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Groundwater Quality for Irrigation Purposes and Classification for Hydrochemical Facies in Parts of Southern Ijaw Local Government Area, Bayelsa State, Nigeria

Adline Nimi Peterside[1], Aduabobo Ibitoru Hart[1,2], Hycienth Ogunka Nwankwoala[3*]

[1]Institute of Natural Resources, Environment and Sustainable Development, University of Port Harcourt, Nigeria
[2]Department of Animal and Environmental Biology, University of Port Harcourt, Nigeria
[3]Department of Geology, University of Port Harcourt, Nigeria
Email: *nwankwoala_ho@yahoo.com

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Abstract

As a result of economic development and rapid growth of the population in Southern Ijaw Local Government Area of Bayelsa State, Nigeria, there have been clear changes in the use of land, resulting in increased demand for water for various uses including agricultural activities. This study examined groundwater quality and classification of hydrochemical facies of communities in the study area. Fifteen (15) communities within the LGA were selected and groundwater from hand-dug well (HDW-15 samples) and borehole (BH-15 samples) was sourced during the wet season (July) and dry season (March) and analyzed for seasonal variation, irrigation purposes and hydrochemical facies classification using a standard method. Based on Sodium Adsorption Ratio (SAR) classification scheme, all groundwater sources in the area are excellent for irrigation purposes because they all have SAR values <3. This implies that SAR values of <3 will not threaten vegetation. The value of sodium percentage (Na%) ranges from 29.81% to 66.13% and 23.30% to 71.89% for hand dug wells in both wet and dry seasons. Similarly, the value of Na% ranged from 3.57% to 16.32% and 3.38% to 19.60% for borehole water in both wet and dry seasons. The groundwater hydrochemistry facies analysis indicated that there was an adjustment in groundwater chemistry during dry season while HDW and BH are linked to different sources. Groundwater in the communities are contaminated for both sources and season; however, showed potential for irrigational purpose. There is a need for continuous monitoring of the water quality, improvement in environmental and sanitation practices while treatment of water is strongly advised.

Keywords

Groundwater Quality, Boreholes, Hand Dug Well, Facies, Irrigation, Seasonal Variation

1. Introduction

Globally, groundwater is one of the most precious sources of natural resources. Groundwater contributes to 80% of rural domestic water needs and 50% of urban water needs. According to World Health Organization [1] [2] [3], 80% of diseases in human beings are caused by water. Problems associated with groundwater exploitation include the following: declining water tables, wells running dry (seasonality) increasing pumping costs, competitive deepening of wells, groundwater subsidence, loss of wetland and flowing springs and rivers, salt water intrusion, groundwater degradation from natural toxins (fluoride and arsenic, spreading or leaking of anthropogenic used substances from point and non-point sources [3] [4] [5].

Groundwater is the major source of drinking water, irrigation, and other domestic activities such as washing, bathing, etc. in the Niger Delta region of Nigeria. Groundwater is in abundance and readily available in the above mentioned part of Nigeria, however, the quality of the water cannot be visually ascertained unless it is analyzed in the laboratory and compared with relevant standards like World Health Organization [1] and Nigeria Standard for Water Quality [6]. The activities of human beings can alter the underground water quality during any of the stages of hydrologic or water cycle which comprises precipitation, surface run-off, infiltration, percolation, evaporation, and transpiration [7]. Infiltration of water through underground rocks, and soil may pick-up natural contaminants even with no human activity or pollution in the area.

The problem of over-exploitation of water resources arising from increasing demand will lead to several future problems in many countries in the world, especially in arid and semi-arid areas. In recent decades, as a result of economic development and rapid growth of the population, there have been clear changes in the use of land, resulting in increased demand for water for various civil, industrial and agricultural activities [8] [9] [10] [11] [12]. As a result of this demand, there is equally an increased pressure on agricultural production coupled with the limited area of land suitable for agriculture, as well as the reduction in the quantity and quality of water for irrigation [10]. This study therefore examined groundwater quality for irrigation purposes and hydrochemical classification of communities in Southern Ijaw Local Government Area of Bayelsa State, Nigeria.

1.1. Description of Study Area

The study area is Southern Ijaw Local Government Area in Bayelsa State, Nigeria. The area lies within Longitude 6˚00'10"N and 6˚25'15"N and Latitude

4°40'07"E and 5°5'20" (**Figure 1**). It is bounded by Ekeremor Local Government in the West, Sagbama in the North-West, Yenegoa and Kolokuma/Opokuma Local Government areas in the north, then in the north-east, it is bounded by Ogbia Local Government area, Brass and Nembe Local Government in the east and finally in the southern axis by the Atlantic ocean.

1.2. Geology and Hydrogeology of the Study Area

The geology of the Niger Delta has been described in detail by various authors [13] [14]. The formation of the Delta started during Early Paleocene and resulted mainly from the buildup of fine grained sediments eroded and transported by the River Niger and its tributaries. The Tertiary Niger Delta is a sedimentary structure formed as a complex regressive off-lap sequence of clastic sediments ranging in thickness from 9000 m - 12,000 m [15]. Starting as separate depocenters, the Niger Delta has coalesced to form a single united system since Miocene. The Niger Delta is a large and ecologically sensitive region, in which various water species including surface and sub-surface water bodies exist in a state of dynamic equilibrium [15] [16]. The Niger Delta is stratified by three lithologic successions; Benin Formation, Agbada Formation and Akata Formation.

The Niger Delta has two most critical aquifers, Deltaic and Benin Formations [17]. With a regularly dendritic waste system, the very penetrable sands of the Benin Formation enable simple penetration of water to revive the shallow aquifers [18] [19]. The aquifers are an arrangement of various aquifer frameworks stacked on one another with the unconfined upper aquifers happening at the best [16] [20] [21].

The recharge of aquifers is immediate from invasion of precipitation, the yearly aggregate of which shifts between 5000 mm at the drift to about 2540 mm landwards. Groundwater in the zone happens in shallow aquifers of overwhelmingly mainland deposits experienced at penetrations of somewhere in the range of 45 m and 60 m. The lithology contains a blend of sand in a fining up arrangement, rock and mud. Well yield is phenomenal, with generation rates of 20,000 liters/hour normal and borehole achievement rate is typically high [22]

2. Methods of Study

2.1. Data Sampling/Collection

The water samples for the study were collected during the dry season (March) and wet season (July) from borehole and hand-dug well groundwater sources around the study area. Specifically, water samples were collected from borehole (15) and groundwater (15) during the dry season and the process was repeated during wet season which implies that a total of sixty (60) samples were collected for the study during both seasons. In order to prevent confusion and mixed up of the water sample, each sample will be tagged according to their sources, and the season they represent and with Roman figure to represent the position of the sample as presented.

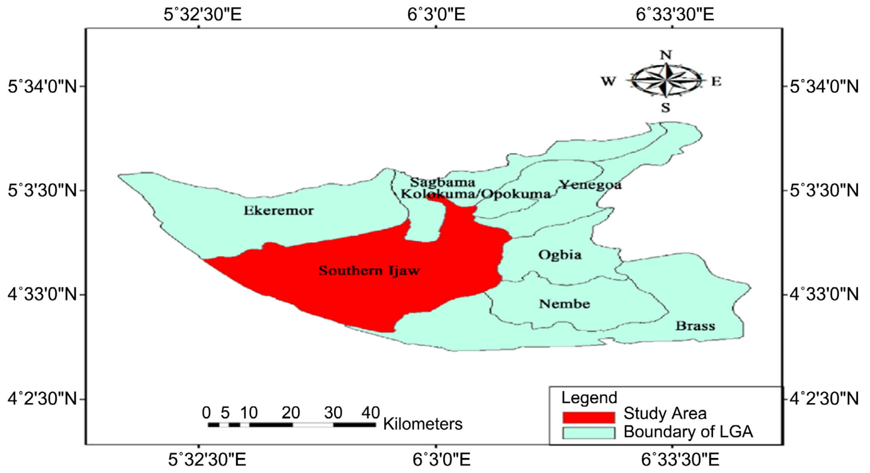

Figure 1. Overview of the study area.

1) Borehole (BH) Water during Wet Season (WS) = BHWS I-XIV;

2) Borehole (BH) Water during Dry Season (DS) = BHDS I-XIV;

3) Hand-dug well (HDW) Water during Wet Season (WS) = HDWWS I-XIV;

4) Hand-dug well (HDW) Water during Dry Season (DS) = HDWDS I-XIV.

With the aid of labeled lucid bottle, water samples were collected from various designated water source. Prior to the water collection the lucid bottles were cleaned with 70% sterilizer in order to prevent impurities and other forms of contamination. Afterwards, the water samples were collected from each designated point and the bottles were fully filled. Thereafter, the filled bottles were immediately placed in the ice-parked cooling medium to arrest continuous microbial activities and preserve the water before being taken to the laboratory for analysis.

2.2. Data Analysis

The collected water samples were transported to the laboratory analysis and all the analyses were carried out by Geospectra Engineering Services Limited, Port Harcourt using standard protocol for laboratory analysis. All parameters were analyzed using the standard laboratory method in accordance with the APHA and other analyses were presented in Table 1.

3. Results and Discussion

3.1. Groundwater Quality for Irrigation Purposes

Assessment of groundwater quality for irrigation was accomplished using SAR, MAR, KR, Na% and Potential salinity (PS). The results of SAR recorded for HDW and BH in wet and dry seasons were all <3. Classification of groundwater having SAR value <10 as excellent for irrigation purposes are described by Richards [23]. Based on SAR classification scheme, all groundwater sources in the area are excellent for irrigation purposes because they all have SAR values <3. This implies that SAR values of <3 will not threaten vegetation while values above 12.0 are considered sodic and will threaten plant survival by increasing soil swell potential and reducing permeability of soil [24].

Table 1. Analytical methods used for groundwater samples analysis.

Analysis	Parameter	Symbol	Unit	Type of Test	Laboratory Standard
Physio-Chemical	pH	pH		In-situ	APHA 4500-H^+B
	Total Dissolved Solids	TDS	mg/L	In-situ	APHA 2540C
	Electrical Conductivity	EC	uS/cm	In-situ	APHA 2510B
	Sodium	Na	mg/L	Laboratory	APHA 3111B
	Calcium	Ca	mg/L	Laboratory	APHA 3111D
	Magnesium	Mg	mg/L	Laboratory	APHA 3111B
	Potassium	K	mg/L	Laboratory	APHA 3111B
	Sulphate	SO4	mg/L	Laboratory	APHA 4500/SO_4-E
	Nitrate	NO_3	mg/L	Laboratory	APHA 4500/NO_3-E
	Chloride	Cl	mg/L	Laboratory	APHA 3111B
	Bicarbonate	HCO_3	mg/L	Laboratory	APHA 3111B
Biological	Total Coliform	TC	(MPN/100ml)	Laboratory	APHA 9221C
Heavy Metals	Iron	Fe	mg/L	Laboratory	APHA 3111B
	Zinc	Zn	mg/L	Laboratory	APHA 3111B
	Manganese	Mn	mg/L	Laboratory	APHA 3111B
	Chromium	Cr	mg/L	Laboratory	APHA 3111D
	Lead	Pb	mg/L	Laboratory	APHA 3111B
	Cadmium	Cd	mg/L	Laboratory	APHA 3111B
	Copper	Cu	mg/L	Laboratory	APHA 3111B

The value of sodium percentage (Na%) ranges from 29.81% to 66.13% and 23.30% to 71.89% for hand dug wells in both wet and dry seasons. Similarly, the value of Na% ranged from 3.57% to 16.32% and 3.38% to 19.60% for borehole water in both wet and dry seasons. Wilcox [25] classifies groundwater suitability for irrigation as follows; Excellent (<20), Good (>20 - 40), Permissible (>40 - 60), Doubtful (>60 - 80) and Unsuitable (>80). Based on this classification, groundwater obtained from boreholes during wet and dry seasons are excellent for irrigation purposes. Meanwhile, the irrigational quality of groundwater obtained from hand dug wells varies from good to permissible to doubtful. Based on sodium percentage, groundwater obtained from boreholes is more suitable for irrigation than groundwater obtained from hand dug wells.

The presence of magnesium in groundwater in high proportions will reduce the overbearing effect of sodium in groundwater. Excess magnesium in water affects the soil by making it alkaline and results in decreased crop yield. Based on Raghunath [26] classification scheme for irrigation water quality, all groundwater obtained from boreholes in the area has non-acceptable quality for irrigational use, having MAR value exceeding 50. Majority of groundwater obtained from hand dug wells in both wet and dry seasons have acceptable irrigation water quality. Only 2 hand dug wells in the wet season and 1 hand dug well in the dry season revealed non-acceptable irrigational water quality.

Kelly's Ratio (KR) was also used for classifying water for irrigation purposes. A KR > 1 shows an excess of sodium and KR < 1 shows its deficit in water [27]. Water with KR < 1 is suitable for irrigation while those with greater ratios are unsuitable [28]. Based on KR, all groundwater obtained from boreholes are unsuitable for irrigation (having KR values >1.0) whereas all hand dug wells have groundwater quality suitable for irrigation (having KR values <1.0). Salinity Potential in groundwater from the study area ranges from 0.33 to 2.83 and from 0.09 to 2.40 for hand dug wells in both wet and dry seasons. Similarly, the value of Salinity Potential ranged from 0.05 to 0.58 and from 0.09 to 2.10 for borehole water in both wet and dry seasons. Salinity potential < 5.0 suggests that groundwater is good to excellent for irrigation purposes. Based on Salinity Potential index, these results are within the classification of good to excellent waters for irrigation purposes. **Table 2** shows groundwater quality models for irrigation purposes while **Table 3** shows results of interpretation for various irrigation water quality models utilized in this study.

Table 2. Groundwater quality models for irrigation purposes.

HDW	SAR	MAR	KR	Na%	PS	SAR	MAR	KR	Na%	PS	Borehole	SAR	MAR	KR	Na%	PS	SAR	MAR	KR	Na%	PS
	Wet Season					Dry Season						Wet Season					Dry Season				
L1 W	0.66	26.49	0.30	53.48	1.04	0.79	39.81	0.39	40.88	2.40	**L1B**	2.42	84.71	2.99	3.75	0.05	2.03	89.47	2.03	3.38	0.09
L2W	0.54	44.65	0.29	40.57	1.59	0.86	45.69	0.58	31.86	1.49	**L2B**	2.01	75.58	1.97	8.06	0.06	2.07	76.29	2.01	7.64	0.55
L3W	0.77	29.03	0.35	47.94	0.52	0.57	19.38	0.20	62.85	1.50	**L3B**	2.22	68.10	2.14	10.02	0.26	2.35	76.21	2.26	7.19	0.65
L4W	0.59	23.34	0.22	59.33	1.01	0.58	21.76	0.20	61.92	1.60	**L4B**	1.93	81.16	1.60	7.07	0.55	1.85	83.90	1.54	6.13	2.10
L5W	0.59	39.66	0.32	45.45	0.39	0.74	27.21	0.41	48.63	0.44	**L5B**	1.33	65.37	1.05	16.32	0.05	1.56	54.61	1.24	19.60	0.61
L6W	0.57	43.72	0.38	38.28	1.09	0.58	35.64	0.30	46.14	1.03	**L6B**	1.49	80.52	1.39	7.54	0.29	1.65	61.17	1.58	13.94	0.80
L7W	0.59	17.85	0.23	65.93	0.92	0.98	38.36	0.75	34.69	0.13	**L7B**	1.46	69.42	1.50	11.67	0.13	1.57	67.02	1.51	12.54	0.82
L8W	0.84	56.66	0.41	29.81	0.76	0.53	20.60	0.18	63.79	0.99	**L8B**	1.85	72.93	2.03	8.57	0.12	2.07	65.40	2.33	9.98	0.82
L9W	0.65	18.93	0.34	57.75	0.61	0.72	24.07	0.34	53.68	0.78	**L9B**	1.57	62.64	1.31	15.61	0.07	1.75	61.55	1.43	15.36	0.11
L10W	0.67	18.22	0.27	61.93	1.08	0.62	17.64	0.23	63.71	1.44	**L10B**	2.51	68.60	2.86	7.68	0.05	2.68	68.75	2.99	7.44	0.70
L11W	0.74	16.13	0.36	59.57	2.83	0.64	27.99	0.25	53.21	0.46	**L11B**	2.10	70.62	2.40	8.46	0.29	1.66	82.63	1.43	6.94	0.14
L12W	0.39	20.98	0.15	66.13	0.43	0.80	24.18	0.38	51.82	0.09	**L12B**	2.28	72.62	2.36	7.87	0.11	1.80	67.68	1.35	13.04	0.18
L13W	0.69	54.55	0.33	33.08	1.43	0.98	60.39	0.60	23.30	0.60	**L13B**	1.76	69.27	1.33	13.09	0.58	2.07	66.01	1.94	11.20	0.49
L14W	0.71	48.26	0.38	37.25	0.39	0.46	13.13	0.16	71.89	1.59	**L14B**	1.65	89.85	1.63	3.57	0.10	2.02	87.05	2.22	3.94	0.45
L15W	0.97	47.09	0.60	32.02	0.33	0.83	32.61	0.43	44.44	0.84	**L15B**	2.05	66.23	2.03	10.73	0.17	1.64	75.59	1.38	9.89	0.83
Minimum	0.39	16.13	0.15	29.81	0.33	0.46	13.13	0.16	23.30	0.09	**Minimum**	1.33	62.64	1.05	3.57	0.05	1.56	54.61	1.24	3.38	0.09
Maximum	0.97	56.66	0.60	66.13	2.83	0.98	60.39	0.75	71.89	2.40	**Maximum**	2.51	89.85	2.99	16.32	0.58	2.68	89.47	2.99	19.60	2.10
Average	0.66	33.70	0.33	48.57	0.96	0.71	29.90	0.36	50.19	1.03	**Average**	1.91	73.17	1.91	9.33	0.19	1.92	72.22	1.82	9.88	0.62

Key: Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), Magnesium Adsorption Ratio (MAR), Kelly's Ratio (KR) and Potential Soil Salinity (PS).

Table 3. Results interpretation for various irrigation water quality models utilized in this study.

Classification scheme	Categories	Range (mg/L)	Number of samples			
			Hand Dug Well (Wet Season)	Hand Dug Well (Dry season)	Borehole (Wet Season)	Borehole (Dry season)
Sodium adsorption ratio (SAR)	Excellent	<10	15	15	15	15
	Good	>10 - 18	Nil	Nil	Nil	Nil
	Fair	>18 - 26	Nil	Nil	Nil	Nil
	Poor	>26	Nil	Nil	Nil	Nil
	Hard	>200 - 300	Nil	Nil	Nil	Nil
	Very hard	>300	Nil	Nil	Nil	Nil
Sodium Percentage (Na%)	Excellent	<20	Nil	Nil	15	15
	Good	>20 - 40	5	3	Nil	Nil
	Permissible	>40 - 60	7	7	Nil	Nil
	Doubtful	>60 - 80	3	5	Nil	Nil
	Unsuitable	>80	Nil	Nil	Nil	Nil
Magnesium adsorption ratio (MAR)	Acceptable	<50	13	14	Nil	Nil
	Non-acceptable	>50	2	1	15	15
Kelly's ratio (KR)	Suitable	<1	15	15	Nil	Nil
	Unsuitable	>1	Nil	Nil	15	15
Potential soil salinity (PS)	Excellent to good	<5	15	15	15	15
	Good to injurious	>5 - 10	Nil	Nil	Nil	Nil
	Injurious to Unsatisfactory	>10	Nil	Nil	Nil	Nil

3.2. Groundwater Quality Classification for Hydro-Chemical Facies

Groundwater classification and typing were achieved using Piper [29] [30], and Durov diagrams. Piper's tri-linear diagram [29] is most widely used to understand the hydrochemistry of any area. Piper's diagram is a major key to the identification and classification of rock-water interaction, solution kinetics, geology and sources of contamination in groundwater [31]. Three water classes were recognized in groundwater from hand dug wells during the wet season which include: Field D (Earth alkaline water with excessive alkali concentration with prevailing bicarbonate), Field A (Normal earth alkaline water with prevailing bicarbonate), Field E ((Earth alkaline water with excessive alkali concentration with prevailing sulphate or chloride). Two additional water classes were recorded for groundwater obtained from hand dug wells during dry season and include; Field B (Normal earth alkaline water with prevailing bicarbonate, sulphate or chloride), Field C (Normal earth alkaline water with prevailing sulphate or chloride). These results show there was an adjustment in groundwater chemistry during dry season. Meanwhile, for groundwater obtained from boreholes in wet and dry season, 2 water classes were identified and include: Field F (Alkali water with prevailing bicarbonate), and Field G (Alkali water with prevailing Sulphate-Chloride). This result shows that groundwater obtained from hand dug wells and those obtained from boreholes are from significantly different sources.

On the Durov plot, the results obtained from hand dug wells during dry season shows significant adjustments in groundwater chemistry. Groundwater obtained from boreholes all plotted in Field 8 and 9 for both wet and dry seasons respectively. According to Lloyd and Heathcoat [32] water classification scheme based on Durov plot, Field 1and 2 is HCO_3 and Ca rich waters, Field 3 is HCO_3 and Na rich waters, Field 4 is Ca and SO_4 rich waters, Field 5 has no dominant anion or cation, Field 6 is SO_4 and Na rich waters, Field 7, 8 and 9 is Na and Cl rich waters.

Stiff [30] diagram classifies groundwater quality on the basis on similarity in shape. Water of similar quality has a distinctive shape. The diagram is plots cations on the left and anions on the right-hand side. Two distinct water types were distinguished from the stiff plots for hand dug wells in the wet season and include: Ca-HCO_3 rich water (L1W, L2W, L3W, L4W, L5W, L6W, L7W, L9W, L10W, L11W, L12W and L14W) and Mg-HCO_3 rich water (L8W, L13W and L15W) (**Figrue 1**). In the dry season, 3 distinct hand dug well water types were identified and include: Ca-HCO_3 rich water (L1W, L3W, L4W, L5W, L6W, L8W, L9W and L12W), Ca-Cl rich water (L10W, L11W, L14W and L15W) and Na+K-HCO_3 rich water (L2W, L7W and L13W) (**Figrue 1**). Only 2 water types were recognized in groundwater obtained from boreholes. **Figures 2-5** show the Piper Trilinear diagrams while **Figures 6-9** show the Durov diagrams. **Figures 10-13** show the Stiff diagrams and distinct shapes of the groundwater in both seasons.

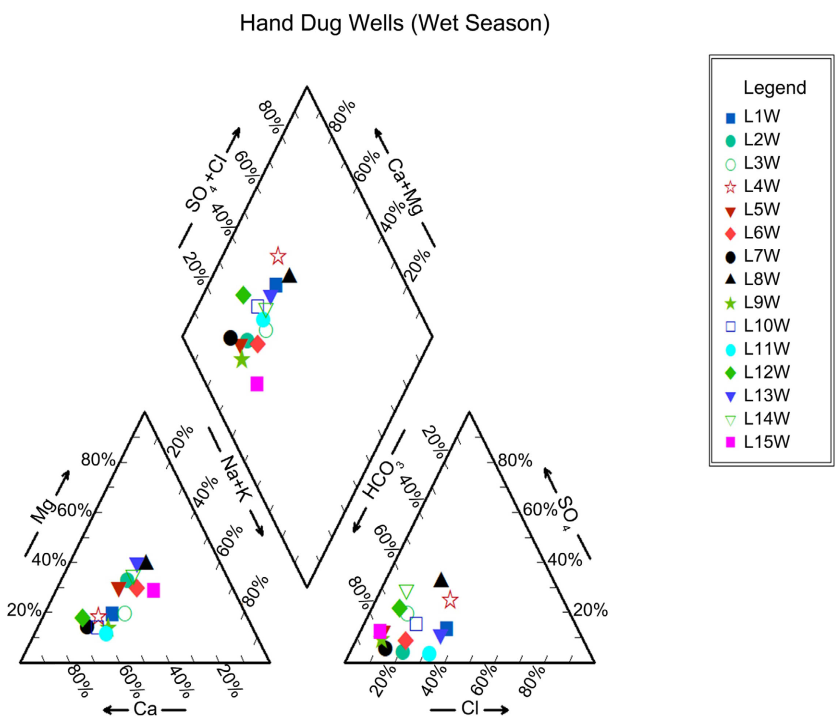

Figure 2. Piper trilinear diagram showing groundwater hydrochemical facies in hdw during wet season.

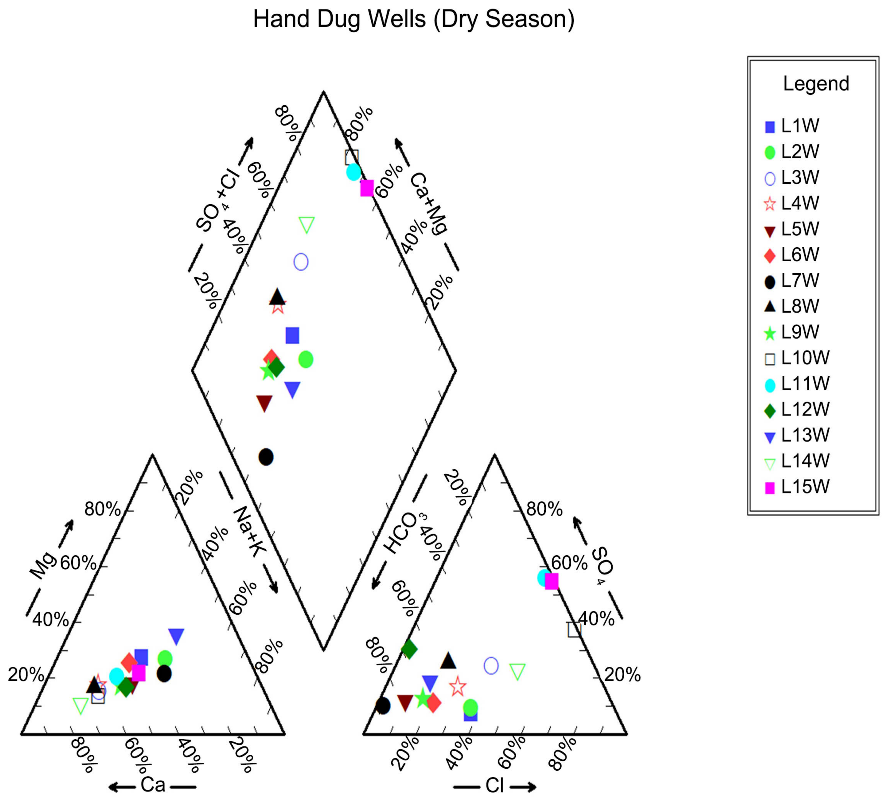

Figure 3. Piper trilinear diagram showing groundwater hydrochemical facies in HDW dry season.

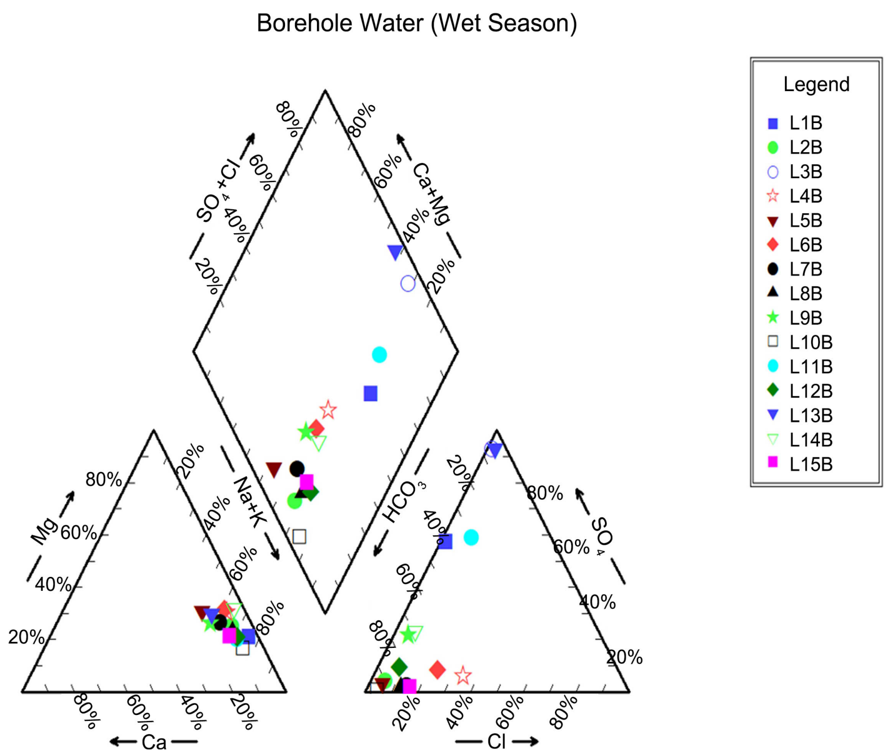

Figure 4. Piper trilinear diagram showing groundwater hydrochemical facies in BH wet season.

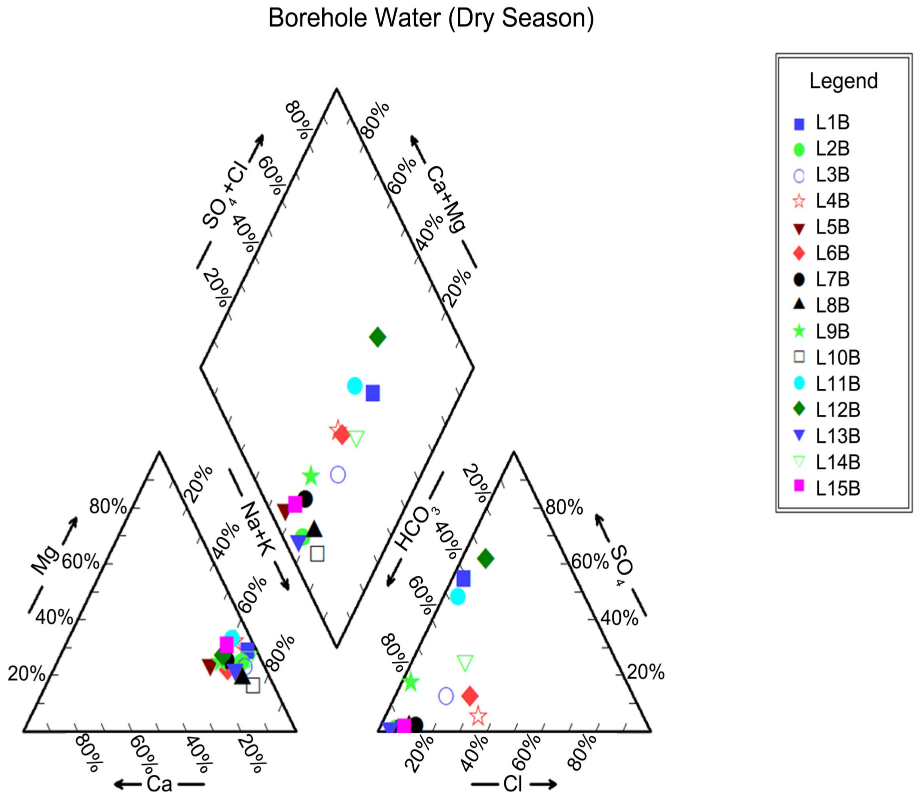

Figure 5. Piper trilinear diagram showing groundwater hydrochemical facies in BH dry season.

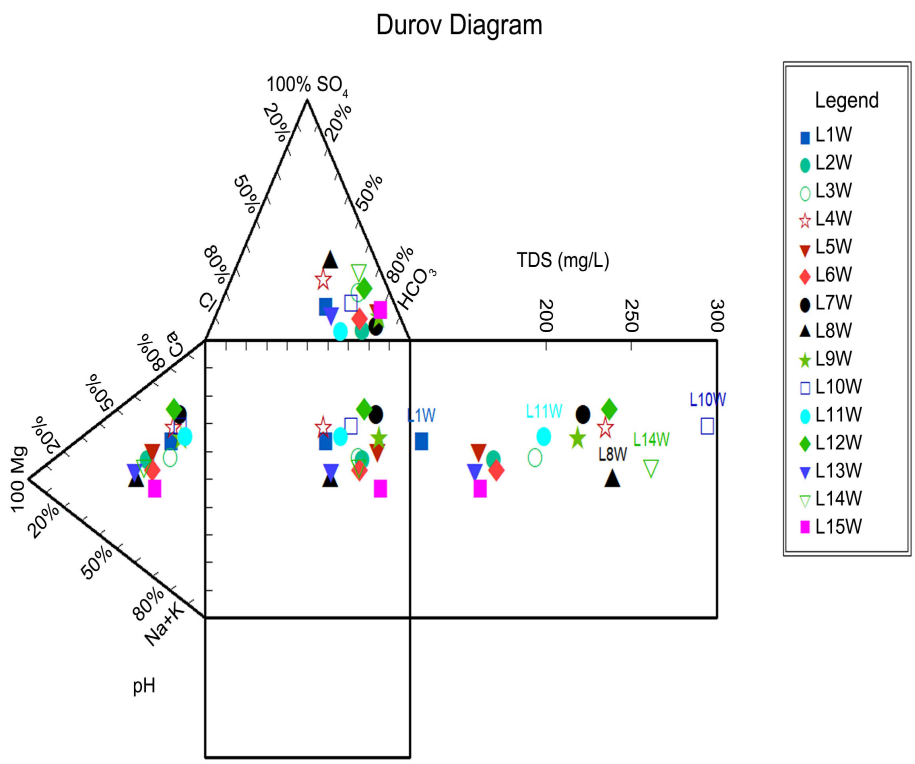

Figure 6. Durov plot depicting hydrochemical processes acting on groundwater sources in HDW during wet season.

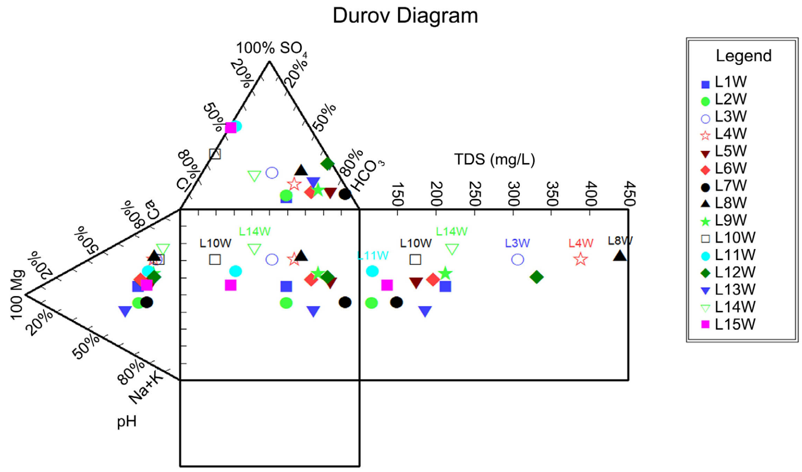

Figure 7. Durov plot depicting hydrochemical processes acting on groundwater sources in HDW during dry season.

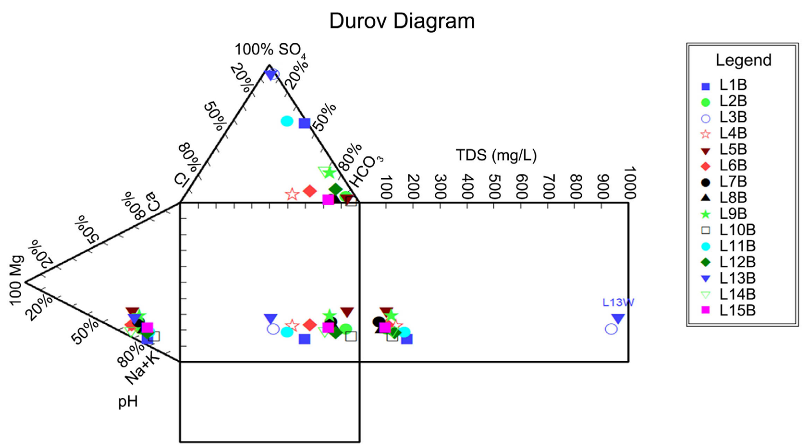

Figure 8. Durov plot depicting hydrochemical processes acting on groundwater sources in BH during wet season.

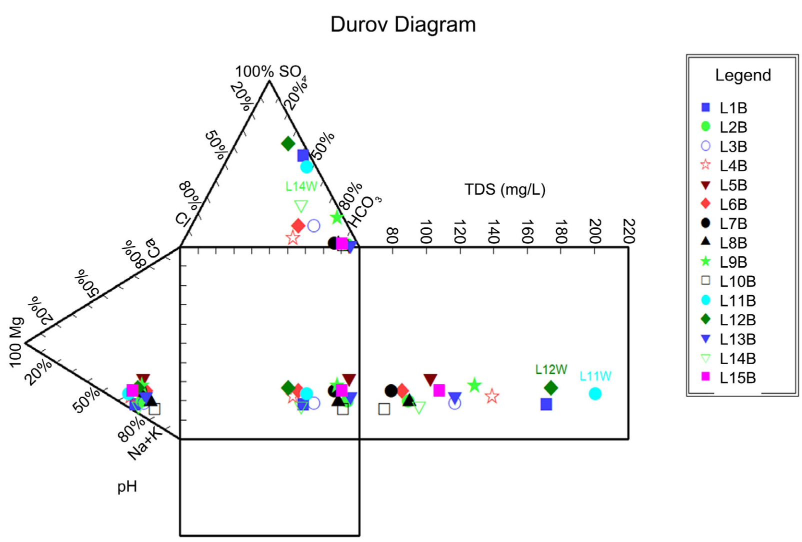

Figure 9. Durov plot depicting hydrochemical processes acting on groundwater sources in BH during dry season.

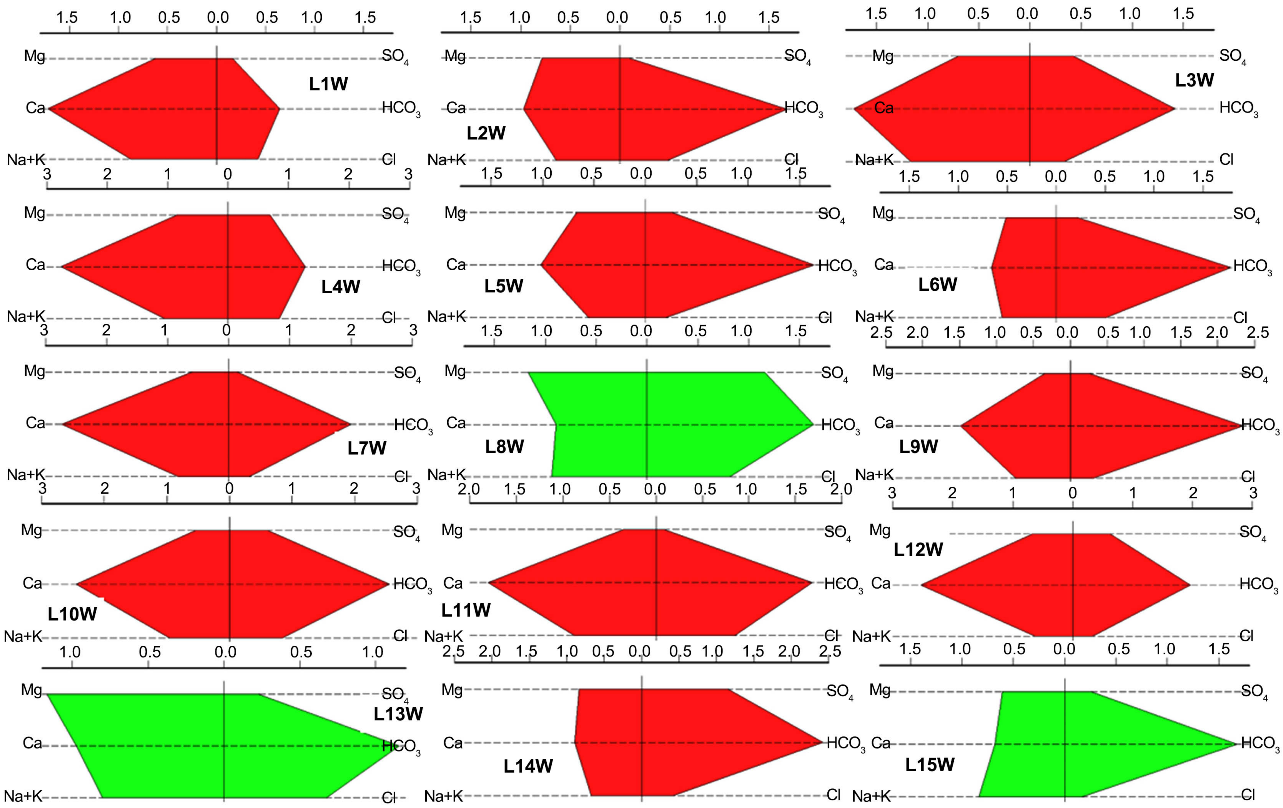

Figure 10. Stiff diagrams of distinct shapes for groundwater from HDW during the wet season.

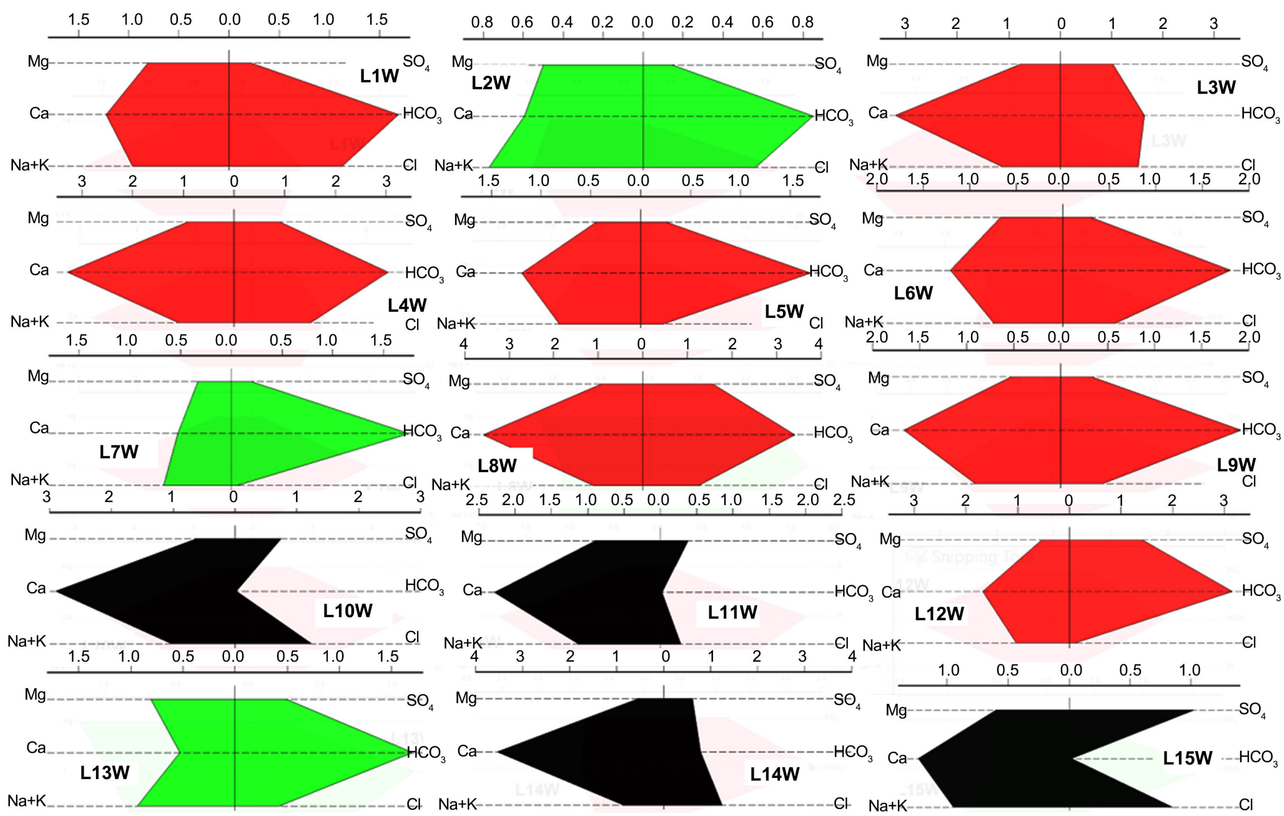

Figure 11. Stiff diagrams of distinct shapes for groundwater from HDW during the dry season.

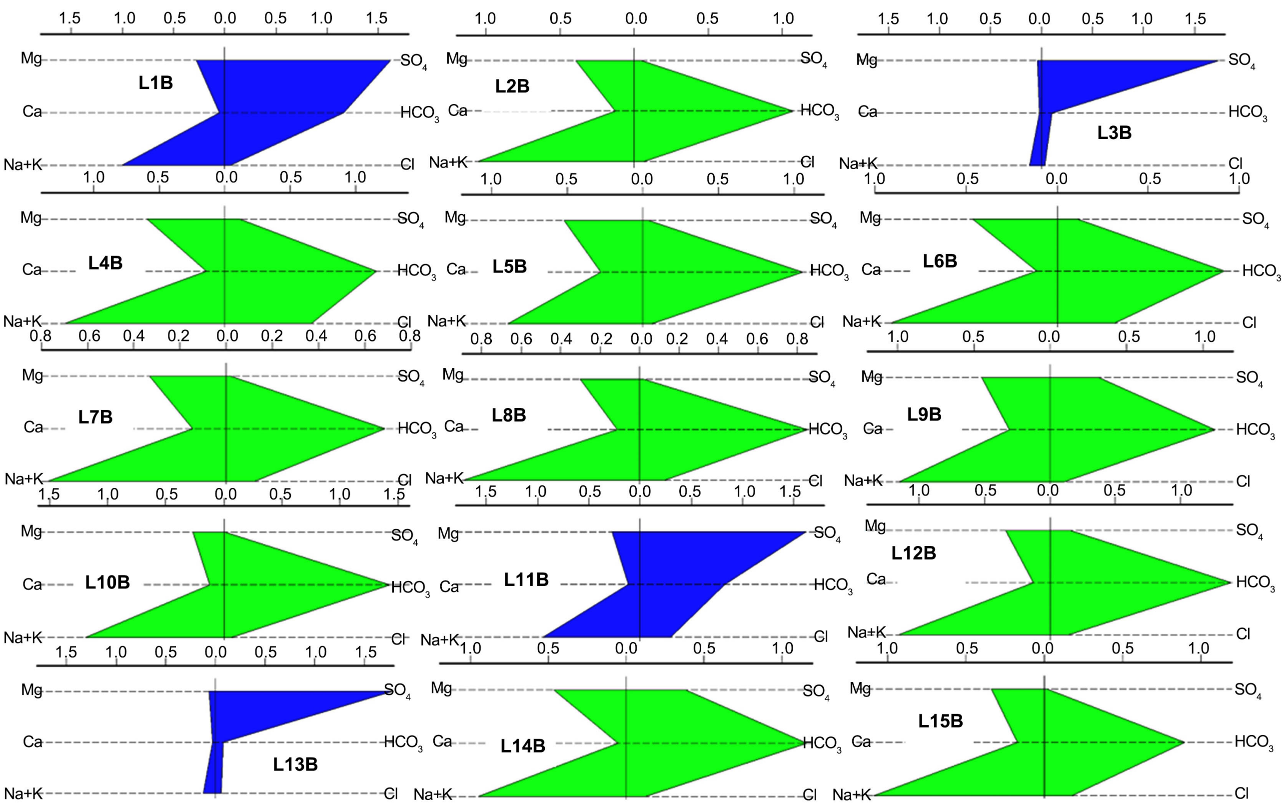

Figure 12. Stiff diagrams of distinct shapes for groundwater from BH during the wet season.

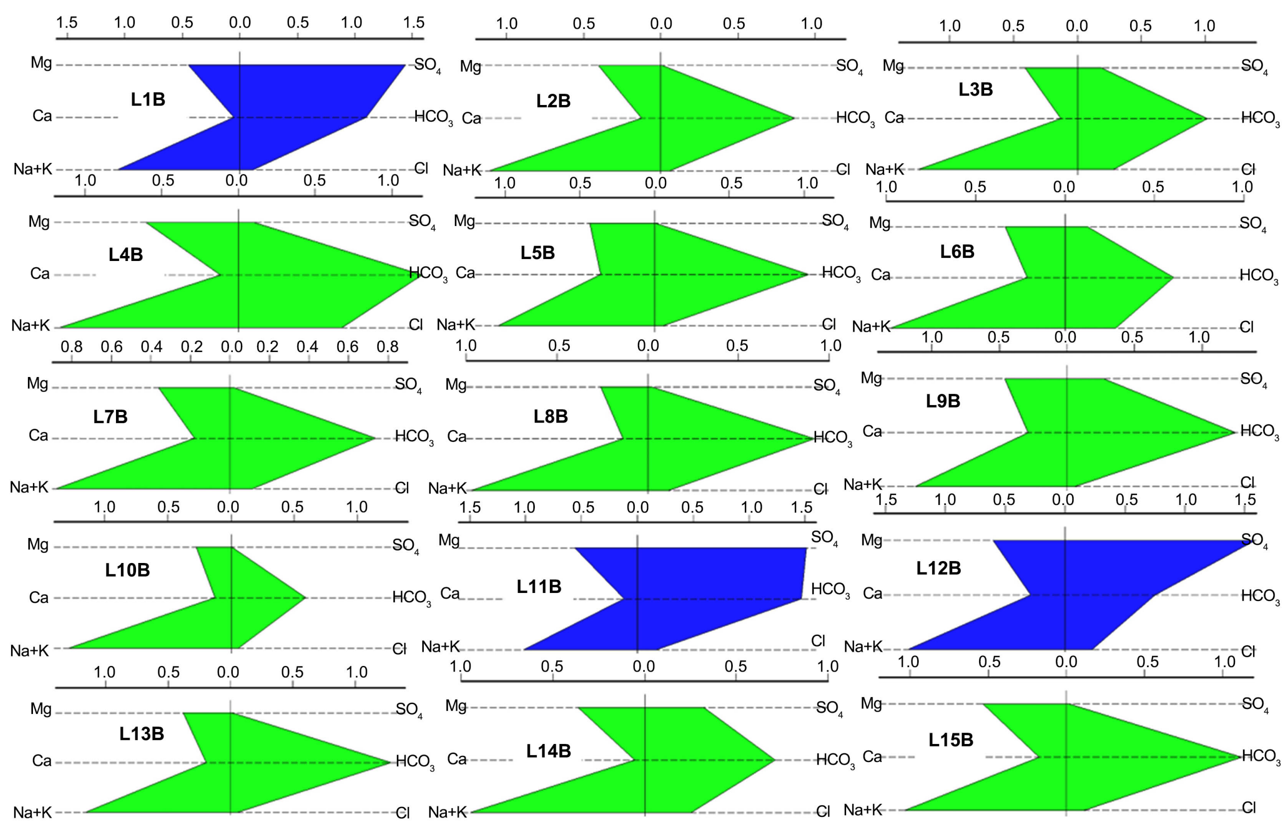

Figure 13. Stiff diagrams of distinct shapes for groundwater from BH during the dry season.

4. Conclusions

1) Based on SAR classification scheme, all groundwater sources in the area are excellent for irrigation purposes because they all have SAR values <3 indicating that such a purpose will not threaten vegetation.

2) Based on Na% classification, groundwater obtained from BH during wet and dry seasons are excellent for irrigation purposes. Meanwhile, the irrigational quality of groundwater obtained from HDW varies from good to permissible to doubtful.

3) MAR classification indicated all groundwater obtained from BH in the area has a non-acceptable quality for irrigational use while most groundwater obtained from HDW in both wet and dry seasons has acceptable irrigation water quality.

4) Based on KR, all groundwater obtained from BH are unsuitable for irrigation (having KR values >1.0) whereas all HDW has groundwater quality suitable for irrigation (having KR values <1.0).

5) Salinity Potential in groundwater from both BH and HDW indicated well to excellent waters for irrigation purposes.

6) The groundwater hydrochemistry facies analysis indicated that there was an adjustment in groundwater chemistry during dry season. Also, the groundwater obtained from HDW and those obtained from BH are from significantly different sources.

Suggested Further Studies

To alleviate the challenges of food insecurity in the country, irrigation farming must be given serious attention. Irrigation practices have been known to enhance food security, promote economic growth and sustainable development, create employment opportunity, improve living conditions of small scale farmers, and recharge subsurface water level. Regular monitoring of the irrigation index and modeling of the hydro-chemical facies for establishment of water type(s) trends in the area is very necessary to achieve sustainable food security in the nearest future.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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