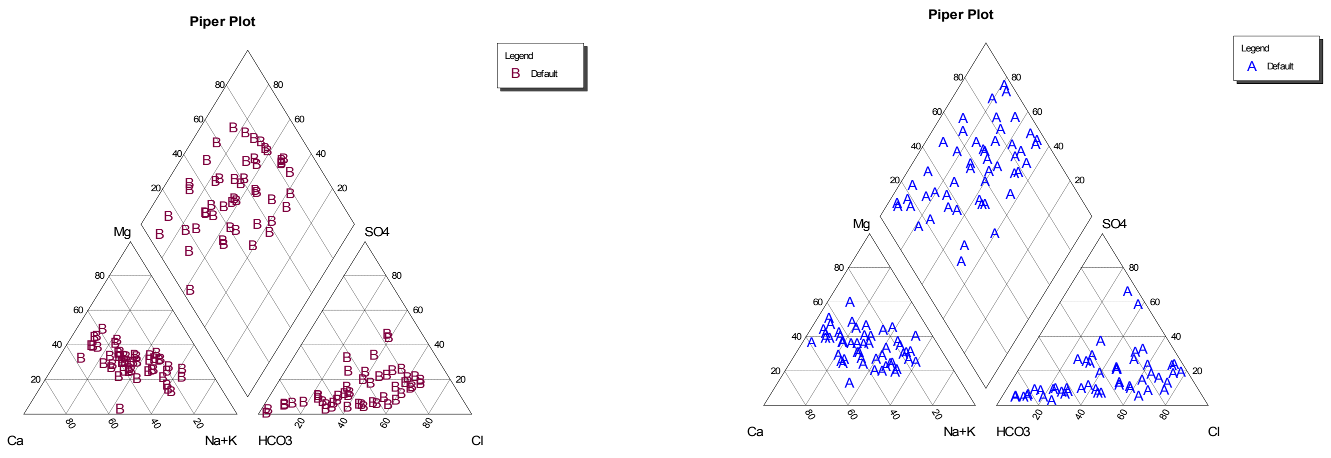
Groundwater samples were collected for pre and post-monsoon seasons and analyzed for various physico-chemical parameters. The quality of groundwater in the study area has been assessed for drinking and irrigation purposes using varies hydrochemical parameters that are suited for domestic and irrigation applications. The groundwater from the study area has pH <7 ranging from 7 to 8 suggesting that the water is

S No	Range	Water classes	Pre-monsoon No. of samples	%	Pre-monsoon No. of samples	%
1	S1-C1	Low sodium-low salinity	1	2	Nil	0
2	S1-C2	Low sodium-medium salinity	8	16	8	16
3	S1-C3	Low sodium-high salinity	28	56	30	60
4	S1-C4	Low sodium-very high salinity	3	6	4	8
5	S2-C3	Medium Sodium-high salinity	2	4	2	4
6	S2-C4	Medium Sodium-very high salinity	8	16	4	8
7	S3-C4	High Sodium-very high salinity	Nil	o	2	4

Table 7: Classification of groundwater based on Wilcox diagram [35].

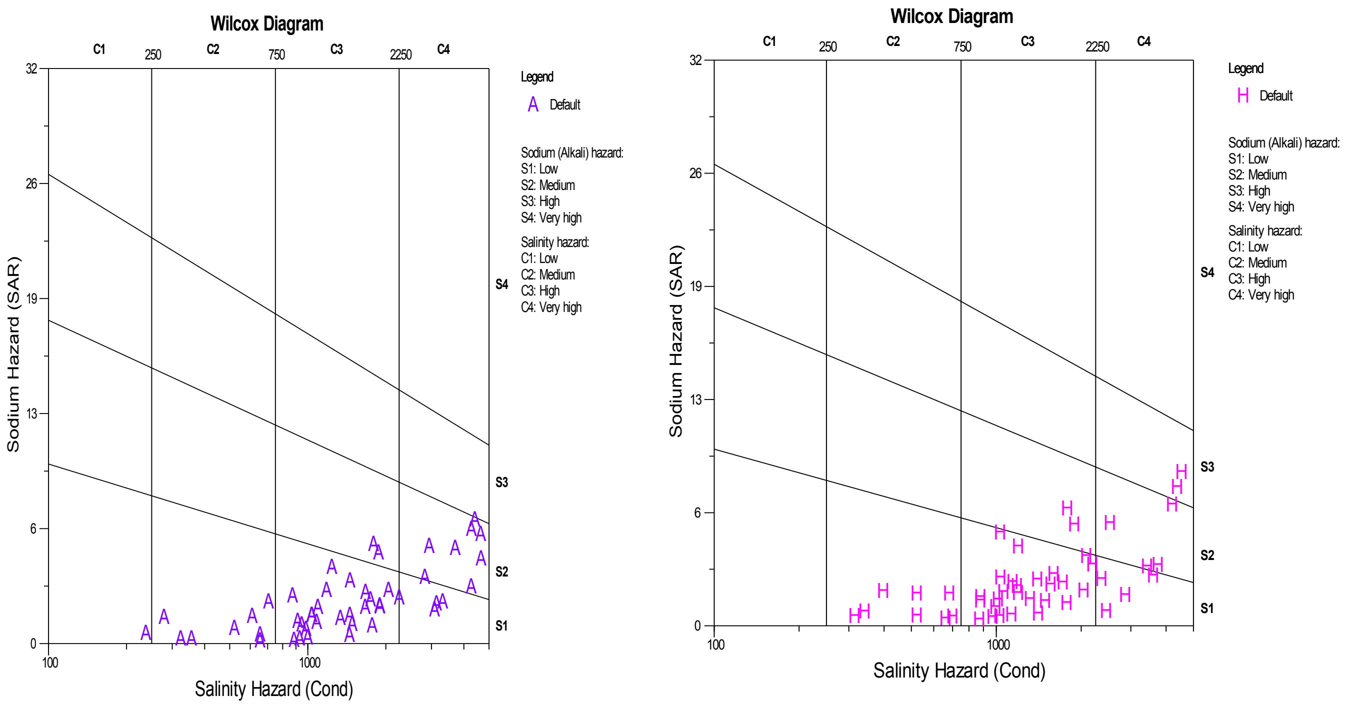
Class	WQI value	Water quality status	Pre-monsoon	Post-monsoon
I	<50	Excellent	07 samples	08 samples
II	50-100	Good water	17 samples	15 samples
III	100-200	Poor water	16 samples	16 samples
IV	200-300	Very poor water	09 samples	09 samples
V	>300	Water unsuitable for drinking	1 samples	02 samples

Table 8: Groundwater quality classification based on WQI values.



(a)Pre-monsoon (b) post-monsoon

Figure 11: Piper diagram showing groundwater and surface water samples (a) Pre-monsoon and (b) Post-monsoon period.



(a) **(b)**

Figure 12: Wilcox (US salinity) diagram for groundwater and surface water samples of the (a) pre-monsoon and (b) post monsoon periods from the study area.

slightly acidic to alkaline in nature and are within permissible limits for drinking purposes. The EC values of the groundwater in the study area reveal that the low sodium and high salinity hence the groundwater is unsuitable for irrigation. However, the TDS of the groundwater suggest that it was classified as freshwater for many samples in the study area. Total hardness (TH) of the groundwater indicates that the majority of samples are suitable for domestic purposes due to low to medium hardness; however some samples in the pre and post-monsoon contain >500 mg/l TH and therefore these are described as very hard and unsuitable for domestic, drinking and irrigation purposes.

The major cations (Ca^{2+}, Mg^{2+}) from the groundwater samples shown considerable variation from the pre to post-monsoon periods.

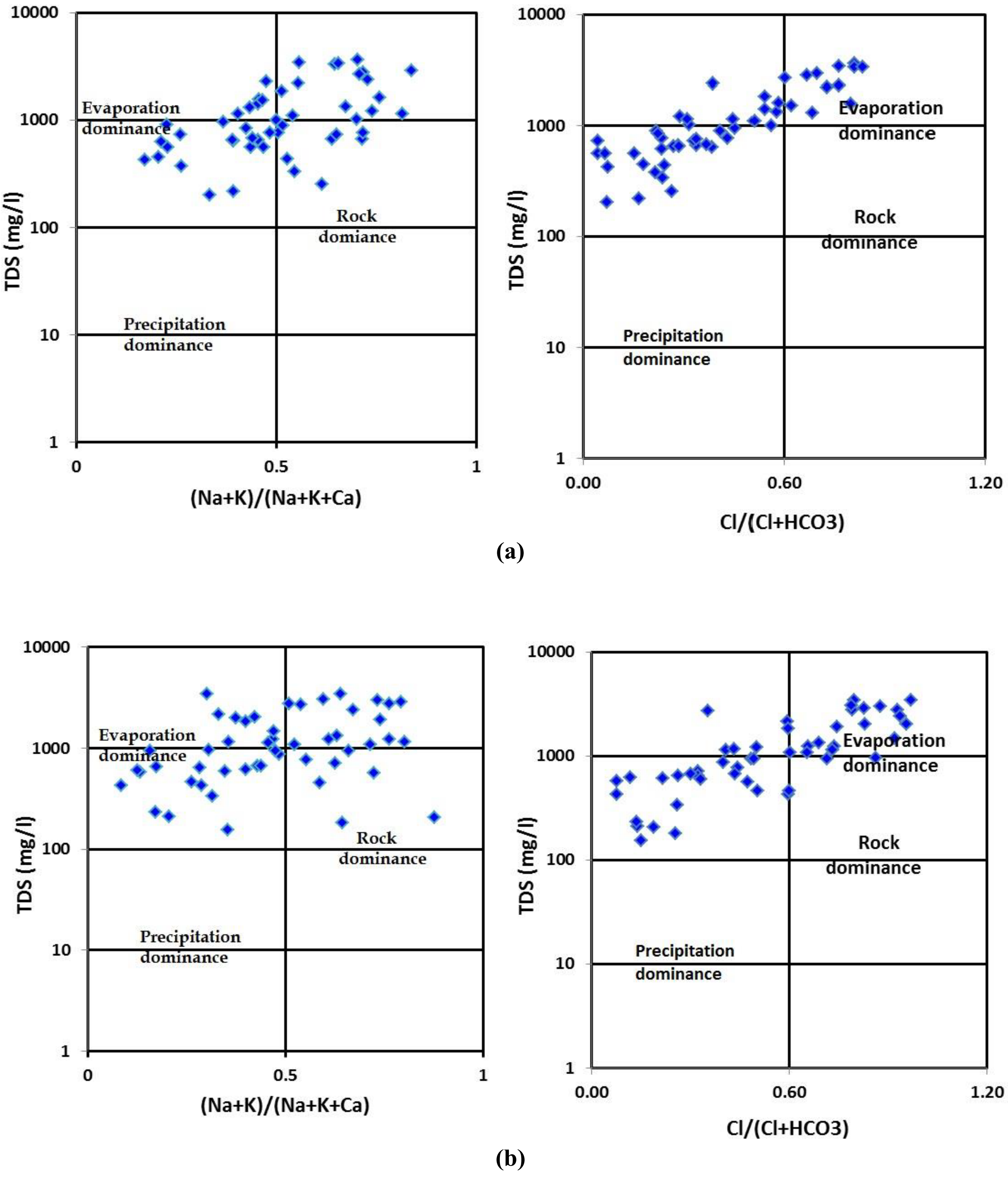


Figure 13: Gibbs plot for groundwater samples for (a) pre-monsoon and (b) post-monsoon periods.

In spite of the variation in their concentration from pre to post-monsoon periods, the majority of samples have values within the permissible limits. The major cations in groundwater distinctly exhibit decreasing order of their averages abundance as (Ca^{2+}>Mg^{2+}). Similarly anions also have varying concentrations from pre to post-monsoon periods. The concentration of anions in groundwater samples show variation from the northern to the southern part of the study area due to water logging where the study area was invaded by Ramappa lake. The anionic concentration is as SO_4^{2-} <Cl^-. Chloride is different from other anionic groups, since it is coherent with Na ion in the study area. Both ions are controlled by the extensive and intensive weathering of granite/gneisses that contain a lot of alkali and plagioclase feldspars, alkali amphiboles, micas apatite and fluorite minerals. Nitrates and Sulfates are affected by excess uses of fertilizers and organic material. Carbonates and bicarbonates in the study area are influenced by the precipitation and atmospheric conditions. The groundwater of the study area are classified on the basis of indices like Salinity index, SAR, KR, RSC, SSP, PI and WQI and different plots like Piper trilinear diagrams, Doneen diagrams, Wilcox diagrams and Gibb's plots for groundwater for the pre and post-monsoon period. The different physico-chemical parameters suggest that the majority of the groundwater samples are good for domestic as well as irrigation use. As per the Piper Tri-linear classification Class II and Class V are increased in pre-monsoon and decreased in post-monsoon, Class I and Class III are decreased in pre-monsoon and increased in post-monsoon and class IV is same in pre and post-monsoon. The majority of groundwater samples are suitable for irrigation as per Kelly's classification. The groundwater of the area are classified as having excellent to good permeability for irrigation on the basis of Doneen's permeability index. Based on Wilcox model, the majority of groundwater samples show low alkalinity hazard (S1) and high salinity hazard (C3) in pre to post-monsoon periods. Gibb's diagram suggests that the groundwater samples are of rock dominance type.

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References

1. Wolf L, Eiswirth M, Hötzl H (2006) Assessing sewer-groundwater interaction at the city scale based on individual sewer defects and marker species distributions. Environmental Geology 49: 849-857.
2. Dixit S, Gupta SK, Tiwari S (2005) Nutrient overloading of a freshwater lake in Bhopal, India. Electronic Green Journal 21: 2-6.
3. Jerry AN (1986) Basic environmental technology (water supply, waste disposal and pollution control). New York: Wiley.
4. Aksoy AO, Scheytt T (2007) Assessment of groundwater pollution around Torbali, Izmir, Turkey. Environmental Geology 53: 19-25.
5. Shivran HS, Dinesh KD, Singh RV (2006) Improvement of water quality though biological denitrification. J Environ Sci Eng 48: 57-60.
6. Rao NS, Subrahmanyam A, Kumar SR, Srinivasulu N, Rao GB, et al. (2012) Geochemistry and quality of groundwater of Gummanampadu sub-basin, Guntur District, Andhra Pradesh, India. Environ Earth Sci 67: 1451-1471.
7. Purushotham D, Prakash MR, Rao AN (2011) Groundwater depletion and quality deterioration due to environmental impacts in Maheshwaram watershed of R.R. District, AP (India). Environ Earth Sci 62: 1707-1721.
8. Bhardwaj V, Sen Singh D (2011) Surface and groundwater quality characterization of Deoria District, Ganga Plain, India. Environ Earth Sci 63: 383-395.
9. Suyash K, Pawar NJ (2011) Site-specific accentuation of heavy metals in groundwaters from Ankaleshwar industrial estate, India. Environ Earth Sci 64: 557-566.
10. Akbal F, Gurel L, Bahadir T, Guler I, Bakan G, et al. (2011) Water and sediment quality assessment in the mid-Black Sea coast of Turkey using multivariate statistical techniques. Environ Earth Sci 64: 1387-1395.
11. Sharma A, Singh AK, Kumar K (2012) Environmental geochemistry and quality assessment of surface and subsurface water of Mahi River basin, western India. Environ Earth Sci 65: 1231-1250.
12. Gupta S, Nayek S, Saha RN (2012) Major ion chemistry and metal distribution in coal mine pit lake contaminated with industrial effluents: constraints of weathering and anthropogenic inputs. Environ Earth Sci 67: 2053-2061.
13. Machender G, Ratnakar D, Narsimha Reddy M, Panduranga Reddy I (2014) Hydrochemical characteristics of surface water (SW) and Groundwater (GW) of the Chinnaeru River basin, northern part of Nalgonda District, Andhra Pradesh, India. Environ Earth Sci 71: 2885-2910.
14. Mohammad V (2012) A Comparison between Horizontal and Vertical Drainage Systems (Include Pipe Drainage, Open Ditch Drainage, and Pumped Wells) in Anisotropic Soils. IOSR Journal of Mechanical and Civil Engineering 4: 7-12.
15. Mohammad V (2012) Comparison of Surface Irrigation Simulation Models: Full Hydrodynamic, Zero Inertia, Kinematic Wave. Journal of Agricultural Science 4: 68-74.
16. Mohammad V (2013) Evolution of Irrigation-Equipped Areas as Share of Cultivated Areas. Irrigation Drainage System Engineering 2: 1.
17. Mohammad V (2013) Increasing Irrigation Efficiency by Management strategies: Cutback and Surge Irrigation. ARPN Journal of Agricultural and Biological Science 8: 35-43.
18. Mohammad V (2014) Handbook of Drainage Engineering Problems. Published by OMICS Group eBooks, 731 Gull Ave, Foster City. CA 94404, USA, pp: 1-126.
19. Mohammad V (2015) Handbook of Environmental Engineering Problems. Published by OMICS Group eBooks, 731 Gull Ave, Foster City, CA 94404, USA, pp: 1-77.
20. Yannopoulos SI, Gerasimos L, Nicolaos T, Wang Li, Valipour M, et al. (2015) Evolution of Water Lifting Devices (Pumps) over the Centuries Worldwide. Water 7: 5031-5060.
21. Khasraghi MM, Mohammad Ali GS, Valipour M (2015) Simulation of open and closed-end border irrigation systems using SIRMOD. Archives of Agronomy and Soil Science 61: 929-941.
22. CGWB (2007) Central Ground Water Board. Ground Water Information, Nalgonda district, Andhra Pradesh, pp: 1-41.
23. CGWB (2013) Central Ground Water Board. Ground Water Information, Warangal district, Andhra Pradesh, pp: 1-25.
24. APHA (1995) Standard methods for the examination of water and waste waters. 19th edn. American Public Health Association, Washington, DC.
25. Hem JD (1991) Study and interpretation of the chemical characteristics of natural water. US Geological Survey Water-Supply, 3rd edn, Scientific Public, Jodhpur.
26. Mandal S, Shiftan ZL (1981) Groundwater resource investigation and development. Academic Press Inc., New York, USA.
27. Huh Y, Tsoi MY, Zaitiser A, Edward JN (1998) The fluvial geochemistry of the river of Eastern Siberia-1 Tributaries of Lena river drainage the sedimentation platform of the Siberia Craton. Geochim Cosmochim Acta 62: 1657-1676.
28. BIS (1991) Specifications for drinking water IS: 1000:1991, Bureau of Indian Standards, New Delhi. In the soils of Tallinn (Estonia). Environ Geoche Health 22: 173-193.
29. WHO (1984) Guidelines for drinking water quality. Vol. 1. World Health Organization, Geneva.
30. Davis SN, Dewiest RJM (1967) Hydrogeology. Wiley, New York, USA.
31. Brown E, Skougstad MW, Fishman MJ (1970) In techniques of water resources investigations of US Geological Survey: Book 5 US Government Printing Office, Washington, DC.

32. Al Ahmadi ME (2013) Hydrochemical characteristics and evaluation of groundwater quality in Wadi As Sab'an, Western Saudi Arabia. International Journal of Scientific and Engineering 4: 1-10.

33. Handa (1969) Description and classification of media for hydrogeochemical investigations. Symposium on groundwater studies in arid and semi-arid region. Roorkee.

34. Kelly WP (1946) Permissible composition and concentration for irrigation waters. In: Proceedings of ASC, p: 607.

35. Paliwal KV (1967) Effect of gypsum application on the quality of irrigation water. Madras Agric J 59: 646-647.

36. Paliwal KV (1972) Irrigation with saline water. IARI, Monograph No. 2. New Science, New Delhi.

37. Wilcox LV (1955) Classification and use of irrigation water. US Department of Agriculture, Circular 969, Washington, DC.

38. USDA (1954) Diagnosis and improvement of saline and alkali soils. U.S. Salinity Laboratory Staff, Government Printing Office, Washington, D.C.

39. Doneen LD (1964) Notes on water quality in agriculture. Published as a water science and engineering paper 4001, Department of Water Science and Engineering, University of California.

40. Ramakrishnaiah CR, Sadashivaiah C, Ranganna G (2009) Assessment of water quality index for the groundwater in Tumkar Taluk, Karnataka State, India. E J Chem 6: 523-530.

41. Bhuven NT, Macwan JEM, Soni Chirag K (2011) Assessment of water quality index of small lake in south Gujarat region, India. In: Proceedings of ISEM-2011, Thailand.

42. Kushtagi S, Srinivas P (2012) Studies on chemistry and water quality index of ground water in Chincoli Taluk, Gulbarga district, Karnataka, India. Int J Environ Sci 2: 1154-1160.

43. Piper AM (1944) A graphical procedure in the geochemical interpretation of water analysis. Trans Am Geophys Union 25: 914-923.

44. Todd DK (2001) Groundwater hydrology. Wiley, Canada, pp: 280-281.

45. Walton WC (1970) Groundwater resources evaluation. McGraw-Hill Book Co., New York, USA.

46. Rechards LA (1954) Diagnosis and improvement of saline and alkali soils, Agricultural Handbook 60. US Department of Agriculture, Washington, DC.

47. Singh AK, Tewary BK, Sinha A (2011) Hydrochemistry and quality assessment of groundwater in part of NOIDA metropolitan city, Uttar Pradesh. J Geol Soc India 78: 523-540.

48. Gibbs RJ (1970) Mechanism controlling water world chemistry. Science 170: 1088-1090.

49. Reddy Sugreeva AG, Reddy DV, Rao PN, Murthy Prasad K (2010) Hydrogeochemical characterization of fluoride rich groundwater of Wailpalli watershed, Nalgonda District, Andhra Pradesh, India. Environ Monit Assess 171: 561-577.