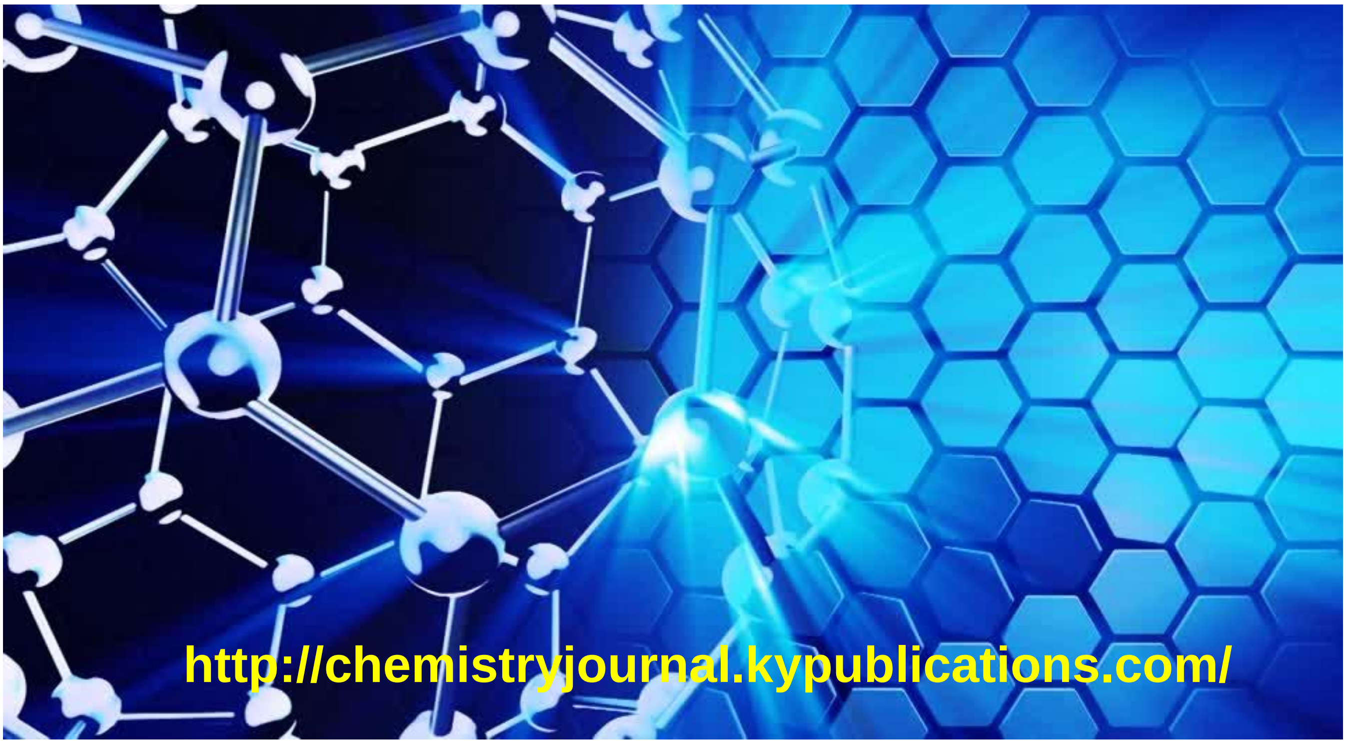

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PHYSICO-CHEMICAL ANALYSIS & GIS-APPROACH FOR MAPPING OF GROUND WATER QUALITY-A CASE STUDY

RESEARCH ARTICLE

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ABSTRACT

The state of Andhra Pradesh, India falls in water stress area. The primary objective of this study is to examine the spatial distribution of different chemical elements with respect to its contamination level of groundwater quality in Anakapalle rural mandal, Andhra Pradesh, India. This has been determined by collecting 270 water samples in three seasons (summer, monsoon & winter) for period of the year 2013 and subjecting the samples to a comprehensive physico-chemical. The aim of the study is to present the data in GIS (kriging method) environment for better understanding the spatial distribution of each chemical parameter and mapping of the current situation of groundwater quality of Anakapalle rural mandal more than 20 chemical parameters of groundwater are selected and compared to the guideline values presented by world health organization (WHO). The water quality index was developed in order to present the overall water quality of the study area. The chemical Index such as SAR, RSC, and KI, % Na, PI and MR were calculated. The results indicated that PI and MR values revealed more than 50% groundwater samples quality is very poor for drinking as well as irrigation practices also.

Keywords: GIS, Groundwater quality parameters, Ordinary Kriging, Groundwater quality index.

INTRODUCTION

Water pollution is a major environmental concern in India. Among the various source of water, groundwater is considered to be the safe for drinking purposes. Groundwater is used for domestic and industrial water supply and also for irrigation purposes in all over the world. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization. According to WHO organization, about 80% of all the diseases in human beings are caused by water[1]. Once the groundwater is contaminated, its quality cannot be restored back easily and to device ways and means to protect it. The greater part of the soluble constituents in ground water comes from soluble minerals in soils and sedimentary rocks. The growing urbanization and industrialization and the consequent pollution of surface water sources, also increased the necessity of using groundwater for various domestic and industrial purposes[3].

Water quality assessment involves evaluation of the physical, chemical, and biological nature of water in relation to natural quality, human effects, and intended uses, particularly uses which may affect human health and the health of the aquatic system itself [4]. The use of GIS technology has greatly simplified the assessment of natural resources and environmental concerns, including groundwater. In groundwater studies, GIS is commonly used for site suitability analyses, managing site inventory data, estimation of groundwater vulnerability to contamination, groundwater flow modelling; modelling solute transport and leaching, and integrating groundwater quality assessment models with spatial data to create spatial decision support systems[5]. A GIS-based study was carried out by various researchers like Ahn and Chon (1999)[6] studied groundwater contamination and spatial relationships among groundwater quality, topography, geology, land use, and pollution sources using GIS in Seoul. Physicochemical aspects of ground water affect quality of water differently in monsoon, summer and winter period. Keeping this in mind, the present study has been therefore designed with the aim to investigate and assess the quality of the surface water in Anakapalle region three seasons of the year 2013 for its suitability by various experimental and theoretical techniques. Considering the above aspects of groundwater contamination and use of GIS in groundwater quality mapping, the present study was undertaken to map the groundwater quality in Anakapalle revenue subdivision (Figure 1), Andhra Pradesh, India. This study aims to visualize the spatial variation of certain physico-chemical parameters through GIS.

Need of the Study

In India, numerous technical and non-technical reports concerning water conservation strategies are available. For example, Survey of India (SoI) topo sheets, Geological survey of India (GSI) surface geological maps, Central Ground Water Board (CGWB) hydro-geologic, water quality, and depth to water maps, all are available only at a scale of 1:25,000 or smaller. These technical maps can best act as primary data sources for decision making at global to regional (district) scale. However, in practice most of the water conservation strategies are to be implemented at regional to local scale. This work bridge the gap between scientific and scale issues by analyzing topographical, hydro-geological, and quality parameters at village scale in a scientific manner. The objective of this user guide is to aid water conservation strategies at village scale through geo-physical and water quality investigations.

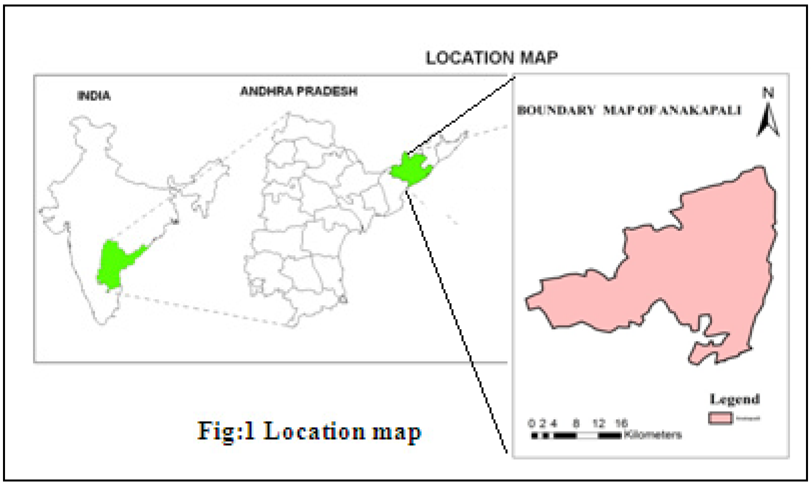

Fig:1 Location map

Study Area

The study area Anakapalle mandal is located in Visakhapatnam district of Andhra Pradesh state in India. Anakapalle is a municipality and sub-district (Mandal) with 31 villages, population of about 1.9 lakh among them about 93 thousand (50%) are male and about 94 thousand (50%) are female. The study area is located between longitude17.6913°N; latitude 83.0039°E on the banks of River Sarada and is covered in the survey of India topographical map numbers 56H65 K/10,11,13,14,15M 65 O/1 and O/2. The area is under influence for fast development of urban agglomeration and industrial growth with mega industries for petroleum, Pharma parks. The present research is carried out in 31 villages of Anakaplle mandal from Summer Season to Winter in three different seasons [(Summer (April-May); Monsoon (August-September)-Winter (November-December)] and tabulated in Table 1.

MATERIAL AND METHOD

GIS-Spatial prediction methods

Geographic information system (GIS) is most effective tool to provide better information for the consumers, policy makers and this helps for taking quick decision. For representing the spatial distribution of sampling locations, the coordinates have been found using the Google Earth satellite view. The interpolation of the water sample values has been done by ordinary kriging interpolation technique in the ArcGIS9.2 software.

ORDINARY KRIGING[12]

Kriging is a linear predictor, meaning that a prediction at any location is obtained as a weighted average of the neighbouring data. The weights used in the kriging estimation are computed so that the variance between the estimated value and the unknown value is minimized**.** Ordinary kriging assumes a constant, but unknown mean, and estimates the mean value as a constant in the searching neighbourhood. Ordinary kriging is mathematically defined as:

$Z(s)=\mu+\varepsilon(s)$

where Z(s) is the value at that location; s is a sampled location; μ is the constant mean and ε(s) are random errors with spatial dependence. The predictor is generated as a weighted sum of the data mathematically defined by the following equation

$\widehat{Z}(s_o)=\sum_{i=1}^{N} \lambda_i Z(s_i)$

where so is the prediction location; N is equal to the number of measured values that will be used to predict the value at the unknown location; λ_i is an unknown weight for the measured value at the i^{th} location, and Z(s*i*) is the measured value at the i^{th} location.

Water quality index [10]

In this study, for the calculation of water quality index, thirteen important parameters were chosen. The WQI has been calculated by using the standards of drinking water quality recommended by the World Health Organization (WHO), Indian council of Medical Research (ICMR) and Bureau of Indian Standards (BIS) has been used for the calculation of WQI of the water body.

The Water Quality Index (WQI) was computed using 10 water quality parameters viz. pH, Total Dissolved Solids, Turbidity, Total Hardness, Fluoride, Chloride, Nitrate, Iron, Sulphate and Dissolved Oxygen of groundwater samples in three seasons on average. WQI indicates a single number like a grade that expresses the overall water quality at a certain area and time based on several water quality parameters.

$W_i = 1/ S_i$

Where, Wi is weightage factor and Si is the highest permitted value of parameter as given by WHO.

$Q_i= \{[(V_{actual}- V_{ideal})/ (V_{standard}- V_{ideal})]*100\}$

Where, Qi is quality rating of parameter, V_{actual} is the mean value of a parameter as obtained from analysis of field samples, $V_{standard}$ is value of water quality parameter as proposed by WHO, V_{ideal} is zero for all parameters except pH where $V_{ideal} = 7$.

$WQI = W_i*Q_i$

The Piper Trilinear Diagram (PTD)[11] is most useful to understand the chemical relationships and problems about the geochemical evolution among groundwater. The chemical quality data of the investigated area are plotted on Pipers Trilinear Diagram for graphical analysis (Figure 9).

Sampling location

Water samples collection: 270 water samples collected during three seasons from Summer Season-Winter in regular intervals in 31 villages/panchayats of Anakapalle sub district. Differential Global Positioning System (DGPS - Trimble) was used to determine the geo-coordinate points of the sampling locations (Table 1). The samples are collected after pumping the well or bore hole for at least an hour. After collection of the samples, the samples are preserved and shifted to the laboratory analysis. Chemical analysis was carried out to determine PH, EC, TDS, TH, Ca, Mg, Na, K, CO_3, HCO_3, Cl-, NO_3, SO_4, Fluoride etc., (Table2) parameters by following standard procedure (APHA-1995)[7] compared with standard values recommended by WHO[8].

The pH, electrical conductivity (EC) and total dissolved solids (TDS) values in samples were recorded in the field itself using Elico Model portable pH-EC-TDS meter instrument. Samples were analyzed in the laboratory for the major ionic concentrations employing standard methods[7]. Concentrations of major cations like Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+) and Potassium (K^+) were determined by flame atomic absorption spectrophotometer and the concentration of major anions chloride (Cl_-), sulphate (SO_4^{2-}) have been determined by ion chromatography. Bicarbonate (HCO_3^-) was determined by acid titration with HCl.

Irrigation water quality[13]

The overall irrigational water quality of the samples collected, certain parameters have been derived. These include – (i) Sodium Adsorption Ratio (SAR), (ii) Soluble Sodium Percentage (SSP), (iii) Permeability Index (PI), (iv) Residual Sodium Carbonate (RSC), (v) Magnesium Adsorption Ratio (MAR) and (vi) Kelly's Ratio/Index (KR/KI). The derived parameters have been shown in Table 3. These parameters help to evaluate the irrigational as well as domestic suitability of ground water in the study area.

Sodium adsorption ratio (SAR): The sodium adsorption ratio (SAR) was calculated using the following equation:

$SAR^* = (Na^+) / \{[(Ca^{2+}) + (Mg^{2+})]/2\}^{1/2}$

Soluble sodium percentage (SSP): It is calculated by the following equation:

$SSP^* = [(Na^+ + K^+)] / [Ca^{2+} + Mg^{2+} + Na^+ + K^+] \times 100$

Permeability index (PI): The permeability of soil is affected by sodium, calcium, magnesium and bicarbonate contents of irrigation water. Doneen[14] calculated the permeability index based on the formula

$PI^* = \{[Na + (HCO_3)1/2)]^*100\} / (Ca + Mg + Na)$

Residual sodium carbonate (RSC): The Residual Sodium carbonate (RSC) is calculated according to[12]: $RSC^* = (CO_3 + HCO_3) - (Ca + Mg)$

Magnesium Adsorption Ratio (MAR) is used for calculating the magnesium hazard caused when it is in equilibrium in groundwater. Magnesium Adsorption Ratio (MAR) is calculated by the equation as:

$MAR^* = (Mg / (Ca + Mg) \times 100$

Kelly's index (KI): Kelly [15] devised an equation for the sodium problem in water.

$KI^* = Na / (Ca + Mg)$

*All concentrations are in meq/L.

RESULTS AND DISCUSSION

Contamination of the groundwater of the Anakapalle Mandal ground water is a major continuing problem not only due to the existence of different point and non-point contaminating sources but also due to the high vulnerability of the aquifer to pollution. Human activities such as the unmanaged handling and dumping of solid wastes, the improper disposal of wastewater, and the concentrated agricultural practices have contributed to the current deteriorating quality of Anakapalle mandal ground water quality. The major ion chemistry of the area showing various quality parameters are given in the Table 2 and types of samples, GPS location of samples given in Table1.

The pH (hydrogen ion concentration) of water is very important indicator of its quality as it depends on the presence of phosphates, silicates, borates, fluorides and some other salts in dissociated form. In general waters having pH between 6.5 and 8.5 are categorized as suitable, whereas waters with pH 7.0 to 8.0 are highly suitable for all purposes. In the present investigation all water samples in three seasons from Summer Season to Winter are within the permissible limits (Table 2)

Electrical conductivity of water is also an important parameter for determining the water quality. It is a measurement of water's capacity for carrying electrical current and is directly related to the concentration of ionized substance in the water. In the present study, EC values of ground water ranged in three seasons in between 2459 µmhos/cm to 2696 µmhos/cm with mean value of 2545 µmhos/cm in Summer Season; between 3043 µmhos/cm to 3463 µmhos/cm with mean value of 3244 µmhos/cm during monsoon and between 2230 µmhos/cm to 2412 µmhos/cm with mean value of 2309 µmhos/cm during Winter seasons. Distribution of EC in samples is shown in Figure 2.

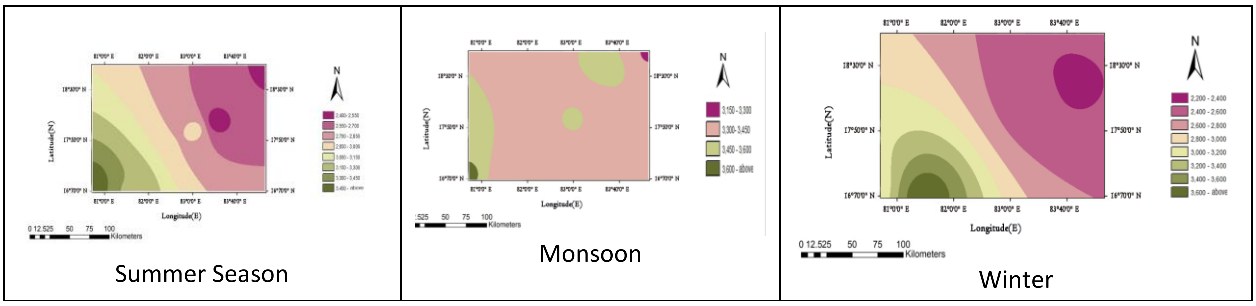

Figure 2: Special distribution maps of EC from Summer Season to Winter Season in 2013

Total dissolved solids (TDS) concentrations is the primary indicator of the total mineral content in water and are related to problems such as excessive hardness. TDS in the water samples of the study area varied from 1568 mg/Lto 1634 mg/Lwith mean value of 1601 mg/Lduring Three seasons of Summer Season.where as in monsoon these values are varied from 1905 mg/Lto 2154 mg/Lwith mean value of 2021mg/L and in Winter 2215 mg/Lto 2354 mg/Lwith mean value of 2275 mg/l. The higher values of TDS are attributed to application of agricultural fertilizer contributing the higher concentration of ions into the groundwater. The distribution of TDS in the surface water samples of the study area is depicted in Figure 3.

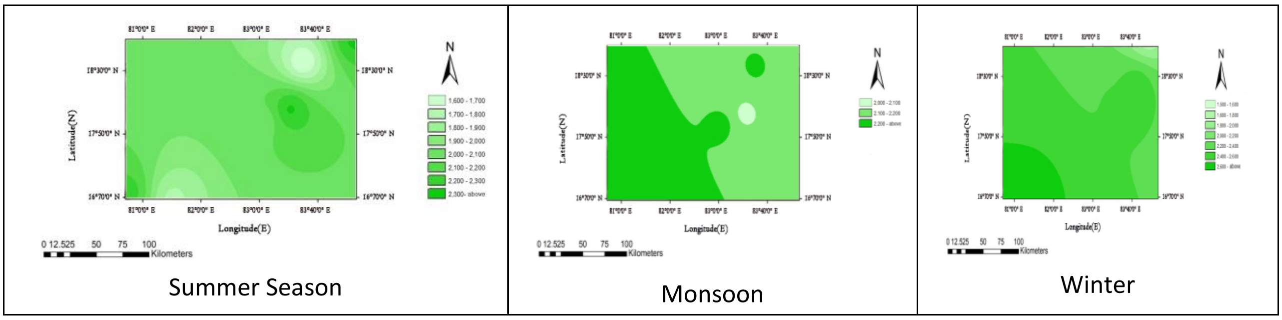

Figure 3: Special distribution maps of TDS from Summer Season to Winter Season in 2013

In groundwater hardness is mainly contributed by bicarbonates, carbonates, sulphates and chlorides of calcium and magnesium. So, the principal hardness causing ions are calcium and magnesium. The acceptable limit of total hardness is 300 mg/Whereas the maximum limit is 600 mg/L[8]. The hardness of analyzed water samples varied from 119.20 to 135.11 mg/Las $CaCO_3$. The highest value of total hardness 780 mg/L was observed in Winter water samples and in Monsoon season of Winter (836.37 mg/L) (table 1). other values vary between 567 mg/L to 587 mg/L with an average of 576 mg/Lin monsoon and in values vary between 587 mg/Land 672 mg/L with an average of 625 mg/L(Table 2). Within the three period waters winter sample is much harder compared to other seasons as evident from figure 4 which depicts the spatial distribution of hardness during both the periods.

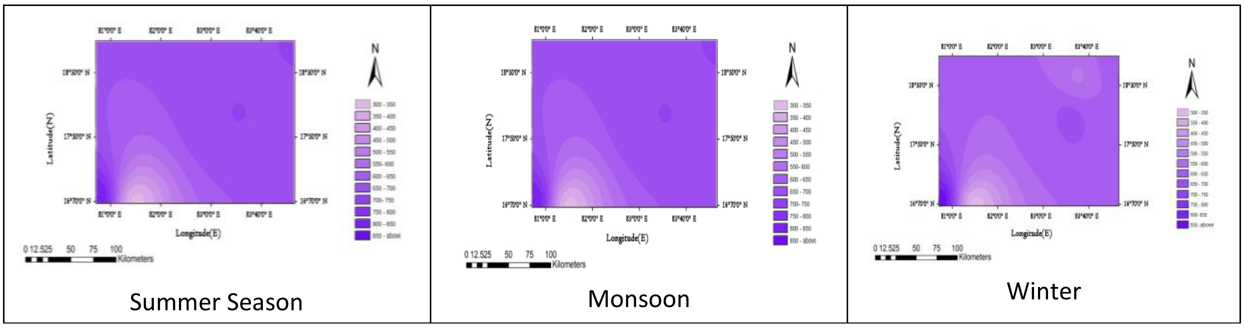

Figure 4: Special distribution maps of Total Hardness from Summer Season to Winter Season in 2013

The chloride content in most of the samples taken from hand pump and few samples from bore well have high chloride concentration and some much higher the permissible limit of 200 mg/l. This may be due to its wide distribution in natural environment. Calcium (Ca) ion concentration in Summer Season with an average value of 157 mg/L, in monsoon it was 159 mg/Land in winter it was 202. The desirable limit of Calcium (Ca) for drinking water is specified by BIS (1991) as 75 mg/Land a maximum permissible limit of 200 mg/L. It is observed that Anakapalle all samples were within the permissible limit except in winter. Magnesium (Mg) concentration varies from 42 mg/l(Summer Season), 52 mg/L(monsoon) and 57 mg/Lin Winter. According to BIS (1991) the desirable values of Mg is 30 mg/Land a maximum permissible limit of 100 mg/l. All samples were within the desirable limit. Presence of DO in water may be due to direct diffusion from air and photosynthetic activity of autotrophs. Oxygen can be rapidly removed from the waters by discharge of oxygen demanding wastes. It is the most important parameter in evaluating water quality.

The DO values obtained in the present study are found within the standards for drinking water. Bio-Chemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are the parameter used to assess the pollution of surface water and ground waters. The values obtained for both these parameters are well within permissible levels (Table 2).

The concentration of chloride is the indicator of sewage pollution and also imparts laxative effect. Porosity soil and permeability also plays a key role in building up the chlorides concentration. The chloride content of studied water samples was exceeding the permissible limit of 250 mg/L prescribed by WHO. In present study, the results of chlorides in all sampling sites from 536 (Summer Season),805 (monsoon) and 824 mg/L(Winter). when compared with seasonal changes, higher values observed in Monsoon seasons (Figure). But in all seasons Cl^{-} concentration it was within the maximum limit of BIS (1000 mg/L).

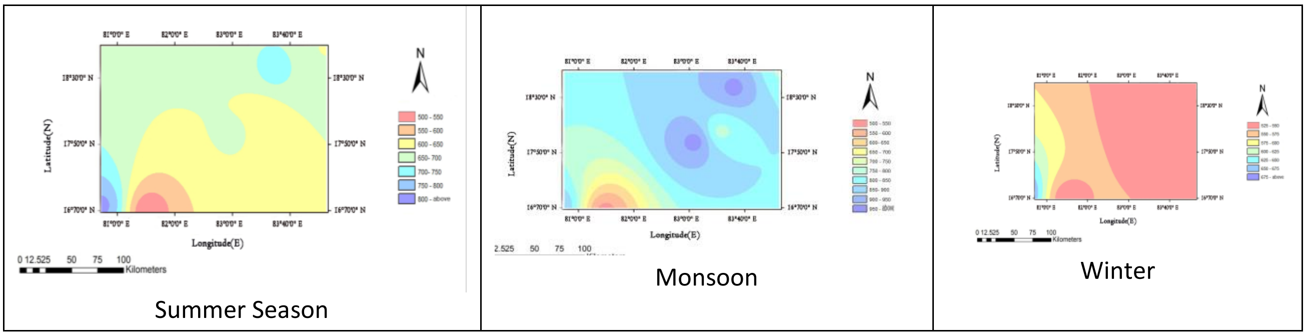

Figure 5: Special distribution maps of Chloride ion from Summer Season to Winter Season in 2013

Sulphate ion will affect the taste of water present in high concentrations (>400mg/L). Sulphate ions do not have any significant detrimental effect on plants and animals. It is essential nutrient for plants. Excess sulphate concentration increases salinity and hardness of water. At levels above 1000 mg/L, sulphate in drinking water can have a laxative effect. As per the BSI standards desirable limit is 200mg/L maximum limit is 400mg/L. Sulfate ion varied from 350-424 mg/L(from Summer Season to Winter Season in 2013). Three seasons of Summer Season and monsoon exceeding the permissible limit. Sulphate cannot readily be removed from drinking water, except by expensive process such as distillation, reverse osmosis or electro dialysis. Figure 6 shows the spatial distribution of 3 periods respectively.

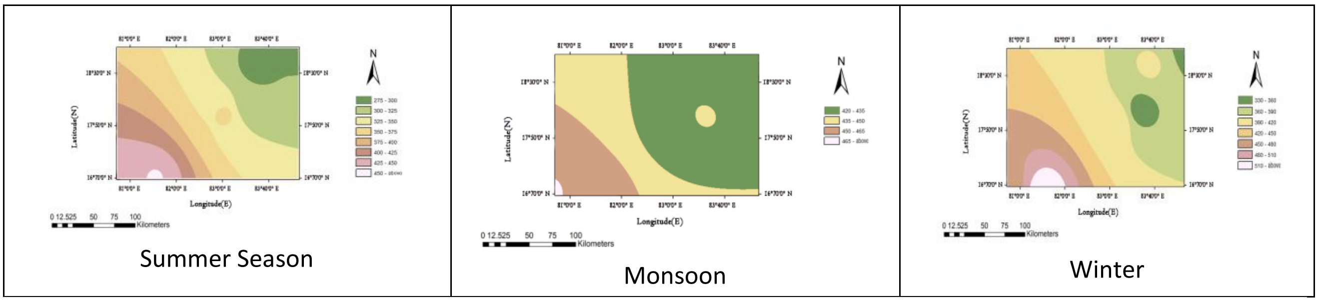

Figure6 : Special distribution maps of sulphate ion from Summer Season to Winter Season in 2013

Sodium is the most abundant element of the alkali-earth group in the earth crust with average value 2.5%. BIS (1991) & WHO (2006) have not given any guideline limit for sodium and potassium in drinking water. Sodium concentration ranged between 80 mg/L to 111 mg/L from Summer Season to Winter (Fig.7). Potassium ion concentration may be harmful to human nervous and digestive system. Potassium concentration ranged between 4 to 6 mg/L from Summer Season to winter (Fig.8). The concentration of potassium in the study area is very low. It is not feasible to assess the suitability of water for drinking purpose as no agency have given any standard with respect to potassium.

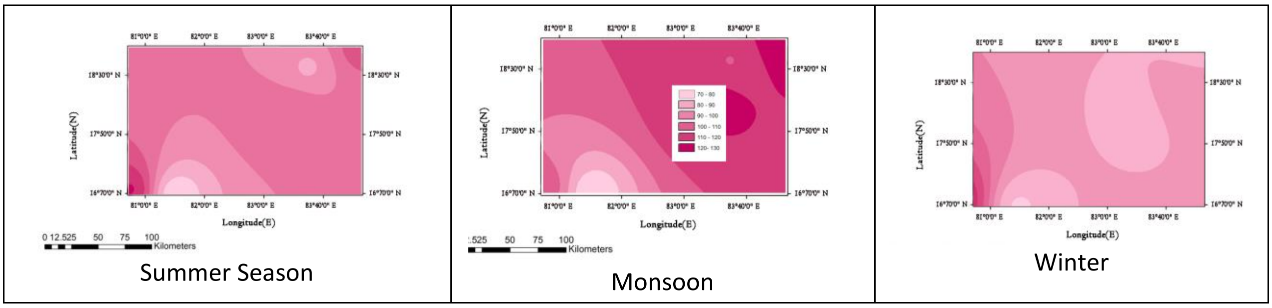

Figure 7: Special distribution maps of Sodium ion from Summer Season to Winter Season in 2013

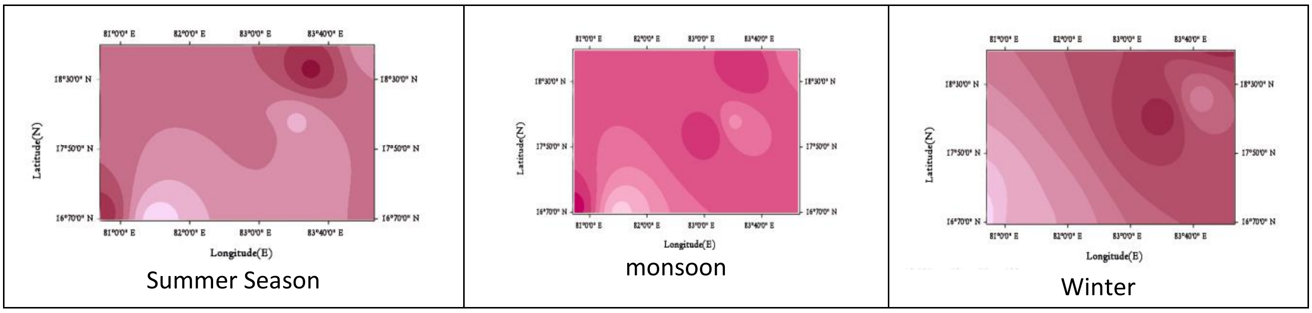

Figure8: Special distribution maps of Potassium ion from Summer Season to Winter Season in 2013

Generally water bodies polluted by organic matter exhibit higher values of nitrate. The concentration of nitrate depends on the activity of nitrifying bacteria which in turn get influenced by DO. In the present study water samples from different sampling stations within the permissible level (40mg/l) except monsoon and winter seasons of Winter (>40mg/l). The high concentration of nitrate in the study area is due to the dumping of solid wastes into the vacant lands. Very few heavy metals are analysed and fallen within the permissible limit.

The suitability of water for drinking purpose is determined from Piper's[16] Trilinear Diagram. It is the graphical representation of chemistry of water samples. The cations and anions are represented by separate ternary plots. The ternary plot is then extrapolated onto the diamond diagram. Piper diagram can predict the water type in three ways – bicarbonate type, sulphate type and chloride type. The bicarbonate type is considered suitable for both drinking and agricultural purpose. Sulphate type is suitable for irrigation. Based on Pipers diagram, the groundwater facies of the area are categorized as alkaline earths exceed alkalies and weak acids exceed strong acids and carbonate hardness exceeds 50%, i. e. chemical properties of water are dominated by alkaline earths and weak acids, few samples also show that no cation – anion pair exceed 50 %.

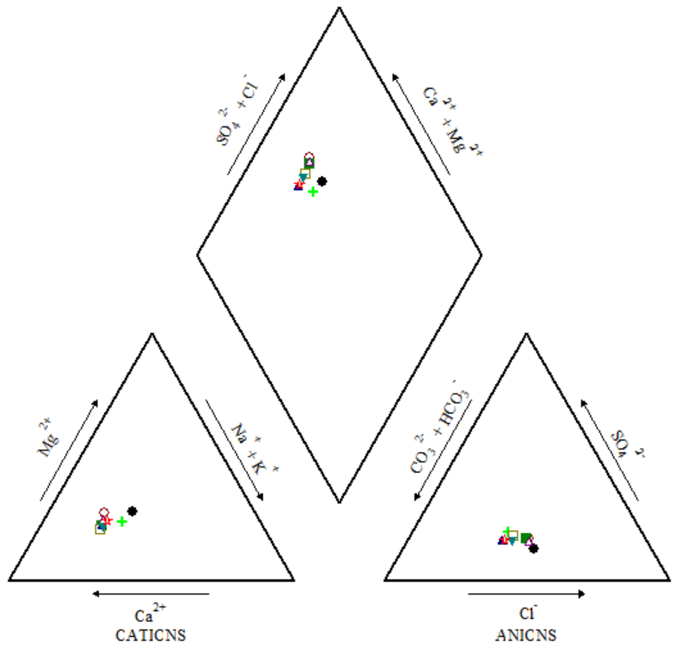

Figure 9: Pipers Trilinear Diagram for graphical analysis

Quality evaluation for agriculture

The water quality for irrigational practices is considered under the following as follows:

SSP: When concentration of sodium ion is high in irrigated water, it tends to be absorbed by clay particles, dispersing magnesium and calcium ions. This exchange process of sodium in water for $Ca^{2+}$and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal draining. As per Todd (1980) SSP values are categorised into suitable (<200) and Unsuitable (>200). Anakapalle ground water fallen suitable category because calculated values for three seasons s and three seasons are less than 200.

KR: Water having KR value less than 1 is considered suitable for irrigation. All samples have KR values less than 1; hence the water is fit for irrigation.

Magnesium Adsorption Ratio (MAR) is used for calculating the magnesium hazard caused when it is in equilibrium in groundwater. MAR is broadly classified into 2 groups. Less than 50 values of groundwater are considered to be suitable for irrigation whereas greater than 50 values are unsuitable. In the present water analysis all samples have the values less than 50; hence the water is fit for irrigation.

Permeability index (PI): The permeability of soil is affected by sodium, calcium, magnesium and bicarbonate contents of irrigation water. Doneen (1964) calculated the permeability index and categorized into 3 types (Table 3). Based on these values calculated values fallen with the second category (80-100).

Residual Sodium Carbonate (RSC): RSC has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose. When the sum of carbonates and bi-carbonates is in excess of calcium and magnesium, there may be a possibility of complete precipitation of calcium carbonate and magnesium carbonate. The concentration of Ca and Mg decreases relative to sodium and the SAR index will be bigger. This will cause an alkalizing effect and increase the pH. Table 3 indicated that the computed RSC values range from 2.32 (Summer Season), 2.45(monsoon) and 2.74 meq/l with an average of 2.48 meq/l revealed that 97% of the samples are within the marginally safe water category as far as RSC is concerned. Figure 10 & 11 shows the spatial distribution of carbonate and bi carbonate concentrations from Summer Season to winter.

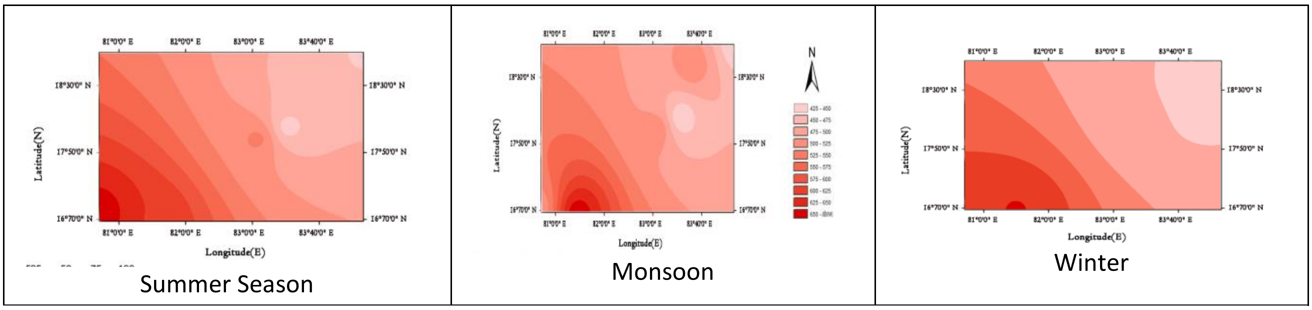

Figure 10: Special distribution maps of carbonate ion from Summer Season to Winter Season in 2013

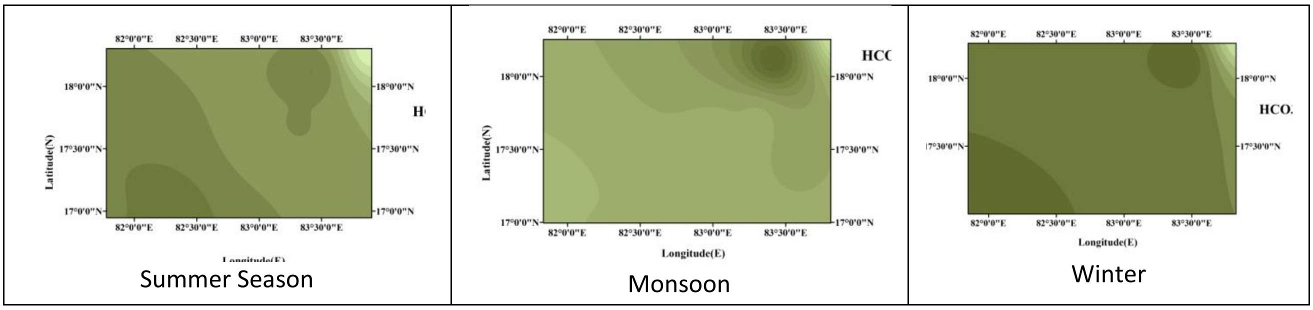

Figure 11: Special distribution maps of bi carbonate ion from Summer Season to Winter Season in 2013

Fluoride ion levels

Groundwater containing fluoride has drawn worldwide attention because of its effect on human health. Fluoride is a trace element typically present in water at levels from 0.1 to 1.5 mg/L. About 62 million people in India are affected with dental, skeletal and /or nonskeletal fluorosis (Sujatha, 2014). Variation in fluoride in collected water sample were 0.68 to 0.92 mg/L approximately 45% (Monsoon); 0.88 to 1.05 mg/L approximately 40% of total collected samples in winter season and 1.52mg/L to 1.94 mg/L of fluoride concentration was observed in 16% of total water samples and identified that need of urgent defluoridation process in summer seasons respectively and figure 12 shows the spatial distribution of 3 periods respectively

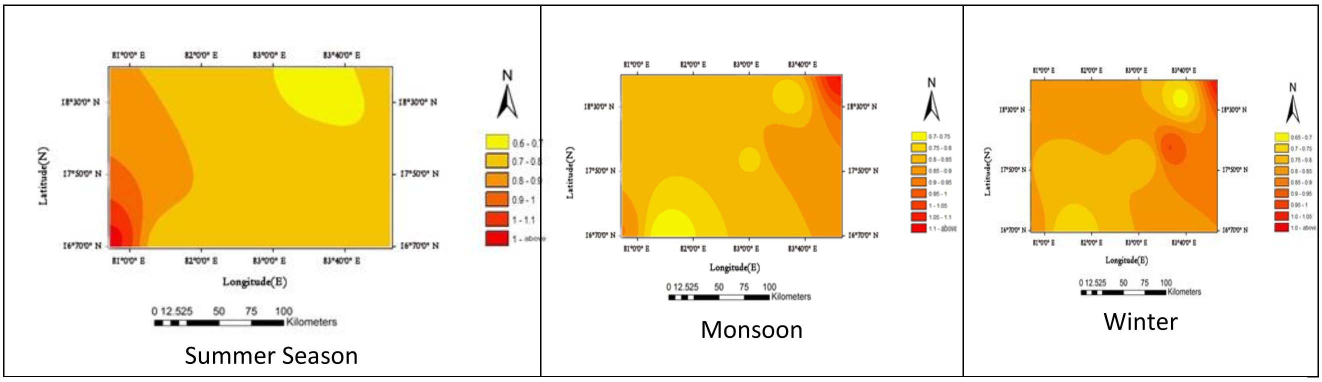

Figure 12: Special distribution maps of Fluoride ion from Summer Season to Winter Season in 2013

Water quality index (WQI)

A water quality index is a means to summarize large amounts of water quality data into simple terms for reporting to management and the public in a consistent manner. The present water quality shows poor quality in three seasons. Variation in water quality index in collected water sample were 74.5 mg/L(Summer Season) 74.82 mg/L (Monsoon), 74.9 mg/L(Winter) and 74.757 mg/L(on average of three seasons) respectively. The water needs further treatment and then can be used for the drinking purpose. The reason of these values of WQI may be the higher values of TDS, Total Hardness etc.,

CONCLUSIONS

On the basis of hydrochemical studies, it may be concluded that the quality of groundwater in certain parts of Anakapalle sub district is affected and not fit for human consumption. In the study area, many of ionic concentrations in the groundwater are at higher levels indicating that they are problematic in one way or the other, if they are consumed without proper treatment. It is significant to note that ground waters of variable quality exist in this area and the quality of the groundwater is being deteriorated in some parts. This is mainly because of percolation from sewage, waste disposal sites and industrial effluents, As the waters are of very hard type, they may pose problem for domestic use also, in particular washing of clothes because of their adverse action with soap and hence, water softening processes for removal of excess hardness is needed. If this is not feasible, it is recommended that these waters may be used only for some industrial and other purposes

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