# *Hydrogeochemical studies of ground waters in Neyveli basin along the Cuddalore coast, SE coast of India*

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*Abstract*— **A detailed study had been carried out on groundwater in Neyveli basin along the Cuddalore coast to establish the hydrogeochemistry and identify the various sources of contaminants as well assess the physical and chemical quality of the groundwater. The groundwater was found to vary considerably in terms of chemical and physical properties. Generally the water was alkaline, high chemical constituents near the coastal region and undersaturated with respect to carbonate minerals. The majority of groundwater clustered towards Mg-Cl, Ca-Cl and Na-Cl facies. Interpretation of data reveals that weathering and ion exchange through which major ions enter the groundwater system. Anthropogenic activities were found to have greatly impacted negatively on the quality of the groundwater.**

Keywords- **Groundwater quality; Anthropogenic activity; ion exchange; Weathering; Neyveli basin.**

## I. INTRODUCTION

Water is the elixir of life, life without water in unimaginable and impossible. It is the prime requirement of the world. Ground water plays an important role being the primary source of water. Ground water is a mixture of various contents since flows below ground and during passage it contact with different rocks and formation. The water quality depends on its time residence. Some time the quality of water deteriorates with variation in formation and residence time, which makes it for serving in to various purposes.

With the changing environment the responsibility of the scientists must be (1) to develop and maintain information on the availability of water resources; (2) to assess, monitor and predict the resulting quality of water bodies and the water related environment; (3) to develop a better scientific understanding of those effects of man's activities that influence the hydrological regimes: and (4) to provide the decision makers the importance of water management with necessary information in the succinct, properly constructed formats such that they will understand the problems and enable them to react appropriately.

The present study mainly aims is to study the impact of entire pumpage from Neyveli mine area including the additional pumping operations (VEERANAM Project) for the drinking water supply to the people of Chennai city on the groundwater quality changes by distinguishing their types, genesis variations through hydro-geochemical studies. The study is intended to identify the movement of salt water migration including the interface through hydrogeochemical approach, which is reported moving presently towards the Neyveli basin from Cuddalore coast (Prasanna et al., 2008) and also the feasibility of artificial recharge to arrest the movement of the sea water.

## II. STUDY AREA

Neyveli basin is located in 250 Km SW of Chennai. The area is located between the geographical coordinates, latitudes of 11° 36' – 11° 70' and between longitudes of 79° 51' – 79° 86'. The region falls in the toposheet of 58 M/11 (Fig.1). Relative humidity of the area was recorded in the eastern part of the district i.e., at Cuddalore ranges between 60 and 83%, whereas in the western part of the district i.e., at Lekkur it ranges between 46.73 and 71.12%. Higher rates of relative humidity are observed during the months of northeast monsoon period i.e., from October-November-December, where as lower rates are observed during the summer months of April and May. The 70 years average annual rainfall of the district is 1160mm. More than 50% of the rainfall occurs during North – East Monsoon. About 30% of the rainfall during South – East monsoon and the balance from January to May. In the study area, from Veeranam to Panruti, the rainfall normally more than the district average. There are three types of aquifers in this region viz., Phreatic aquifers, aquifer under semi – confined to confined conditions and alluvial aquifers. Phreatic aquifers found in the areas with the top Cuddalore sand stone. Along the river, shallow aquifers are available which are also under water table conditions. Generally, thickness of the top Cuddalore sand stone extends up to depth of about 100m below ground level, where the alluvial formation along the river various from 20m to 40m below ground level. But these aquifers are very shallow. The confined aquifers are deep in nature. These aquifers available from about 100m to 450m below ground level. Yield form the shallow aquifers are less than that from deep aquifers.

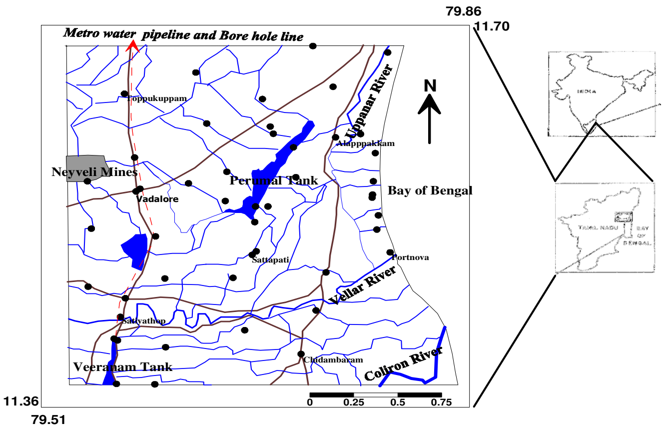

Figure 1. Study area and sample location map

## III. METHODOLOGY

The water samples were collected during post monsoon (February 2006) and pre monsoon (July 2006) seasons to broadly cover seasonal variation (Fig. 1). A total of 55 water samples were collected from bore wells. One litre of water samples was collected in polyethylene bottle two times a year to broadly cover seasonal variation along with lithology. Then it was sealed and brought to laboratory for analysis and stored properly (4ºC) before analysis.

The samples collected were analyzed for major cations like, Ca and Mg by Titrimetry, Na and K by Flame photometer (CL 378); anions, Cl and $HCO_3$ by Titrimetry, $SO_4$, $PO_4$, and $H_4SiO_4$ by Spectrophotometer (SL 171 minispec) and Nitrate and Fluoride by ion electrodes. EC and pH were determined in the field using electrode (Eutech). The analyses were done by adopting standard procedures (APHA 1998).

## IV. RESULTS AND DISCUSSION

### A. *Hydrogeochemistry*

The chemical composition (range and average) of ground waters of the Veeranam region in the post and pre monsoon periods of 2006 are shown in Tables 1 & 2 (Appendix). In general, pH of the waters is alkaline in nature. The pH is controlled by total alkalinity of the ground water and partially of sea water. pH in the study area varies from 6.8 to 7.6 and 6.4 to 7.8 in post monsoon and pre monsoon periods. EC is the ability of a substance to conduct electric current. The measure of conductivity is directly proportional to the strength of the water. EC and TDS higher value represent in the post and pre monsoon. They indicate that dissolution of infiltration rain water and over exploration of groundwater in the agriculture purposes. EC varies from 410 µs/cm$^2$ to 1630 µs/cm$^2$ and 125µs/cm$^2$ to 2630µs/cm$^2$ in post monsoon and pre monsoon. Total dissolved solids (TDS) ranges vary from 287 to 1141 and 87.50 to 1841 in post monsoon and pre monsoon. Sodium is the dominant cations followed by Ca, Mg and K and bicarbonate is the dominant anion followed by Cl, $SO_4$, $PO_4$ in both the seasons. The silica concentration is higher in pre monsoon period. Phosphate concentration is around less than 2mg/l in all these aquifers. Leaching effects of infiltered waters carrying the organic manure and fertilizer effluence rich in P from the agriculture soil enhance its concentration in the groundwater. Nitrate concentration is higher in post monsoon and some location excess over the prescribed level of 44 mg/l, (WHO 1993). This may be leaching of organic matter from the soils and leaching of soluble nitrogenous fertilizers from agriculture fields.

### B. *Spatial distribution*

The Figure 2a and 2b represents the distribution of EC values in the aquifer. In general, Ec found to high concentration in the coastal area. In this diagram EC ranges various in pre monsoon is higher than the post monsoon. Higher concentrations near coastal area mainly indicate the presents of saline water in the coastal area. The diagram 3a and 3b represents the TDS values in the aquifers. It appears to the waters in both seasons generally increases towards the coast in the groundwater flow direction. This may indicate mainly saline water intrusion by over exploration of groundwater in Neyveli mines area. The diagram 4a and 4b represents the Cl concentration in the area. The near coastal area consists of shallow aquifers mainly contaminated by the salt water. The post monsoon represent the Cl concentration is low comparatively the pre monsoon season that may be due to the rainwater dilution process and river process. The Neyveli mines area also represents the high concentration due to the groundwater exploration and some other human activity and industries. This diagram shows a high concentration in coastal area and increasing season wise. The river flow direction is south east direction that why the tidal influence is more the coastal area. The Ec, TDS and Cl contour diagram mainly shows the seasonal variation of concentration in the area. Mainly coastal area affected by the salt water intrusion that may due to the over exploration of groundwater in metro project and agriculture and domestic purposes.

### *C. Geochemical Classification*

The geochemical evolution of groundwater can be understood by plotting the concentration of major cations and anions in the piper trilinear diagram (Piper 1944) (Fig 5a and 5b). The plots shows mainly the Mg – Cl , Ca – Cl, Na-Cl and Na – HCO3 type in post monsoon season and in pre monsoon is mainly Mg – Cl and Ca – Cl types. Na – Cl type indicate the dominance of rock weathering followed by evaporation, leaching and sea water contamination.

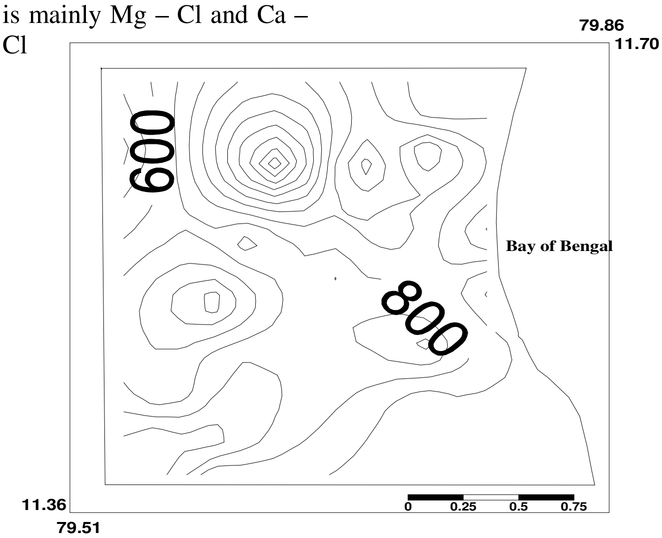


Figure 2a. Ec in Post monsoon February 2006

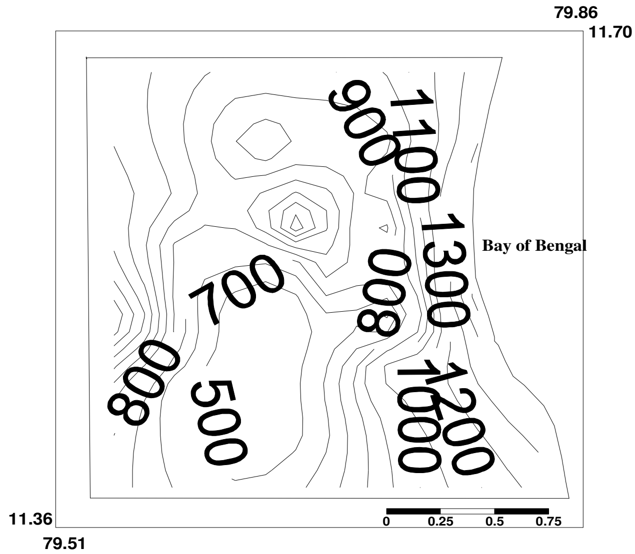


Figure 2b: Ec in Pre monsoon July 2006

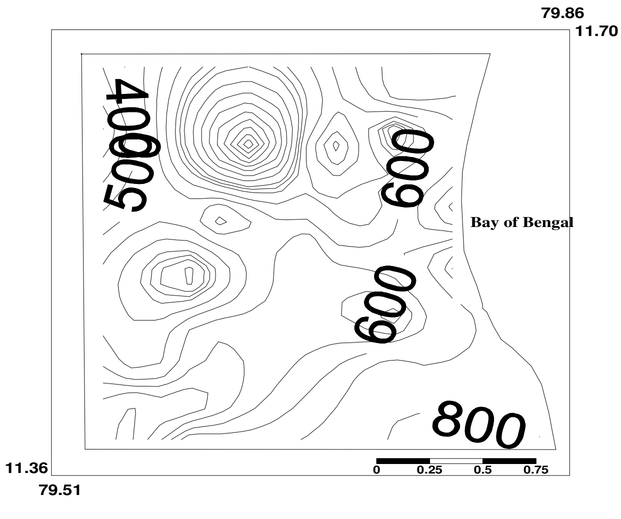


Figure 3a: TDS in Post monsoon Feb 2006

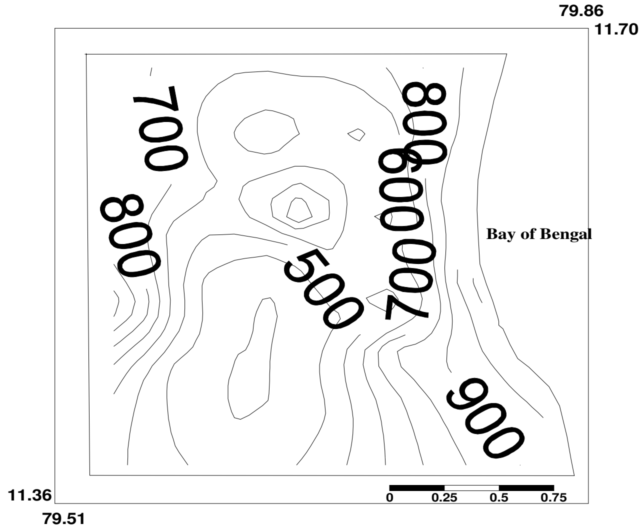


Figure 3b: TDS in Pre monsoon July 2006

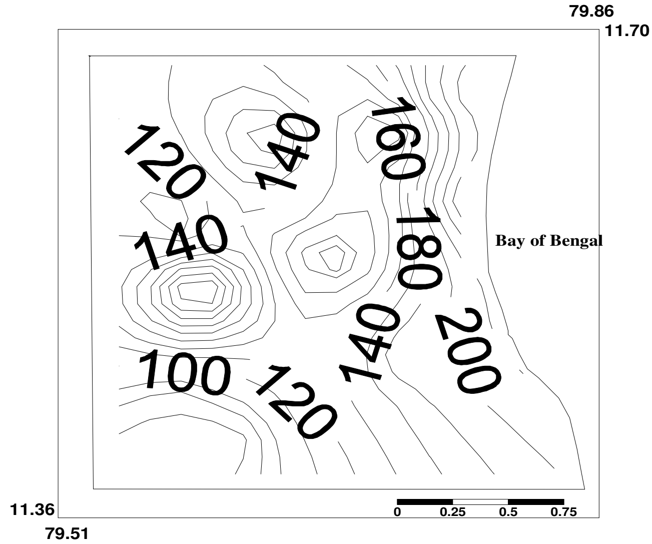


Figure 4a: Cl in Post monsoon Feb 2006

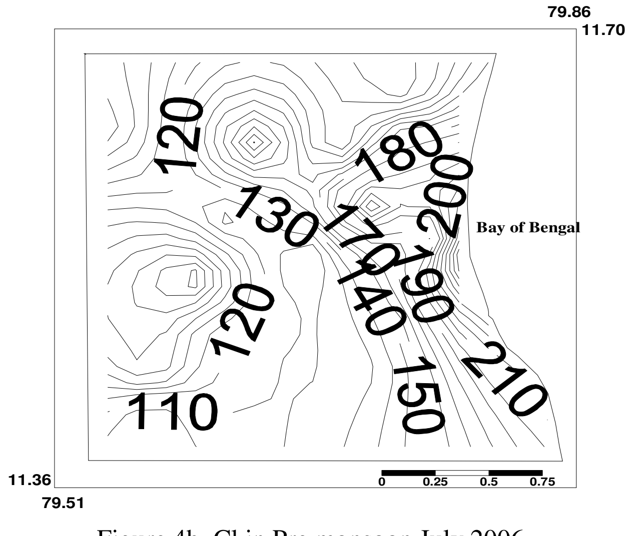


Figure 4b. Cl in Pre monsoon July 2006

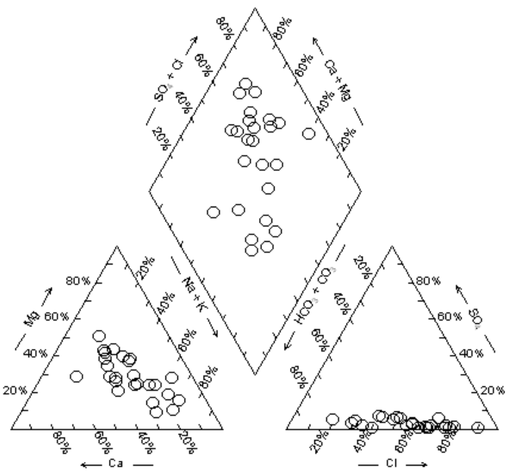


Figure 5a: Piper diagram in Post monsoon in Feb 2006

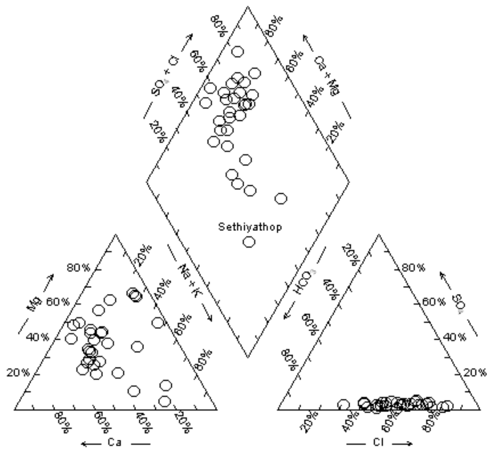


Figure 5b: Piper diagram in Pre monsoon in July 2006

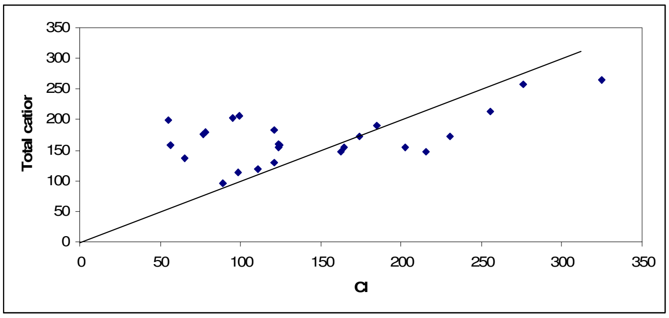


Fig 6a: Relation between total cations and chlorine in post monsoon 2006

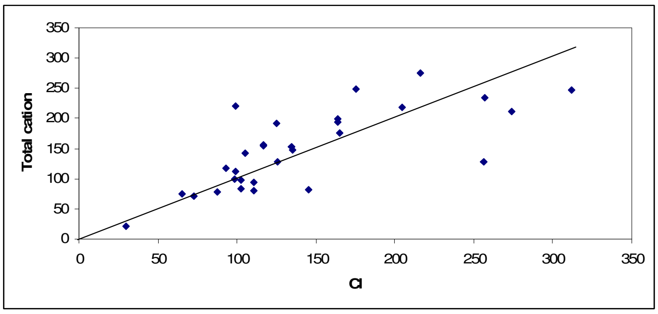


Figure 6b: Relation between total cations and chlorine in pre monsoon 2006

*D. Salt water contamination*

Coastal aquifers have their end boundaries in contact with sea water and are always under dynamic equilibrium (Handa 1986). The abundance of Na, Cl, and $SO_4$ over other irons in the groundwater at few locations indicates the possible sea water contamination in this area. These ions increasing the EC and total dissolved solids.

The total cations versus chloride (Fig 6a & 6b) illustrate the seawater influence as well as this plot influence samples have been plotted along the seawater mixing line. Most of the pre monsoon samples fall along the seawater mixing line then the post monsoon samples. This indicate that pre monsoon samples were highly contaminated with the saline water due to the over exploitation of groundwater. The upward deviation from the mixing line seems to be caused by other chemical reactions providing cations without changing chloride concentration. Because of the influence, it's likely that the chemistry of these samples is highly affected by cation exchange. Ion exchange between Na and Ca often occurs in ground waters of coastal aquifers (Appelo and postma 1994).

### *E. Variation of LogPCO$_2$*

Post monsoon samples fall slightly lesser than the atmospheric value (-3.5) indicates that the groundwater just entered in to the system or resistance time in the aquifer matrix is considerably lesser (Fig 7). Higher PCO$_2$ values were noted in the pre monsoon samples indicates additional CO2 is acquired from the soil formation during the infiltration to the zone of saturation.

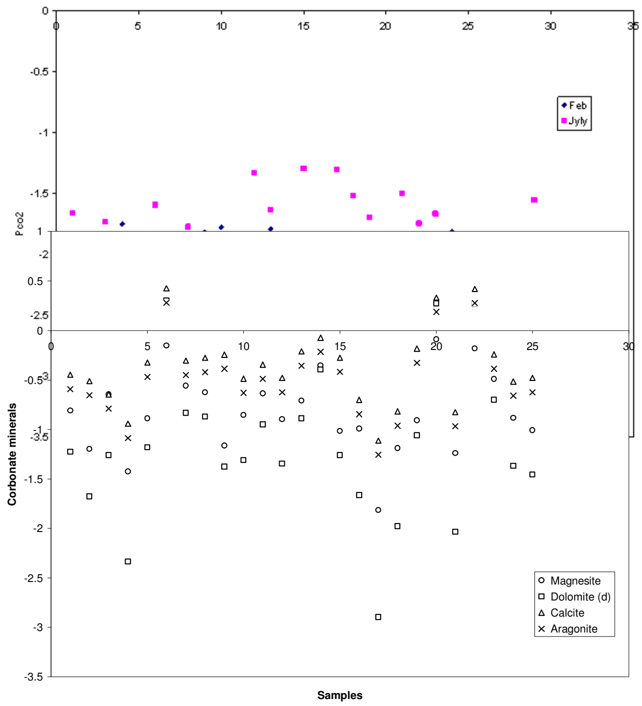


Figure 8a. Saturation index of Carbonates (post monsoon)

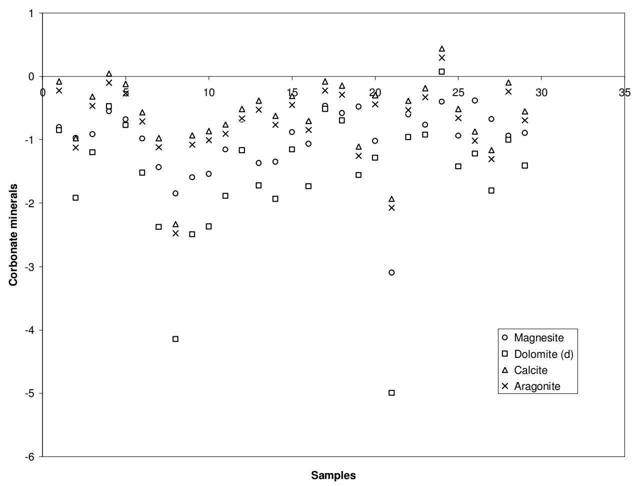


Figure 8b. Saturation index of Carbonates (pre monsoon)

### *F. Saturation index of Carbonate minerals*

WATEQ (Trusdell and Jones 1973) used for the identification of the saturation index. By using the saturation index approach it is possible to predict the reactive mineralogy of the subsurface from groundwater data. in the present study to determine the chemical equilibrium between mineals and water, saturation indices of Magnasite,calcite, Dolomite and Aragonite were calculated (Fig 8). The saturation index of the Magnasite, calcite, Dolomite and Aragonite of groundwater in post monsoon samples fall in the under saturated zone indicates dilution of rainwater. Some representations fall in near saturated zone indicates precipitation. Same trend was followed in pre monsoon samples.

### *G. Factor analysis*

In post- monsoon first three factors show Eigen values >1; thus these three factors were chosen. In pre-monsoon only two factors have Eigen values >1; thus these two factors were chosen for the subsequent factor extraction.

*Factor 1 Post- monsoon*

Factor I of post-monsoon samples has high loading in the ions Na, K and NO$_3$. The concentration of Na, K and NO$_3$ in seawater is much greater than that in continental water. Therefore, factor I can be associated with the salt water inundation which leached into the aquifer system, which increases the concentrations of these ions by its percolation and longer residence time i.e marine water inundation during high tides and from the 2004 tsunamis inundation remnants which enhances leaching and may be the most important process affecting the ion concentrations of the ground water in these aquifer. This factor accounts for 34.60 % of the variance of the concentrations of the samples, which is a higher percentage than that attributable to the other factors. Cl concentration average is around 145.13 ppm it may be the direct salt water intrusion affecting the aquifers. Figure 9a shows the aerial distribution of factor scores for factor I of post-monsoon. It can be seen from the figure, the Uppanar river mouth highly affected by the tidal action indicates above 0.2 contours. This is due to the river water seepage into the aquifer system in the monsoon period and the center part of the area is higher concentration that is indicating the predominance of weathering along with sediment water interactions. Result of factor analysis (Table 3, Appendix) of the groundwater chemistry data (n=25) indicates three trends (factors) that can be related to various controlling processes presumed to have produced the different water species. This suggests that saltwater inundation and percolation into the aquifer along with signatures of natural water recharge and water-soil -sediment interaction were the predominantly factors. A small zone in the south-central portion of town shows exceptionally high scores. This area is the agriculture intense activity area and consequently witnesses' higher groundwater abstraction. This probably establishes local freshwater depression cones, which induces saltwater infiltration into this area. Over drafting of the groundwater in the area thus was the main factor for infiltration of salt water induced by the local over exploitation of groundwater for various purposes.

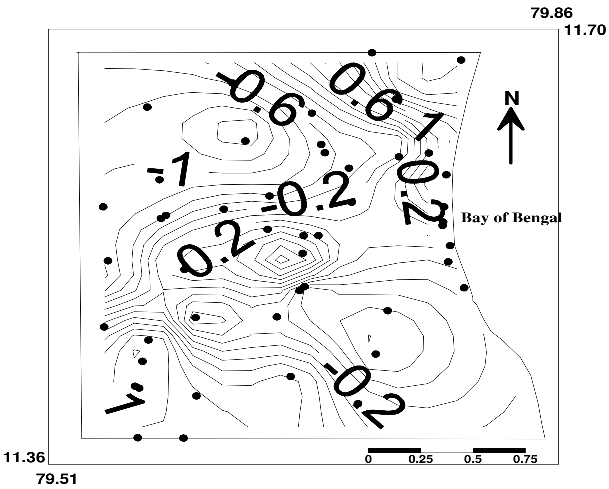


Figure 9a: Factor score – 1 Post monsoon

*Factor 2 Post- monsoon*

Factor II of the post-monsoon samples includes mainly Ca, Mg and Cl. Even though the seawater has a higher concentration than the continental water, the contribution of Cl and Ca in this factor indicates that the interaction of water with the aquifer formations is high. Further the Mg average concentration is 38.82 ppm may be due to the uptake of Mg by ion exchange sites on clays and other Mg rich minerals (Ramanathan and others 1988) (Table 3). Figure 9b shows the aerial distribution of factor scores of factor II (post-monsoon) is represented the Mg affected area due to sediment water interaction and weathering processes. The figure 9b shows that the entire coastal area affected by Cl due to the over exploration of Groundwater. Ca is rich in shallow aquifers when compared to the pre-monsoon period. Central part of the study area indicates that above 0.2 contours is over exploration of groundwater due to the Neyveli lignite mining area.

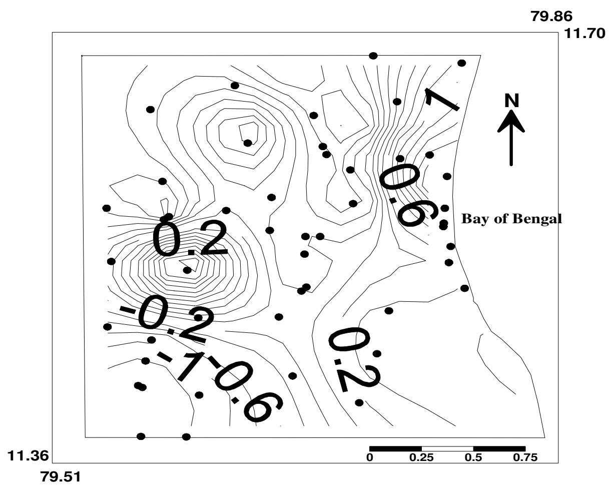


Figure 9b: Factor score – 2 Post monsoon

*Factor 3 Post- monsoon*

The factor III of post-monsoon samples is represented mainly by $SO_4$ and $NO_3$ with negligible loading of cations. The alkaline pH is responsible for higher loading of $SO_4$. Spatial distribution of this factor score (Fig 9c) is mainly represented the northeast part is above 0.2 mainly present in the Neyveli lignite mines which is impacted by the mine water and agriculture used water percolations add $NO_3$. Surface run-off is main important factor because the confined aquifers from lignite mines is pumped daily and is used in the agriculture and domestic purposes, that ultimately percolates into groundwater through Alluvial aquifers.

*Factor 1 Pre- monsoon*

The pre-monsoon factor I, loaded heavily with Na, K and $NO_3$, resembles the concentration of seawater. Na showed low concentrations in the post-monsoon period and reaches high concentrations in the pre-monsoon water sample. The higher concentrations of Na, K and $NO_3$ are due to the storm and high tide in the coastal area during the period, which activate the penetration of seawater into the groundwater system through seepage. Figure 10a shows the areal distribution of factor I scores and also the extent of the saltwater intrusion in the pre-monsoon period. Seawater intrusion is higher in the pre-monsoon period is compared to the post monsoon period. It may be also due to higher amount of groundwater exploration in this area due to the dry climate condition exist in this area, and this clearly induces the seawater intrusion added to that is the tidal effect, which cause saline water intrusion into the groundwater system.

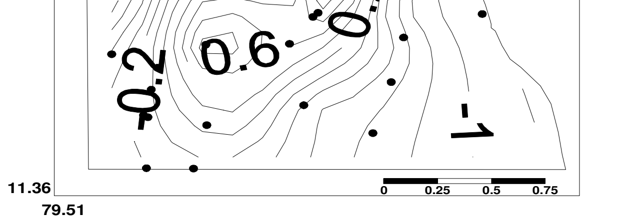


Figure 9c: Factor – 3 Post monsoon

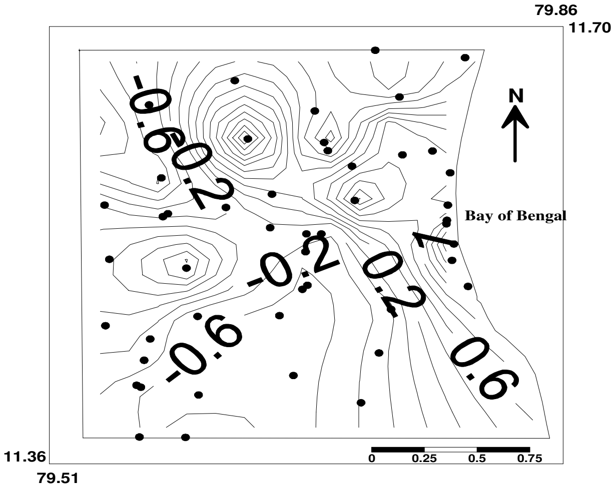


Figure 10a: Factor – 1 Pre monsoon

*Factor 2 Pre- monsoon*

The factor 2 of pre-monsoon samples is represented mainly by Ca, Mg and Cl, as the shallow aquifers are intensively used for agricultural purposes. Figure 10b shows the distribution of factor score as indicated by the Ca, Mg and Cl, which are in high concentrate in the southwest and near coastal region of the study area.

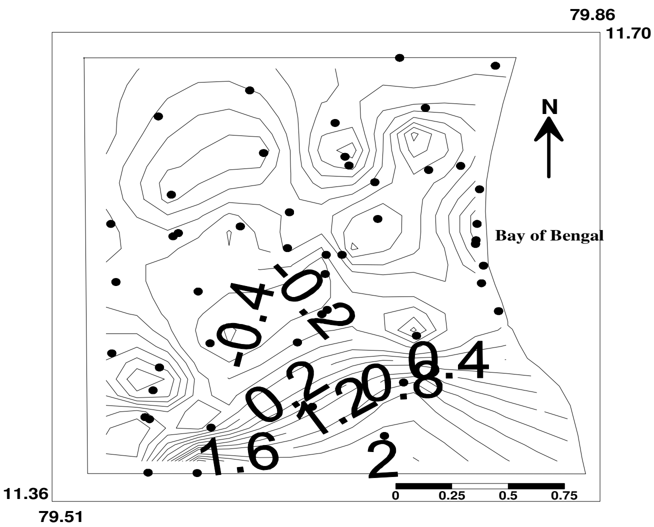


Figure 10b: Factor – 2 Pre monsoon

V. CONCLUSION

The groundwater in the Neyveli basin have economic significant, representing the district greatest hydrostructure with fresh water. In rural communities within the district, groundwater plays a vital role in the supply of fresh water. The conductivity of groundwater is highly variable with high values close to the coastal zone. Sodium is the dominant cations followed by Ca, Mg and K and bicarbonate is the dominant anion followed by Cl, $SO_4$, $PO_4$. Analysis of the hydrogeochemical survey data from groundwater revealed multiple anthropogenic influences on the groundwater quality. The highly impaired sites were located close to the urbanized, agricultural and industrialized areas which have high population density. From a chemical point of view, either seawater intrusion or up conning of brackish water underneath followed by ion exchange occurs along the coastal zone of the basin.

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**Appendix-Table 1: Chemical data of the groundwater in post monsoon in 2006**

| S.NO | pH | Ec | TDS | Ca | Mg | Na | K | Cl | $HCO_3$ | $H_4SIO_4$ | $PO_4$ | $SO_4$ | F | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.4 | 867 | 606.9 | 21.74 | 16.18 | 42.00 | 50.00 | 120.71 | 186.42 | 18.38 | 0.18 | 18.29 | 0.21 | 11.70 |
| 2 | 7.3 | 564 | 394.8 | 25.54 | 8.93 | 82.00 | 60.00 | 76.70 | 172.56 | 21.10 | 0.18 | 14.63 | 0.26 | 56.00 |
| 3 | 7.3 | 675 | 472.5 | 12.50 | 21.25 | 72.00 | 31.00 | 65.25 | 260.25 | 12.29 | 0.17 | 13.35 | 0.19 | 2.75 |
| 4 | 6.8 | 1045 | 731.5 | 43.78 | 24.67 | 30.00 | 15.00 | 98.80 | 115.25 | 17.52 | 0.18 | 1.78 | 0.02 | 18.80 |
| 5 | 7.6 | 780 | 546 | 33.67 | 15.70 | 28.00 | 18.00 | 89.00 | 95.25 | 30.02 | 0.19 | 1.46 | 0.20 | 28.80 |
| 6 | 7.5 | 580 | 406 | 102.25 | 45.63 | 76.00 | 41.00 | 324.58 | 291.36 | 26.16 | 0.20 | 2.89 | 0.71 | 3.99 |
| 7 | 7.2 | 590 | 413 | 64.25 | 61.25 | 28.00 | 18.00 | 230.71 | 159.23 | 13.94 | 0.19 | 23.98 | 0.26 | 2.58 |
| 8 | 7.1 | 480 | 336 | 59.98 | 45.67 | 34.00 | 21.00 | 123.60 | 221.50 | 19.69 | 0.20 | 22.39 | 0.04 | 18.80 |
| 9 | 7.2 | 670 | 469 | 43.48 | 8.93 | 72.00 | 82.00 | 99.56 | 248.15 | 28.47 | 0.20 | 21.78 | 0.52 | 3.66 |
| 10 | 7.2 | 460 | 322 | 22.25 | 16.18 | 115.00 | 49.00 | 95.36 | 272.84 | 9.52 | 0.19 | 2.23 | 0.22 | 2.89 |
| 11 | 7.3 | 1340 | 938 | 43.48 | 37.92 | 41.00 | 35.00 | 124.56 | 155.56 | 12.20 | 0.30 | 7.71 | 0.10 | 6.27 |
| 12 | 7.4 | 1630 | 1141 | 38.59 | 25.25 | 52.00 | 32.00 | 215.60 | 100.00 | 14.89 | 0.20 | 3.58 | 0.28 | 4.04 |
| 13 | 7.2 | 570 | 399 | 43.48 | 23.43 | 50.00 | 63.00 | 78.00 | 266.67 | 11.15 | 0.19 | 4.30 | 0.44 | 11.90 |
| 14 | 7.5 | 1243 | 870.1 | 50.72 | 45.17 | 45.00 | 14.00 | 202.20 | 164.89 | 23.29 | 0.20 | 5.81 | 0.04 | 2.01 |
| 15 | 7.1 | 967 | 676.9 | 88.67 | 27.56 | 21.00 | 18.00 | 164.70 | 145.25 | 19.19 | 0.55 | 5.55 | 0.07 | 3.96 |
| 16 | 7.1 | 410 | 287 | 43.48 | 37.92 | 51.00 | 40.00 | 174.25 | 108.50 | 16.58 | 0.21 | 5.51 | 0.04 | 3.39 |
| 17 | 7 | 1189 | 832.3 | 45.25 | 15.25 | 84.00 | 68.00 | 255.67 | 50.62 | 14.98 | 0.23 | 1.86 | 0.03 | 60.50 |
| 18 | 6.9 | 1520 | 1064 | 55.69 | 40.25 | 34.00 | 18.00 | 162.50 | 102.50 | 21.62 | 0.76 | 1.36 | 0.13 | 3.03 |
| 19 | 7.1 | 1345 | 941.5 | 95.65 | 30.67 | 90.00 | 42.00 | 275.63 | 180.25 | 30.12 | 0.22 | 3.42 | 0.39 | 16.10 |
| 20 | 7.6 | 1106 | 774.2 | 71.60 | 45.89 | 41.00 | 31.00 | 184.56 | 248.15 | 22.02 | 0.20 | 8.76 | 0.11 | 5.07 |
| 21 | 7.2 | 580 | 406 | 24.72 | 16.18 | 55.00 | 24.00 | 110.60 | 103.50 | 6.63 | 0.36 | 0.53 | 0.30 | 17.20 |
| 22 | 7.5 | 870 | 609 | 72.46 | 30.67 | 65.00 | 31.00 | 54.76 | 377.78 | 22.02 | 0.20 | 19.20 | 0.18 | 45.60 |
| 23 | 7.3 | 530 | 371 | 39.35 | 37.92 | 63.00 | 14.00 | 123.60 | 223.46 | 27.40 | 0.19 | 16.32 | 0.07 | 1.29 |
| 24 | 7.2 | 430 | 301 | 22.25 | 16.18 | 85.00 | 35.00 | 56.60 | 248.15 | 33.03 | 0.21 | 6.98 | 0.19 | 25.50 |
| 25 | 7.1 | 510 | 357 | 48.58 | 24.56 | 64.00 | 45.00 | 120.70 | 161.73 | 31.14 | 0.21 | 8.27 | 0.08 | 53.20 |

**Appendix-Table 2: Chemical data of the groundwater in pre monsoon in 2006**

| Sno | pH | EC | TDS | Ca | Mg | Na | K | Cl | $HCO_3$ | $PO_4$ | $SO_4$ | $SIO_4$ | F | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.10 | 1120.00 | 784.00 | 72.46 | 23.43 | 78.96 | 17.20 | 125.35 | 288.89 | 0.20 | 14.44 | 38.18 | 1.063 | 5.66 |
| 2 | 7.20 | 290.00 | 203.00 | 21.74 | 37.92 | 15.69 | 5.62 | 145.20 | 85.19 | 0.09 | 8.09 | 16.86 | 0.659 | 7.43 |
| 3 | 7.00 | 810.00 | 567.00 | 74.58 | 32.56 | 34.25 | 15.25 | 116.70 | 196.30 | 0.09 | 6.54 | 11.65 | 0.929 | 9.42 |
| 4 | 7.40 | 1250.00 | 875.00 | 105.40 | 45.17 | 45.25 | 16.21 | 274.00 | 140.74 | 0.92 | 6.94 | 8.76 | 0.626 | 4.7 |
| 5 | 7.20 | 1150.00 | 805.00 | 145.56 | 68.56 | 20.25 | 12.50 | 312.25 | 116.05 | 0.25 | 6.15 | 12.98 | 0.746 | 9.5 |
| 6 | 6.80 | 760.00 | 532.00 | 79.89 | 52.41 | 28.56 | 15.66 | 165.25 | 171.60 | 0.79 | 7.94 | 10.32 | 0.613 | 6.2 |
| 7 | 6.90 | 410.00 | 287.00 | 43.48 | 25.63 | 16.35 | 14.56 | 98.56 | 85.19 | 0.54 | 6.46 | 16.34 | 0.839 | 4.67 |
| 8 | 6.50 | 430.00 | 301.00 | 7.25 | 37.92 | 21.78 | 16.75 | 102.50 | 54.32 | 0.96 | 6.99 | 11.36 | 0.623 | 3.04 |
| 9 | 7.00 | 380.00 | 266.00 | 43.48 | 16.18 | 32.50 | 1.28 | 110.85 | 72.84 | 0.08 | 5.13 | 13.16 | 0.5594 | 5.6 |
| 10 | 6.90 | 330.00 | 231.00 | 65.25 | 23.43 | 32.56 | 6.35 | 256.36 | 79.01 | 0.17 | 8.11 | 6.91 | 0.5592 | 1.5 |
| 11 | 7.00 | 540.00 | 378.00 | 65.22 | 45.17 | 23.56 | 8.88 | 105.00 | 79.01 | 0.08 | 9.26 | 16.91 | 0.983 | 6.59 |
| 12 | 6.70 | 1170.00 | 819.00 | 84.58 | 97.89 | 35.89 | 16.84 | 257.05 | 258.02 | 0.11 | 17.13 | 20.79 | 0.931 | 10.1 |
| 13 | 7.00 | 870.00 | 609.00 | 50.72 | 8.93 | 85.25 | 7.88 | 134.24 | 239.51 | 0.11 | 0.66 | 47.20 | 0.669 | 5.4 |
| 14 | 7.00 | 630.00 | 441.00 | 57.97 | 18.56 | 24.56 | 10.87 | 99.15 | 116.05 | 0.09 | 0.83 | 8.12 | 0.826 | 14.7 |
| 15 | 6.70 | 1500.00 | 1050.00 | 123.69 | 56.58 | 52.58 | 15.65 | 175.18 | 276.54 | 0.24 | 17.16 | 7.54 | 0.945 | 7.46 |
| 16 | 7.10 | 580.00 | 406.00 | 50.72 | 37.92 | 27.98 | 12.05 | 125.60 | 91.36 | 0.10 | 13.17 | 47.32 | 0.764 | 35.1 |
| 18 | 6.80 | 2630.00 | 1841.00 | 141.25 | 98.58 | 21.25 | 14.65 | 216.36 | 350.62 | 0.11 | 10.62 | 33.91 | 0.895 | 7 |
| 19 | 6.90 | 1610.00 | 1127.00 | 121.50 | 75.89 | 11.20 | 10.42 | 204.42 | 264.20 | 0.09 | 23.10 | 25.35 | 0.802 | 33.3 |
| 20 | 7.10 | 821.00 | 574.70 | 7.25 | 52.41 | 93.30 | 2.37 | 116.70 | 264.20 | 0.08 | 12.00 | 67.26 | 0.788 | 12.8 |
| 21 | 7.30 | 598.00 | 418.60 | 72.56 | 23.43 | 42.56 | 8.88 | 135.25 | 103.70 | 0.08 | 11.60 | 29.98 | 1.315 | 4.46 |
| 22 | 6.40 | 125.00 | 87.50 | 14.49 | 1.69 | 45.25 | 10.47 | 72.56 | 79.01 | 0.08 | 4.18 | 28.65 | 1.304 | 2.24 |
| 23 | 7.10 | 1012.00 | 708.40 | 43.48 | 45.36 | 94.25 | 16.66 | 163.48 | 239.51 | 0.17 | 16.01 | 3.73 | 0.864 | 10.1 |
| 24 | 7.20 | 1240.00 | 868.00 | 36.23 | 16.18 | 142.43 | 25.25 | 99.15 | 356.79 | 0.08 | 10.90 | 39.63 | 1.294 | 4.74 |
| 25 | 7.80 | 301.00 | 210.70 | 65.22 | 16.18 | 23.95 | 12.05 | 93.30 | 196.30 | 0.08 | 2.62 | 26.28 | 0.607 | 11.5 |
| 26 | 7.50 | 312.00 | 218.40 | 36.23 | 23.43 | 26.13 | 11.68 | 102.50 | 72.84 | 0.08 | 4.36 | 1.53 | 1.073 | 3.37 |
| 27 | 7.60 | 290.00 | 203.00 | 7.25 | 37.92 | 21.78 | 10.96 | 87.46 | 128.40 | 0.09 | 4.29 | 4.31 | 1.259 | 3.3 |
| 28 | 7.40 | 271.00 | 189.70 | 7.25 | 37.92 | 25.04 | 10.33 | 110.85 | 103.70 | 0.09 | 4.60 | 4.08 | 0.938 | 2.79 |
| 29 | 7.70 | 258.00 | 180.60 | 36.23 | 8.93 | 20.25 | 9.42 | 65.25 | 116.05 | 0.08 | 4.84 | 5.12 | 0.942 | 4.15 |
| 30 | 6.80 | 879.00 | 615.30 | 76.89 | 59.66 | 54.58 | 2.82 | 163.48 | 190.12 | 0.08 | 14.82 | 5.93 | 0.815 | 2.79 |

**Appendix-Table 3: Rotated Factor Verimax-Post-monsoon n=25**

| | Component | | | |
|---|---|---|---|---|
| | Factor 1 | Factor 2 | Factor 3 | Communalities |
| Ca | -0.12 | 0.88 | 0.10 | 0.799 |
| Mg | -0.64 | 0.64 | 0.22 | 0.866 |
| Na | 0.86 | 0.06 | 0.15 | 0.757 |
| K | 0.84 | 0.07 | 0.12 | 0.727 |
| Cl | 0.09 | 0.89 | -0.31 | 0.894 |
| $HCO_3$ | 0.22 | 0.01 | 0.88 | 0.832 |
| $SO_4$ | -0.14 | -0.14 | 0.79 | 0.669 |
| $NO_3$ | 0.54 | -0.23 | -0.17 | 0.369 |
| Eigenvalues | 2.77 | 1.62 | 1.52 | |
| Cumulative % | 34.60 | 54.89 | 73.91 | |

**Appendix-Table 4: Rotated Factor Verimax-Pre-monsoon n=30**

| | Component | | | |
|---|---|---|---|---|
| | Factor 1 | Factor 2 | Factor 3 | Communalities |
| Ca | 0.871 | 0.054 | 0.144 | 0.79 |
| Mg | 0.793 | 0.076 | 0.378 | 0.776 |
| Na | 0.054 | 0.859 | 0.076 | 0.82 |
| K | 0.208 | 0.649 | -0.129 | 0.48 |
| Cl | 0.901 | 0.087 | 0.054 | 0.813 |
| $HCO_3$ | 0.266 | 0.819 | 0.303 | 0.833 |
| $SO_4$ | 0.381 | 0.356 | 0.705 | 0.769 |
| $NO_3$ | 0.076 | -0.127 | 0.889 | 0.812 |
| Eigenvalues | 3.241 | 1.781 | 1.072 | |
| Cumulative % | 40.519 | 62.783 | 76.184 | |