Impact Assessment Due to Geochemical Effects on the Quality of Groundwater along the Bay of Bengal of Visakhapatnam District, Andhra Pradesh, India

Sowjanya Pasupureddi[1*] and B. B. V. Sailaja[1]

[1]*Department of Inorganic and Analytical Chemistry, Andhra University, Visakhapatnam, AP, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors were equally involved in the design, review of literature, collection and analysis of the data. Both authors read and approved the final manuscript.

Article Information

Original Research Article

ABSTRACT

Aims: The present study was aimed at finding the geomorphological impacts on the quality groundwater quality along the Bay of Bengal of Visakhapatnam district of Andhra Pradesh, India.
Study Design: Groundwater samples were collected and assessed for the identification of various geochemical impacts on the quality of groundwater along the coast.
Place and Duration of Study: Groundwater samples along the coast of Bay of Bengal of Visakhapatnam district of Andhra Pradesh were collected during two seasons in April and November of 2015.
Methodology: 24 groundwater samples of bore and open wells along the coast were systematically analyzed for their physiochemical parameters during Pre and Post Monsoon seasons. The results were interpreted for various geochemical assessments with correlative approach in order to evaluate the impacts on the groundwater quality.
Results: The correlated statistical analysis revealed that there are deviations in some parameters

_____

*Corresponding author: E-mail: sowji626@gmail.com;

from the prescribed WHO and ISI standards of potable water. The concentrations of some of the constituents were found relatively high in the Post Monsoon season than in the Pre Monsoon. The mechanisms controlling the groundwater chemistry were found to be attributed to the rock weathering. The geochemical evolution of the zones indicates that there was much movement in the groundwater under the influence of the local topography and thus at times favoring the development of intrusion zones along the coast. The hydro-geochemical facies with respect to the flow pattern of water indicated that the groundwater did suffer due to the impacts of the elevated as the study area is topographically a low lying area.

Conclusion: It can be concluded that the groundwater along the Bay of Bengal coast of Visakhapatnam has been under sever geological and chemical impacts from the local and elevated lands. The recent geomorphological changes that took place along the coast have impacted its quality and the development of intrusion zones is evident from the assessment.

1. INTRODUCTION

The dependence on groundwater for various needs has been increased in many folds in recent years and it is reaching to a new heights. Llamas and Martinez [1] even felt that, intensive groundwater usage and its consequences slowly generate social conflict. Groundwater has been defining the ways and means of settlements of human beings since ages. Its dependability signifies the strong relation with development in many fields as of its naturally good quality and widespread occurrence. The groundwater along the coastal corridor does suffer impacts of natural and anthropogenic origins which impart periodic and permanent besides qualitative and quantitative changes. The problem would be more obvious with coasts as they are generally topographically low lying areas compared to the plain or the hilly areas. According to Kotra, the coastal groundwater's fate had always been highly circumspect with the surroundings [2]. Hem, rightly felt that, the understanding of the processes that control the water quality is needed before one can speak or act intelligently towards the aim of water-quality control and improvement [3].

Groundwater dependence has been an easy way as of its presence in most areas and the ready to use phenomenon makes it's the most wanted natural resource. The advantage with groundwater is that, it is not readily susceptible for any quality impartations whereas on the other hand the surface waters are the most susceptible by way of mixing of various forms of water. Groundwater do pollute at any give region but takes considerable amount of time in showing its effects and Johnson [4] reported that, the type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of the soil through which water flows prior to reaching the aquifers. It has been reliable since ages and maybe its natural filtration phenomenon in its segregation makes it devoid of any qualitative implications, except in some places based on the geology. But the reliability now-a-days has been a brain storming aspect for anyone who wants to gulp from the any groundwater source. It was established that, groundwater composition in a region depends on the natural (such as the wet and the dry deposition of atmospheric salts, evapo-transpiration, soil/ rock-water interactions) and that of the anthropogenic processes, which can alter or modify the natural system of hydrological cycle [5].

Groundwater along the coasts do lose its identity very quickly due to the segregation of various types of water do merge into these low lying areas was reported in many earlier studies [6,7]. It is obvious that the influence from the flow of surface water, drainages etc. flowing to merge into the sea bring considerable affects in to the groundwater and thus makes it very difficult in maintain its own characteristics. Any change seems natural with these resources but the randomness and magnifications it brings is making the groundwater suffer severely in its quality and quantity [8,9]. These changes may be natural or anthropogenic, seasonal or attributed by any other factor but, it's the groundwater which is bearing the burn of being the polluted. In evaluating these, the present study was aimed at study the geomorphological impacts on the groundwater quality. It was expected that based on some reports on the quality of the coastal groundwater along Visakhapatnam district of Andhra Pradesh might had suffered severe geomorphological impacts due to recent Hud-Hud Cyclone, Tsunami, torrential rains and

floods along the coast. It was obvious that these major environmental impacts would impart their mark on the quality of the groundwater along the coast due to major geophysical and geological transformations.

The present study was taken up from the survey made from the previous studies reported in the area. Earlier groundwater studies and reports included the effects of the industrialization [10,11], geophysical assessments [12,13], salinity effects of the coastal groundwater [14] and intrusion zones [15] in the study area. In recent times many studies related to the coastal groundwater were also reported around the world. Landmeyer studied the Altalntic coastal groundwater quality [16], Kurunc et al. [17] reported the seasonal variation on groundwater quality, and Gunaalan et al. [18] reported on the geochemical variations on coastal groundwater quality. Other studies reported on the coastal areas include, impact of urbanization, agriculture, meteorological were also looked as case studies [19-21]. It was concluded based on the recent natural calamities which hit the coast would certainly influence the prospects of the groundwater to an extent and aimed at this study to investigate those impact's influences. It was also felt that taking the entire district as the study area would give a better idea in understanding these impacts rather than confining to an extent along the coast. The limitations in the sample collection include, the source should be the nearest one to the coast at any given area and should be potable and might be an open or bore well. Further considerations like the exclusion of the points being monitored by the district Groundwater Board, privately owned and maintained was also part of the limitations in the sample collection. In places where a cluster of wells were present, the sample with the average of the EC and pH was considered as the sample. For the better understanding of the seasonal effects, Pre Monsoon (April, 2015) and Post Monsoon (November, 2015) were analyzed.

Visakhapatnam district (VSP) is one of the North Eastern costal districts of Andhra Pradesh and it lies between $17°15'$ and $18°32'$ of Northern latitude and $18°54'$ and $83°30'$ of Eastern latitude. Orissa state is on its North with part of Vizianagaram district and on the Southern side are the Godavari districts and with Bay of Bengal on the East. It enjoys a semi-humid to semiarid climate with an average temperature of $17°C$ in winter to $39°C$ in summer [22]. It comes under the Southwest monsoon (June-September) with an average rainfall of 900mm per annum. The map with the sampling stations is shown in Fig. 1.
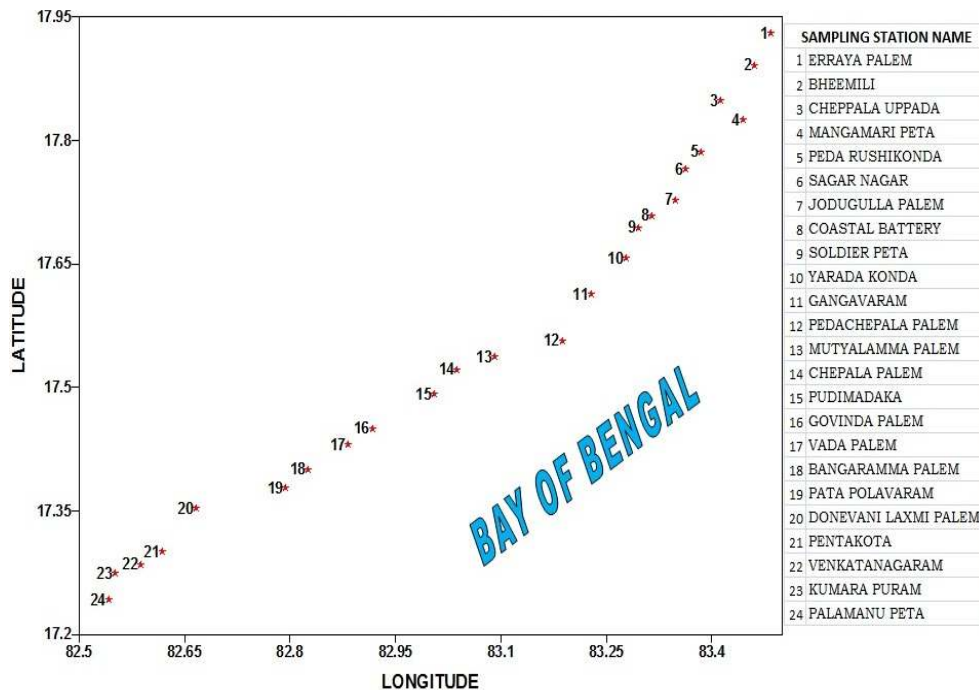

Fig. 1. Map of the study area showing the sampling stations

2. MATERIALS AND METHODS

Being a long coast over 150 KM, it took considerable time in fixing the sampling stations with due representation of the entire area under study and 24 stations were finalized. The interactions with the Groundwater Board gave a clear idea of the stations they monitor and the ground level realties in collecting the samples along the coast. The initial marking of the coordinates from the district top sheets for the coordinates varied from the onsite marking using the GPS (Garmin). Triple distilled water was used in the preparation of the solutions made from the AR (Analytical Reagent) and GR (Guaranteed Reagent) grade reagents during analysis. Surfer 8.0 was used to generate the base map with limits of the coordinates and later the sampling stations were posted accordingly in the map.

pH and EC were noted along with date, sample tag with other local surroundings of the sample on the site itself in 2 L plastic bottles. Care was taken in filling up the bottle up to the neck without air bubbles after double rinse with the sample water. All the samples were analyzed of the following parameters using standard groundwater methods [23]. The parameters are Total Dissolved Solids (TDS) and the anionic species include Carbonates (CO_3^{2-}), bi-carbonates (HCO_3^-), Chlorides (Cl^-), Nitrates (NO_3^-), Phosphates (PO_4^{3-}) and Sulphates (SO_4^{2-}). Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+) and Potassium (K^+) analysis included the cationic species. In the materials subjected to analysis represent the water quality assessments fall in the dilute solutions it best fits the expression in parts per million (ppm) rather than per cent, all the calculations were done with respect to ppm [23].

The pH in the water samples was measured using a 'Elico' (model LI 120) (readability 0.01) pH meter. Electrical conductivity was measured in micro-Siemens/cm (µS/cm) using a "Systronics" conductivity meter. The total dissolved solids were estimated by gravimetric method. Carbonate and bicarbonate and Sulphates ions were titrimetically analyzed and Chloride was done through Argentometric method. Nitrates were estimated titrimetrically after reduction to ammonia using sodium hydroxide as the titrant. Phosphate in the water samples was determined by the Ascorbic acid method. Whereas Calcium and Magnesium ions were estimated by the complex metric titration

method using EDTA. Sodium and Potassium were analyzed through flame photometry.

3. RESULTS AND DISCUSSION

The pH of the collected groundwater fell in the range of 7.12 to 8.14 in the Pre Monsoon (PRM) and 7.24 to 8.52 in the Post Monsoon (POM) in the study area. The Electrical Conductivity (EC) values of the water samples range from 748 to 2254 in PRM and 710 to 3100 µSiemens/cm in the POM. Whereas, the Total Dissolved Solids (TDS) of PRM and POM range from 520 to 1448 and 484 to 2112 ppm respectively. The concentrations of the cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) of the PRM in the area are 28 to 122, 16 to 84, 46 to 480 and 2 to 94 ppm respectively. The same in POM are 36 to 104, 18 to 117, 52 to 480 and 1 to 110 ppm. The anionic (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^- and PO_4^{3-}) concentrations of PRM and POM in the groundwater samples range from 0 to 20, 72 to 510, 54 to 472, 9 to 106, 2 to 44 and 0.02 to 2.10 ppm; and 0 to 40, 74 to 427, 48 to 610, 6 to 186, 1 to 58 and 0.02 to 3.12 ppm respectively. The chemical analysis data of all the parameters of the two seasons has been statistically summarized in Table 1.

The pH values in the study area indicate the predominant alkaline nature of the groundwater. The higher mean in the Post Monsoon indicate the dilution of the groundwater even more than in the Pre Monsoon and the possible reason would be the mixing of the fresh rainwater and also due to the increase in the alkali concentrations. The electrical conductivity and TDS are directly related to each other and were dependent on the fluctuations in the ionic concentrations of the constituents. The higher mean in the Post Monsoon can be attributed to the highly dissolved alkali and alkaline earths with respect to their bicarbonates and chlorides. Other small amounts of dissolved organic matter do reflect the EC and TDS values as well. The same can be applied for the other cations and anions mean values which are higher in the Post Monsoon than in the Pre Monsoon, where the factors like flooding, leaching etc. enhance more dissolution of the ions into the groundwater. Also the hydraulic fluctuations due to increased flow taking place in the drainage channels often dissolve their environs of the groundwater table and thus the increase in the ionic concentrations can also be interpreted. Haloi and Sarma (2012), felt that at times the flood water reaching any low lying areas, the time and extent of contact of the minerals with the water do dissolve them in due course of time [24].

Table 1. Statistical analysis of the physiochemical constituents of the groundwater

Parameter*[1] (Sample no: 24)	Minimum		Maximum		Mean		Standard deviation	
	PRM	POM	PRM	POM	PRM	POM	PRM	POM
pH	7.12	7.24	8.14	8.52	7.57	7.68	0.29	0.37
E.C.	748	710	2254	3100	1301.71	1531.83	487.75	666.49
TDS	520	484	1448	2112	909.50	1076.21	332.15	436.24
Ca^{2+}	28	36	122	104	57.50	60.54	21.82	19.23
Mg^{2+}	16	18	84	117	38.79	48.88	17.60	28.66
Na^+	46	52	480	480	155.79	212.67	100.24	132.42
K^+	2	1	94	110	15.63	22.79	21.68	31.49
CO_3^{2-}	0	0	20	40	3.33	5.00	7.61	12.16
HCO_3^-	72	74	510	427	236.33	263.04	96.61	100.04
Cl^-	54	48	472	610	165.04	233.58	103.62	164.09
SO_4^{2-}	9	6	106	186	53.00	66.92	30.08	40.01
NO_3^-	2	1	44	58	19.25	18.79	12.94	13.63
PO_4^{2-}	0.02	0.02	2.10	3.12	0.45	0.63	0.55	0.76

All parameters are expressed in mg/L, except pH and E.C.; TDS = Total Dissolved Solids,
E.C. = Electrical Conductivity (µSiemens/cm);
1 = All values are rounded to nearest number after two values from decimal

3.1 The Mechanisms Controlling Groundwater Chemistry

The origin of groundwater chemistry can be evaluated from their geochemical ratios which establish the facts about their chemical similarities. According to Sarin et al. [25], the source for the ions in the groundwater can be predicted using the HCO_3^-: Cl^- ratio along with $Ca^{2+} + Mg^{2+}$: TC (Total Cations) and $Na^+ + K^+$: TC ratios. They further stated that, the cationic and anionic ratios of sodium and chloride also has to be included with the above in cases where their percentage of contribution in the total numbers is as significant as others. In the study area, the mean HCO_3^-: Cl^- ratio in PRM and POM is more than unity with values of 1.43 and 1.12 respectively. The alkaline earths, $Ca^{2+} + Mg^{2+}$: TC (Total Cations) and alkalies, $Na^+ + K^+$: TC ratios mean values in the are less than unity, which are 0.35 and 0.64 in the PRM and in POM they are 0.31 and 0.68 respectively.

With the above conditions in the study area, the principal source for the chemical ions would be the rock weathering. An earlier lithological report of Rao and Srihari [26] on the existence of red sediment dominance with kaolinite with subordinate illite is the general clay-mineral assemblage in both the red sediments and the soils along the coast signifies the above observations. As the sampling source has coastal origin, it is obvious that the sodium and chloride ratio would contribute significant information for the assessment of the source of ions in the groundwater. In general, with the ratios of alkaline earths and alkalies with their total numbers showing values less than unity, their values should be more than unity in order to support the above prediction. But, the mean of sodium and chloride ratios of 0.94 and 0.91 in the two seasons are less than unity in the study area. Even though there are cases which validate the criteria, the overall scenario looks quite opposite, supporting the view that rock weathering is not the only source but also other factors play their part in the genesis of the chemical ions in the groundwater.

3.2 Chloro Alkaline Indices

Dominance of the local variations from place to place makes groundwater chemistry change quite appreciably. According to Schoeller [27], this can be understood by the study of two Base Exchange Index patterns of the particular area. These indexes are,

$$CAI_1 = Cl^- - (Na^+ + K^+) : Cl^- \quad \text{and}$$

$$CAI_2 = Cl^- - (Na^+ + K^+) : (SO_4^{2-} + HCO_3^- + CO_3^- + NO_3^-).$$

Where CAI_1 and CAI_2 are Chloro Alkaline Indices 1 and 2).

When there is an exchange of Na^+ and K^+ in the groundwater with Mg^{2+} or Ca^{2+} in the rock/weathered products (clays), both the indices will be positive. If there is a reverse exchange,

then both the indexes will be negative. In the study area, mean values of the two indices of the two seasons are 0.13 and 0.30. In general, groundwater with negative values of both the indices signify that the host rocks are the primary source for dissolved ions in the area, but as in the above cases where the values obtained are positive. As the study areas lies along the coast where the groundwater flow pattern is generally altered due to the various forms of waters coming from different sources. In the present case where most of the areas are topographically low lying and hence there is every possibility of mixing of waters from elevated zones. The above might act as a supplement of the ions along with the source rock to the groundwater in the study area.

3.3 Geochemical Assessment for Groundwater Evolution

Geochemical evolution and the possible sources for dissolved salts in the groundwater were identified using the Piper's trilinear diagram [28]. It was obtained by the combination of the percentages of the total of cations and anions and the zones represent their natural composition (Fresh, Marine and Mixed) type in study area. In the Pre Monsoon the samples which fall under the zone 5 (Fresh water type) are 1, 3, 7, 9 and 20 and the same in Post Monsoon are 9, 13, and 14. They comprise 21% and 13% of the whole samples in those seasons. Likewise, the PRM and POM season's zone 9 (Mixed water type) constitute the samples of 5, 13, 14, 17, 18 19, 21, 23 and 24; and 1, 3, 4, 5, 15, 17 and 20. They represent 37% and 29% of the season's samples. Whereas the samples which represented the zone 7 (Marine water type) of the two seasons are 2, 4, 6, 8, 10, 11, 12, 15, 16 and 22; and 2, 6, 7, 8, 10, 11, 12, 16, 18, 19, 21, 22, 23 and 24. They constituted 42% and 58% of the share of the samples in the study area. These zones were represented in the Piper diagrams in Figs. 2a and 2b.

The overall representation of the zones shows that the carbonate hardness, non-carbonate alkali and mixed type of water have been a dominant factor in the study area. The fresh water environment can be attributed to the carbonate hardness resulted from the dominance of the alkaline earths (Ca^{2+} and Mg^{2+}) and that of the weak acids (CO_3^{2-} and HCO_3^-) indicating the interaction of soil on the groundwater. In cases of mixed water, it was evident that the cations and anions that are not excessive of 50% in their total

concentration with due dominance of various geochemical interactions and local variations in the geology. Whereas dominance of the marine type water can be attributed to the non-carbonate alkali originated from the abundance of alkalis (Na^+ and K^+) and strong acids (Cl^- and SO_4^{2-}) interactions coupled with the topographic low lying effects along the coastal environment.

Significant deviations from one type to other with respect to the TDS value greater than 1000 ppm were observed in the above cases. In general samples with this value represent the marine environment in the diagram but, stations were observed falling in the zone with lesser values or falling in other zones with the value. In the PRM, stations 8, 12 and 10 were observed in marine zone with TDS values lesser than 1000 ppm and the same for POM was observed in stations 18, 21 and 22. Whereas, stations 13 and 24 in PRM and 4 and 15 of POM deviated from the marine zone even after being with the required TDS value. It can be understood that the under saturation environment towards the new environment and thus in due course of time shifting to the old compositions generally yield these type of characteristics. The recent geomorphological impacts received by the coast in recent changes bringing extensions or compressions between the fractures in the rocks to allow a different type of water into the formers environment and thus exhibiting the variation would be a possible strong reason as well. The marine characteristics observation in the fresh and mixed water zones might be resulting from the forced intrusion of seawater due to over exploitation of groundwater's, where the upward pressure would force the surrounding waters to pave their way out by widening the linear fractures in the rocks. It was reported that under these circumstances, the hydraulic gradients on land result in groundwater seepage near shore and may contribute to flows further out on the shelf from confined aquifers [29].

3.4 Hydro Geochemical Facies

Back [30] introduced the concept of hydro-geochemical facies to explain the distribution and genesis of principal groups or types of groundwater in a selected area and stated that it reflects the dominant type of chemical processes in a lithological framework and pattern of water flow in it. The hydro-geochemical facies are (a) Na+ > Ca2+ > Mg2+ : HCO3- > Cl- > SO42- and (b) Na+ > Mg2+ > Ca2+ : HCO3- > Cl- > SO42- and Cl- > HCO3- > SO42- according to the

classification. In the Pre Monsoon 63% of the total samples (1, 3, 4, 5, 6, 8, 9, 10, 11, 14, 16, 19, 21, 23 and 24) and 54% of the Post Monsoon samples (1, 2, 4, 5, 8, 9, 12, 13, 14, 15, 18, 21 and 22) belong to the Na+:HCO3- type, indicating the presence of similar sources for the origin and hence they are responsible for the similar environmental hydro geological conditions. The occurrence of Na+: Cl- type in the PRM constituted 4% (sample 15) and 12% (samples 7, 16 and 23) can be attributed to their local variations of the geological conditions like clay horizons, low lying areas and backwater zones. The other samples which don't belong to the above classes can be considered as the mixed group of the above combinations. The various hydro-geochemical facies of the study area are shown in the Table 2.
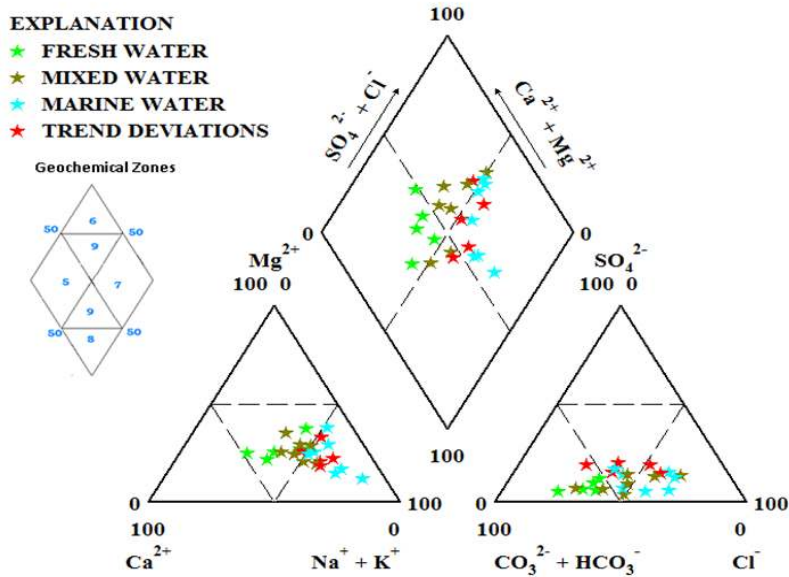

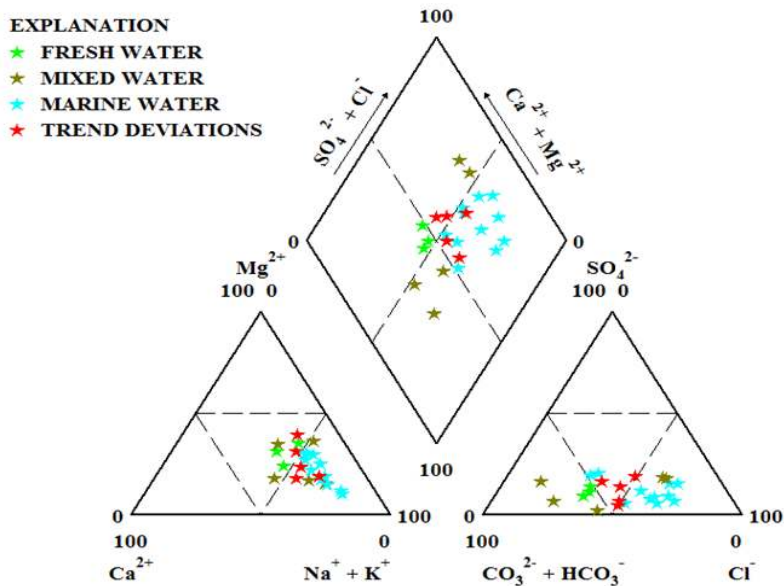**Fig. 2a. Geochemical evolution of groundwater – Pre monsoon**

Fig. 2b. Geochemical evolution of groundwater – Post monsoon

Table 2. Hydro-geochemical facies classification of groundwater samples in the study area

Hydro-geochemical facies	Distribution of groundwater samples	
	Pre monsoon	Post monsoon
$Na^+ > Ca^{2+} > Mg^{2+}$: $HCO_3^- > Cl^- > SO_4^{2-}$	1, 3, 4, 5, 6, 10, 11, 14, 19, 21, 23 and 24	1, 2, 4, 5, 8, 9, 12, 13, 18, 21 and 22
$Na^+ > Mg^{2+} > Ca^{2+}$: $HCO_3^- > Cl^- > SO_4^{2-}$: $Cl^- > HCO_3^- > SO_4^{2-}$	8, 9 and 16 15	14 and 15 7, 16 and 23

3.5 Hydro-geochemical Facies with Groundwater Flow Pattern

Ophori and Toth [31] had correlated the hydro-geochemical facies with the flow pattern of groundwater system. According to them, low TDS, Mg^{2+} : Ca^{2+} ratio and SO_4^{2-} and high HCO_3^- occur in the recharge areas. Whereas the opposite conditions, such as high TDS, Mg^{2+} : Ca^{2+} ratio and SO_4^{2-} and low HCO_3^-, are associated with the discharge areas. They further stated that the groundwater's of Ca^{2+} - Mg^{2+} - HCO_3^- and Na^+ - HCO_3^- types are dominant in the recharge areas, while Ca^{2+} - Mg^{2+} - SO_4^{2-} - HCO_3^- and Na^+ - HCO_3^- types occur in the discharge areas. Recharge involves the downward movement and influx of groundwater to an aquifer; discharge involves the upward movement and out fluxes of groundwater from an aquifer. Recharge and discharge activities are usually spatially limited to a small portion of an aquifer. The most common recharge areas are hills, up dip outcrops or erosion exposures of confined aquifers, alluvial fans along mountain front s, and ephemeral stream bottoms in dry regions. Common natural discharge areas include perennial stream valleys in humid regions, swamps, springs, lakes, and the oceans. Recharge rates are difficult to calculate. However, numerous estimates have been made by various techniques that include water-balance computations, geophysical measurements that trace the movement of water in the shallow subsurface, and various chemical (notably chloride mass balances) and isotopic methods [32].

According to the correlation of hydro-geochemical facies with the flow pattern of groundwater system, the low TDS (<1000 mg/L), low Mg^{2+} : Ca^{2+} ratio and SO_4^{2-} (<100mg/L), and high HCO_3^- : Cl^- ratio in stations (PRM: 1, 3, 5, 7, 10, 14, 20, 21 and 23; POM: 1, 3, 5, 13, 18, 21 and 22) type hydro-geochemical facies observed in the parameters suggest that these areas lie in the predominant recharge zones. Nevertheless, in cases of high Mg^{2+}: Ca^{2+} ratio (PRM: 8, 9 and 15; POM: 3, 7, 14, 15, 16 and 23 stations, where it is >1.1), indicate the association of these areas are with discharge source. These fluctuations in some stations from the Pre to Post Monsoon and the absence of other stations in neither of the classification indicate the mixed nature of the groundwater and can be caused by either the low concentrations of Ca^{2+} due to ion exchange between Ca^{2+} and Na^+ or by the preferential removal of Ca^{2+} by precipitation as carbonates (kankar and/or calcrete). This can also be confirmed by low mean values of the $Na^+ + K^+$ and $Ca^{2+} + Mg^{2+}$ with Total Cations and a slightly higher mean that of the Na^+ with Cl^-. The various hydro-geochemical ratios were shown in Table 3.

Table 3. Hydro-geochemical ratios of the groundwater samples in the study area

Hydro-geochemical ratio	Pre monsoon	Post monsoon
Mg^{2+} : Ca^{2+}	0.74	0.80
HCO_3^- : Cl^-	1.89	1.82
$Ca^{2+} + Mg^{2+}$: Total Cations	0.40	0.34
$Na^+ + K^+$: Total Cations	0.60	0.66
Na^+ : Cl^-	0.94	1.15

4. CONCLUSION

The present study on the physiochemical assessments with respect to two seasons has revealed the various influences that the groundwater in the study area. Based on the analysis it was clear that most of the parameters in both seasons showed significant deviations from the prescribed standards of ISI or WHO. The parameters which deviated from the specified range to the maximum include TDS, Sodium, Chloride and Bicarbonate and others with an extent. It was observed from the overall assessments that the Post Monsoon groundwater samples were under more impacts than that of the Pre Monsoon. The primary reason might be the low lying topography of the study area where the effects from the elevated severely imparting qualitative changes. The carbonate hardness results from the dominance of alkaline earths (Ca^{2+} and Mg^{2+}) and that of the weak acids (HCO_3^-) indicating the influence of

soil chemistry on the groundwater chemistry as observed in the geological assessment and represents the freshwater environment and the earlier reports of the local lithology confirms the present findings. It is evident from the geochemical ratios that the local groundwater chemistry involving rock weathering in generating the ion in these groundwater's and mechanisms controlling these strengthen the present findings. The interchanges from the recharge and discharge zones with season indicate that these are highly influenced due to the geological effects along the coast. The mixed and marine traces from non-carbonate alkali in various stations are due to abundance of alkalies (Na^+, K^+) and strong acids (Cl^- and SO_4^{2-}) and are the curtsey of clay horizons and topographic lows as observed in the coastal belts as the dominance of red sediments along the coast.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Llamas MR, Martínez-Santos P. Intensive groundwater use: Silent revolution and potential source of social conflicts. Journal of Water Resources Planning and Management. 2005;131(5):337-341.
2. Kotra KK, Vasantha Y. Coastal groundwaters – a geo-hydro chemical exploration for factors controlling genesis and spatial distribution of fluoride. International Journal of Environment and Resource. 2012;1(2):50-61.
3. Hem JD. Study and interpretation of the chemical characteristics of natural water. U.S. Geol. Survey on water supply. 1959. Paper Pub.; 1473.
4. Johnson CC. Land application of waste– An accident waiting to happen. Ground Water. 1979;17:69–72.
5. Singh PK, Malik M, Mohan D, Singh VK, Singh S. Evaluation of groundwater quality in northern Indo-Gangetic alluvium region. Environmental Monitoring and Assessment. 2006;112:211–230.
6. Valiela I, Costa J, Foreman K, Teal JM, Howes B, Aubrey D. Transport of groundwater-borne nutrients from watersheds and their effects on coastal waters. Biogeochemistry. 1990;10(3):177-197.
7. Wang CH, Chiang CJ, Peng TR, Liu WC. Deterioration of groundwater quality in the coastal pingtung plain, southern Taiwan. IAHS Publication; 1999.
8. Appleyard S. The impact of urban development on recharge and groundwater quality in a coastal aquifer near Perth, Western Australia. Hydrogeology Journal. 1995;3(2):65-75.
9. Gerritse RG, Barber C, Adeney JA. The impact of residential urban areas on groundwater quality: Swan Coastal Plain, Western Australia. CSIRO Water Resources Series (3); 1990.
10. Kumar YP, King P. Assessment of ground water quality in Visakhapatnam Area, Andhra Pradesh, India. Fundamentals of Limnology. 2005;24:39-45.
11. Naidu YS, Subba Rao C, Prasad N, Prasad PR. Decadal status of a major industrial belt on the local groundwaters: A case study in Visakhapatnam (India). Journal of Environmental Science & Engineering. 2010;52(3):245-254.
12. Asadi SS, Raju MV, Rani PN, Sekar SK. Pollution prevention study using remote sensing and GIS: A model study from Visakhapatnam district, Andhra Pradesh. International Journal of Engineering Science and Technology. 2011;3(6):27-35.
13. Dhakate R, Kumar VS, Amarender B, Sankaran S, Rao VG. Integrated geophysical and hydrochemical approach for locating fresh water locations in a coastal terrain. Water Resources Management. 2015;29(9):3401-3417.
14. Ganapati PN, Murthy VSR. Salinity and temperature variations of the surface waters off the Visakhapatnam coast. Andhra Univ. Mem. Oceanography. 1954; 1:125-142.
15. Sarma VV, Krishnaiah N. Quality of groundwater in the coastal aquifer near Visakhapatnam, India. Ground Water. 1976;14(5):290-295.
16. Landmeyer JE. Assessment of groundwater quality of atlantic coastal plain aquifers, Aiken County, South Carolina. In Groundwater from the Mountains to the Sea in the Central Atlantic Region. Ngwa; 2016.
Available:https://ngwa.confex.com/ngwa/mscar16/webprogram/Paper11009.html
17. Kurunc A, Ersahin S, Sonmez NK, Kaman H, Uz I, Uz BY, Aslan GE. Seasonal changes of spatial variation of some groundwater quality variables in a large

irrigated coastal Mediterranean region of Turkey. Science of the Total Environment. 2016;554:53-63.

18. Gunaalan K, Asanthi HB, Gamage TPD, Thushyanthy M, Saravanan S. Geochemical variations of groundwater quality in coastal and karstic aquifers in Jaffna Peninsula, Sri Lanka. In Management of Water, Energy and Bio-resources in the Era of Climate Change: Emerging Issues and Challenges. Springer International Publishing. 51-61.

19. Lee JY, Song SH. Evaluation of groundwater quality in coastal areas: implications for sustainable agriculture. Environmental Geology. 2007;52(7):1231-1242.

20. Prasanth SS, Magesh NS, Jitheshlal KV, Chandrasekar N, Gangadhar K. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. Applied Water Science. 2012;2(3):165-175.

21. Reich CD, Shinn EA, Hickey TD, Tihansky AB. 2002. 25 Tidal and Meteorological Influences on Shallow Marine Groundwater Flow in the Upper Florida Keys; 2002. Available:http://sofia.er.usgs.gov/publicatio ns/papers/tidalmeteorological/tidalmet_sec ure.pdf

22. Report in Year Book by Groundwater Board submitted to Govt. of Andhra Pradesh, by Deputy Engineer, Visakhapatnam Zone. 2007-08;12.

23. APHA, AWWA, WPCF. Standard methods for the examination of water and waste water. 19th ed., APHA, Washington D. C. 1995;I:47.

24. Haloi N, Sarma HP. Heavy metal contaminations in the groundwater of Brahmaputra flood plain: An assessment of water quality in Barpeta District, Assam (India). Environmental Monitoring and Assessment. 2012;184(10):6229-6237.

25. Sarin MM, Krishnaswamy S, Dilip K, Somayajulu BLK, Moore WS. Major ion chemistry of the Ganga-Brahmaputra river system-weathering processes and fluxes to the Bay of Bengal. Geochimica Cosmochim Acta. 1989;53:997-1109.

26. Rao ND, Srihari Y. Clay mineralogy of the late pleistocene red sediments of the Visakhapatnam region, east coast of India. Sedimentary Geology. 1980;27(3):213218-215227.

27. Schoeller H. Geochemistry of groundwater. In: Groundwater Studies-An International Guide for Research and Practice, UNESCO, Paris. 1977;1–18.

28. Piper AM. A graphical procedure in the geochemical interpretations of water analyses. American Geophysics Union Trans. 1994;25:914-923.

29. Burnett WC, Bokuniewicz H, Huettel M, Moore WS, Taniguchi M. Groundwater and pore water inputs to the coastal zone. Biogeochemistry. 2003;66(1-2):3-33.

30. Back W. Origin of hydrochemical facies of groundwater in the Atlantic coastal plain. Int. Geol. Cong., 21st Session, Part I, Geochemical Cycles. 1960;87-95.

31. Ophori DU, Toth MP. Pattern of groundwater chemistry, Ross Creek Basin, Canada. Ground Water. 1989;27:20-26.

32. Seth Rose. Groundwater Recharge and Discharge. Groundwater. Encyclopedia of Life Support Systems (EOLSS). III. Available:http://www.eolss.net/sample-chapters/c07/e2-09-06-07.pdf