CASE STUDY

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GROUNDWATER QUALITY MONITORING AND EVALUATION IN AND AROUND KAKINADA, ANDHRA PRADESH

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PREFACE

The quality of groundwater is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring. Therefore, determination of groundwater quality is important from the point of view to see the suitability of water for a particular use, e.g. public water supply, irrigation, industrial applications, fish culture and power generation etc.

Kakinada, being a coastal area, the groundwater quality of this area is affected due to various reasons, particularly saltwater intrusion, tidal influx of sea water, water logging etc. So far, no detailed investigations, either qualitative or quantitative, on groundwater quality of Kakinada town have been carried out. Hence in the present study a detailed investigations has been carried out to understand the chemical characteristics of groundwater of this region.

Under the project area interaction with regional centres, Environmental Hydrology Division at the Head Quarter at Roorkee proposed to take up the study on "Groundwater Quality Monitoring and Evaluation in and around Kakinada in the East Godavari District of Andhra Pradesh". The study has been carried out jointly by Environmental Hydrology Division, NIH, Roorkee and Deltaic Regional Centre, Kakinada.

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ABSTRACT

The detailed investigations of the chemical quality of groundwater in Kakinada town in the East Godavari District of Andhra Pradesh have been carried out to evaluate the suitability of water for irrigation and domestic applications. The quality of groundwater of the region has been studied based on the complete analysis of twenty nine water samples. Various parameters, viz., pH, conductance, total dissolved solids, alkalinity, hardness, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium have been determined for all the samples and compared with the guidelines to evaluate its suitability for irrigation and domestic applications. The higher values of certain parameters at various locations indicate the influence of sea water and make the water unsuitable for various domestic applications. The values of sodium adsorption ratio indicate that majority of samples falls under the category of low to high sodium hazards.

An attempt has also been made to classify the quality of groundwater on the basis of Stiff, Piper trilinear and U.S. Salinity Laboratory classifications. As per the Stiff classification, most of the samples were found to be of either sodium chloride type or sodium bicarbonate type. In the Piper trilinear diagram, majority of the groundwater samples of the study area fall in the Na + K - Cl + SO_4 hydrochemical facies. According to the U.S. Salinity Laboratory Classification of irrigation water, most of the samples fall under water type C3-S1 (high salinity and low SAR), C3-S2 (high salinity and medium SAR), C4-S2 (very high salinity and medium SAR) and few samples under water type C2-S1 (medium salinity and low SAR) and C4-S4 (very high salinity and very high SAR). It is recommended that any water source must be thoroughly analysed and studied before being used for domestic applications and proper water management strategies should be adopted for agricultural and other developmental activities.

1.0 INTRODUCTION

1.1 General

In India, most of the rural areas, towns and cities do not have access to safe drinking water although the country made spectacular progress in certain areas of science and technology during the last five decades since Independence. There are two sources of drinking water that are available to man. The first one is surface sources which includes lakes, streams, reservoirs etc. and the second one, is groundwater sources which includes wells, borewells and springs etc.

Due to rapid industrialisation and urbanisation and consequent threat of water pollution, the problem of providing safe drinking water to our growing population has become more critical now. Hence the first requirement is to assess the quality, environmental factors influencing quality of groundwater and the available quantity of drinking water in rural and urban set up.

Groundwater is used for domestic supply, industries and agriculture in most parts of the world as it is a replenishable resource and has inherent advantages over surface water. There has been a tremendous increase in the demand for fresh water due to growth in population. The rapid growth of urban areas has affected the groundwater quality due to over exploitation of resources and improper waste disposal. Hence there is always a need for and concern over the protection and management of groundwater quality.

Further, with increasing environmental pollution it is absolutely necessary to ascertain the potability of water before it is used for human consumption. Water is one of the major carrier of several diseases of both chemical and bacteriological origins and hence careful assessment of the quality of water is essential. The quality of groundwater is usually described according to its physico-chemical characteristics. Therefore, the analysis of water samples to determine the abiotic and biotic factors have been attracted considerable attention in the last few years.

The typical uses of water in an urban house hold are confined to drinking, bathing, toilet-flushing, kitchen and laundry uses, utensil cleaning, lawn watering, automobile washing etc. Industries and business establishment in the municipal areas also use a very large amount of water for various purposes. The average consumption of water in urban areas is estimated between 100 to 1500 lit./person/day. About 75-80 % of municipal water supply is ultimately discharged to the drains as wastewater.

The untreated surface and shallow groundwaters are the main source of domestic water supply in the rural areas of our country. Water from these sources is often heavily polluted through the surface washings, seepage from cesspools, septic tanks and manure pits, exposing the population to the dangers of water borne diseases.

Now-a-days, shallow tube wells commonly known as hand pumps have become very popular and are being extensively used in areas where groundwater table is not very deep. Even in coastal areas like Kakinada where regular supply of treated water exists, hand pumps have been installed for domestic purposes. These ground water sources are getting polluted due to the improper disposal of domestic and industrial effluents, salt water intrusion, tidal influx of sea water, extensive use of fertilizers and pesticides for higher crop yields etc. At many places, surroundings of these hand pumps are very unhygienic, and hence water from this source is sometimes suspected as a carrier of enteric infections. Hence it becomes necessary to monitor the groundwater quality of the area to assess its suitability for various uses. The study has been carried out to observe and understand the variation in quality of shallow groundwater, sea water and aquaculture ponds effect, effect of salt water creek, to delineate the potable and non-potable zones.

Keeping this in mind, the study has been planned with the following three objectives :

1. To see the suitability of water for various uses particularly drinking and irrigation purposes.

2. To determine correlations among water quality constituents.

3. To assess extent of contamination through regular monitoring of groundwater quality.

1.2 Review

Groundwater resources are observed to be depleting while the demand is ever increasing. Pollution of this basic commodity assumes greater importance in this context. The major occupation in India being farming, rendering of vast stretches of fertile land useless while the farmers take to other professions for livelihood should be viewed seriously. It is therefore considered essential that pollution control measures are strictly followed. The people have to organise and push the administrative machinery to enforce rules.

In India, the Central Ground Water Board (CGWB) is maintaining monitoring stations throughout the country to measure the condition and trends of groundwater quality and quantity in relation to standards and guidelines and is to a great extent representing the total special situation particularly in Indo-Gangetic valley. Some of the State Groundwater Departments are also monitoring the water quality and quantity of their states. However, limited case studies have been carried out in the important cities and coastal areas.

Muralikrishna and Sumalatha (1992) have studied the ground water quality of Kakinada area. They have reported that the quality of groundwater in the area is safe for drinking as well as construction purposes. They also recommended that any water source must be thoroughly analysed and studied before being used for domestic or construction purposes.

Ramaswami and Rajaguru (1991) have conducted study on groundwater quality at Tiruppur town in Coimbatore district of Tamil Nadu for the assessment of groundwater quality to evaluate the impact of industrialization and improper waste management. Their findings indicate that values of several parameters exceeded the permissible limits pointing out to the necessity of proper treatment and disposal of wastes discharged into the area.

Ravichandran and Pundarikanthan (1991) have attempted to evaluate the quality of groundwater in the city of Madras with the context of polluted waterways of the city. A total of 150 groundwater samples were collected based on square km grid pattern within the city limits. The results show that between Buckinghum canal and coastline in North Madras area, the chloride concentration is increasing towards coast due to saline intrusion. Multiple regression analysis conducted by the authors indicated that the area around the north Buckingham canal may have regional contamination taking place from the near by waste sources.

Govardhan (1990) carried out the study on groundwater pollution in different mandals of district Nalgonda, A.P. The study concludes that the groundwater during the complex flow history passes through various geological formations and also interacts with the surface water bodies leading to the consequent pollution in the shallow aquifers. The study also shows that the concentration of heavy toxic metals in shallow aquifers in the area is much higher than the permissible limits. It was also suggested that groundwater from the deeper aquifer may be tapped for drinking purpose to avoid the health hazards as a consequent of polluted shallow aquifers in different localities of the district.

Narayana and Suresh (1989) have studied the chemical quality of groundwater of Mangalore city, Karnataka. They concluded that the groundwater of Mangalore is of Na-Ca-Cl, Na-Ca-HCO_3, Na-Ca-Cl- HCO_3 and Ca-Mg-Cl types and the city has two distinct groundwater zones namely Na-Ca-Cl and Na-Ca-HCO_3. Variation in the groundwater chemistry may be attributed to (i) topographic variation with corresponding changes in the vegetative cover and (ii) high conductivity along the estuary that is due to sea water intrusion.

Elengo (1992) have carried out the study on groundwater quality in coastal regions of South Madras. Their result shows that in most parts of the study area the water is suitable for domestic and irrigational use. However, there are few places where the water is not suitable even for irrigation.

Vijayaram (1989) have carried out the pollution studies of groundwater in Sembattu, Tiruchirapalli in relation to surface disposal of garbage, sewage and other industrial wastes and reported that most of the groundwater samples are not suitable for the purpose of drinking, irrigation and industrial utilisation.

1.3 Scope of the Study

The quality of groundwater is the resultant of all processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring. Therefore, The quality of groundwater varies from place to place with the depth of water table. It may also vary with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it. The kind and concentration of dissolved solids depends on the source of salts and sub-surface environment.

Kakinada, being a coastal area, the groundwater quality of this area may change due to various reasons like saltwater intrusion, tidal influx of sea water, water logging, domestic and industrial contamination etc. The groundwater quality variation problem can be understood only by regular monitoring of quality of water. Due to rapid urbanisation of Kakinada town the quality of groundwater may deteriorate further in future. Therefore, it was proposed to take up water quality monitoring work in Kakinada area. Samples from 29 dug wells scattered in and around Kakinada town have been collected from shallow unconfined aquifers for evaluation of the quality of water of the region.

2.0 SOURCES OF GROUNDWATER CONTAMINATION

There are many sources that contribute contaminants to the groundwater. The major sources which contribute to pollution problems are:

- Land disposal of solid wastes,
- Sewage disposal on land,
- Agricultural activities,
- Petroleum leakage and spills,
- Deep well disposal of liquid wastes, and
- Urban runoff and polluted surface water

2.1 Land Disposal of Solid Wastes

Solid wastes (mostly garbage and industrial waste) is disposed in landfills where it decomposes and produces a leachate that can contaminate underlying groundwater. Landfills range from unmanaged dumps where refuse is piled up with little or no regard for environmental effects, to carefully designed and operated "Sanitary" landfills.

The amount of leachate produced in a landfill depends on the amount and distribution of rainfall, hydraulic conductivity of cover soil (if any), evaporation from cover soil and freezing and thawing. If the soil below the fill is relatively impermeable, percolation of leachate to underlying ground water is retarded. The chemical composition of landfill leachate depends on the nature of the refuse, on the leaching rate and on the age of the fill.

The hardness of leachate and contaminated ground water is due to the dissolution of Ca and Mg compounds by CO_2 (which forms carbonic acid) produced by the decomposition of the refuse. The type of leachate produced depends upon the type of refuse.

Landfills are point source of pollution and the leachate movement in the sub soil forms a narrow band or plume, unless of course, the ground water is stagnant.

2.2 Sewage Disposal on Land

Sewage enters the ground intentionally from septic tanks, cesspools and systems where sewage is applied to land for crop irrigation, ground water recharge or simply disposal. Unintentional entry of sewage into the underground environment include leakage from sewers, sewage lagoons and from streams or dry washes in which sewage effluent is discharged.

The capability of soil to remove suspended and dissolved constituents from sewage is utilized in land treatment systems, where sewage is applied to land with sprinklers, irrigation furrows or borders, or infiltration basins.

2.3 Agricultural Activities

Modern agriculture is based on extensive use of fertilizers and pesticides to obtain high crop yield. Some of the chemicals applied to farm land, however, move down with the deep percolating water from the root zone and can contaminate underlying groundwater. Manure piles, feedlots and similar concentrations of animal waste are other possible sources of ground water contamination. Deep percolation water from irrigation fields in arid region tends to have high salt content, which adversely affects underlying ground water. With the exception of manure piles, agriculture is an area of diffuse source of groundwater contamination. In humid areas the major contaminant is nitrate, where as TDS and NO_3 are of most concern in arid irrigated areas.

2.4 Petroleum Leakage and Spills

Gasoline and other petroleum products can enter soils and aquifers from leaking pipelines or storage tanks and from accidents involving tank, trucks or rail road cars. Most ground water contamination cases are caused by underground tanks from gasoline stations. The main problem of petroleum contamination of ground water is taste. Toxicity is not a problem because the water is already undrinkable due to taste and odour well before concentrations reach toxic levels.

2.5 Deep Well Disposal of Liquid Wastes

Injection of liquid wastes, mainly of industrial origin, has been widely adopted as a waste disposal practice. The purpose of this procedure is to isolate hazardous substances from the biosphere. As the discharge of pollutants to rivers and lakes has become increasingly objectionable, and as legislation for protection of surface water resources have become more stringent, the use of deep permeable zones for liquid waste disposal has become an increasingly attractive waste management option for many industries.

Deep injection of liquid wastes causes a point source of ground water pollution and contaminates the deeper aquifers, otherwise safe from pollution. Due to deep injection, the pollutants traverse relatively a thin column of soil and also the time lag between the pollution discharge and arrival of pollutants to ground water is reduced.

2.6 Urban Runoff and Polluted Surface Water

Many streams receive municipal and industrial waste water. Seepage of such water into underlying ground water may adversely affect ground water quality. Urban runoff may infiltrate directly into the ground through pavements after it has reached a stream, or via recharge pits or "dry wells" constructed for disposal of storm runoff.

3.0 DESCRIPTION OF THE STUDY AREA

The study area, Kakinada also called the Port city, is situated in the East Godavari District of Andhra Pradesh on the seashore of Bay of Bengal. It is the capital of the East Godavari District. The confluence of river Gowthami Godavari with Bay of Bengal is just 30 kms from Kakinada at Yanam. Geographically the study area is located at 16^0 56' N latitude and 82^0 15' E longitude at about 3.9 m above mean sea level. The area of the city is 31 sq. km. with a population of 2,79,875 according to 1991 census.

3.1 Physiography

The study area is almost a plain terrain slightly sloping towards Bay of Bengal with the elevation varies from 2.6 meters at Port station to 3.9 m. There are no hills in the study area and also there is no forest area. East of the Vakalpudi area is covered with marshy swamps and somewhat polluting the groundwater nearby.

3.2 Drainage and Water Supply

The study area is served by medium and minor drains draining the waste water into Bay of Bengal through salt water creek. The major drain is the Chideela pora, started from Nagamallithota area and flowing through the city and joining the salt water creek, named, upputera. All the drains are joining this salt water creek and finally joining the sea. Main cargo handling of the ships is done through this salt water creek. This creek is dividing Kakinada into two parts named Kakinada town and Jagannadha puram.

The Yeleru drain bifurcates at Samalkot into East and West Yeleru drains and joining the salt water creek after Indrapalem locks. Another irrigation drain called Gaderu drain coming from Sarpavaram area is joining the Yeleru east drain near Pratapnagar and finally joining the salt water creek, down of the

Indrapalem locks.

The water supply for the entire town is of Municipal Supply by the water drawn from the Godavari river from Dowleswaram barrage. The Godavari eastern Main canal from the Head Sluice of the Doweleswaram barrage bifurcates into two canals near Jegurupadu. One branch called Samalkot canal after flowing through Dwarapudi, Anaparthi, Medapadu etc. reaches to Samalkot lock. Here the water is diverted into the Summer storage tank called Maharshi Samba Murthy Reservoir. The excess water of this canal flowing through Madhav Patnam, V. Krishna Puram reaches to Indrapalem lock and finally into salt water creek. Another branch of the Eastern main canal called Kakinada canal after flowing through Ippanapadu, Tossipudi lock, Chinatapalli lock reaches to Aratlakatla. This water is pumped into the Aratlakatla summer storage tank. The excess water of this canal joins the salt water creek near Kovvur.

The water from the Maharshi Sambamurthy reservoir by gravity and from Aratlakatla summer storage tank by pumping reaches to the victoria water works in the town. From this point after filtration and purification it is distributed for the public.

3.3 Hydrogeology

The area is covered with coastal alluvium of recent origins, consists of fine to medium grain sands with clay and beach sands. As there are no streams or canals across the town the main recharge is due to rain fall only. The average depth of the wells vary from 2.7 to 5.5 m in the area. Depth to water table with respect to ground level varies from 0.6 to 3.5 m. As the water table is at shallow depths, the bore wells are drilled to few mts. only beyond which salt water may intrude into the wells. The groundwater in and around the Kakinada is of variety of tastes from potable to saline due to the influence of sea.

3.4 Climate

Being the coastal region it has tropical climate with hot summers and cold winters. It is very warm in April to June with a maximum temperature of 40^0 C and the coldest months are December and January having minimum temperature of 20^0 C. The minimum temperature during April to June varies from 26 to 29^0 C while the maximum temperature for the same period varies from 35 to 37^0 C. In December and January the maximum temperature varies from 27 to 29^0 C, while the minimum temperature ranges from 19 to 21^0 C.

3.5 Meteorology

The study area has two distinct monsoons, the south west monsoon from June to September and the north east monsoon from October to December with dry period from January to May. More than half of the annual rainfall is brought by the south west monsoon, while the large portion of the rest occur in October and November. The annual normal rainfall of the District is 1159 mm while for Kakinada it is 1095 mm. The average evaporation rate varies from 2.5 to 9 mm/day. The area frequently experiences with heavy cyclones almost every year due to the depression developed in Bay of Bengal during N-E monsoon period. Thunderstorms also brings rainfall to Kakinada during the hot season.

3.6 Land Use

The predominant soil around the Kakinada town is alluvium. The main crops grown around the town are paddy and sugarcane. The sources of the irrigation is the Godavari canal water and sometimes the monsoon rains. There are mainly two cropping seasons namely Kharif and Rabi. The Kharif season commences from June when the irrigation water is released through the canal system from Dowleswaram barrage and extends upto November. The Rabi season is from December to April of the succeeding year. The usual cropping pattern in the study area is

Pady Paddy pulses or fodder crop.

Due to the brackishness of the water, the areas not suitable for irrigation are flourishing with aquaculture along the coast of the sea. As the brackish water aquaculture is growing day by day around Kakinada city, the irrigated fertile lands are also converted into aquaculture farms due to their good returns in money. If this trend continues the fertile lands will become useless for irrigation by slowly depositing salt and at the same time, groundwater may be contaminated.

3.7 Sources of Pollution in the Study area

The mechanism of groundwater pollution is quite different from the surface water and is more complicated. The process of groundwater is much slow and the time lag between pollution discharge at land surface and when pollutants reach groundwater may take several years. According to the World Health Organisation estimate, about 80% of water pollution in a developing country like India is caused by domestic wastes. Especially the intrusion of saltwater into aquifer system in coastal regions depends on the exploitation of groundwater. The intending salt water makes large zones of the aquifer unsuitable for the mankind.

The sources of pollution may vary slightly from place to place and depends on their topographical conditions. Especially the coastal regions may face more problems like saltwater intrusion, cyclonic storms, drainage congestion, backwater of sea, prawn and fish culture, natural tanks etc. other than urban and industrial contamination.

Due to the shallow groundwater table in Kakinada the saltwater intrusion effect may be negligible in middle of the city but the effect is more towards the Bay of Bengal. The main sources of groundwater pollution in Kakinada is as follows :

(i) due to the shallow water table, the rate of infiltration is low and during the monsoon period the rainwater remains on the surface for days together and there is no proper drainage system in the city, the natural system has been disturbed by laying the new roads for colonies growing in the city.

(ii) due to natural tanks and temple tanks which are evenly located in the city. The water in the tanks are totally contaminated. Some of the important tanks are are Annamma Tank, Pindala Tank, Market tank, Raja Tank, Kulayi tank and Boat club tank. The seepage from these tanks may pollute the wells nearby the influence zone of the tanks. All the above tanks are isolated tanks and there is no inter connection between them.

(iii) though there are two big fertiliser industries, namely, Godavari Fertilisers and Chemicals Ltd. and Nagarjuna Fertilisers and Chemicals Ltd. located on the coast and far away from the city and water letting out into the sea from the factories is treated and using natural gas fuel, the pollution to the groundwater from these sources may be negligible.

(iv) due to the salt creek which is flowing in the city at a length of 2 to 3 kms approximately. The creek is being used as navigational and fishing purposes.

(v) inviting the saltwater into the fresh aquifers for aquaculture development and converting the paddy fields to the prawn and fish ponds may cause the groundwater pollution in the area of Kakinada city.

(vi) due to rapid development of built up area in Kakinada city, the huge quantity of domestic waste, seepage from septic tanks may influence the groundwater quality of this region.

4.0 Methodology

4.1 Sampling and Preservation

Sampling is one of the most important and foremost step in collection of representative water sample for groundwater (or any other water) quality studies. Moreover, the integrity of the sample must be maintained from the time of collection to the time of analysis.

During the present investigations twenty nine water samples covering the Kakinada city in the East Godavari District of Andhra Pradesh were collected from different wells for the purpose of studying the water quality of this area. The wells from which samples have been collected, are being used for domestic and irrigation purposes. Two surveys were conducted in the month of October 1994 and January 1995.

The water samples were collected by dip (or grab) sampling method. Depth integrated samples were collected by lowering the container in the open wells. Some parameters like temperature, pH and conductance were measured in the field at the time of sample collection using portable kits. For other parameters, samples were preserved by adding an appropriate reagent.

The samples thus collected, were stored in clean polyethylene bottles fitted with screw caps and brought to the laboratory in the sampling kits for detailed physico-chemical analysis.

4.2 Water Quality Parameters

The quality of water depends on a large number of individual constituents. Some parameters are of special importance and deserve frequent attention and observation, other gives a rough picture of water body and its quality status.

During the present study the chemical properties and constituents of water analysed are pH, conductance, TDS, Alkalinity (carbonate and bicarbonate), hardness, nitrate, phosphate and major cations and anions.

pH

pH value represents the concentration of hydrogen ions (H^+) in water and is a measure of acidity and alkalinity of water. A pH value below 7.0 indicates acidic character while pH greater than 7.0 are inductive of alkaline character of water.
Most natural water range from pH 4 to 9 and are often slightly basic due to the presence of carbonates and bicarbonates.

Electrical Conductivity

Electrical conductivity is a measure of water's capacity for conveying electrical current and is directly related to the concentration of ionized substances in the water. Solution of most inorganic acids, bases and salts are relatively good conductors. Conductivity measurements are commonly used to determine the purity of demineralised water and total dissolved solids in boiler, cooling tower water, irrigation and domestic supply.

Alkalinity (Carbonate and Bicarbonate)

Alkalinity refers to the capability of water to neutralize acids. The presence of carbonates, bicarbonates and hydroxides is the most common cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amounts from the action of carbonates upon the basic materials in the soil. Natural waters may also contain appreciable amounts of carbonates and hydroxide alkalinities, particularly surface waters blooming with algae. The algae take up carbonate for its photosynthesis activities and raise the pH.

Hardness

The hardness of water was originally defined in terms of its ability to precipitate soap. Calcium and magnesium ions are the principle causes although iron, aluminium, manganese and hydrogen ions are capable of producing the same effect. High concentrations of the letter ions are not commonly found in natural waters. In conformity with current practice, total hardness is defined as characteristic of water which represents the total concentration of calcium and magnesium expressed as their calcium carbonate equivalent. Temporary hardness is caused by the presence of bicarbonates of calcium and magnesium, whereas permanent hardness is mostly due to sulphates.

Chloride

Chloride is one of the major inorganic anion in water and wastewater. It is present in all potable water supplies and in sewage, usually as a metallic salt. When sodium is present in drinking water, chloride concentration in excess of 250 mg/L give a salty taste. High chloride concentrations in water are not known to have toxic effects on man, though large amounts may act corrosively on metal pipes and be harmful to plant life. The maximum allowable chloride concentration of 250 mg/L in drinking water has been established for reasons of taste rather than as a safeguard against physical hazard.

Sulphate

Sulphate appears in natural waters in a wide range of concentrations. Mine waters and industrial effluents frequently contain large amounts of sulphate from pyrite oxidation and the use of sulfuric acid. Sodium and magnesium exert cathartic action and hence its concentration above 250 mg/L in potable water is objectionable. Sulphate cause a problem of scaling in industrial water supplies and problem of odour and corrosion in wastewater treatment due to its reduction to hydrogen sulfide.

Nitrogen

In water the forms of nitrogen of greatest interest are, in order of decreasing oxidation state, nitrate, nitrite, ammonia and organic nitrogen. All these forms of nitrogen, as well as nitrogen gas, are biochemically interconvertible and are components of the nitrogen cycle.

Total oxidized nitrogen is the sum of nitrate and nitrite nitrogen. Nitrate generally occurs in trace quantities in surface water but may attain high levels in groundwater. High levels of nitrate in water indicate the introduction of biological waste or contamination due to leaching from heavily fertilised fields. Nitrate rich effluents discharged into receiving waters can degrade water quality by encouraging excessive growth of algae. Drinking waters containing excessive amounts of nitrates can cause infant methaemoglobinaemia (blue babies). For this reason a limit of 10 mg nitrate as nitrogen/L has been established in public drinking water supplies.

Phosphate

Phosphorous occurs in natural waters and in wastewaters almost solely as phosphates. Phosphates are used widely in municipal and private water treatment systems and are commonly grouped into three types. Orthophosphates, condensed (pyro, meta or poly) phosphate, and organically bound phosphate. The orthophosphate is the only form determined directly. The other types require pretreatment for conversion to the orthophosphate form for analysis.

A certain amount of phosphate is essential to organisms in natural water and is often the limiting nutrient for growth. Too much phosphate can produce eutrophication or over fertilization of receiving waters, especially if large amounts of nitrates are present. This results in the rapid growth of aquatic vegetation in nuisance quantities and an eventual lowering of the dissolved oxygen content of the lake or stream due to the decay of aquatic vegetation.

Sodium

Sodium, the sixth most common element, is present in nearly all natural waters. The levels may very from less than 1 mg/L to more than 500 mg/L. Ratio of sodium to total cations is important in agriculture and human pathology. Soil permeability can be harmed by a high sodium ratio.

Potassium

Potassium ranks seventh among the elements in order of abundance, yet its concentration in most drinking waters seldom reaches 20 mg/L. However, occasional brines contain more than 100 mg/L potassium. Potassium is less common in the groundwater .

Calcium

Calcium is one of the principle cations in groundwater. In the sedimentary rocks, calcium occurs as carbonates; and in alluvium it occurs as limestone. Calcium carbonate imparts the property of hardness to water together with sulphate, carbonates and bicarbonates.

Magnesium

After calcium, magnesium is the most important alkaline earth metal present in the groundwater. It is one of the important contributor to the hardness of water. The magnesium concentration in water may vary from practically zero to several hundred ppm, depending on the source of water.

4.3 Analytical Methods

Physico-chemical analysis were conducted following User's Manual on Physico-chemical Analysis of Water and Wastewater (Jain and Bhatia, 1987). Some parameters like temperature, pH and electrical conductance were determined in the field at the time of sample collection using portable meters.

Chloride was estimated by argentometric method in the form of silver chloride. Alkalinity was determined by titrimetric method using phenolphthalein and methyl orange indicator.

Total hardness and calcium hardness were determined by EDTA titrimetric method while magnesium hardness was calculated by deducting calcium hardness from total hardness. Calcium (as Ca^{++}) was calculated by multiplying calcium hardness with 0.401 while magnesium (as Mg^{++}) by multiplying magnesium hardness with 0.243.

Nitrogen in the form of nitrate was determined by using UV-VIS spectrophotometer.

Sodium and potassium were determined by flame-emission method using flame photometer.

Phosphate was estimated by stannous chloride method in the form of molybdenum blue while sulphate by gravimetric method.

The summary of analytical methods and equipment used in the study are given in Table 1.

Table 1. Summary of Analytical Methods and Equipment Used

Parameter	Analytical method	Equipment used
pH	Electrometric	Portable pH meter
Conductivity	Wheatstone bridge	Conductivity meter
Temperature	Thermometric	Thermometer
TDS	Gravimetric	-
Alkalinity	Titrimetric	-
Hardness	Titrimetric	-
Calcium	Titrimetric	-
Magnesium	Titrimetric	-
Chloride	Silver nitrate	-
Sulphate	Gravimetric	-
Phosphate	Ascorbic acid	Spectrophotometer
Nitrate-nitrogen	UV absorbance	Spectrophotometer
Sodium	Flame-emission	Flame photometer
Potassium	Flame-emission	Flame photometer

5.0 RESULTS AND DISCUSSION

The quality of groundwater, as determined by its chemical and biological constituents, its sediment content and temperature is of great importance in determining its suitability for a certain use, such as public water supply, irrigation, industrial application etc. Generally higher proportion of dissolved constituents are found in groundwater than in surface water because of greater interaction of groundwater with various materials in geologic strata. Presence of some minerals, beyond a certain limit may make the water injurious for public water supply, irrigation or industrial purposes.

The quality of water also varies from place to place, strata to strata and season to season. The water drown from a place, from certain strata at particular time of year may be unsuitable whereas it may be good enough at the other times of the year. Water should therefore meet the standards for the specific use to which it is put.

In the present study, groundwater quality variation at different places (Fig. 1), covering Kakinada town in the East Godavari District of Andhra Pradesh, have been evaluated during October 1994 and January 1995 with reference to the suitability of water for various uses and the results are discussed below.

5.1 Hydrochemical Database and Classification

In order to evaluate the quality of groundwater of the study area for various uses, a number of quality parameters have been determined during October 1994 and January 1995 at various locations (Fig. 1) by direct measurement on the spot, or later in the laboratory after taking samples. The hydrochemical data for the two sets of samples collected are presented in Table 2 & 3 respectively.

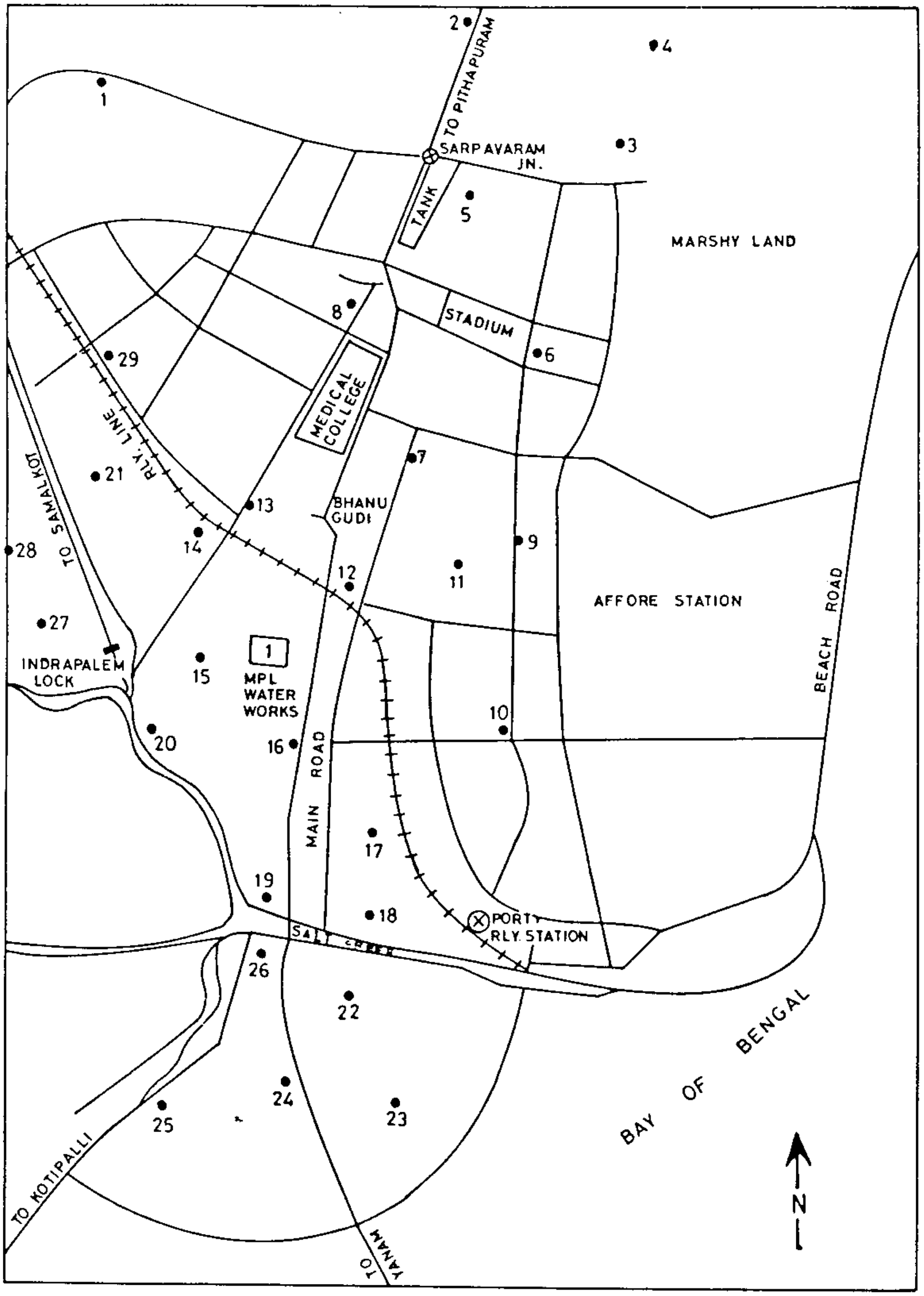

Fig. 1. General Plan of Sampling Locations

INDEX OF THE OBSERVATION WELLS AS SHOWN IN FIG. 1

Well No.	Location
1	Sarpavaram
2	Balaji Nagar
3	Valasapakalu
4	Vakalapudi
5	Ramanayya Peta
6	R R Nagar
7	Madhav Nagar
8	Nagamallithota
9	Godarigunta
10	Sambamurthy Nagar
11	Shanti Nagar
12	Perraju Peta
13	Kondayya Palem
14	Gandhi Nagar
15	Rama Rao Peta
16	Surya Rao Peta
17	Suryanarayana Puram
18	Budam Peta
19	Temple Street
20	Frazer Peta
21	Pratap Nagar
22	Revenue Colony
23	Gogudanayya Peta
24	MSN Charties
25	Turangi
26	Paradesamma Peta
27	Indra Palem
28	Chidiga
29	Madhura Nagar

Table 2. Hydro-chemical Data for the Groundwater Samples (October 1994)

S. No.	Sample Location	pH	Cond µS/cm	TDS	Alk	Hard	Cl	SO4	PO4	NO3	Na	K	Ca	Mg
1	Sarpavaram	7.3	2115	1400	340	674	270	133	0.26	176	180	93	150	60
2	Balaji Nagar	7.2	1036	730	300	276	127	37	0.26	26	100	46	83	26
3	Valasapakalu	7.5	3510	2398	508	688	625	238	0.21	168	400	249	106	102
4	Vakalapudi	7.4	2040	1410	584	440	270	98	0.32	31	280	96	93	50
5	Ramanayya Peta	7.2	1404	900	228	364	179	42	0.47	152	90	80	86	35
6	R R Nagar	7.5	1003	625	240	258	107	50	0.22	12	90	36	60	25
7	Madhav Nagar	7.3	1405	990	308	288	187	102	0.91	61	205	70	73	25
8	Nagamallithota	7.3	2248	1428	320	556	293	121	0.10	145	200	63	110	68
9	Godarigunta	7.2	1773	1234	248	268	277	103	0.66	152	240	132	60	28
10	Samurthy Nagar	7.4	739	472	164	194	61	61	0.23	45	70	36	49	17
11	Shanti Nagar	7.3	734	428	208	160	45	23	0.05	5.0	50	26	41	13
12	Perraju Peta	7.5	2810	1840	516	494	397	126	0.41	133	344	156	99	59
13	Kondayya Palem	7.7	1841	1232	360	238	177	98	1.42	110	220	168	51	26
14	Gandhi Nagar	7.5	1521	1062	384	382	176	82	0.18	57	200	73	86	40
15	Rama Rao Peta	7.4	1081	714	280	296	115	62	0.50	55	90	60	85	20
16	Surya Rao Peta	7.6	1916	1390	476	396	245	92	0.36	55	290	144	75	50
17	Suryanarayana Pura	7.5	1469	1105	452	202	125	100	0.85	30	240	132	46	20
18	Budam Peta	7.4	1263	840	296	224	97	70	0.71	96	130	76	68	12
19	Temple Street	7.5	2490	1832	448	562	367	319	0.66	55	310	168	112	68
20	Frazer Peta	7.5	1306	870	300	300	143	68	0.39	121	110	86	81	23
21	Pratap Nagar	7.4	1352	820	344	300	83	97	0.18	28	110	56	80	24
22	Revenue Colony	7.4	2410	1680	556	542	257	144	0.56	178	265	93	137	48
23	Gogudanayya Peta	7.6	4460	3310	1052	624	807	121	1.80	122	820	292	150	60
24	MSN Charties	7.4	605	390	168	98	53	17	0.08	3.6	70	33	28	8
25	Turangi	7.4	3940	2655	472	1022	789	162	0.06	298	450	156	267	86
26	Paradesamma Peta	7.5	3990	2546	620	768	611	248	0.32	152	440	240	126	109
27	Indra Palem	7.3	3980	2800	630	960	757	355	0.59	92	475	240	232	92
28	Chidiga	7.2	957	685	140	260	125	77	1.30	117	90	39	68	21
29	Madhura Nagar	7.6	87	590	230	252	89	38	0.34	51	65	36	56	26

All values are expressed in mg/L unless otherwise indicated.

Table 3. Hydro-chemical Data for the Groundwater Samples (January 1995)

S. No.	Sample Location	pH	Cond µS/cm	TDS	Alk	Hard	Cl	SO4	PO4	NO3	Na	K	Ca	Mg
1	Sarpavaram	7.3	1915	1240	332	534	158	113	0.76	273	100	81	132	50
2	Balaji Nagar	7.0	770	500	170	244	124	3	0.33	24	72	12	69	17
3	Valasapakalu	7.6	3400	2287	571	704	639	185	0.25	155	480	198	95	113
4	Vakalapudi	7.5	1890	1212	517	372	254	29	0.61	6.2	285	23	85	39
5	Ramanayya Peta	7.2	1380	860	196	386	151	58	1.09	246	82	44	95	37
6	R R Nagar	7.6	890	570	296	298	104	12	0.43	Nil	70	33	67	32
7	Madhav Nagar	7.6	1200	640	310	226	74	10	2.46	26	108	14	50	25
8	Nagamallithota	7.5	2330	1380	396	480	248	83	0.34	222	210	61	127	40
9	Godarigunta	7.6	1570	920	268	226	114	26	2.86	200	164	63	56	21
10	Samurthy Nagar	7.6	1160	830	428	406	102	51	0.27	60	148	7.5	82	50
11	Shanti Nagar	7.5	1570	1130	546	334	166	46	0.21	36	237	41	98	22
12	Perraju Peta	7.6	4200	1498	518	444	330	86	0.75	93	342	31	84	57
13	Kondayya Palem	7.7	1560	1010	304	262	122	41	2.48	213	132	112	51	34
14	Gandhi Nagar	7.4	1500	1022	384	406	178	55	0.41	111	185	35	104	36
15	Rama Rao Peta	7.5	1000	690	268	314	106	30	1.30	98	80	33	88	23
16	Surya Rao Peta	7.5	2350	1385	520	434	214	80	1.08	53	264	50	101	44
17	Suryanarayana Puram	7.6	1610	1172	510	224	184	54	1.30	2.2	250	74	48	26
18	Budam Peta	7.5	1410	1020	460	348	140	44	0.63	53	188	62	80	35
19	Temple Street	7.5	3250	2240	610	888	482	491	1.12	8.0	474	136	265	55
20	Frazer Peta	7.5	1480	1060	334	394	164	49	1.55	157	150	93	104	33
21	Pratap Nagar	7.4	1940	1240	342	600	206	175	0.33	169	145	31	175	40
22	Revenue Colony	7.6	2400	1640	676	522	276	8	2.32	187	340	22	131	48
23	Gogudanayya Peta	7.5	3500	2270	950	420	500	2	1.20	Nil	530	104	72	58
24	MSN Charties	7.7	629	430	184	162	64	30	0.25	6.2	40	56	31	20
25	Turangi	7.7	2840	1836	382	740	484	166	0.40	200	265	76	185	68
26	Paradesamma Peta	7.4	3750	2520	604	864	660	19	0.65	262	420	150	159	114
27	Indra Palem	7.4	3650	2450	668	870	624	318	1.76	151	440	124	151	120
28	Chidiga	7.4	1300	812	136	450	220	100	2.34	124	70	11	131	42
29	Madhura Nagar	7.1	940	620	204	352	72	30	0.12	133	60	3.5	76	39

All values are expressed in mg/L unless otherwise indicated.

Different accepted and widely used graphical methods such as Stiff diagram, Piper trilinear diagram and Wilcox diagram are adopted in the present investigations to study the quality of water. Stiff classification (Stiff, 1951) is used to classify the type of water based on dominant cations and anions. Piper classification (1953) is used to express similarity and dissimilarity in the chemistry of different water samples based on the dominant cations and anions. U.S Salinity Laboratory Classification (Wilcox, 1955) is used to study the suitability of groundwater for irrigation purposes. The results of all the aforesaid classifications are discussed in the following pages.

5.2 Water Quality Evaluation for Domestic Purpose

On the domestic front, water is required for drinking, cooking, washing and bathing. The toxicity is due to excessive total dissolved solids, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium etc. The level of concentration and the toxicity caused by these constituent is discussed below.

pH

A pH range of 6.5 to 8.5 is normally acceptable as per guidelines suggested by WHO (1984) and BIS (1983). The pH value in the study area was always found towards alkaline side and lies in the range 7.2 to 7.7 (Table 2 & 3), which is well within the limits prescribed by WHO and BIS for drinking water.

Conductance

The conductivity value is used as a criterion for expressing the total concentration of soluble salts in water. The conductivity value in the study area varies from 605 to 4460 µS/cm during October 1994 (Table 2) and from 629 to 4200 µS/cm during January 1995 (Table 3) with most of the samples having conductivity value between 1000 to 2000 µS/cm.

Alkalinity

The presence of carbonates, bicarbonates and hydroxides is the most common cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amounts from the action of carbonates upon the basic materials in the soil. The alkalinity values in the study area varies from 140 to 1052 mg/L during October 1994 (Table 2) and from 136 to 950 during January 1995 (Table 3).

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) indicate the general nature of water quality or salinity. Water containing more than 500 mg/L of TDS in not considered desirable for drinking water supplies, though more highly mineralised water is also used where better water in not available. For this reason, 500 mg/L as the desirable limit and 1500 mg/L as the maximum permissible limit has been suggested for drinking water. The TDS value in the groundwater of Kakinada region varies from 390 to 3310 mg/L during October 1994 (Table 2) and from 430 to 2425 mg/L during January 1995 (Table 3), with about twenty five percent samples having TDS value much beyond the permissible limit of 1500 mg/L. The high values of TDS observed in the study area at some places may be either due to either sea water intrusion or tidal influx of sea water. The high value of TDS in groundwater at some places in the study area makes it unsuitable for a number of domestic applications.

Sodium

Sodium concentration more than 50 ppm makes the water unsuitable for domestic use. The sodium concentration in the groundwater from Kakinada region varies between 50 and 820 mg/L during October 1994 and between 60 and 480 during January 1995 (Table 3). It is evident from Table 2 & 3 that the concentration of sodium is much higher in most of the samples than the one required for domestic applications and thereby making the water unsuitable even for domestic applications.

Calcium, Magnesium and Total Hardness

Calcium, magnesium and total hardness in the water are inter-related and hence combined in the description. The upper limits for calcium and magnesium for drinking water and domestic use are 75 and 30 mg/L respectively (BIS, 1983). In groundwater of the area under study, calcium and magnesium ranges from 28 to 267 and from 8 to 109 mg/L respectively during October 1994 (Table 2). The same were found to be in the range 31 to 265 and 17 to 114 mg/L respectively during January 1995 (Table 3). Toxicity due to these ions are shown by most of the samples in the study area.

Calcium and magnesium along with their carbonates, sulphates and chlorides makes the water hard, both temporarily and permanent. A limit of 300 mg/L has been recommended for potable waters (BIS, 1983). The groundwater in the area contains these ions in quite high concentrations. The total hardness as $CaCO_3$ ranges between 98 to 1022 mg/L during October 1994 (Table 2) and between 162 to 888 mg/L during January 1995. Such high values of hardness has also been reported by Muralikrishna and Sumalatha (1992). From the hardness point of view, the groundwater of the area is very hard and is not suitable for many domestic applications. Also, hardness produces intestinal troubles and need more fuel and more time to cook.

Chloride

Limits to chloride content have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended for drinking water supplies (BIS, 1983; WHO, 1984). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. A concentration of more than 250 mg/L of chloride makes the water unsuitable for a number of domestic applications. The chloride content in the Kakinada region ranges from 45 to 807 mg/L during October 1994 (Table 2) and from 64 to 660 mg/L during January 1995 (Table 3).

Sulphate

A limit of 150 mg/L has been suggested for drinking water supplies (BIS, 1983). Sulphate content more than 150 mg/L is objectionable for many domestic purposes. Water containing more than 500 ppm sulphate tastes bitter and beyond 1000 ppm, it has purgative effect. The sulphate content in the groundwater of Kakinada region lies well below the permissible value for domestic applications except at few places only.

Nitrate

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L as nitrate has been prescribed by WHO (1994) and BIS (1993) for drinking water supplies. Its concentration above 45 mg/L in drinking water may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may likely to cause carcinogenic diseases. The distribution of nitrate in groundwater of the study area indicates that levels of concentration are high in several parts of the town. The nitrate concentration in groundwater of the study area varies largely with a maximum value of 178 mg/L during October 1994 and 273 mg/L during January 1995.

5.3 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. A good quality water has the potential to cause maximum yield under good soil and water management practices.

However, the quality of irrigation water depends primarily on its silt and salt content. The usefulness of water for irrigation is mainly evaluated based on the following criteria:

Total Concentration of Soluble Salts (TDS)

Water used for irrigation always contains measurable quantities of dissolved substances which, as a general collective term, are called salts. They include relatively small but important amounts of dissolved solids originating from dissolution or weathering of the rocks and soils and dissolving of lime, gypsum and other salt sources as water passes over or percolates through them. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. The total concentration of soluble salts in irrigation water can thus be expressed for the purpose of classification of irrigation water as follows:

Zone	TDS (mg/L)	Conductivity (µS/cm)
Low Salinity Zone	< 200	< 250
Medium Salinity Zone	200-500	250-750
High Salinity Zone	500-1500	750-2250
Very High Salinity Zone	1500-3000	2250-5000

In the study area the TDS value varies from 390 to 3310 mg/L during October 1994 (Table 2) and from 430 to 2425 mg/L during January 1995 (Table 3). Majority of the samples (60-70 %) of the study area falls under high salinity zone, such water cannot be used on soils with restricted drainage. Special management for salinity control may be required and plants with good salt tolerance should be selected. About 30 % samples of the study area falls under very high salinity zone. Very high salinity waters are not suitable for irrigation under ordinary conditions.

Relative Proportion of Sodium to Other Cations (SAR)

While a high salt concentration in water leads to formation of a saline soil, a high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of a water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{[(Ca^{+} + Mg^{+})/2]^{0.5}}$$

The sodium percentage is calculated as;

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for a given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicate little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazard for a given SAR.

The value of SAR in the groundwater samples of the study area ranges from 1.74 to 14.31 during October 1994 (Table 4) and from 1.36 to 11.27 in January 1995 (Table 5). As evident from Table 4 & 5, the groundwater of the study area falls under the category of low to high sodium hazards, which reveals that the groundwater of the study area is susceptible to sodium hazard. Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Medium sodium water presents an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions. This water may be used on coarse-textural or organic soils with good permeability. High sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management like good drainage, high leaching and organic matter additions.

The sodium percentage in the study area was found to vary from 43.2 to 77.8 % during October 1994 (Table 4) and from 6.42 to 75.5 % during January 1995 (Table 5). The high sodium saturation in the water samples of the study area directly causes calcium deficiency.

5.2 Classification of Waters

In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate and salt tolerance of crop. The groundwater of the study area has been classified using Stiff classification, Piper trilinear classification and U.S. Salinity Laboratory classification and results are discussed below and compiled in Table 6 & 7.

Stiff Classification

The Stiff classification (Stiff, 1951) is used in the

Table 4. Values of Sodium Adsorption Ratio and Sodium Percentage (October 1994)

S.No.	Sample Location	SAR	Na%
1	Sarpavaram	3.14	45.1
2	Balaji Nagar	2.45	46.8
3	Valasapakalu	6.65	63.5
4	Vakalapudi	5.82	62.6
5	Ramanayya Peta	2.07	45.4
6	R R Nagar	2.46	48.9
7	Madhav Nagar	5.28	65.2
8	Nagamallithota	3.70	48.2
9	Godarigunta	6.42	72.3
10	Sambamurthy Nagar	2.20	50.8
11	Shanti Nagar	1.74	47.6
12	Perraju Peta	6.76	65.9
13	Kondayya Palem	6.25	74.8
14	Gandhi Nagar	4.47	58.2
15	Rama Rao Peta	2.28	48.0
16	Surya Rao Peta	5.71	65.6
17	Suryanarayana Puram	7.44	77.8
18	Budam Peta	3.82	65.0
19	Temple Street	5.70	61.4
20	Frazer Peta	2.78	54.1
21	Pratap Nagar	2.77	51.0
22	Revenue Colony	4.96	56.3
23	Gogudanayya Peta	14.31	77.6
24	MSN Charties	3.00	65.3
25	Turangi	6.13	53.6
26	Paradesamma Peta	6.93	62.4
27	Indra Palem	6.68	58.3
28	Chidiga	2.45	49.0
29	Madhura Nagar	1.80	43.2

Table 5. Values of Sodium Adsorption Ratio and Sodium Percentage (January 1995)

S.No.	Sample Location	SAR	Na%
1	Sarpavaram	1.88	6.4
2	Balaji Nagar	2.01	41.5
3	Valasapakalu	7.88	64.9
4	Vakalapudi	6.42	63.5
5	Ramanayya Peta	1.81	37.6
6	R R Nagar	1.76	39.4
7	Madhav Nagar	3.11	52.7
8	Nagamallithota	4.16	52.6
9	Godarigunta	4.74	65.9
10	Sambamurthy Nagar	3.18	44.7
11	Shanti Nagar	5.63	62.9
12	Perraju Peta	7.06	63.8
13	Kondayya Palem	3.51	61.7
14	Gandhi Nagar	3.99	52.3
15	Rama Rao Peta	1.96	40.8
16	Surya Rao Peta	5.52	59.6
17	Suryanarayana Puram	7.22	73.8
18	Budam Peta	4.41	58.7
19	Temple Street	6.92	57.6
20	Frazer Peta	3.28	53.0
21	Pratap Nagar	2.57	37.1
22	Revenue Colony	6.46	59.4
23	Gogudanayya Peta	11.27	75.5
24	MSN Charties	1.38	49.8
25	Turangi	4.23	47.6
26	Paradesamma Peta	6.21	56.1
27	Indra Palem	6.49	56.2
28	Chidiga	1.36	24.9
29	Madhura Nagar	1.40	27.8

Table 6. Summarized Results of Water Classification (October 1994)

S.No.	Sample Location	Stiff Classification	Piper Trilinear Classification	U.S. Salinity Laboratory Classification
1	Sarpavaram	Sodium chloride	Ca-Mg-Cl-SO4	C3-S1
2	Balaji Nagar	Sodium bicarbonate	Ca-Mg-CO3-HCO3	C3-S1
3	Valasapakalu	Sodium chloride	Na-K-Cl-SO4	C4-S2
4	Vakalapudi	Sodium bicarbonate	Na-K-Cl-SO4	C3-S2
5	Ramanayya Peta	Sodium chloride	Ca-Mg-Cl-SO4	C3-S1
6	R R Nagar	Sodium bicarbonate	Ca-Mg-Cl-SO4	C3-S1
7	Madhav Nagar	Sodium chloride	Na-K-Cl-SO4	C3-S2
8	Nagamallithota	Sodium chloride	Ca-Mg-Cl-SO4	C3-S1
9	Godarigunta	Sodium chloride	Na-K-Cl-SO4	C3-S2
10	Sambamurthy Nagar	Sodium bicarbonate	Na-K-Cl-SO4	C2-S1
11	Shanti Nagar	Sodium bicarbonate	Ca-Mg-CO3-HCO3	C2-S1
12	Perraju Peta	Sodium chloride	Na-K-Cl-SO4	C4-S2
13	Kondayya Palem	Sodium bicarbonate	Na-K-Cl-SO4	C3-S2
14	Gandhi Nagar	Sodium bicarbonate	Na-K-Cl-SO4	C3-S1
15	Rama Rao Peta	Sodium bicarbonate	Ca-Mg-Cl-SO4	C3-S1
16	Surya Rao Peta	Sodium bicarbonate	Na-K-Cl-SO4	C3-S2
17	Suryanarayana Puram	Sodium bicarbonate	Na-K-CO3-HCO3	C3-S2
18	Budam Peta	Sodium bicarbonate	Na-K-Cl-SO4	C3-S1
19	Temple Street	Sodium chloride	Na-K-Cl-SO4	C4-S2
20	Frazer Peta	Sodium bicarbonate	Na-K-Cl-SO4	C3-S1
21	Pratap Nagar	Sodium bicarbonate	Na-K-CO3-HCO3	C3-S1
22	Revenue Colony	Sodium bicarbonate	Na-K-Cl-SO4	C4-S2
23	Gogudanayya Peta	Sodium chloride	Na-K-Cl-SO4	C4-S4
24	MSN Charties	Sodium bicarbonate	Na-K-CO3-HCO3	C2-S1
25	Turangi	Sodium chloride	Na-K-Cl-SO4	C4-S2
26	Paradesamma Peta	Sodium chloride	Na-K-Cl-SO4	C4-S2
27	Indra Palem	Sodium chloride	Na-K-Cl-SO4	C4-S2
28	Chidiga	Sodium chloride	Ca-Mg-Cl-SO4	C3-S1
29	Madhura Nagar	Sodium bicarbonate	Ca-Mg-Cl-SO4	C3-S1

Table 7. Summarized Results of Water Classification (January 1995)

S.No	Sample Location	Stiff Classification	Piper Trilinear Classification	U.S. Salinity Laboratory Classification
1	Sarpavaram	Calcium bicarbonate	Na-K-CO3-HCO3	C3-S1
2	Balaji Nagar	Calcium chloride	Ca-Mg-Cl-SO4	C3-S1
3	Valasapakalu	Sodium chloride	Na-K-Cl-SO4	C4-S2
4	Vakalapudi	Sodium bicarbonate	Na-K-CO3-HCO3	C3-S2
5	Ramanayya Peta	Calcium chloride	Ca-Mg-Cl-SO4	C3-S1
6	R R Nagar	Sodium bicarbonate	Ca-Mg-CO3-HCO3	C3-S1
7	Madhav Nagar	Sodium bicarbonate	Na-K-CO3-HCO3	C3-S1
8	Nagamallithota	Sodium chloride	Na-K-Cl-SO4	C4-S2
9	Godarigunta	Sodium bicarbonate	Na-K-Cl-SO4	C3-S1
10	Sambamurthy Nagar	Sodium bicarbonate	Ca-Mg-CO3-HCO3	C3-S1
11	Shanti Nagar	Sodium bicarbonate	Na-K-CO3-HCO3	C3-S2
12	Perraju Peta	Sodium chloride	Na-K-Cl-SO4	C4-S2
13	Kondayya Palem	Sodium bicarbonate	Na-K-Cl-SO4	C3-S1
14	Gandhi Nagar	Sodium bicarbonate	Na-K-Cl-SO4	C3-S1
15	Rama Rao Peta	Calcium bicarbonate	Ca-Mg-Cl-SO4	C3-S1
16	Surya Rao Peta	Sodium bicarbonate	Na-K-Cl-SO4	C4-S2
17	Suryanarayana Puram	Sodium bicarbonate	Na-K-CO3-HCO3	C3-S2
18	Budam Peta	Sodium bicarbonate	Na-K-CO3-HCO3	C3-S1
19	Temple Street	Sodium chloride	Ca-Mg-Cl-SO4	C4-S2
20	Frazer Peta	Sodium bicarbonate	Na-K-Cl-SO4	C3-S1
21	Pratap Nagar	Calcium chloride	Ca-Mg-Cl-SO4	C3-S1
22	Revenue Colony	Sodium bicarbonate	Na-K-CO3-HCO3	C4-S2
23	Gogudanayya Peta	Sodium bicarbonate	Na-K-CO3-HCO3	C4-S3
24	MSN Charties	Sodium bicarbonate	Ca-Mg-CO3-HCO3	C2-S1
25	Turangi	Sodium chloride	Ca-Mg-Cl-SO4	C4-S2
26	Paradesamma Peta	Sodium chloride	Na-K-Cl-SO4	C4-S2
27	Indra Palem	Sodium chloride	Na-K-Cl-SO4	C4-S2
28	Chidiga	Calcium chloride	Ca-Mg-Cl-SO4	C3-S1
29	Madhura Nagar	Calcium bicarbonate	Ca-Mg-Cl-SO4	C3-S1

present study to define the type of water based on the presence of dominant cations and dominant anions. The Stiff graphical method plots four major cations (Ca, Mg, Na+K, Fe) on the left side and four major anions (HCO_3 + CO_3, SO_4, Cl, NO_3) on the right side. The original Stiff plot connects the points on the diagram and produces a pattern which, when compared to another analysis, is useful in making comparisons of waters. In modified Stiff diagram the length of each line defines the concentration of a particular cation and anion. Concentrations on the diagram are expressed in milliequivalents per liter. Since iron and nitrate are normally present in insignificant concentrations, most natural waters can be represented as solutions of three major cations (calcium, magnesium, sodium with or without potassium) and three major anions (bicarbonate plus carbonate, sulphate, chloride with or without nitrate).

The chemical analysis data of all the twenty nine samples have been studied using Stiff classification and the results of the same have been summarized in Table 6 & 7. It is evident from Table 6 & 7 that out of the twenty nine samples analysed, thirteen samples were found to be of sodium chloride type and sixteen samples of sodium bicarbonate type in October 1994 survey. However in January 1995 survey, seven samples were found to be of sodium chloride type, fifteen samples of sodium bicarbonate type, four samples of calcium chloride type and three samples of calcium bicarbonate type.

Piper Trilinear Classification

Piper (1953) developed a form of trilinear diagram which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in groundwater, modifications in the character of a water as it passes through an area, and related geochemical problems. For the Piper trilinear diagram, groundwater is treated substantially as though it contained three cation constituents (Mg, Na+K and Ca) and three anion constituents

(Cl, SO_4 and HCO_3). The diagram presents graphically a group of analysis on the same plot.

The diagram combines three distinct fields of plotting two triangular fields at the lower left and lower right respectively and an intervening diamond-shaped field. All three fields have scales reading in 100 parts. In the triangular field at the lower left, the percentage reacting values of the three cation groups (Ca, Mg, Na) are plotted as a single point according to conventional trilinear coordinates. The three anion groups (HCO_3, SO_4, Cl) are plotted likewise in the triangular field at the lower right. Thus, two points on the diagram, one in each of the two triangular fields, indicate the relative concentrations of the several dissolved constituents of a groundwater. The central diamond-shaped field is used to show the overall chemical character of the groundwater by a third single-point plotting, which is at the intersection of rays projected from the plottings of cations and anions. The position of this plotting indicates the relative composition of a groundwater in terms of the cation-anion pairs that correspond to the four vertices of the field. The three trilinear plottings will show the essential chemical character of a groundwater according to the relative concentrations of its constituents.

The chemical analysis data of all the twenty nine samples have been plotted on trilinear diagram for both the surveys (Fig. 2 & 3) and results are summarized in Table 6 & 7. The cation plots in the diagram reveals that, majority of the samples falls in sodium or potassium type, followed by no dominant type. The anion plots in the diagram indicate that the samples fall in no dominant type followed by chloride and bicarbonate type. These two trilinear plots indicate that the groundwater of the study area are of sodium or potassium, chloride, bicarbonate and no dominant types.

The Piper trilinear diagram combines three different areas for plotting, two triangle areas (cation and anion) and an

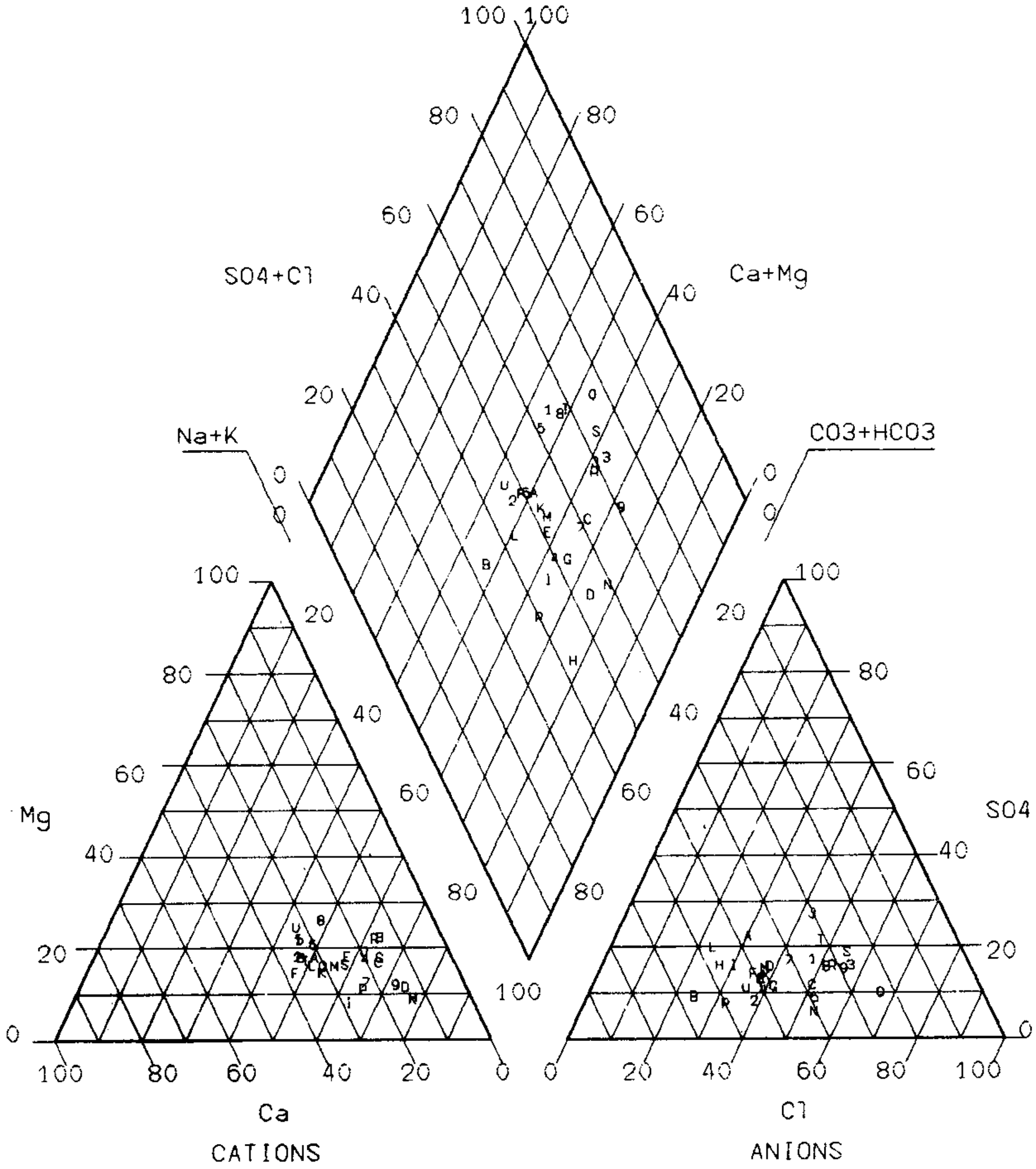

Fig. 2. Piper Trilinear Diagram Showing Chemical Character of Groundwater (October 1994)

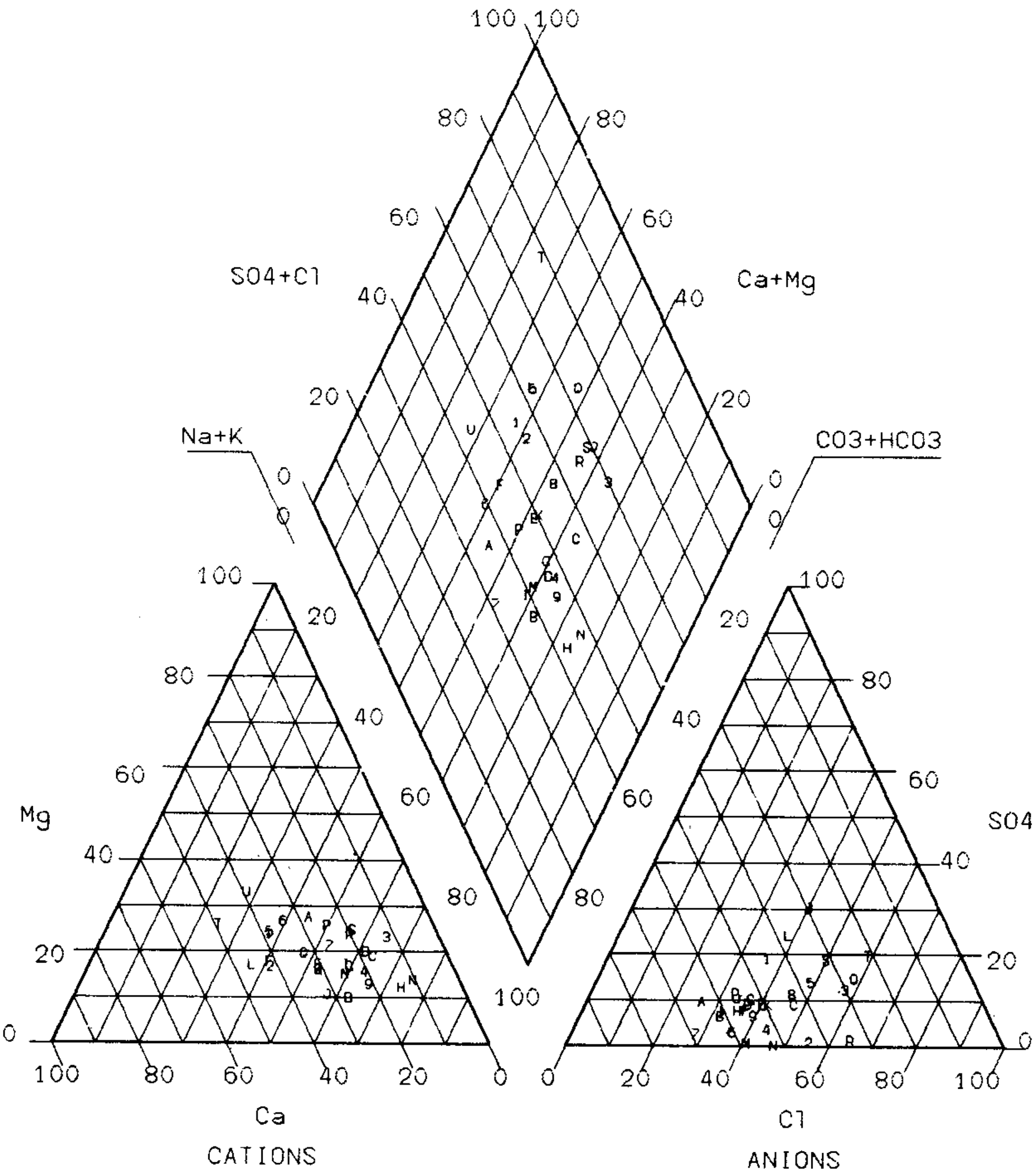

Fig. 2. Piper Trilinear Diagram Showing Chemical Character of Groundwater (January 1995)

SAMPLE IDENTIFICATION FOR PIPER TRILINEAR DIAGRAM

Well No.	Label	Location
1	1	Sarpavaram
2	2	Balaji Nagar
3	3	Valasapakalu
4	4	Vakalapudi
5	5	Ramanayya Peta
6	6	R R Nagar
7	7	Madhav Nagar
8	8	Nagamallithota
9	9	Godarigunta
10	A	Sambamurthy Nagar
11	B	Shanti Nagar
12	C	Perraju Peta
13	D	Kondayya Palem
14	E	Gandhi Nagar
15	F	Rama Rao Peta
16	G	Surya Rao Peta
17	H	Suryanarayana Puram
18	I	Budam Peta
19	J	Temple Street
20	K	Frazer Peta
21	L	Pratap Nagar
22	M	Revenue Colony
23	N	Gogudanayya Peta
24	O	MSN Charties
25	P	Turangi
26	Q	Paradesamma Peta
27	R	Indra Palem
28	S	Chidiga
29	T	Madhura Nagar

intervening diamond shaped area (combined field). Using this diagram waters can be classified into four different hydrochemical facies. Majority of the samples of the study area falls in Na - K - Cl - SO_4 facies.

U.S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by sodium absorption ratio (SAR).

A diagram for use in studying the suitability of groundwater for irrigation purposes, named after Wilcox (1955), is based on the sodium adsorption ratio (SAR) and conductivity of water expressed in µS/cm.

The chemical analysis data of all the twenty nine samples have been plotted on Wilcox diagram for the two sets of data (Fig. 4 & 5) and the results of the same have been summarized in Table 6 & 7. It is evident from Table 6 that during October 1994, out of the twenty nine samples analysed, three samples were found to be of C2-S1 type (medium salinity and low SAR) which is suitable for irrigation purposes, twelve samples were found to be of C3-S1 type (high salinity and low SAR), which is also fit for irrigation purpose in general, but may cause some problem where the soil permeability is very poor. Six samples are of C3-S2 type (high salinity and medium SAR), such water can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected. Seven samples are of C4-S2 type (very high salinity and medium SAR), which are not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and very salt-tolerant

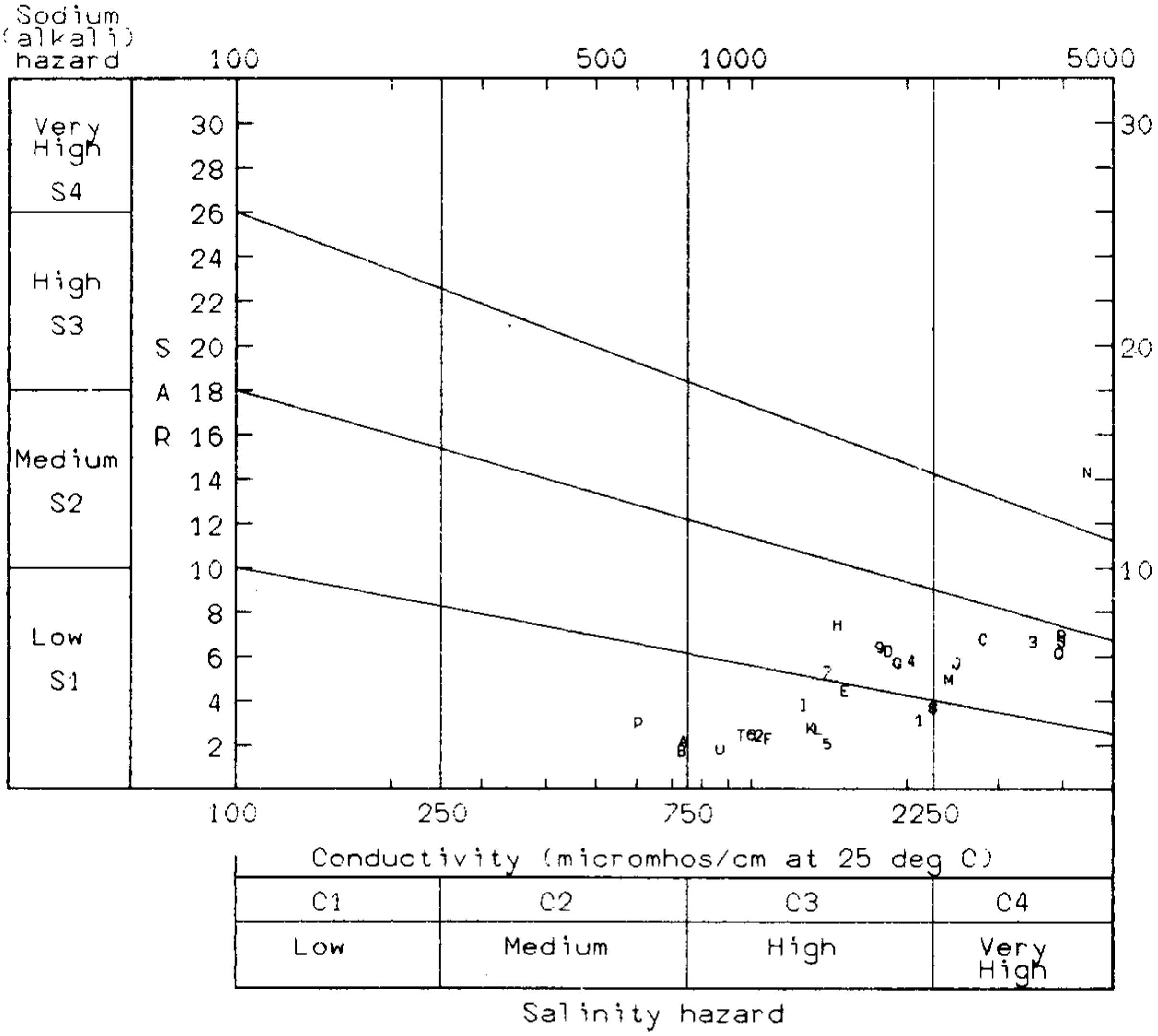

Fig. 4. U.S. Salinity Laboratory Classification
(Wilcox Diagram, October 1994)

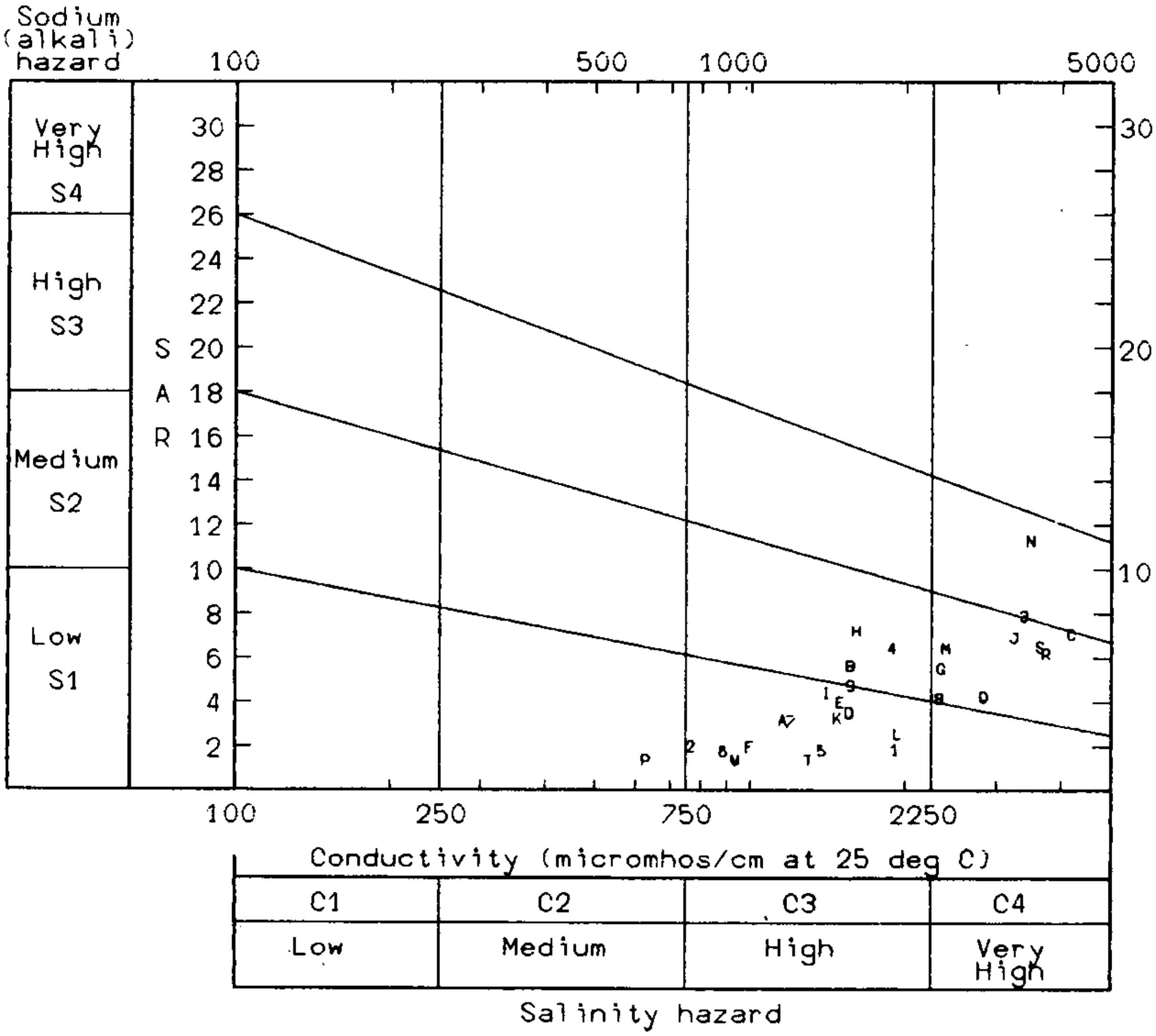

Fig. 5. U.S. Salinity Laboratory Classification (Wilcox Diagram, January 1995)

SAMPLE IDENTIFICATION FOR WILCOX DIAGRAM DIAGRAM

Well No.	Label	Location
1	1	Sarpavaram
2	2	Balaji Nagar
3	3	Valasapakalu
4	4	Vakalapudi
5	5	Ramanayya Peta
6	6	R R Nagar
7	7	Madhav Nagar
8	8	Nagamallithota
9	9	Godarigunta
10	A	Sambamurthy Nagar
11	B	Shanti Nagar
12	C	Perraju Peta
13	D	Kondayya Palem
14	E	Gandhi Nagar
15	F	Rama Rao Peta
16	G	Surya Rao Peta
17	H	Suryanarayana Puram
18	I	Budam Peta
19	J	Temple Street
20	K	Frazer Peta
21	L	Pratap Nagar
22	M	Revenue Colony
23	N	Gogudanayya Peta
24	O	MSN Charties
25	P	Turangi
26	Q	Paradesamma Peta
27	R	Indra Palem
28	S	Chidiga
29	T	Madhura Nagar

crops should be selected. One sample from Gogudanayya Peta was found to be of C4-S4 type (very high salinity and very high SAR), which is not at all suitable for irrigation purposes. Very high salinity, as observed in the sample from Gogudanayya Peta, is harmful for the plant growth physically by reducing the uptake of water through modification of osmatic processes or chemically by metabolic reactions caused by the toxic constituents. Besides this, the salinity of this magnitude, changes the soil structure, permeability and aeration which in turn effects the plants growth and yield of crops considerably. The main effect of such high concentration of sodium, as observed in the groundwater of Gogudanayya Peta, are the reduction in soil permeability and hardening of soil. Both these effects are caused by the replacement of calcium and magnesium ions by sodium ions of the soil clays and colloids. Low permeability and hardening of soil hinders plant growth.

During January 1995 survey, one sample was found to be of C2-S1 (medium salinity and low SAR) which is suitable for irrigation purpose, fifteen samples were found to be of C3-S1 type (high salinity and low SAR), which is also fit for irrigation purpose in general, but may cause some problem where the soil permeability is very poor. Three samples are of C3-S2 type (high salinity and medium SAR) and nine samples are of C4-S2 type (very high salinity and medium SAR). One sample of Gogudanayya Peta was found to be of C4-S3 type (very high salinity and very high SAR), which is not suitable for irrigation purposes. High salinity is harmful for the plant growth and changes the soil structure, permeability and aeration which in turn effects the plant growth and yield of crop considerably.

6.0 CONCLUSIONS

The chemical characteristics of groundwater of Kakinada town have been studied on the basis of chemical analysis results of water samples collected from open wells.

From the results of the study it is concluded that the quality of groundwater varies widely from place to place. It varied significantly within the same locality also.

Higher values of certain constituents at various locations indicate that the water is not suitable for domestic applications. Hence it is recommended that any water source must be thoroughly analysed and studied before being used for domestic applications.

Higher values of certain constituents at some locations indicate the influence of sea water.

An attempt has also been made in this study to classify the hydrochemical characteristics of groundwater of the study area based on the classification schemes of Stiff, Piper trilinear and U.S. Salinity Laboratory classification. As per the Stiff classification, most of the samples were found to be of either sodium chloride type or sodium bicarbonate type. The Piper trilinear diagram indicate that majority of samples fall under Na - K - Cl - SO_4 hydrochemical facies.

The U.S. Salinity Laboratory classification of irrigation water indicate that only at few locations water can be used safely for irrigation with most crops on most soils. At most of the other places proper water management strategies need to be adopted for agricultural and other developmental activities.

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