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GROUND WATER QUALITY MONITORING AND EVALUATION IN AND AROUND GREATER GUWAHATI (ASSAM)

PART - II : CHEMICAL ANALYSIS

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Mapping of Cations

Mapping of Anions

Mapping of Different Parameters for Irrigation Purpose

ABSTRACT

Groundwater quality of Greater Guwahati is presented based on the physico-chemical characteristices of thirty samples collected on grid pattern. The various parameters analysed include pH, Electrical Conductivity, Temperature, DO, TDS, Alkalinity, Hardness, Na^+, K^+, Ca^{++}, Mg^{++}, NO^-_3, SO^{--}_4, Cl^- and F^-. The results were compared with water quality standards prescribede by BIS and WHO.

Various parameters like Kellye's Ratio, Sodium Adsorption Ratios (SAR), Residual Sodium Carbonate (RSC), Magnesium hazards, Sodium % and Permeability Index were determined to evaluate the suitability of groundwater for irrigation purposes. On the basis of these parameters it is concluded that the water is suitable for irrigation purpose. The study shows that water at some places require treatment before using for drinking purpose.

An attempt has also been made to classify the quality of groundwater on the basis of Stiff pattern diagram, Piper trilinear diagram, USSL classification, Gibbs variation classification, Durove trilinear classification, Doneen's classification and Wilcox classification. As per the Stiff classification, most of the samples were found to be of either Mg-HCO3 type or Mg-Cl type. In the Piper's trilinear diagram, ground water samples of the study area fall in the $Ca+Mg-HCO_3$ and $Ca+Mg-SO_4+Cl$ hydrochemical facies. According to the USSL Classification of irrigation water, samples fall under water type C2-S1 (medium salinity and low SAR) and few samples fall under C3-S1 (high salinity and low SAR) and C1-S1 (low salinity and low SAR) type. Gibbs variation diagrams show that the chemistry of ground water is mainly controlled by the litho units of the area. According to Doneen's classification most of the samples are class-I type for irrigation use. As per the Wilcox classification, most of the samples are excellent to good class and few are good to permissible. Durove's trilinear classification shows that in cation type, majority of the samples are Mg^{++} and intermediate type while, in anion type, samples fall in HCO^-_3, Cl^- and intermediate category.

1.0 INTRODUCTION

Of the total amount of about 1500 million km^3 of water in the hydrosphere, about 95% of it is sea water, 4% is frozen as snow in mountains and cold regions, and only 1% is available for human activity. It is confined in ground water, rivers, lake, soil profile, atmosphere and biological system. Out of this, ground water forms 99% of the available water (Dooge, 1973). Ground water forms the major source of water supply for domestic, irrigational and industrial purposes. Ground water is now receiving considerable attention in environmental studies.

The quality of water is as much important as its quantity. The quality of ground water depends on a large number of individual hydrological, physical, chemical and biological factors. Generally higher proportion of dissolved constituents are found in ground water then in surface water because of greater interaction of ground water with various materials in geologic strata.

Drinking water should be free from any toxic elements, living and non-living organism and excessive amount of minerals that may be hazardous of health. There are certain chemical substances which, if present in drinking water at concentration greater then definite limits, may be injurious to human health. Some of these chemical substances are regarded as essential constituents in drinking water and if, they are not present at sufficient concentration limits, human health is affected.

The quality of ground water is of great importance in determining the suitability of a particular ground water for a certain use like public water supply, irrigation, industrial application etc. The quality of ground water is the resultant of all processes and reactions that have acted on the water from the moment is condensed in the atmosphere to the time it is discharged by a well. Therefore, the quality of ground water varies from place to place, with the depth of water table, and from season to season and is primarily governed by the extent and composition of dissolved solids in it.

Ground water quality studies are essential for critical evaluation of water for various purpose such as domestic, agricultural and industrial supplies. Ground water quality variation problem can be understood only by the regular monitoring of quality of water. In Greater Guwahati rapid industrial and population growth has taken place during the last decade. This is likely to become manifold in near future with increasing industrialization and urbanization. Guwahati saw its first burst of expansion during the period 1960-1965 with the setting up of the Oil refinery, the New Guwahati Goods Yard, the Army Cantonment and the Oil India Campus. The second burst of explosion witnessed the city was in 1972, when the State Capital was shifted to Dispur, on the south-eastern tip of the city. Within a very short time, population of the city, incremented by lakh, creating a tremendous pressure on housing, office space and other infrastructural facilities. These expansions did not see any commensurate expansion of infrastructural facilities and basic needs of the city. At this time, the municipal water supply system was extended to serve only the capital complex of perhaps 15,000 people, while the rest of the city continued to depend on ground water sources like dug wells and tubewells.

Guwahati is the premier city of North east India. At present the population of the city are increasing daily and now it stands on about 10 (Ten) Lakh. The growth of population in the city has made the water supply scheme of Guwahati Municipality inadequate. As a results, the major parts of the population depended on different sources of water like ponds, wells, tanks etc. It is suspected that rapid industrialisation, explosion of population, bad sewage disposal system etc. have affected the ground water bodies in Guwahati area making water of some area unfit for drinking and other purposes. Therefore, it was proposed to study ground water quality in and around Greater Guwahati. The study of ground water quality involves the study of various constituents in ground water and the relation of these constituents to water use. In the area of study ground water is extensively used for irrigation as well as drinking purposes. The study has been carried out to observe and understand the variation in quality of shallow ground water to delineate the potable and non potable zones.

Considering the rapid growth of population and imbalancing eco-system, it has become very important to monitor the quality of ground water for human consumption. This regional centre of National Institute of Hydrology has already started the ground water quality assessment and providing valuable information to field organisations who are implementing ground water supply scheme. In this report an attempt has been made to highlight the water quality monitoring aspects of drinking and irrigation water problems of Greater Guwahati. The information collected and reflected in this report would be of very much helpful to the scientists and engineers who are directly or indirectly involved in maintaining and executing the drinking water supply, minor or lift irrigation, town planning etc.

The main objective of the study was to see the suitability of water for various designated uses and was aimed at (i) to see the regional variation in the quality of shallow ground water, (ii) to delineate the bad water quality zone for irrigation and drinking purpose, (iii) possible source of pollution if any, (iv) project the regional quality behavior of ground water by means of a variety of thematic maps and assessment using numerical processing techniques, (v) to determine correlation among water quality constituents and (vi) to assess extent of contamination through regular monitoring of ground water quality.

2.0 REVIEW

2.1 Significance of Parameters Used in Water Analyses:

Alkalinity :

As far as is known, the alkalinity of a water has little public health significance. Highly alkaline waters are usually unpalatable, and consumers tend to seek other suppliers. Chemically treated waters sometimes have rather high pH values which have met with some objection on the part of consumers. Alkalinity is important in a number of ways, excessive alkalinity may render water unsuitable for irrigation depending on the nature of the cations, or improving the matrix resistance to low pH caused by acid rain or waste water. Alkalinity is an important parameter because its value determines the amounts of chemicals needed to be added in water treatment. It is the sum total of constituents of water that are responsible for raising the pH of water above 4.5. The total amount of CO_3, HCO_3, OH, PO_4, SiO_2 and other bases are together measured by the alkalinity value as mg/l of $CaCO_3$. Alkalinity is not a health hazard unless the value exceeds 400 mg/l as $CaCO_3$. Natural alkalinity helps to buffer pH changes and is thus important for fish and other aquatic life. Excessive alkalinity cause eye irritation and soil and plant damage. Information concerning alkalinity is used in a variety of ways in environmental engineering practice like in chemical coagulation, water softening, corrosion control, buffer capacity etc..

Sodium :

The ranks sixth in order of abundance among the element present in most of the natural waters. Sea water is especially rich in this element. It is an important element which harms human physiology if present in high concentration and therefore saline water is unusable for most of the human needs such as drinking, domestic, irrigation or industrial. The ratio of sodium to total cations is important for plant growth. High sodium adversely affects the soil aggregation and crumb structure. Sodium in irrigation water gradually gets accumulated in surface soils and cause sodicity and renders soils unproductive and create wastelands. pH also rises to unfavorable levels. Sodium can be easily analysed by an atomic absorption spectrometer or by a flame photometer.

Potassium :

This element ranks seventh in order of abundance among elements required as a co-factor for as many as over forty enzymes and it has important role in stomatal movement. It also maintains electroneutrality in plant cells. In natural waters, it never assumes toxic proportions and remains less then 10 mg/l and natural source is through weathering of rocks. High potassium may act as a laxative. It is analysed by an atomic absorption spectrometer or by a flame photometer.

Calcium :

Calcium deficiency is often a problem (rather than its abundance) and it causes leaves to curl or roll and become chlorotic. In man its deficiency causes several diseases especially of bone. This element is quite abundantly found dissolved in water because of the abundance of calcareous rocks throughout the world. Water running across such rocks get enough of calcium salts. Ground water, lakes, rivers have calcium in form of bicarbonates, causing temporary hardness. It content varies normally between 10 to 100 ppm. Besides natural sources, industries and city sewage may also contribute to calcium enrichment of water bodies. Mostly abundance of calcium is not a health hazard but hard waters cause other problems such as wastage of soap, scaling in domestic water supply pipe lines and in boilers power plants etc. Small quantity of calcium present in domestic water supply forms a vary thin protective layer of calcium carbonate on the inner wall of the pipeline and prevents corrosion due to other chemicals present in traces.

Magnesium :

Mg with Ca also cause by far the greatest portion of the hardness occurring in natural waters. Appreciable concentration of Mg with Ca results in scale formation in boiler, pipes and cooking utensils. Mg concentration of more than 125 mg/l can have a cathartic and diuretic effect. Mg in soft water may amount to only 1 or 2 mg/l but water in areas that contain large quantities of dolomite or other Mg bearing rocks may contain 20 mg/l or several hundred mg/l of mg ions. In some considerations it is important to know the amount of Mg hardness in water. For example it is necessary to know the Mg hardness or the amount of Mg ions in order to calculate lime requirements in lime-soda ash softening. Mg is essential minerals for the living body and is relatively non-toxic in concentration normally encountered in nature. Mg occurs in all kinds of natural water with Ca, but its concentration remains generally lower than the Ca.

Phosphate :

In all natural waters like ground water, lakes, rivers, etc. phosphate is always found. Ultimate source is the mineral matter of rocks, but largely being insoluble, its incorporation into water system from rock sources is very slow. But in water bodies around villages, towns and cities, enough phosphate is reached from detergents, sewage and industrial effluents. Despite being an essential element phosphate enrichment of water beyond desired level is a very common feature and this result into increased fertility, rapid and lush growth of blue-green algae and/or macrophytes almost choking the entire water body. Such a process of overfertility is known as eutrophication. The acceptable level of total inorganic phosphate in water is 0.03 to 0.40 mg/l. Normally phosphate is in short supply in natural waters due to which there is a limited growth algae and higher aquatic plants. Additions of this element in different forms like orthophosphate, pyrophosphate, metaphosphate, monohydrogen and dihydrogen phosphate, etc. cause enhanced or explosive growth of algae and/or aquatic weeds like water hyacinth. This leads to eutrophic deterioration of water body. Further, continued eutrophication leads to rapid upwelling of the water body. The limited capacity of the fresh water bodies is reduced by silting and many ponds and water bodies permanently loose their aquatic entity and become terrestrial in nature.

Chloride :

Chloride ions is among the commonest anions found in most of the fresh waters in high abundance in all marine and coastal waters. Whether chlorine is an essential element or not for plant growth, all plants do encounter it an nature and chloride is stored in plant and animal body and as sodium chloride it is definitely beneficial to most organism. Potable waters may contain small quantity of chloride without any harmful effect. If it is in the range of 200 mg/l there is no salty taste, but the taste becomes detectable as it exceeds 250 mg/l in form of sodium chloride. But when with chloride anion, the dominant cation is potassium or magnesium, the salty taste is not felt even upto 1000 mg/l. Municipal and domestic waste water contains higher sodium chloride then in the raw or domestic water supply as enough of the common salt consumed by man and cattle pass out of the body unutilized and add to salt content of the sewage. High chloride content in irrigation water gradually leads to accumulation of salt and adversely affects the soil property. Chloride ions corrode concrete and metallic pipes to certain extent. If it is form of magnesium chloride, the water on boiling produces hydrochloric acid which corrodes the boilers and reduces the life of boilers.

Sulphate :

In nature, sulphate is of widespread occurrence and is present in most waters ranging from trace to thousands of mg/l. Mining operations release huge quantity of sulphates. Industries and sewage and domestic wasters also contribute significant quantity of sulphates to lakes and rivers. Fumes emitted by thermal and super thermal power houses, and other industries emit huge quantity of sulfur dioxide which reacts with atmospheric moisture and precipitates in form of sulfuric and sulfurous acids and reach to lake, river and ground waters. There it dissociates in form of sulphates and sulphites. Sulphate corrode the concrete and metallic pope lines through the formation of sulphuric acid. Sulphate is the important constituent of hard water in form of calcium and magnesium sulphate which reduces the water quality. At 300-400 mg/l level is imparts an unwanted taste to drinking water and at 500 mg/l it becomes bitter and there after begins to affect the digestive system.

Nitrate :

Nitrates are usually present in traces in surface waters, but in some ground waters nitrates may be high. High nitrate and nitrites in drinking water cause a disease, particularly in children called methemoglobinemia in which skin becomes blue. Drinking water must not contain more than 10 mg/l nitrate nitrogen. In many factory waters, the effluents contain upto 30 mg/l nitrate nitrogen. While nitrate is a fertilizer, its high dose may limit the growth of plants. Nitrate in dissolved state percolate down through the soil profile and reach to ground water. The some part of heavy nitrogenous fertilizer applied to agricultural fields year after year find their way to ground water through percolation and to rivers and lakes through runoff. These are serious health hazards as the drinking water with high nitrate nitrogen of 30 to 40 mg/l results into poor oxygenation of blood hemoglobin and the blood turns blue. Animals like cattle, pigs, etc. also get badly affected and sometimes die due to high nitrate in drinking water. It is necessary for health authorities, therefore in areas where is found nitrate content of water is known to be in excess of the limiting concentrations, to be vigilant and to warn the population of the potential dangers of using the water for infant feeding and to inform them of alternative sources of water that may be used with safety.

Hardness :

Hardness of water is characterized by the ease or difficulty one has in getting a lather from soap and by the mineral scale that forms when water is heated as in a steam boiler. Although several possible solutes are known to cause hardness in water, the most common are the carbonates and bicarbonates of calcium and magnesium. An analyst customarily reports hardness as mg/l of $CaCO_3$. The following classification has been proposed by the USGS, but it is only a guide to classifying waters and is not offered as a precise scale of hardness.

Hardness Range in mg/l of $CaCO_3$	**Water Quality**
0-60	Soft
61-120	Moderate Hard
121-180	Hard
More than 180	Very Hard

Very soft water feels slick on body, as though the soap were still there. Water with a little hardness, which is to say with Ca and Mg ions, is favored for irrigation, too, as it tends to maintain higher soil permeability and allow infiltration to take place. Water hard or moderately hard water is used as a public supply, it is frequently softened so that it will have less than 100 mg/l of hardness.

2.2 Guidelines on Quality of Drinking Water :

In India urban population which constitutes about 25% of total population is provided water after conventional treatment. however, in rural areas, which presently constitutes about 75 % of the total population, the problem of the water quality is acute. Conservation of water quality is necessary to provide wholesome water to most of the people and to prevent the people from epidemics. Standards have been fixed by I.S.I. (now known as B.I.S., 1983) to guide the personnel involved in water supply management.

In view of the wide variations in the chemical composition of water in different parts of the world, rigid standards of chemical quality can not be established. The limits there after designated "acceptable" apply to a water that would be generally acceptable by consumers; values greater than those listed as "allowable" would markedly impair the potability of the water. However, these limiting concentrations are indicative only and can be desregarded in specific instances.

The Indian Council of Medical Reseaech (ICMR), (India, 1975) and WHO (1971) have published guidelines for drinking water with the object of stimulating improvement in drinking water quality and to encourage higher standards. Some values are mandatory and must be complied with while others are not pertinent.

The original manual of standards of quality for drinking water was published in 1962 by ICMR and it was adopted generally. Later on it was updated in 1975 by a working group of ICMR. The WHO guidelines for drinking water quality (1984) superceeds both European (1970) and International (1971) standards for drinking water. As per the recommendation of ICMR (1975), WHO (1971) and ISI (1983) the quality standards for drinking water are given in Appendix-I, II and III respectively. The desirable and maximum permissible limits are given for essential chemical compounds.

3.0 DESCRIPTION OF THE STUDY AREA

3.1 Physiographical Setting :

Guwahati the ancient city of Pragjyotishpura, is bounded between 26°7'-26°12' N latitude and 91°40' - 91°48' E longitude. The mighty Brahmaputra flows along the city's northern periphery. The southern and the eastern sides of the city are bounded by rows of hills. The Jalukbari-Azra plain constituting the western boundary of the city (Fig. 3.0).

The city is situated on a undulated plain area with varying altitude, on the average 50-60 meters above mean sea level. It is surrounded by a semicircle of thickly wooded hills on all sides except the North where the river Brahmaputra flows. The encircling hills are Nilachal, Chunsale, Fatasil, Kalaphar, Narakasur, Japorigog, Gotanagar and Jalukbari. Other hills are Navagraha, Kharguli and Ramcha Hills. In the central part of the city there is a small hillock by the name of Sarania.

3.2 Climatological Condition :

Because of the uneven topography with built up area, marshy land, and hills surrounding the valley giving it the shape of a bowl, the temperature distribution is not uniform on the surface throughout the year. Ground level inversion of temperature is a very common phenomenon in winter months. Low level thermal stratification is also observed in the bowl area.

Throughout the year wind flows the river Brahmaputra towards the city. During premonsoon period (February-May) the air which enters the city from Brahmaputra river seems to show trajectories, confined between Brahmaputra river and Chandmari, Ulubari, Kalapahar and Bhutnath with centre near about Machkhowa. another branch of wind entering the city is channellised in the north-east

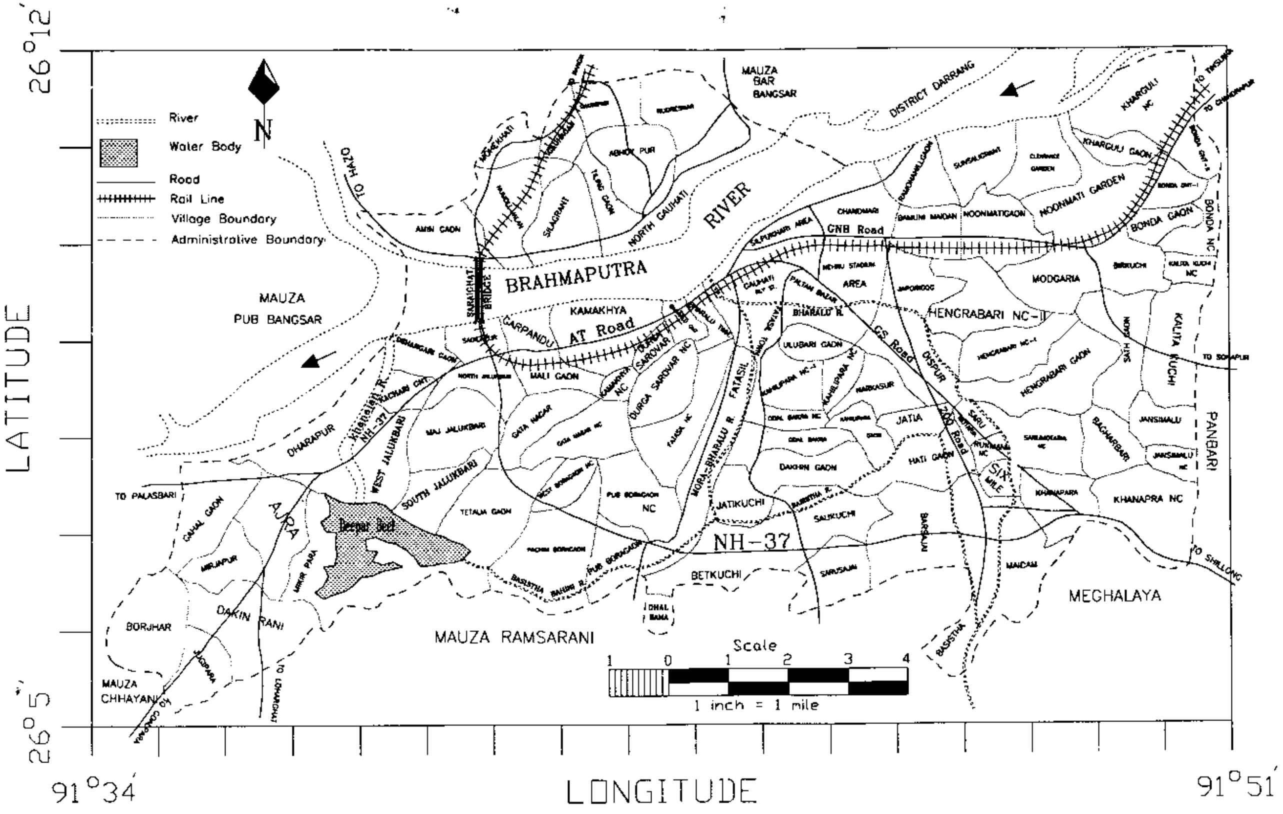


FIG. 3.0 : STUDY AREA MAP OF GREATER GUWAHATI
(MAP SOURCE - TOWN AND COUNTRY PLANNING ORGANIZATION, GUWAHATI)

another branch of wind entering the city is channellised in the north-east direction and blows towards Dispur guided by the R.G. Baruah Road. During monsoon period (June-September), wind from all directions tend to coverage at Paltanbazar area. During post-monsoon period (October-January) a similar convergence is seen in the Panbazar-Paltanbazar area. From the air pollution point of view the Paltanbazar-Panbazar-Beltola-Noonmati area are very prone from June to January. The mean wind speed at the surface, for the city as a whole, is 0.56 m/Sec. The wind speed is highest during in the post-monsoon season.

The distribution of rainfall in the city is not uniform. The rainy season extends from March to October. Average annual rainfall is 160 cm. During pre-monsoon period the highest rainfall occurs at Bhaskar-Chandmari area followed by Dispur and the belt from Bhralu to Panbazar on the northern side of the railway line. Lower rainfall occurs at Fatasil, Kalapahar and Bhutnath. During post-monsoon, Japrigog and Panbazar area shows high rainfall, lowest being at Bhutnath, Kalapahar and Fatasil area.

On the average, the fringe hilly areas and the belt between Brahmaputra and rail line from Bharalu to Panbazar get heavy rainfall; the central part of the city, along the Bharalu river from Fatasil to Ulubari, gets less rainfall.

The humidity of the city is very high. It does not go below 70 per cent. Several factors contribute to the high humidity of the city. These are (1) presence of a big water body like Brahmaputra river, (2) tributary like Bharulu passing through the heart of the city, (3) presence of ponds, marshy land and green hills and (4) bowl shaped topography of the city. During pre-monsoon period, the relative humidity is highest along the river side area upto Chenikhuti (79%). Relatively high humidity is also found in the forest covered areas of Japorigog (70%). Lowest humidity area during the period is Kalapahar (67%).

During post-monsoon period, the central part of the city from East to West shows lowest humidity (75%) which gradually increases towards the North and South. The humidity gradient increases more steeply towards Brahmaputra. The lowest humidity month is March (65%) and highest humidity months are July and September (90%).

3.3 Water Supply, Sewerage and Drainage :

There is no integrated grid for supply of water in the Master Plan area of Guwahati. This premier city of Assam, in this later part of the 20th century, provides piped drinking water to only 15% of its population, leaving the rest to fend for themselves with tube wells, shallow wells, ponds etc.. Due to this region, water borne diseases like gastro-enterritis, typhoid, jaundice and amoebaesis are very common in the city people. the older areas and settlements are fortune enough to have piped water out of plants commissioned by the British and subsequently in the 1960's whereas the newer settlements and colonies that have sprung up during the last twenty years have been deprived of piped water. There is acuate shortage of water in some areas. Unplanned growth of the city is the primary reason for this.

Guwahati has no scientific sewage disposal system. On a guess estimate, about 50 per cent of the areas is served by septic tanks discharging untreated effluent in to cutting roadside drains that have become the breeding grounds of mosquitoes and flies, with the other 50 per cent being served by that abomination called the pit latrine streets and roads are littered with garbage as the Guwahati Municipal Corporation does not have any effective system of garbage collection and disposal. Storm water drainage takes place through the Bharalu river and the Basistha river either directly or indirectly through the Dipar Beel and the Khana river to the Brahmaputra. In the North bank of the master plan area, the storm water discharge is either directly to the river Brahmaputra or via the Ghorajan river. However, due to rapid growth of the city and obstructions to the drainage channels by illegal occupation and construction activities, the existing capacities of the natural channels like Bharalu and the Basistha are found to be inadequate to carry the storm water and other surface run-off during the monsoon months. As a whole, the drainage system in the city is very inadequate.

3.4 Commercial Activities :

Guwahati is the only city in the Northeast region with a population of over ten lakh and the nerve centre of all trade, commerce, business, education, culture, it created employment avenue for the unemployed youths of the state and outside as well. In order to accommodate this big chunk of employees, businessman, students and daily wage earners, people started construction of residential and commercial complexes in and around the city without following any guideline or proper planning. The Fancybazar-Mahkhowa-Athgaon-A.T. Road area is the centre of all business activities. The area is extremely over-crowded with narrow roads, slow moving transport and inadequate space for loading and unloading of a large number of trucks during day and night. This area in the city produces the largest amount of garbage.

Food and vegetable markets are also located in various areas of the city in a most unorganised manner. Motor garages have scattered along the GS road, RG Barua Road, and in the Adabari area. The Beltola area has become the centre of inter-state carrier agencies with thousands of trucks parked at any time during day and night. Shopping centres, weekly markets, food stalls, restaurants, big hotels, hospitals have sprung up in each locality. The land available for commercial activities being extremely inadequate all the shopping areas are cramped creating environmental problems for the city.

3.5 Land Use Pattern :

The master plan area of Guwahati covers about 262 km^2 of which nearly 62% is usable land. The unusable land consists of hills, water bodies and very low lying areas. The very large amount of land being used for transport and communication is due to the large areas under occupation of the NE railway. The extremely small amount of land for parks and recreation is very conspicuous. There has been a steady increase in land utilised for residential, commercial and industrial purpose.

3.6 Sources of Industrial Pollution :

Guwahati in general is industrially backward region. However, unscientific exploitation of natural resources and the existing industries are posing a serious problem to the environment of the area. A large number of small, medium and big industries are located within the master plan area of Guwahati. According to the census of 1991 there were 669 industrial units, of which 19.73% were engaged in various metal products, 17.34% in chemicals, 15.40%, in paper products and printing, 11.5% in repair and servicing, 9.72% in wood products and 6.58% in food products. Only 43 units were located inside an Industrial Estate, while all the others were scattered all over the city. The growth of industries can be termed as haphazard and environmentally unsafe. Some of the large and medium scale industries in the city, creating environmental problems are as follows:

- Thermal Power Station, Fertichem Ltd. and NTC's Spun Mill at Chandrapur.
- Statefed Vanaspati Plant, Kamrup Paper Mills, Assam Ispat Limited, Chemical Units and Assam Caffeine Industry at Amingaon.
- Dye House and Neone Tubes Limited at Pub-Boragaon.
- Assam Carbon Products Limited at Birkuchi (eastern part of the city).
- Indian Oxygen Limited's Plant, Jalan Industrial Corporation, G. L. Industries, Jalan Iron and Steel Company and Guwahati Roller Flour Mill at G. S. Road.

- Brahmaputra Jute Mill at Kalapahar Area.
- Assam Asbestos Limited at Narengi.

Besides these, a number of large printing presses, hospitals, nursing homes, big hotels, saw mills, soap factory, dairy industry etc. are located in various parts of the city. There is no strict boundary between residential and industrial-cum-commercial establishments.

3.7 Environmental Problems of Greater Guwahati :

Ground water is mostly polluted from waste water discharge by industries, seepage from the sewage line, application of insecticides on the agricultural land, seepage from septic tanks etc.. Quality monitoring of ground water is very essential because during summer it is the only remaining source to provide water. Ground water pollution is much more dangerous than surface water pollution as ground water once polluted can not be recovered very easily and is almost unusable for a very long time. Ground water problems are more acute in the areas which are densely populated, are thickly industrialized and have shallow ground water table. Some of the problems caused by industrial establishments and other development activities in the Guwahati are being focussed.

- Discharge of ammonical effluents, discharge of chromium bearing effluents, discharge of arsenic, release of sulphur dioxide into atmosphere and release of oily effluents are the the main pollution problems associated with Chemical and Fertichem industry at Chandrapur in Upper Guwahati area.
- Pollution problems due to Paper Mill at Amingaon are mainly - release of pollutants beyond limits, release of mercury bearing effluents, dumping of lime sludge, dumping of fly ash and release of coloured effluents.
- The unauthorised settlers construct latrines besides dwelling houses, urinate here and there in utter disregard to hygience. Some settlers keep cattle

for commercial purpose also all this has destroyed the peaceful, hygienic condition of the colonies. Private residential areas are having their own sanitary tanks. After a few years these tanks will pose a great problem for the people. It will spoil and pollute the ground water.

- Due to lack of proper seepage, rainwater gets flooded during monsoons. Even the water enters the house and if it rains continuously.
- The effluents discharged from the Noonmati refinery sometimes pollute the well water posing health hazards.
- Another major problem is garbage disposal. The garbage disposal bins provided by the Gauhati Municipal Corporation are often non-existent and even in places where they are found totally inadequate to cope with the huge volume of waste generated. They are also placed on the busy roads at very inconvenient positions, obstructing the passage of traffic and causing huge pills of rubbish to be dumped on the busy main roads, clearance of rubbish is also very irregular and not done regularly.
- Haphazard construction of houses and commercial establishments, without making any provision for drains, has lad to water logging problems. Also during high flood, there is reverse flow from the Brahmaputra through the Bharalu river, inundating many areas.
- Due to massive destruction of the green hilly cover around the city, the water table drastically dropped down. Because tree plays a vital role in retaining water. And this is the reason that ring wells in the areas like Birubari, Navagraha, Kalapahar, Chandmari, Geetnagar, Kahilipara, Christian Basti, Ganeshguri etc. remain dry and face acute water crisis round the year bearing a few months of monsoon. The other problems due to hill cutting are destruction of top soil of excavated areas, soil erosion during rainy season in particular and storm water accompanied by heavy silt after every severe rainfall etc. Due to the lack of proper drainage system, the rain water along with mud come downwards and block the drains and due to this water over flow on the roads.

4.0 MATERIALS AND METHODS

In order to achieve the objective of the study, a number of quality paramters have been determined at several sites by direct measurement at site and by taking samples and doing analysis in the laboratory. The following methodologies have been followed in the study:

4.1 Site Selection :

The factors, identified for proper selection of ground water sampling sites within Greater Guwahati include objectives of the study, location, number and spacing of wells, vertical location of screen material, type of well casing and screen, surrounding environmental conditions, public interference, general use of the wells and industrial activities in the region (Table 4.1).

By considering these above considerations study area has been divided into thirty equal grids and water samples have been collected grid wise from open dug wells (Fig. 4.1).

4.2 Sampling and Preservation :

Water samples were collected by dip or grab sampling method using standard water sampler (Hydro-Bios, Germany) (Fig. 4.2). The water samples collected were stored in pre-cleaned polyethylene bottles and preserved by adding an appropriate reagent as per standard procedures (Jain and Bhatia, 1987).

4.3 Methods of Analysis and Equipment Used :

Physico-chemical analysis were conducted following standard methods (APHA, 1995; Jain and Bhatia, 1987). Some physical parameters like pH, electrical

TABLE 4.1 - IDENTIFICATION AND GENERAL USE OF THE WELLS

S. NO.	ZONE NO.	SAMPLING SOURCE	LOCATION	WELL TYPE	USE OF THE WELL	LOCALITY
1	1	DUG WELL	DEEPAR BEEL	TEMPLE WELL	GENERAL USE	SWAMPY AREA
2	2	DUG WELL	BORAGAON	PERSONAL WELL	DRINKING AND DOMESTIC	NEAR NATIONAL HIGHWAY
3	3	DUG WELL	KATAKIPARA	PERSONAL WELL	DRINKING AND DOMESTIC	NEAR NATIONAL HIGHWAY
4	4	DUG WELL	BEHARBARI	PERSONAL WELL	DRINKING AND DOMESTIC	RESIDENTTIAL AREA
5	5	DUG WELL	GOSEWA BELTOLA	PERSONAL WELL	DRINKING AND DOMESTIC	HILLY AND FOREST AREA
6	6	DUG WELL	NATUN BAZAR	COMMUNITY WELL	GENERAL USE	MARKET PLACE
7	7	DUG WELL	EIGHT MILE	COMMUNITY WELL	DRINKING AND DOMESTIC	CATTLE FARM
8	8	DUG WELL	AJRA	PERSONAL WELL	DRINKING AND DOMESTIC	AIRPORT AREA
9	9	DUG WELL	JALUKBARI	PERSONAL WELL	DRINKING AND DOMESTIC	RESIDENTIAL AREA
10	10	DUG WELL	GITA NAGAR	COMMUNITY WELL	DRINKING AND DOMESTIC	HILLY AND FOREST AREA
11	11	DUG WELL	FATASIL AMBARI	COMMUNITY WELL	DRINKING AND DOMESTIC	RESIDENTIAL AREA
12	12	DUG WELL	ODAL BOKRA	COMMUNITY WELL	GENERAL USE	RESIDENTIAL AREA
13	13	DUG WELL	HATIGAON	PERSONAL WELL	DRINKING AND DOMESTIC	RESIDENTIAL AREA
14	14	DUG WELL	DOWN TOWN	PERSONAL WELL	DRINKING AND DOMESTIC	RESIDENTIAL AREA
15	15	DUG WELL	BAGHARBARI	PERSONAL WELL	DRINKING AND DOMESTIC	RESIDENTIAL AREA
16	16	DUG WELL	MALIGAON	PERSONAL WELL	DRINKING AND DOMESTIC	RESIDENTIAL AREA
17	17	DUG WELL	DURGASAROVAR	TEMPLE WELL	GENERAL USE	TEMPLE AREA
18	18	DUG WELL	KAHILIPARA	COMMUNITY WELL	GENERAL USE	SCHOOL BOUNDARY
19	19	DUG WELL	ULUBARI	COMMUNITY WELL	GENERAL USE	NEAR NH AND PETROL PUMP
20	20	DUG WELL	HENGRABARI	COMMUNITY WELL	DRINKING AND DOMESTIC	HILLY AREA
21	21	DUG WELL	SATHGAON	PERSONAL WELL	IRRIGATION AND GENERAL	AGRICULTURAL AREA
22	22	DUG WELL	DOLGOVIND	TEMPLE WELL	GENERAL USE	TEMPLE AREA
23	23	DUG WELL	PALTAN BAZAR	COMMUNITY WELL	GENERAL USE	MARKET PLACE
24	24	DUG WELL	BAMUNI MAIDAN	COMMUNITY WELL	DRINKING AND DOMESTIC	STATE BANK COLONY
25	25	DUG WELL	SHYAM MANDIR	COMMUNITY WELL	DRINKING AND DOMESTIC	TEMPLE AREA
26	26	DUG WELL	BONDA GAON	PERSONAL WELL	DRINKING AND DOMESTIC	RESIDENTIAL AREA
27	27	DUG WELL	DURGESHWARI	TEMPLE WELL	GENERAL USE	TEMPLE AREA
28	28	DUG WELL	RUDRESHWAR	TEMPLE WELL	GENERAL USE	RESIDENTIAL AREA
29	29	DUG WELL	NOONMATI	COMMUNITY WELL	DRINKING AND DOMESTIC	SCHOOL BOUNDARY
30	30	DUG WELL	KHARGOLI	COMMUNITY WELL	DRINKING AND DOMESTIC	HOTEL BOUNDARY

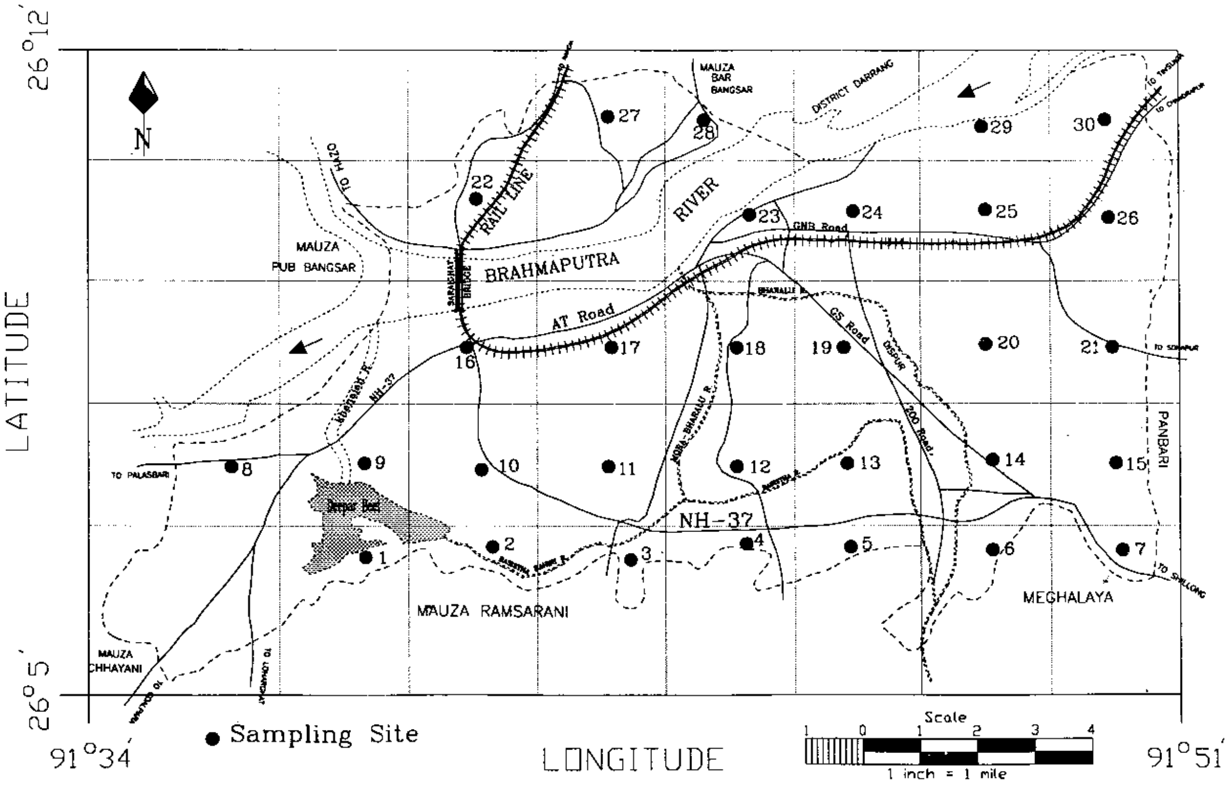


FIG. 4.1 : STUDY AREA MAP OF GREATER GUWAHATI SHOWING SAMPLING SITES

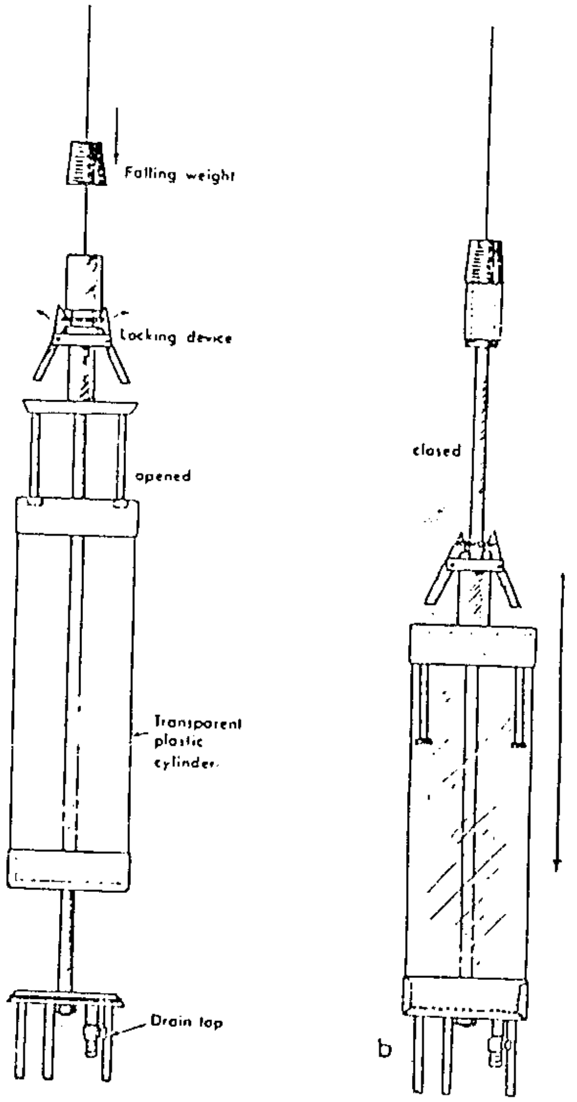


FIG. 4.2 : STANDARD WATER SAMPLER FOR GRAB SAMPLING
(A) OPEN AND (B) CLOSED

conductivity, oxidation reduction potential, temperature and dissolved oxygen were determined in the field at the time of sample collection. The pH, temperature, DO, ORP and EC were determined by using portable kits.

The total hardness and calcium hardness were determined by EDTA titrimetric method, while magnesium hardness determined by deducting calcium hardness from total hardness. Calcium (as Ca^{++} ions) was calculated by multiplying calcium hardness with 0.401 while magnesium (as Mg^{++} ions) by multiplying magnesium hardness with 0.243. Non Carbonate Hardness was calculated by using following formula:

$$NCH\ (ppm) = [(epm\ of\ Ca^{++} + epm\ of\ Mg^{++}) - (epm\ of\ CO^{--}_3 + epm\ of\ HCO^{-}_3)] * 50$$

When the difference is negative NCH = 0.

Sodium and potassium contents were determined using flame emission method. Chloride was determined by argentometric method in the form of silver chloride. Alkalinity was determined by titrimetric method using methyl orange method. Phosphate and nitrate were determined using UV-VIS Spectrophotometer. The sulphate was determined by gravimetric method and fluoride by SPANDS method.

5.0 RESULTS AND DISCUSSION

evaluating its suitability for irrigation and domestic purposes. The physical and chemical analyses of ground water of the area are given in Table 5.3 and 5.4 respectively. In the present study, ground water quality variation at different places (Fig. 4.1) covering Guwahati city in the Kamrup district of Assam, have been evaluated with reference to suitability of water for various uses and the results are discussed below.

5.1 Hydrochemical Database :

Once a sample of ground water has been analysed in a laboratory, methods for reporting water analyses must be consider. From an understanding of expressions and units for describing water quality, standards can be established so that analyses can be interpreted in terms of the ultimate purpose of the water supply. In a chemical analysis of ground water, concentration of different ions are expressed by weight or by chemical equivalence. Concentration of the common ions found in groundwater are reported by weight-per-volume units of milligrams per liter (mg/l or ppm). Positively charged cations and negative charged anions combine and dissociated in definite weight ratios. By expressing ion concentrations in equivalent weights, these ratios are readily determined because one equivalent weight of a cation will exactly combine with one equivalent weight of an anion. The combining weight of an ion is equal to its formula weight divided by its charge. When the concentration in ppm is divided by the combining weight, an equivalent concentration expressed in milliequivalents per liter (meq/l) results. Most of the graphical classification of ground water require milliequivalents per liter information of different quality parameters and ions like Stiff, Collin's bar diagram, kelly's ratio, SAR calculation etc. To see the importance of milliequivalent weight of the ions in ground water analysis,

TABLE 5.1 - STATUS OF CATIONS AND ANIONS IN MILLIEQUIVALENT PER LITRE

ZONE no.	CALCIUM	MAGNESIUM	POTASSIUM	SODIUM	CHLORIDE	SULPHATE	PHOSPHATE	NITRATE	Bi-CARBONATE
1	1.44	4.37	0.06	0.84	0.48	0.72	0.03	0.00	1.64
2	1.22	1.91	0.06	0.82	1.19	0.60	0.04	0.01	2.59
3	2.73	3.33	0.12	1.50	1.48	1.38	0.03	0.03	2.97
4	0.40	0.43	0.06	0.72	0.24	0.03	0.03	0.00	0.82
5	0.43	3.38	0.16	1.33	2.75	0.10	0.03	0.01	0.82
6	3.35	4.11	0.83	1.75	1.84	0.76	0.03	0.05	3.16
7	1.69	3.75	0.15	1.37	1.58	0.24	0.03	0.01	3.30
8	0.61	2.54	0.15	0.22	2.64	0.51	0.03	0.06	1.32
9	3.06	0.71	0.02	1.48	1.31	0.31	0.03	0.01	3.27
10	2.42	3.56	0.05	2.09	4.83	0.73	0.03	0.06	4.88
11	2.40	6.72	0.04	1.51	3.55	1.49	0.05	0.01	1.64
12	3.52	1.91	0.14	0.98	0.65	0.40	0.04	0.00	3.93
13	2.59	2.88	0.09	1.75	1.41	0.74	0.03	0.00	4.00
14	1.96	3.65	0.03	1.80	2.82	0.16	0.04	0.02	3.25
15	0.32	2.60	0.12	1.88	1.94	0.43	0.03	0.03	3.29
16	1.13	5.24	0.40	0.71	1.41	2.11	0.08	0.05	1.65
17	1.80	2.02	0.13	2.01	2.79	0.68	0.03	0.09	1.34
18	1.76	3.53	0.12	1.59	1.83	0.56	0.03	0.01	2.63
19	5.99	3.70	0.33	2.26	2.82	3.56	0.03	0.06	1.01
20	0.75	3.60	0.08	0.73	0.77	0.24	0.03	0.02	0.98
21	1.25	8.80	2.38	2.44	3.92	2.80	0.10	0.02	3.94
22	1.32	2.12	0.30	0.86	1.44	0.66	0.08	0.00	1.65
23	0.52	1.32	0.06	0.02	0.52	0.06	0.04	0.00	1.32
24	0.28	6.59	0.41	1.67	2.35	3.04	0.03	0.06	2.64
25	0.35	1.90	0.04	0.98	2.62	0.10	0.03	0.01	0.67
26	1.58	3.02	0.66	1.68	0.51	0.29	0.03	0.01	2.32
27	3.53	5.21	1.20	2.05	1.60	0.71	0.05	0.04	3.95
28	1.21	5.23	0.86	1.46	5.53	0.80	0.08	0.02	1.67
29	2.01	3.39	0.04	1.08	3.17	0.64	0.03	0.00	2.96
30	1.80	1.82	0.15	1.48	1.85	0.41	0.03	0.03	2.30
MAX.	5.99	8.80	2.38	2.44	5.53	3.56	0.10	0.09	4.88
MIN.	0.28	0.43	0.02	0.02	0.24	0.03	0.03	0.00	0.67
AVG.	1.78	3.44	0.31	1.37	2.06	0.84	0.04	0.02	2.40

results in ppm have been converted to meq/l and presented in Table 5.1 for the use in different classifications of ground water.

5.2 Water Quality Evaluation and Classification for Irrigation Purpose :

The chemical quality of water is an important factor to be considered in evaluating its suitability for irrigation purposes. Features that need to be considered are concentration of total salts (TDS), Electrical Conductivity (EC), Sodium Concentration, Carbonate and Bicarbonate Concentration (CO3-HCO3) and Boron etc., which may have important effects on plants and soils. The chemical analyses of ground water of the area are given in Table 5.2, 5.3, 5.4 and 5.5.

On the basis of the chemical character of ground water, an attempt was made for the suitability of ground waters for irrigational purposes and its probable effects on plan growth. Various parameters like Kellye's ratio, Sodium Adsorption Ratios (SAR); SAR (adjusted); Residual Sodium Carbonate (RSC); Magnesium hazards and Soluble percent were determined to evaluate the suitability of ground water for irrigation purposes (Table 5.2). On the basis of Kelley's ratio, Residual Sodium Carbonate and Sodium Adsorption Ratio (adjusted), it is proposed that the water is suitable for irrigation according to the specifications proposed by various agencies. SAR values when plotted in the U.S salinity laboratory staff diagram, most of the water belong to the C2-S1 class, indicating that the ground water can be used for all type of crops on soil of medium to high permeability. However, if the soil has low permeability, it can be used for growing moderate to good salt-tolerant crops with some leaching precautions.

To correctly evaluate the suitability of water for irrigation purpose, certain ratios and classifications are of fundamental importance and are discussed as follow.

TABLE 5.2 - DIFFERENT CRITERIA FOR SUITABILITY OF GROUND WATER FOR AGRICULTURAL USE

ZONE NO.	Sodium Adsorption Ratio (SAR)	Adjusted SAR	Na(%)	Doneen's Permeability Index	Mg Hazard (%)	Kelley's Ratio	Residual Sodium Carbonate	Doneen's Classification	Wilcox classification on the basis of	
									Na%	& Conductivity
1	0.49	0.89	13.43	31.86	75.19	0.14	-4.18	Class-I	EXCELLENT	EXCELLENT
2	0.66	1.17	22.06	61.56	61.09	0.26	-0.54	Class-I	Good	Good
3	0.86	1.79	21.14	42.62	54.97	0.25	-3.10	Class-I	Good	Good
4	1.11	0.86	48.42	104.87	51.20	0.86	-0.01	Class-III	PERMISSIBLE	EXCELLENT
5	0.96	1.29	28.10	43.46	88.64	0.35	-2.99	Class-I	Good	EXCELLENT
6	0.90	1.96	25.71	38.28	55.10	0.23	-4.30	Class-I	Good	PERMISSIBLE
7	0.83	1.73	21.82	46.85	68.94	0.25	-2.13	Class-I	Good	Good
8	0.18	0.26	10.52	40.66	80.62	0.07	-1.83	Class-I	EXCELLENT	EXCELLENT
9	1.08	2.09	28.43	62.61	18.78	0.39	-0.50	Class-I	Good	Good
10	1.21	2.75	26.32	53.28	59.55	0.35	-1.09	Class-I	EXCELLENT	PERMISSIBLE
11	0.71	1.39	14.54	26.29	73.69	0.17	-7.47	Class-I	EXCELLENT	PERMISSIBLE
12	0.60	1.29	17.09	46.29	35.17	0.18	-1.49	Class-I	Good	Good
13	1.06	2.28	25.16	51.90	52.71	0.32	-1.47	Class-I	Good	Good
14	1.07	2.23	24.58	48.60	65.05	0.32	-2.36	Class-I	Good	Good
15	1.56	2.85	40.73	77.05	89.06	0.64	0.38	Class-I	PERMISSIBLE	Good
16	0.40	0.73	14.84	28.17	82.24	0.11	-4.72	Class-I	EXCELLENT	Good
17	1.46	2.25	35.89	54.35	52.77	0.53	-2.48	Class-I	Good	Good
18	0.98	1.92	24.39	46.65	66.69	0.30	-2.67	Class-I	Good	Good
19	1.03	1.82	21.10	27.33	38.15	0.23	-8.68	Class-I	Good	PERMISSIBLE
20	0.50	0.73	15.67	33.90	82.76	0.17	-3.37	Class-I	EXCELLENT	EXCELLENT
21	1.09	2.57	32.41	35.4[illegible]	87.55	0.24	-6.12	Class-I	Good	PERMISSIBLE
22	0.66	1.06	25.21	49.93	61.75	0.25	-1.79	Class-I	Good	Good
23	0.02	0.02	4.16	62.80	71.90	0.01	-0.52	Class-II	EXCELLENT	EXCELLENT
24	0.90	1.86	23.26	38.55	95.86	0.24	-4.24	Class-I	Good	Good
25	0.93	0.98	31.30	55.70	84.33	0.44	-1.58	Class-I	Good	EXCELLENT
26	1.11	2.05	33.72	50.95	65.61	0.36	-2.29	Class-I	Good	Good
27	0.98	2.28	27.16	37.46	59.61	0.24	-4.78	Class-I	Good	EXCELLENT
28	0.81	1.49	26.47	34.80	81.21	0.23	-4.78	Class-I	Good	Good
29	0.66	1.34	17.21	43.29	62.84	0.20	-2.43	Class-I	EXCELLENT	Good
30	1.10	1.94	31.07	58.82	50.31	0.41	-1.32	Class-I	Good	Good
MAX.	1.56	2.85	48.42	104.87	95.86	0.86	0.38			
MIN.	0.02	0.02	4.16	26.29	18.78	0.01	-8.68			
AVG.	0.86	1.59	24.40	47.81	65.78	0.29	-2.83			

5.2.1 Kelley's Ratio :

Kelly et. al. (1940) have proposed that the potential sodium problem in irrigation waters could be reliably evaluated on the basis of the following ratio:

$$\text{Kelley's Ratio} = Na^{+} / (Ca^{++} + Mg^{++})$$

where all the concentrations are expressed in epm. Kelly et. al.(1940) mentioned that if this ratio is less then unity, the water is suitable for irrigation purpos; if it is two or more, the water is unsuitable while water with value between one and two are marginal. It is seen from Table 5.2 that Kelley's ratio when calculated for ground water of Guwahati it varies from 0.01 to 0.86. As mentioned earlier, the Kelley's ratio of the present water is remain less then unity, indicating that the water is suitable and free from salinity hazard.

5.2.2 Sodium Adsorption Ratio (SAR) and Adjusted SAR :

Sodium concentration is very important in classifying irrigation waters because sodium by the process of base exchange may replace calcium in the soil and there may reduce the permeability of the soil to water, if the process continues it has an adverse effect on plant growth. The relatively of sodium ion the exchange reaction with soil is expressed in terms of a ratio known as Sodium Adsorption Ratio (SAR) which is defined as:

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

where all ion concentrations are expressed in epm. The SAR value of the ground water of the study are varies from 0.02-1.56 with the average value of 0.86 (Table 5.2).

Ayers and Branson (1975) have suggested that the SAR (adjusted) will be a

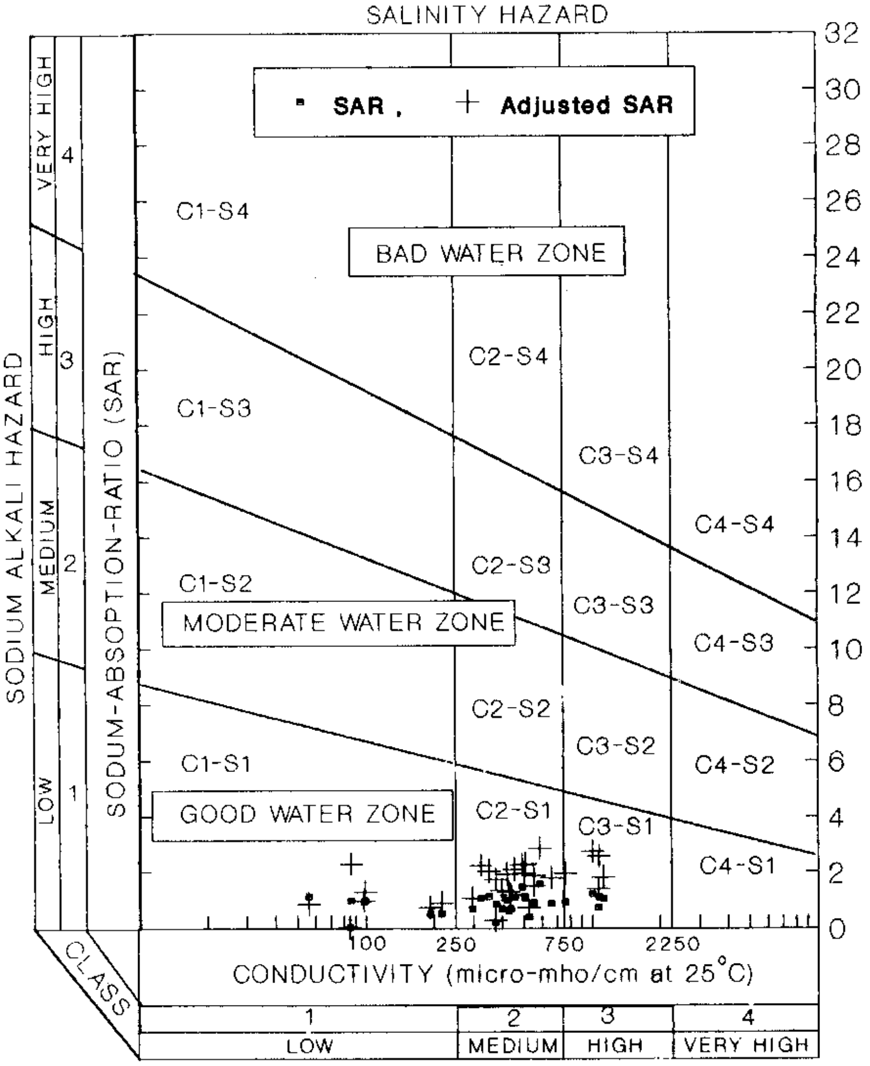


FIG. 5.1 : U.S. SALINITY LABORATORY CLASSIFICATION

useful parameter to determine sodium hazards which can be calculated by the following formula:

$$SAR\ (adjusted) = SAR\ [\ 1+ (\ 8.4 - pHe\ )]$$

Where pHe is the equilibrium pH and it is calculated as follows:

$$pHe = (pK'_2-pKc')+p([HCO^-_3]+p[Ca^{++} + Mg^{++}]$$

(pK'_2-pKc') is essentially the Ca^{++}, Mg^{++}, and Na^+ ion concentration in epm, $p(HCO^-_3)$ is the carbonate and bicarbonate concentration in epm, and $p(Ca^{++} + Mg^{++})$ is concentration of these ions in epm.

It is seen from Table 5.2 that the value of SAR (adjusted) varies from 0.02-2.85 and the average value is 1.59.

The U.S Salinity Laboratory Staff (1954) has published a diagram in which the value of SAR are plotted on an arithmetical scale against Electrical Conductance (EC) on a log scale and different classes of water have been marked on the diagram. In the present study the data plots of water samples are shown in Fig. 5.1. The plot shows that the most of the samples are fall in the C2-S1 class, while from remaining samples, some are falling in C1-S1 and some are in C3-S1 class (Table 5.2). This suggests that ground water has medium salinity and low sodium hazard.

In order to correctly assess these facts, the Ayers and Branson (1975) formula is applied by calculating SAR (adjusted). These workers have suggested that if the value of SAR (adjusted) is less then 3, the ground water have no problem pertaining to sodium adsorption. In the present case, the value are less then 3 (as mentioned earlier), therefore the water is safe from sodium hazards (Table 5.2).

5.2.3 Residual Sodium Carbonate (RSC) :

Eaton (1950) suggested that water having carbonate and bicarbonate ions in excess of calcium plus magnesium will lead to much greater alkali formation then is indicated by its SAR and thereby decreasing the soil permeability. The carbonate and bicarbonate hazards on water quality can be determined in terms of Residual Sodium Carbonate (RSC) which is define by the following equation:

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

Where all concentrations are expressed in epm. In the ground water of the Guwahati area, the values of RSC varies from -8.68 to +0.38 epm (Table 5.2).

Bicarbonate concentration has been suggested as an additional information for irrigation water. If the water contains a high concentration of bicarbonate ions, there may be tendency for Ca^{++} and Mg^{++} ions to precipitate in the soil as carbonate. As a consequence, the relative proportion of sodium increases and gets fixed in the soil permeability. To evaluate the bicarbonate hazards, "Residual Sodium Carbonate" value after Eaton (1950), have been calculated and the values were presented earlier. According to Eaton, on the basis of RSC the water is divided into three categories i.e., good if RCS<1.25 epm; medium if RSC>1.25-2.50 epm and bad if RSC >2.50 epm. Looking to this fact, it can be safely concluded that the ground water of the present area is safe from bicarbonate hazards because the value of RSC varies from -8.68 to +0.38 epm (Table 5.2).

5.2.4 Magnesium Hazard :

Paliwal (1972) has used the ratio $(Mg^{++} * 100)/(Ca^{++} + Mg^{++})$ as an index of magnesium hazard to irrigation water. A critical examination of Table 5.2 reveals that magnesium ratio for ground water of the area varies from 18.78 - 95.86 with the average value of 65.78.

The term Mg hazard has been used by Paliwal (1972) to evaluate the hazardous effects of Mg^{++} to irrigation water. Paliwal (1972) states that Mg hazard is likely to be developed in the soil when this ratio exceeds 50%. The degree of hazardous effects would increase with the increase of Mg^{++}/Ca^{++} ratio. However the harmful effect of Mg^{++} of irrigation water on soil is likely to be reduced by the release of Ca^{++} on dissolution of $CaCO_3$ if present in the soil. This concept has been utilized in the present study for evaluating the irrigation applicability of ground waters. In the present case, it may be mentioned here that most of the samples, this ratio exceeds to 50% (Table 5.2), indicating that suitable measures have to be taken to avoid Mg hazard.

5.2.5 Soluble Sodium Percent (SSP) or Na% (Wilcox classification) :

Wilcox (1948) has proposed another classification scheme for rating irrigation water on the basis of specific electrical conductance, soluble sodium per cent (SSP). The SSP is calculated by the following formula:

$$SSP \text{ or } Na\% = (Na^{+} + K^{+}) * 100 / (Ca^{++} + Mg^{++} + Na^{+} + K^{+})$$

Where all concentrations are expressed in epm. The following scheme of classification was given by Wilcox:

Water Classes	**SSP**	**Conductivity (Micro mho/cm)**
Excellent	20	250
Good	20-40	250-750
Permissible	40-60	750-2000
Doughtful	60-80	2000-3000
Unsuitable	80	3000

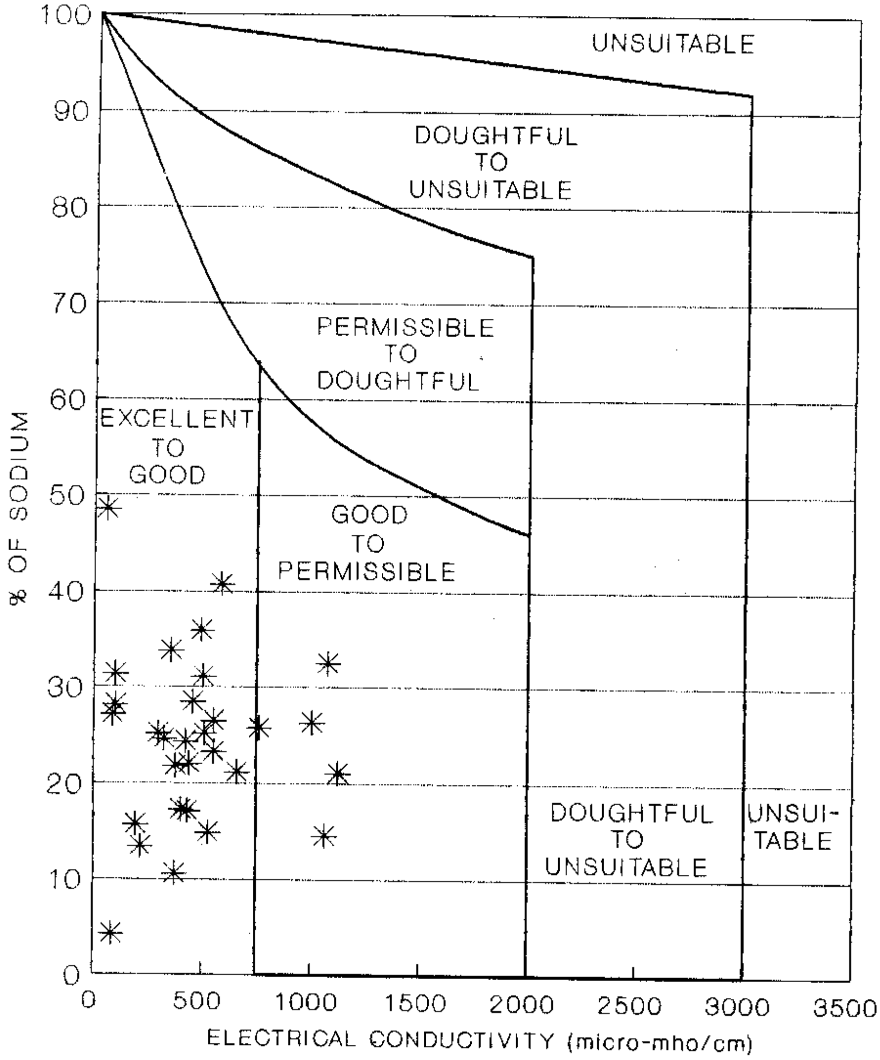


FIG. 5.2 : WILCOX CLASSIFICATION FOR IRRIGATION WATER

The value of specific electrical conductance in ground water of Guwahati varies from 56.0 to 1123 micro-mhos/cm at 25°C and the value of SSP (Na%) varies from 4.16 to 48.42 with an average value of 24.40 (Table 5.2).

When the classification scheme of Wilcox (1948) is applied to the ground water of the present area, it shows that the ground water belong to "Excellent-Good" and "Good - Permissible" classes (Fig. 5.2).

5.2.6 Chloride Tolerance :

Ayers and Branson (1975) have proposed the tolerance limit of chloride in irrigation water.

Ayers and Branson (1975) have proposed the following limits of chloride tolerance in waters to be used for irrigation purposed:

Constituents	No problem	Increased problem	Sevier
From Root Absorption (meq/l)	4.00	4-10	10+
From Folic Absorption (meq/l)	3.00	3+	-

It is observed from the Table 5.4 chloride concentration of ground water varies from 0.24-5.53 ppm. A comparison of the present values with the values proposed by Ayers et. al. revels that ground waters of the area are suitable for irrigation purposes.

5.2.7 Doneen's Permeability Index :

Doneen (1962) has developed a chart based on permeability index (PI) for classification of irrigation water for soils of medium permeability. The

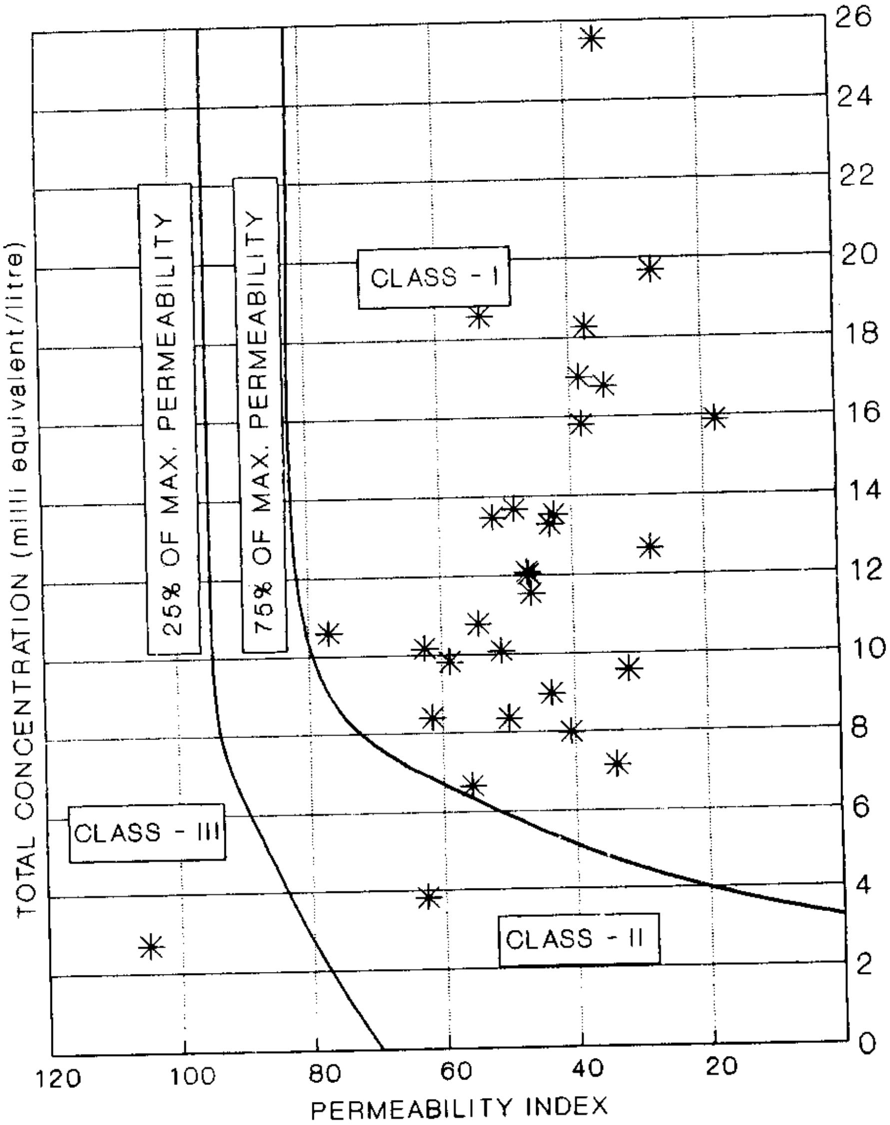


FIG. 5.3 : DONEEN'S CLASSIFICATION FOR IRRIGATION WATER

permeability index (PI) is calculated as below :

$$PI = [Na^+ + SQRT\ (HCO^-_3)] / (Ca^{++} + Mg^{++} + Na^+)$$

Where all the ionic concentrations are expressed in epm. According to this classification, the water is good for irrigation if it belongs to class I or II in the Doneen's chart diagramed (Fig. 5.3). When the classification scheme of Doneen is applied to the ground water of the present area, it shows that the ground water samples belong to Class-I except the samples of grid no. 23 (Class-II) and 4 (Class-III) (Table 5.2).

5.2.8 Total Concentration of Soluble Salts (TDS) :

Total salt concentration of soluble salts in irrigation waters can be adequately expressed for the purpose of diagnosis and classification in terms of electrical conductivity. In general, waters with conductivity values below 750 micro-mhos/cm are satisfactory for irrigation in so far salt content is concerned, although salt sensitive crops may be adversely affected by the use of irrigation waters having conductivity affected by the use of irrigation waters having conductivity values in the range 250 to 750 micro-mhos/cm are (USDA, 1954). Waters in the range of 750 to 2250 micro-mhos/cm are widely used, an satisfactory crop growth is obtained under good management and favorable drainage conditions, but saline conditions will develop if leaching and drainage are inadequate. Use of waters with conductivity values above 2250 micro-mhos/cm, is the exception. However, in this case the more salt tolerant crops can be grown with such waters, only if sub-soil drainage is good.

In addition, for best quality of irrigation water total dissolve solids should be below 800 mg/I (Jermer, 1987). In general water is good for irrigation, if total dissolved solids are below 1000 mg/l. However, this limit can be increased to 1700 mg/l, in case calcium forms 25% of the total bases in the irrigation water (Raghunath, 1982).

The total concentration of soluble salts in irrigation water can be expressed for the purpose of classification of irrigation water as follows :

Zone	TDS (ppm)	Conductivity(micro-mhos/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 27.0 to 1123.0 ppm. Majority of the samples (about 65%) of the study area falls under medium salinity zone. About 20% samples of the study area falls under low salinity zone and remaining 15% fall in high salinity zone. High salinity zone water can not be used on soils having very low drainage. In such case special management criteria for salinity control may be required and plants of good salt tolerance should be selected.

5.3 Water Quality Evaluation for Domestic Purpose :

The objectives of any water supply scheme are to provide safe and wholesome water to the users in adequate quantities, and to make it widely available to the users in order to encourage personnel and household hygiene. Safe and wholesome water can be defined as uncontaminated water (hence unable to infect its users with waterborne disease), free from excessive amounts of mineral of organic matters, and free from poisonous substances. The intensive use of natural resources and the large production of wastes in modern society often pose a threat to groundwater quality and has already resulted in many incidents of

TABLE 5.3 - PHYSICAL AND REDOX PARAMETERS OF GROUND WATER

Zone no.	pH	Oxidation Reduction Potential m-V	Dissolved Oxygen ppm	Conductivity μ-mho/cm	Total Dissolved Solids ppm	Water Table m,bgl	Temperature °C
1	6.27	193.00	6.42	216.00	108.00	1.20	28.60
2	6.26	185.00	6.48	438.00	219.00	0.70	28.20
3	5.79	178.00	6.08	659.00	330.00	1.90	27.10
4	5.65	164.00	5.98	56.00	27.00	5.50	25.70
5	6.12	181.00	6.23	99.00	49.00	2.63	27.70
6	5.95	179.00	5.98	762.00	381.00	0.80	29.70
7	6.08	180.00	6.04	377.00	189.00	1.14	26.60
8	5.91	189.00	6.19	374.00	187.00	0.60	27.40
9	6.40	189.00	6.58	455.00	228.00	0.60	28.80
10	6.95	209.00	6.24	1004.00	503.00	0.97	27.80
11	6.48	198.00	6.28	1064.00	534.00	2.20	26.60
12	7.00	218.00	6.31	429.00	215.00	12.30	25.50
13	6.70	201.00	6.58	509.00	254.00	5.10	35.60
14	7.60	238.00	6.40	323.00	161.00	2.25	27.50
15	6.46	196.00	6.28	585.00	293.00	3.20	21.70
16	6.54	200.00	6.48	526.00	263.00	0.80	27.50
17	6.21	183.00	6.09	490.00	245.00	1.70	26.30
18	6.50	200.00	5.48	422.00	211.00	2.10	26.80
19	5.98	181.00	6.20	1123.00	562.00	2.80	25.60
20	6.10	182.00	5.82	192.00	96.00	6.32	26.60
21	6.72	203.00	6.27	1075.00	538.00	2.10	26.80
22	6.08	181.00	6.68	296.00	148.00	2.30	26.30
23	7.50	236.00	6.80	85.00	42.00	5.10	28.10
24	7.50	243.00	7.02	552.00	326.00	5.70	29.30
25	5.82	178.00	6.25	98.00	49.00	0.50	28.80
26	6.60	202.00	6.31	352.00	176.00	3.30	26.00
27	6.45	198.00	6.34	86.00	543.00	1.21	27.20
28	5.99	193.00	6.08	552.00	276.00	4.85	25.60
29	6.60	205.00	6.39	401.00	200.00	4.00	28.00
30	6.30	192.00	6.42	502.00	251.00	4.80	26.50
MAX.	7.60	243.00	7.02	1123.00	562.00	12.30	35.60
MIN.	5.65	164.00	5.48	56.00	27.00	0.50	21.70
AVG.	6.42	195.83	6.29	470.07	253.47	2.88	27.33

groundwater contamination. Among all the uses of water, domestic use of water has prime importance. In domestic use water is required for essential daily routine works like drinking, cooking, washing, bathing etc. The parameters affect the toxicity of ground water for domestic uses are discussed below.

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, fluoride, phosphate, sodium, potassium, calcium and magnesium etc. The level of concentration and the toxicity caused by these constituents are 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 acidic side and lies in the range 5.65 to 7.6 (Table 5.3) In most of the sites it is below 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 56 to 1123 µ-mhos/cm with most of the samples having conductivity value between 300 to 600 µ-mhos/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 the considerable amounts from the action of carbonates upon the basic materials in the soil. The alkalinity values in the study area varies from 40 to 298 mg/L (Table 5.4).

TABLE 5.4 - CHEMICAL PARAMETERS OF GROUND WATER SAMPLES

ZONE NO.	ALKALINITY ppm	SODIUM ppm	CALCIUM ppm	MAGNESIUM ppm	POTASSIUM ppm	CHLORIDE ppm	NITRATE ppm	SULPHATE ppm	PHOSPHATE ppm	FLOURIDE ppm
1	100.00	19.34	28.87	52.49	2.41	17.20	0.00	34.38	1.06	0.00
2	157.90	18.94	24.34	22.93	2.41	42.40	0.66	28.84	1.21	1.04
3	180.90	34.57	54.62	40.00	4.77	52.40	1.93	66.36	1.04	0.72
4	50.00	16.50	8.10	5.10	2.41	8.40	0.00	1.64	1.01	0.23
5	50.00	30.51	8.65	40.51	6.31	97.60	0.57	4.86	1.02	0.86
6	192.80	40.15	66.97	49.32	32.56	65.20	2.93	36.71	1.09	0.25
7	201.40	31.52	33.76	44.95	5.69	56.00	0.56	11.48	1.03	0.00
8	80.28	5.09	12.19	30.42	5.79	93.80	3.85	24.36	1.03	1.10
9	199.40	34.06	61.27	8.50	0.67	46.40	0.53	14.88	1.03	0.33
10	297.90	48.00	48.36	42.71	1.90	171.40	3.50	35.28	1.03	1.14
11	100.20	34.78	47.96	80.58	1.49	126.00	0.61	71.73	1.74	1.36
12	239.80	22.60	70.32	22.89	5.28	23.00	0.22	19.18	1.12	0.97
13	243.80	40.15	51.73	34.60	3.64	50.00	0.22	35.63	1.01	0.64
14	198.40	41.29	39.22	43.79	1.28	100.00	1.20	7.73	1.17	1.49
15	200.94	43.20	6.38	31.15	4.87	69.00	1.98	20.60	1.02	1.20
16	100.62	16.29	22.61	62.83	15.64	50.00	2.87	101.25	2.60	0.85
17	81.84	46.26	36.09	24.19	4.97	99.00	5.50	32.41	1.03	0.04
18	160.30	36.61	35.28	42.38	4.56	65.00	0.68	26.69	1.03	0.21
19	61.44	52.06	119.89	44.37	12.82	100.00	3.57	171.02	1.02	2.36
20	60.00	16.80	15.00	43.20	3.03	27.40	1.38	11.31	1.06	0.43
21	240.10	56.10	25.02	105.61	92.82	139.26	1.46	134.34	3.28	2.06
22	100.60	19.85	26.30	25.47	11.54	51.20	0.16	31.70	2.62	0.84
23	80.64	0.42	10.35	15.89	2.41	18.60	0.16	2.90	1.12	0.29
24	161.00	38.44	5.69	79.12	16.15	83.40	3.69	145.97	1.06	0.85
25	40.92	22.60	7.06	22.79	1.69	93.00	0.56	4.69	1.03	0.38
26	141.44	38.63	31.68	36.26	25.90	18.00	0.72	13.99	1.04	0.00
27	241.20	47.26	70.58	62.50	46.92	56.80	2.77	33.85	1.46	0.20
28	101.74	33.55	24.22	62.79	33.59	196.40	1.28	38.32	2.44	0.81
29	180.62	24.92	40.10	40.68	1.49	112.40	0.08	30.63	1.01	0.41
30	140.24	34.06	35.92	21.82	5.79	65.80	1.81	19.53	1.03	0.23
MAX.	297.90	56.10	119.89	105.61	92.82	196.40	5.50	171.02	3.28	2.36
MIN.	40.92	0.42	5.69	5.10	0.67	8.40	0.00	1.64	1.01	0.00
AVG.	146.21	31.49	35.62	41.33	12.03	73.17	1.51	40.41	1.31	0.71

Total Dissolved Solids (TDS) :

Total dissolved solids (TDS) indicate the general nature of water quality or salinity. Water containing more then 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralised water is also used where better water is not available. For this reason, 500 mg/L as the desirable limits and 1500 mg/L as the maximum permissible limit has been suggested for drinking water. The TDS value in the groundwater of Guwahati region varies from 27 to 562 mg/L (Table 5.3).

Sodium :

Sodium concentration more then 50 ppm makes the water unsuitable for domestic use. The sodium concentration in the groundwater from Guwahati region varies between 0.42 and 56.10 (Table 5.4) It is evident from Table 5.4 that the concentration of sodium is lower in all samples except grid no. 21 for domestic applications and thereby making the water suitable 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 study area, calcium and magnesium ranges from 5.69 to 119.89 and from 5.1 to 105.61 mg/L respectively (Table 5.4). Toxicity due to Magnesium is 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 $CaCO_3$

TABLE 5.5 - STATUS OF HARDNESS IN GROUND WATER

Zone No.	Calcium Hardness	Magnesium Hardness	Non Carbonate Hardness	Total Hardness
1	72.00	216.04	208.91	288.04
2	60.66	94.34	26.97	155.00
3	136.20	170.94	154.94	307.14
4	20.20	21.00	0.52	41.20
5	20.08	166.72	149.43	186.80
6	167.00	203.00	214.89	370.00
7	84.20	185.00	106.61	269.20
8	30.40	125.20	91.42	155.60
9	152.80	35.00	25.15	187.80
10	120.60	175.80	54.68	296.40
11	119.60	331.60	373.52	451.20
12	176.60	94.20	74.62	270.80
13	129.00	142.40	73.66	271.40
14	97.80	180.20	117.89	278.00
15	15.92	128.66	0.00	144.58
16	56.40	258.60	235.84	315.00
17	90.04	99.56	123.93	189.60
18	88.00	174.40	133.39	262.40
19	299.00	182.60	434.24	481.60
20	37.40	177.80	168.32	215.20
21	62.40	434.60	305.79	497.00
22	65.60	104.80	89.42	170.40
23	25.80	65.40	25.98	91.20
24	14.20	325.60	211.92	339.80
25	17.60	93.80	79.07	111.40
26	79.00	149.20	114.35	228.20
27	176.00	257.20	239.16	433.20
28	60.40	258.40	238.78	318.80
29	100.00	167.40	121.70	267.40
30	89.60	89.80	65.77	179.40
MAX.	299.00	434.60	434.24	497.00
MIN.	14.20	21.00	0.00	41.20
AVG.	88.82	170.31	142.03	259.13

ranges between 41 to 497 m/L (Table 5.5). From the hardness point of view, the groundwater of the area is hard to very hard in nature in most of the sites 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 test 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 has been reported from intake of waters containing even higher content of chloride. A concentration of more then 250 m/L of chloride makes the water unsuitable for a number of domestic applications. The chloride content in the Guwahati region ranges from 8.4 to 197 mg/L (Table 5.4).

Sulphate :

A limit of 150 mg/L has been suggested for drinking water supplies (BIS, 1983). Sulphate content more then 150 m/L is objectionable for many domestic purposes. Water containing more then 500 ppm sulphate tastes bitter and beyond 1000 ppm, it has purgative effect. The sulphate content in the groundwater of Guwahati region lies well below the permissible value for domestic applications except at grid no. 19 (Table 5.4).

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 know as methaemoglobinaemia (blue babies) which generally affects bottlefed infants. Repeated heavy doses of nitrates on ingestion may likely to cause carcinogenic diseases. The distribution of nitrate in groundwater of the study areas indicates that levels of concentration in groundwater of the study areas varies from 0.00 to 5.5 m/L (Table 5.4).

Fluoride :

Fluoride occurs in almost all natural water supplies. fluoride in high concentration are not a common constituents of surface water, but they may occur in detrimental concentrations in groundwaters. There are significant regional differences in the health effects of consuming varying levels of fluoride and WHO suggests limits based on the mean average annual temperature of the area. As per the standard a desirable limit is 1.0 mg/L and an upper limit is 1.5 mg/L. Concentration of 1.5 mg/L can caused mottling of the teeth. In a review, by the Royal college of physicians (1976) relatively mild osteoflurotic symptoms were connected with fluoride levels as low as 1-3 mg/L in water. Prolonged ingestion of water with high fluoride content leads to skeletal fluorosis in adults and children. If no alternative source is available water must be treated to reduce the fluoride level. The fluoride level in the study area varies from 0.04 to 2.36 mg/L (Table 5.4). In grid no. 19 and 21 fluoride level is found more then 1.5 mg/L which may cause mottling of the teeth and skeletal fluorosis problems.

Phosphate :

Phosphate enters groundwater from several sources like human excretion, phosphatic detergents, food processing industries, agriculture infiltration from fields where phosphatic fertilizer have been use, cattle feedlots, domestic or wild duck waster, free leaves, atmospheric fallout etc. High phosphate content is likely to accelerate eutrophication of water when other growth promoting factors are present. Generally a phosphate phosphorus con concentration of more then 0.025 mg/L in entrapped water and 0.05 mg/L in stream water stimulates excessive and obnoxious growth of algae and other aquatic plants resulting in undesirable tastes and odours. Total phosphate content in excess 0.1 mg/L in water interferes with coagulation in water treatment plants. The phosphate content in the groundwater of Guwahati region varies from 1.01 to 3.23 mg/L. It is evident from table 5.4 that the concentration of phosphate is much higher in all samples.

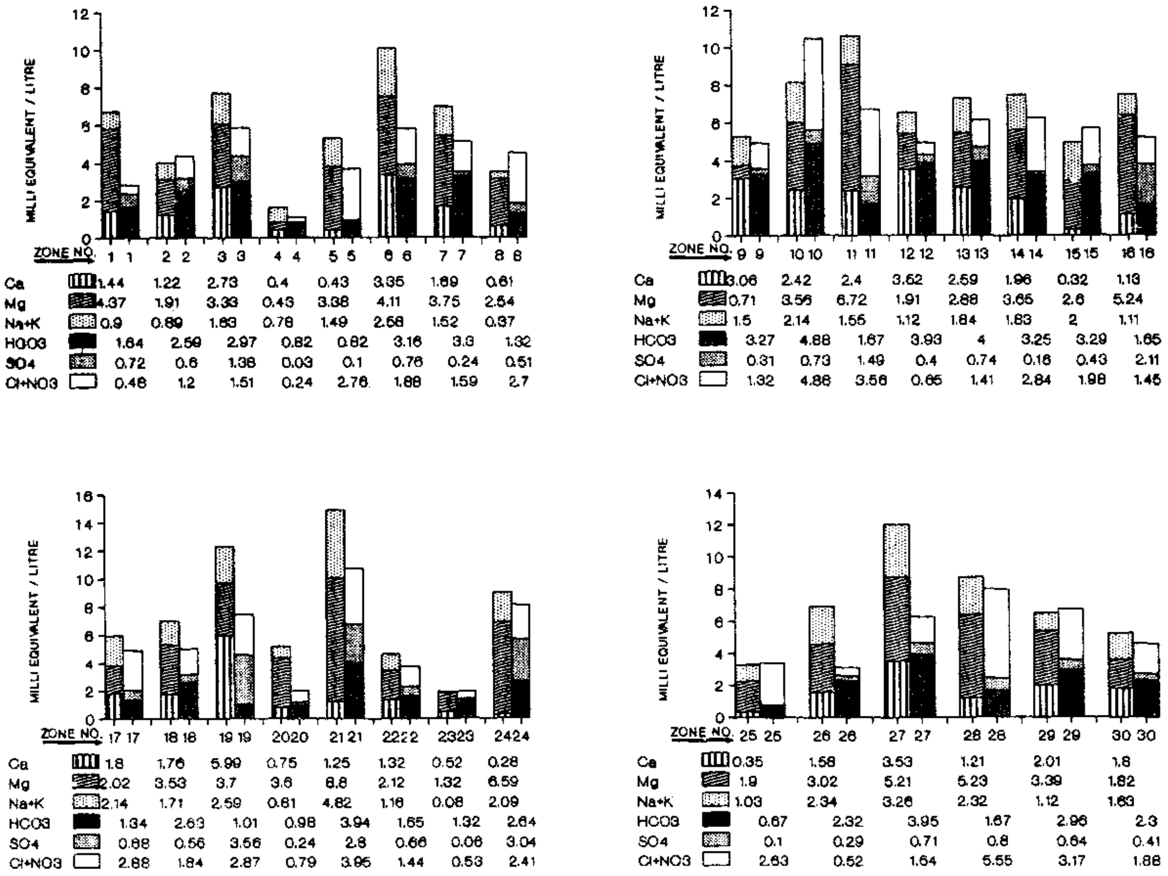
5.4 Graphical Presentation and Classification of Ground Water :

Tables showing results of analyses of chemical quality of ground water may be difficult to interpret, particularly where more than a few analyses are involved. To overcome this, graphical representations are useful for display purpose, for comparing analyses, and for emphasizing similarities and differences. Graphs can also aid in detecting the mixing of water of different compositions and in identifying chemical processes occurring as ground water moves (Todd, 1980).

Graphical representations of the concentrations of different ions in a water sample have been developed from time to time. The most common are : (1) The Collin (1923) bar diagram, (2) the Stiff (1951) pattern diagram, (3) the Piper (1944) diagram, (4) the Back (1961) diagram, (5) the Schoeller (1962) diagram, (6) the Durov (1948) trilinear diagram, (7) the Gibbs (1970) diagram, and (8) the Hortigon's (1975) initial profile diagram.

5.4.1 Collin's Bar Diagramm :

The Collin's (1923) bar diagramm is used by USGS (Hem, 1959). Here each analysis appears as a vertical bar having a height proportional to the total concentration of anions or cations, expressed in milliequivalents per liter. The left half of a bar represents cations, and the right half anions. These segments are divided horizontally to show the concentration of major ions or groups of



ZONE NO.		1 1	2 2	3 3	4 4	5 5	6 6	7 7	8 8
Ca	▥	1.44	1.22	2.73	0.4	0.43	3.35	1.69	0.61
Mg	▨	4.37	1.91	3.33	0.43	3.38	4.11	3.75	2.54
Na+K	░	0.9	0.89	1.63	0.78	1.49	2.58	1.52	0.37
HCO3	■	1.64	2.59	2.97	0.82	0.82	3.16	3.3	1.32
SO4	▒	0.72	0.6	1.38	0.03	0.1	0.76	0.24	0.51
Cl+NO3	□	0.48	1.2	1.51	0.24	2.76	1.88	1.59	2.7

ZONE NO.		9 9	10 10	11 11	12 12	13 13	14 14	15 15	16 16
Ca	▥	3.06	2.42	2.4	3.62	2.59	1.96	0.32	1.13
Mg	▨	0.71	3.56	6.72	1.91	2.88	3.65	2.6	5.24
Na+K	░	1.5	2.14	1.55	1.12	1.84	1.83	2	1.11
HCO3	■	3.27	4.88	1.67	3.93	4	3.25	3.29	1.65
SO4	▒	0.31	0.73	1.49	0.4	0.74	0.16	0.43	2.11
Cl+NO3	□	1.32	4.88	3.56	0.65	1.41	2.84	1.98	1.46

ZONE NO.		17 17	18 18	19 19	20 20	21 21	22 22	23 23	24 24
Ca	▥	1.8	1.76	5.99	0.75	1.25	1.32	0.52	0.28
Mg	▨	2.02	3.53	3.7	3.6	8.8	2.12	1.32	6.59
Na+K	░	2.14	1.71	2.59	0.61	4.82	1.16	0.08	2.09
HCO3	■	1.34	2.63	1.01	0.98	3.94	1.65	1.32	2.64
SO4	▒	0.88	0.56	3.56	0.24	2.8	0.66	0.06	3.04
Cl+NO3	□	2.88	1.84	2.87	0.79	3.95	1.44	0.53	2.41

ZONE NO.		25 25	26 26	27 27	28 28	29 29	30 30
Ca	▥	0.35	1.58	3.53	1.21	2.01	1.8
Mg	▨	1.9	3.02	5.21	5.23	3.39	1.82
Na+K	░	1.03	2.34	3.26	2.32	1.12	1.63
HCO3	■	0.67	2.32	3.95	1.67	2.96	2.3
SO4	▒	0.1	0.29	0.71	0.8	0.64	0.41
Cl+NO3	□	2.63	0.52	1.64	5.55	3.17	1.88

FIG. 5.4 : COLLIN'S BAR DIAGRAME PRESENTATION FOR CATIONS AND ANIONS

closely related ions and identified by distinctive shading patterns. Usually there are six subdivisions but more can be used. In the present study on the basis of total anions and cations ground water samples have been plotted according to Collin's bargraph to represent concentration of different ions and these are shown in Fig. 5.4.

5.4.2 Stiff Pattern Diagram :

Pattern diagrams, first suggested by Stiff (1951), for representing chemical analyses by four parallel horizontal and one vertical axes are illustrated by Fig. 5.5. Concentrations of four major cations (Na^+, K^+, Ca^{++}, Mg^{++},) are plotted to the left of a vertical zero axis and four major anions (Cl^-, SO^{--}_4, HCO^-_3, NO^-_3+PO^{--}_4) to the right; all values are in milliequivalents per liter. The resulting points, when connected, form an irregular polygonal pattern; waters of a similar quality define a distinctive shape. The chemical analysis data of all the thirty samples have been studied using stiff classification and the results of the same have been presented in Table 5.6. From the table seventeen samples were found magnesium bicarbonate type, seven samples of magnesium chloride type, two samples are of calcium bicarbonate type and from the remaining four samples two are magnesium sulphate type and other is sodium bicarbonate type and calcium sulphate type. From the results the waters show predominant magnesium-bicarbonate characters.

5.4.3 Piper's Trilinear Diagram :

One of the most useful graphs for representing the comparision of water quality analyses is the trilinear diagram by Piper (1944) shown in Fig. 5.6. The diagram consists of two lower triangular fields and a central diamond-shaped field. all of the three fields have scales reading in 100 parts. Here cations expressed as percentage of total cations in milliequivalents per liter, plot as

TABLE 5.6 - DIFFERENT CLASSIFICATIONS OF GROUND WATER

Zone No.	Different Classifications						
	Stiff	USSL	Piper's Trilinear	Back's Classification (1961)	Gibbs	Durov's classification on the basis of	
						Cation Type	Anion Type
1	Mg-HCO3	C1-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Mg Type	HCO3 Type
2	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type
3	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type
4	Na-HCO3	C1-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	PPD	Intermediate	HCO3 Type
5	Mg-Cl	C1-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	PPD	Mg Type	Cl Type
6	Mg-HCO3	C3-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type
7	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Mg Type	HCO3 Type
8	Mg-Cl	C2-S1	Ca-Mg-SO4-Cl	Ca-Mg-Cl-SO4-HCO3	RD	Mg Type	Cl Type
9	Ca-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Ca Type	HCO3 Type
10	Mg-HCO3	C3-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Intermediate
11	Mg-Cl	C3-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Cl Type
12	Ca-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Ca Type	HCO3 Type
13	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type
14	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type
15	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Mg Type	HCO3 Type
16	Mg-SO4	C2-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Intermediate
17	Mg-Cl	C2-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Intermediate	Cl Type
18	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Mg Type	HCO3 Type
19	Ca-SO4	C3-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Intermediate	Intermediate
20	Mg-HCO3	C1-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Intermediate
21	Mg-HCO3	C3-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Intermediate
22	Mg-HCO3	C2-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Intermediate	Intermediate
23	Mg-HCO3	C1-S1	Ca-Mg-HCO3	Ca-Mg-HCO3-Cl-SO4	PPD	Mg Type	HCO3 Type
24	Mg-SO4	C2-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Intermediate
25	Mg-Cl	C1-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	PPD	Mg Type	Cl Type
26	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type
27	Mg-HCO3	C1-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type
28	Mg-Cl	C2-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Cl Type
29	Mg-Cl	C2-S1	Ca-Mg-SO4-Cl	Ca-Mg-Na-Cl-SO4-HCO3	RD	Mg Type	Intermediate
30	Mg-HCO3	C2-S1	Ca-Mg-HCO3	Ca-Mg-Na-HCO3-Cl-SO4	RD	Intermediate	HCO3 Type

**

USSL - US Salinity Laboratort
RD - Rock Dominance
PPD - Precipitation Dominance

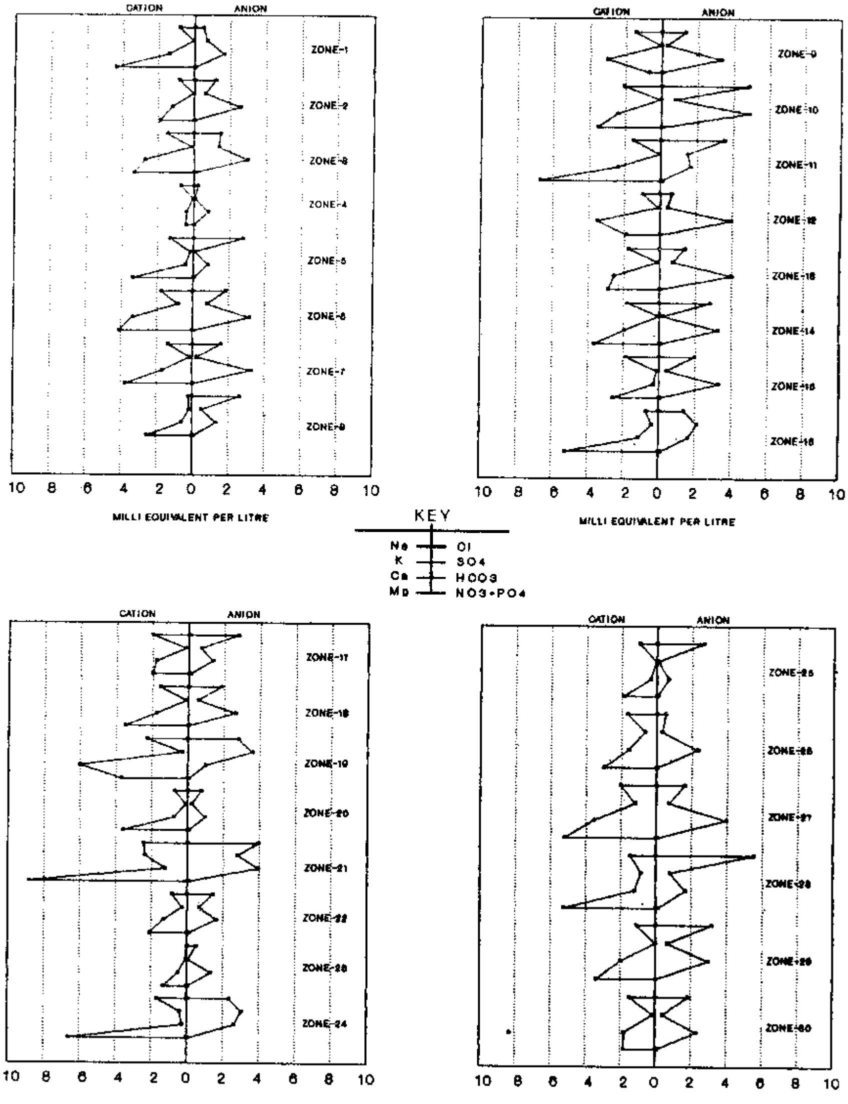


FIG. 5.5 : STIFF PATTERN DIAGRAMES FOR GROUND WATER ANALYSIS

a single point on the left triangle; while anions, similarly expressed as percentage of total anions appear as a point in the right triangle. These two points are then projected into the central diamond-shaped area parallel to the upper edges of the central area. The position of this plotting indicates the relative composition of a ground water in terms of the cation-anion pairs that correspond to the four vertices of the field. This single point is thus uniquely related to the total ionic distribution. The trilinear diagram conveniently reveals similarities and difference among ground water samples because those with similar qualities will tend to plot together as groups.

A piper diagram is best when data are noisy. By classifying samples on the piper diagram, one can identify geologic units with chemically similar water. Noisy data can also be smoothed before plotting on a map or cross section. The facies mapping approach (Back, 1961), is one way of smoothing chemical data. Samples are classified according to facies with two templates for the Piper diagram (Fig. 5.7), one for the cations and other for the anions. The limited number of possibilities for classifying the chemical data effectively eliminates local variability yet preserves broad trend.

The piper trilinear diagram combines three different areas for plotting, two triangle areas (cation and anions) and an 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 $Ca^{++}+Mg^{++} - HCO^{-}_{3}$ and $Ca^{++}+Mg^{++} - SO^{--}_{4}+Cl^{-}$ facies (Table 5.6). According to Back (1961) classification majority of the ground water samples of Guwahati falls in two main facies i.e. $Ca^{++}+Mg^{++}+Na^{+} - HCO^{-}_{3}+Cl^{-}+SO^{--}_{4}$ and $Ca^{++}+Mg^{++}+Na^{+} - Cl^{-}+SO^{--}_{4}+HCO^{-}_{3}$. From remaining two samples, one sample found in $Ca^{++}+Mg^{++}-Cl^{-}+SO^{--}_{4}+HCO^{-}_{3}$ and other in $Ca^{++}+Mg^{++} - HCO^{-}_{3}+Cl^{-}+SO^{--}_{4}$ facies (Table 5.6).

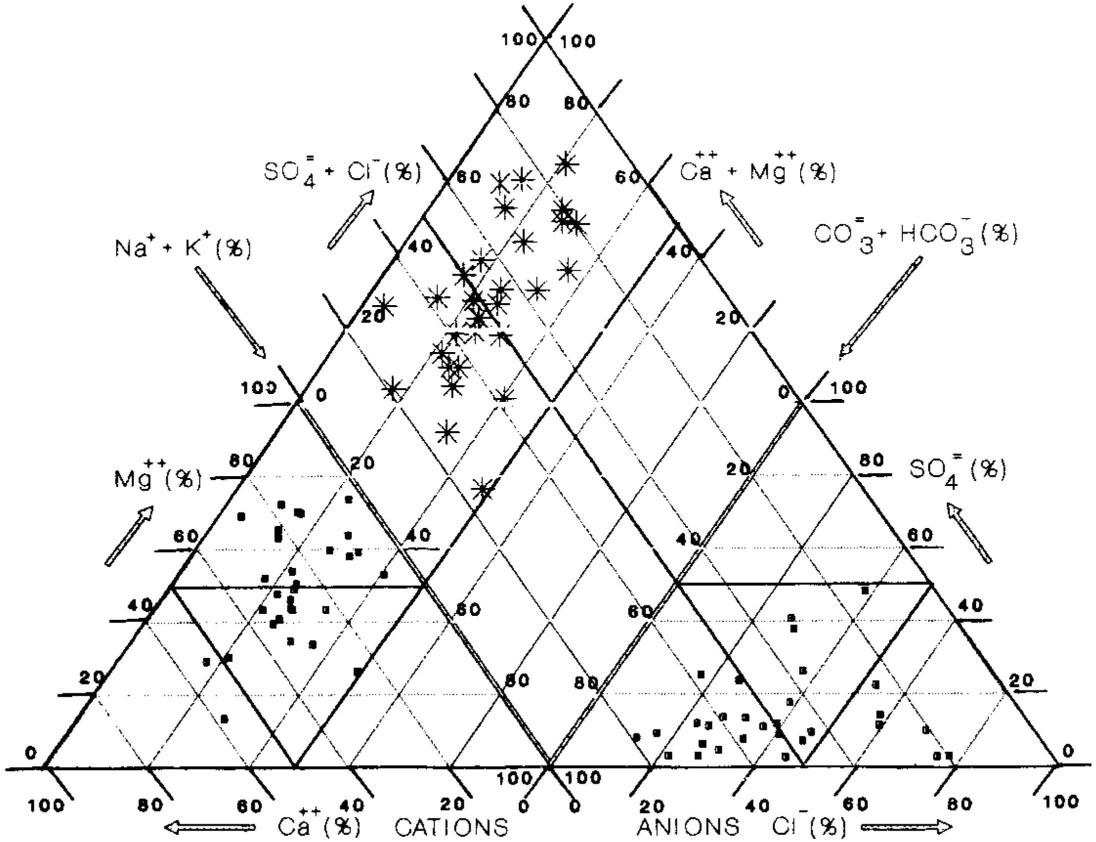


FIG. 5.6 : PIPER'S TRILINEAR CLASSIFICATION FOR GROUND WATER

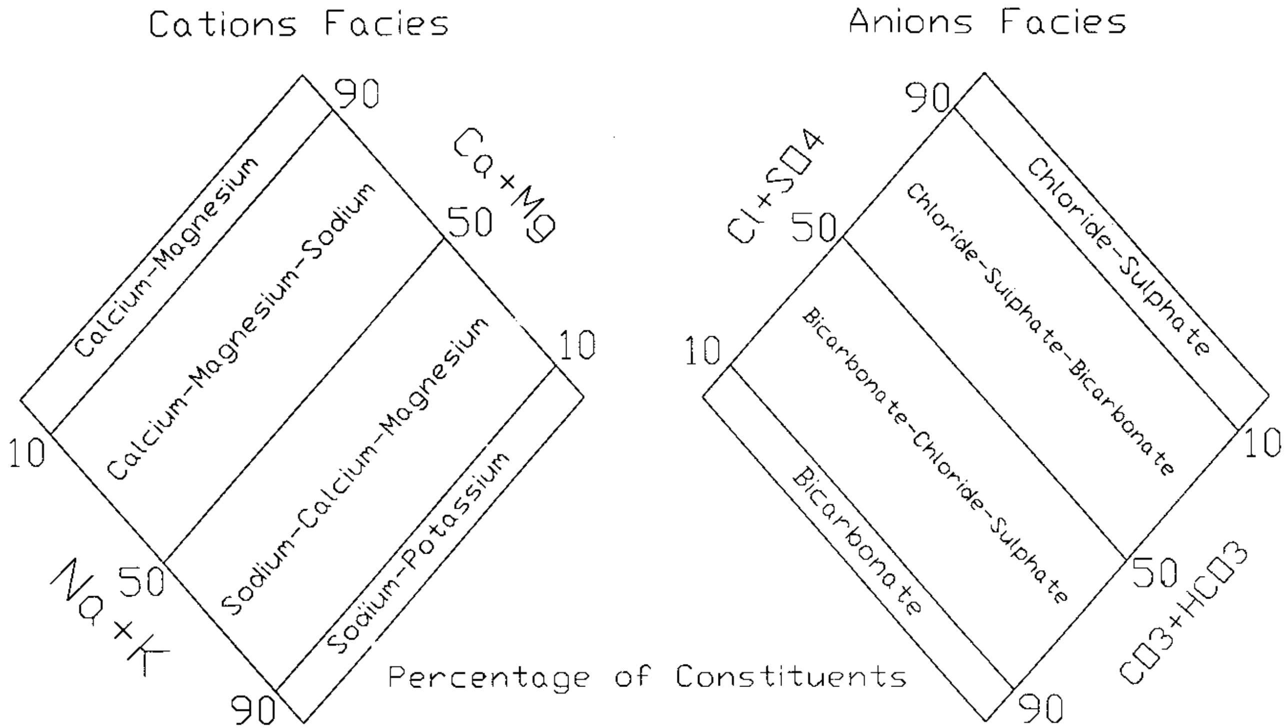


Fig. 5.7 : Back's Templates for Classifying Waters into Facies for Cations and Anions

5.4.4 Schoeller Diagram :

In Europe the semilogarithmic diagram developed by Schoeller (1967) is widely employed for comparing ground water analyses. In the present study, the principle ionic concentration, expressed in milliequivalents per liter, are plotted on six equally spaced logarithmic scales in the arrangement shown by Fig. 5.8. The points thus plotted are joined by straight lines. This type of graphs shown not only the absolute value of each ion but the concentration differences among various ground water analyses. Because of logarithmic scale, if a straight line joining the two points of two ions in one water sample is parallel to another straight line joining the other two points of the same two ions in another water sample, the ratio of the ions in both analyses is equal.

5.4.5 Durov's Double Triangular Diagram :

The Durov's (1948) triangular diagram combines three different areas for plotting, two triangle areas for cations (top triangle) and anions (left triangle) classification and one rectangular shaped area (combined field of Na^++K^+ and HCO^-_3) for salt water intrusion information (Fig. 5.9)... In the triangular field at the lower left, the percentage reacting values of the three anion groups (Cl^-, HCO^-_3, SO^{--}_4) are plotted as a single point according to conventional trilinear co-ordinates. The three cation group (Na^++K^+, Ca^{++}, Mg^{++}) are plotted likewise in the triangular field at the top triangular.

In the present study Durov's double triangular diagram has also been used to diagnose the appearance of salt water in grouundwater samples. The trilinear chart indicates that among the cation group, the samples mostly Mg^{++} and intermediate type (out of 30 samples 16 samples are Mg^{++} type and 12 are intermediate). Two samples are Ca^{++} type. Whereas in anion group, the HCO^-_3 and intermediate type has a majority (out of 30 samples 16 samples are bicarbonate

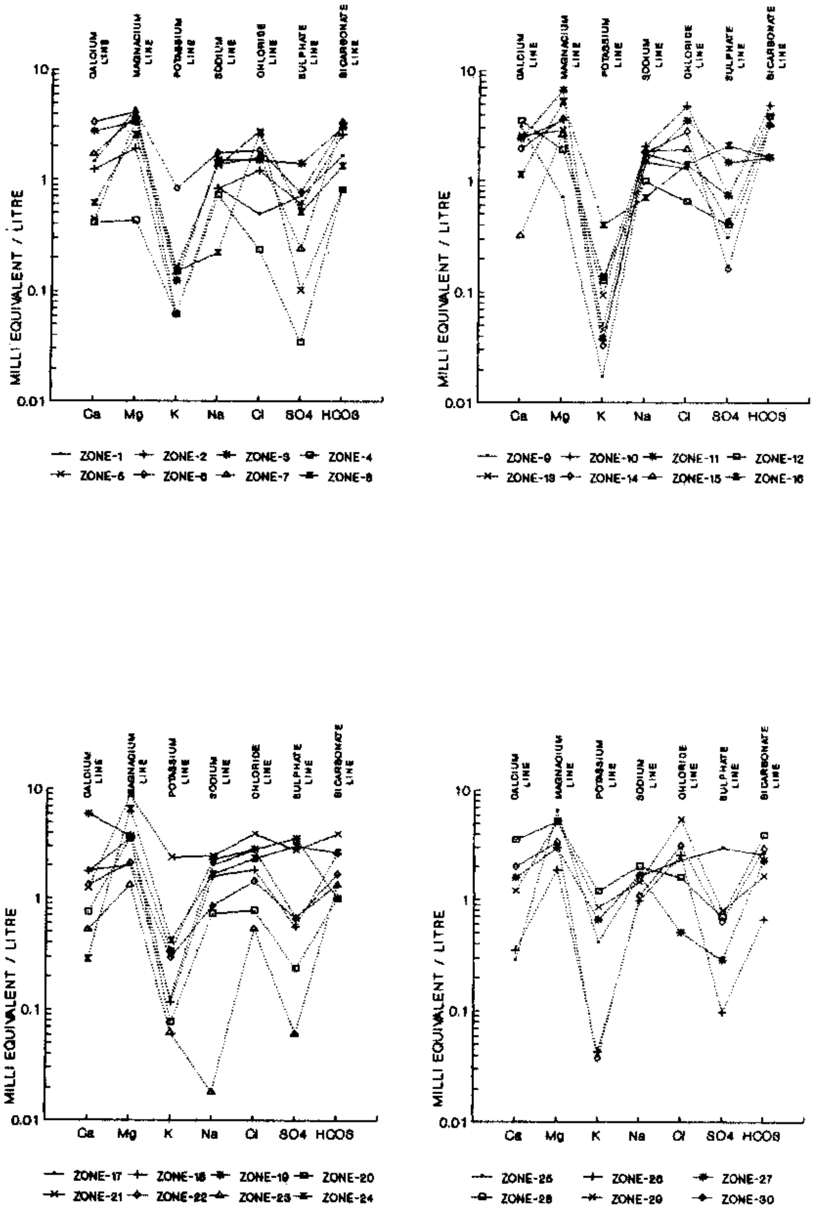
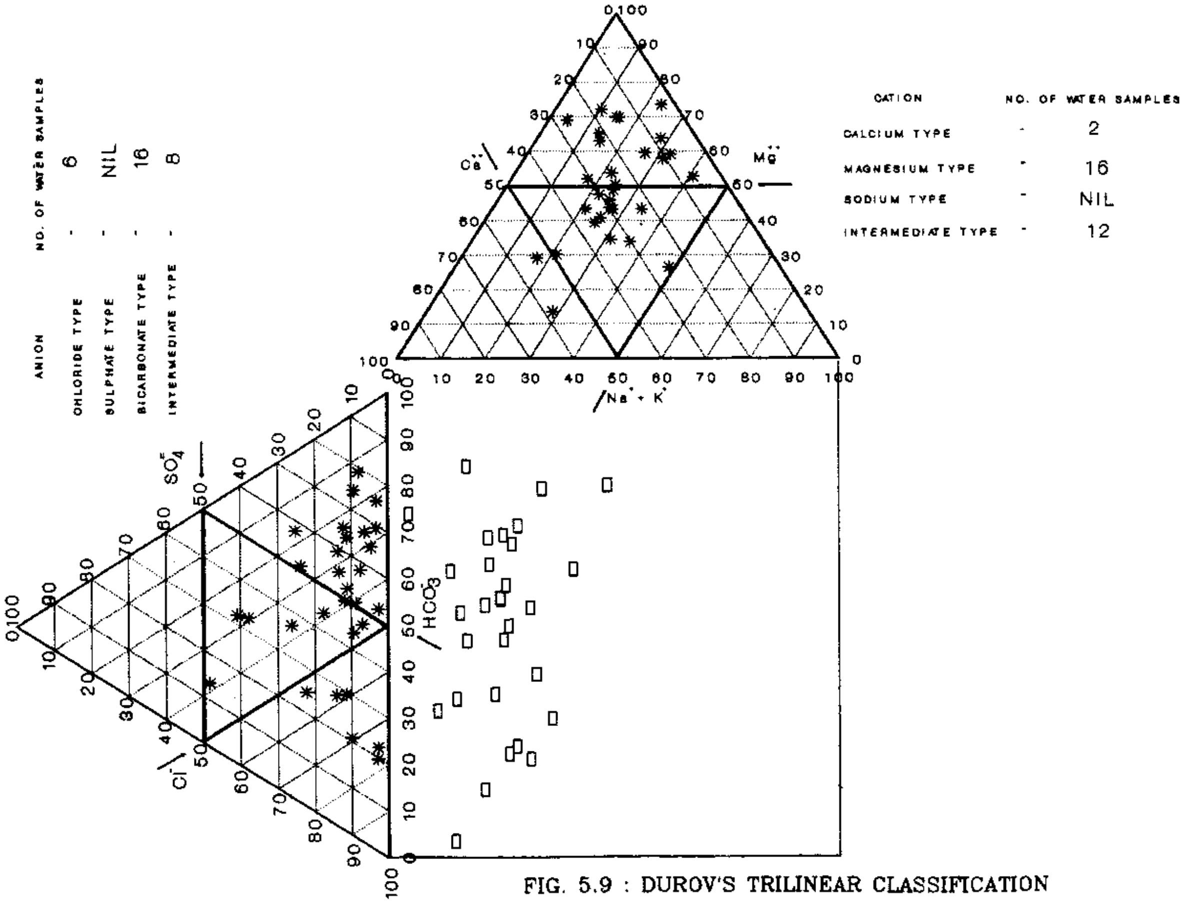


FIG. 5.8 : SCHOLLER DIAGRAM FOR ANIONS AND CATIONS



CATION		NO. OF WATER SAMPLES
CALCIUM TYPE	-	2
MAGNESIUM TYPE	-	16
SODIUM TYPE	-	NIL
INTERMEDIATE TYPE	-	12

ANION		NO. OF WATER SAMPLES
CHLORIDE TYPE	-	6
SULPHATE TYPE	-	NIL
BICARBONATE TYPE	-	16
INTERMEDIATE TYPE	-	8

FIG. 5.9 : DUROV'S TRILINEAR CLASSIFICATION

type and 8 are intermediate). Six samples belong to chloride type (Table 5.6). The plots show that the waters are mostly Mg^{++}-HCO^-_3 type (above 60%) in both cases. Like wise, the plots between Na^++K^+ and HCO^-_3 fall at the left hand side of the Durov's square indicate clearly the fresh water characteristics i.e. absence of salt water intrusion in the ground water of Guwahati.

5.4.6 Gibbs' Diagram :

Gibbs (1970) plotted TDS of world water against the cation ratio (Na to Na+Ca) in ppm. When the scatter of data points are enclosed, a boomrange-shaped figure emerges. In its centre are waters with about 50 to 500 ppm TDS and cation ratio from near zero to about 0.6. Gibbs indicates that rock dominance or the watershed's geochemical nature primarily influence these waters. As TDS increases, the cation ratio increases, forming the upper leg of the boomerang with the major oceans at its apex. Gibbs points out that waters become saline as rates of evaporative salinization exceed precipitation and the cation ratio increases from the selective precipitation of Ca^{++} over Na^+. As TDS decreases, the cation ratio also increases to form the lower leg. Gibbs attributes this trend to the dilution of the waters by the dominance of rainfall or high runoff over evapoconcentration and the presence of sea salts, mainly NaCl, in high-rainfall coastal areas, which result in high cation ratios. A similar diagram emerges when TDS is plotted against the anion ratio (Cl^- to Cl^-+HCO^-_3). It illustrates the three major mechanism that regulate the chemistry of the world's water: (1) Evapoconcentration; (2) selective mineral precipitation; and (3) rainfall of variable composition.

In the present study Gibbs (1970) variation diagram (Fig. 5.10 and 5.11) are used to study the mechanisms of controlling the chemistry of ground water. The ratios of (1) $[(Na^+ + K^+)/(Na^+ + K^+ + Ca^{++})]$ and (2) $[Cl^-/(Cl^- + HCO^-_3)$ have been

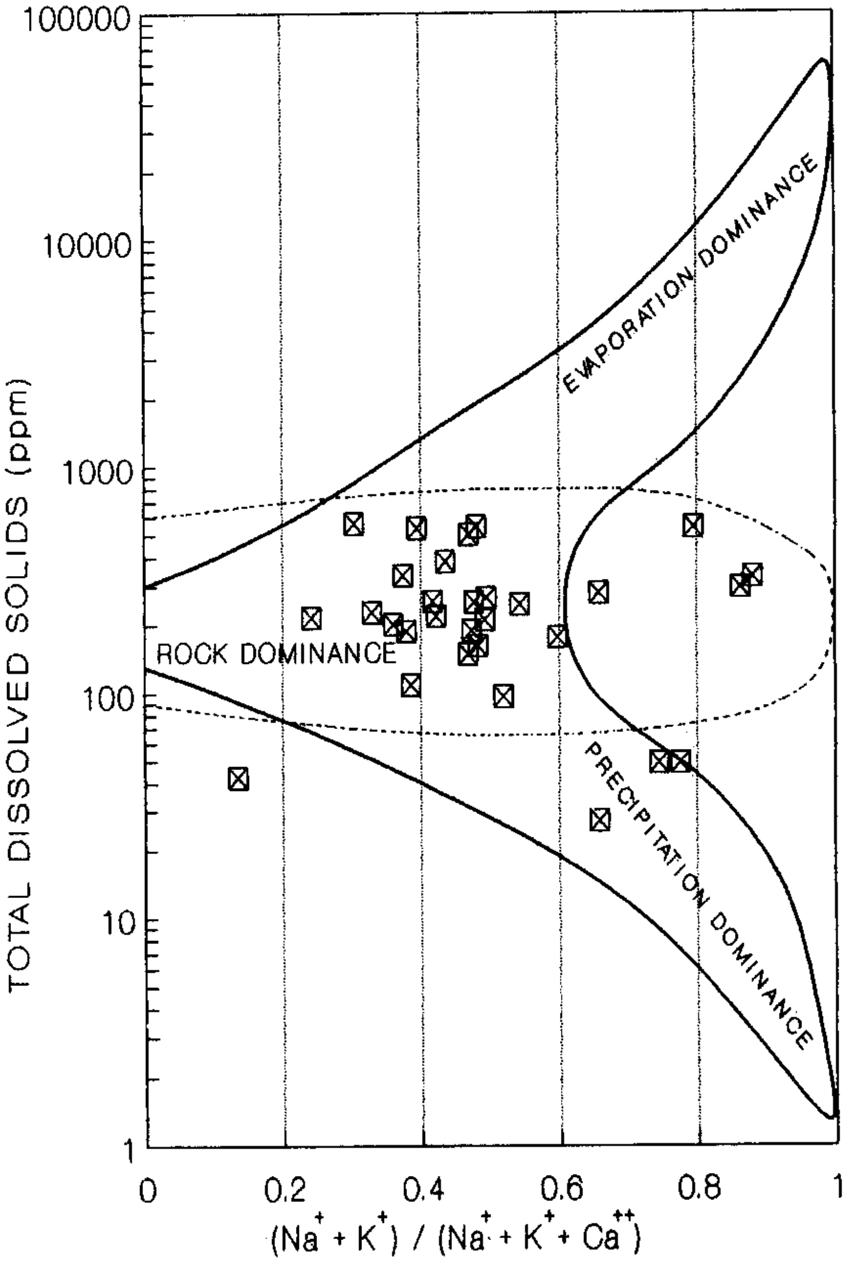


FIG. 5.10 : MECHANISM CONTROLLING THE GROUND WATER CHEMISTRY CATIONS-GIBB'S RATIO 1

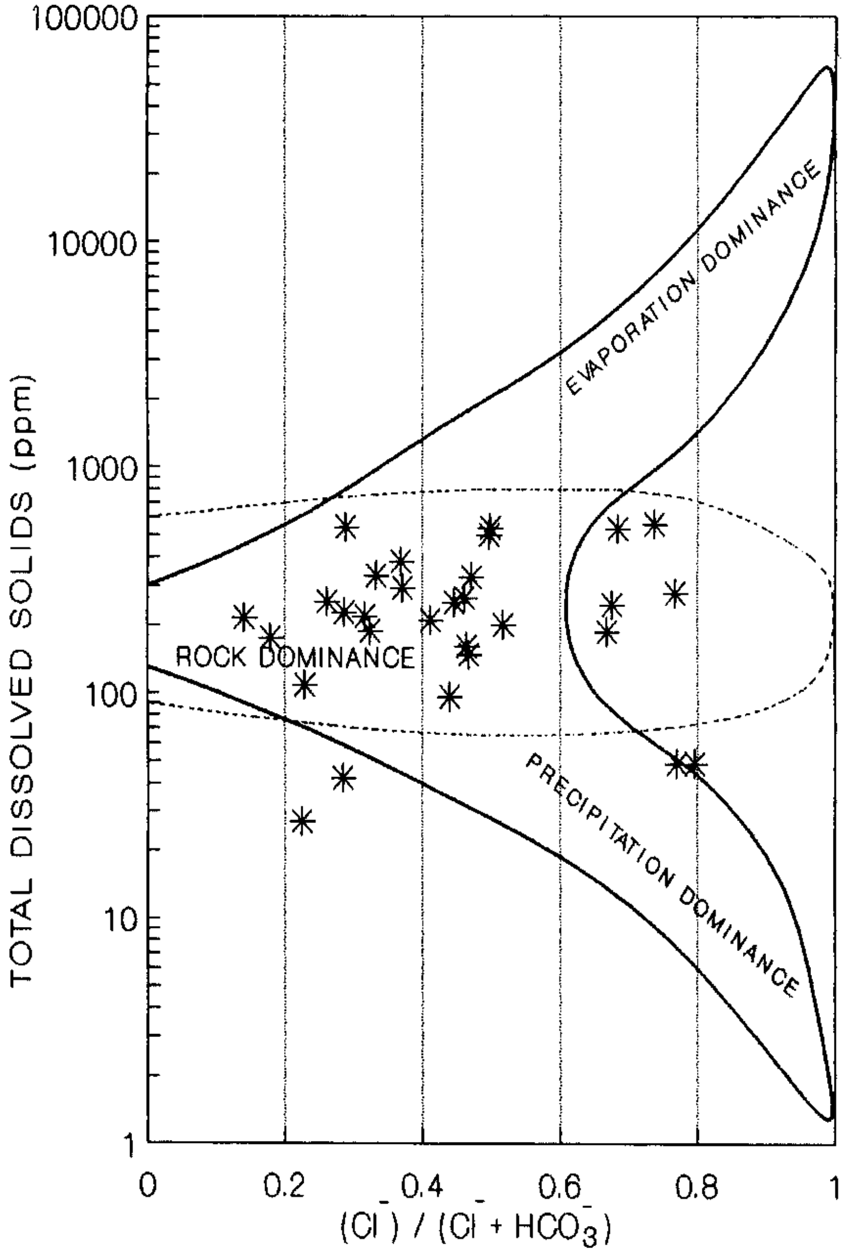


FIG. 5.11 : MECHANICS CONTROLLING THE GROUND WATER CHEMISTRY ANIONS–GIBB'S RATIO 2

plotted against TDS. It is observed that the density of distribution of the points are confined to central rock dominance field indicating that the chemistry of ground water of Guwahati is mainly controlled by the rock type of the region (Table 5.6).

5.4.7 Hortigon's Initial Profile Diagram :

Following Hortigon's (1975) initial profiles of water quality of various parameters have been prepared. A 20 cell histogram is drawn for each variable. Grossly rounded minima and maximum values are taken. The period marking the boundaries of the cell are used only for visualiastion. The first 5 cell are taken as low value, next 10 cell are taken as a moderate value and last 5 cell as a higher value. Profiles are drawn which are also shown in Fig. 5.12 and 5.13 for physical and chemical parameters respectively.

In this study, attempt has been made to find out water quality of thirty ring wells. Parameters were found are Electrical Conductivity, ORP, Temperature, pH, DO, TDS, Alkalinity, Hardness, Ca^{++}, Mg^{++}, NO^-_3, SO^{--}_4, Cl^- and F^-. The results were compared with water quality standard of WHO to find out the degree of pollution in these water bodies by using statistical analysis (Hortigon's initial profile) has been used for determining the lower and higher concentration of water quality parameters. This study shows that water of the some wells considered here require treatment before using them for drinking purpose. Most of the parameters are within the maximum permissible limit of WHO Standards for drinking water, (1971). The diagrams indicate that the quality of ground water samples in the area are corrosive. Samples from grid no. 11, 14, 19 & 21 are showing fluoride concentration more than the permissible limit (>1.2 ppm) of WHO.

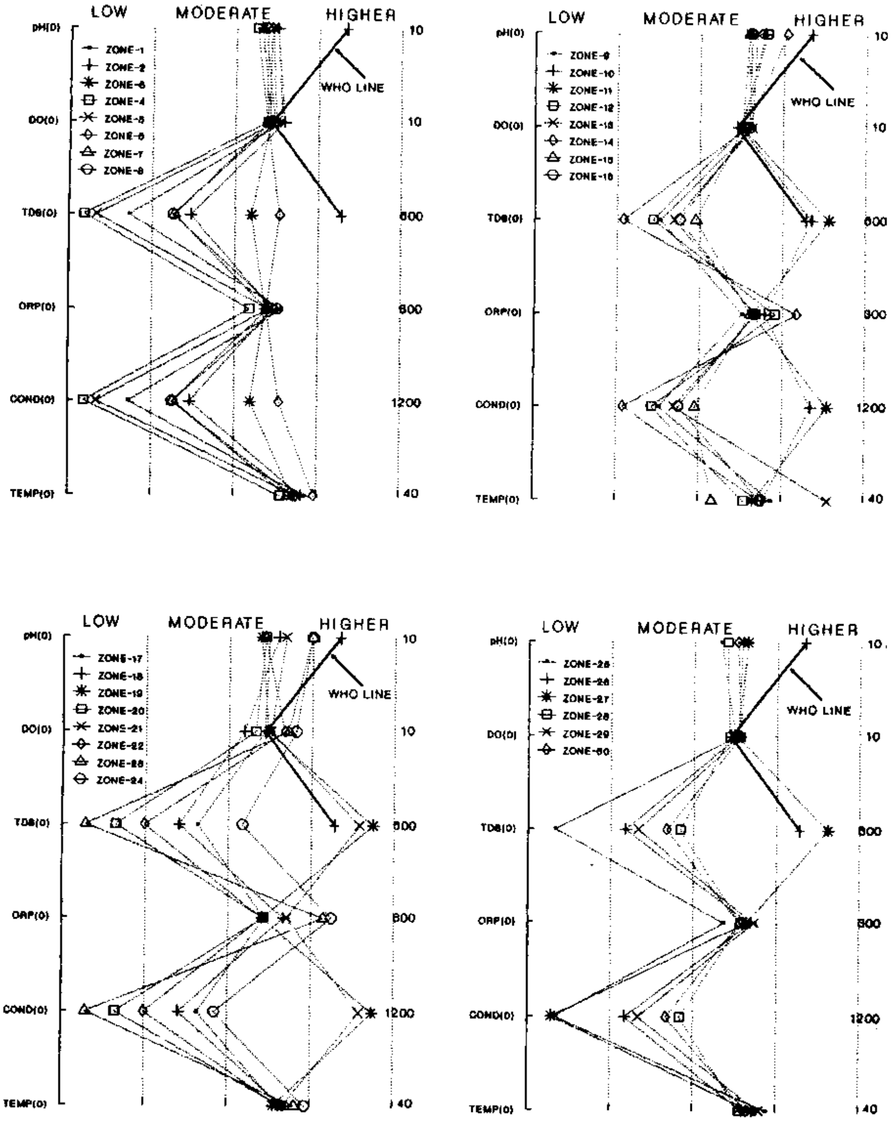


FIG. 5.12 :INITIAL PROFILE FOR PHYSICAL AND REDOX PARAMETERS

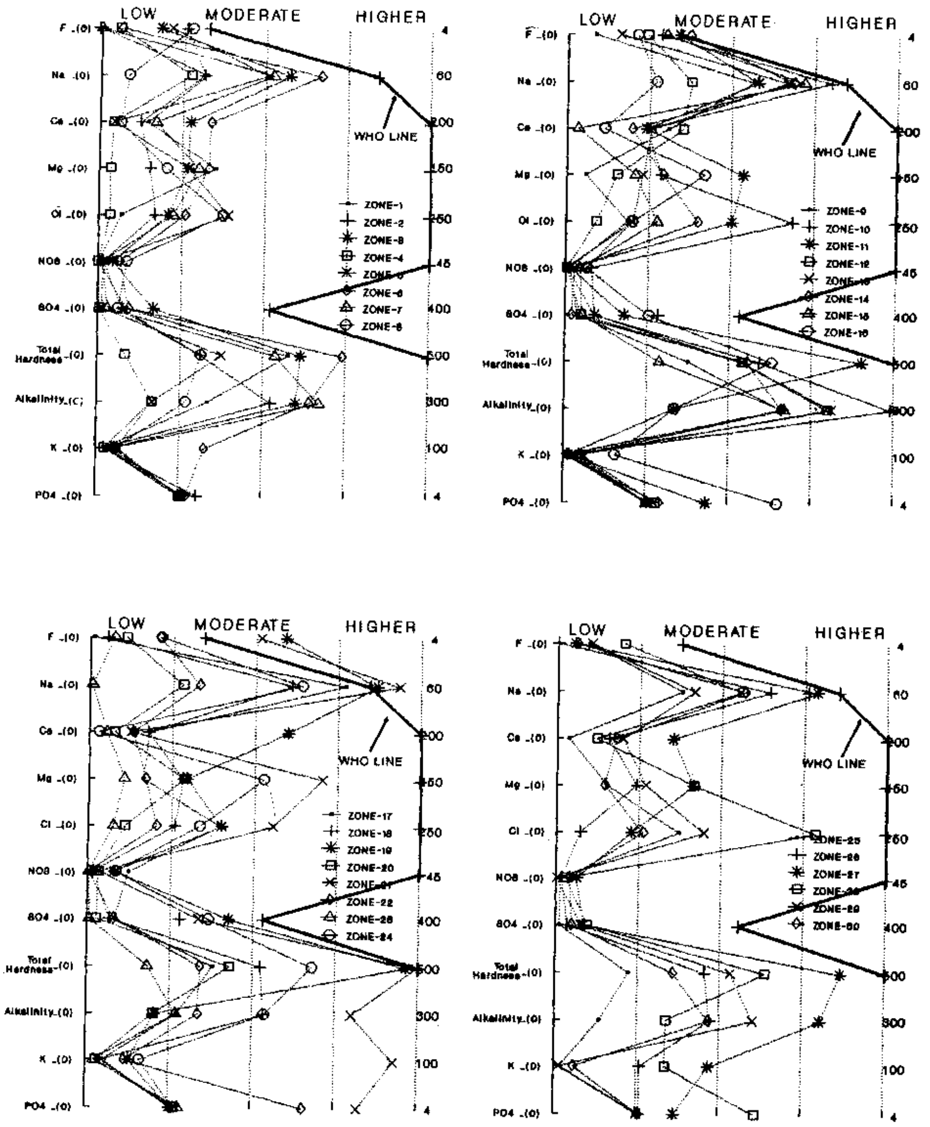


FIG.5.13 :HORTIGON'S INITIAL PROFILE FOR CHEMICAL PARAMETERS

5.5 Water Quality Maps :

Water quality of ground water bodies in a region can be studied by plotting the results of analysis of water samples on maps, by means of symbols, a shading, a bar graph, a small pie circle, etc. Lines of equal concentration of ions (i.e. contour lines) and different parameters can also be drawn. Areas of concentration of specific elements (e.g. fluoride concentration) and problematic areas can be identified and corrective measures employed in corrosive or incrusting water. The water quality maps may be shaded to identify areas of waters having a particular range of concentration. To sea these advantages and using equal distribution of sampling points on the map of Guwahati, thematic/contour maps have been prepared for different water quality parameters along with latitude and longitude information (Fig. 5.14 to 5.39).

The prepared thematic maps expose the zones of these characteristics, which may help farmers, town planners and local authorities like municipal water supply organization, public health engg. etc. to go in for alternative applications and particular use like drinking, irrigation, industrial etc. The outcome of this work is of much use to the agriculturalists and town planning organizations in their decision making. The prepared maps projects the regional behavior of ground water in very simple visualize way. In that way any layman can know the quality of ground water and their behavior and also effect on different applications in his locality.

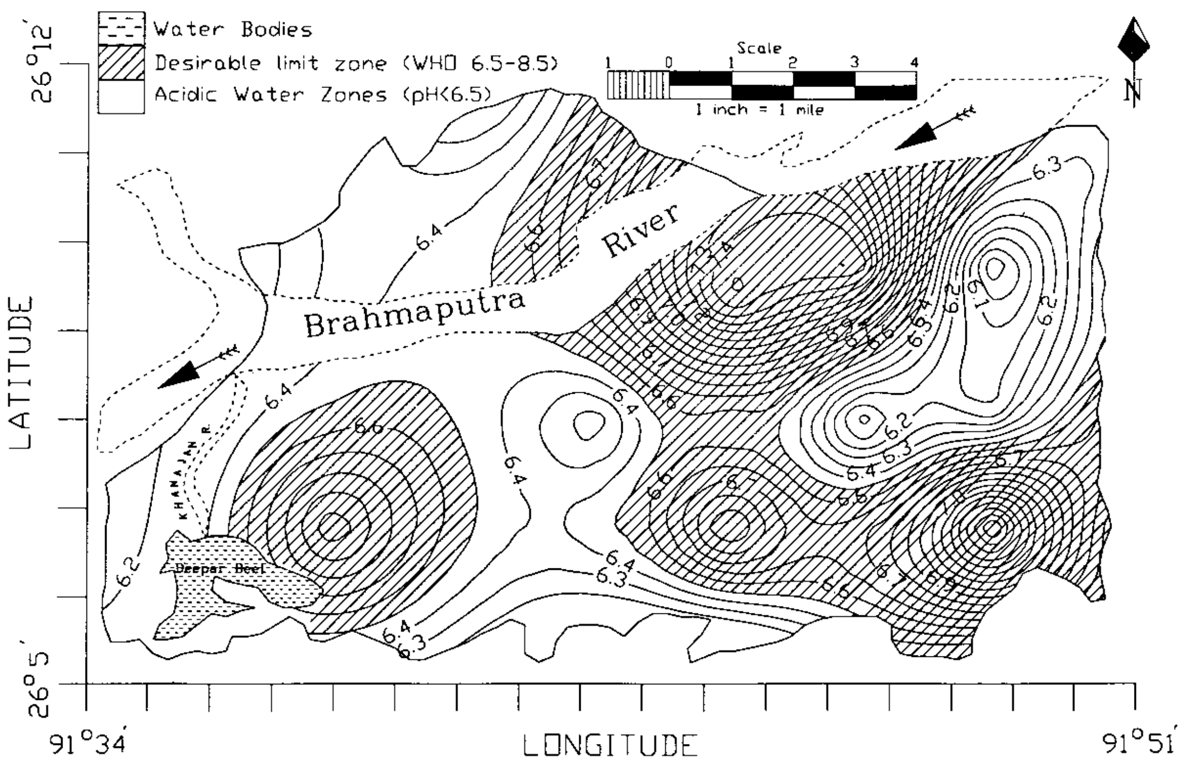


Fig. 5.14 : pH Map

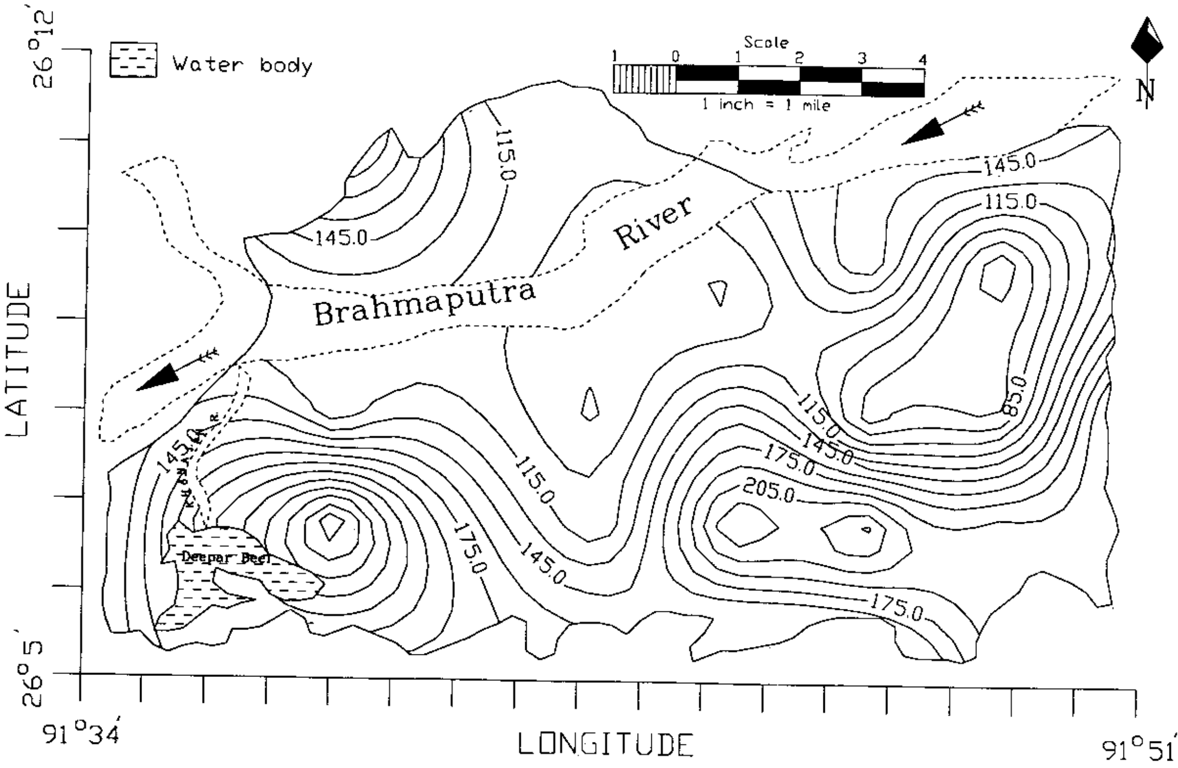


Fig. 5.15 : Alkalinity (ppm) Map

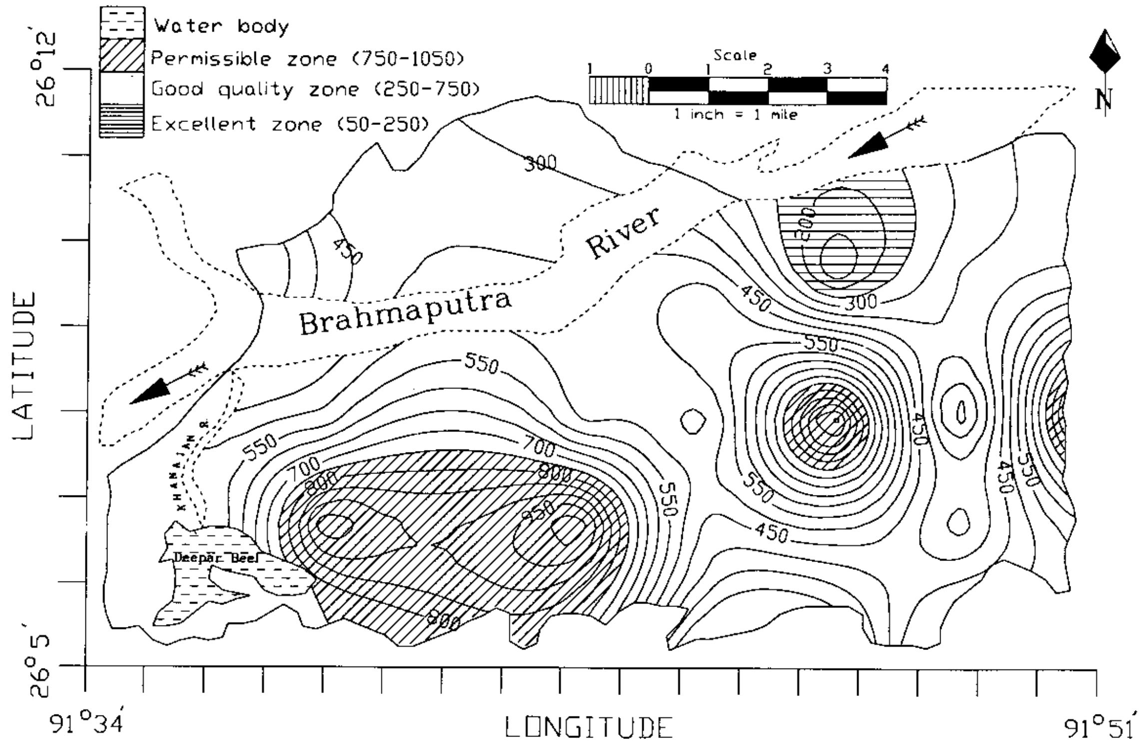


Fig. 5.16 : Conductivity (micro-mho/sec) Map

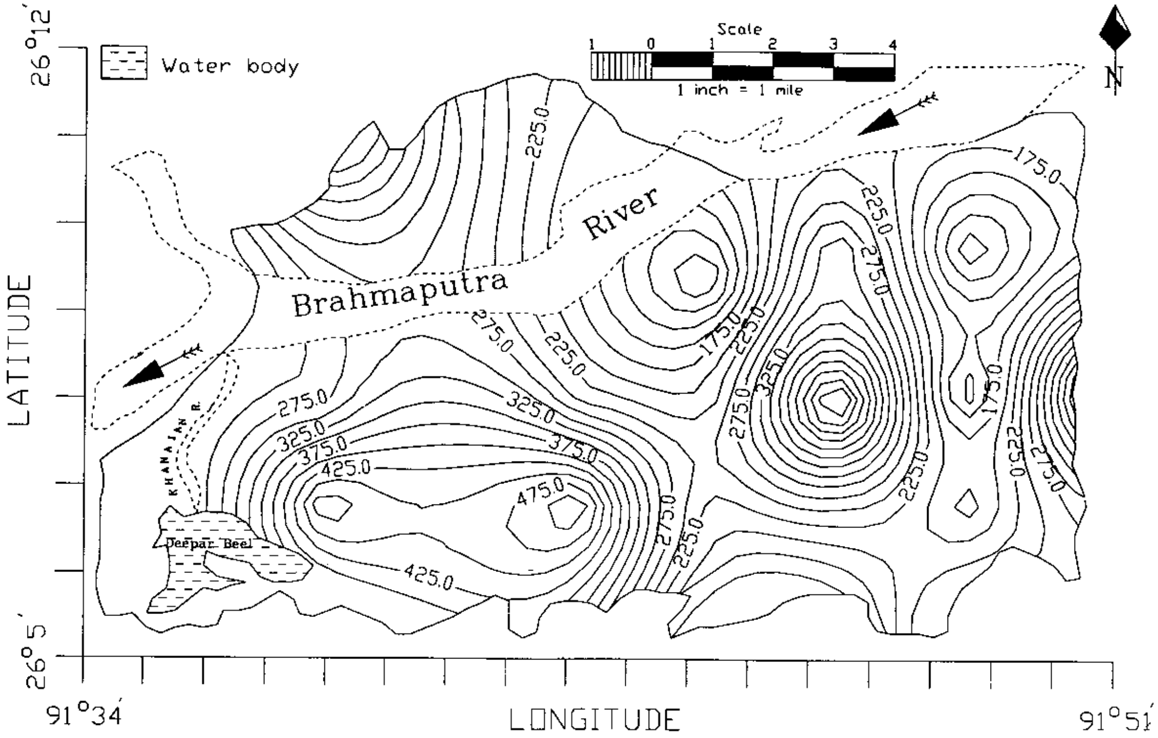


Fig. 5.17 : Total Dissolved Solids (ppm) Map

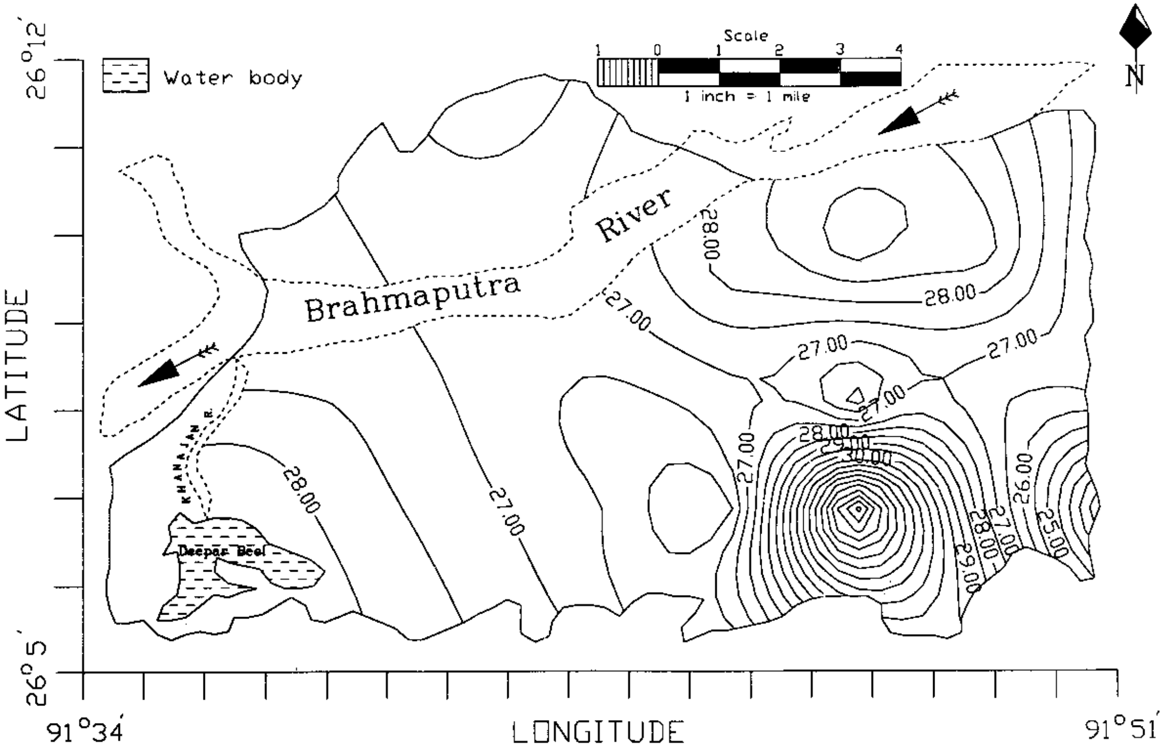


Fig. 5.18 : Temperature (degree C) Map

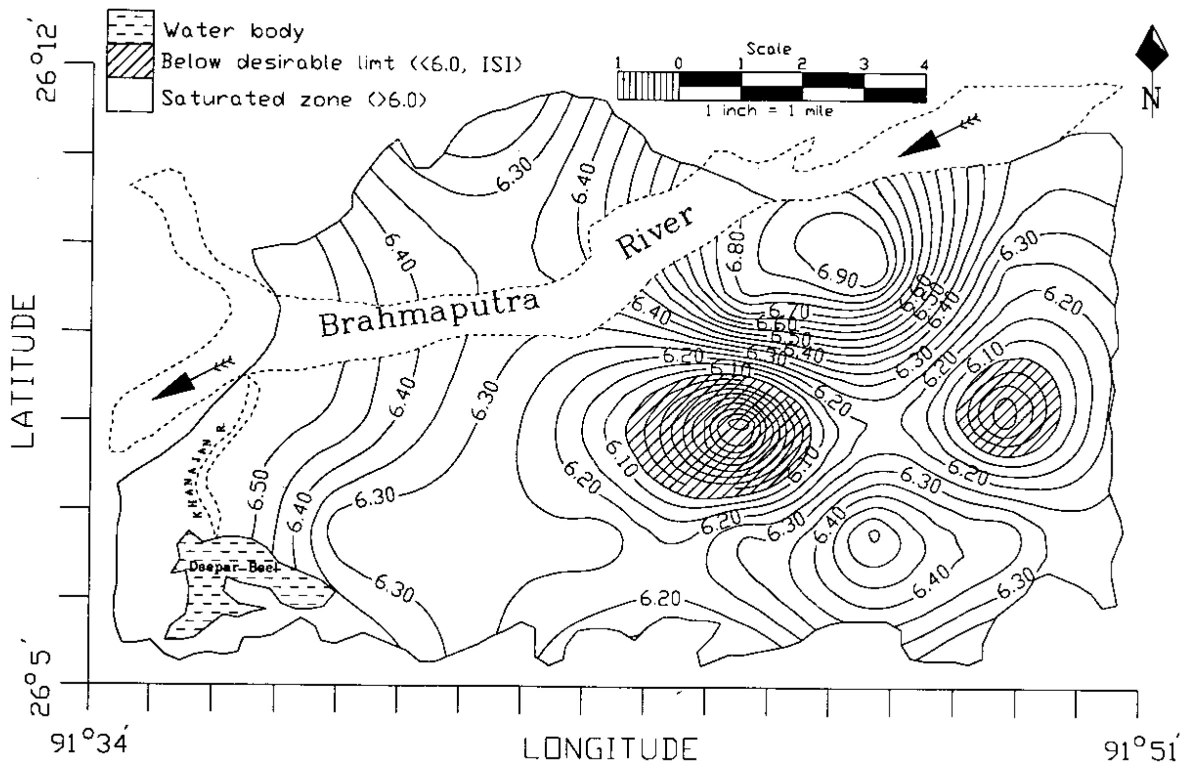


Fig. 5.19 : Dissolved Oxygen (ppm) Map

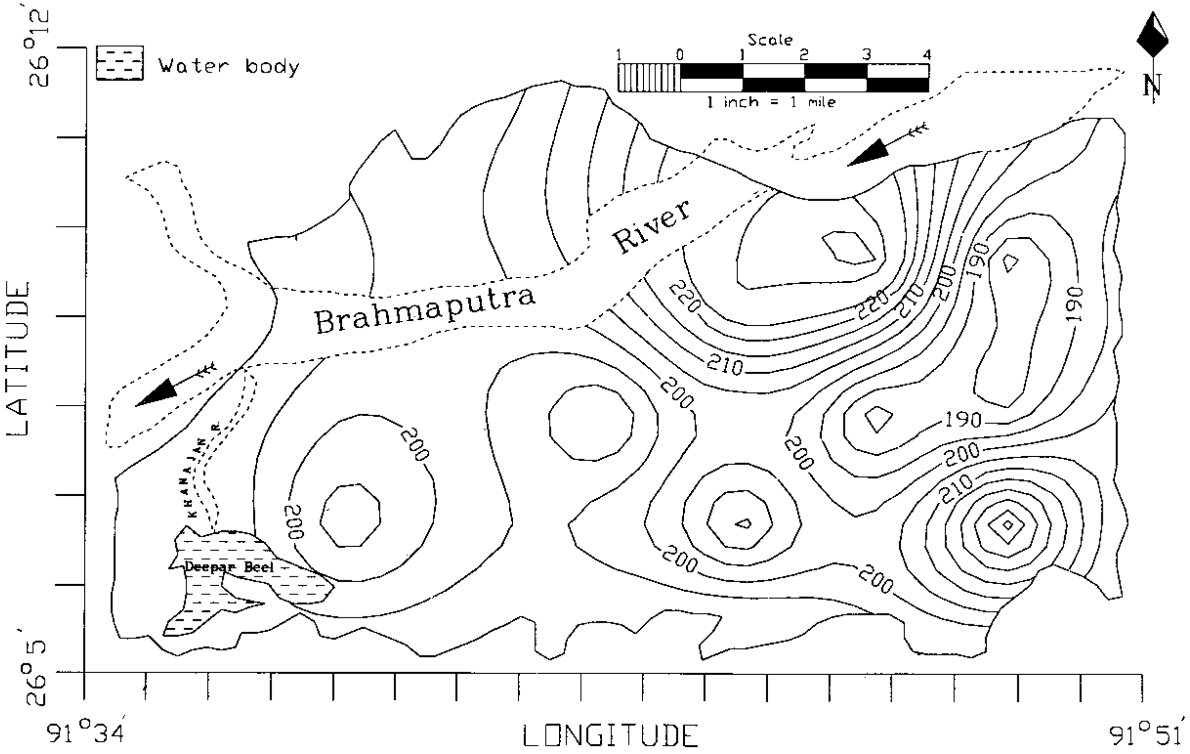


Fig. 5.20 : Oxydation Reduction Potential (m-V) Map

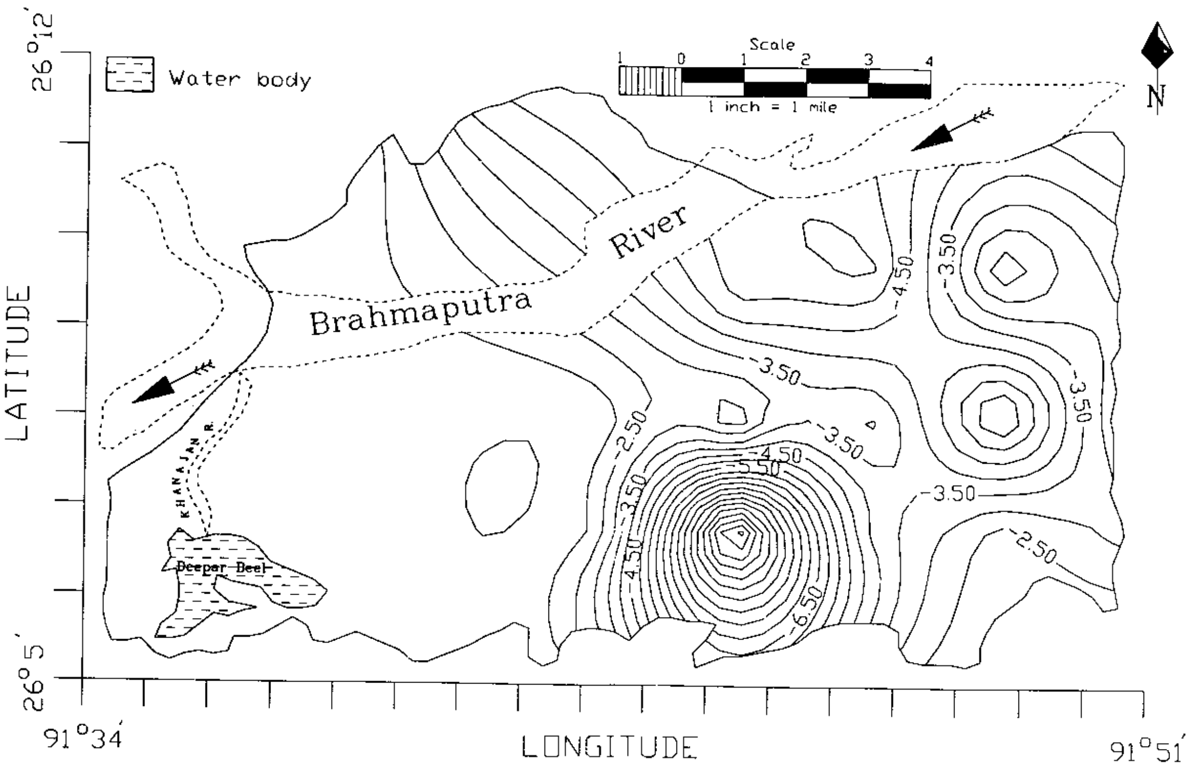


Fig. 5.21 : Variation in Groundwater Table Map(m,bgl)

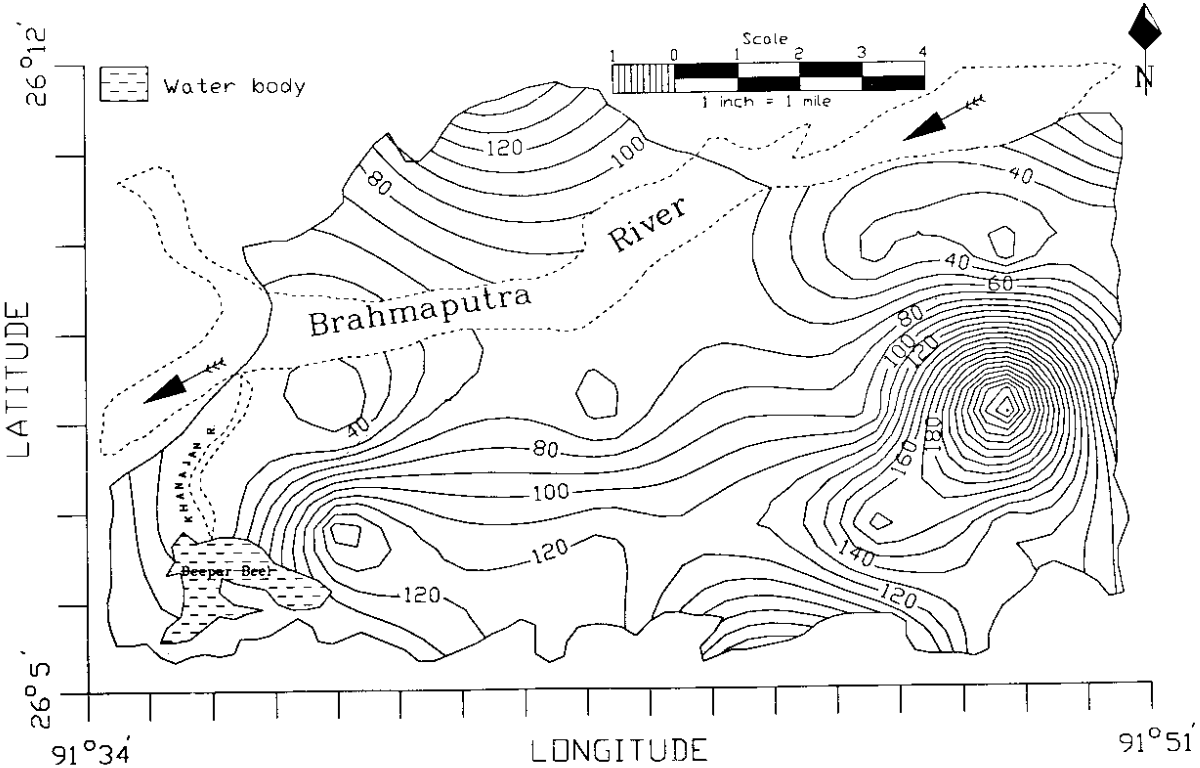


Fig. 5.22 : Calcium Hardness (ppm) Map

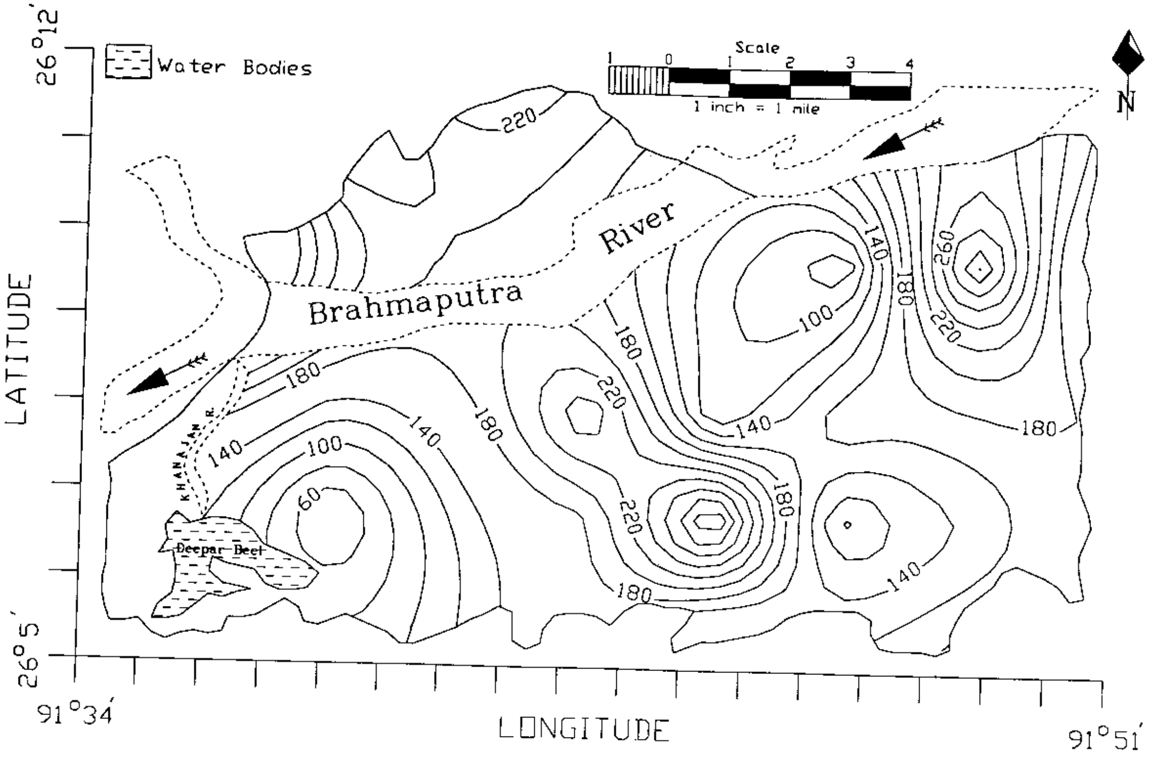


Fig. 5.23 : Magnesium Hardness (ppm) Map

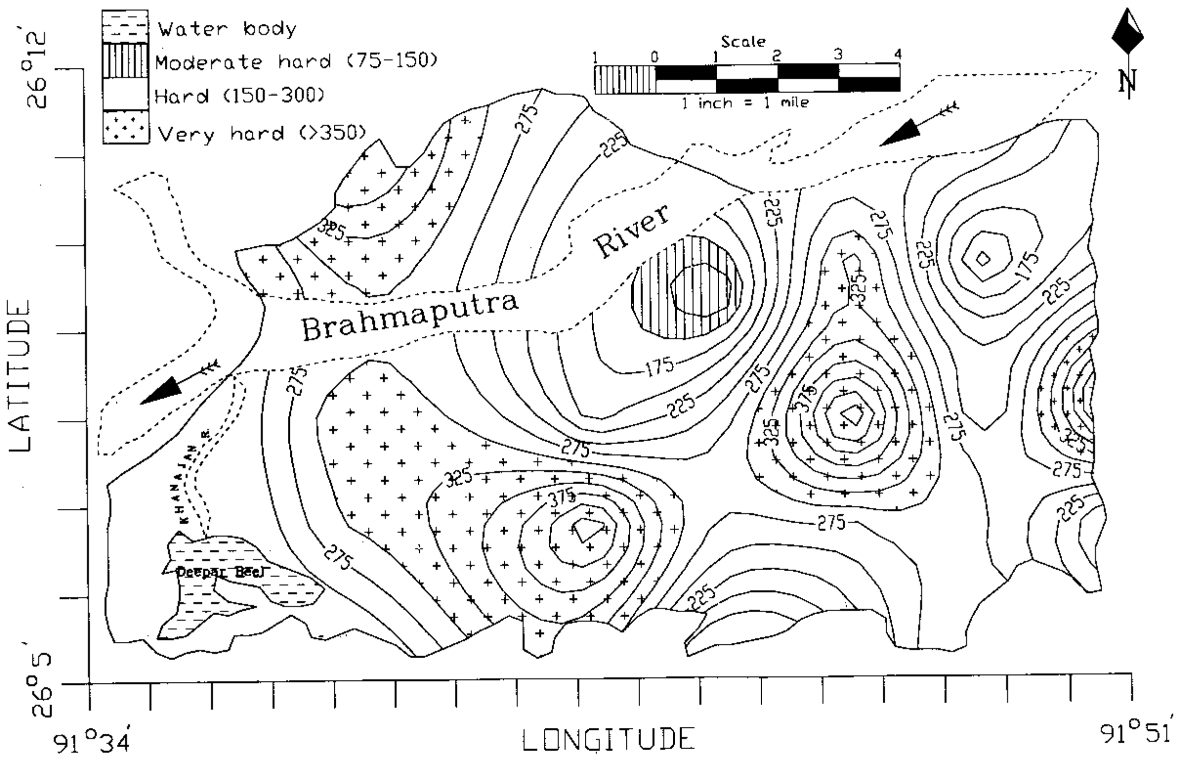


Fig. 5.24 : Total Hardness (ppm) Map

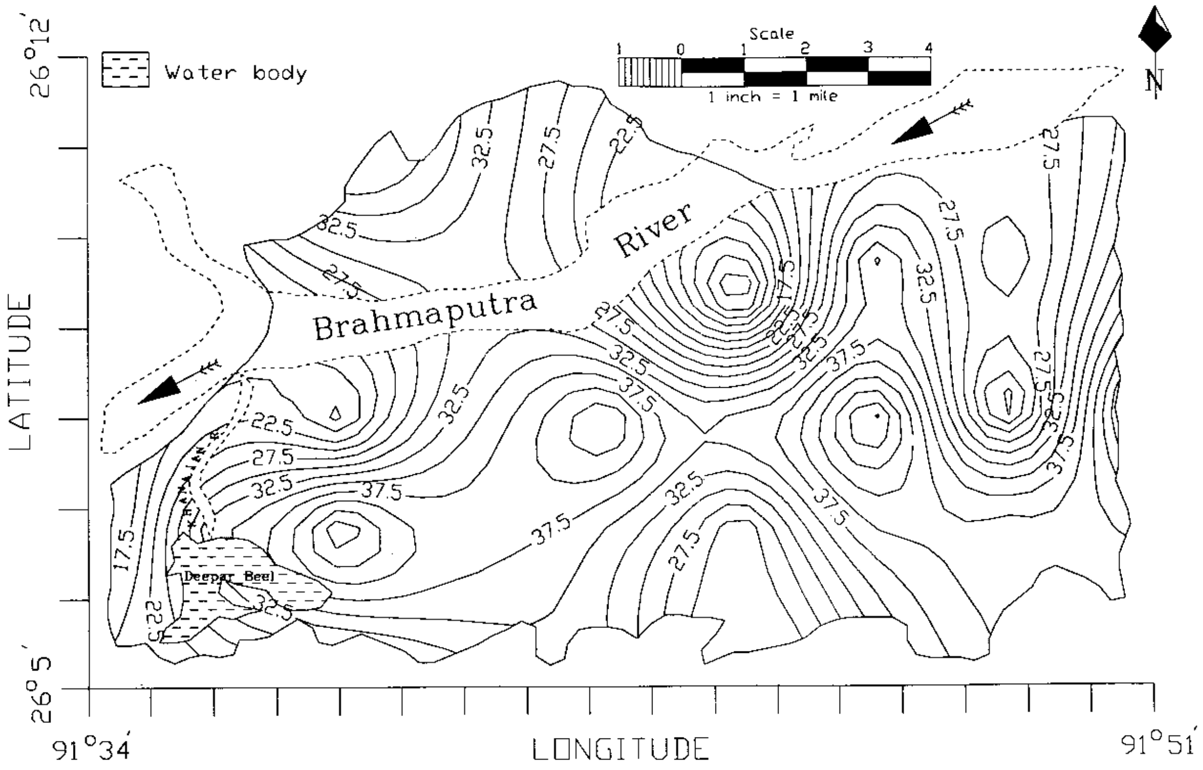


Fig. 5.25 : Sodium (ppm) Map

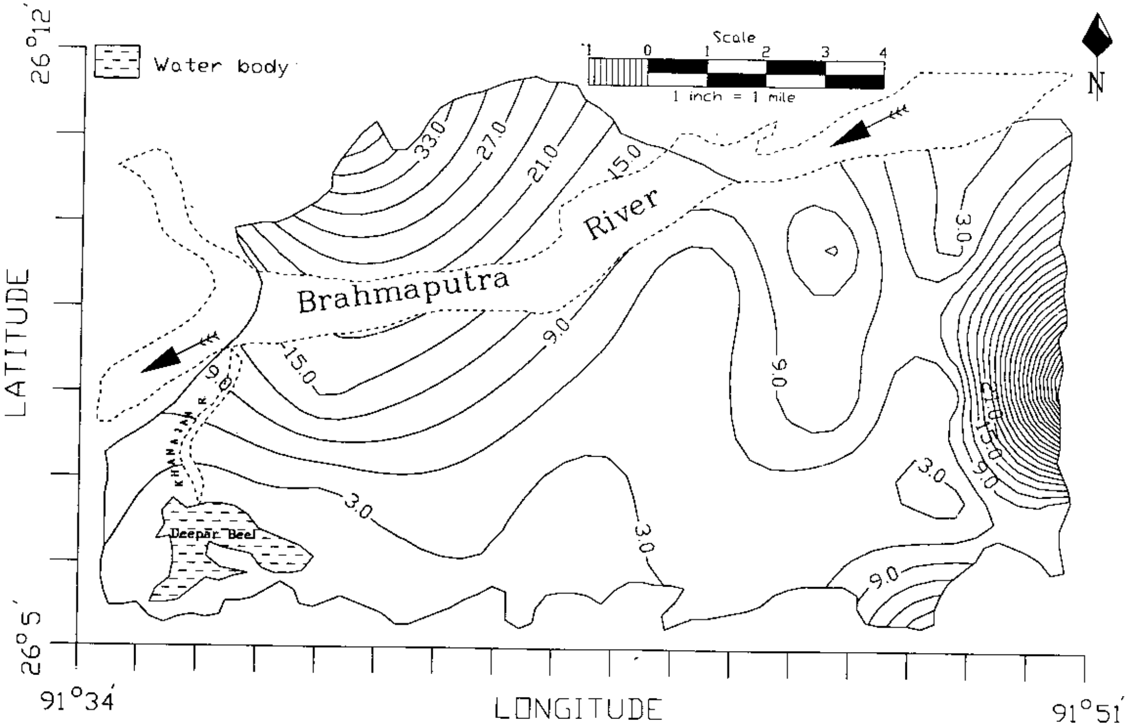


Fig. 5.26 : Potassium (ppm) Map

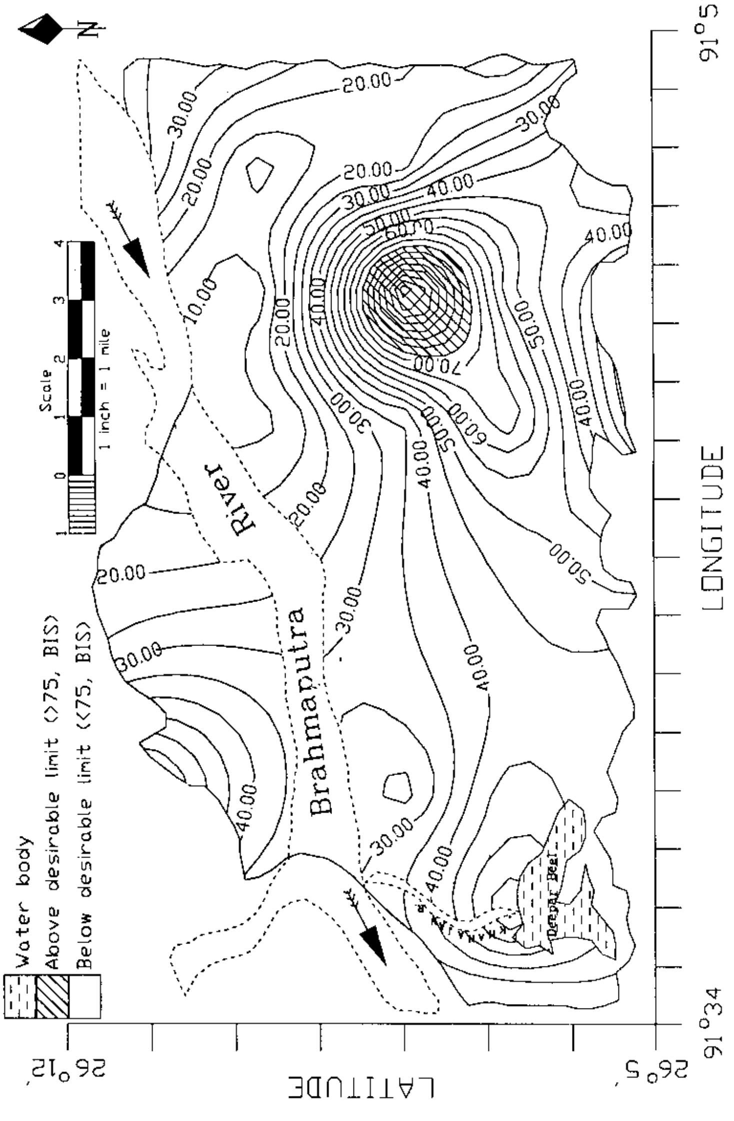


Fig. 5.27 : Calcium (ppm) Map

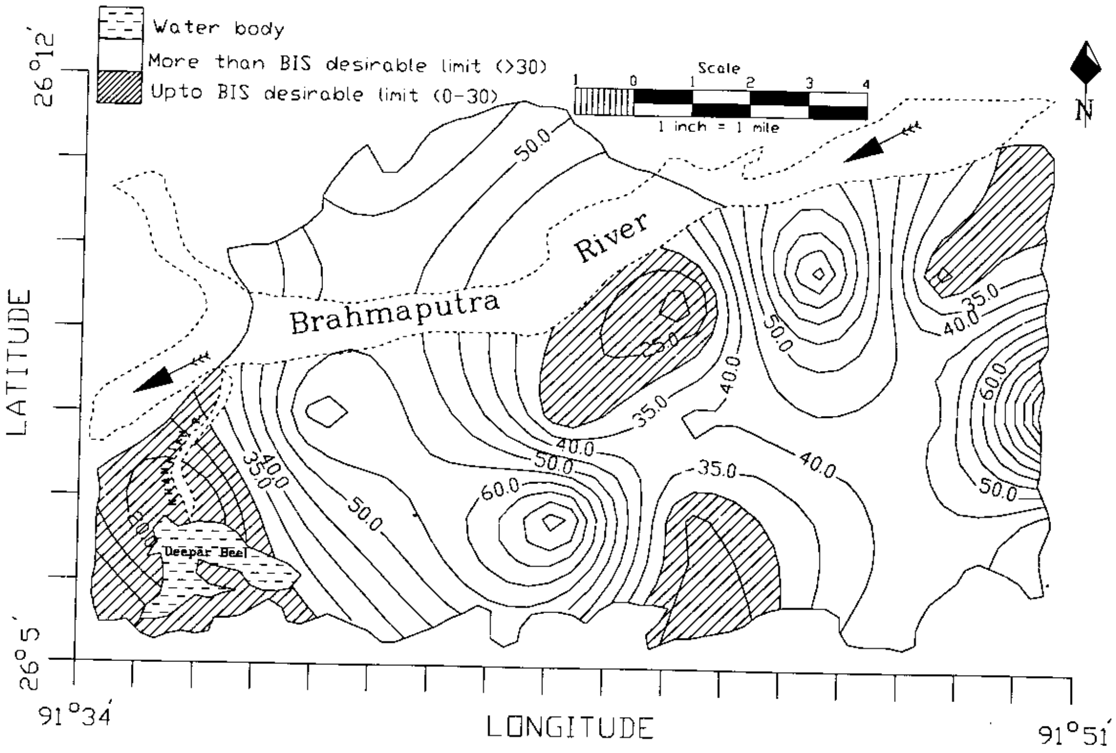


Fig. 5.28 : Magnesium (ppm) Map

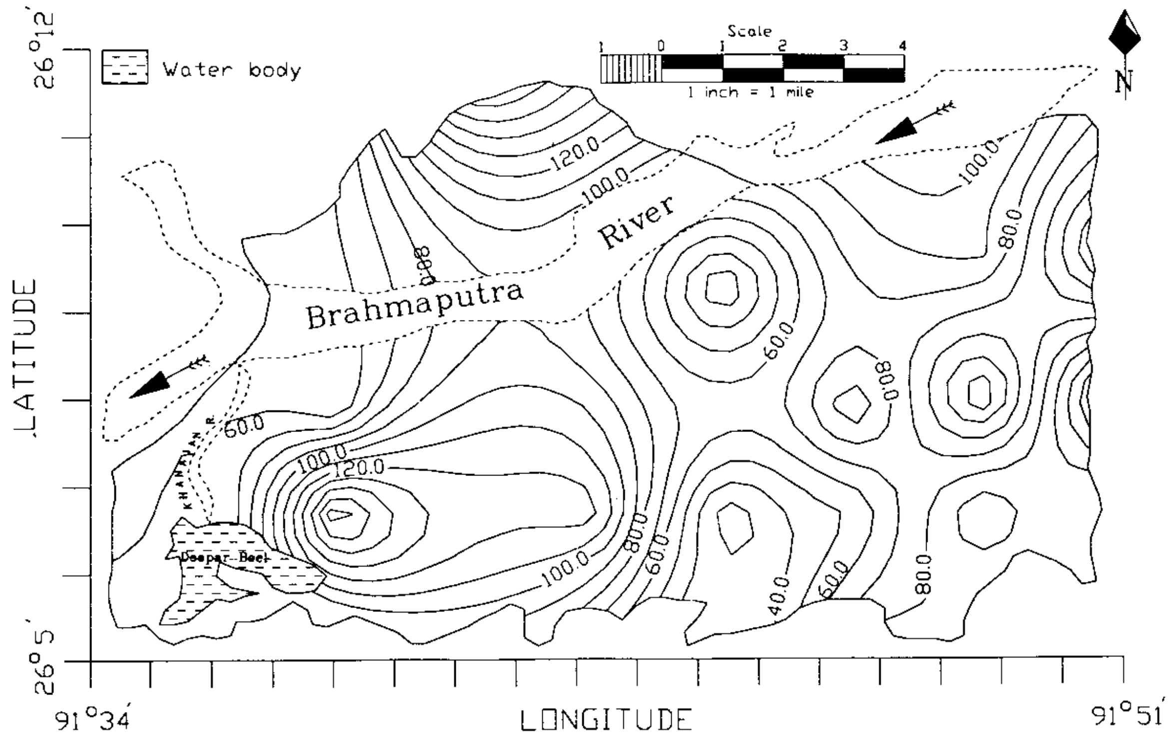


Fig. 5.29 : Chloride (ppm) Map

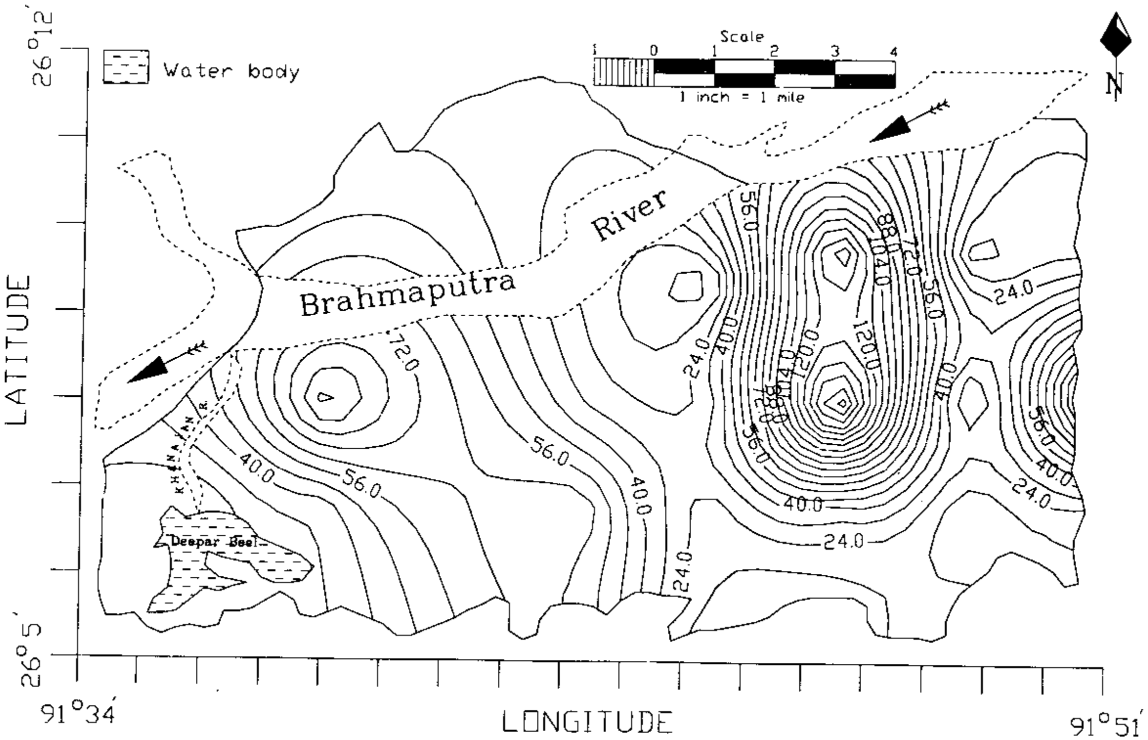


Fig. 5.30 : Sulphate (ppm) Map

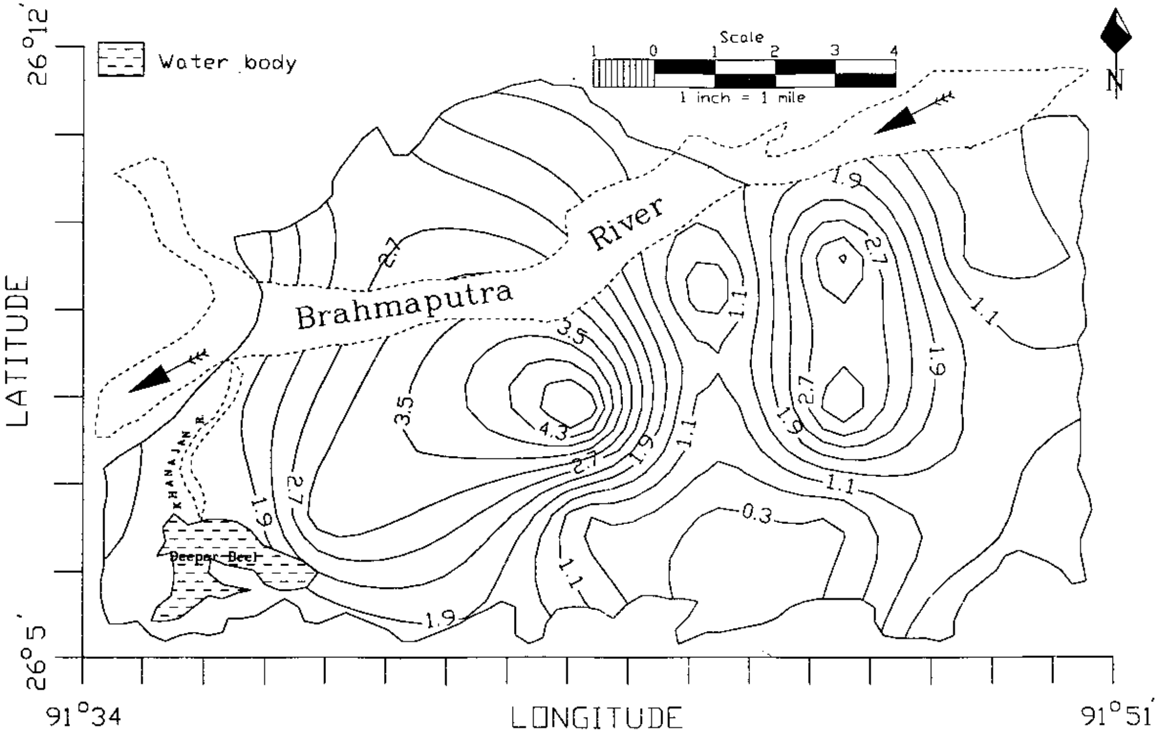


Fig. 5.31 : Nitrate (ppm) map

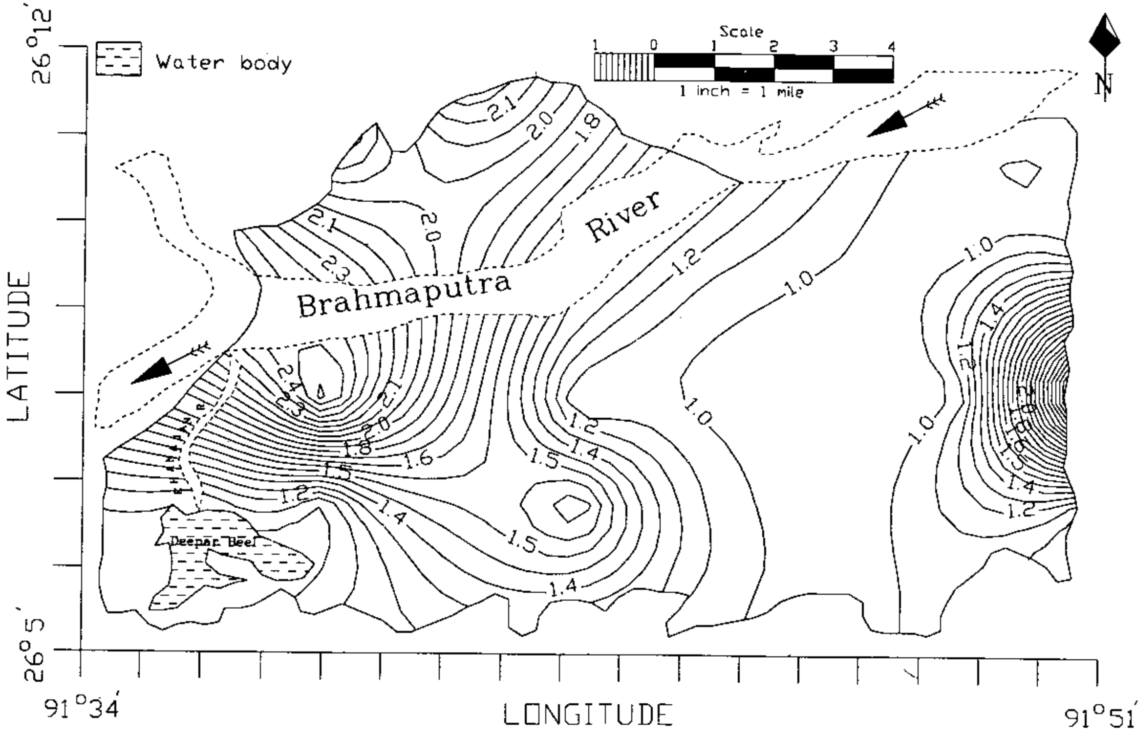


Fig. 5.32 : Phosphate (ppm) Map

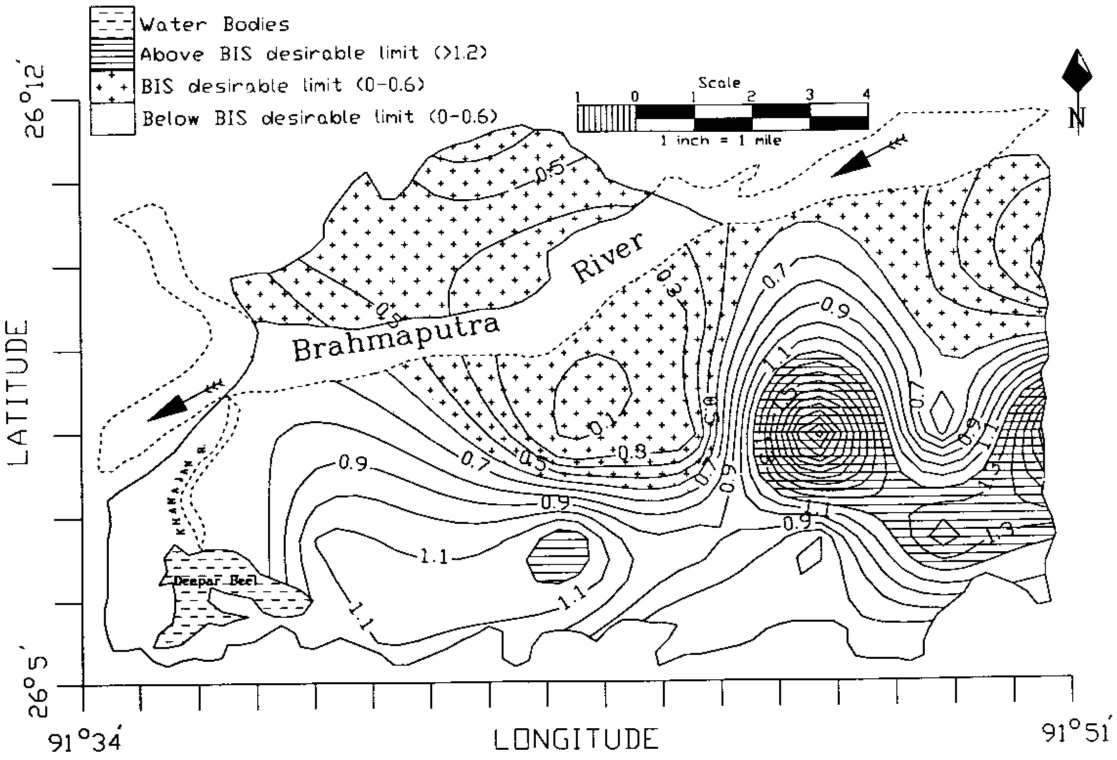


Fig. 5.33 : Fluoride (ppm) Map

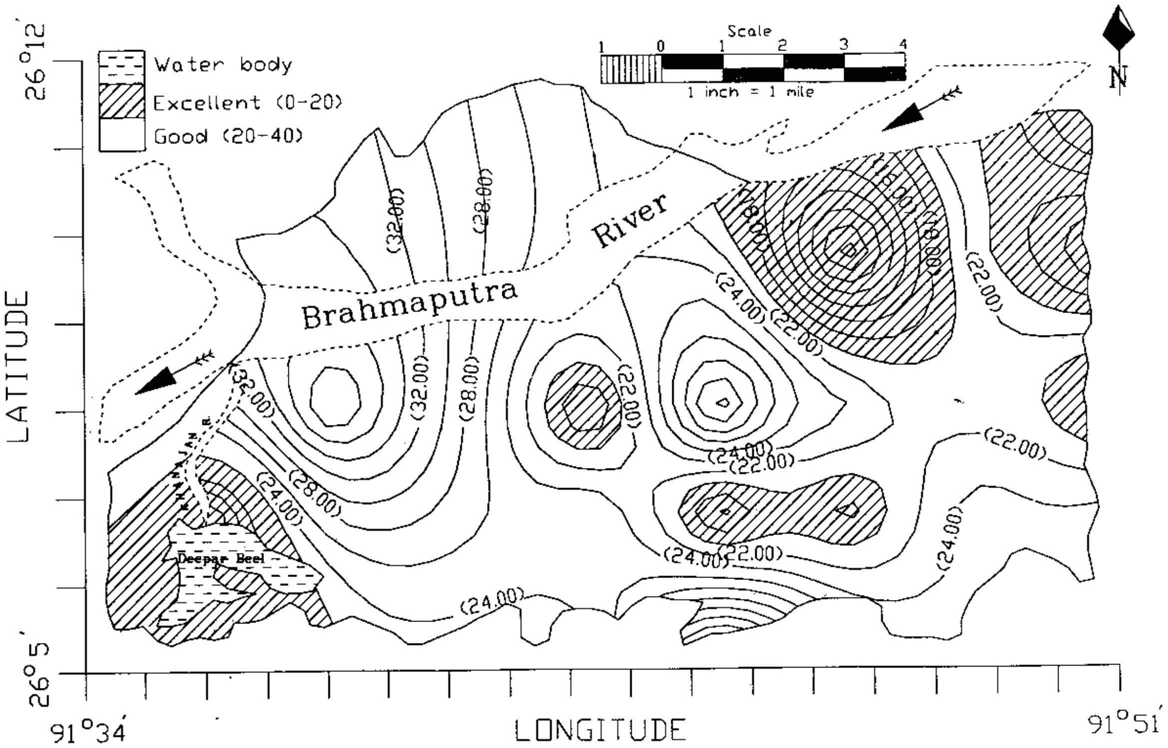


Fig. 5.34 : Sodium Percentage Map

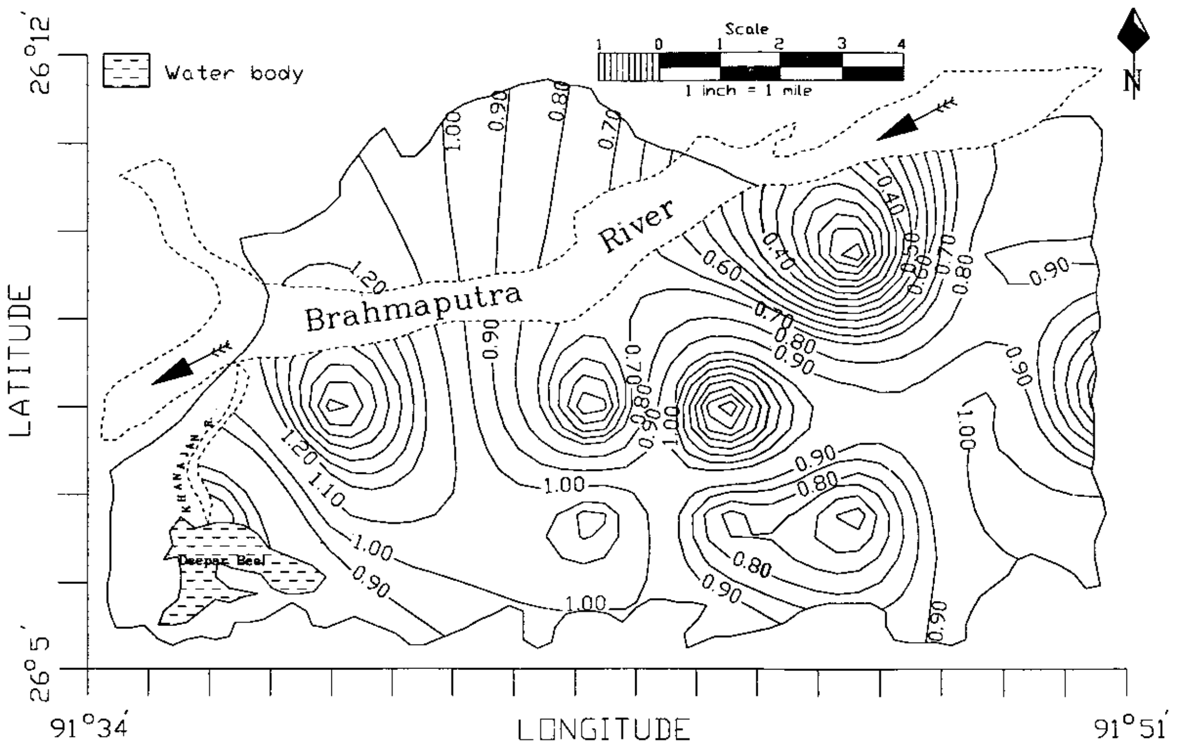


Fig. 5.35 : Sodium Adsorption Ratio map

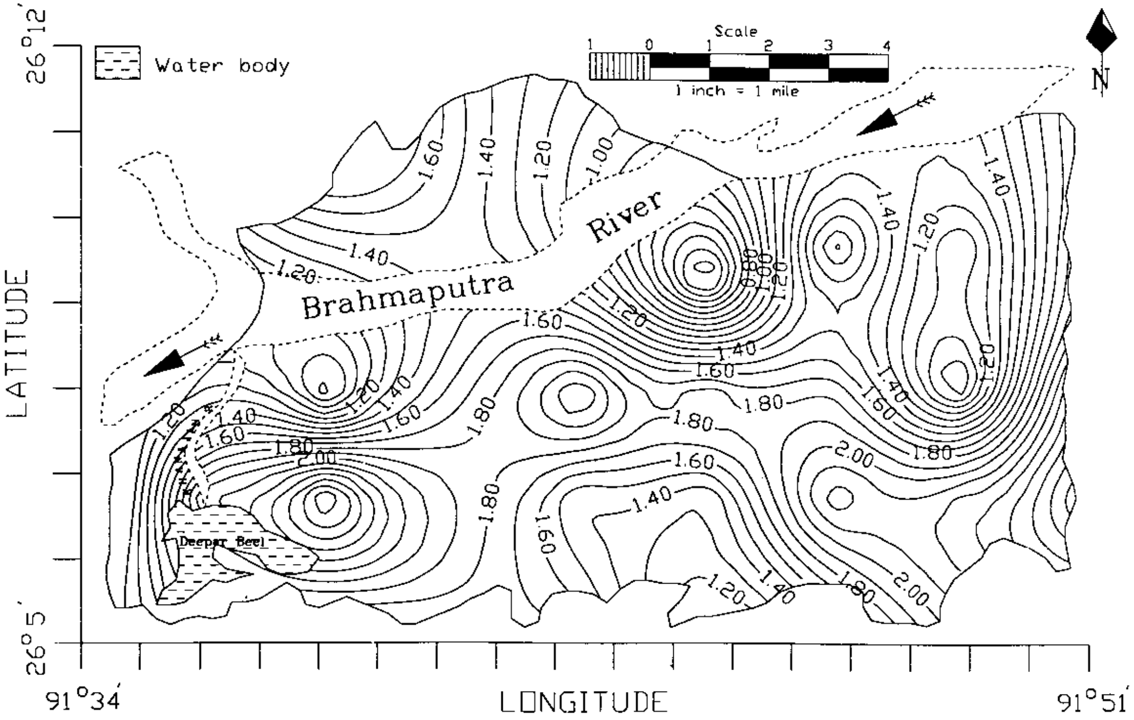


Fig. 5.36 : Adjusted Sodium Adsorption Map

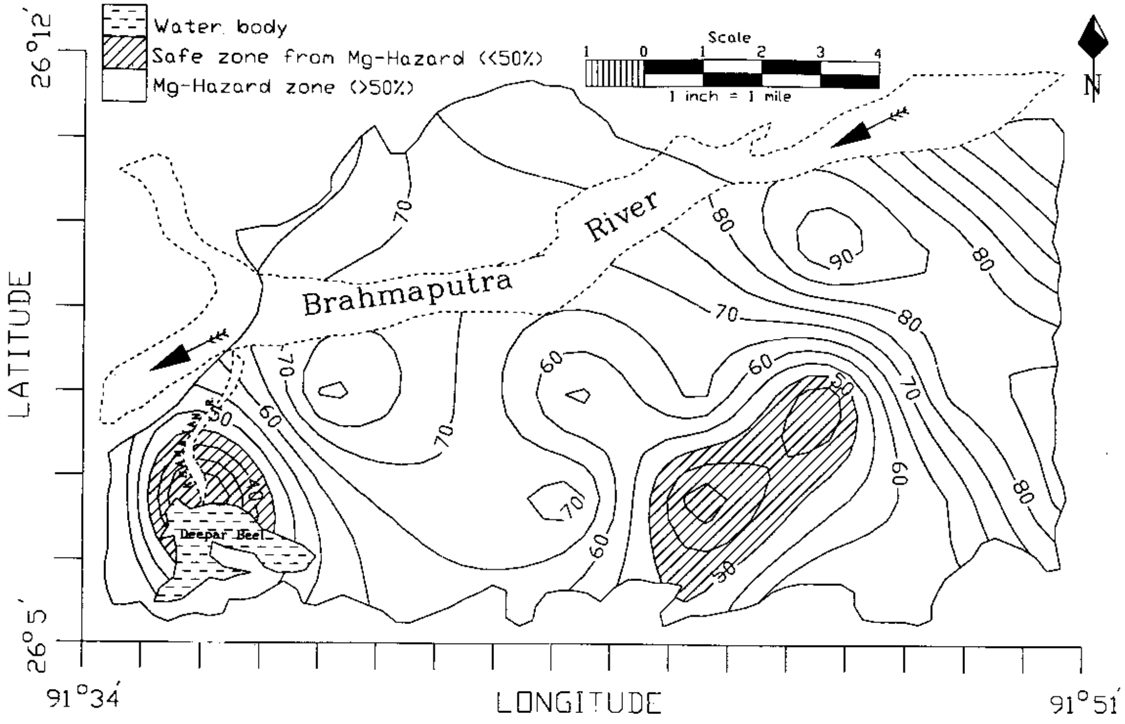


Fig. 5.37 : Magnesium Hazard (%) Map

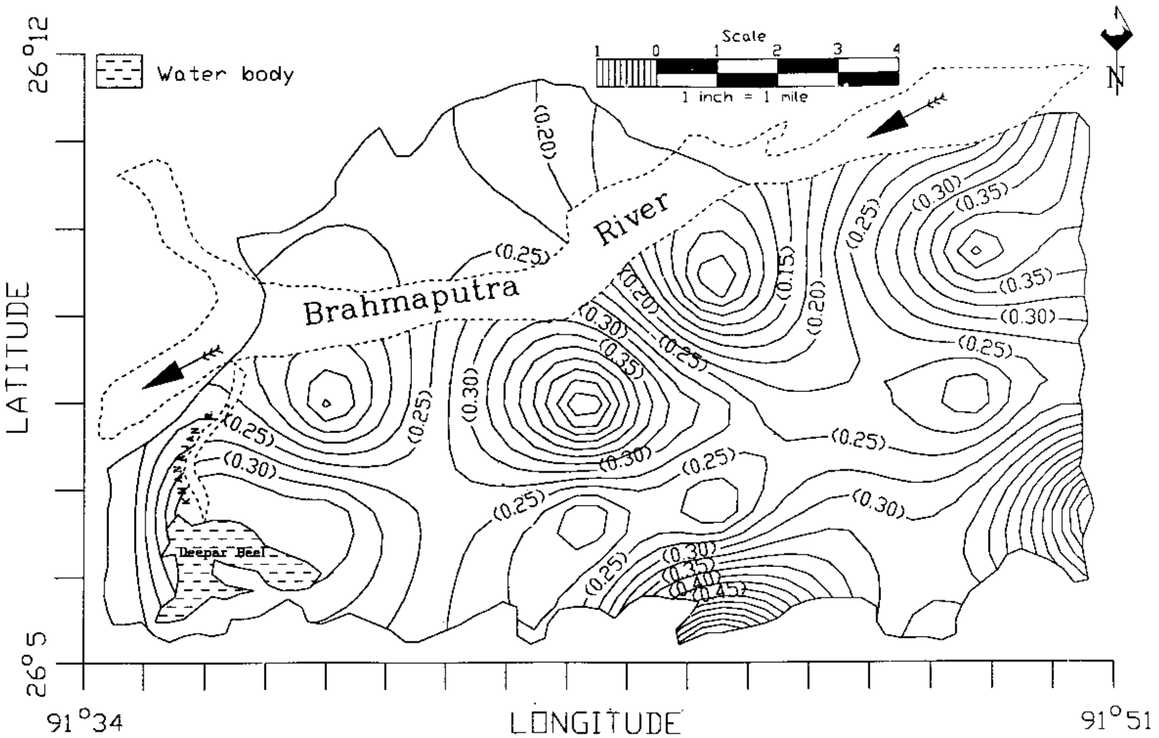


Fig. 5.38 : Kelley's Ratio Map

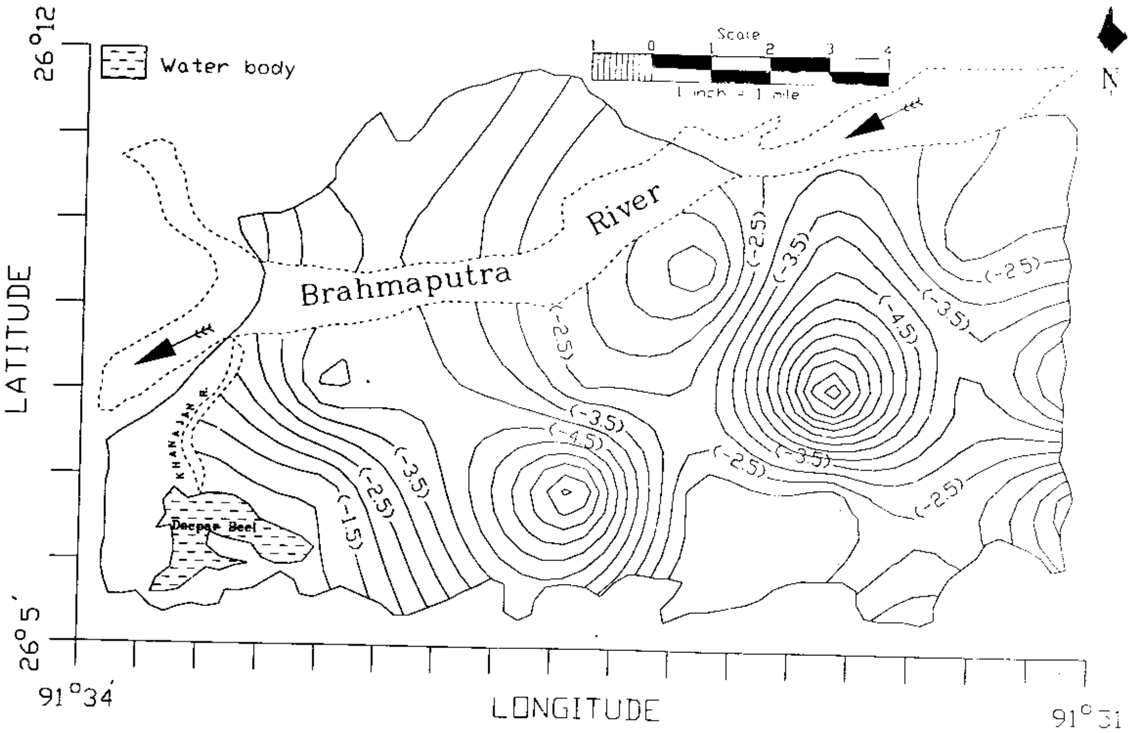


Fig. : 5.39 : Residual Sodium Carbonate Map

6.0 CONCLUSIONS

Planning and implementation of ground water supply programme demands data pertaining to phisico-chemical characteristics of water. A system of continuous monitoring of ground water supply programme is necessary to assess the effectiveness of various water supply scheme of the entire area. Time series data is necessary for monitoring the quality of safe drinking water to protect it from possible sources of contamination. The qualitative physico-chemical properties of water as reflected in this report can be utilised for effective treatment processes for removal of different chemical impurities to make the water safe.

The report presents an analysis of the ground water quality data, obtained on the water samples from 30 open wells in the Greater Guwahati. Various physical and chemical constituents like pH, total dissolved solids, temperature, ORP, conductivity etc. were estimated at sites and in the water quality laboratory of the institute, major chemical parameters were determined as Na^+, K^+, F^-, Cl^-, Ca^{++}, Mg^{++}, SO^{--}_4, NO^-_3, PO^{--}_4 and alkalinity. Further, temporal variation of ground water quality at these 30 specified locations were also marked and analysed. The problematic zones were delineated and spatial distribution of ground water contamination in the area was attempted to be mapped.

Suitability of water for drinking and irrigation purposes have been tested with reference to available standards on the basis of chemical parameters. The present report indicates that water quality of Greater Guwahati is generally safe so far as the physico-chemical properties are concerned except excessive Iron. Analysis and ground water quality problems related to Iron will discuss in the next coming report which will cover details of tracer elements in ground water of Greater Guwahati.

The study is focussed on the variation of ground water quality (physical and chemical) in the area and the following points emerged from the analysis of the physical and chemical properties of ground water samples.

1. As per the stiff classification, most of the samples were found to be of either Mg-HCO_3 type or Mg-Cl type.

2. According to the USSL Classification of irrigation water, samples fall under water type C2-S1 (medium salinity and low SAR) and few samples fall under C3-S1 (high salinity and low SAR) and C1-S1 (low salinity and low SAR) type.

3. According to Doneen's classification most of the samples are class-I type for irrigation use.

4. As per the Wilcox classification based on conductivity and % of Sodium, samples are excellent to good.

5. Durove's trilinear classification shows that in cation type, majority of the samples are Mg and intermediate type while, in anion type, samples fall in HCO_3, Cl and intermediate category.

6. Due to falling of majority of the points in central portion of the Gibb's variation diagram, lithology seems to be the main controlling factor of chemistry of ground water in Guwahati.

7. Based on the low pH value (< 7.0) of the all samples, it is concluded that well waters are corrosive in nature.

8. Based on the total solids, which is less than 1000 ppp in all the sites,

ground water of the Guwahati could be classified as fresh water.

9. Most of the samples are having low concentration of fluorides (<0.6 ppm), which may cause dental carries in children. Samples from grid no. 11, 14, 19 & 21 are showing fluoride concentration more than permissible limit (>1.2 ppm), which may cause mottling of teeth and skeletal fluorosis (bone disorder) problems in the human body. Hence it is necessary to check the fluoride level in each and every house well under these grids, so that residents of these grids can prevent from high fluoride concentration related disease.

10. Most of the samples are hard to vary hard in nature, which will cause the economic disadvantag of soap wastage during bathing and cloth washing.

11. A piper diagram classification is best when the data are noisy. By classifying samples on the piper diagram, one can identify geologic units with chemically similar water, and define the evolution in water chemistry.

12. Except Mg hazard ground water is suitable for irrigation purpose. For Mg sensetive crops suitable measures have to be taken to avoid Mg hazard.

13. The plots between Na+k and HCO3 fall at the left hand side of the Durov's square, indicate clearly the fresh water charecteristics i.e. absence of salt water intrusion in the ground water of Guwahati.

14. When chemical data vary systematically in space, it is often to plot and contour concentrations on maps or cross sections. This presentation makes it obvious how individual parameters vary. Any measured or calculated parameter can be represented in this way, which is an advantage over other approaches that involve specific combination of ions. One problem is the large number of figures that could be required to describe fully the chemistry of an area. However, given the usefulness of these diagrams, the limitation is not a serious one.

7.0 REFERENCES

1. Agricultural Salinity Assessment and Management, American Society of Civil Engineers, Tanji, K. K. (editor), New York (1990), Nature and Extent of Agricultural Salinity, 1-17pp.

2. Ambasht, R. S. (1990), Environment & Pollution, Students' Friends & Co., Varanasi.

3. Ayers, R. S., and Branson, R.L. (1975), Guidelines for Interpretation of Water Quality for Agriculture, University of California, Extension Mimeographed, pp 13.

4. Ayers, R. S. and West Cot, D. W. (1985), FAO Irrigation Drainage Paper 29 (Rev1), Rome, Italy.

5. Back, W. (1961), Techniques for Mapping of Hydrochemical Facies, USGS, Prof. Paper 424-D, pp 380-382.

6. Buckley, C. B. and L. Keil (1990). Acid Deposition- Drinking Water Quality and Health. pp 145-158. Acid Water in Wales. R. W. Edwards, A.S. Gee and J. H. Stoner (Editors). Kluwer Academic Publishers, The Netherlands.

7. Collins, W. D. (1923), Graphical Representation of Water Analysis, Ind. Eng. Chem., V.15, pp 394.

8. Domenico, P. A. and F. W. Schwart (1990), Physical and Chemical Hydrogeology, John Wiley & Sons, New York.

9. Donahue, R. L., W. M. Raymond and J. C. Shickluna (1990), Soils, Prentice Hall of India P. Ltd., New Delhi.

10. Doneen, L. D. (1962), The Influence of Crop and Soil on Percolating Waters, Biennial Conference on Groundwater Recharge.

11. Durov, S. A. (1948), Natural Waters and Graphic Representation of Their Composition, Dokl. Akad. Nank., SSSR, 59, pp 87-90.

12. *Eaton, F. M. (1950), Significance of Carbonate in Irrigation Water, Soil Sci, Vol 69 no. 2 pp 123-133.*

13. *Gibbs, R. J. (1970), Mechanisms Controlling World's Water Chemistry, Science, Vol. 170, pp 1088.*

14. *Gupta D. C., Irrigation Suitability of Surface Waters for Agricultural Developing of the area around Mandu, pp 63-71, Journal of Applied Hydrology.*

15. *Goldberg, V. M. (1973), The Movement of Fresh and Salt Water Towards a Water Intake in The Coastal Areas. Intern Symp. Development of Groundwater Resources College of Engineering Madras, pp 11-22.*

16. *Handa, B. K. (1975), Geochemistry and Genesis of Flouride Containing Ground Waters in India, Ground Water, Vol. 13, No. 3, pp 275-281.*

17. *Hem, J. D. (1959), Study and Interpretation of the Chemical Charecteristics of Natural Water, U.S.G.S. Water Supply Paper 1473, pp 363.*

18. *Hortigon, J. A. (1925), Clustering Algorithms, John Wiley and Sons, p 28-32.*

19. *Indian Council of Medical Research (1975), Manual of Standards of Quality for Drinking Water Supplies, Special Report Series no.44, New Delhi.*

20. *ISI, India Standard Institute (1983), Indian Standard Specification for Drinking Water, IS-10500.*

21. *Jain, C. K. and K. K. S. Bhatia, Physico-Chemical Analysis of Water and Waste Water, Users Manual-26, NIH, Roorkee. 1987-88.*

22. *Jal Vigyan Sameeksha, (Hydrology Review), Theme - Water Quality, Publication of High Level Technical Committee on Hydrology, NIH, Roorkee, June 1988.*

23. *Jermer, M. K. (1987), Water Resources and Water Management, Elsevier Science Pub. Amsterdam, The Netherlands, pp 169-207.*

24. Kelley, W.P., Brown, S.M. and Liebig, G.F., Jr. (1940) Chemical Effects of Saline Irrigation Water on Soil, Soil Sci, Vol. 49, pp 95-107.

25. Kumaraswamy, K. and Sivagnanam (1991), Diagnosing Salt water Intrusion in Vaippar Estuary of the Cholamandal Coast, India. Trans. Inst. Indian Geographers, Vol. 13, No. 1 pp 43-51.

26. Langenegger, O. (1989), Ground water Quality - An Important Factor for Selecting Handpumps, pp 531-541, Ground Water Economics, Custodop E. and A. Gurgui (Editors), Elsevier, The Netherlands.

27. Lokeah, V. H. and M. K. Shenoy, Geomorphological and Hydrogeochemical Studies of Pangala River Basin of Karnataka, Hydrology Journal Vol. XIX No.1, 1996. pp 33-43.

28. Love, S. K. (1944). Cation Exchange in Ground Water Contaminated with Sea Water Near Miami, Florida. Trans. Ameri. Geophy. Union, Vol 25 pp 951-955.

29. Mindler, A. B. and A. C. Enstien (1986), Measurements and Control in Reverse Osmosis Desalination, Measurements and Control in Water Desalination, Lior, M. (Editor), pp. 347-351, Elsevier, The Netherlands.

30. Paliwal, K. V. (1992), Irrigation with Saline Water, I.A.R.I., Monograph no. 2 (New series), New Delhi.

31. Piper, A. M. (1944), A Graphical Procedure in the Geochemical Interpretation of Water Analysis, U. S. Geol. Surv. Ground Water Note 12.

32. Radhakrishan, I. (1981), Sea Water Encroachment in the Coastal Aquifers of Orissa (India), Geol, jl., C. 29, pp 105-114.

33. Raghunath, H. M., Ground Water (1990), Wiley Eastern Limited, New Delhi.

34. Sarma, C. and S. K. Sarma (1988), A Study of Physico-Chemical Qualities of the Water of Three Ring Wells and Two Ponds in Guwahati Area, Journal of the Assam Science Society, Vol. 31, No. 1, Dec. 1988, pp.33-42.

35. Sawyer, C.M. and P. L. McCarty (1978), Chemistry for Environmental Engineers, Tata Mc Graw Hill Inc., New York.

36. Schoexen, D. and H. F. Scholer (1985), Drinking Water Materials - Field Observations and Methods of Investigation, Ells Harvard Limited, England.

37. Schoeller, H. (1967), Qualitative Evaluation of Groundwater (In Methods and Techniques of Groundwater Investigation and Development) Water Res. Series-33 UNESCO, pp 44-52.

38. Sinha, A. K., R. Boojh and P. N. Vishwanathan (1989), Water Pollution - Conservation and Management, Gyanodaya Prakashan, Nainital.

39. Standard Methods for Examination of Water and Waste Water (1995), APHA, Public Health Association, American Water Works Assoc. and Water Pollution control Fed., 19th Edition, American Public Health Association, Washington DC.

40. Stednick. J. D. (1991), Wild Land Water Quality Sampling and analysis, Academic Press Inc., California, U.S.A.

41. Stiff, H. A., Jr. (1951), The Interpretation of Chemical Water Analysis by Means of Patterns, J. Petrol, Tech, Vol. 3, No.10, pp. 15-16.

42. The Use of Saline Waters for Crop Production (1992), FAO Publ. No. 48.

43. Todd, D. K. (1980), Ground Water Hydrology, 2nd Edition, John Wiley & Sons Inc, New York.

44. U.S. Salinity Laboratory Staff (1954), Diagnosis and Improvement of Saline and Alkaline Soils, U.S.D.A Handbook no. 60, pp 160.

45. Water Quality for Agriculture (1994), FAO Publication No. 29.

46. Water and Water Pollution (Handbook) Vol-I, edited by Leonard L. Ciaccio and Marcel Dekker, Inc., New York (1971), Chemical, Physical and Biological Characteristics of Irrigation and Soil Water, J.D. Rhodes and Levn Bernstien, 144 - 222 pp.

47. WHO (1971), International Standards for Drinking Water, World Health Organization.

48. Wilcox, L. V. (1948), The Quality of Water for Irrigation Use, U.S.D.A. Tech. Bull. 162, Washington D.C., pp 40.

49. Wilcox, L. V. (1955), Classification and Use of Irrigation Waters. U.S. Department of Agriculture, Circ 969, Washington DC, 19pp.

50. Yuqun Xue, Jichun Wu, Peimin Liu Jianji Wang, Qingbo Jiang and Hangwen Shi (1993), Sea-Water Intrusion in the Costal Area of Laizhou Bay, Distribution of Sea-Water Intrusion and its Hydrochemical Characteristics, Ground Water, Vol 31, No 4, pp 532-537.

Appendix - I

Drinking Water Quality Standards in India

[As per ICMR (1975)]

S.No.	Characteristics	Acceptable Limit **	Rejection **
1.	Turbidity (JTU)	2.5	10
2.	Color (Platinum cobalt scale)	5	25
3.	Taste and odor	Unobjectionable	
4.	pH value	6.0 to 8.5	-
5.	Total dissolved solids	500	1500
6.	Hardness as $CaCO_3$	200	600
7.	Chloride as Cl	200	1000
8.	Sulfate as SO_4	200	400
9.	Fluoride as F	1.0	1.5
10.	Nitrates as NO_3	45	45
11.	Calcium as Ca	75	200
12.	Magnesium as Mg	30	150
13.	Iron as Fe	0.1	1.0
14.	Manganese as Mn	0.05	0.5
15.	Copper as Cu	0.05	1.5
16.	Zinc as Zn	5	15
17.	Phenolic compounds	0.001	0.002
18.	Anionic detergents as MBAS	0.2	1.0
19.	Mineral oil	0.01	0.3
Toxic Materials			
20.	Arsenic as As	0.05	0.05
21.	Cadmium as Cd	0.01	0.01
22.	Chromium as Hexavalent Cr.	0.05	0.05
23.	Cynide as Cd	0.05	0.05
24.	Lead as Pb	0.1	0.1
25.	Selenium as Se	0.01	0.01
26.	Mercury as Hg	0.001	0.001
27.	Polynuclear aromatic hydrocarbons (PAH) (ug/l)	0.2	0.2
Radio activity			
28.	Gross alpha activity (pCi/l)	3	3
29.	Gross beta activity (pCi/l)	30	20

** ppm otherwise specified

Appendix - II

Drinking Water Quality Standards
[As per WHO (1971)]

S.No.	Characteristics	Highest Desirable **	Maximum Prmissible **
1.	Turbidity (J.T.U. unit)	5	25
2.	Color (Platinum cobalt scale)	5	50
3.	Taste and odor	Nothing Disagreable	
4.	pH value	7.0 to 8.5	6.5 to 9.2
5.	Total dissolved solids	500	1500
6.	Hardness as CaCO3	100	600
7.	Chloride as Cl	200	1000
8.	Sulfate as SO4	200	400
9.	Fluoride as F	1.0	1.5
10.	Nitrates as NO3	45	45
11.	Calcium as Ca	75	200
12.	Magnesium as Mg	30	150
13.	Iron as Fe	0.1	1
14.	Manganese as Mn	0.05	0.5
15.	Copper as Cu	0.05	1
16.	Zinc as Zn	5	15
17.	Phenolic compounds	0.001	0.002
18.	Anionic detergents as MBAS	0.2	1
19.	Mineral oil	0.01	0.3
	Toxic Materials		
20.	Arsenic as As	----	0.05
21.	Cadmium as Cd	----	0.01
22.	Chromium as Hexavalent Cr.	----	0.05
23.	Cynide as Cd	----	0.05
24.	Lead as Pb	----	0.1
25.	Selenium as Se	----	0.01
26.	Mercury as Hg	----	0.001
27.	Polynuclear aromatic hydrocarbons (PAH) (ug/l)	----	0.2
	Radio activity		
28.	Gross alpha activity (pci/l)	3	3
29.	Gross beta activity (pci/l)	30	30

** ppm otherwise specified

Appendix - III

Drinking Water quality Standards in India

S.No.	Characteristics	Desirable Limit **
1.	Turbidity (NTU) max	10
2.	Color (Haxen Unit) max	10
3.	Taste and odor	Unobjectionable
4.	pH value	6.5 to 8.5
5.	Total dissolved solids	300
6.	Hardness as CaCO3	300
7.	Chloride as CI	250
8.	Sulfate as SO4	150
9.	Fluoride as F	0.6 to 1.2
10.	Nitrates as NO3	45
11.	Calcium as Ca	75
12.	Magnesium as Mg	30
13.	Iron as Fe	0.3
14.	Manganese as Mn	0.1
15.	Copper as Cu	0.05
16.	Zinc as Zn	5.0
17.	Phenolic compounds	0.001
18.	Anionic detergents as MBAS	0.2
19.	Mineral oil	0.01
Toxic Materials		
20.	Arsenic as As	0.05
21.	Cadmium as Cd	0.01
22.	Chromium as Hexavalent Cr.	0.05
23.	Cynide as CN	0.05
24.	Lead as Pb	0.1
25.	Selenium as Se	0.01
26.	Mercury as Hg	0.001
27.	Polynuclear aromatic hydrocarbons (PAH) (ug/l)	----
Radio activity		
28.	Gross alpha activity (µCi/mL, Max)	10^{-8}
29.	Gross beta activity (µCi/mL, max)	10^{-7}

** ppm otherwise specified
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