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ASSESSMENT OF GROUND WATER QUALITY OF AGARTALA

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PREFACE

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 only remaining source to provide the water in most of the cities in India. Ground water pollution is much more dangerous than surface water pollution as ground water once polluted cannot be recovered very easily and is almost unusable for a very long time. Another aspect is that surface water pollution is visible whereas ground water pollution is invisible and spoils the system without notice.

With the rapid increase of environmental pollution, it has become absolutely necessary to ascertain the potability of water before use for human consumption. Ground water is an invaluable commodity available in very limited quantities to man and other living beings. The usefulness of ground water to a great extent depends on its chemical and trace elements characteristics.

Detailed knowledge of hydrological systems forms an integral part of the sustainable resource development. Isotope techniques are effective tools for satisfying critical hydrological information needs like the origin of ground water, recharge, residence time, impact of climate change on water resources, interconnections between water bodies, among others. Isotopes provide information that sometimes could not be obtained by other techniques. Stable and radioactive environmental isotopes have now been used for more than four decades to study various aspects of hydrological systems. This report provides an overall scenario related to physical, chemical, trace elements and stable isotopes in ground water of Agartala and Tezpur area of north east region of India.

A comprehensive set of measurements of oxygen and hydrogen isotopic ratios taken from a variety of locations for the first time to determine the Local Meteoric Water Line (LMWL), Local Ground Water Line (LGWL) and Local Surface Water Line (LSWL) by using the isotopic values of rainfall, ground water and surface water respectively. These equations will be useful as a reference point for future studies in this area that use stable isotopes of Hydrogen and Oxygen to determine sources of ground-water recharge, to determine water-mineral exchange, to evaluate surface-water and ground-water interaction, and to analyze many other geochemical and hydrological problems.

R.D. Singh
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ABSTRACT

The quality of water depends on a large number of individual hydrological, physical, chemical and biological factors. The quality of ground water varies from place to place as well as from strata. It may also vary with seasonal changes. Ground water quality assessment and town planning are closely related. For proper utilization of ground water for various purposes, understanding of geochemical controls and for study of the extent of ground water pollution and in order to take remedial measures, it is of paramount importance to carry out systematic monitoring of ground water quality.

Ground water quality variation problem can be understood only by the regular monitoring of quality of water. In Agartala and Tezpur city of NE Region of India, rapid industrial and population growths have been taken place during the last decade. Therefore, it was proposed to study ground water quality in and around Agartala and Tezpur city.

In the present study different ground water classification methods on the basis of Stiff pattern diagram, Piper trilinear diagram, US Salinity Laboratory classification, Gibbs variation classification, Durov's trilinear classification, Doneen's and Wilcox classification are reviewed.

To evaluate the suitability of ground water for irrigation purposes various parameters like Kelley's Ratio, Sodium Adsorption Ratios (SAR), Residual Sodium Carbonate (RSC), Magnesium hazards, Sodium % and Permeability Index have also been reviewed. In the report two main environmental stable isotopes of Hydrogen (δ^2H‰) and Oxygen (δ^{18}O‰) are also determined from the collected ground water samples in the nuclear hydrology lab of NIH, Roorkee and presented in this report.

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1.0 INTRODUCTION

Ground water quality studies are not only essential for critical evaluation of water for various purpose such as domestic, agricultural and industrial supplies but also these give important clues about geological history of the area. Some of major, minor and trace constituents present in circulating waters give idea about the influence of soil and rocks through which these waters have passed and may not be known earlier. With the advent of industrialization and inadequate attention paid to protect the environment, degradation in water quality including that of ground water has become one of the challenges of modern times.

The quality of ground water depends on number of individual hydrological, physical, chemical, geological and biological factors. The quality of water is as much important as its quantity. 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. A wide variety of pollutants physical, chemical, biological and radiological have been identified in the environment consequent to urbanization, industrialization and new technological developments.

The ground water problems are more acute in the areas which are densely populated, thickly industrialized and have shallow ground water table. Water is one of the major carrier of several diseases of both chemical and trace elements origin. For proper utilization of water for various purposes, understanding of geochemical controls and for study of the extent of ground water pollution and in order to take remedial measures, it is of paramount importance to carry out systematic monitoring of ground water quality.

Shortage of drinking water and its contamination is fast emerging as a global phenomenon. With most countries witnessing a rapid growth in their populations, the problem stands to assume alarming proportions in the near future. North Eastern States of India accounts for the largest storehouse of replenishing freshwater, but the people of the hill region often lack access to safe and adequate drinking water. This water has the potential of posing serious health hazard to the population in the region.

Isotope Hydrology deals with the application of isotopes as tracers in water resources development and management. Applications of isotopes in hydrology are based on the general concept of tracing, in which either intentionally introduced isotopes or naturally occurring (environmental) isotopes are employed. Environmental isotopes (either radioactive or stable) have a distinct advantage over injected (artificial) tracers in that they facilitate the study of various hydrological processes on a much larger temporal and spatial scale through their natural distribution in a hydrological system. Thus, environmental isotope methodologies are unique in regional studies of water resources to obtain time and space integrated characteristics whereas the artificial tracers generally are effective for site-specific, local applications. Generally isotope tracers are not used as independent tools but to supplement hydrogeological, geophysical and geochemical information and for a better understanding of the processes taking place in a hydrological system. Therefore, in hydrological investigations, isotope techniques should be used routinely along with hydrochemical and hydrogeological techniques. As all isotopic, hydrogeological, hydrochemical, and hydrodynamic interpretations are space and time related, it is imperative that one should consider all the related aspects of water sampling and prevailing hydrogeological conditions in a study area.

The increasing water demand due to population growth, economical development, irrigation and industrial activities has led to heavy exploitation of ground water resources in many parts of the NE Region of India, particularly in the capital cities and district head quarters of all seven states of this region. The water resources available for exploitation in this region are often restricted to ground water sources. Drilling of bore wells for domestic and irrigation purposes has increased drastically due to the fact that the open wells are drying up during the summer periods.

Exploitation of this vital source leads to lowering of the ground water table and water quality deterioration. Ground water is recharged primarily by rainfall and surface water bodies such as rivers, lakes, tanks etc. Better understanding by the ground water system and its recharge characteristics are very much important to know the safe yield and to evolve plans for optimal utilization of the ground water resources. Isotopes and isotope-based techniques are increasingly used for the ground water investigations.

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, irrigation water supply, town planning etc.

Objectives :

1. To characterize the ground water sources for its physical, chemical and trace elements related quality so that sources may be identified for drinking water/irrigation water as the case may be.
2. To compare water quality of the sources with the standard drinking water quality norms.
3. To see the variation of ground water quality parameters through thematic maps.
4. Determination of environmental stable isotopes of hydrogen and oxygen in ground water.
5. To establish the correlation between environmental stable isotopes and different water quality parameters of ground water.
6. To see the irrigation suitability of ground water.
7. To classify the ground water according to different available criteria.
8. To identify and establish a network of ground water sampling collection sites in the study area that can be used for future stable isotope monitoring.
9. To establish the Local Ground and Surface Water Line using the isotopic data of ground and surface water of Agartala and Tezpur area.
10. To develop the Local Meteoric Water Line using the oxygen and hydrogen isotopic data of rainfall from Guwahati network station.

2.0 REVIEW

2.1 Different Test, Nature and Significance of Parameters Used in Water Quality

Conductivity

Most of the salts dissolved in water are in ionic forms by which water is capable to conduct electricity. The capacity of water to conduct electric current is known as conductivity. Conductivity is a convenient, rapid method of estimating the amount of dissolved solids. It is a numerical expression of the ability of an aqueous solution to convey an electric current. This property is related to the total concentration of ionized substances and their respective concentrations, mobility, and valence and to the temperature at which the measurement is made. Solutions of most inorganic acids and bases are relatively good conductors. Organic compounds that do not dissociate in aqueous solutions are not good conductors.

Turbidity

It is, principally caused by the presence of coliform or very finely divided suspended matter, the main causes are silt, clay, sand, microscopic biota, organic matter etc. The higher amount of turbidity produces water unfit for domestic use. It also causes profound adverse effect on the biota of natural water as it blocks the gills of fish and reduces the penetration of light which in turn minimize the primary productivity.

The term turbid is applied to waters containing suspended matter that interferes with the passage of light through the water or in which the visual depth is restricted. In lake or other waters existing under relatively quiescent conditions, most of the turbidity will be due to colloidal and extremely fine dispersions. In rivers under flood conditions, most of the turbidity will be due to relatively coarse dispersions.

pH

pH is a term used rather universally to express the intensity of the acid or alkaline condition of a solution. It is a way of expressing the hydrogen ion concentration, or more precisely, the hydrogen ion activity. It is important in almost every phase of environmental engineering practice. In the field of water supplies, it is a factor that must be considered in chemical coagulation, disinfection, water softening, and corrosion control. In wastewater treatment employing biological processes, pH must be controlled within a range favorable to the particular organisms involved. Chemical process used to coagulate wastewaters, dewater sludges, or oxidize certain substances, such as cyanide ion, require that the pH be controlled within rather narrow limits. For these reasons and because of the fundamental relationships that exist between pH, acidity and alkalinity, it is very important to understand the theoretical as well as the practical aspects of pH. The measurement of pH is of great importance as many chemical and biochemical reactions take place at a particular pH or within a very narrow range.

Total Dissolved Solids (TDS)

Total solids is a measure of dissolved and suspended impurities of water. In natural water many minerals, salts and organic substances are present in dissolved form, known as dissolved solids. While silts, sand, clay etc. are present in suspended form, known as suspended solids. Higher concentrations of these are much harmful to the biota of the water body and also to man when he uses it for various purposes. An increase in the values of total solids shows an increase in the pollution, may be physical or chemical. The total solids content for potable waters usually ranges from 20 to 1000 mg/l, and as a rule, hardness increases with total solids. In all other liquid materials, the amounts of undissolved colloidal and suspended matter increase with the degree of pollution.

Temperature

Temperature of ground water varies with the climate and the season. Its measurement is useful to indicate the trend of various chemical and biological activities. A rise in water temperature leads to the faster chemical and biochemical reactions. Biological activity is also enhanced by higher temperature upto 60 °C. Kinetics of BOD is also regulated to some extent by water temperature. It may also affect some other characteristics of water like dissolution of gases, pH, conductivity etc.

Sodium (Na^+)

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. pH also rises to unfavorable levels.

Potassium (K^+)

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.

Calcium (Ca^{2+})

Calcium deficiency is often a problem (rather than its abundance) and it causes leaves to curl or roll and become chlorotic. Its deficiency in human body 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 gets enough of Ca^{2+} salts. Ground water, lakes, rivers have Ca^{2+} 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 Ca^{2+} 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 Ca^{2+} present in domestic water supply forms a very 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^{2+})

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

Phosphate (PO^{2-}_4)

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.

Chloride (Cl^-)

Chloride ion is among the commonest anions found in most of the fresh waters in high abundance in all marine and coastal waters. 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 the 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. 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 (SO_4^{2-})

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, 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 corrodes the concrete and metallic pipe 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 (NO_3^-)

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 finds 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 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 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. 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^{2+} and Mg^{2+} 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. 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 (mg/l of $CaCO_3$)	**Water Quality**
0 - 60	Soft
61- 120	Moderate Hard
121 - 180	Hard
> 180	Very Hard

2.2 Classification of Isotopes

In this section, a brief review of various stable and radioisotopes applied in hydrological investigations is made. Isotopes can be classified in two important categories, (i) stable isotopes and (ii) unstable isotopes. Stable isotopes are the atoms of an element, which are satisfied with the present arrangement of proton, neutron and electron. On the other hand, unstable isotopes are the atoms of an element which do not satisfy with the present arrangement of atomic particles and disintegrate by giving out alpha (α), beta (β) particles and/or gamma (γ) radiation etc. and transform into an another type of atom. This process continued till the stable nuclide (element) is formed. Because of disintegration or the property of giving out radiation, the unstable isotopes are also called radioactive isotopes. For example, ^1H and ^2H are stable isotopes while ^3H is unstable. Similarly ^{12}C and ^{13}C are stable isotopes while ^{14}C is unstable. On the other hand, isotopes of oxygen (^{16}O, ^{17}O and ^{18}O) are stable.

Isotopes can also be classified as natural and artificial isotopes, i.e., the isotopes that occur naturally are called natural isotopes while those produced in a reactor or laboratory under controlled conditions are known as artificial isotopes. Normally the artificially produced isotopes are radioactive while stable and radioactive, both types of isotopes occur naturally.

Another category of isotopes has been devised that is called environmental isotopes. These isotopes have different types of categories i.e. naturally occurring stable and radioactive isotopes and radioisotopes introduced into the atmosphere due to anthropogenic activities etc. The environmental radioisotopes whether naturally occurring due to cosmic ray interaction with various gaseous molecules or anthropogenically produced and become the part of hydrological cycle are safe in normal conditions and do not pose any threat to human health.

There are nine isotopic configurations for water, which are distinguished by their mass numbers as well as their characteristics. However, because of the low abundance of the heavier isotopes, almost all water molecules are of three isotopic combinations.

Characteristics of three types of water molecules: (from Hoefs 1997)

Property	$^1H_2{}^{16}O$	$^2H_2{}^{16}O$	$^1H_2{}^{18}O$
Density (20°C, in g cm^{-3})	0.997	1.1051	1.1106
Temperature of greatest density (°C)	3.98	11.24	4.30
Melting point (760 Torr, in °C)	0.00	3.81	0.28
Boiling point (760 Torr, in °C)	100.00	101.42	100.14
Vapour pressure (at 100°C, in Torr)	760.00	721.60	?
Viscosity (at 20°C, in centipoise)	1.002	1.247	1.056

2.3 Environmental Isotopes

Environmental isotopes, both stable and radioactive, occur in the atmosphere and the hydrosphere in varying concentrations. So far, the most frequently used environmental isotopes include those of the water molecule, hydrogen ^2H or D also called deuterium, and ^3H also called tritium) and oxygen (^{18}O), as well as of carbon (^{13}C and ^{14}C also called radiocarbon or carbon14) occurring in water as constituents of dissolved inorganic and organic carbon compounds. ^2H, ^{13}C and ^{18}O are stable isotopes of the respective elements whereas ^3H and ^{14}C are radioactive isotopes. The stable isotopes are usually measured, using an isotope ratio mass spectrometer, in terms of the isotope ratios of the less abundant to more abundant isotope, e.g.,$^2H/^1H$ and $^{18}O/^{16}O$ (^1H and ^{16}O being the number of atoms of the most abundant isotopes of the respective elements). The radioactive isotopes are measured either by counting of their radioactive decays (low level counting, e.g., by liquid scintillation counter) or the number of atoms (using accelerator mass spectrometry (AMS)) in a given sample.

Use of Environmental Stable Isotopes : The stable isotopes of water, O-18 and deuterium, have been commonly used in hydrologic studies. They are used by hydrologists because they are naturally occurring, do not decay over time, and are conservative within the watershed. ^{18}O and deuterium isotopic concentrations vary seasonally, and are also observed in precipitation. Isotopes undergo fractionations according to mass differences during phase changes. Isotopically heavier precipitation occurs as rain (typically ~ -3‰ - 0‰ for O-18), while snow is dramatically lighter (~ -20‰, O-18). By recognizing the isotopic variations of source waters, they can be distinguished from each other using analytical tools such as hydrograph separation. Stable isotopes can be used within a mine system by giving information about precipitation inputs into the subsurface mine workings. A well mixed, ground water dominated system will not vary much isotopically, while a system (or source) receiving seasonal input (event water) will vary considerably more. The significance in determining this when approaching a mine from a remediation standpoint is the applicability of remediation. If the mine, particularly the source of contamination, is dominated by ground water, the remediation approach would be considerably different than a system which has a large component of event water.

2.4 Deuterium (^2H) and Oxygen-18

Hydrogen has two stable isotopes, the hydrogen atom (^1H, with abundance of 99.984 %), and deuterium (^2H, the principal component of heavy water with abundance of 0.015 %). The ratio of these isotopes can be used as an ideal tracer of water molecule in hydrological cycle. Similar to hydrogen isotopes, oxygen has three stable isotopes i.e., ^{16}O (99.76 %), ^{17}O (0.04 %) and ^{18}O (0.2 %). In terrestrial materials, the ^{17}O geochemistry echoes that of the 5 times more abundant ^{18}O and therefore in hydrological applications ^{17}O is usually not considered separately. The stable isotope measurements of hydrogen and oxygen isotopes are generally made using isotope ratio mass spectrometer (IRMS) and are reported as permil (‰) difference from the standard, Standard Mean Ocean Water (SMOW) or Vienna Standard Mean Ocean Water (VSMOW), the internationally accepted reference standard for stable isotopes of hydrogen and oxygen in water samples.

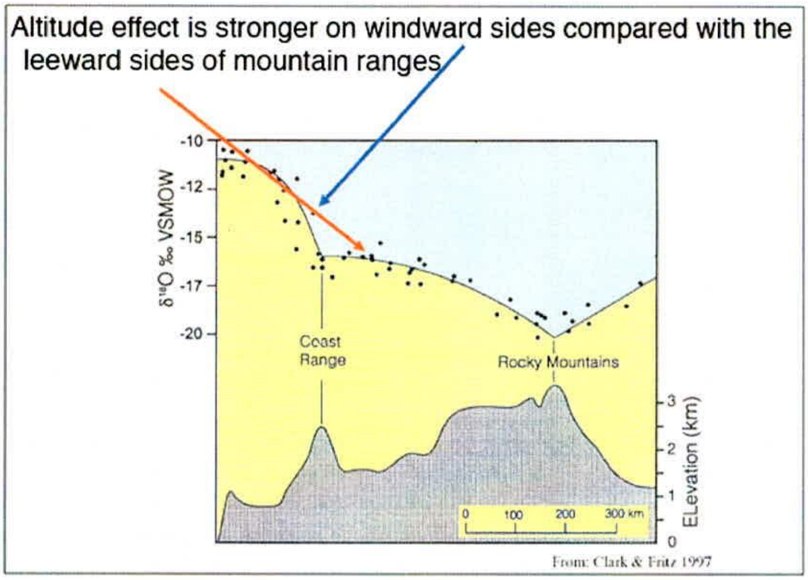
Most of the applications of stable isotopes of hydrogen and oxygen in ground water studies use the variations in isotopic ratios in atmospheric precipitation, that is, the input to a hydrogeological system. These variations result from a variety of physical processes, the most important being evaporation and condensation. During evaporation, the light molecule of water, H216O, is more volatile than the heavier molecules (that is, 1H2H16O or H218O). When this atmospheric water vapour undergoes successive cooling and condensation with production of clouds and precipitation, the less volatile (heavy) water molecules condense preferentially, leaving a residual vapour more and more depleted in ^2H and ^{18}O. A worldwide relation between ^{18}O of precipitation and mean annual air temperature (with some exceptions) has been observed. This dependency on temperature produces different effects like seasonal isotope variations of precipitation (winter precipitation is depleted in heavy isotopes with respect to summer precipitation), latitude effect (high latitude precipitation is depleted with respect to low latitude precipitation), and altitude effect (heavy isotope content of precipitation decreases with increasing altitude). These effects allow the use of these isotopes to delineate various hydrogeological processes as well as indicators of past and present climate changes and of palaeowaters.

In most aquifers, isotopic composition of water does not change further unless exchange with the oxygen of rocks occurs. The isotopic composition of ground water is thus related to that of precipitation in the recharge area of an aquifer at the time of recharge. Ground water may be of a very old age, and climatic conditions of the region at the time of recharge may have been different from those of today. This implies that the isotopic composition of precipitation could have been different from the present one, due to the correlation between values and temperature. Stable isotopes of hydrogen and oxygen have been extensively used to characterize different components and the dynamics of the geothermal waters. Stable isotopes of hydrogen and oxygen are thus the most useful in gaining insights into various aspects of different components of the hydrological cycle.

2.5 Factors Affecting the Variation on Isotopic Composition

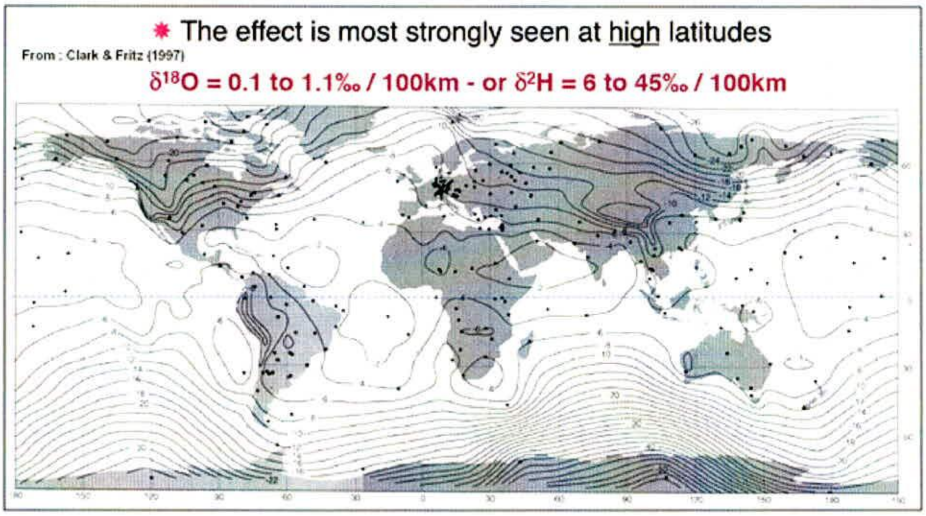
Different waters in water cycle are characterized by different isotopic composition with different temporal and spatial variation. For precipitations worldwide, isotopic compositions are mainly controlled by the temperature when they experience evaporation, from which a series of isotopic effects are derived. They are such:

Altitude Effect: Mountain ranges usually have isotopically lighter water than surrounding areas. As heavy isotopes in water vapor masses may sink prior to light isotopes and so δ values of precipitations are usually depleted with altitude increases. On the windward side of a mountain, the $\delta^{18}O$ and δD values of precipitation decrease with increasing altitude. Typical gradients are -0.15 to -0.5 ‰ per 100m for ^{18}O, and -1.5 to -4 ‰ per 100m for D. This pattern is often not observed in interior mountains, for snow, or on the leeward side of mountains.


Altitude effect is stronger on windward sides compared with the leeward sides of mountain ranges

From: Clark & Fritz 1997

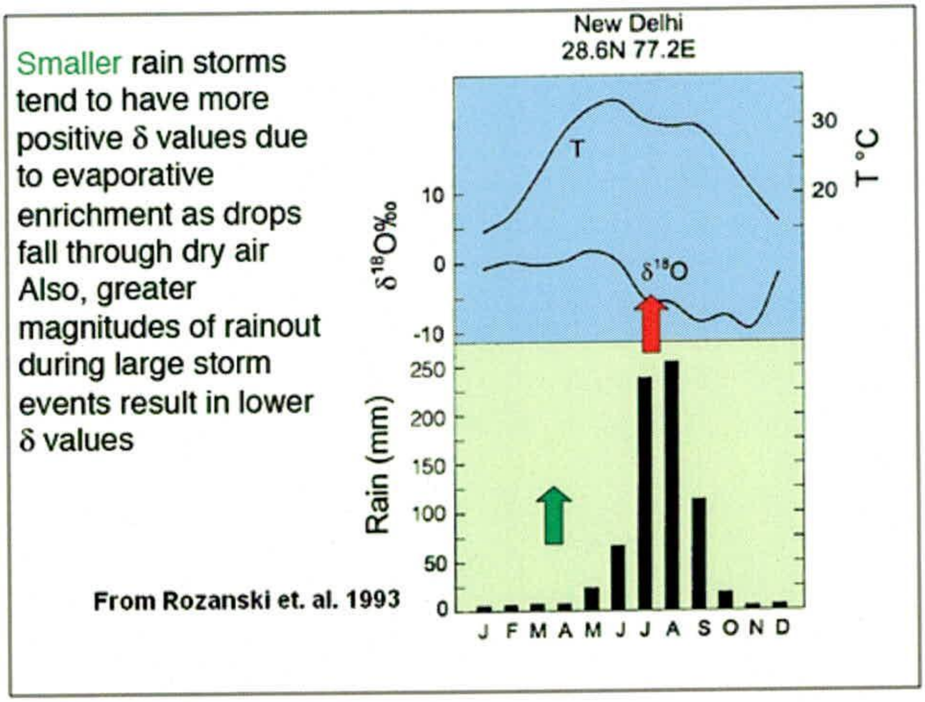
Latitude Effect : Isotopic composition of precipitation decreases with a higher latitude


✱ The effect is most strongly seen at <u>high</u> latitudes

From : Clark & Fritz (1997)

$\delta^{18}O$ = 0.1 to 1.1‰ / 100km - or $\delta^{2}H$ = 6 to 45‰ / 100km

Amount Effect: Isotopic compositions usually correlate with the amount of each rain event, and it often takes on a lighter isotopic composition for heavy rains and heavier for rains with long duration and small intensity.



Smaller rain storms tend to have more positive δ values due to evaporative enrichment as drops fall through dry air Also, greater magnitudes of rainout during large storm events result in lower δ values

From Rozanski et. al. 1993

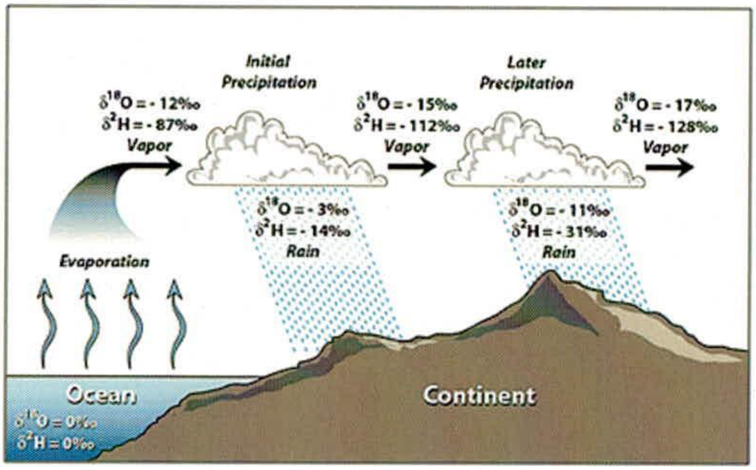
Continental Effect: Similar to the altitude effect, when water vapor evaporated from seawater surface or other origins moves across a continent, heavy isotopes tends to penetrate more easily. So coastal precipitations have heavier isotopic compositions and the inner ones are lighter. In any region with even minor relief, orographic precipitation will occur as a vapour mass rises over the landscape. Rainout proceeds as the air mass cools, imparting a decrease on precipitation. At higher elevation air cools adiabatically (by expansion), thus driving rainout. At higher altitudes where the average temperatures are lower, precipitation will be isotopically depleted.

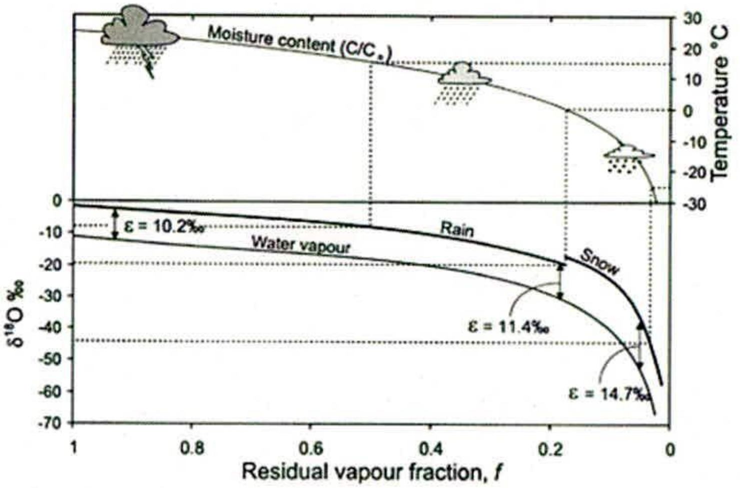
As a result of kinetic and equilibrium processes during evaporation from the ocean and subsequent condensation, the ratios of the stable isotopes of hydrogen (^{1}H and ^{2}H or deuterium) and oxygen (^{16}O and ^{18}O) in water within a particular air mass vary with temperature during condensation and with relative humidity during evaporation (Clark and Fritz, 1997). The stable isotope ratios of water vapor in an air mass reflect the origin of the air mass, and the ratios in the precipitation that evolves from the air mass reflect both the origin of the air mass and the conditions under which condensation occurs. As an air mass travels away from the ocean (or other source areas for water vapor) and precipitation occurs, precipitation that is enriched in the heavier isotopes leaves the air mass first. The remaining water vapor then is composed of lighter isotopes. Subsequent precipitation has an increasingly lighter stable isotope composition.

This depletion effect has been called the "continental effect" and results in lighter stable isotope ratios farther away from the ocean. Furthermore, a strong linear correlation exists between mean annual isotopic composition of precipitation and mean annual surface air temperature. As a result, precipitation at higher latitudes has a lighter stable isotope composition than precipitation closer to the equator. This temperature effect also is seen as a result of elevation; cooler temperatures at higher elevations result in δ^{18}O depletion that varies between -0.15 and -0.5 permil per 100 m rise in elevation (Clark and Fritz, 1997).

- Water evaporates from the ocean » phase change #1
- The vapor that forms has a more negative d^{2}H or d^{18}O value than the source (ocean) water
- Water condenses from the cloud vapor » phase change #2
- The rain has a more positive d^{2}H or d^{18}O value than the cloud (vapor) water
- The remaining cloud vapor becomes more depleted in ^{2}H and ^{18}O (has a lower d^{2}H or d^{18}O value)

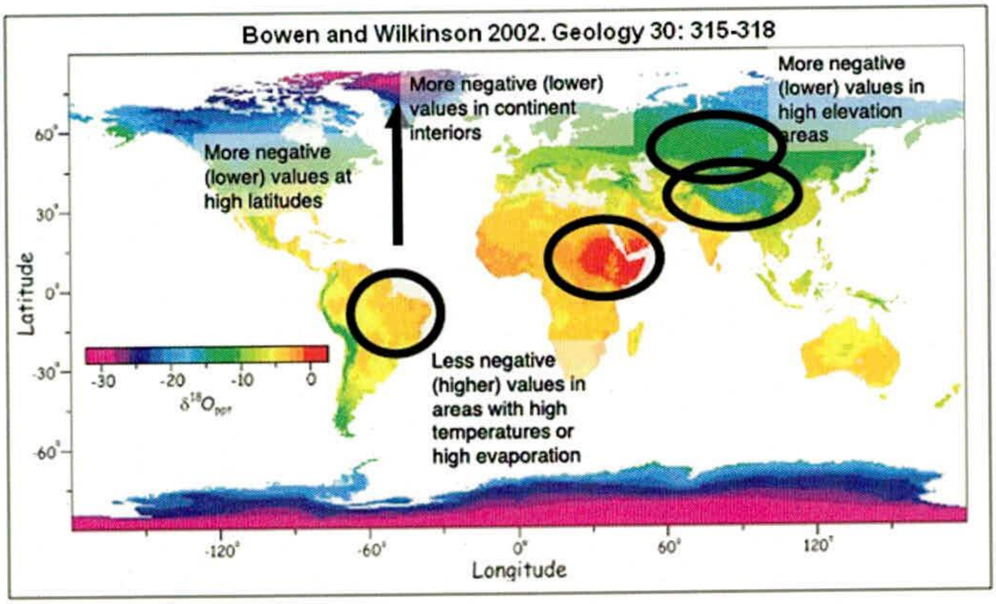
Rainout effect on d^{2}H and d^{18}O values (based on Hoefs 1997 and Coplen et al. 2000).





(from Clark and Fritz 1997)

Seasonal Effect: Isotopic composition varies with local temperature, especially for the monthly mean temperature. Generally, rains have heavier isotopic composition in high temperature months.


Bowen and Wilkinson 2002. Geology 30: 315-318

More negative (lower) values in continent interiors

More negative (lower) values in high elevation areas

More negative (lower) values at high latitudes

Less negative (higher) values in areas with high temperatures or high evaporation

Based on the effects above and other characteristics, isotopic composition can help to study the origin and movement of water vapor. Since 1950s, a series of isotopic studies have been carried out worldwide, and by far, a series of accomplishments have been achieved in distinguished aspects of water cycle based on environmental isotopes worldwide. Nowadays, environmental isotopes (stable and radioactive) are widely used for hydrological investigations.

2.6 Defining The Global and Local Meteoric Water Line (GMWL and LMWL)

Because of the differences in molecular weight fractionation occurs in which the heavier isotope is concentrated in the less mobile phase, i.e. liquid rather than vapour. In natural waters fractionation is due primarily to evaporation; although isotopic changes can occur in thermal springs or in soil waters rich in carbon dioxide. Hence measurement of the ratio of the heavier isotopic species to the lightest can yield information on palaeoclimatology, sources of ground water recharge and discharge and mixtures of ground water of different origins. Measurement of the ratio is by atomic adsorption mass spectrometry and careful field sampling and preparation techniques are required. The concentrations of isotope ratios are reported relative to SMOW (Standard Mean Ocean Water), which is a standard water sample kept at the International Atomic Energy Agency in Vienna. Units are delta values in parts per million (‰) defined as:

$$\delta = \frac{[{}^{R}\text{sample} - {}^{R}\text{SMOW}]}{{}^{R}\text{SMOW}} \text{ x } 1000$$

in which R refers to the measured ratio. Generally the mean isotopic composition of rainfall is strongly correlated with mean annual air temperature so that there is also a close correlation with latitude. Thus, at tropical latitudes the relative depletion of $\delta^{18}O$ and δ-deuterium is less than at locations further from the equator. Also, the concentration of $\delta^{18}O$ is correlated with δ-deuterium on a global scale, although each may vary considerably in precipitation on the local scale.

Due to parallel isotopic fractionation, isotopic compositions for δD and $\delta^{18}O$ vary in similar modes, and so there is a good relationship between them. In 1961, Harmon Craig (1961) found the linear relationship between δD and $\delta^{18}O$, which was called Global Meteoric Water Line (GMWL). The GMWL defines the relationship of $\delta D\text{-}\delta^{18}O$ in worldwide fresh surface waters:

$$\delta D = 8 * \delta^{18}O + 10$$

Here all the results used SMOW as reference.

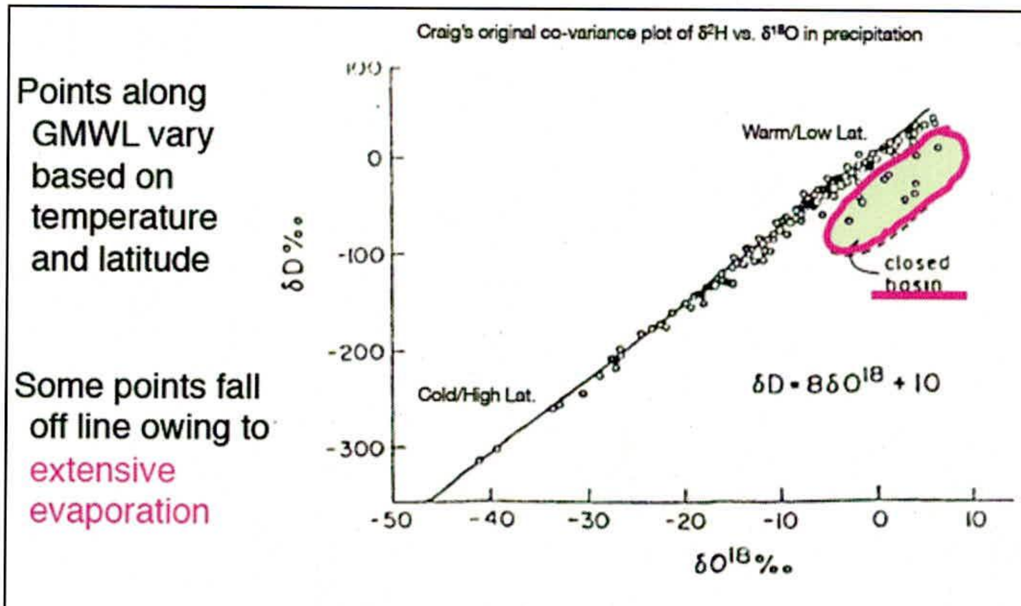


Fig. Isotopic data of about 400 samples of rivers. lakes and precipitation from various parts of the world. The best-fit line was termed the *meteoric line*. It equation as found by Craig (1961a), is $\delta\Delta = 8\delta^{18}O + 10$. The data in the encircled zone of 'closed basins' is for East African lakes with intensive evaporation.

Through subsequent monitoring of isotopic compositions for precipitations by Global Network for Isotopes in Precipitation (Rozanski et al., 1993), the relationship was refined to be:

$$\delta D = 8.13 * \delta^{18}O + 10.8$$

And here, the analysis results have been changed to VSMOW standard.

This relation was developed as an average of many local water lines that differ from the GMWL as a result of climatic and geographic factors. Differential fractionation of δ^2H and δ^{18}O occurs as a function of humidity during primary evaporation of water vapor from the ocean and as a function of temperature during secondary evaporation as rain falls from a cloud. These two factors affect the slope and intercept of the Local Meteoric Water Line (LMWL) and produce a different LMWL at different locations.

Relationship between δ^{18}O and δ^2H (GMWL) holds information about precipitation dynamics

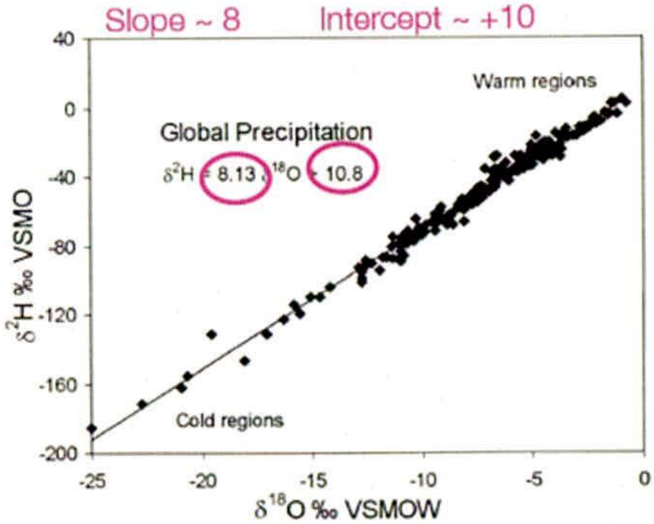


Fig. The meteoric relationship for ^{18}O and ^{2}H in precipitation. Data are weighted average annual values for precipitation monitored at stations in the IAEA global network. compiled in Rozanski et al. (1993).

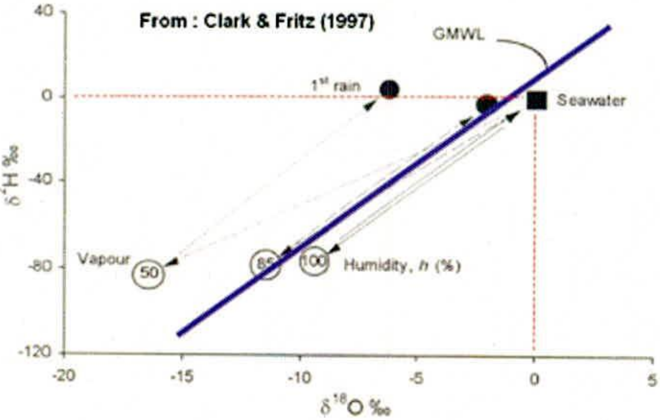
From : Clark & Fritz (1997)

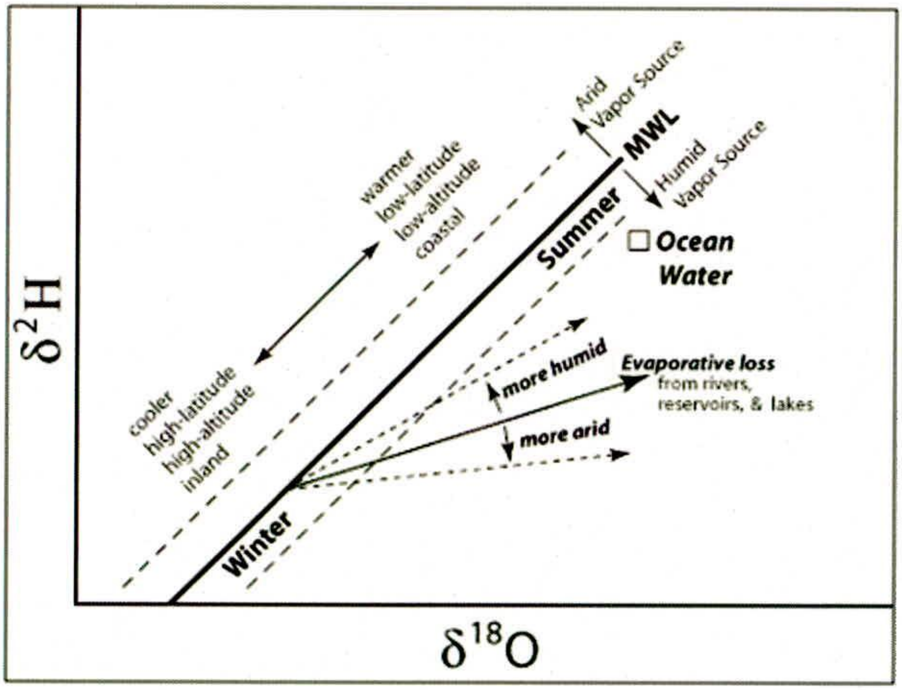
As δ value is integrated reflection of geographic and meteoric information, relationships between δD and δ^{18}O in different regions may vary in some degree, and in this sense they are usually called Local Meteoric Water Line. Samples which fall below the GMWL often result from evaporation.

Humidity affects oxygen and hydrogen differently such that the slope of the evaporation line will vary due to changes in relative humidity. At very low relative humidities (< 25%) the slope of the evaporation line will be close to 4; for moderate relative humidities (25% to 75%) the slope will be between 4 and 5; only for relative humidities above 95% does the slope approach 8, the slope of the meteoric water line (Clark and Fritz 1997). Likewise, relative humidity affects the isotopic composition of the water vapor. This is primarily reflected in the d value, or deuterium excess, of the meteoric water line. If the vapor source region for precipitation is arid (low humidity), *d* values will be high, upwards of 20. In contrast, *d* values for humid regions will be low, approaching 0.

Vapor from seawater at 85% humidity and subsequent rain from this vapor shows d-excess of +10‰

Globally, the average water vapor forms at RH=85% thereby resulting in GMWL with +10‰ intercept (not same as d-excess!)





LMWLs are useful and necessary for information about local hydrological processes, like:

- Evaporation and transpiration water vapor
- River origins
- Soil water dynamics etc.
- Local rain sources
- Stream dynamics

2.7 Application of Environmental Stable Isotopes

The most commonly employed stable isotopes are ^{18}O and ^{2}H, which are often used for assessment of the "genesis" (origin) of water, particularly in ground water systems; processes involved in the replenishment (process-tracing); for estimating mixing proportions of different sources or component flows (component-tracing); and studying hydraulic relations between ground water and surface waters or between different aquifer units within a given ground water system. One of the most important factors governing the use of these isotopes is the isotopic fractionation occurring during phase changes, i.e. condensation or evaporation, which is mainly a temperature dependent activity. The isotopic changes thus induced, is a conservative property of the water during its circulation in the hydrological systems, and it is a finger-print of the history of the processes involved in its formation and circulation. The stable isotopes are excellent indicators of the circulation of water.

In nature, most ground water is renewed by the direct infiltration of precipitation and surface water or by subsurface inflow, and thus originates from precipitation. Owing to evaporation and exchange processes, the isotope content and time and space distribution can change during the transition from precipitation to ground water and sometimes in the ground water itself.

Specifically, the Isotope can be used for tracing the source, movement, and pollution of ground water. For example:

(a) In most of the cases, more than 60 % of ground water is drawn through deep tubewells from the deeper aquifers, but the managers do not know anything about the recharge zones and recharge source to the deeper aquifers. Isotopes like Oxygen-18 or deuterium and Carbon-14 can provide such useful information.

(b) In ground water management, particularly in arid and semiarid regions, it is important to estimate the recharge rate to avoid over exploitation of the aquifer. Isotopes can help in identifying and estimate recharge rate to the aquifer.

(c) Ground water management in mountainous region is a challenge due to lack of information about the source and origin of springs. Isotopes can be used to deduce such information for the better management of watersheds in mountainous region.

(d) Salinization of ground water either by irrigation or by seawater encroachment is an issue of concern in many non coastal and coastal areas around the world. Isotope techniques along with chemistry can distinguish the source of salinity in ground water, resulting in the development of appropriate management practice.

(e) Polluted ground water may remain in the aquifer for centuries, and is very difficult if not impossible to clean up. Isotope techniques can assess the vulnerability of ground water to pollution from the surface by determining how rapidly it moves and where it is being recharged. In some cases it is also possible to identify the source of pollution.

(f) Percolation tanks have been constructed in many parts of the country (particularly in hard rock areas), for artificial recharge of the aquifers in the command area. Isotope techniques could help in the studying the efficacy of these percolation tanks by estimating the contribution of the tank to the ground water.

Similarly, the isotopes can be used for a number of investigations related to surface water studies. For Example:

1. Stream Flow Measurements in mountainous regions.
2. Snow Water Equivalent and Snowmelt Contribution.
3. Dynamics and Sedimentation in Lakes and Reservoirs.
4. Sediment Transport in rivers and Harbors.
5. Water Balance & Dynamics of Lakes.
6. Effluent Dispersion in Surface Waters.
7. Surface Water and Ground water Interaction.
8. Hydrograph Separation.

Stable isotopes are also useful for several important aspects of global change research. One major area is to use stable isotope ratios to reconstruct past environmental conditions, which is possible when a compound is laid down and preserved over time. Some common examples would include ice profiles, the shells of mollusks, and tree rings. Similarly for ecosystems, the isotopic composition of soil organic matter reflects the plant material that occupied the surface in the past. Another very common application of stable isotopes is as a tracer to identify where materials had originated.

2.8 Ground water Sampling for ^{2}H and ^{18}O

Ground water samples can be collected from hand pumps, private and government tube wells, piezometers, springs, artesian wells, open wells/dug wells etc. However, it is necessary to ensure that a sample represents *in situ* ground water without any contamination, evaporation, or effect of exchange with the atmosphere. Further, ground water quality and isotopic composition may vary with depth and location. Therefore, the best way to collect the representative ground water samples is to first collect the hydrogeological data of the study area. This helps to select sampling points and depth of sampling in different aquifers. Periodic sampling in wet and dry seasons may be necessary to understand spatial and temporal variations.

In mountainous regions, natural springs can be considered as ideal source for sampling ground water and the dissolved constituents. The sampling point should be located as close as possible to the discharge point of a spring to minimize the loss of gases and to get unaltered representative water sample.

When the ground water samples are to be collected from shallow aquifers, handpumped wells and shallow tube wells can be used after purging the standing water column for a few minutes. Shallow domestic wells or dug wells are found in large numbers in many of the countries. These wells are regularly used for irrigation and drinking water supplies and mostly represent shallow aquifers. But these are open and large in diameter; the ground water in such wells is often subjected to evaporation and therefore it is not suitable for sampling. Such samples should be avoided if a nearby shallow hand-pumped well or tube well is available. However, if there is no other source, water samples can be collected from such wells after continuous pumping for various isotopic analyses.

Most of the production wells that are developed by various agencies/individuals for irrigation purposes tap ground water from the deeper aquifers. These sources may be used to sample the deeper ground water. But in these cases, the ground water could be a mixture of ground waters from different depth horizons. Wells of different depths with single screens are preferred to wells with multiple screens. Piezometers constructed to monitor ground water in different aquifers are most suitable for isotopic analyses. Air jet pumps must be avoided, as the atmospheric air will alter the samples. Tube wells should be operated for 10-15 minutes to flush out the standing water column before sampling. One should check the plumbing system prior to sampling to avoid inadvertent sampling of ground water mixed with water softeners and purifiers, aeration with atmospheric air, etc. as these alter the water chemistry and isotope composition of dissolved constituents in ground water. Bottles should be filled completely and airtight seal must be ensured. If the samples are to be stored for longer period, they should be sealed with wax and stored at low temperature (4 ^{o}C). No other treatment such as filtration and preservation is required. On site measurements like sample temperature, pH, conductivity, dissolved oxygen, alkalinity, etc. along with all other relevant site information should be recorded. Caution should be exercised to crosscheck the information on labels and that recorded in the field notebook.

2.9 Graphical Presentation and Classification of Ground Water

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 Durov (1948) trilinear diagram, and (6) the Gibbs (1970) diagram.

Collin's Bar Diagram : The Collin's (1923) bar diagram 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 closely related ions and identified by distinctive shading patterns. Usually there are six subdivisions but more can be used (Fig. 2.1).

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. 2.2. Concentrations of four major cations (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+},) are plotted to the left of a vertical zero axis and four major anions (Cl , SO^{2-}_{4}, HCO^{-}_{3}, NO^{-}_{3}+ PO^{2-}_{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.

Piper's Trilinear Diagram : One of the most useful graphs for representing the comparison of water quality analyses is the trilinear diagram by Piper (1944) shown in Fig. 2.3. 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 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.

The facies mapping approach (Back, 1961), is also one way of smoothing chemical data (Fig. 2.4).

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. 2.5). In the triangular field at the lower left, the percentage reacting values of the three anion groups (Cl^{-}, HCO^{-}_{3}, SO^{2-}_{4}) are plotted as a single point according to conventional trilinear co ordinates. The three cation group (Na^{+}+K^{+}, Ca^{2+}, Mg^{2+}) are plotted likewise in the triangular field at the top triangular.

Gibbs' Diagram : Gibbs (1970) plotted TDS of world water against the cation ratio (Na^{+} to Na^{+}+ Ca^{2+}) in ppm. When the scatter of data points are enclosed, a boomerang 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^{2+} 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 evapo-concentration 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 mechanisms that regulate the chemistry of the world's water: (1) Evapo-concentration; (2) selective mineral precipitation; and (3) rainfall of variable composition (Fig. 2.6).

2.10 Classification for Irrigation Purpose

Kelley's Ratio : Kelley et. al. (1940) have stated that the potential sodium problem in irrigation waters could be reliably evaluated on the basis of the following ratio:

Kelley's Ratio = $Na^{+} / (Ca^{2+} + Mg^{2+})$

where all the concentrations are expressed in epm. Kelley et. al. (1940) mentioned that if this ratio is less then unity, the water is suitable for irrigation purpose; if it is two or more, the water is unsuitable while water with value between one and two are marginal.

Sodium Adsorption Ratio (SAR) or USSL Classification : 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 sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the sodium adsorption ratio (SAR) (Fig. 2.7). The following formula is used to calculate SAR:

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

where all ion concentrations are expressed in epm.

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:

$$RSC = (CO^{2-}_{3} + HCO^{-}_{3}) - (Ca^{2+} + Mg^{2+})$$

where all concentrations are expressed in epm.

In irrigation waters having high concentration of bicarbonates, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate. Ground water could be classified based on RSC. It can be grouped as Good (< 1.25), Doubtful (1.25-2.5) and Unsuitable (> 2.5). Continues use of waters having RSC more than 2.5 meq/l leads to salt build up which may hinder the air and water movement by clogging the soil pores and lead to degradation of the physical condition of soil. RSC (2.5-4) can be used effectively with the addition of gypsum.

Magnesium Hazard : Paliwal (1972) has used the ratio $(Mg^{2+} * 100)/(Ca^{2+} + Mg^{2+})$ as an index of magnesium hazard to irrigation water. 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^{2+}/Ca^{2+} ratio. However the harmful effect of Mg^{2+} of irrigation water on soil is likely to be reduced by the release of Ca^{2+} on dissolution of $CaCO_3$ if present in the soil.

Soluble Sodium Percent (SSP) or Na% (Wilcox classification) : The SSP is calculated by the following formula (Wilcox (1948) :

$$SSP \text{ or } Na\% = (Na^{+} + K^{+}) * 100 / (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})$$

where all concentrations are expressed in epm. The following scheme of classification was given by Wilcox (Fig. 2.8):

Water Classes	SSP	Conductivity (micro mho/cm)
Excellent	<20	<250
Good	20 - 40	250 - 750
Permissible	40 - 60	750 - 2000
Doubtful	60 - 80	2000 - 3000
Unsuitable	>80	>3000

Doneen's Permeability Index : The permeability index (PI) is calculated as below (Doneen, 1962) :

$$\mathrm{PI} = [\mathrm{Na}^{+} + \mathrm{SQRT}(\mathrm{HCO}^{-}_{3})] / (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+})$$

Where all the ionic concentrations are expressed in epm. According to this classification, the water is good for irrigation if it falls to class I or II in the diagram (Fig. 2.9).

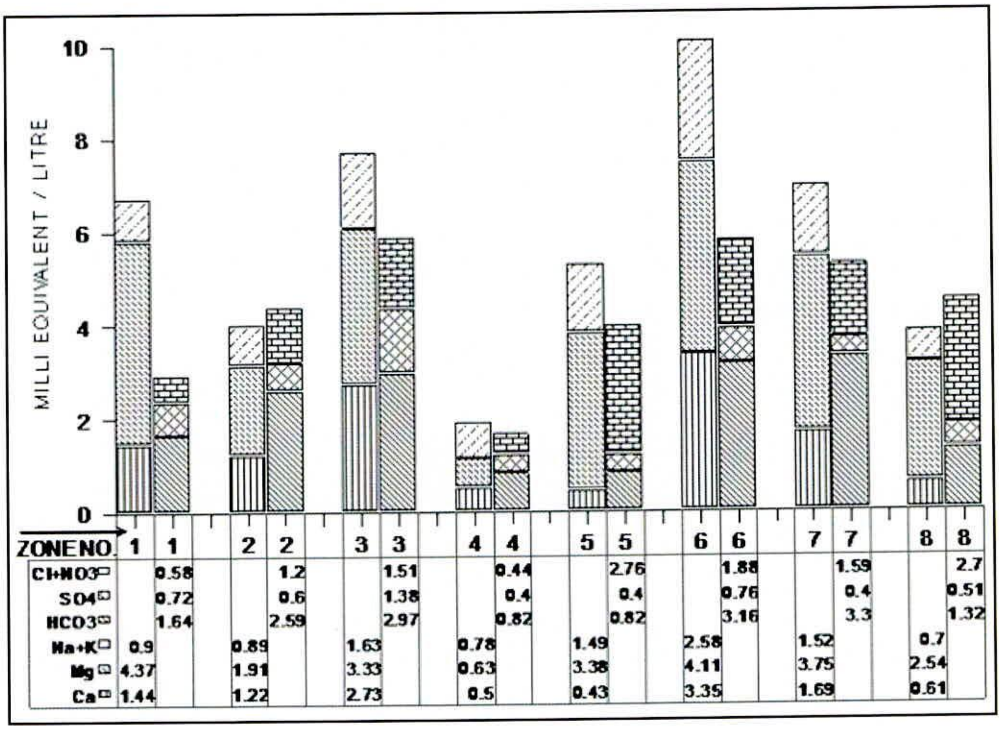
Chloride Tolerance : Ayers and Branson (1975) have proposed the following limits of chloride tolerance in waters to be used for irrigation purposed:

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

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.

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



ZONE NO.	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8
Cl+NO3 ▭		0.58		1.2		1.51		0.44		2.76		1.88		1.59		2.7
SO4 ▨		0.72		0.6		1.38		0.4		0.4		0.76		0.4		0.51
HCO3 ▨		1.64		2.59		2.97		0.82		0.82		3.16		3.3		1.32
Na+K ▭	0.9		0.89		1.63		0.78		1.49		2.58		1.52		0.7	
Mg ▨	4.37		1.91		3.33		0.63		3.38		4.11		3.75		2.54	
Ca ▨	1.44		1.22		2.73		0.5		0.43		3.35		1.69		0.61	

Fig 2.1: Collin's Bar Diagram Presentation for Cations and Anions (Typical Sample Diagram)

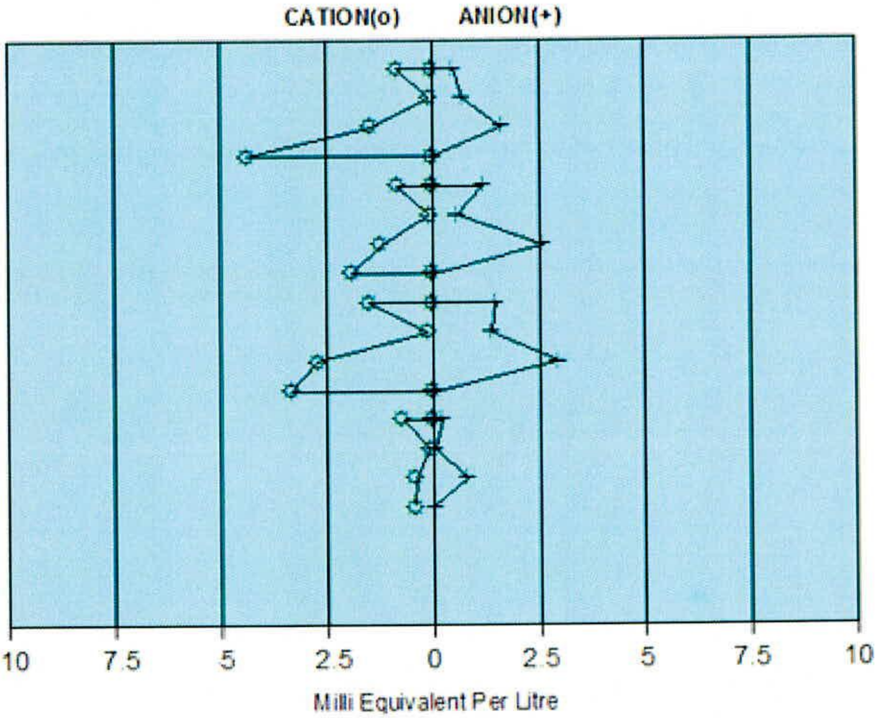
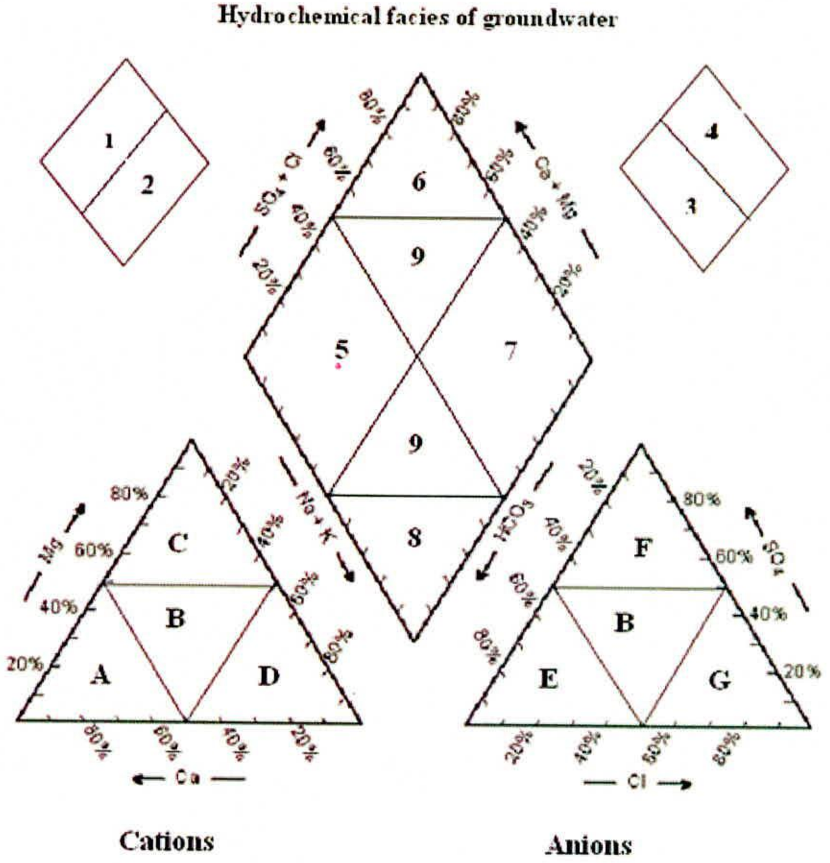


Fig. 2.2 : Stiff Pattern Diagram for ground water Analysis (Typical Sample Diagram)



A- Calcium type
B- No Dominant type
C- Magnesium type
D- Sodium and potassium type
E- Bicarbonate type
F- Sulphate type
G- Chloride type

Subdivision of the diamond Characteristics of corresponding subdivisions of diamond-shaped fields

1-Alkaline earth (Ca^{2+}+Mg^{2+}) exceeds alkalies (Na^{+}+K^{+}).

2- Alkalies exceed alkaline earths.

3- Weak acids (CO^{2-}_{3}+HCO^{-}_{3}) exceed Strong acids (SO^{2-}_{4}+Cl^{-}).

4- Strong acids exceed weak acids.

5- Magnesium bicarbonate type.

6- Calcium-chloride type.

7- Sodium-chloride type.

8- Sodium-Bicarbonate type.

9- Mixed type (No cation-anion exceeds 50%).

Fig. 2.3 : Piper's Trilinear Classification for Water Analysis

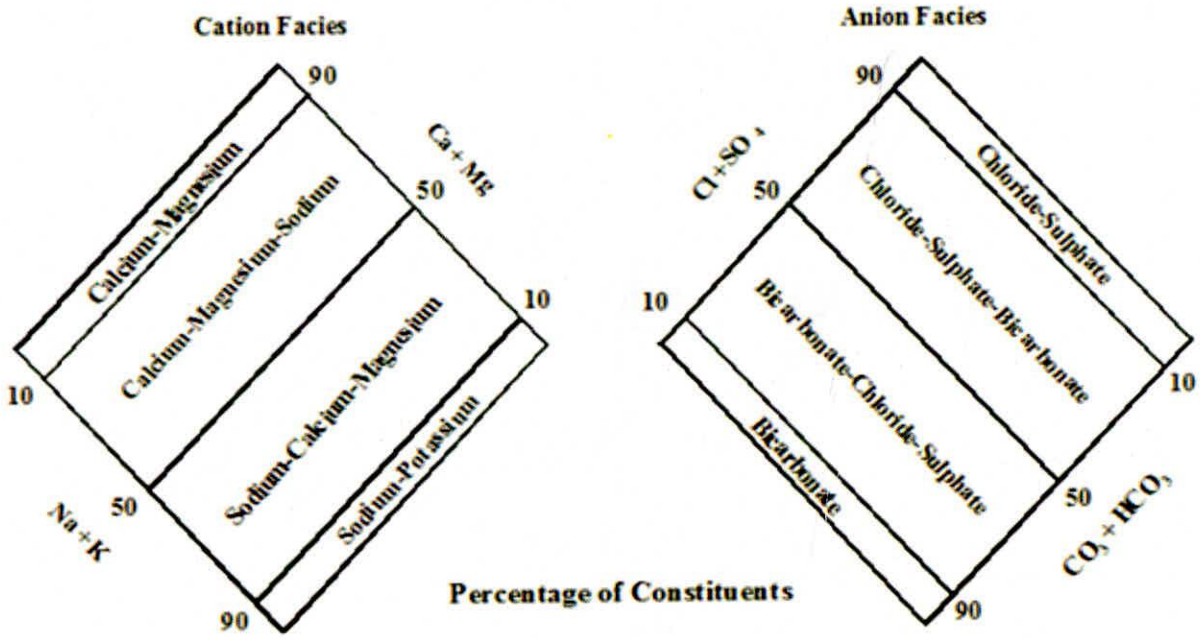


Fig. 2.4 : Back's Templates for Classifying Water into Facies for Cations and Anions

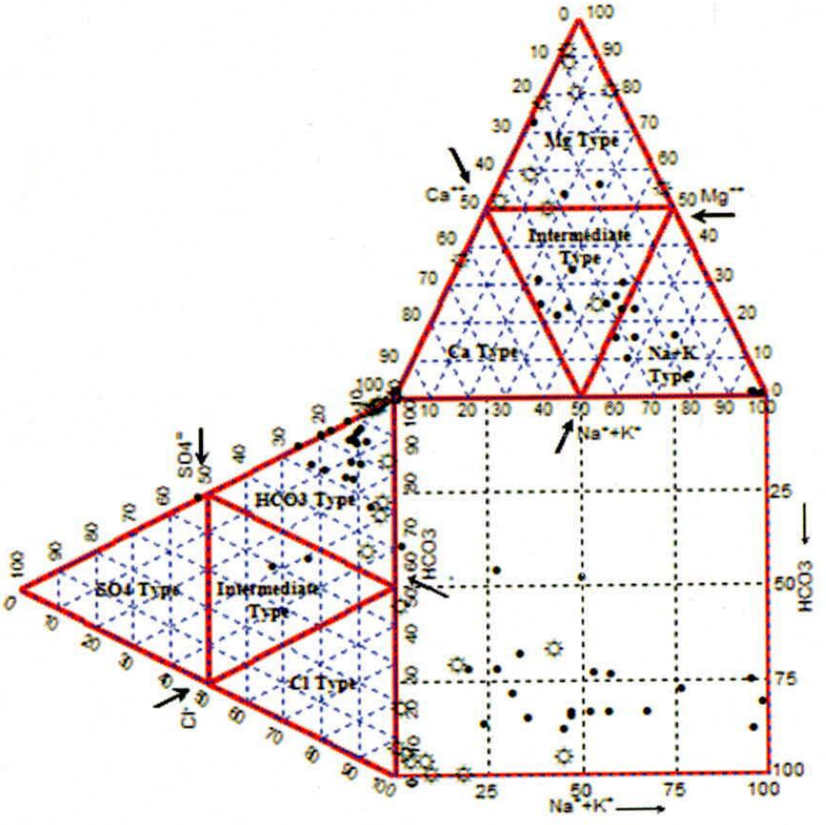


Fig. 2.5 : Durov's Trilinear Classification (Typical Sample Diagram)

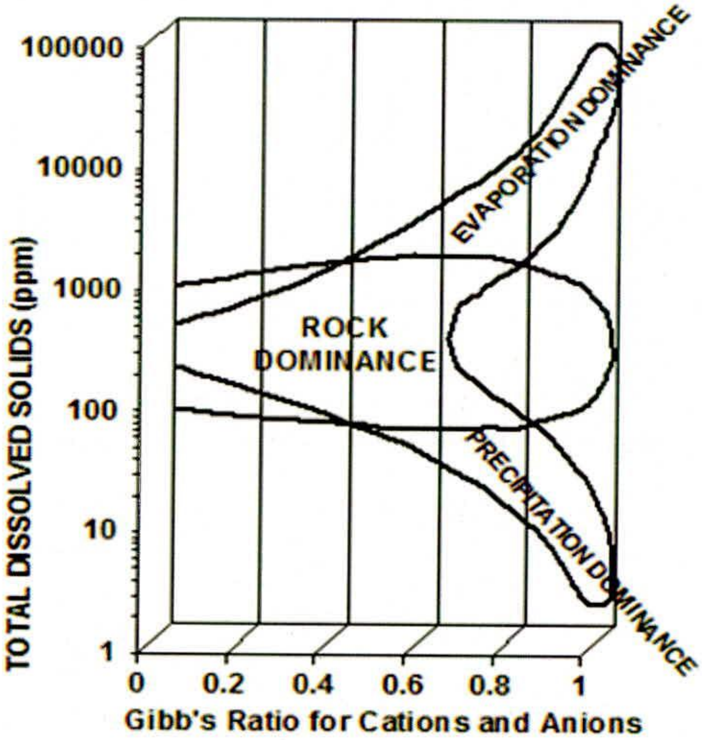
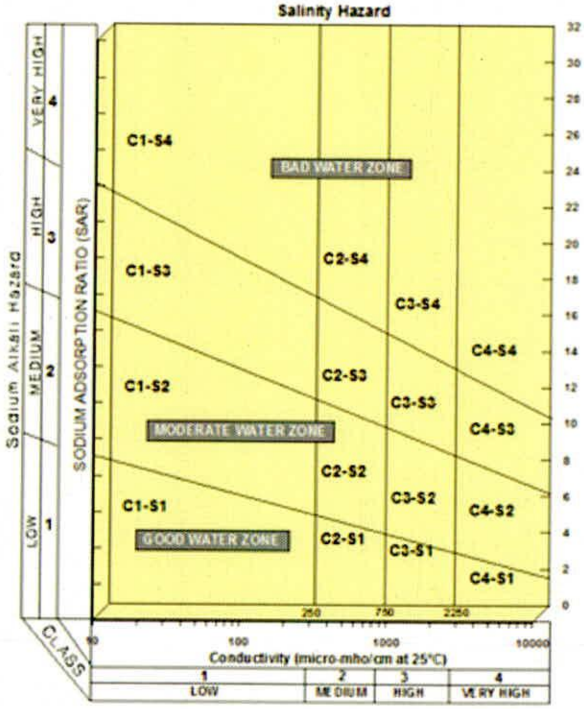


Fig. 2.6 : Gibb's Mechanism for the Ground water Chemistry



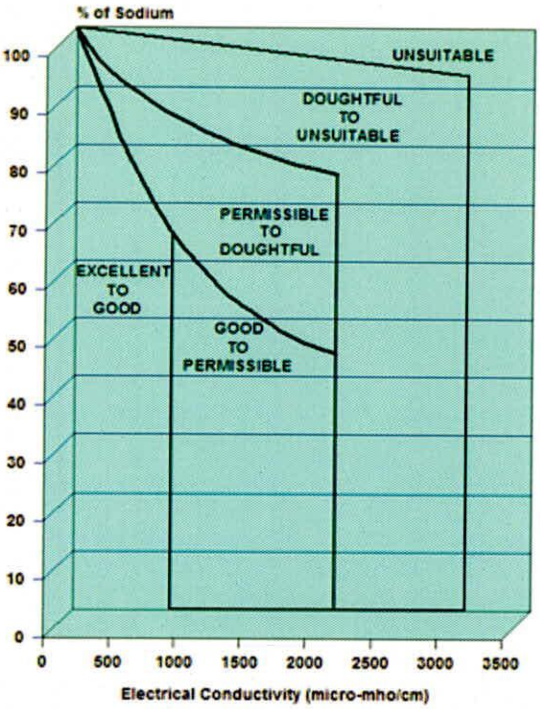


Fig. 2.7 : U.S. Salinity Laboratory Classification

Fig. 2.8 : Wilcox Classification

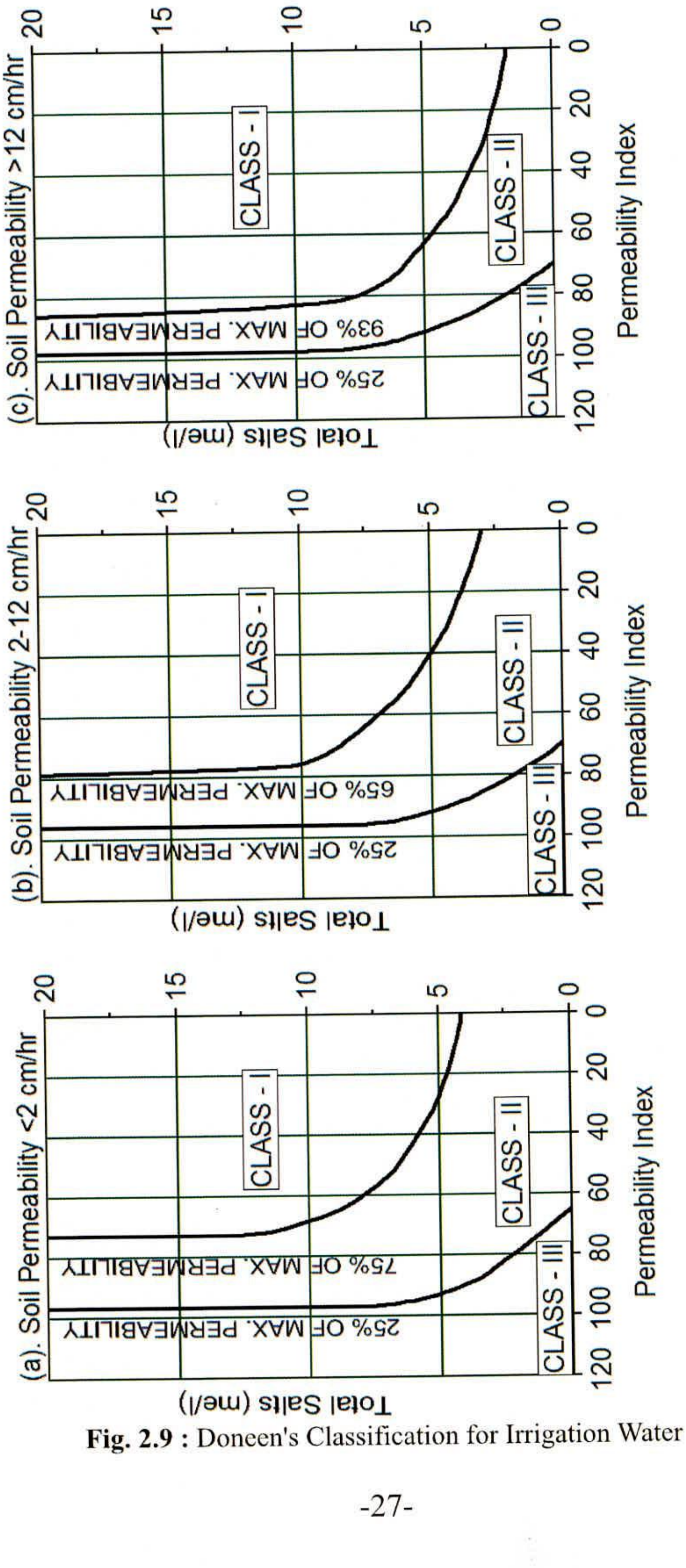


Fig. 2.9 : Doneen's Classification for Irrigation Water

3.0 STUDY AREA AND SAMPLING POINTS

3.1 Agartala for Ground Water Sampling

Agartala is the capital of Tripura. It has got a population of around 2,00,000 inhabitants. Agartala, is bounded between 23°53' - 23°8' N latitudes and 91°15' - 91°25' E longitudes (Fig.3.2). The Howrah River flows along the city's northern periphery. Agartala is situated at a height of 14.50 meters above the sea level. It lies on the Haora River and is located 2 km from Bangladesh. The city is situated in a plain along the Haora River, though the city also extends to the low lying hills on its northern parts.

The climate of Agartala is generally hot and humid. The average maximum temperature is 35 °C in May-June and the average minimum temperature is 10.5 °C in December-January. The average rainfall is around 230 cm/annum. The monsoon starts generally in April and continues upto September. Summer starts in March and continues upto May and is followed by rainy season extending over about three-four months (May-August). The pleasant season lasts only for about two months (September and October). Then follows winter which continues up to February

Agartala is subjected to annual flooding due to its unique physiographic setting and poor drainage conditions within the city. The hill towns generally have localized drainage problems, and suffer from landslips caused by water intrusion in some areas as well as by erosion and bank cutting.

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 area of Agartala. The growth of industries can be termed as haphazard and environmentally unsafe. There is no strict boundary between residential and industrial cum commercial establishments.

3.2 Tezpur for Ground Water Sampling

Tezpur is a hilly town and located on the northern bank of the river Brahmaputra. It has undulated topographical nature. Tezpur is located at 92°47' to 92°49' E longitude and 26°37' to 26°39' N latitude (Fig. 3.3) under Sonitpur district (26°28'- 27°08' N lat. to 92°19'- 93°47' E long.) of upper Assam.

The present boundary of the Tezpur is the river Gabharu in the west, the Brahmaputra in the south, and presently the township is extending upto Dekargaon with the possibility of further expansion towards the north.

Altitude varies from 69 to 76 meters. Region falls within the climatic zone I which comprises North and North East India and adjoining the parts of Nepal, Bangladesh and North Burma.

It has humid sub tropical climate with an average annual rainfall of 1870 mm per year. The rainy season extends from March to October. Nearly 65-70 % of the total rainfall is received during June to Sep. from the south west monsoon.

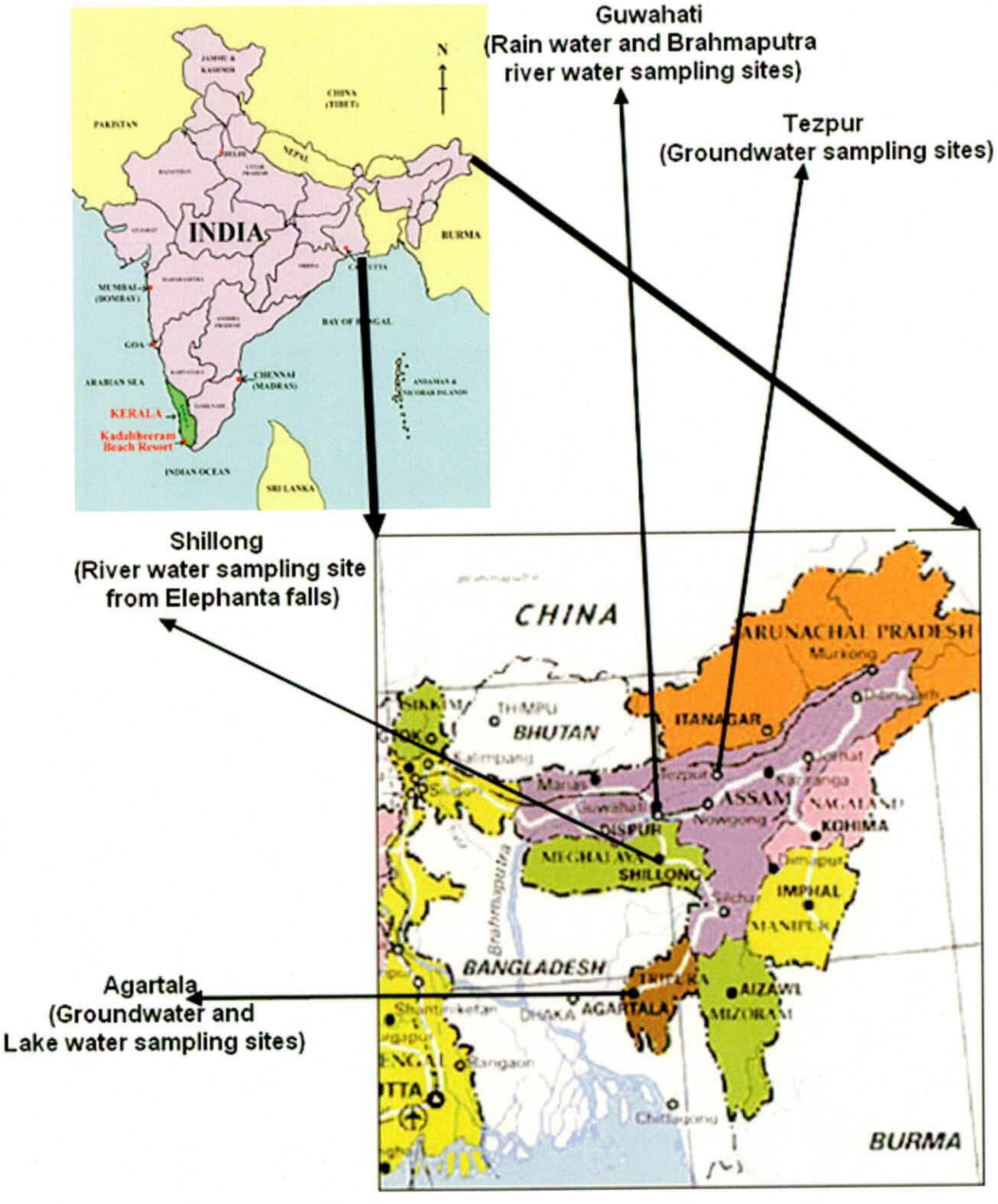
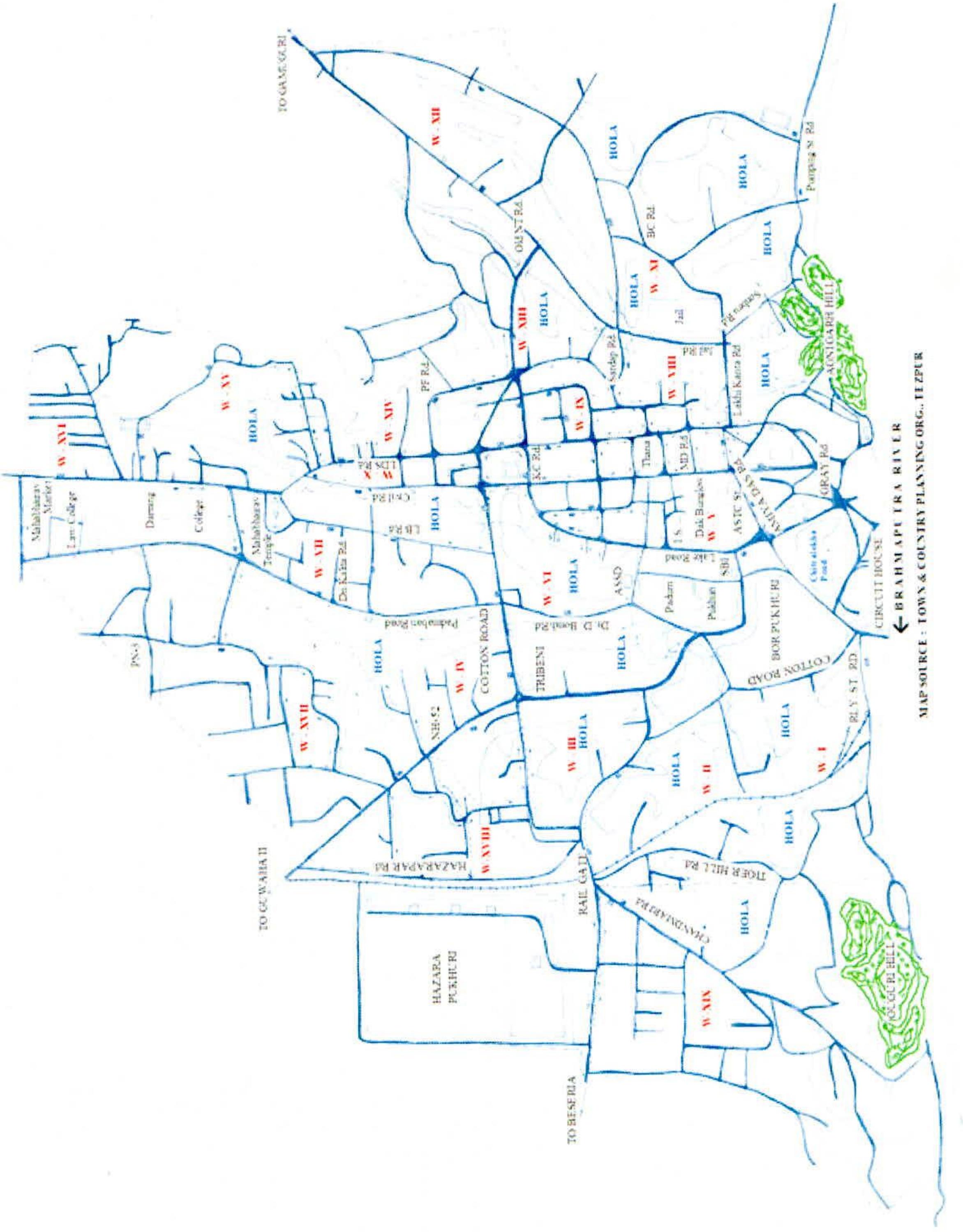


Fig. 3.1 : Sampling point location on NE Map

Fig. 3.2 : Study area map of Agartala



MAP SOURCE : TOWN & COUNTRY PLANNING ORG., TEZPUR

Fig. 3.3 : Study area map of Tezpur

The hottest months of the year are May to July. The cool season is from Nov. to Feb. with the lowest temperature recorded in January. Max. temp. ranges from 25 to 36 °C while the min. ranges from 9 to 24.5 °C. 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.

The humidity of the city is very high. It does not go below 70 %. 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 Gabharu passing through the heart of the city, (3) presence of ponds, marshy land and green hills and (4) bowl shaped topography of the city. Relative humidity percentage is generally lowest in the month of March which varies from 65-70 percentage and the highest is recorded in July Aug. which is above 80 %.

Geology of the area is such that cretaceous sandstones lie on an irregular surface of quartzites and other metamorpliic rocks. The basal bed is conglomerate, embedded with sand followed by glyconitic sands and carbonaceous sandstone which contains plant remains. There is much lateral variation and most of the sand stones are unforsriliferous.

Phytogeographically Tezpur can be divided in to five different zones.

(1) Bank of Brahmaputra river, (2) Hilly areas, (3) Plain land, (4) Low land and (5) Lakes and ponds.

These five zones provide varied microclimatic and ecological conditions.

Variations of mean monthly climatological parameters (temp., relative humidity, ETo, rainfall) in Agartala (ground and lake water sampling site), Tezpur (ground water sampling site), Shillong (river water sampling site) and Guwahati (precipitation network site) are presented through Fig. 3.4, 3.5, 3.6 and 3.7 respectively.

3.3 Rudrasagar National Lake, Agartala for Lake Water Sampling

The Rudrasagar Lake falls in the Melaghar Block under Sonamura Sub-Division in the West Tripura District and at a distance of about 55 km from the state capital of Tripura. Geographically the lake is situated in between 23°29' N and 90°01' E. Rudrasagar is a wetland of national importance identified by the Ministry of Environment and Forest, Government of India, considering its ecological and socio-economic significance. It is a floodplain wetland within Gumti River basin which periodically used to get inundated leading to sustainable fisheries and agriculture development. The drastic reduction of forest cover in the catchment and hydrological intervention by construction of a channel connecting it with Gumti led to shrinkage of the wetland area from 1000 ha prior to 1950s to less than 100 ha at present. Major soil erosion in catchment area of the lake is also one of the key problems to decrease the lake area and to decrease the depth of the lake. Presently, more than half of the lake area has been reclaimed for cultivation of food crops and vegetables. Brick kilns and paddy fields

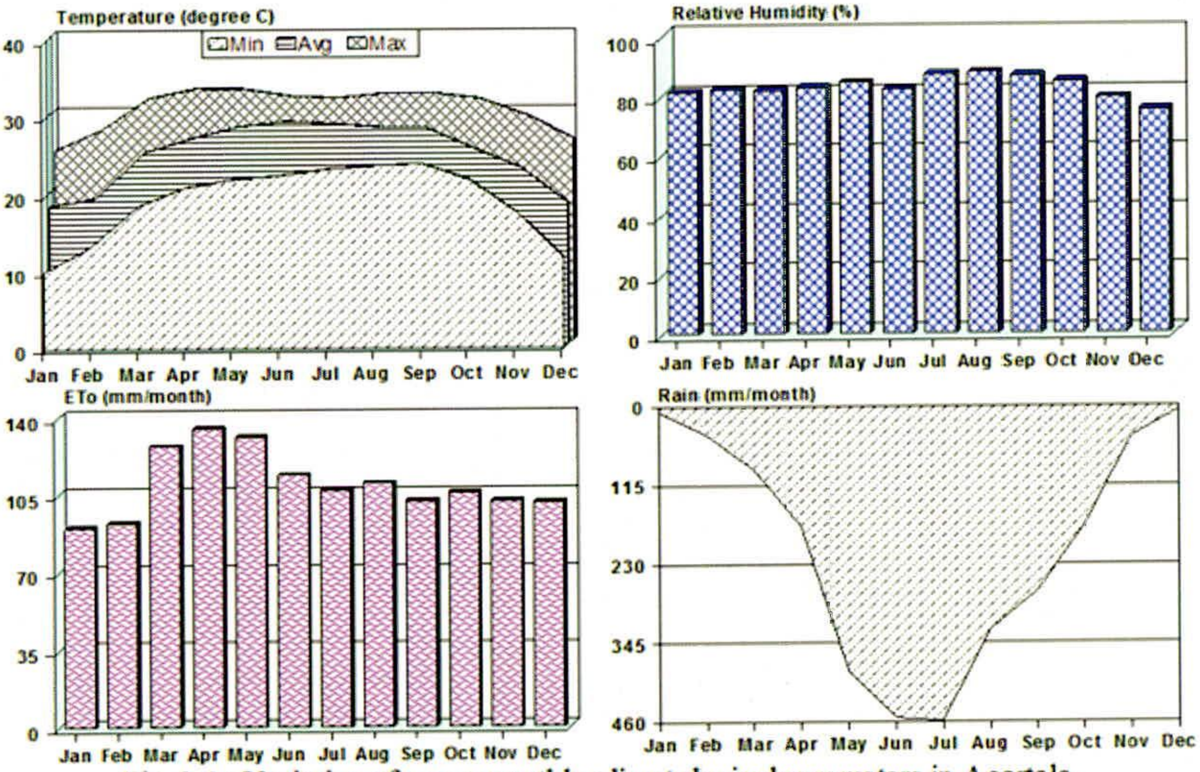


Fig. 3.4 : Variation of mean monthly climatological parameters in Agartala

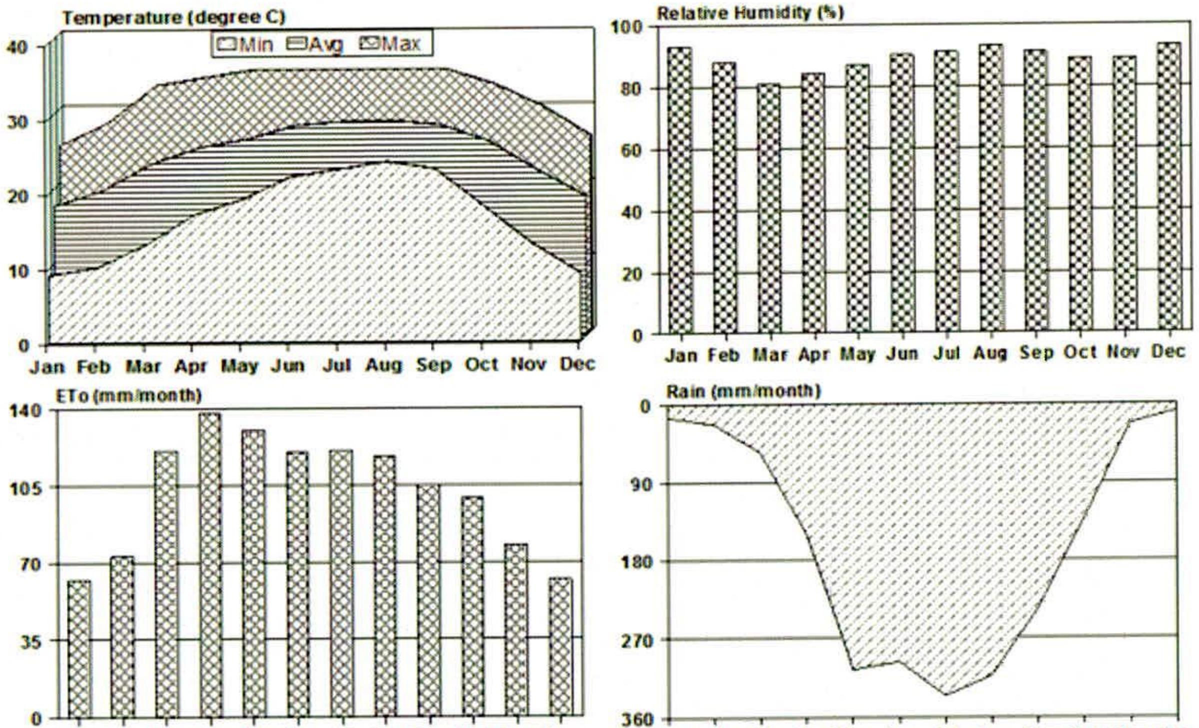


Fig. 3.5 : Variation of mean monthly climatological parameters in Tezpur

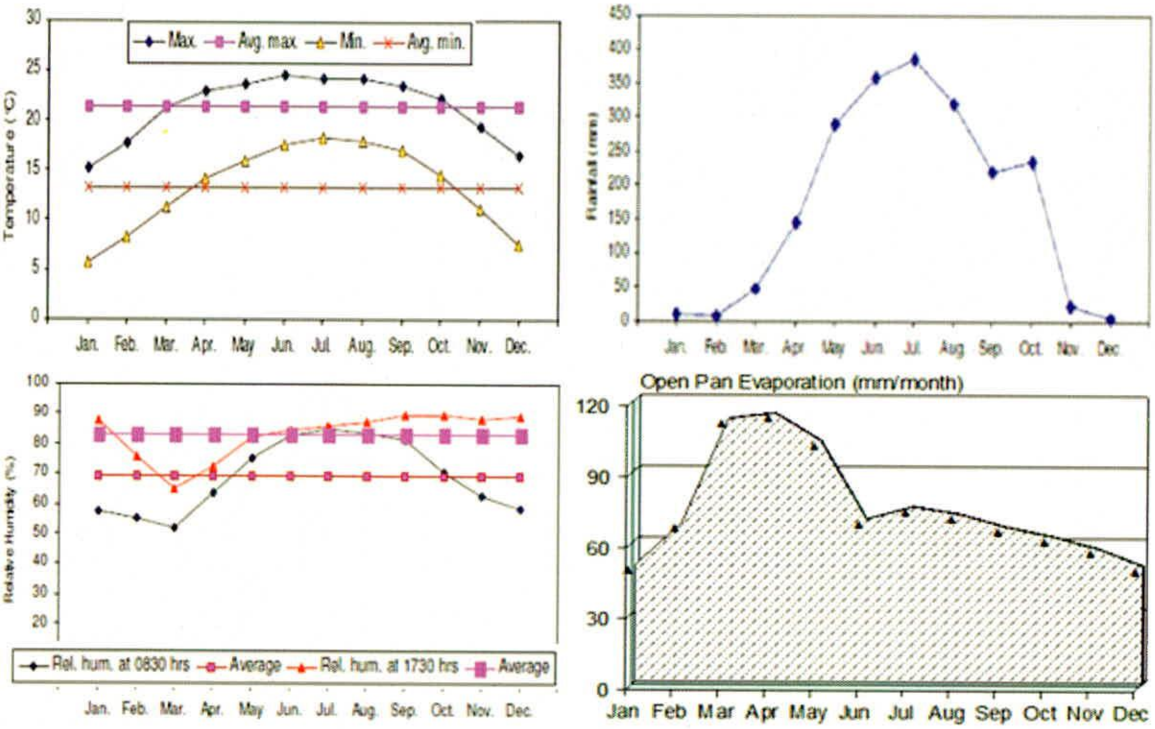


Fig. 3.6 : Variation of mean monthly climatological parameters in Shillong

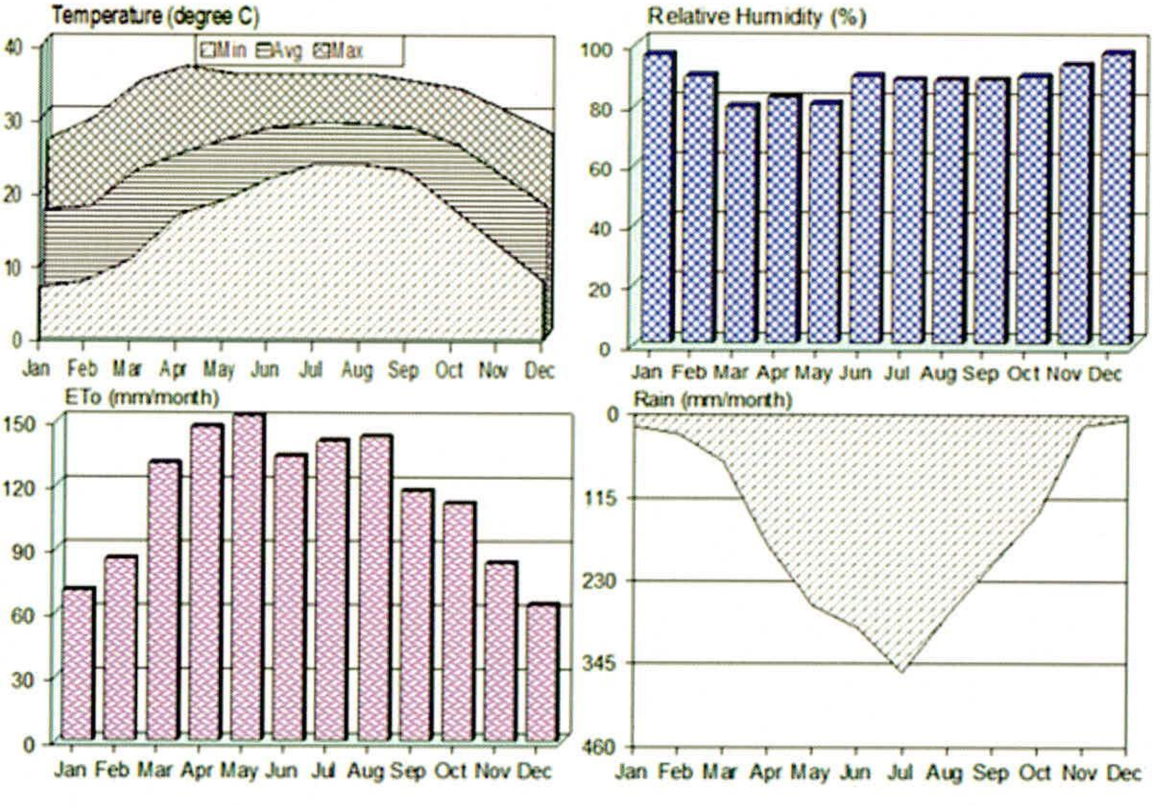


Fig. 3.7 : Variation of mean monthly climatological parameters in Guwahati

have sprung up in the Rudrasagar area. Construction of bunds and embankments within and around the wetland has totally altered its natural hydrological regimes. At present the lake is facing serious anthropogenic threat which is deleterious to the living being sustained therein.

According to the Annual Report (2005-2006) of Ministry of Environment and Forest Govt. of India, Rudrasagar Lake is listed in the *"List of Wetlands Identified Under National Wetland Conservation Programme"* and was mentioned in *"The List of Wetlands of International Importance Under Ramsar Convention (India)"*. Rudrasagar Lake (Ramsar site no. 1572.) was identified as Ramsar site on 08/11/05 at the 'CoP' 09 (Conference of Parties) meeting held at Uganda during 8-15 November, 2005. Secretary General, Convention on Wetlands, Ramsar site has declared and included Rudrasagar Lake as in the list of wetlands of International Importance.

Hydromorphologically, Rudrasagar Lake is a natural sedimentation reservoir, which receives flow from three perennial streams namely, Noacherra, Durlavnaraya cherra and Kemtali cherra. After settling the sediment from the received flow, clear water discharges into the river Gomati through a connective channel namely Kachigang. The lake bed has been formed by silt deposition. As such no rock formation is found with 50m is silt (Clay loam) and below formation is sandy. Surrounding hillocks are of soft sedimentary formation. Owing to high rainfall and downstream topography, the wetland is regularly flooded with 4-5 times annual peak.

Pollution of the lake has faced the problem due to the following reasons (Deka 2010) :

- Point sources of the non-agricultural pollutant run off as such, anthropogenic pollutants introduced solid and semisolid.
- Anthropogenic malpractices such as dumped garbage, deposition of solid waste materials and construction etc. along the shoreline.
- Uncontrolled growth of water hyacinth caused loss of biodiversity.
- Agricultural activity (use of pesticides and fertilizers) in the adjacent to the lake area.
- Deforestation, filling, draining and degradation of wetland areas
- Lack of awareness, scientific knowledge and negligence in protection by law.
- Competition for using lake water such as for drinking, irrigation, fishing, recreation etc.
- Untreated or inadequately treated domestic and industrial effluents from point sources located all over the basin.
- Siltation in the form of cultural immersion of idols.
- Ownership and legal status of the lake and the inhabitants around the lake are not clearly defined.

3.4 Sipahijala Sanctuary Lake, Agartala for Lake Water Sampling

The Sepahijala Wildlife Sanctuary is located around 35kms from Agartala, the capital city of Tripura. The sanctuary was incepted in the year 1987 as a measure to protect the wildlife of the place. The sanctuary covers an area of around 18.53 km^2 and abounds in varied type of vegetation cover.

3.5 Elephanta Falls, Shillong for River Water Sampling

Shillong, the capital of Meghalaya occupies the northern slopes and foothills of Shillong peak at an average an altitude of 1,496 metres above sea level. Out of State's total urban population of 4,52,612 persons, as per 2001 Census, the Shillong Urban Area has a population of 2,67,662 which represents nearly 59 % of the State's urban population. Out of a total urban population of East Khasi Hills district which is 2,77,967, nearly 97 % are residing in Shillong Urban Area.

It is situated on a plateau bound on the north by the Umiam gorge, on the northwest by the great mass of the Diengiei Hills that rise up to a height of 1,823 meters (6,077 ft.) above sea level, and on the northeast by the hills of the Assam valley.

Climate is one of the most important factors of geographical environment to which man is subject to. It governs agriculture, forests, supply of water, human settlements, industries, tourism, etc. The climate of East Khasi Hills District including the Shillong city ranges from temperate in the plateau region to the warmer tropical and subtropical pockets on the Northern and Southern regions.

The months of December and January seems to be the coldest month in the city and the hottest months are June to September when the temperature varies from 23-25 °C.

The city is influenced by the southwest monsoon, which begins generally from May and continues till September. The weather is humid for the major part of the year except for the relatively dry conditions between the months of December and March. The average rainfall of Shillong is 172.3 mm/month as per 2005 monthly rainfall. Moderate rainfall is the result of its location in the rain shadow zone. Of the total rainfall about 2/3rds falls in the months of June to September brought about by the Southwest monsoon winds.

The Elephanta Falls situated on Umdiengpun River is located at a distance of 12 km from Shillong town. Elephanta falls was called *"Ka Kshaid Lai Pateng Khohsiew"* meaning three steps waterfalls in the local Khasi language. The British later named it Elephanta falls because of the huge elephant like rock near to this fall.

3.6 The Brahamputra River Basin and Precipitation Sampling Site, Guwahati

The Brahamputra river originates in a great glacier mass in the Kails range of the Himalayas south of lake Gunkund in south-west Tibet and running eastward through Tibetan Plateau of China as the Yalutsangpo for about 1,700 km parallel to the main Himalaya. The river enters into India as the Siang-Dihang and flow through the valley of Assam as the Brahamputra for about 720 km before entering Bangladesh to join the Ganga river. The river has eight significant tributaries in India. These are Manas, Kamerg or Jia Bharali, Subansiri, Dibang, Lohit, Buri Dihing, Tista, Jaldhaka. The catchment of Brahamputra occupies an area of about 5,80,000 km^2 out of which 2,93,000 km^2 in Tibet

(China), 2,40,000 km^2 in India & Bhutan and 47,000 km^2 in Bangladesh. The Brahamputra has highest discharge of all rivers in the India and it is a severe flood prone river in the north-east.

The river Brahamputra is divided in three parts as upper reach (from its origin to Indo-China border), middle reach (from Indo-China border to Indo-Bangla border) and lower reach (from Indo-Bangla border to its outfall in Bay of Bengal). The upper part of Brahamputra river passes from the Trans- Himalayan of Tibet, Greater Himalayas, the Lesser Himalaya and Sub- Himalayan ranges. The Trans-Himalayan is made up of sedimentary formations, the Greater Himalayan consist of granites and gneisses. The Lesser Himalayan ranges are made up of shales, slates and phyllites and basaltic rocks. The lower most ranges called sub-Himalayas consist of mainly sand-stones. The precipitation sampling is being done from a site located near Guwahati (Lat. 26^{0}11' N Long. 91^{0}47' E) in the north-eastern part of India.

All sampling point location on North East Region map of India is shown in Fig. 3.1.

4.0 MATERIALS AND METHODS

Site Selection

The factors, identified for proper selection of ground water sampling sites within Agartala and Tezpur area 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 & 4.2 and Fig. 4.1 to 4.4). The ground water quality survey locations were chosen (dug/open wells, tube well, bore well etc.) so that they depict the influence (if any) of the prevailing anthropogenic activity as well as industrial activity of the study area.

Sampling and Preservation

Ground water sampling and testing were done as per the guidelines of APHA (1995). Samples were collected from one of the following three types of wells: i) *Open dug wells* in use for domestic or irrigation water supply, ii) *Tube wells* fitted with a hand pump or a power-driven pump for domestic water supply or irrigation; iii) *Hand Pumps,* used for drinking. Open dug wells, which are not in use or have been abandoned, were not used for sampling. Samples from the production tube were collected after running the well for about 10 minutes. Water samples from dug wells were collected by grab sampling method using standard water sampler (Hydro Bios, Germany). The water samples collected were stored in pre cleaned polyethylene bottles and preserved by adding an appropriate reagent as per standard procedures (APHA-1995). The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra pure nitric acid (2ml/lit.)

While collecting the samples, the depth of water in the wells was also measured. Samples were collected in clean polyethylene bottles fitted with screw caps. Some physical parameters like temperature, pH, conductivity, were measured at the spot by means of portable water testing kits.

For determination of stable environmental isotopes, sampling was done as per the method described in the review section. The isotopic analyses (δ^2H, $\delta^{18}O$) of the water samples were carried out at the Nuclear Hydrology Laboratory of the National Institute of Hydrology (NIH), Roorkee, using Dual Inlet Isotope Ratio Mass Spectrometer (DIIRMS), for δ^2H measurements, and Continuous Flow Isotope Ratio Mass Spectrometer (CFIRMS), for $\delta^{18}O$ measurements. The ^2H and $\delta^{18}O$ were measured by Pt-H_2 and CO_2 equilibration methods, respectively, following the standard procedure [Epstein and Mayeda, 1953; Brenninkmeijer and Morrison, 1987]. To determine δ^2H and $\delta^{18}O$, a three point calibration equation was used with the isotopic water standards VSMOW, GISP, and standard light arctic precipitation obtained from the IAEA (precision is ±1.0‰ and ±0.1‰ for δ^2H and $\delta^{18}O$, respectively). Due care was taken for having isotopic analytical results of water samples analyzed with CFIRMS and DIIRMS comparable using the measured values of $\delta^{18}O$ secondary standards with DIIRMS.

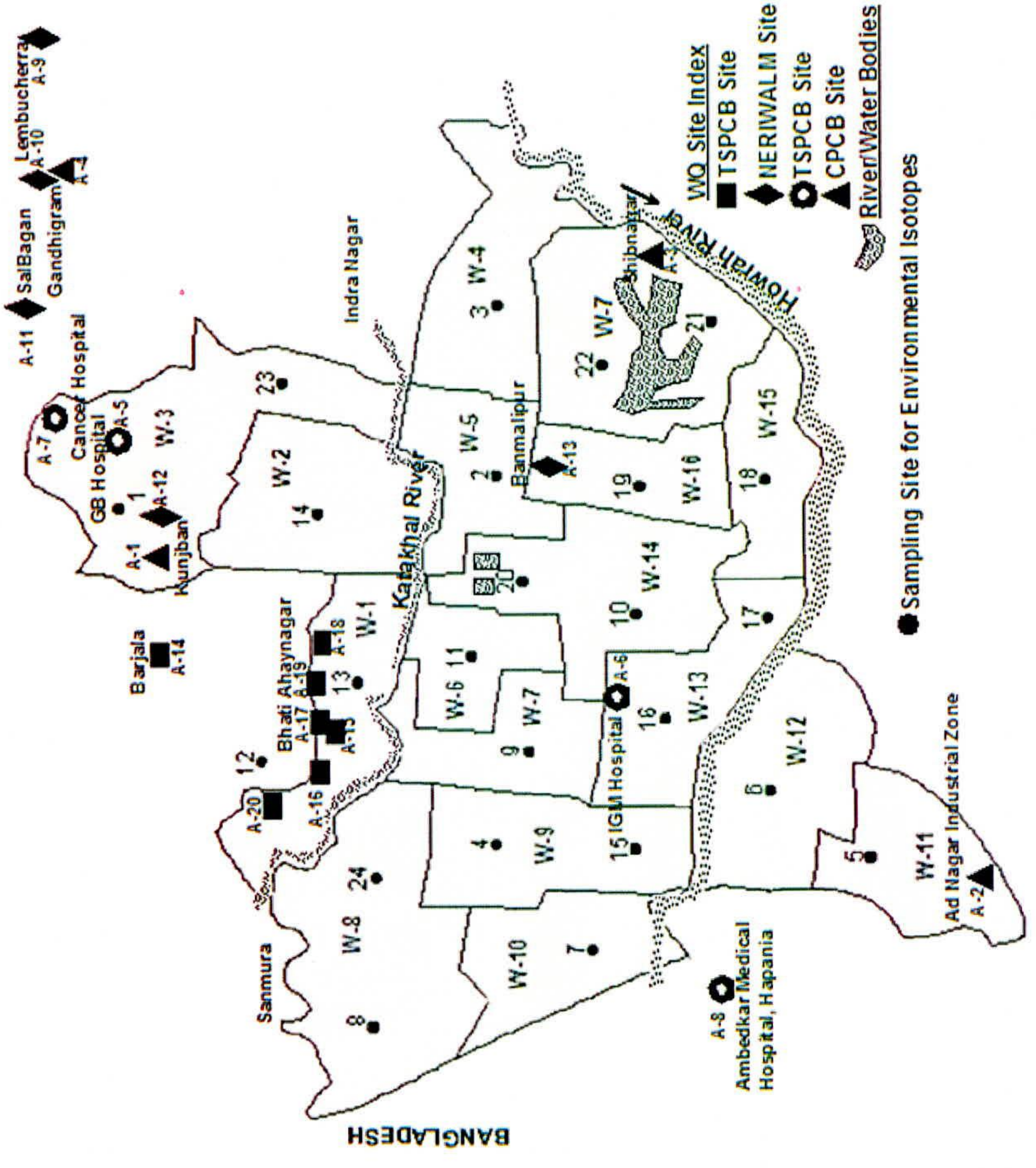


Fig. 4.1 : Map showing ward wise(W-1 to W-17) sampling sites in Agartala for environmental stable isotopes of hydrogen and oxygen

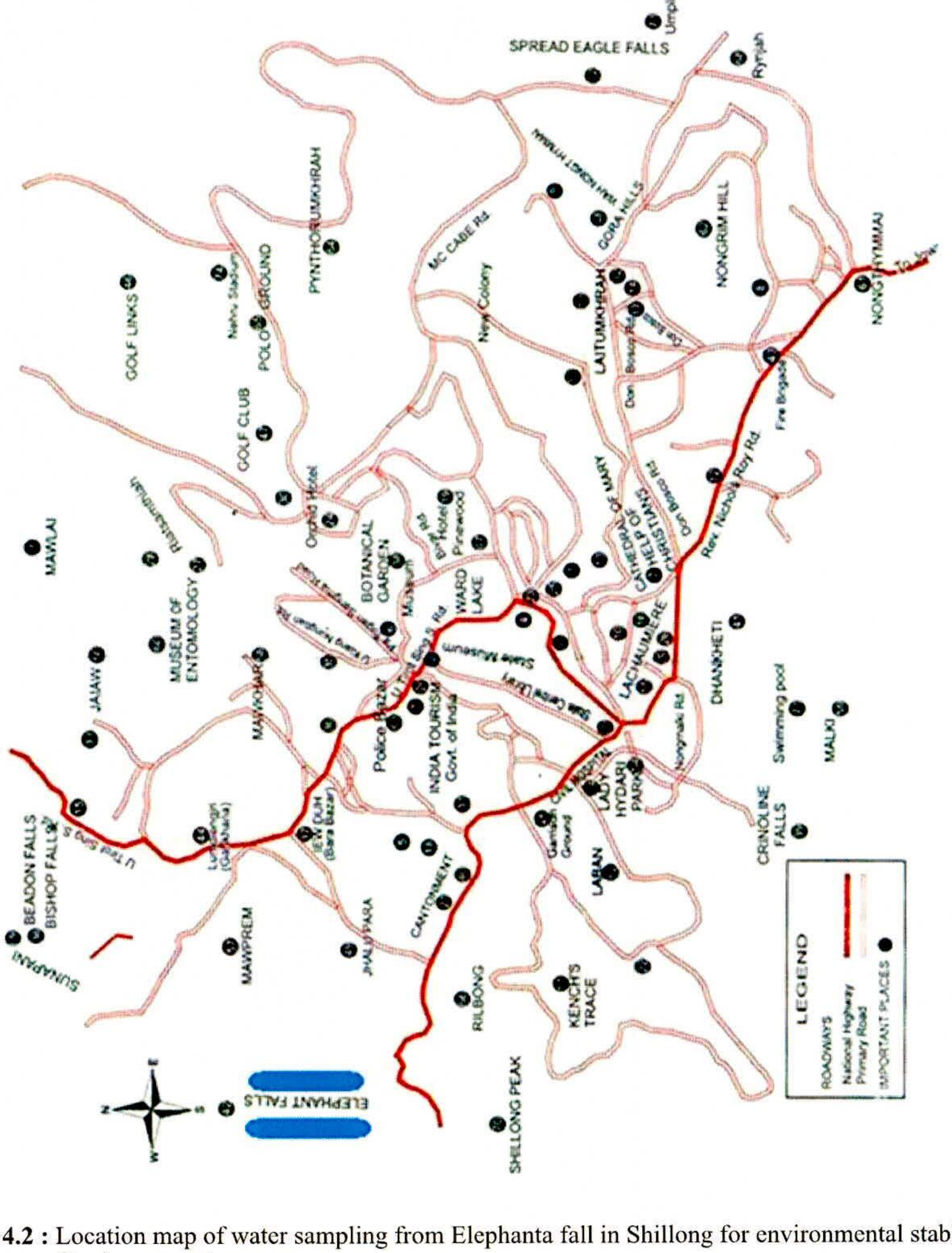


Fig. 4.2 : Location map of water sampling from Elephanta fall in Shillong for environmental stable isotopes of hydrogen and oxygen

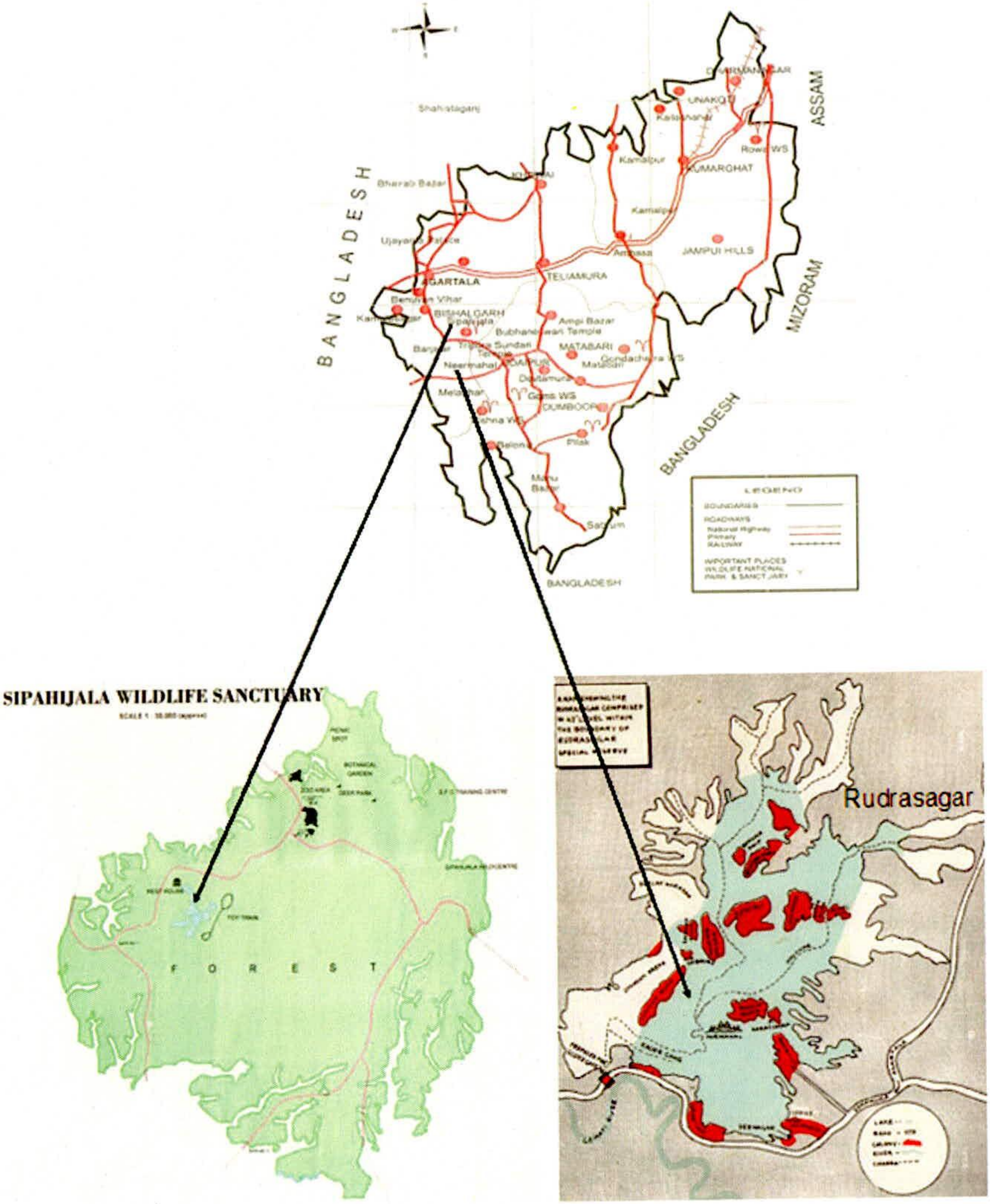


Fig. 4.3 : Location map of water sampling in Rudrasagar lake and Sipahijala lake for environmental stable isotopes of hydrogen and oxygen

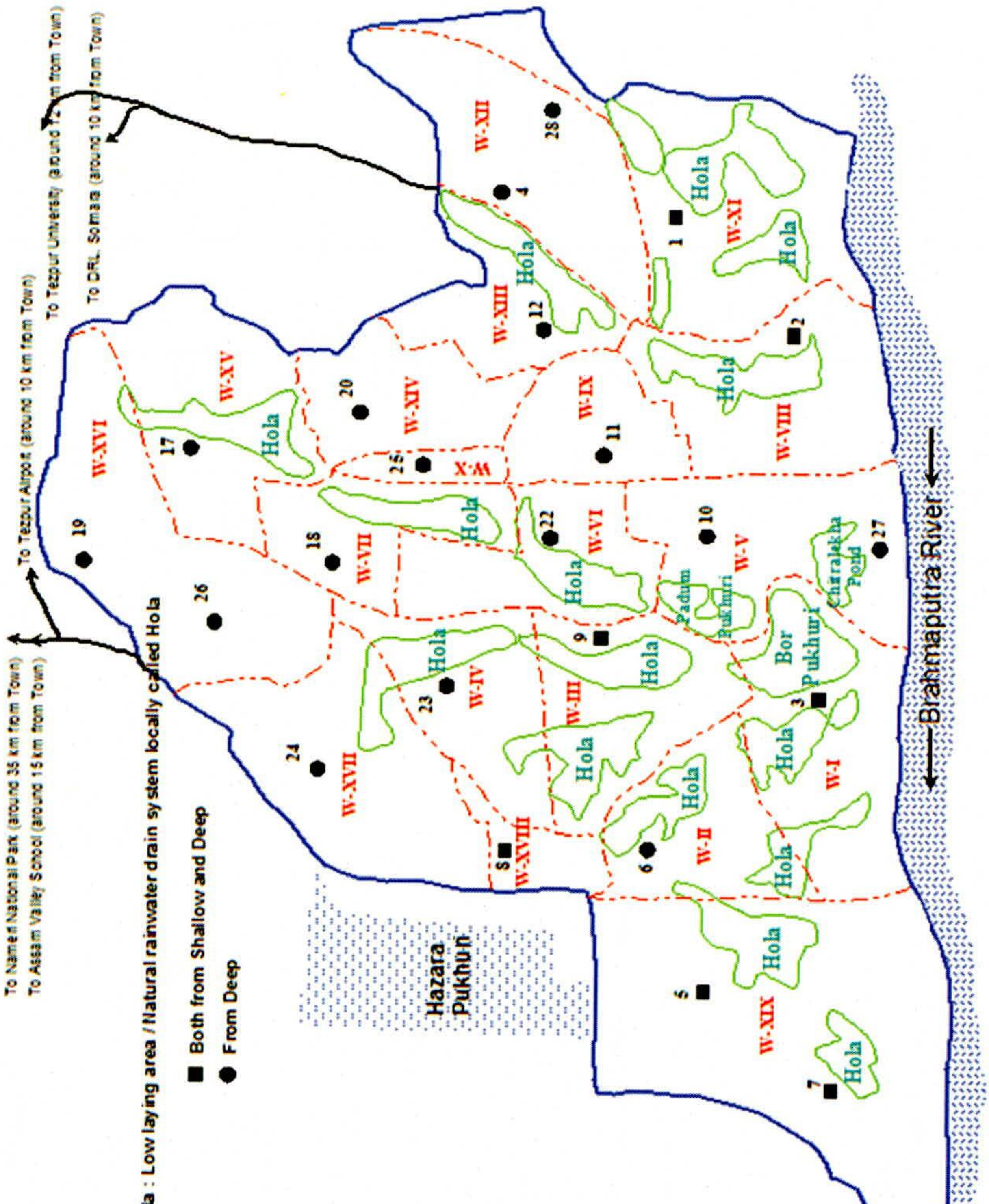


Fig. 4.4 : Map showing ward wise (W-1 to W-19) sampling sites in Tezpur for environmental stable isotopes of hydrogen and oxygen

5.0 RESULTS AND DISCUSSION

5.1 Physical and Chemical Characteristics of Ground Water of Agartala and Tezpur

In the present study, ground water quality data (mainly : temperature, pH, EC, TDS, DO, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, alkalinity, HCO^{-}_{3}, Cl^{-}, SO^{2-}_{4}, NO^{2-}_{3}, PO^{2-}_{4}, hardness, trace elements etc.) of Agartala and Tezpur have been evaluated for different uses. In-situ measurements of temperature, pH and EC were made using portable instruments. Standard Water Sampler was used for grab sampling from dug wells. The water quality of the Agartala city has been evaluated based on the data of NERIWALM, CPCB and TSPCB. Quality of ground water was evaluated for drinking and other purpose on the basis of the available standards like BIS, WHO etc.

pH : BIS desirable limit of pH is 6.5 to 8.5. Overall variation of pH was found in Agartala is from 4.3 to 8.25 (Table 5.1 and 5.3) and Tezpur from 6.3 to 7.3 (Table 5.4). The results show that water quality of Agartala (with average pH of 6.06) is skewed towards the acidic nature. But the water quality of Tezpur (with average pH is 6.82) is within to the recommended value of BIS. Lower values of pH (towards acidic) in Agartala was seen nearby the areas of AD Nagar (south Agartala) and Salbagan area. AD Nagar is the industrial zone of Agartala, which clearly indicates anthropogenic activities. Geogenic factors may be the region for lower pH of ground waters in other parts of Agartala.

Conductivity : 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 of Agartala varies from 70-570 µ-mho/cm with an average value of 207 µ-mho/cm. In Tezpur, range of conductivity value in ground water is 90-440 µ-mho/cm with an average value of 210 µ-mho/cm.

Alkalinity : The presence of carbonates, bicarbonates and hydroxides is the most common cause of alkalinity in natural waters. The alkalinity values in the study area of Agartala vary from 15.40 to 160 mg/l with an average value of 79.42 mg/l. For Tezpur area, variation of Alkalinity is found from 40 to 170 mg/l with an average value of 84 mg/l.

DO : Value of dissolved oxygen in the water indicates the low residual of biological available organic materials. In ground water of Agartala, the DO was found in the range of 0.2 to 6.33 mg/l with an average value of 2.25 mg/l. In Tezpur, DO was found in the range of 1-8.9 mg/l with an average value of 4.1mg/l. BIS limit of DO is of 6.0 mg/l.

Sodium : Sodium concentration more than 50 mg/l makes the water unsuitable for domestic use. The sodium concentration in the ground water of Agartala varies 1.0 to 75.83 mg/l. In Tezpur area the concentration of sodium was found in the range of 4.31 to 75.0 mg/l. Average value of Sodium in Agartala and Tezpur area is found 26.9 and 23.25 mg/l respectively.

Calcium, Magnesium and Total Hardness : Calcium, Magnesium and Total Hardness in the water are inter related and hence combined in the description. As per BIS, the upper limits for calcium and magnesium for drinking water and domestic use are 75 and 30 mg/l respectively. Calcium and magnesium content in ground water of Agartala and Tezpur were found below the permissible limit in all the sampling sites.

Calcium and Magnesium along with their carbonates, sulphates and chlorides make the water hard, both temporarily and permanent. BIS has recommended a limit of 300 mg/l for potable waters. In ground water of Agartala total hardness as $CaCO_3$ ranges between 9.04 to 133.30 mg/l. In Tezpur area, total hardness as $CaCO_3$ varies between 24-148 mg/l.

Non Carbonate Hardness was calculated by following formula and presented in Table 5.8 :

$$NCH\ (ppm) = [(epm\ of\ Ca^{2+} + epm\ of\ Mg^{2+})\ \ (epm\ of\ CO^{2-}_3 + epm\ of\ HCO^{-}_3)] * 50$$

When the difference is negative NCH = 0.

Bicarbonate : Bicarbonate is the dominant anion, followed by chloride and sulfate. Bicarbonate in the study area of Agartala and Tezpur ranges from 18.79 to 195.25 mg/l and 48.77 to 207.29 mg/l respectively.

Chloride : Chloride concentration of the ground water samples in the study area is varying from 2.45 to 24.5 mg/l for Agartala and 8.86 to 53.17 mg/l for Tezpur. A limit of 250 mg/l chloride has been recommended by BIS and WHO for drinking water purpose.

Sulphate : Sulphate concentration when exceeds more than 200 mg/l causes a bitter taste in drinking water. Sulphate content in ground water of Agartala and Tezpur area varies in between 7.1 to 83.37 mg/l and 1.2 to 8.5 mg/l respectively (within permissible limit of BIS).

Nitrate : Nitrates in drinking water as such are not toxic to health and about 85% of ingested nitrates are rapidly adsorbed from gastrointestinal tract in normal healthy individuals and adsorbed nitrates are excreted by the kidneys. But, if the nitrates are converted into nitrites which occur commonly, then toxic effects are encountered and may cause potential health hazards. Drinking water standard (BIS) for nitrate is 45 mg/l. Nitrate was found much below the permissible limit in all the sampling sites of Agartala and Tezpur area. Its concentration above 45 mg/l in drinking water may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants.

Phosphate : Phosphate enters ground water from several sources like detergents, food processing industries, agriculture infiltration from fields where fertilizers have been used. In Agartala, PO^{2-}_4 varies from 0.0 to 0.10 mg/l. In Tezpur, it varies from 0.32 to 1.37 mg/l. It is evident that the concentration of phosphate in Tezpur area is higher side as compared to Agartala.

Iron : Water containing ferrous iron is clear and colorless because the iron is completely dissolved. When exposed to air, the water turns cloudy due to oxidation of ferrous iron into reddish brown ferric oxide. The concentration of iron in natural water is controlled by both physico chemical and microbiological factors. It is contributed to ground water mainly from weathering of ferruginous minerals of igneous rocks such as hematite, magnetite and sulphide ores of sedimentary and metamorphic rocks.

Water containing iron does not show deleterious effect on human health, its presence in drinking water is objectionable for various reasons. Excessive iron content makes the water turbid, discoloured and imparts an astringent taste to water. As per the standards set by BIS, the permissible level of iron is 0.3 mg/l. Above 1.0 mg/l of iron in drinking water is not considered to be suitable for drinking purposes. In Agartala, the amount of iron in ground water is relatively very high as compared to Tezpur. In ground water of Agartala, iron concentration was found in the range of 0.01-19.28 mg/l. While in Tezpur, iron concentration was observed in the range of 0.04 to 5.73 mg/l.

In concentrations exceeding 1-2 mg/l, iron appreciably affects the taste of beverages, while precipitation of iron salts on the food products, on fabrics, paper etc. affects the quality of these products and also increased cost of water treatment for drinking purpose.

Heavy Metals : The result shows that concentration of lead, nickel and cadmium in ground water of Tezpur are within BIS permissible limit (<0.05 mg/l). In Agartala, copper, manganese and zinc were also tested for their concentration in ground water. In Agartala concentration of lead, nickel, cadmium, copper, manganese and zinc were observed in the range of (0.001-0.69), (0.01-0.43), (0.001-0.096), (0.0-0.096), (0.02-9.8) and (0.02-5.71) respectively.

Results related to physical, chemical and heavy metals are presented through Table no. 5.1 to 5.5 and Fig. 5.1 to 5.10.

Larson-Skold Corrosivity Index : The Larson-Skold Index, sometimes called the Larson Ratio and defined as (Christian 2008) :

$$\text{Larson-Skold Index} = (\text{epm Cl}^- + \text{epm SO}^{2-}_4)/(\text{epm HCO}^-_3 + \text{epm CO}^{2-}_3)$$

Corrosion is an electrolytic process that takes place on the surface of the metal, which severely attacks and corrodes away the metal surfaces. Most of the problems are associated with salinity and encrustation problems. The Larson-Skold index describes the corrosivity of water towards mild steel. Water samples having corrosivity ratio less than 0.8 is considered to be noncorrosive, while the index value between 0.8 to 1.2 is to be considered as moderate corrosive nature. Water with Larson-Skold Index greater than 1.2 shows a tendency towards high corrosion rates. In the present study, most of the water samples have corrosivity index less than 0.8 and within the permissible limits except one sample of Agartala from the site no. A-21 (Table 5.8).

5.2 Graphical Presentation and Classification of Ground Water

Collin's Bar Diagram : Collin's bar graphs on the basis of total anions and cations as found in the ground water samples of Agartala and Tezpur area, have been plotted to represent concentration of different ions (in milli-equivalent/l) and shown through Fig. 5.11 to 5.13.

Stiff Pattern Diagram : Chemical analysis data of all the samples of Agartala and Tezpur have been studied using stiff classification and the results of the same have been presented through Fig. 5.14 to 5.16 and Table 5.6.

Piper's Trilinear Diagram : By classifying samples on the piper diagram, one can identify geologic units with chemically similar water. Noisy data can also be smoothened before plotting on a map or cross section. In the present study results of Agartala and Tezpur on Piper's trilinear diagram are shown in Fig. 5.17 and related classifications are presented in Table 5.6 against each sampling site.

Back's Classification : In this classification, samples are classified according to facies with two templates for the Piper diagram. According to Back's (1961) classification majority of the ground water samples of Agartala fall in two main facies i.e. $Ca^{2+}+Mg^{2+}+Na^{+}$ $HCO^{-}_{3}+Cl^{-}+SO^{2-}_{4}$ and $Na^{-}+Ca^{2+}+Mg^{2+}$ - $HCO^{-}_{3}+Cl^{-}+SO^{2-}_{4}$. While in Tezpur, majority of samples fall in the facies of $Ca^{2+}+Mg^{2+}$ - HCO^{-}_{3} and $Ca^{2+}+Mg^{2+}+Na^{-}$ - $HCO^{-}_{3}+Cl^{-}+SO^{2-}_{4}$ (Fig. 5.18-5.19 and Table 5.6).

Durov's Double Triangular Diagram : In the present study, Durov's double triangular diagram has also been used to classify the ground water of Agartala and Tezpur. Results are shown in Fig. 5.20 and Table 5.6.

Gibbs' Diagram : The mechanism controlling chemical relationships of ground water based on aquifer lithology has been studied following Gibbs (1970). In the present study, Gibbs variation diagram (Fig. 5.21) also used to study the mechanisms of controlling the chemistry of ground water. The ratios of (1) $[(Na^{+}+K^{+})/(Na^{+}+K^{+}+Ca^{2+})]$ and (2) $[Cl^{-}/(Cl^{-}+HCO^{-}_{3})$ have been plotted against TDS. It is observed that the density of distribution of the points is confined to rock dominance field (Table 5.6).

5.3 Water Quality Evaluation and Classification for Irrigation Purpose

Kelley's Ratio : It is seen from Table 5.7 that Kelley's ratio when calculated for ground water of Tezpur, it varies from 0.01 to 0.83. As mentioned earlier, the Kelley's ratio of the ground water of Tezpur is remain less then unity, indicating that the water is suitable for irrigation and free from salinity hazard. For Agartala, it varies from 0.02 to 69.96. Kelly's ratio more than unity is not suitable for irrigation purpose due to salinity hazard.

Sodium Adsorption Ratio (SAR) and Adjusted SAR : The SAR values of the ground water of Tezpur area fluctuated from 0.01 to 1.81 with the average value of 0.36 (Table 5.7).

Ayers and Branson (1975) have suggested that the SAR (adjusted) will be a useful parameter to determine sodium hazards which can be calculated by the following formula:

$$\text{SAR (adjusted)} = \text{SAR}\,[\,1 + (\,8.4 - \text{pH}_c)]$$

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

$$\text{pH}_c = (\text{pK}'_2 - \text{pK}'_c) + \text{p(Alkalinity)} + \text{p}(\text{Ca}^{2+} + \text{Mg}^{2+})$$

$(\text{pK}'_2 - \text{pK}'_c)$ is essentially obtained from Ca^{2+}, Mg^{2+}, and Na^+ ion concentration (in epm), p(Alkalinity) is obtained from the carbonate and bicarbonate concentration (in epm), and $\text{p}(\text{Ca}^{2+} + \text{Mg}^{2+})$ is obtained from the concentration of these ions in epm.

It is seen from Table 5.7 that the value of SAR (adjusted) for Tezpur area varies from 0.02 to 3.38 and the average value is 0.52. Variation of SAR values in the ground water of Agartala is found from 0.04 to 21.23 with the average of 3.09 (Table 5.7). While values of SAR (adjusted) varies from -1.08 to 6.67 with the average value of 1.54. Values of pH_c above 8.4 indicate a tendency to dissolve lime from the soil through which the water moves: water below 8.4 indicates a tendency to precipitate lime from the water applied.

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 from Agartala and Tezpur areas are shown in the self explained Fig. 5.22.

A yers and Branson (1975) have suggested that if the value of SAR (adjusted) is less then 3, the ground water have no problem pertaining to sodium adsorption.

Note : Temperature Correction to Conductivity in USSL Diagram - *Conductivity is greatly influenced by temperature. Most fluids increase in conductivity as temperature increases. Most ionic solutions will increase about 2% for each 1°C increase. Unfortunately, this temperature coefficient (TC) is not linear. In the case of high resistance water it can be closer to 5 % or so per °C. Many instruments adjust the conductivity value based on a TC and display a value that is said to be corrected or normalized to 25 °C. The meter will automatically make corrections to the reading and display a value as if the sample was 25 °C, no matter what the actual temperature is. Some instruments use a fixed TC of 2 % per °C. Although conductivity cell response is immediate, temperature corrected values will fluctuate as the temperature measurement stabilizes.*

(In the present case conductivity was measured with instrument having auto temperature compensate (ATC) facility, which produced the results equivalent to 25 °C. Hence there is no need to normalize the measured conductivity values to 25 °C.)

Residual Sodium Carbonate (RSC) : To evaluate the bicarbonate hazards, "Residual Sodium Carbonate" values after Eaton (1950), have been calculated and presented in Table 5.7. In the ground water of Agartala and Tezpur areas, the value of RSC varies from -1.06 to +0.44 epm and -2.11 to +3.15epm respectively (Table 5.7).

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 value lies between 1.25 to 2.50 epm and bad if RSC >2.50 epm.

Magnesium Hazard : In the present case, it may be mentioned here that most of the samples of Agartala and Tezpur areas, Mg Hazard Ratio exceeds to 50 % (Table 5.7), indicating that suitable measures have to be taken to avoid Mg hazard.

Soluble Sodium Percent (SSP) or Na% (Wilcox classification) : Classification scheme of Wilcox (1948) is applied to the ground water of Agartala and Tezpur area, and shown through Table 5.7 and Fig. 5.23. According to this classification criteria, maximum samples of Agartala and Tezpur area fall under "excellent to good" criteria.

Doneen's Permeability Index : Classification scheme of Doneen is applied to the ground water of Agartala and Tezpur area and presented in Table 5.7 and Fig. 5.24. From the result it is found that maximum samples fall under class-II and class-III category.

Chloride Tolerance : It is observed from the Table 5.3 & 5.4 that, chloride concentration of ground water varies from 0.25 1.5 meq/l for Tezpur and 0.07 to 0.69 meq/l for Agartala. 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 purpose from chloride toxicity point of view.

Total Concentration of Soluble Salts (TDS) : Overall TDS values for both the study area i.e. Agartala and Tezpur are found in the range of 40 to 440 mg/l. It means ground water samples of the study area fall under low to medium salinity zone and is free from high salinity zone water. High salinity zone water cannot 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.

5.4 Sampling well and ground water level related information

From the observation it can be seen that fluctuation of ground water level in the study area varied between 40 to 400 ft (BGL) for Agartala and 5 to 40 ft (BGL) for Tezpur. Fig. 5.25 and 5.27 show the condition of ground water level with respect to different sampling sites in Agartala and Tezpur area.

While computing the different physical, chemical, trace elements and isotope results related to ground water of Agartala and Tezpur area, information related to sampling wells of the study area were also analyzed like age of wells, type of wells, ground water depth during sampling, no. of persons using the well water, type of use like domestic, drinking, bathing, cooking etc. These information are presented through Fig. 5.25 to 5.32. By observing these figures one can easily understand the properties of sampling well related information within the study area. This information may be used to correlate with other water quality parameters of Agartala and Tezpur area in future if proper data set will be made available. Information is also projected using thematic maps for Agartala and Tezpur area.

5.5 Radar Diagram to show the Variation of Oxygen and Hydrogen Isotopes

Radar Chart is the clock face form of a line chart. It represents each data series as a line around a central point. The category (x) variable is plotted at equally spaced points around the clock. The (y) variable is plotted as a radius, so each category has its own y-axis radiating from the center.

Some scenarios where radar chart type could be used

- When we want to compare the aggregate values of a number of data series.
- Graphically display the differences between actual and ideal performance, thereby using this chart to define performance and identifying strengths and weaknesses.
- This is also an ideal chart to use when the categories have a natural cyclic order, for example, seasons of the year.

Radar charts supports plotting the axis values in the reverse direction / clockwise direction also.

In the present study site specific variation of oxygen and hydrogen isotopes are presented through Fig. 5.33 and 5.35 in radar diagram for Agartala and Tezpur area respectively.

5.6 Environmental Stable Isotopes of Hydrogen and Oxygen

A comprehensive set of measurements of oxygen and hydrogen isotopic ratios in ground waters as well as waters from river, lakes and precipitation taken from a variety of locations in North East Region of India has been carried out for the first time.

For determination of environmental stable isotopes of Hydrogen (d^2H ‰) and Oxygen ($d^{18}O$ ‰), 24 ground water samples from Agartala city in Tripura state and 38 water samples (shallow and deep) from Tezpur city in Assam state were collected from different ground water sources like open dug wells, tube wells, hand pumps etc.

Surface Water (River and Lake)

Relative isotopic ratios reported as $\delta^{18}O$ and δ^2H for water from the Elephanta Falls situated on Umdiengpun river of Meghalaya were found -6.61 and -48.29 permil respectively (Table 5.1). The values of $d^{18}O$ and δ^2H for water from the Rudrasagar National Lake, Agartala found as -3.35 and -21.66

permil respectively. The values of $\delta^{18}O$ and $\delta^{2}H$ for water from Sepahijala Sanctuary lake, Agartala were found -2.20 and -21.35 permil respectively (Table 5.1).

Ground Water for Agartala

This report presents relative stable isotopic ratios of hydrogen and oxygen (reported as $\delta^{18}O$ ‰ and $\delta^{2}H$ ‰, respectively) in water from 24 ground-water sites and 2 surface water near the Agartala. The two surface-water sites and 24 ground-water sites were sampled in 2006.

Relative isotopic ratios reported as $\delta^{18}O$ and $\delta^{2}H$ for water from the 24 ground-water sites ranged from -4.85 to -3.43 permil and from -32.99 to -21.00 permil, respectively (Table 5.1).

Ground Water for Tezpur (Shallow)

The Tezpur ground waters as sampled from shallow open dug wells have stable oxygen and hydrogen isotope ratios ranging from -5.95 to -3.24 ‰ & –37.22 to –22.33 ‰, (Table 5.2(a)) respectively.

Ground Water for Tezpur (Deep)

Relative isotopic ratios reported as $\delta^{18}O$ ‰ and $\delta^{2}H$ ‰, for water from the 10 ground water sites ranged from -5.55 to -3.29 ‰ and -37.36 to -25.24 ‰, respectively (Table 5.2(a)).

Rain Water

Deuterium and oxygen-18 have also been studied extensively in precipitation samples of Guwahati network station from July 2003 to Oct 2005 (Table 5.9). The values of $d^{18}O$ and $\delta^{2}H$ for water from the precipitation as received in Guwahati network station found as -9.40 to -0.20 and -76.90 to -3.60 permil respectively (Table 5.9).

Generally, it appears that a variation in the isotopic values of the rain occur according to the quantity of rainfall. At higher precipitation quantity, the isotopic values are depleted as compared to at lower summer rainfall quantity during the month of March and April.

Development of Local Meteoric Water Line

The stable isotopes of hydrogen and oxygen can be used to characterize the precipitation and other sources of water in a region or area. Globally, the stable isotopic compositions of precipitation have been explained in the form of a global meteoric waterline (GMWL) by Craig (1961). The GMWL represents the variation of $\delta^{2}H$ with respect to $\delta^{18}O$ in precipitation and can be used to identify the source of water, mixing, and other hydrological processes. The meteoric waterline is represented in its generalized form as $\delta^2H = A \times \delta^{18}O + d$, where A represents the slope and *d* represents the intercept or D excess (^{2}H excess).

Figure 5.36 to 5.42 and 5.44 (a) to 5.44 (b) provide the information of plots of δ^2H versus $\delta^{18}O$ with the Global Mean Meteoric-Water Line shown for reference. Data points that lie close to this line indicate ground waters originating as direct recharge from precipitation. Points lying on the Local Evaporation Line indicate ground waters originating from surface water having undergone varying degrees of evaporation.

Linear-regression analysis was applied to stable oxygen and hydrogen isotope ($\delta^{18}O$ ‰ and δ^2H ‰) data in ground water, lake water, river water and precipitation water samples collected during 2006-07 to determine the Local Meteoric Water Line (LMWL), Local Ground Water Line (LGWL) and Local Surface Water Line (LSWL) for NE region of India. Regression results for the Rain Water samples yielded a LMWL defined by the equation $\delta^2H = 7.28\ d^{18}O - 4.81$ ($r^2 = 0.968$). This equation will be useful as a reference point for future studies in this area that use stable isotopes of oxygen and hydrogen ($\delta^{18}O$ ‰ and δ^2H ‰) to determine sources of ground-water recharge, to determine water-mineral exchange, to evaluate surface-water and ground-water interaction, and to analyze many other geochemical and hydrologic problems.

Regression analysis also was completed for the datasets sorted to investigate regional variation. Results and regression parameters are listed in Table 5.10. Regression parameters comprise the correlation coefficient (r^2), the standard error for the regression (SE), and the number of samples considered for each analysis. A regression model is a good fit to the data when the correlation coefficient is large (approaching 1.0), the standard error is relatively small in relation to the magnitude of the data (Helsel and Hirsch, 1992). The confidence in the regression parameters for describing the fit of the regression model to the data tends to increase with the number of samples (larger datasets, n greater than 30, Table 5.10).

The meteoric water line specific to a location or region is controlled by local factors specific to the climate of that region, including the oceanic origin of the water vapor and storm tracks characteristic of the region, and secondary evaporation of the precipitation. Such local factors work together to produce the slope and *d*-excess specific to that LMWL.

The deviation of the data from the GMWL reflects evaporation in the studied ground water bodies of Agartala and Tezpur, as shown in Fig. 5.36, 5.38, 5.39, 5.41 and 5.42.

The results of oxygen and hydrogen isotope analyses of the lake and river waters are presented in a $d^{18}O$–δD plot (Fig. 5.37) with respect to the Global Meteoric Water Line (GMWL), which correlates fresh surface waters on a global scale (Craig 1961).

Mountain ranges usually have isotopically lighter water than surrounding areas. The mountains get rain from many air masses because of the orographic effect, whereas lower areas get rain less frequently, and only from air masses that have more moisture and thus have been subjected to less rainout previously. This effect can be seen evidently in Fig. 5.43 (a, b and c).

The isotope values of rain water samples from the beginning of July 2003 to Oct 2005 are given in Fig. 5.44(a). The stable isotope composition of water samples collected from the precipitation and ground water of the NE area is presented in Fig. 5.44(b). It shows that the stable isotope composition of the precipitation of Guwahati network station is markedly different from that of the ground water samples, which fall on the local meteoric line. It is therefore concluded that the local precipitation is influencing in recharging the ground water system of the study areas.

Deuterium-excess

Departure from the GMWL can be quantified by a parameter know as the "*Deuterium Excess*" = DE. Deuterium-excess is a measure of the relative proportions of ^{2}H and ^{18}O in the sample. Deuterium-excess, defined by *d* (in permil) = $d^{2}H$ - 8 $d^{18}O$ (Dansgaard, 1964), can be thought of as an index of deviation from the GMWL of Craig (1961), which has a *d*-excess value of 10 permil. Review of *d*-excess values can be a useful diagnostic tool for $d^{2}H$ and $d^{18}O$ results because *d*-excess can be correlated with conditions at the source area for the water vapor in an airmass and the nature of the airmass prior to the moisture falling as rain or snow (Clark and Fritz, 1997; Froehlich and others, 2002). Partial evaporation of the sample, either as the precipitation falls from the cloud or during storage in the rain gauge during warm and dry conditions, can result in low or even negative *d*-excess values. Low temperature and lower humidity in the source area for the water vapor that the precipitation is derived from yield large *d*-excess values. On a global scale, *d*-excess values range from about -2 permil to about 10 to 15 permil (Froehlich and others, 2002). For the northern hemisphere, *d*-excess values tend to be largest in December and January and smallest in June and July (Kreutz and others, 2003).

The deuterium excess can be used to:

- Infer humidity at the moisture source. If most of the moisture in an air mass was transferred to the atmosphere under low-humidity conditions, the air mass will have a larger DE than other air masses.
- Distinguish different moisture sources that produced recharge for old ground water.

The plot of deviation in D excess versus slope of LMWL, LGWL and LSWL is shown in Fig. 5.44(c). This plot clearly indicates that there is a relationship between slopes and D excess that varies linearly with r^{2}=0.63.

Depth Profile and Increasing Trend

The composition of oxygen-18 and deuterium in ground waters varies mainly as a result of changes in the isotopic composition of rainfall and the processes of evaporation. The large range and depth wise variations of isotopic values indicate that ground water at different depths has been impacted by one or more of the following processes: direct recharge from local rivers, and recharge under different climatic conditions.

Depth wise variation in the stable isotope composition of the ground water samples from Agartala and Tezpur are presented in Fig. 5.45 (a) and 5.45 (b).

The increasing trend of δ^2H and $\delta^{18}O$ in ground water samples of Agartala and Tezpur area are presented through Fig. 4.46(a) to 4.47(b). A similar trend of D-excess and Slope of different developed LMWL, LGWL and LSWL are presented through Fig. 5.47(c) and 5.47(d) respectively.

Interaction of shallow and deep well aquifer systems, surface and groundwater systems

Investigation on the influence of surface water bodies in recharging ground water aquifers is one of the critical aspects in ground water investigations. Environmental stable isotope investigations are extensively used to study the interaction of two water bodies. Surface water system has a stable isotope composition significantly different from that of the local ground water system. The stable isotope content of the surface and ground water could be used to determine the interaction of the surface water and ground water. Evaporation from the surface water body causes enrichment in stable isotope components, Deuterium and Oxygen-18, while the stable isotope composition of ground water has not undergone evaporation. Interaction of the surface water body with the ground water system indicates no significant difference in the stable isotope composition of their water samples. Insignificant difference in the stable isotope compositions of two aquifer systems indicates their interaction with each other.

Although river water should originate from meteoric precipitation, relationship of these two waters has not clearly understood. It is often said that the isotopic ratios of river water are nearly same as the annual mean values of precipitation in the surrounding area (Aggarwal et. al., 2000). At the same time, it is the fact that one third or more of precipitation are returned into the atmosphere through evapotranspiration processes, and it is not obvious whether or not the isotopic ratios of water retuned into the atmosphere is the same as those of the residual part which is discharged into river. Lots of observed results have been reported about the isotopic ratios of river water, while precise comparison of those results with precipitation is quite few (Aggarwal et. al., 2000).

% Frequency Diagram/ Histogram of Stable Isotopes

The histogram is a pictorial representation of data which is regularly used to reveal the scatter or distribution of values obtained from measurements of a single quantity. There are no hard and fast rules about choosing the width of intervals for a histogram, but a good histogram:

- is easy to construct, so intervals are chosen to reduce the risk of mistakes when preparing a grouped frequency distribution.

- reveals the distribution of the data clearly. If too many intervals are chosen then the number of values in each interval is small and the histogram appears 'flat' and featureless. At the other extreme, if the histogram consists of only two or three intervals, then all the values will lie in those intervals and the shape of the histogram reveals little.

In choosing the total number of intervals, N, a useful rule of thumb is to calculate N using

$$N = \sqrt{n}$$

where n is the number of values. Once N has been rounded to a whole number, the interval width, w, can be calculated using

$$w = range/N$$

where range is defined as

$$\text{range} = \text{maximum value - minimum value}$$

Fig. 5.47 (e) and 5.47(f) show the percentage frequency of $\delta^{18}O$ ‰ and $\delta^{2}H$ ‰ of water samples as collected from different locations of NE region. According to % frequency diagram of $\delta^{18}O$ ‰ and $\delta^{2}H$ ‰ of ground water samples of Agartala, 83.33 % and 62.5 % of water samples fall under the range of -5.0 to -4.0 of $\delta^{18}O$ ‰ and -30.0 to -25.0 of $\delta^{2}H$ ‰ respectively. Majority of ground water samples of Tezpur fall in the range of -5.5 to -5.0 of $\delta^{18}O$ ‰ (50%) and -35.0 to -30.0 of $\delta^{2}H$ ‰ (52.63%).

In the case of rainfall samples only, as collected from Guwahati network station for the period from July 2003 to Oct 2005, it is found that 63.64 % samples fall in the range of -10.0 to -8.0 of $\delta^{18}O$ ‰ and 45.45 % under range of -70.0 to -60.0 of $\delta^{2}H$ ‰.

By clubbing all samples of ground waters, lake waters, precipitation and river water, it is observed that 76.71 % of samples fall in the range of -6.0 to -4.0 of $\delta^{18}O$ ‰ while 87.68 % of samples are under the range of -40.0 to -20.0 of $\delta^{2}H$ ‰ (Fig. 5.47(f)).

5.7 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. 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. The water quality maps may be shaded to identify areas of waters having a particular range of concentration 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 town planning organizations in their decision making. The prepared maps can project the regional behavior of ground water in very simple visualize way. In the present study ground water quality maps were prepared for different parameters for Agartala and Tezpur area and presented through Fig. nos. 5.48 to 5.65.

5.8 Pearson's Correlation's Matrix

The usual procedures of interpretation of chemical quality data of ground water with the help of plots of different ions and pairs of ions sometimes seem to be inadequate because these procedures do not define similarities and dissimilarities between all the ions simultaneously. In such cases where we need a rapid and simultaneously comparison between all the ions it is advisable to use Pearson's correlation's matrix technique. Normal interpretation of hydrochemical data is substantiated by multivariate analyses. Correlation's matrix analysis searches similar pair of relationship such as correlation in a large symmetric matrix. The method organizes a large data set into groups with similar characters and provides pair by pair comparison between various constituents. The results of correlation's matrix analysis can be presented in an easily understandable two-dimensional staircase table. The observer can pick up groups at any desired value of similarity or dissimilarity according to their correlations.

Correlation's matrix analysis can be successfully used to determine the dominating constituents, which control the ground water quality of a region. In the present study interpretation of stable isotopes and chemical data are accomplished by using correlation's matrix analysis. Results related to correlation's matrix analysis of different parameters related to ground water of Agartala and Tezpur town are presented in Table 5.11 and 5.12 respectively.

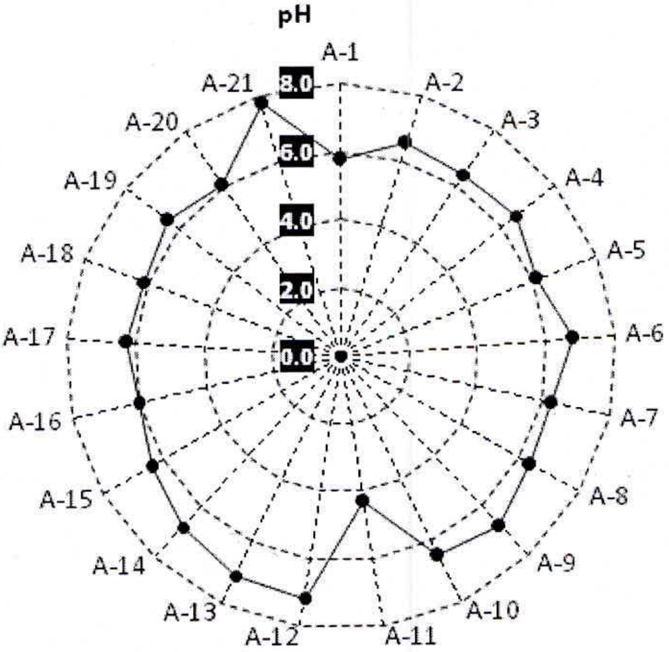


Fig.5.1 : Status of pH in gr. water of Agartala through Radar Diagram

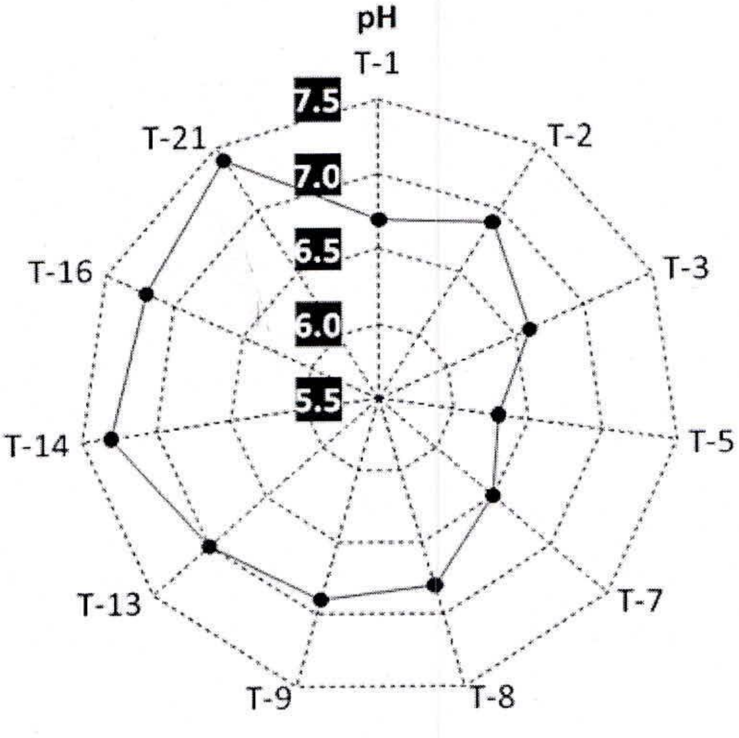


Fig.5.2 : Status of pH in ground water of Tezpur through Radar Diagram

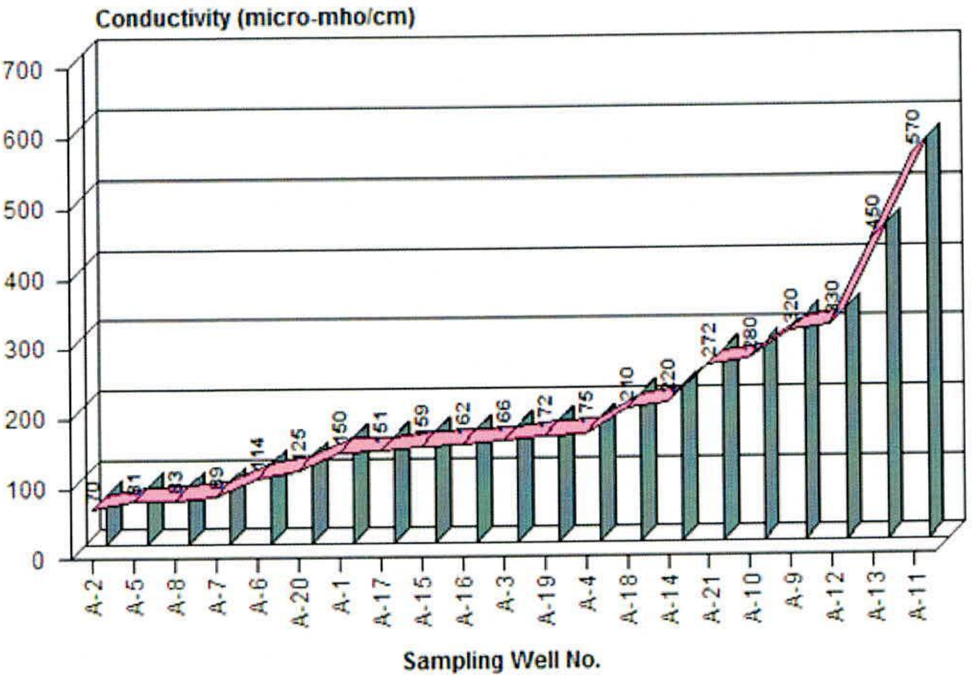


Fig. 5.3 : Increasing Trend of Conductivity (micro-mho/cm) in Ground Water of Agartala

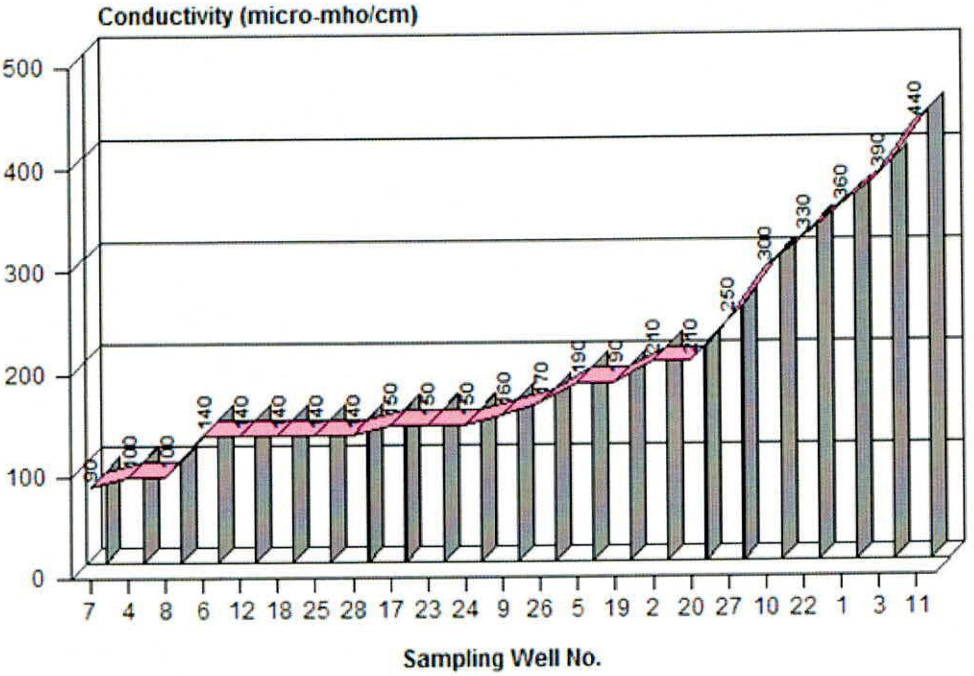


Fig. 5.4 : Increasing Trend of Conductivity (micro-mho/cm) in Ground Water of Tezpur

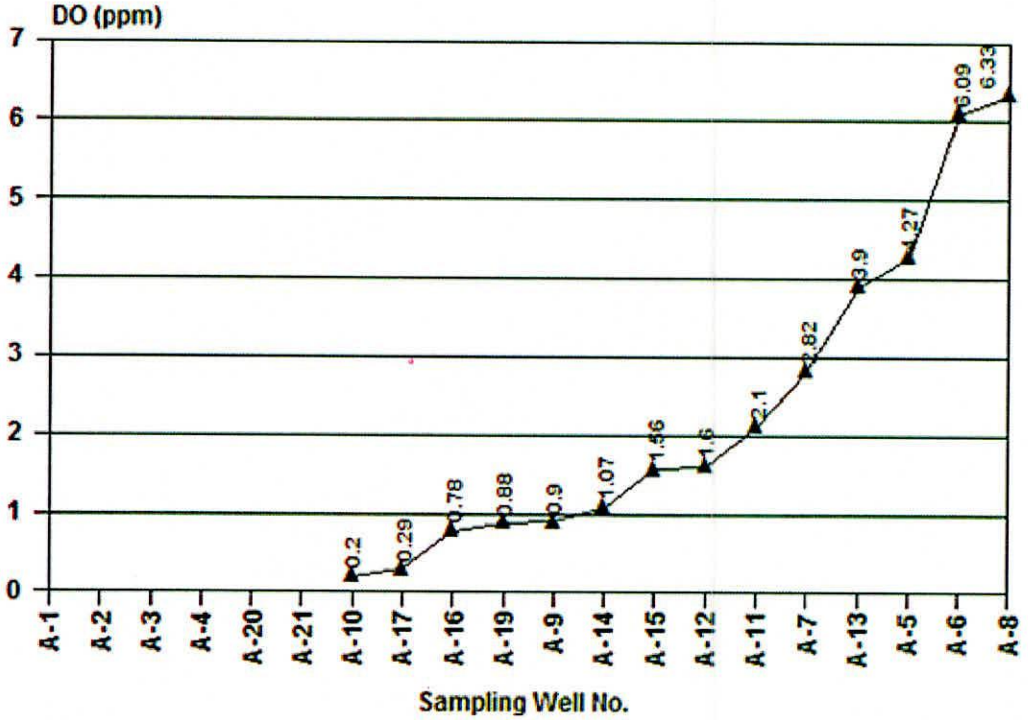


Fig.5.5 : Increasing Trend of DO (ppm) in Ground Water of Agartala

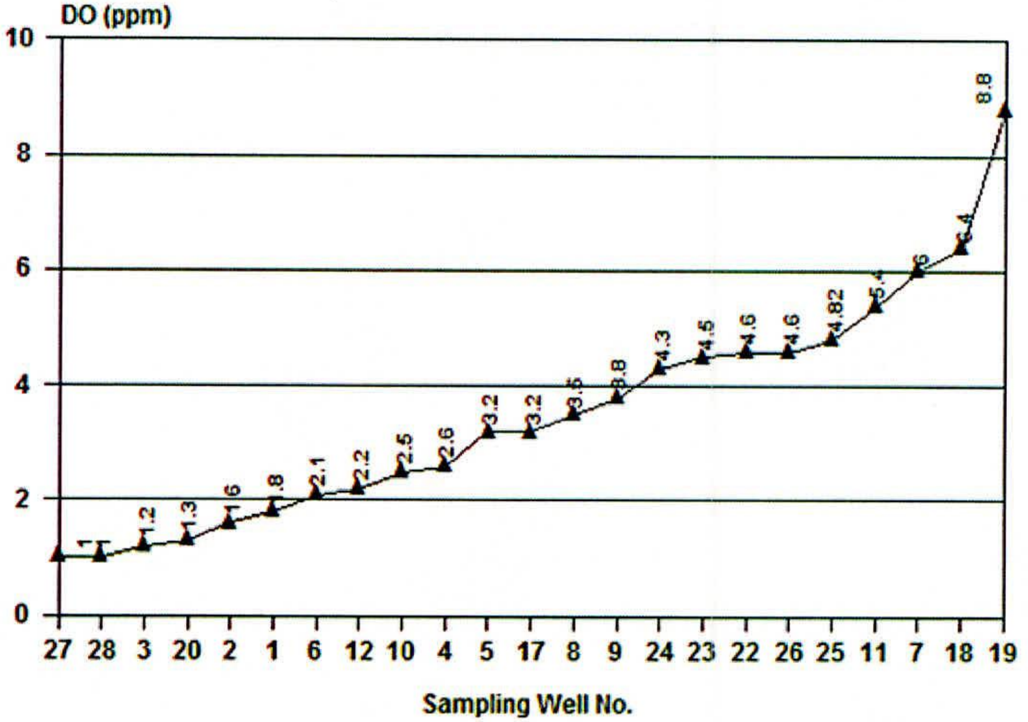


Fig.5.6 : Increasing Trend of DO (ppm) in Ground Water of Tezpur

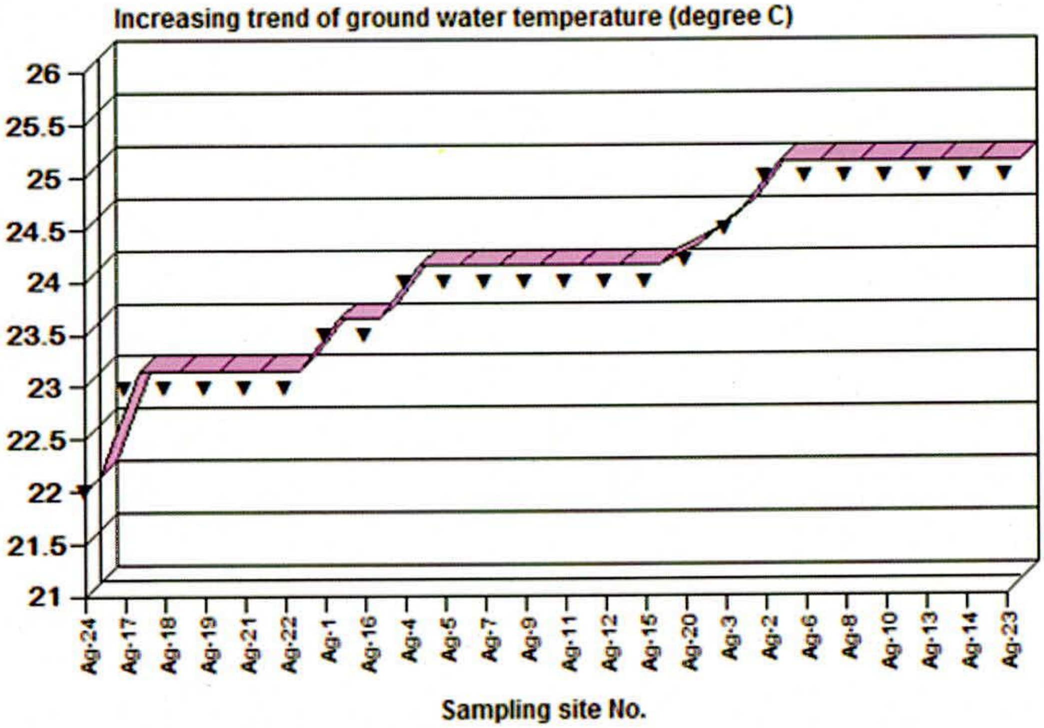


Fig.5.7 : Status of temperature (degree C) in gr. water of Agartala

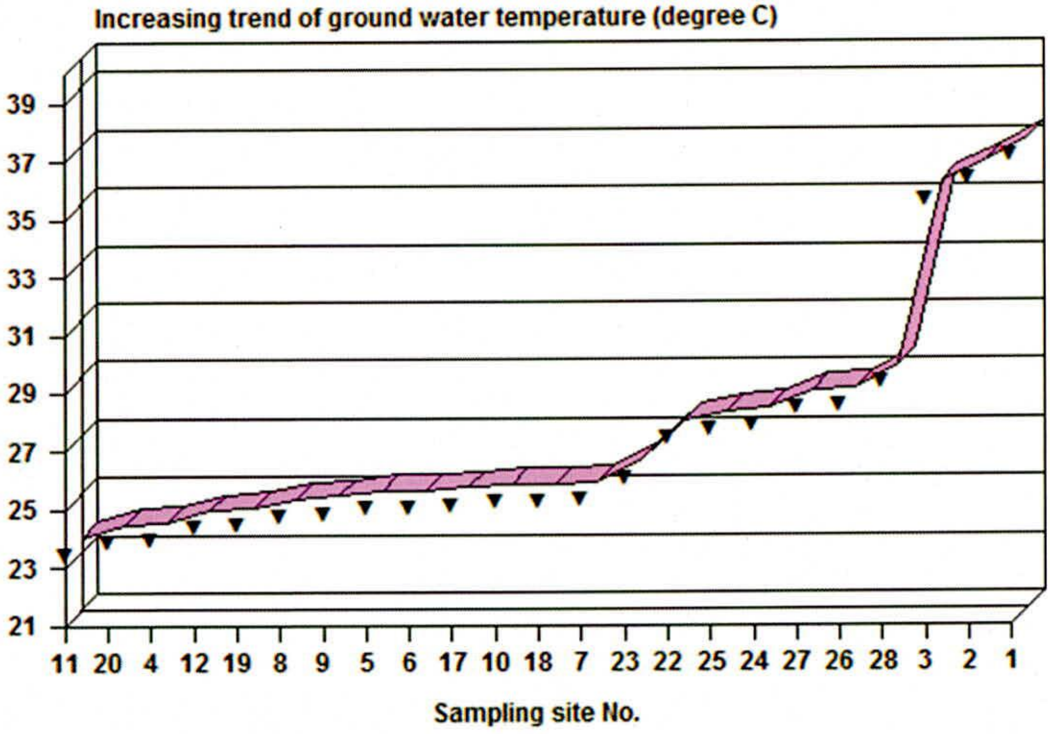


Fig.5.8 : Status of temperature (degree C) in ground water of Tezpur

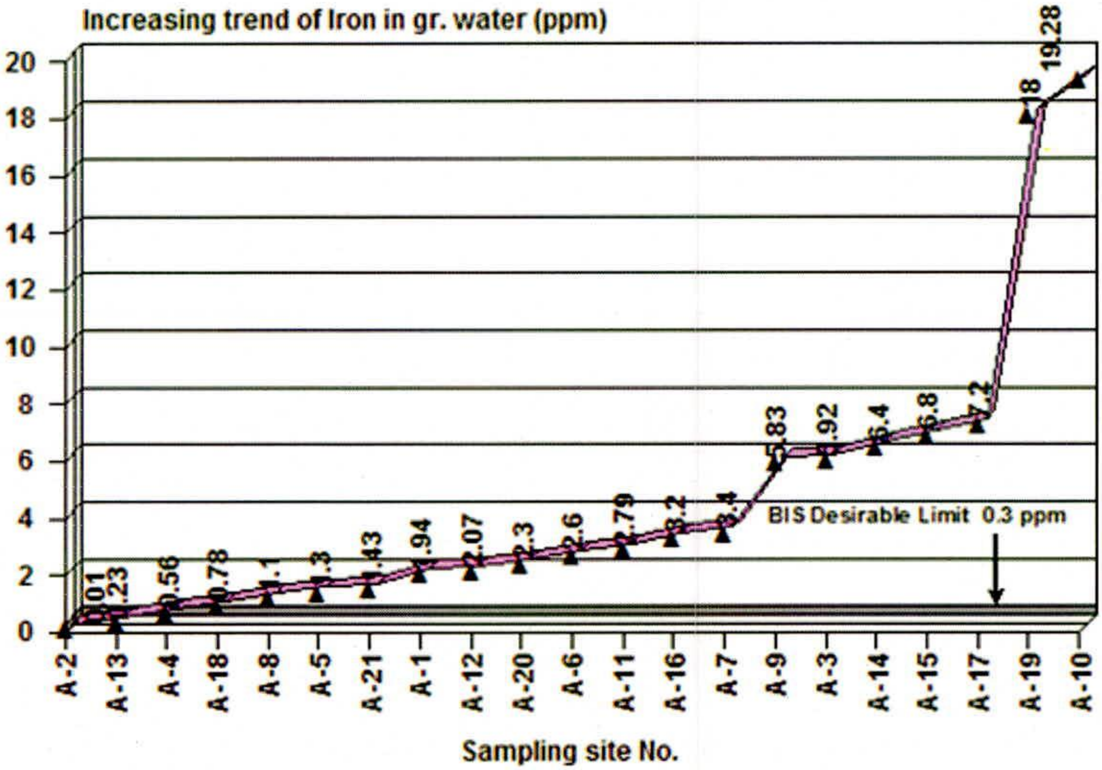


Fig.5.9 : Status of Iron in ground water of Agartala

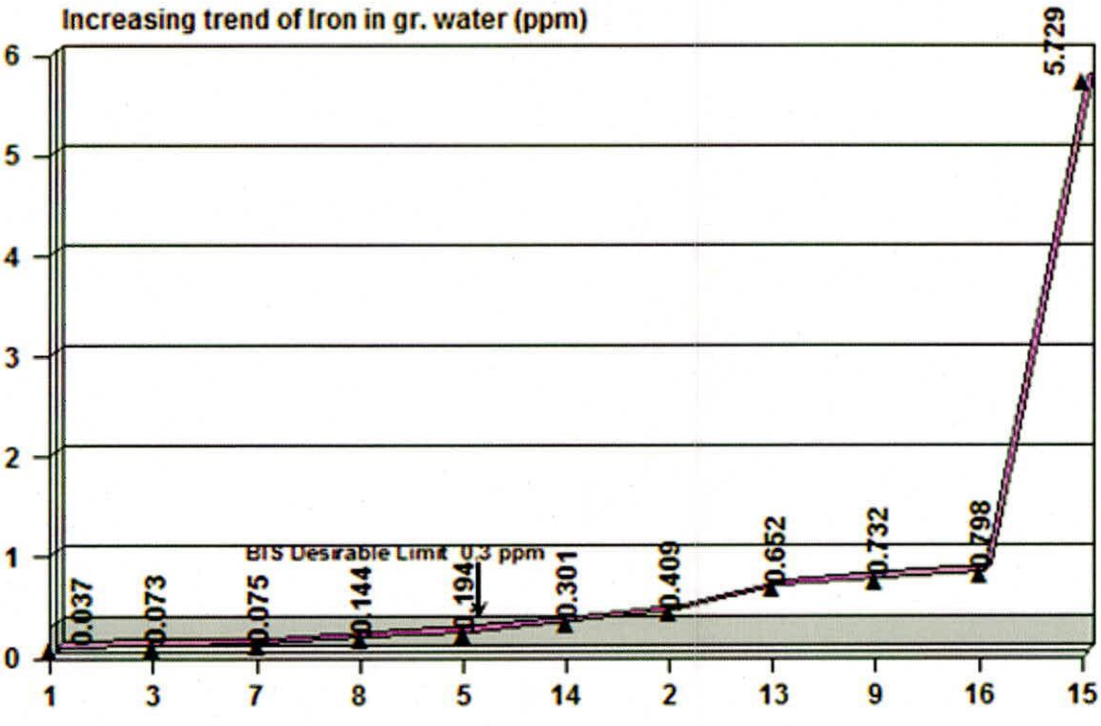
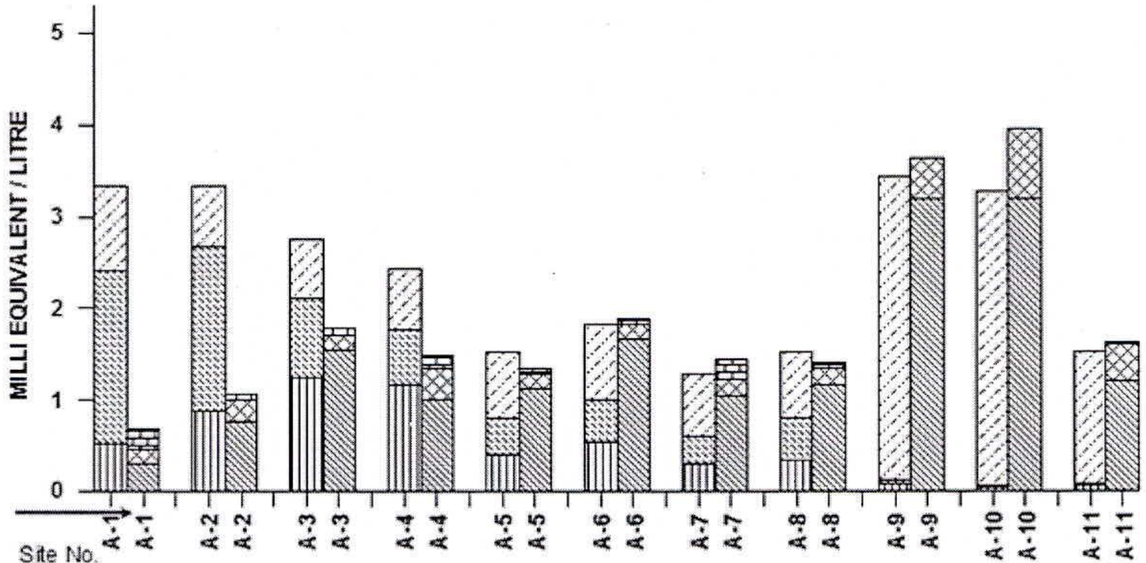
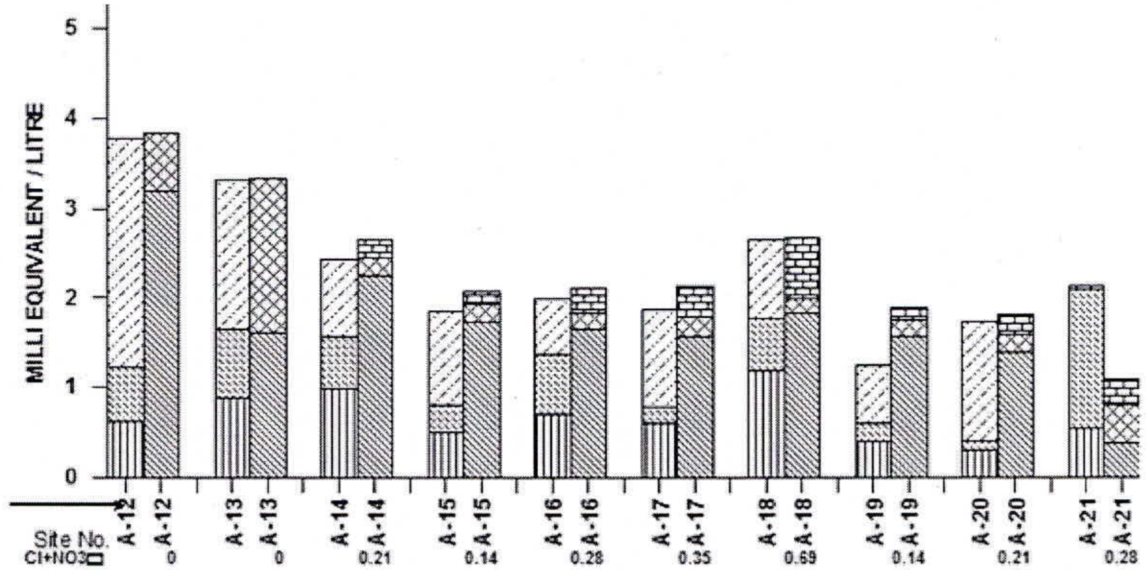


Fig.5.10 : Status of Iron in ground water of Tezpur



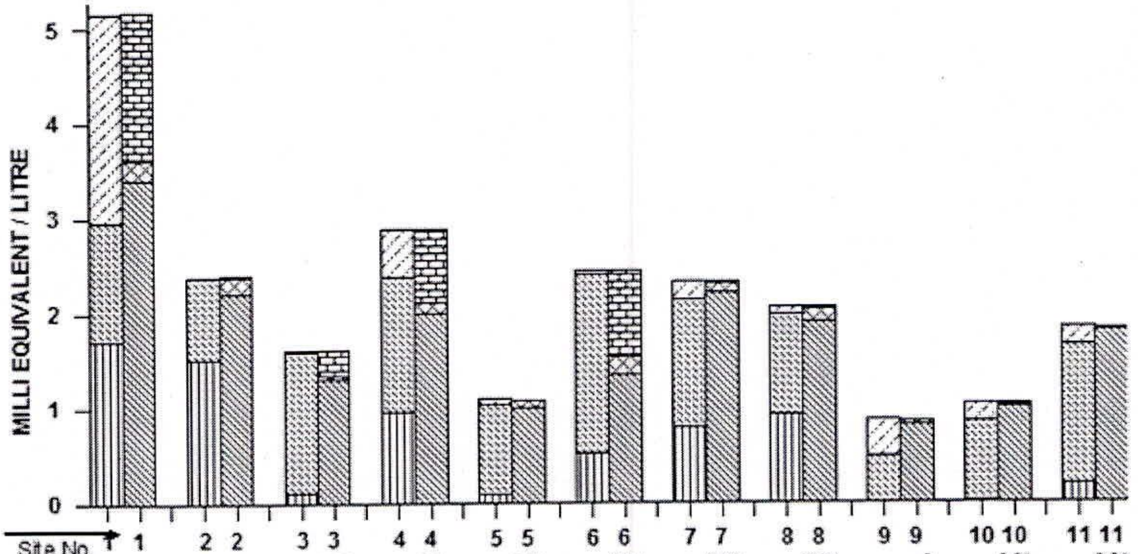
Site No.	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11
Cl+NO3 ▭	0.22	0.07	0.07	0.14	0.07	0.07	0.21	0.07	0	0	0.01
SO4+PO4 ▨	0.15	0.23	0.17	0.35	0.16	0.16	0.18	0.18	0.44	0.75	0.41
HCO3 ▨	0.31	0.77	1.54	1	1.12	1.66	1.05	1.16	3.2	3.2	1.2
Na+K ▭	0.93	0.66	0.66	0.67	0.72	0.83	0.69	0.72	3.3	3.22	1.45
Mg ▨	1.88	1.78	0.86	0.6	0.4	0.45	0.3	0.45	0.04	0.02	0.02
Ca ▥	0.53	0.89	1.24	1.16	0.4	0.55	0.3	0.35	0.09	0.03	0.05

Fig 5.11 : Collin's Bar Diagram Presentation for Cations and Anions for Agartala



Site No.	A-12	A-13	A-14	A-15	A-16	A-17	A-18	A-19	A-20	A-21
Cl+NO3 ▭	0	0	0.21	0.14	0.28	0.35	0.69	0.14	0.21	0.28
SO4+PO4 ▨	0.64	1.74	0.19	0.2	0.18	0.22	0.16	0.18	0.2	0.42
HCO3 ▨	3.2	1.6	2.25	1.73	1.65	1.56	1.82	1.56	1.39	0.38
Na+K ▭	2.54	1.67	0.86	1.05	0.63	1.08	0.88	0.65	1.32	0.04
Mg ▨	0.62	0.77	0.57	0.29	0.67	0.19	0.57	0.19	0.1	1.54
Ca ▥	0.61	0.88	0.99	0.5	0.69	0.59	1.19	0.4	0.3	0.54

Fig 5.12 : Collin's Bar Diagram Presentation for Cations and Anions for Agartala



Site No.	1	2	3	4	5	6	7	8	9	10	11
Cl+NO3 ▭	1.55	0.01	0.26	0.76	0.01	0.91	0.02	0.01	0	0.01	0.01
SO4+PO4 ▨	0.22	0.19	0.05	0.12	0.07	0.19	0.1	0.14	0.05	0.02	0.02
HCO3 ▨	3.4	2.2	1.3	2	1	1.34	2.2	1.9	0.8	1	1.8
Na+K ▭	2.2	0.01	0.02	0.49	0.05	0.04	0.19	0.07	0.39	0.19	0.18
Mg ▨	1.25	0.86	1.48	1.43	0.95	1.89	1.35	1.06	0.47	0.83	1.47
Ca ▥	1.71	1.52	0.11	0.96	0.09	0.51	0.78	0.92	0	0.01	0.19

Fig 5.13 : Collin's Bar Diagram Presentation for Cations and Anions for Tezpur

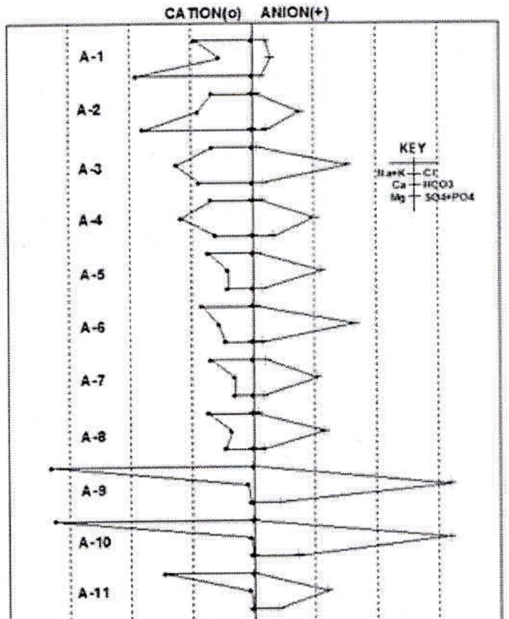


Fig. 5.14 : Stiff Pattern Diagram for Agartala

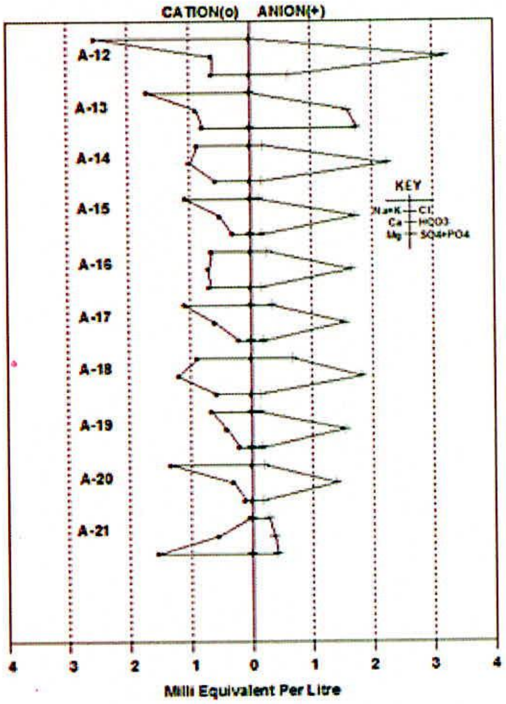


Fig. 5.15 : Stiff Pattern Diagram for Agartala

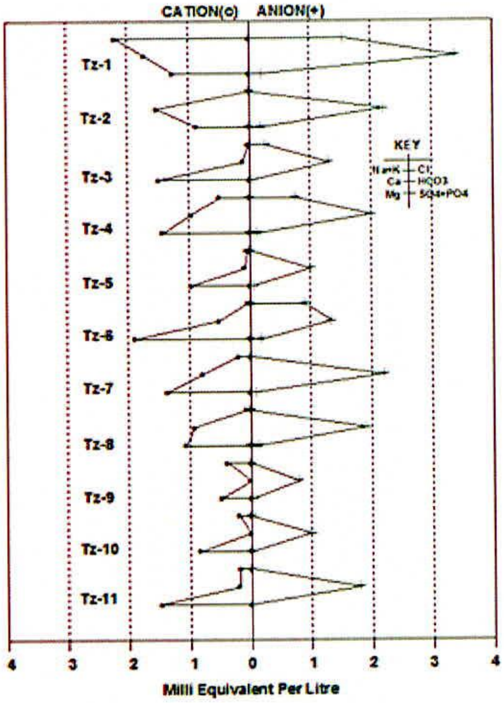


Fig. 5.16 : Stiff Pattern Diagram for Tezpur

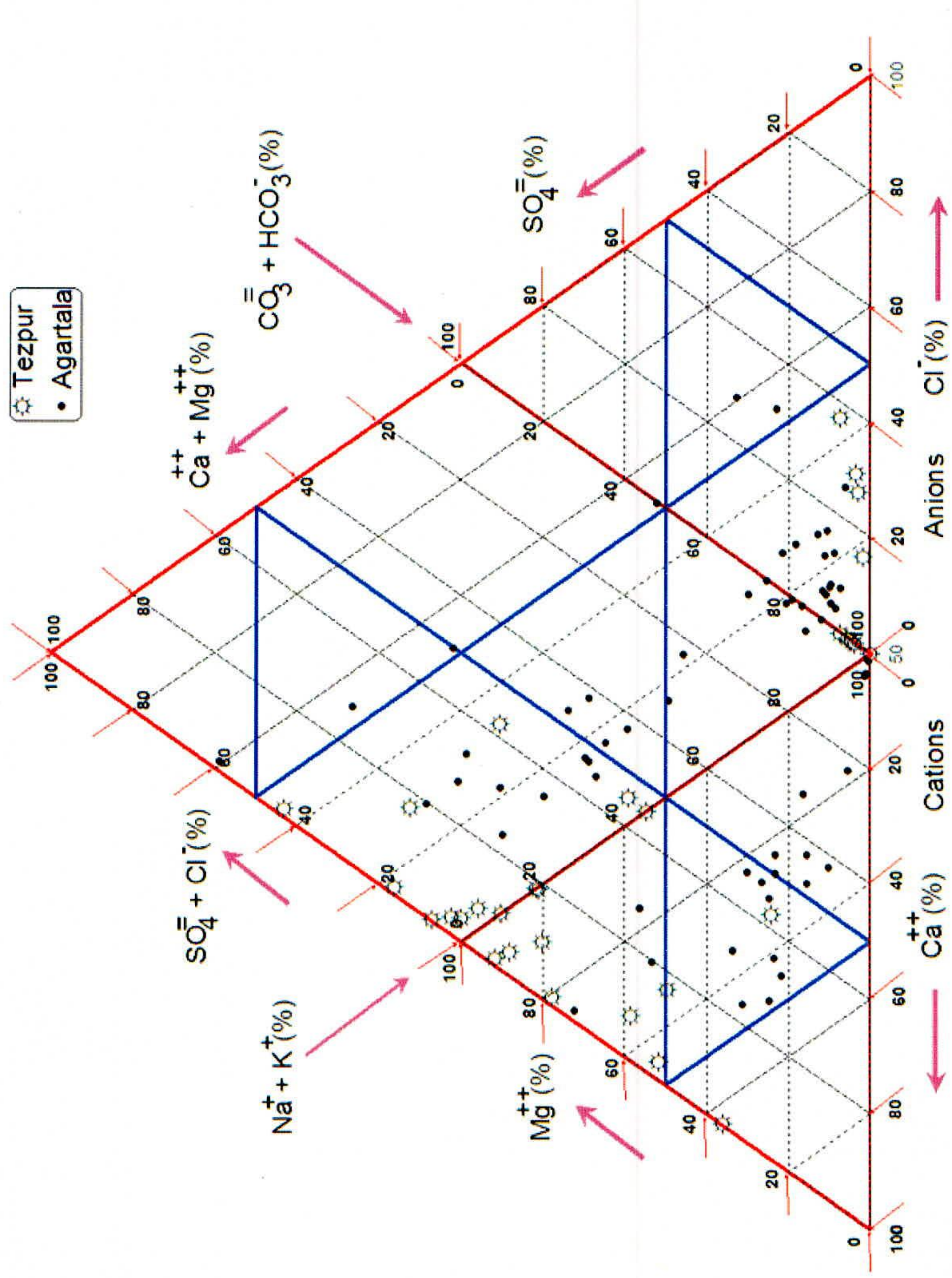


Fig. 5.17 : Piper's Trilinear Classification for Ground Water Analysis of Agartala and Tezpur

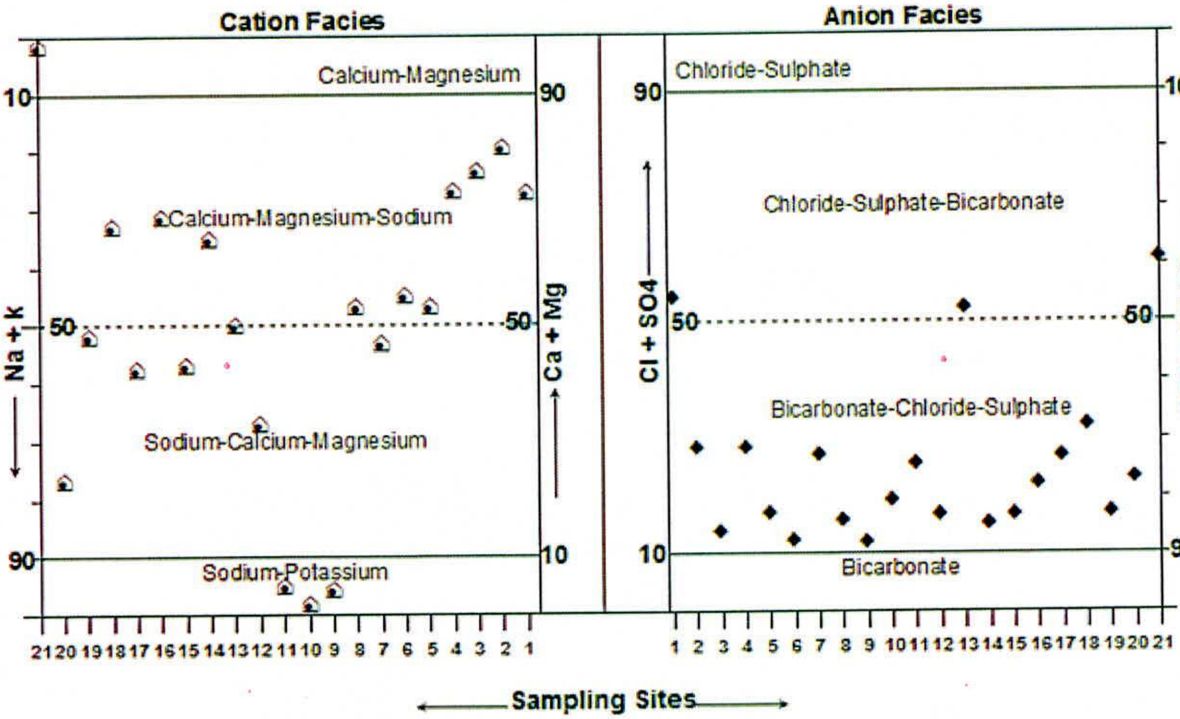


Fig. 5.18 : Back's Classification of Ground Water in Agartala (A-1 to A-21)

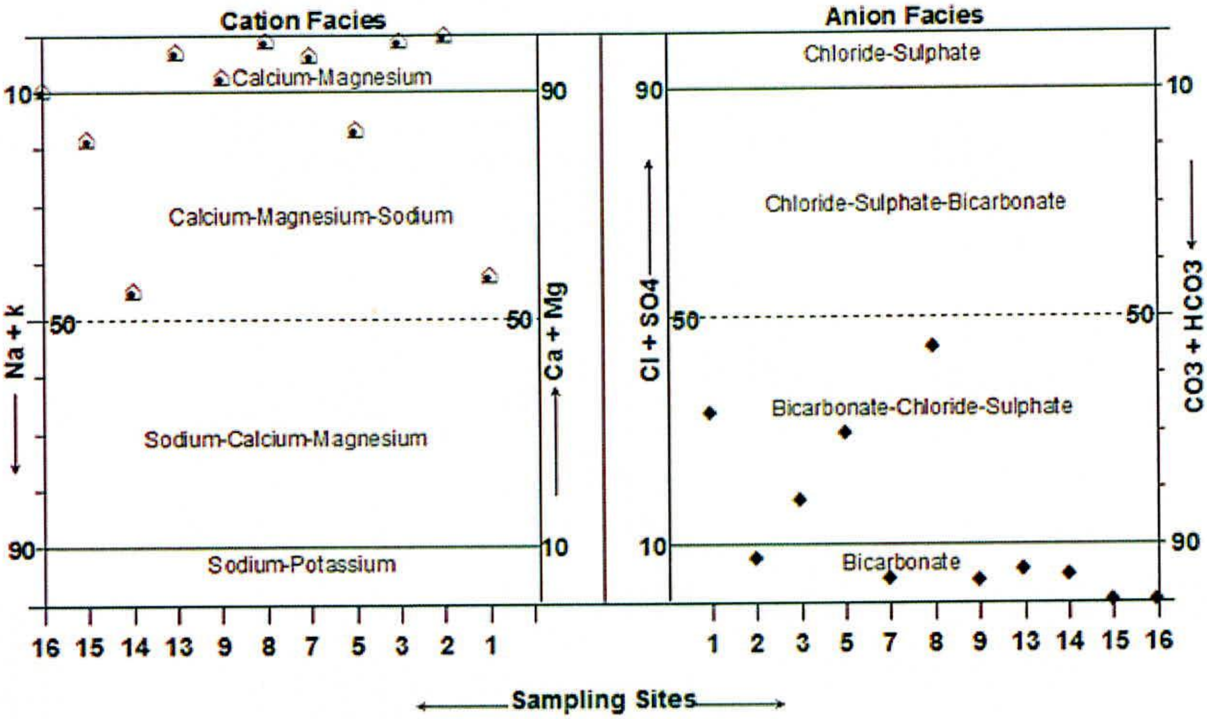
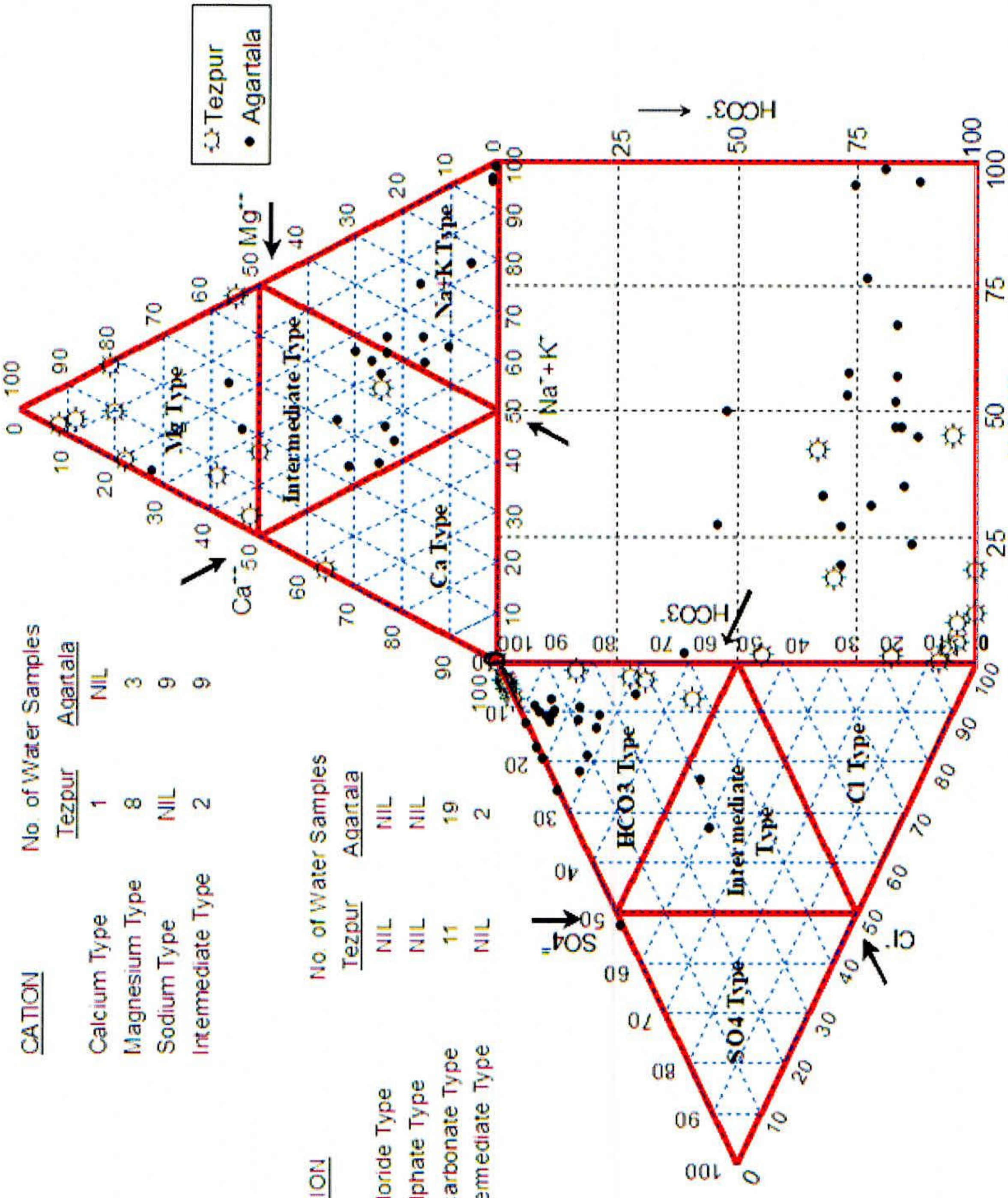


Fig. 5.19 : Back's Classification of Ground Water in Tezpur



CATION	No. of Water Samples Tezpur	No. of Water Samples Agartala
Calcium Type	1	NIL
Magnesium Type	8	3
Sodium Type	NIL	9
Intermediate Type	2	9

ANION	No. of Water Samples Tezpur	No. of Water Samples Agartala
Chloride Type	NIL	NIL
Sulphate Type	NIL	NIL
Bicarbonate Type	11	19
Intermediate Type	NIL	2

Fig. 5.20 : Durov's Classification of ground water for Agartala and Tezpur

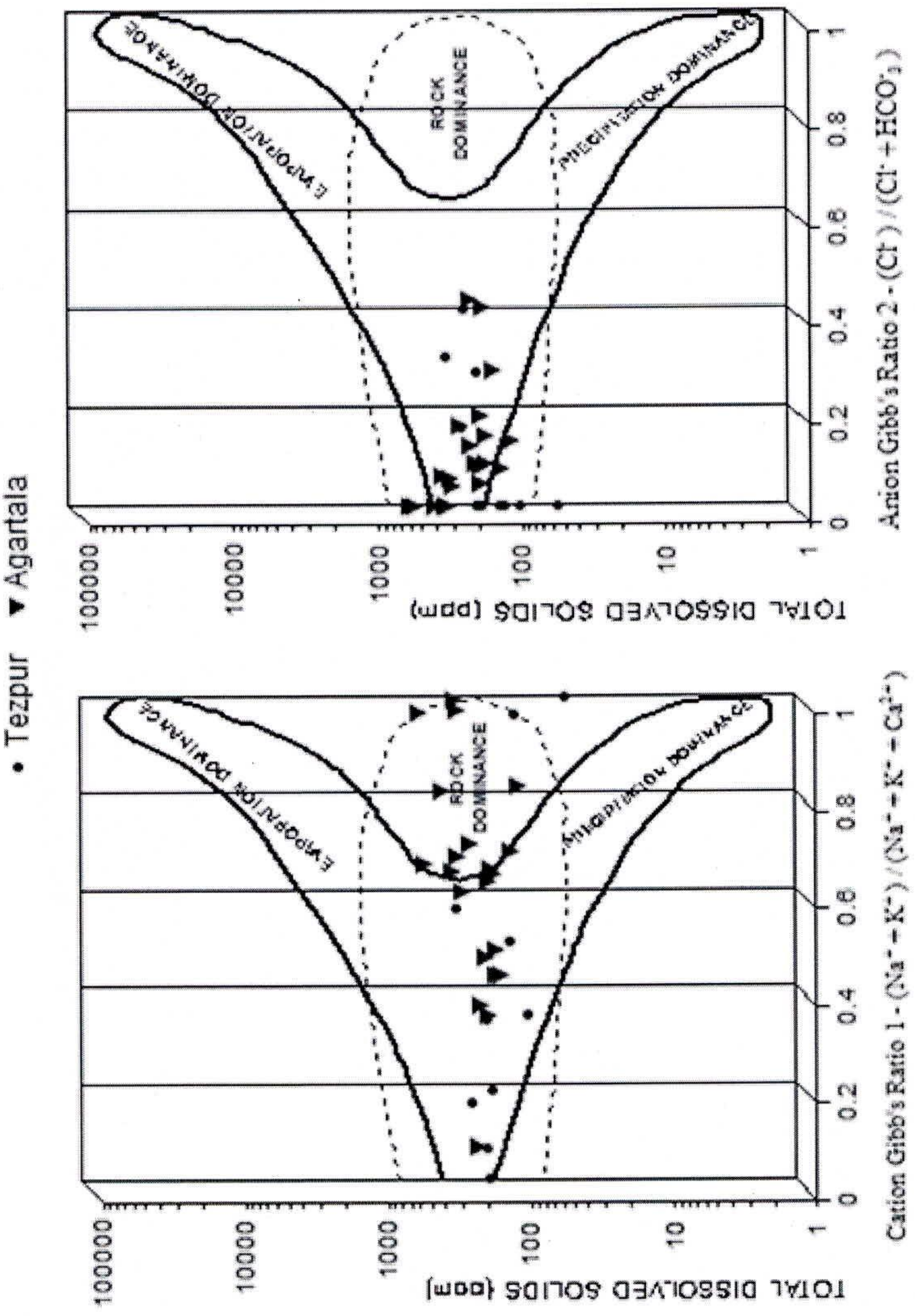


Fig. 5.21 : Gibb's Mechanism Controlling the Ground Water Chemistry

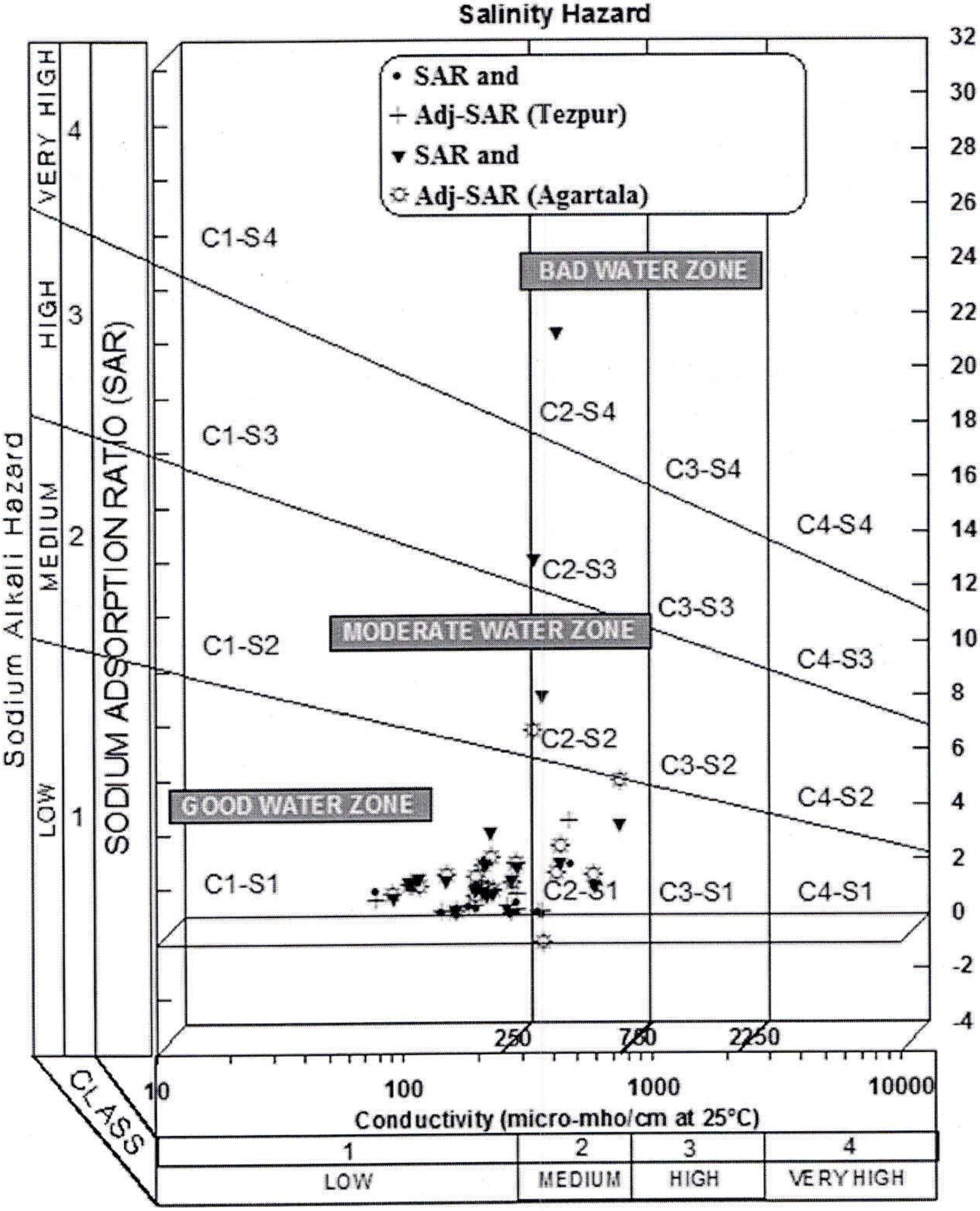


Fig. 5.22 : U.S. Salinity Laboratory Classification

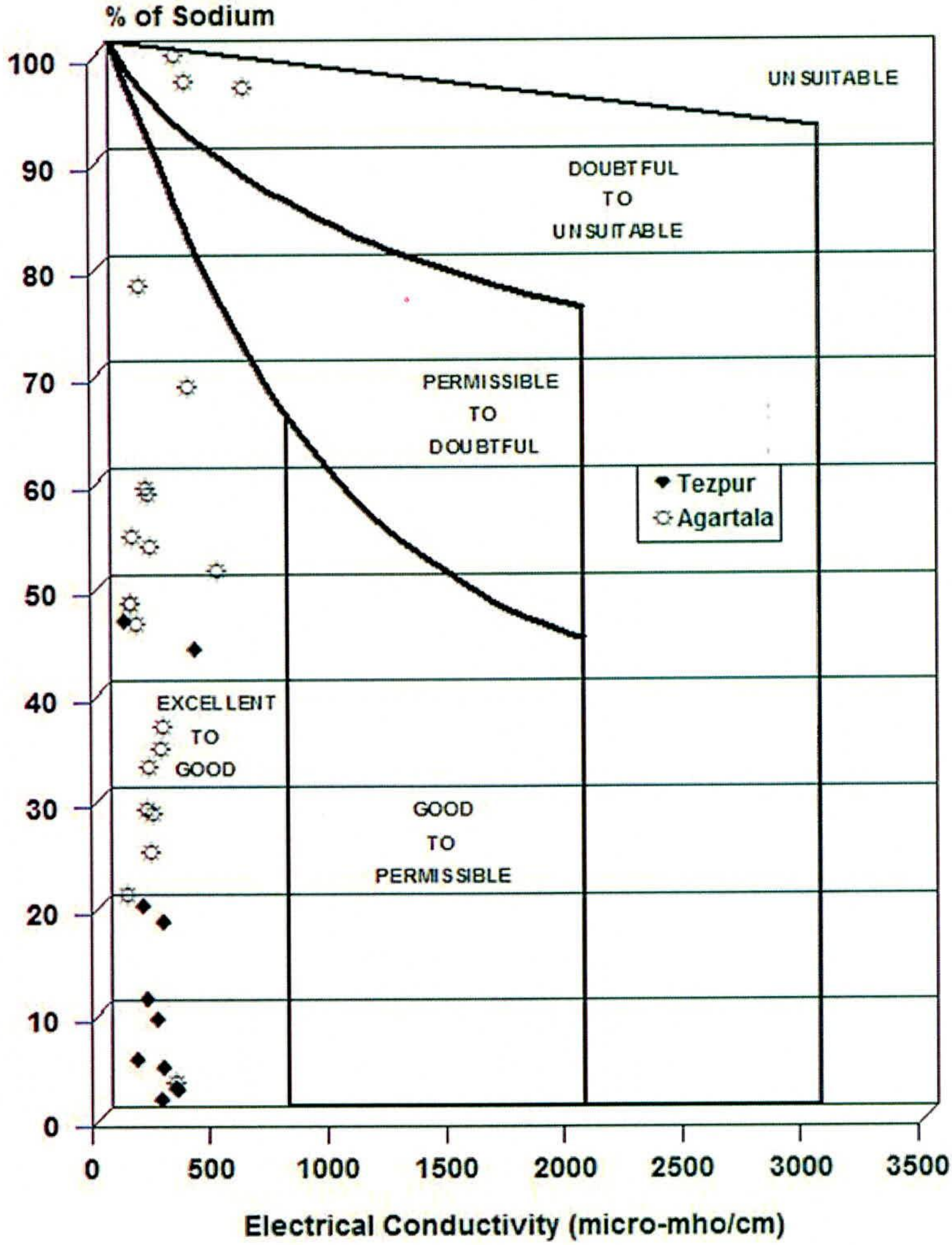


Fig. 5.23 : Wilcox Classification

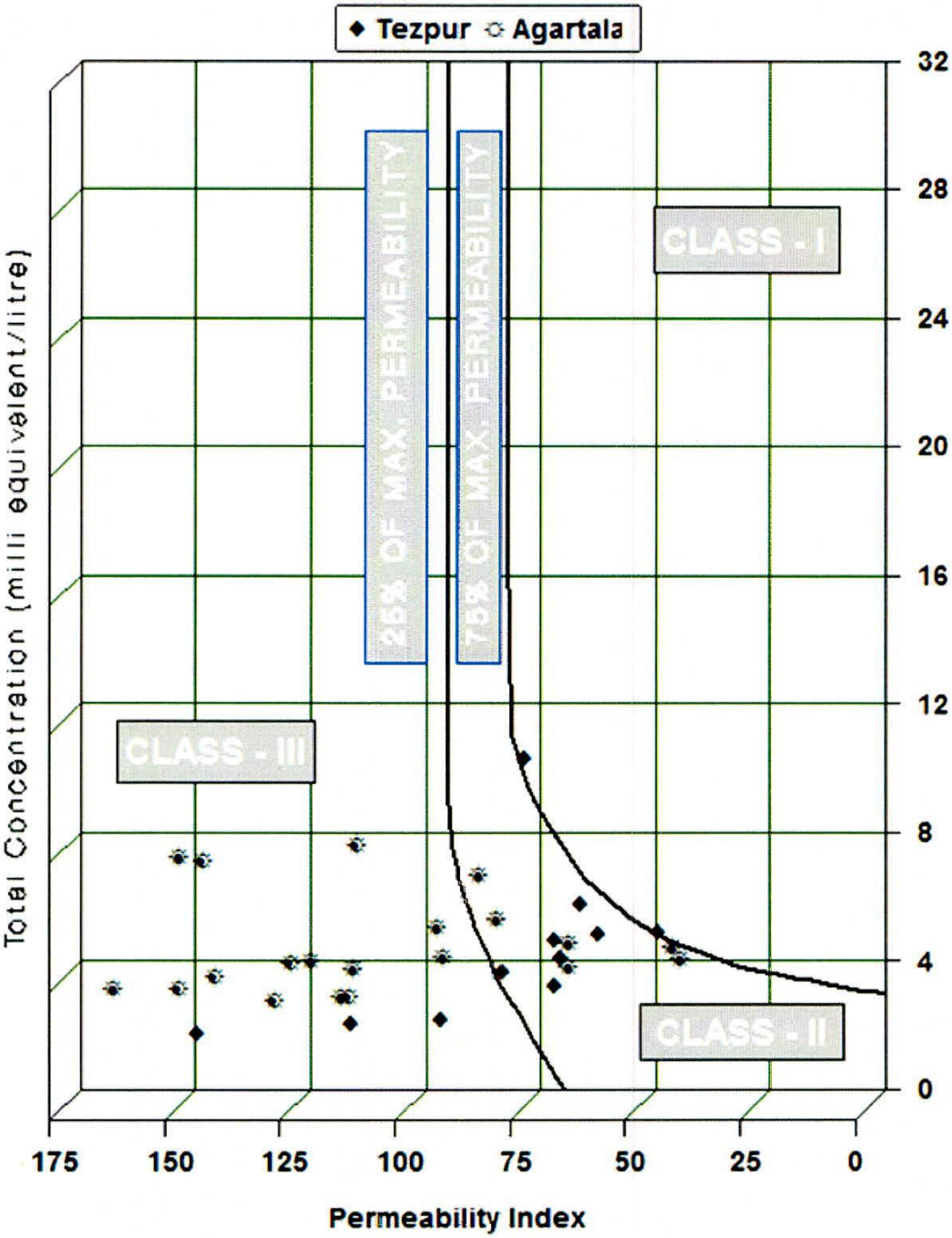


Fig. 5.24 : Doneen's Classification for Irrigation Water

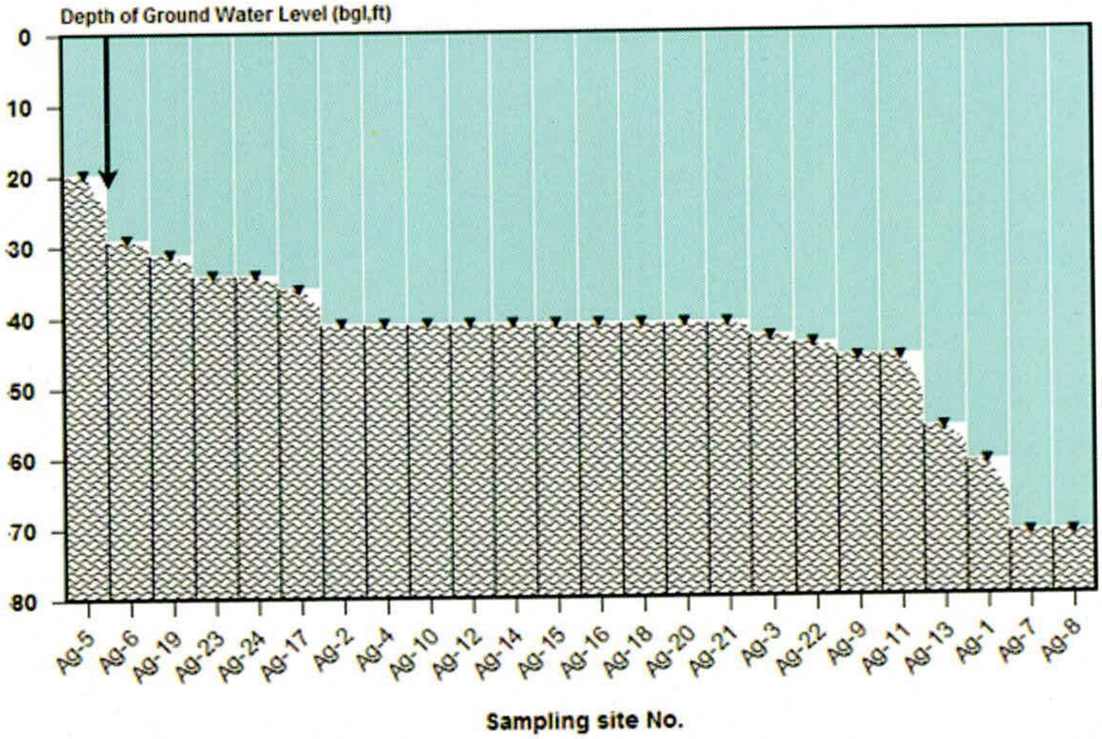


Fig. 5.25 : Status of ground water level in Agartala

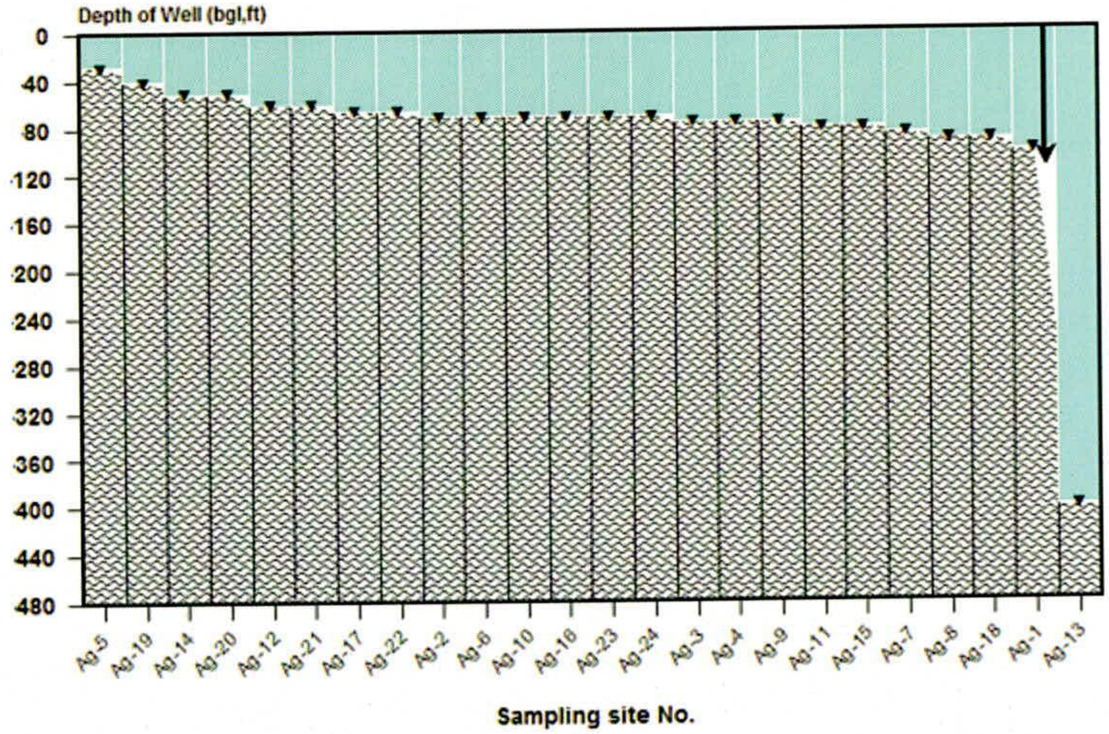


Fig. 5.26 : Status of sampling well depth in Agartala

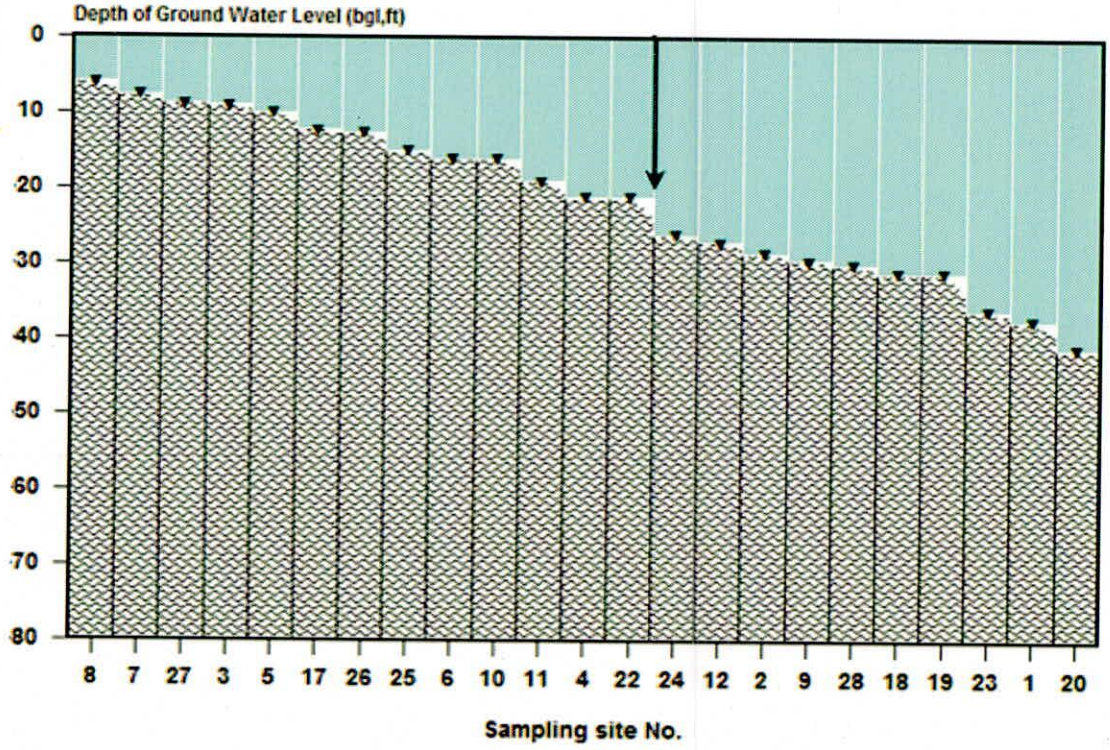


Fig. 5.27 : Status of ground water level in Tezpur

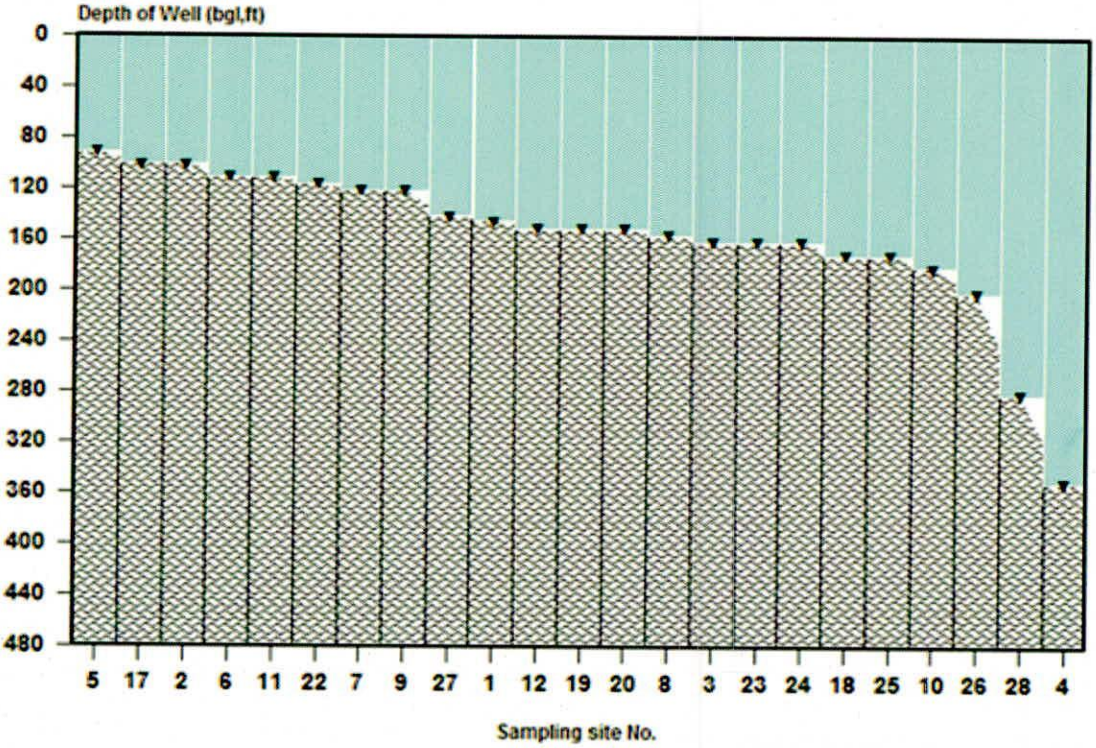


Fig. 5.28 : Status of sampling well depth in Tezpur

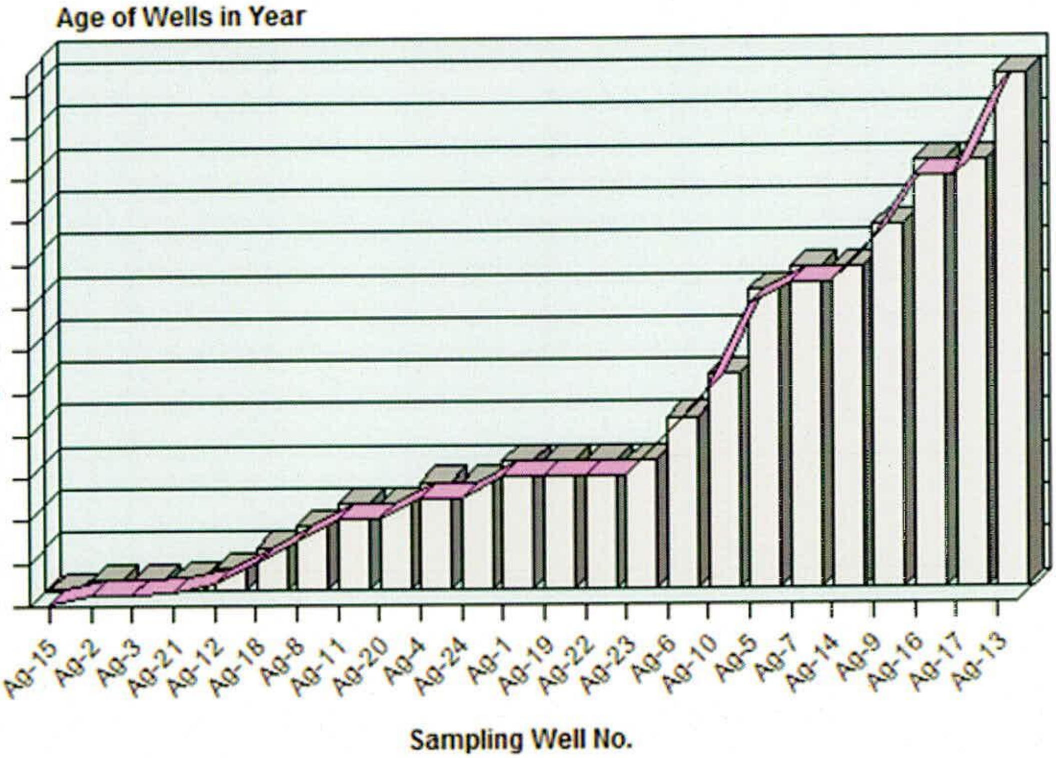


Fig. 5.29 : Age of Sampling Wells in Agartala

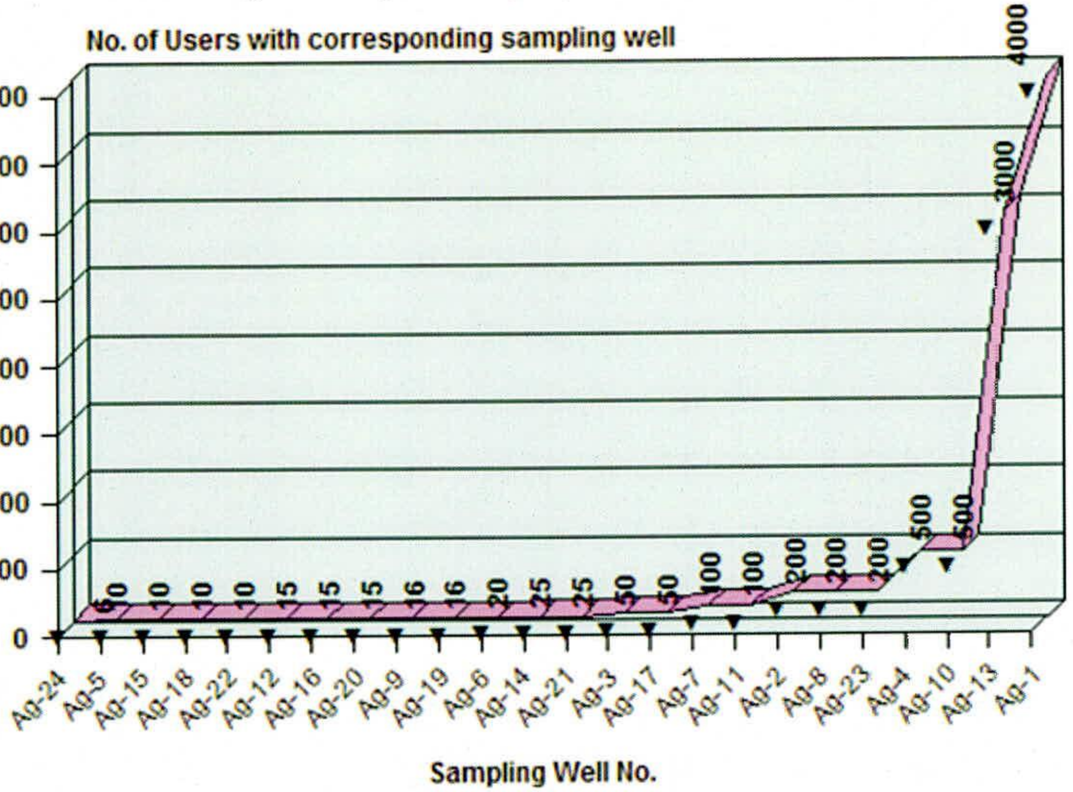


Fig. 5.30 : Status of Users with Corresponding Sampling Well in Agartala

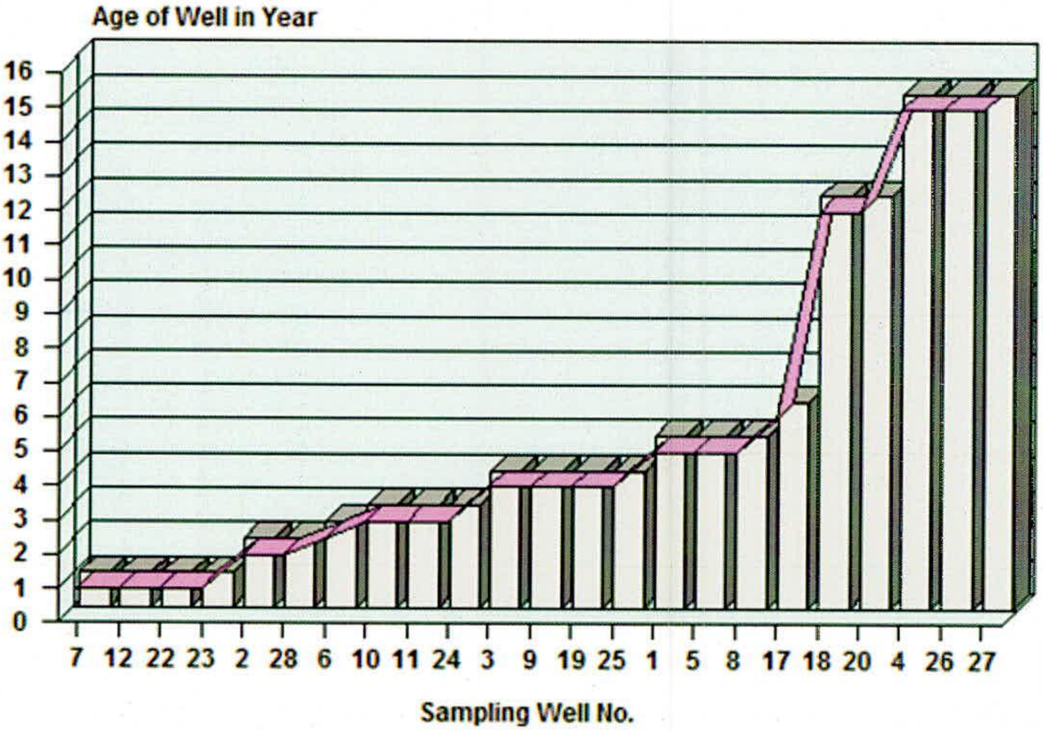


Fig. 5.31 : Age of Sampling Wells in Tezpur

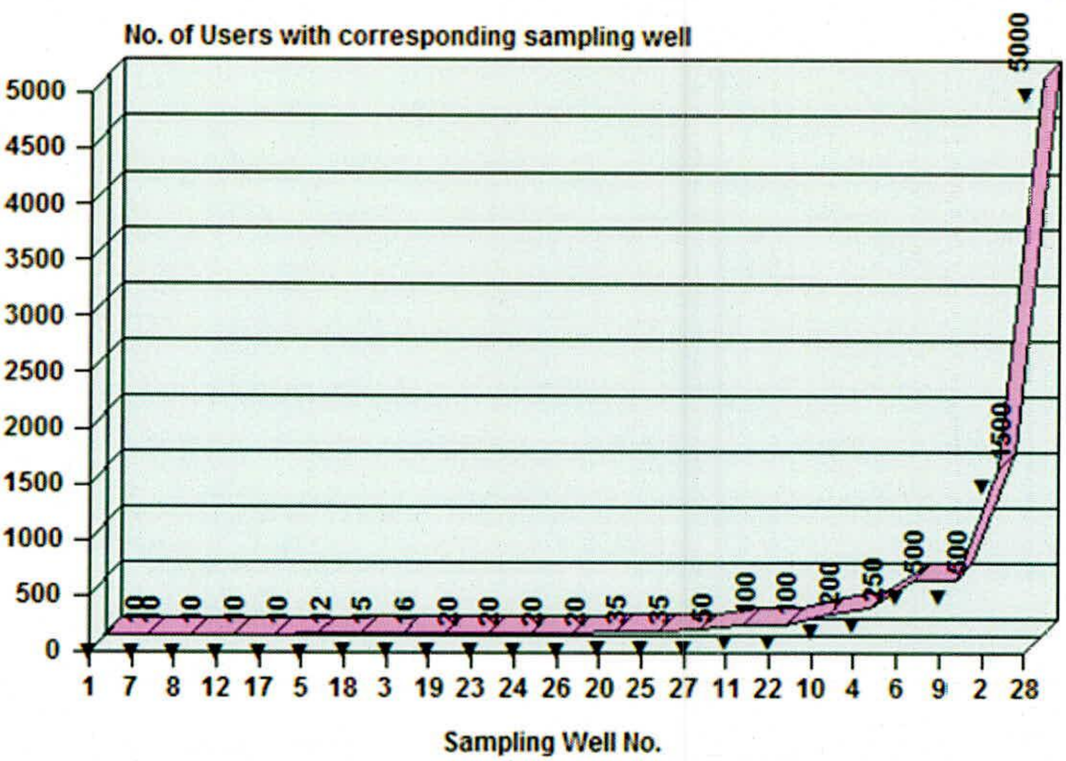


Fig. 5.32 : Status of Users with Corresponding Sampling Well in Tezpur

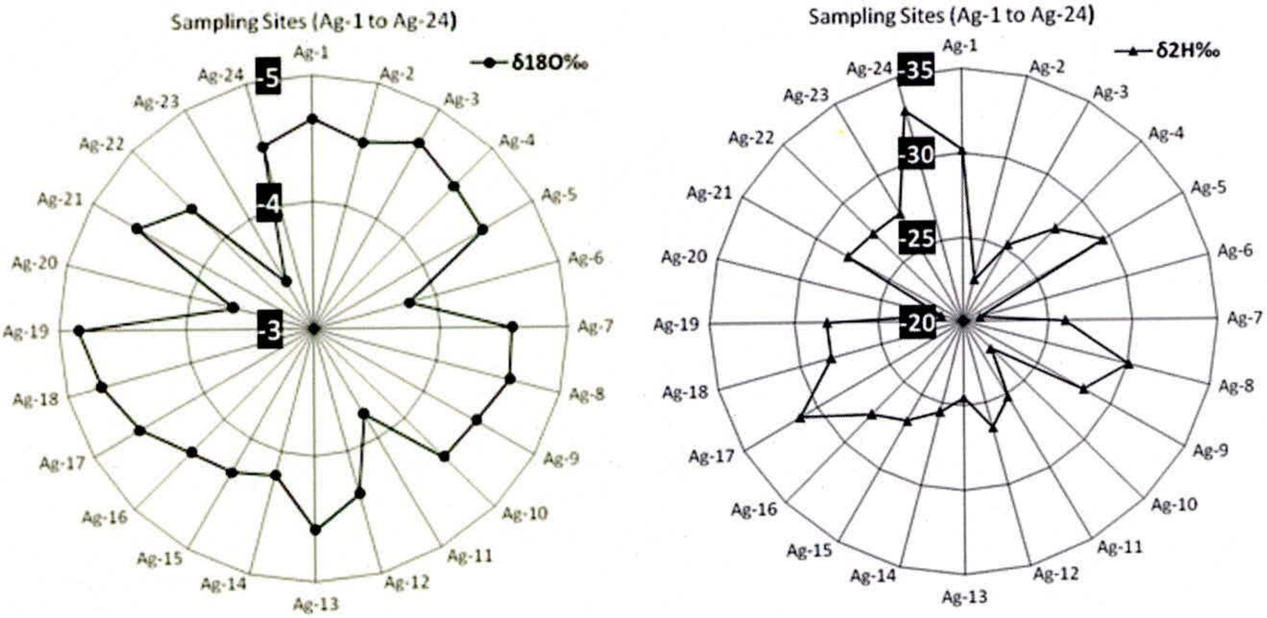


Fig. 5.33 : Radar diagram for variation of oxygen and hydrogen isotopes in gr.water of Agartala

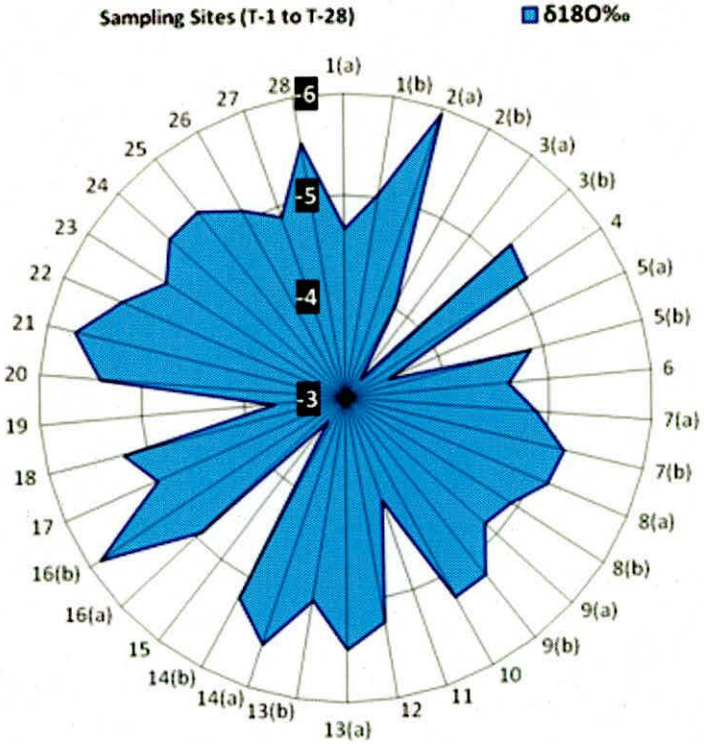


Fig. 5.34 : Variation of oxygen isotope through radar diagram in ground water of Tezpur

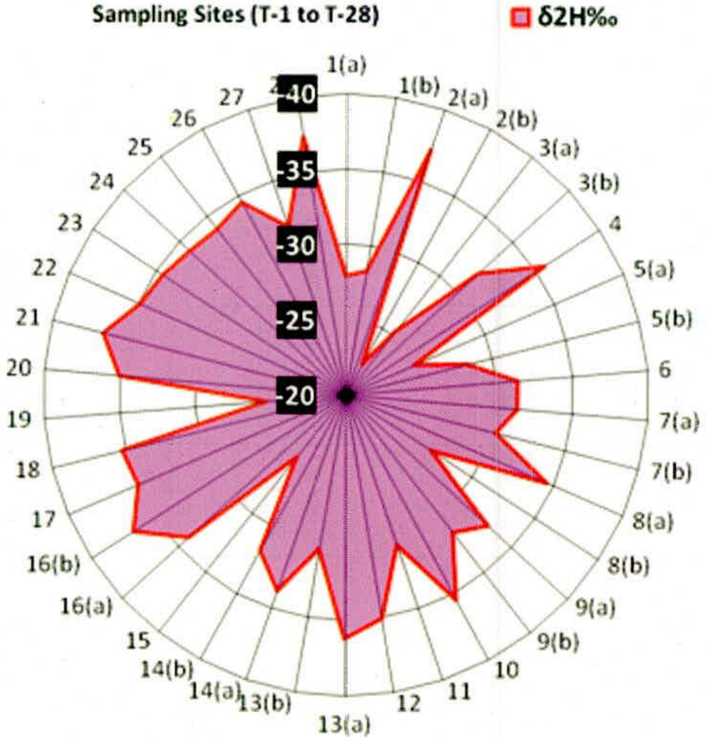


Fig. 5.35 : Variation of hydrogen isotope through radar diagram in ground water of Tezpur

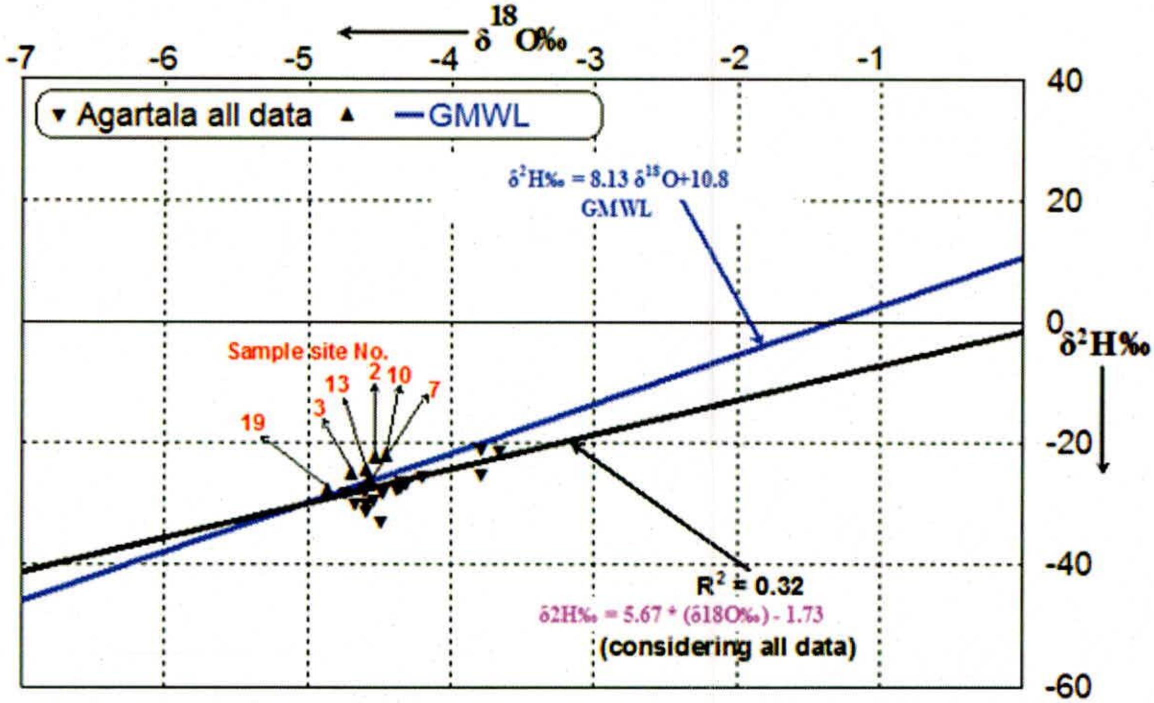


Fig. 5.36 : Correlation between hydrogen and oxygen isotope of gr. water of Agartala

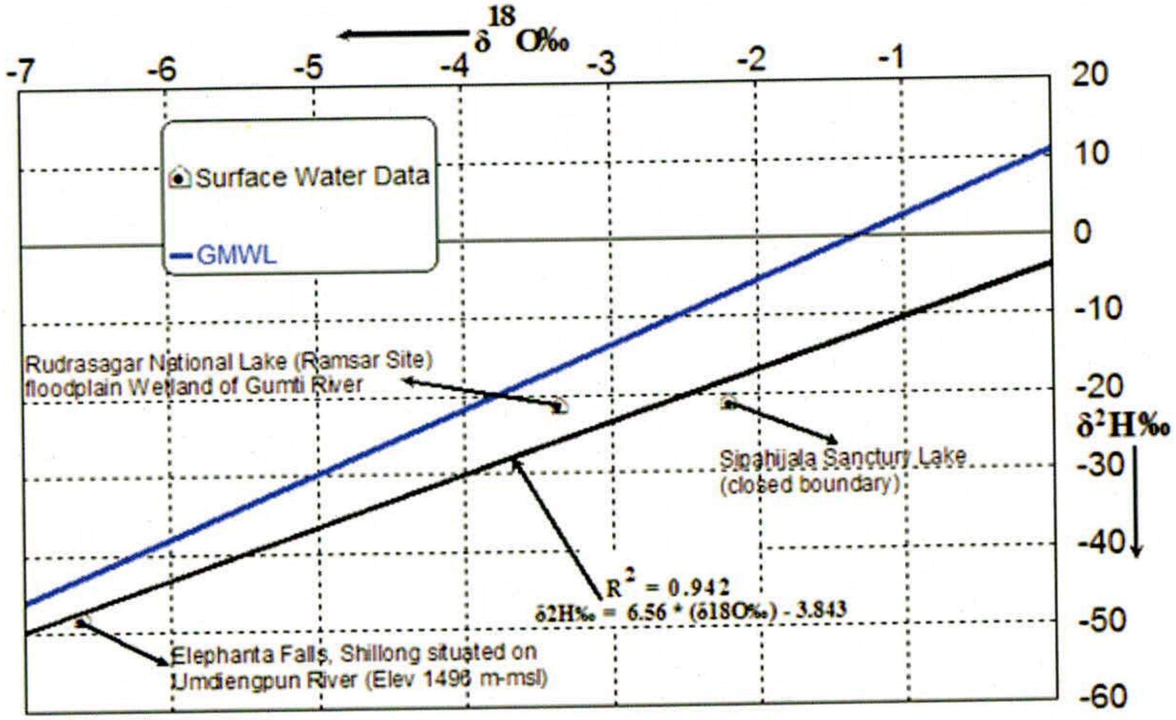


Fig. 5.37 : Correlation between hydrogen and oxygen isotope of surface water

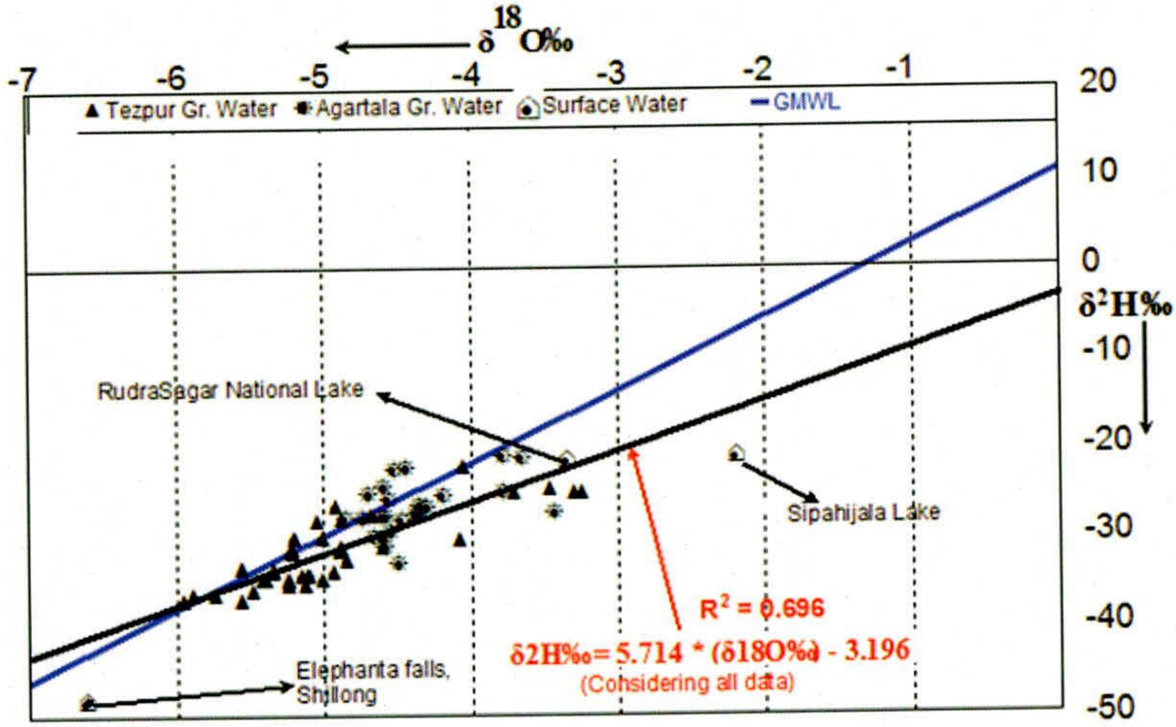


Fig. 5.38 : Correlation between hydrogen and oxygen isotope of gr. and surface water

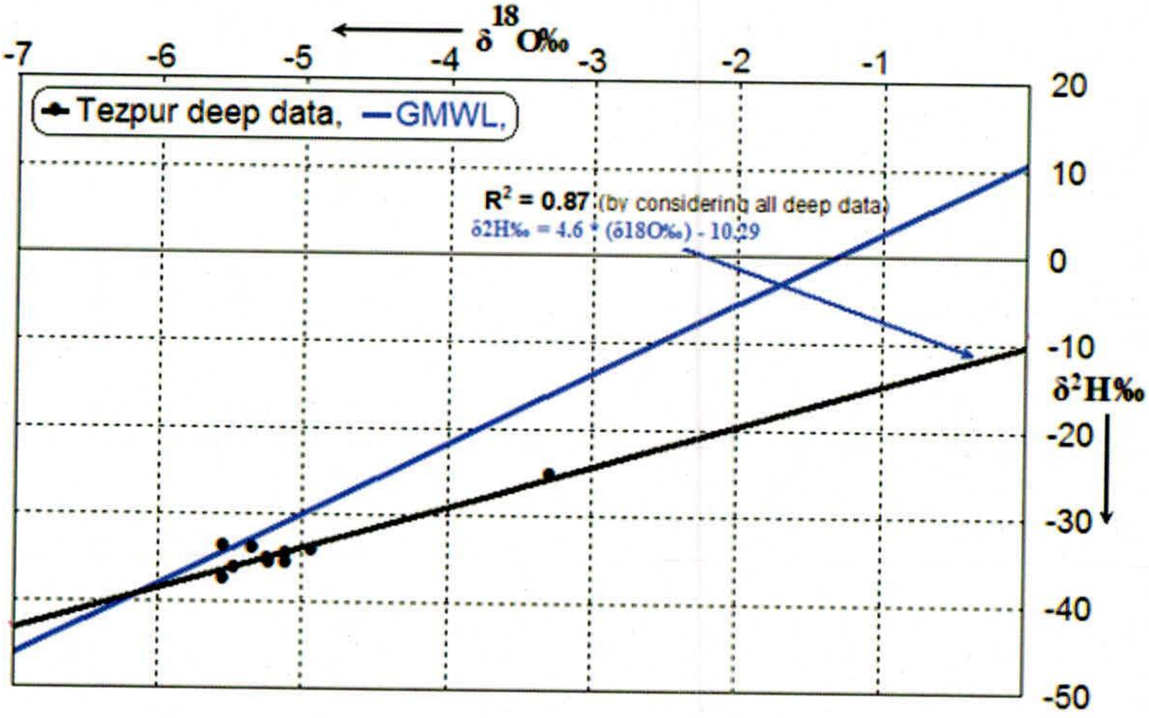


Fig. 5.39 : Correlation between hydrogen and oxygen isotope of gr. water (deep) of Tezpur

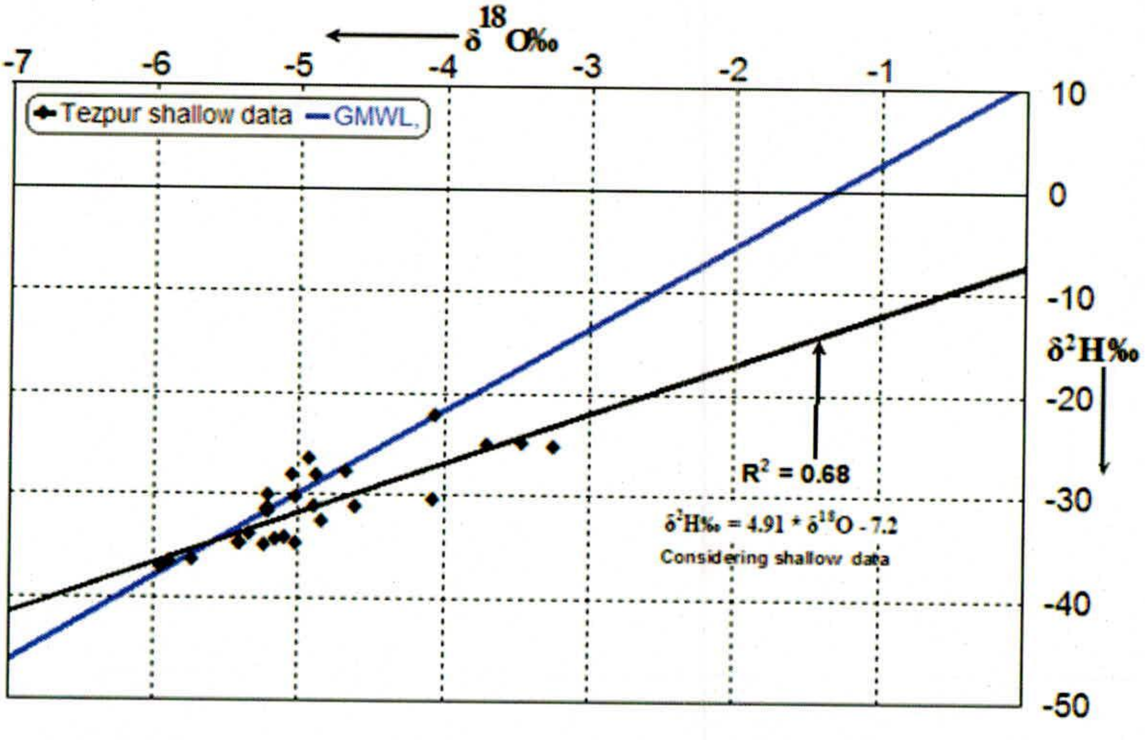


Fig. 5.40 : Correlation between hydrogen and oxygen isotope of gr. water (shallow) of Tezpur

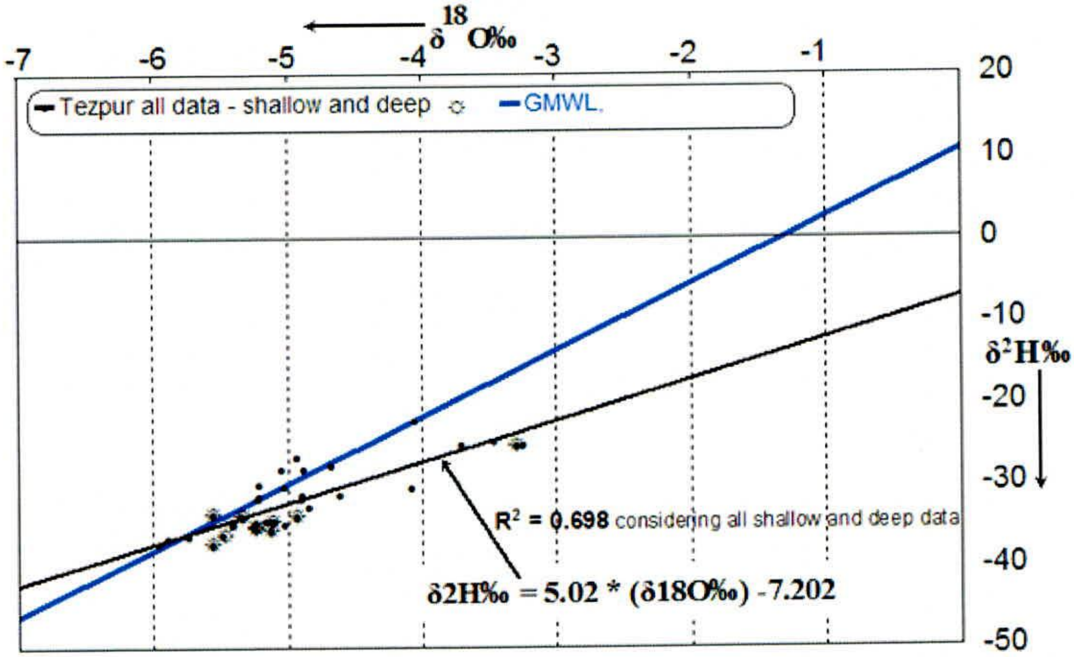


Fig. 5.41 : Correlation between hydrogen and oxygen isotope of gr. water of Tezpur

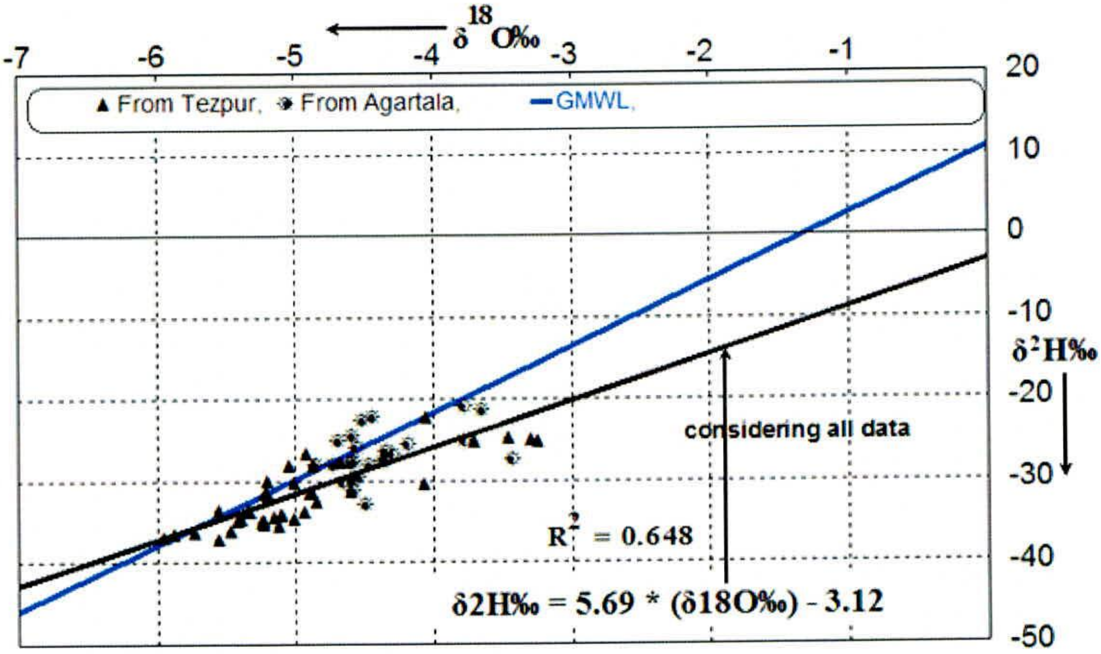


Fig. 5.42 : Correlation between hydrogen and oxygen isotope of gr. water of Agartala and Tezpur

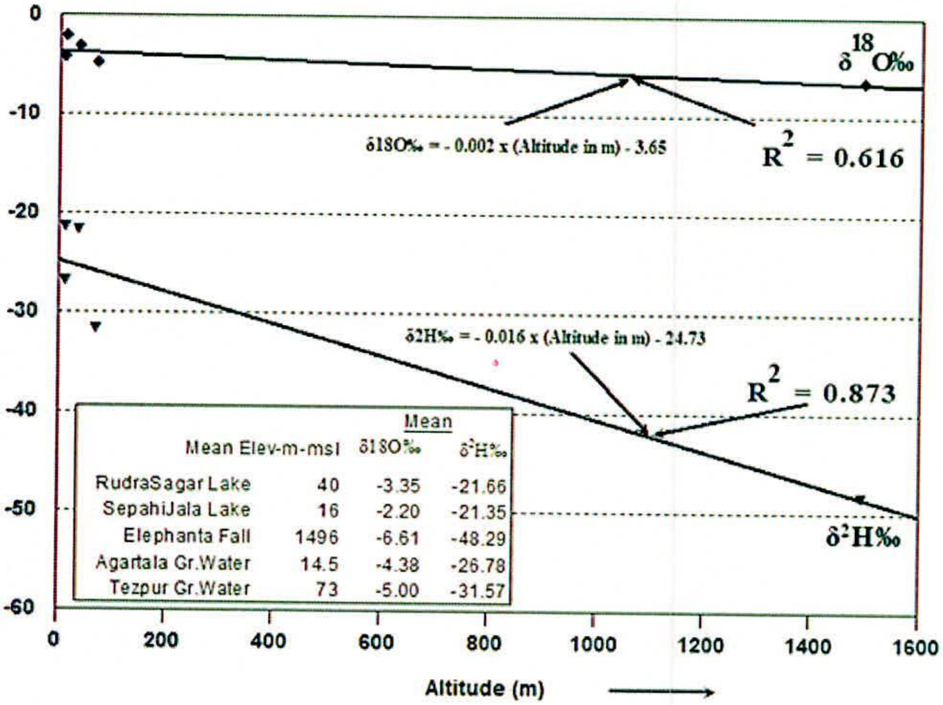


Fig. 5.43(a) : Correlation between altitude with hydrogen and oxygen isotope (average) of ground and surface water

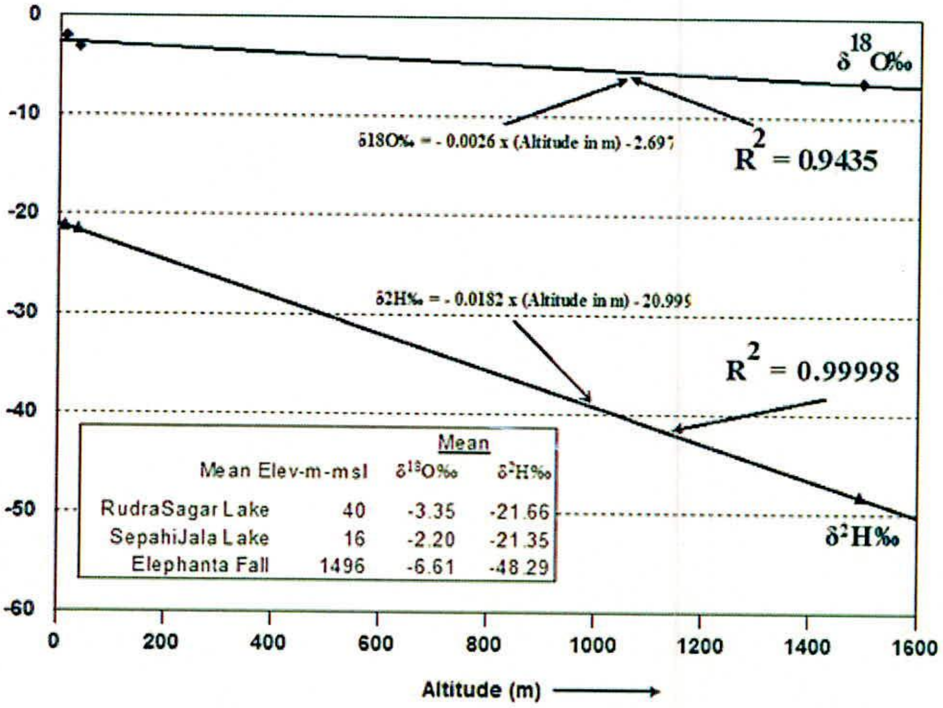
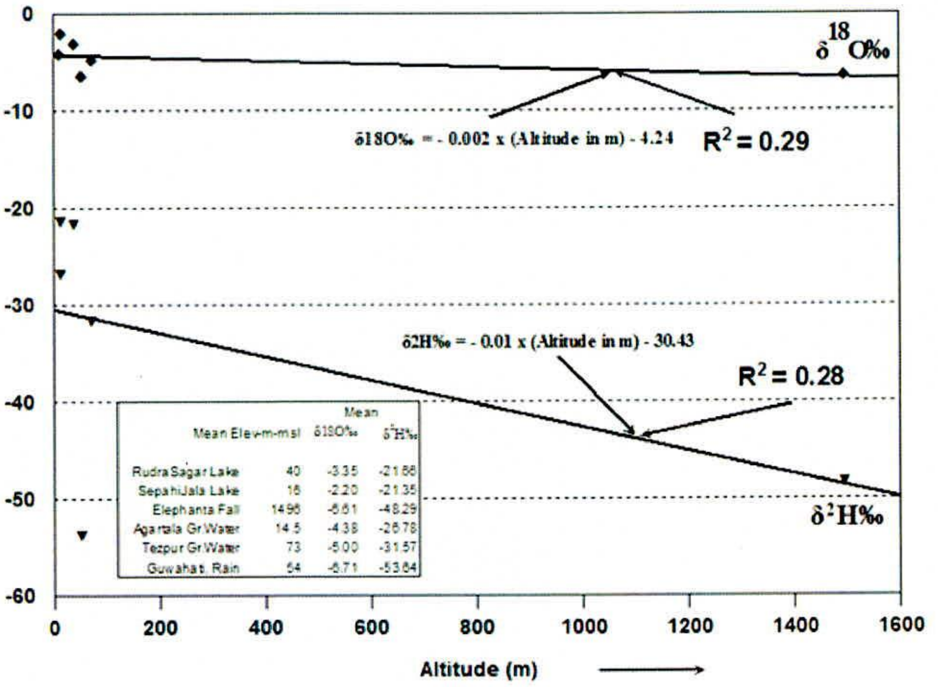


Fig. 5.43(b) : Correlation between altitude with hydrogen and oxygen isotope of surface water



	Mean Elev-m-msl	Mean δ18O‰	δ2H‰
Rudra Sagar Lake	40	-3.35	-21.66
SepahiJala Lake	16	-2.20	-21.35
Elephanta Fall	1496	-6.61	-48.29
Agartala Gr.Water	14.5	-4.38	-26.78
Tezpur Gr.Water	73	-5.00	-31.57
Guwahati Rain	54	-6.71	-53.64

Fig. 5.43(c) : Correlation between altitude with hydrogen and oxygen isotope (average) of Rain, Ground and Surface Water

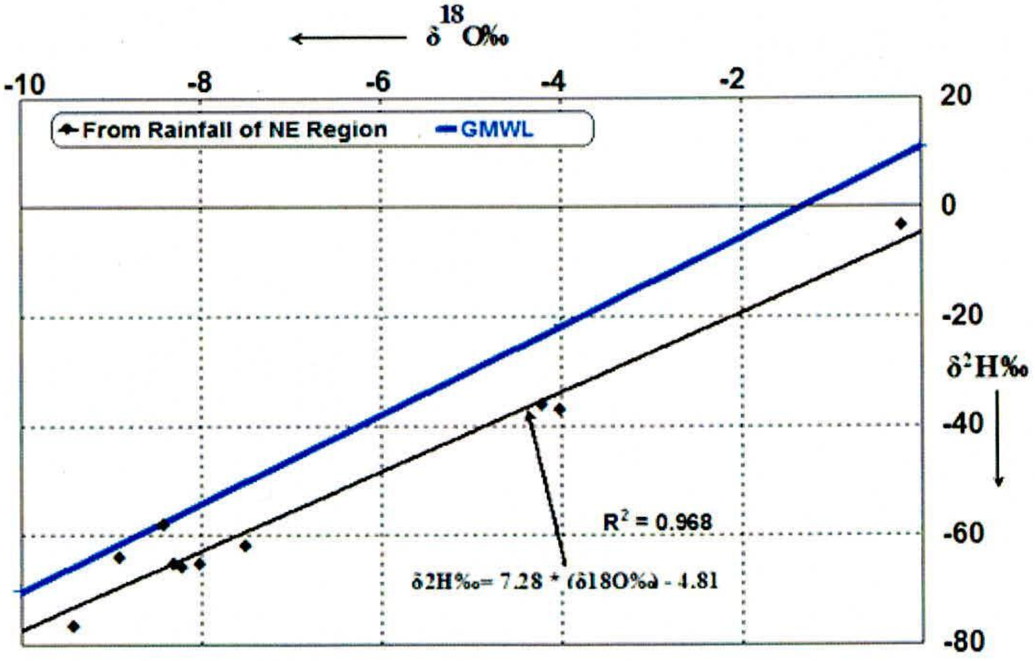


Fig. 5.44(a) : Correlation of hydrogen and oxygen isotope in rain water samples of NE region

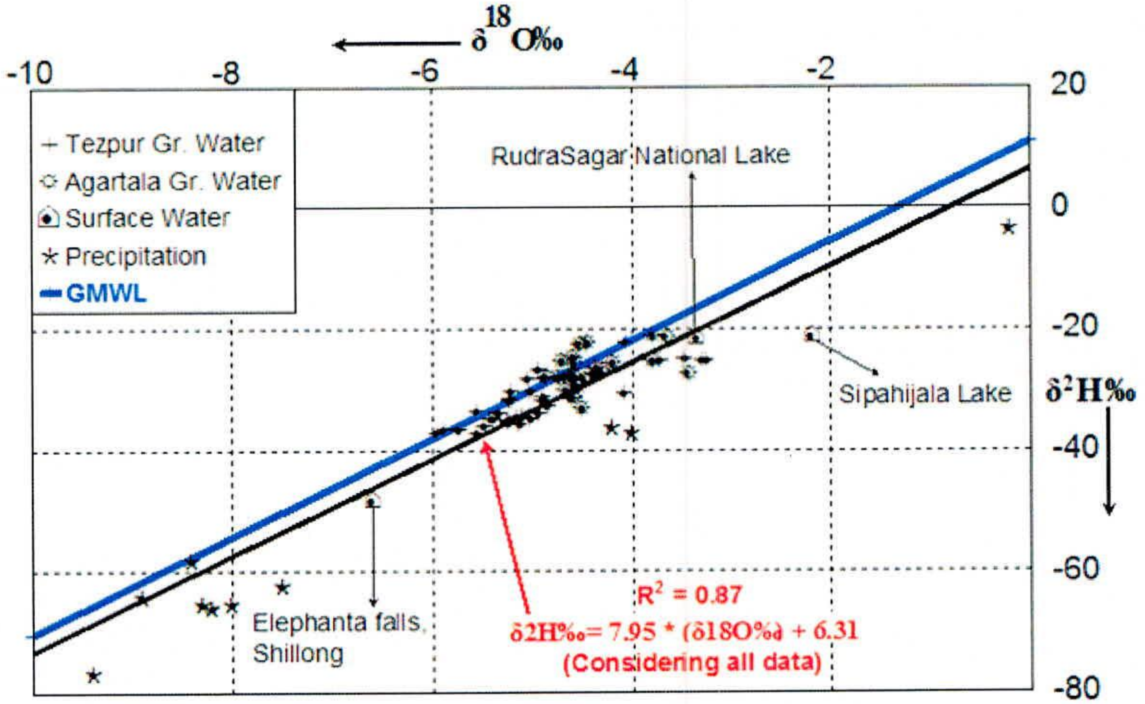


Fig. 5.44(b) : Regional Water Line between hydrogen and oxygen isotopes FOR NE region

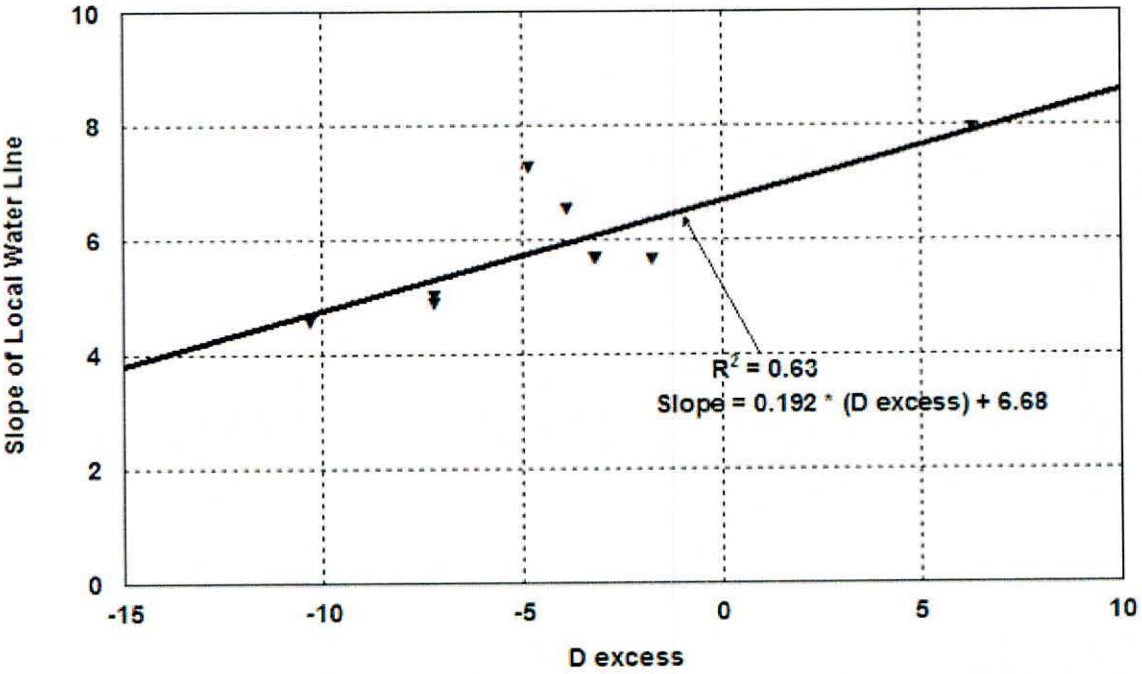


Fig. 5.44(c) : Plot of Slope versus D excess as derived from different Local Water Lines

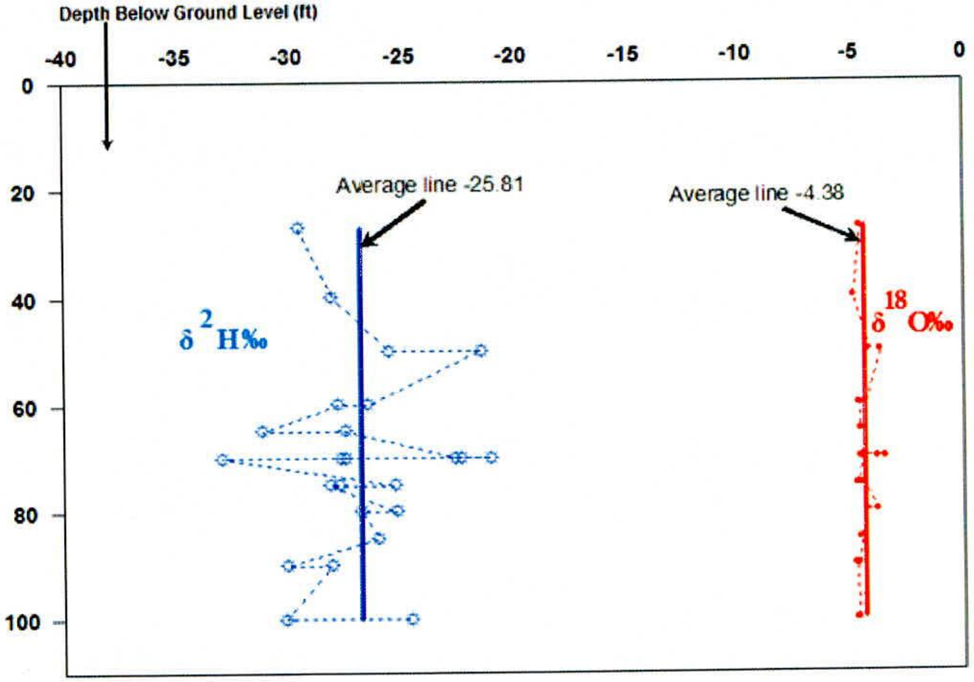


Fig. 5.45(a) : Depth wise variation of hydrogen and oxygen isotopes in ground water of Agartala

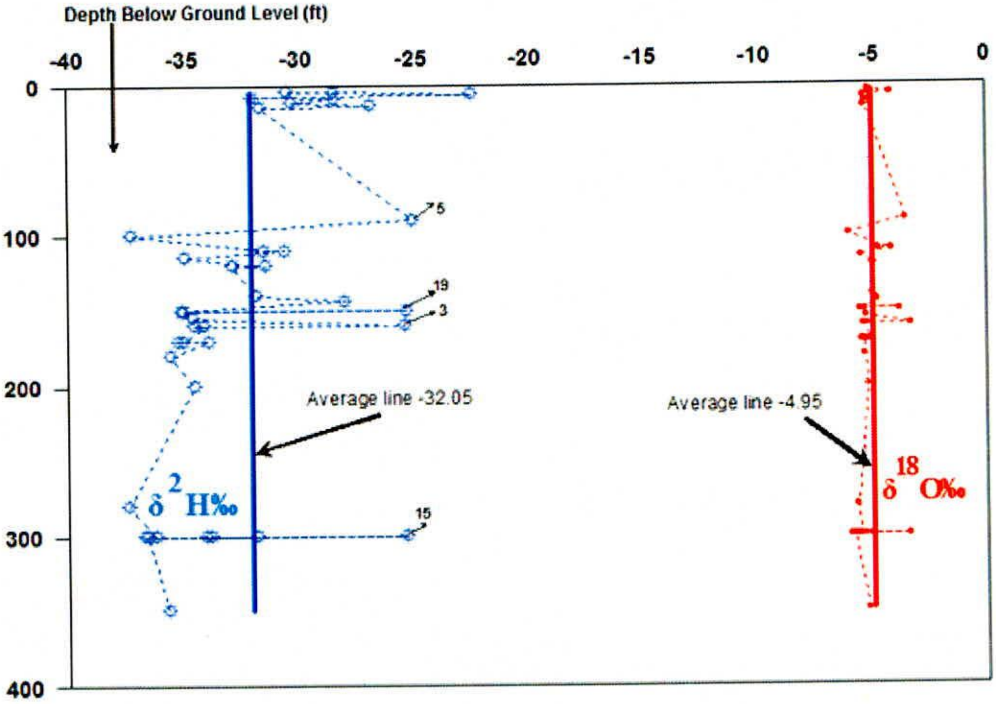


Fig. 5.45(b) : Depth wise variation of hydrogen and oxygen isotopes in ground water of Tezpur

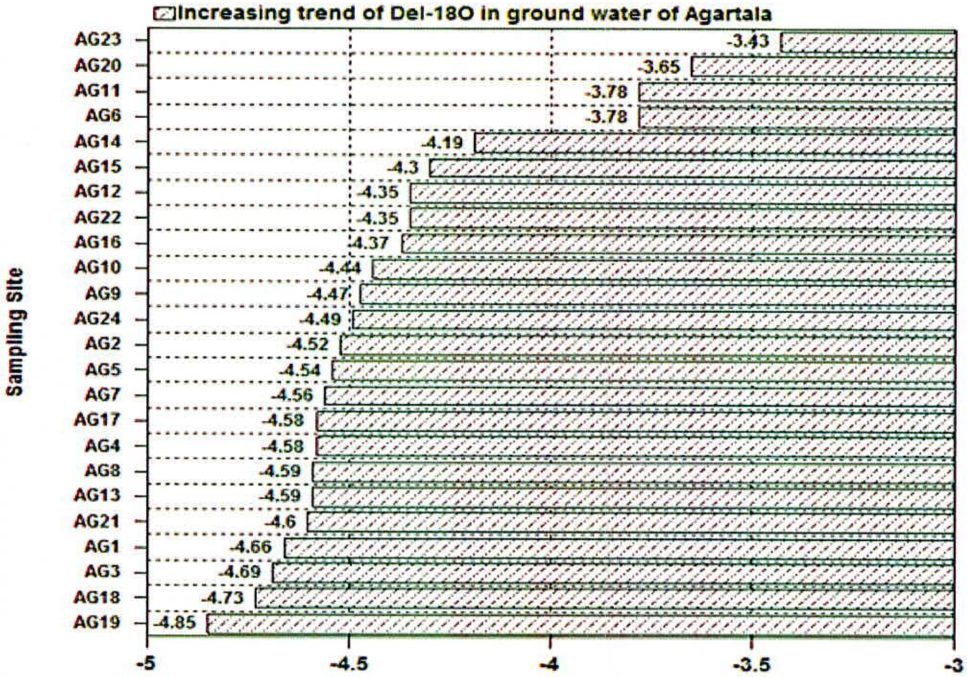


Fig. 5.46(a) : Increasing trend of ?18O in ground water of Agartala

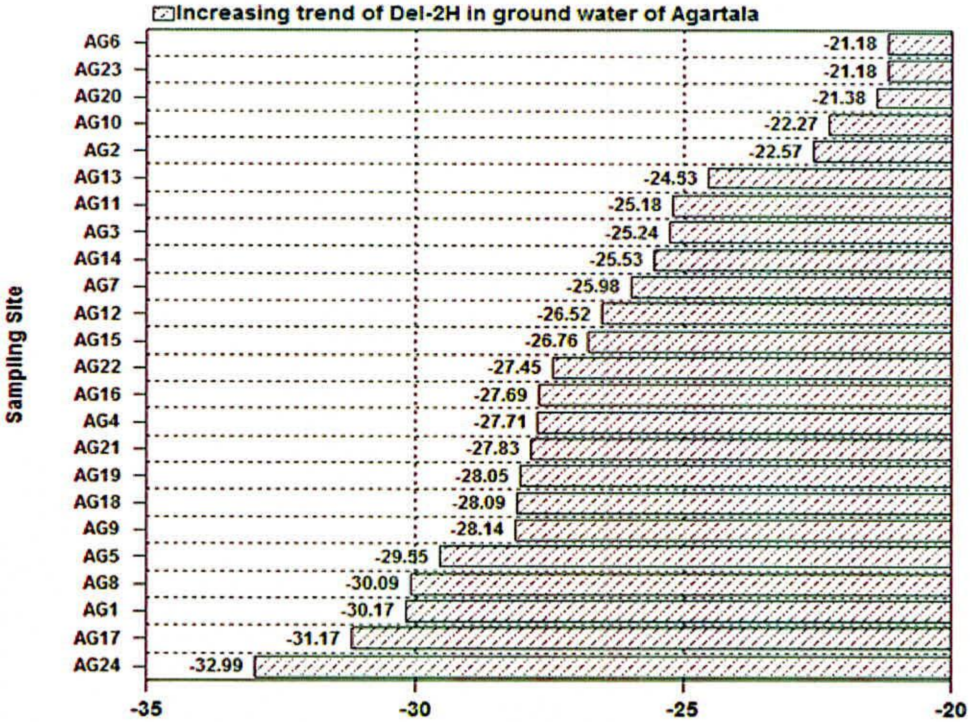


Fig. 5.46(b) : Increasing trend of ?2H in ground water of Agartala

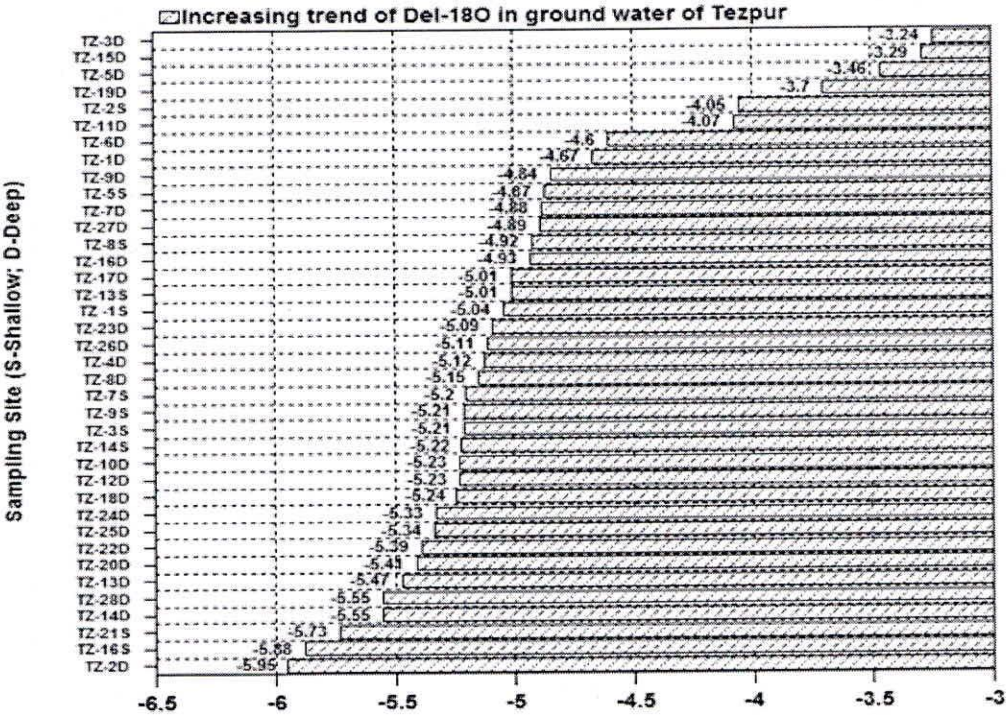


Fig. 5.47(a) : Increasing trend of ?18O in ground water of Tezpur

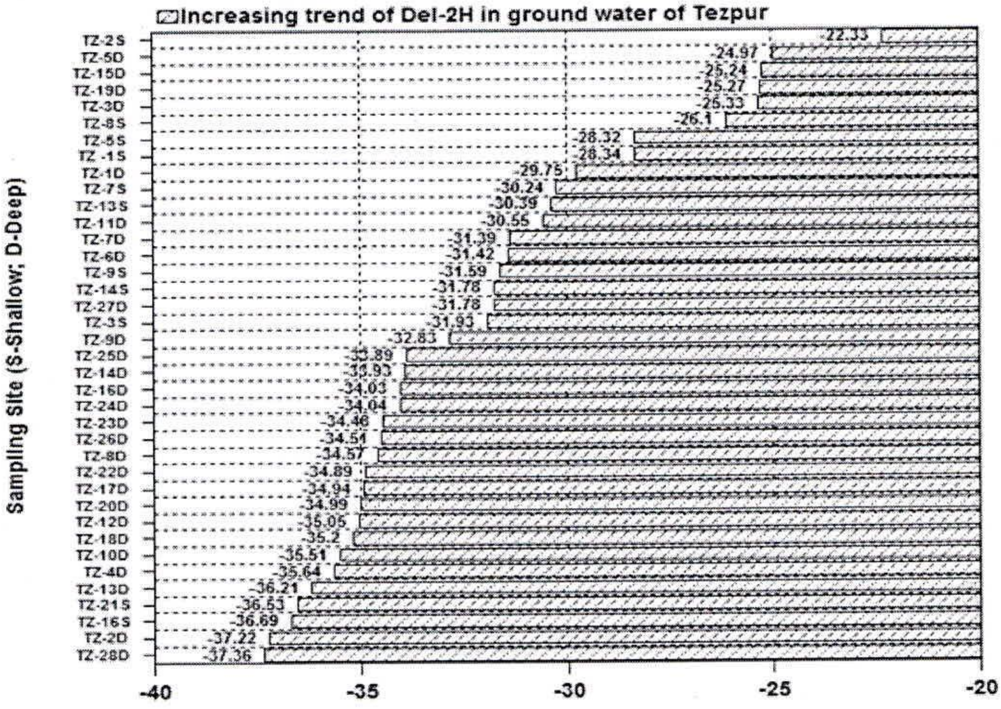


Fig. 5.47(b) : Increasing trend of ?2H in ground water of Tezpur

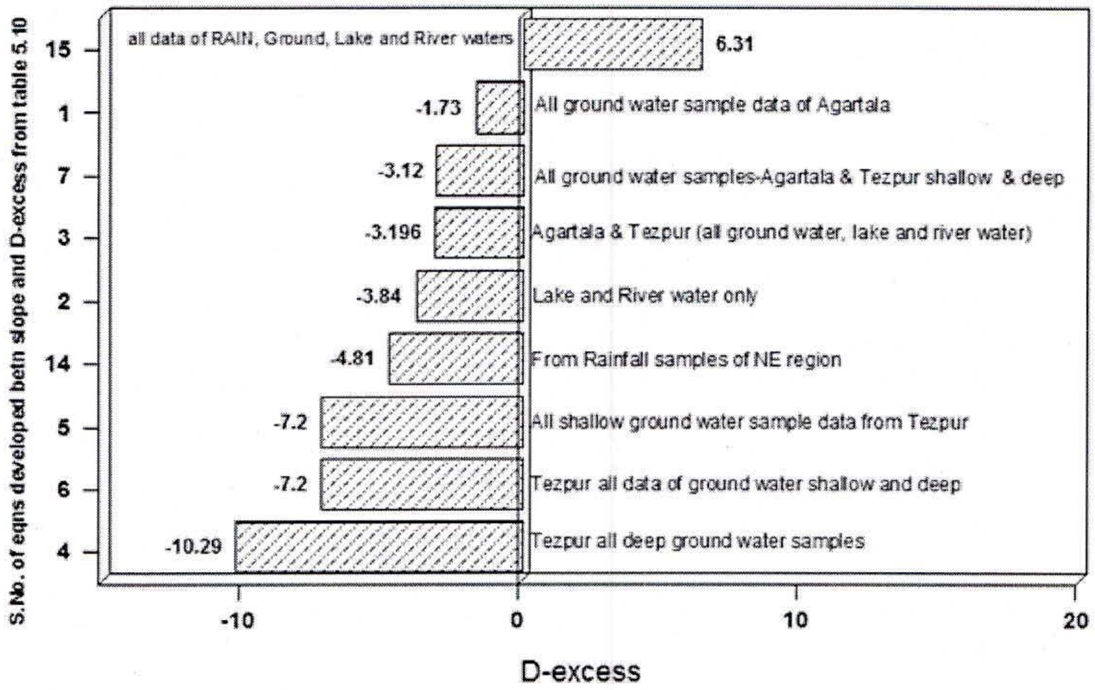


Fig. 5.47(c) : Increasing trend of D excess from developed Local Water Lines under different combinations

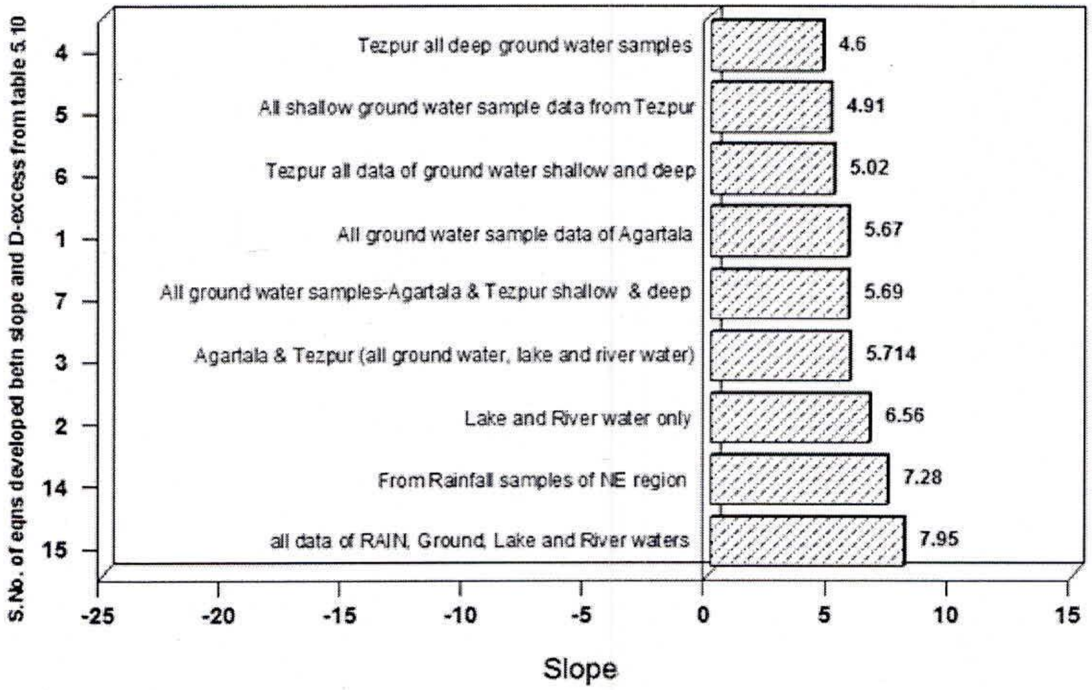


Fig. 5.47(d) : Increasing trend of Slope of different developed Local Water Lines under various combination

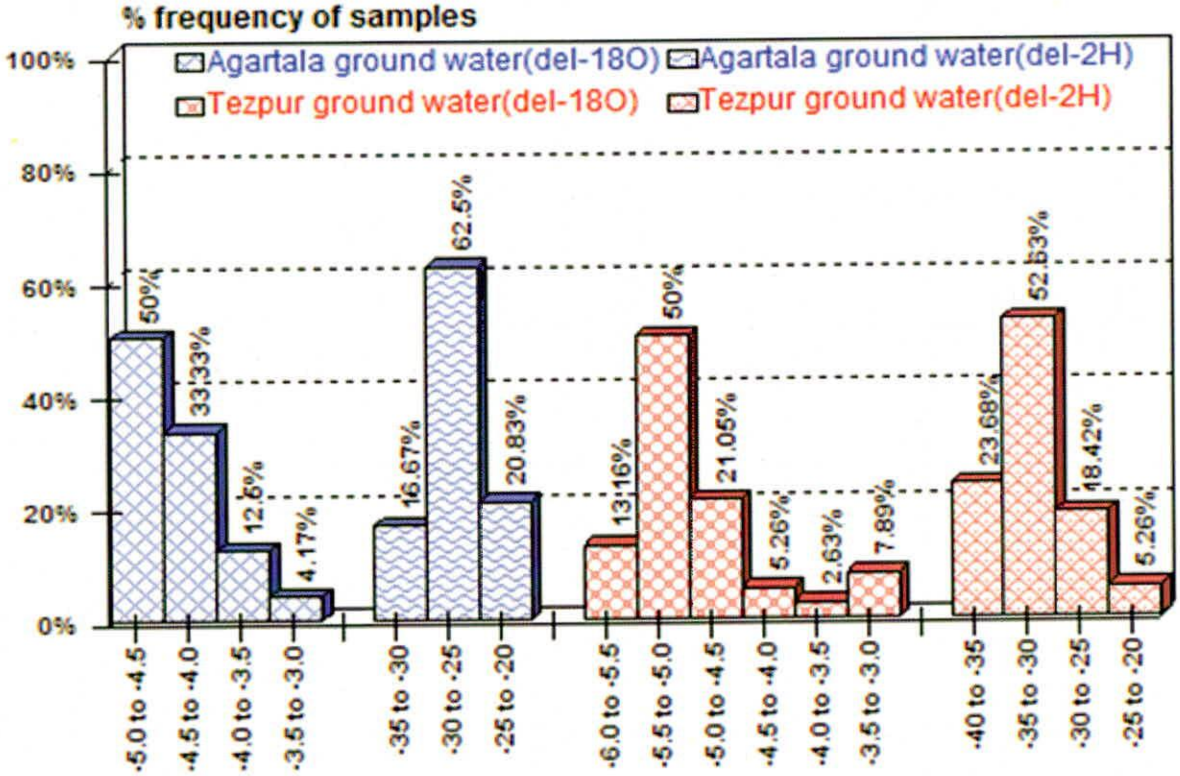


Fig. 5.47(e) : % Frequency of ground water samples of Agartala and Tezpur taken separately

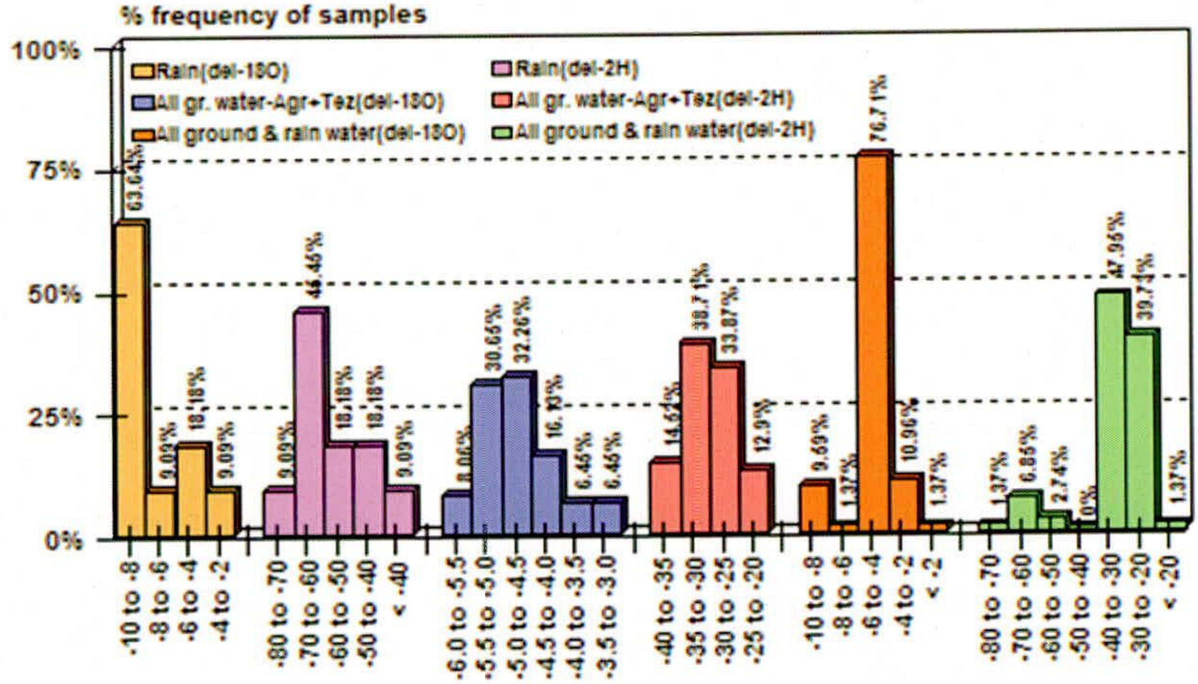


Fig. 5.47(f) : % Frequency of ground water of Agartala and Tezpur with rain water samples

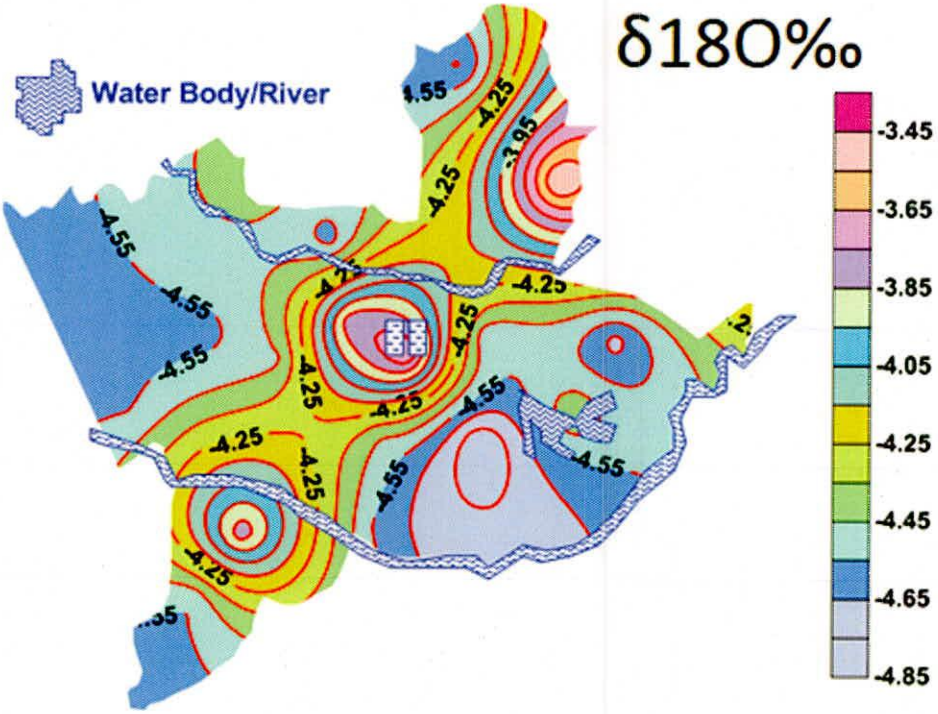


Fig. 5.48(a) : Variation of oxygen isotope in ground water of Agartala through thematic map

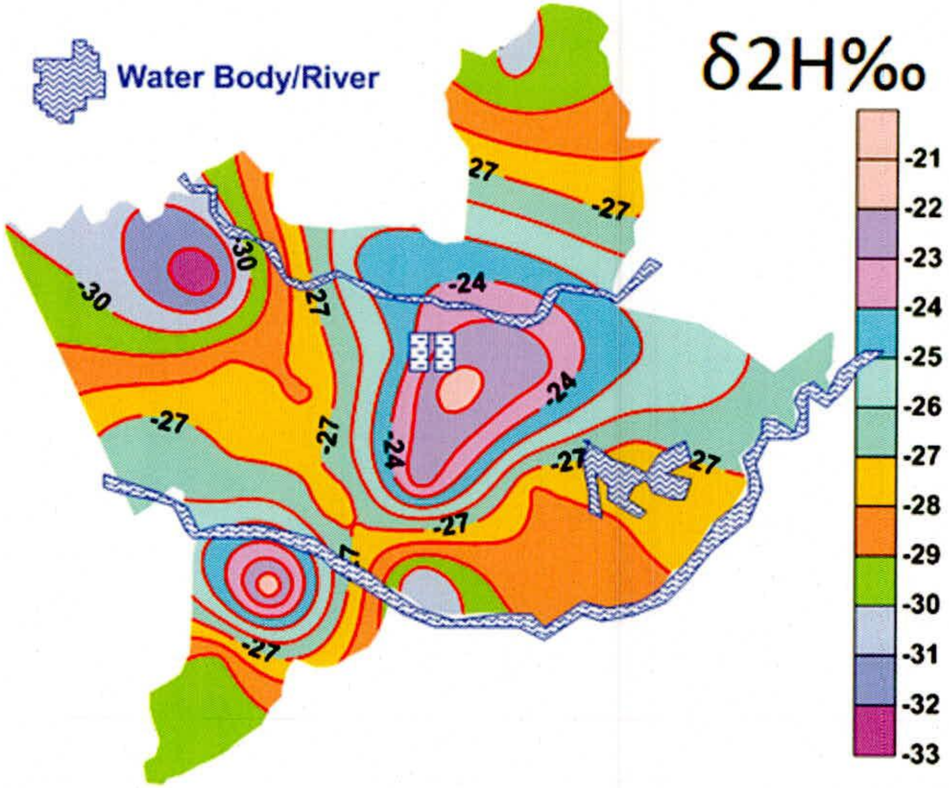


Fig. 5.48(b) : Variation of hydrogen isotope in ground water of Agartala through thematic map

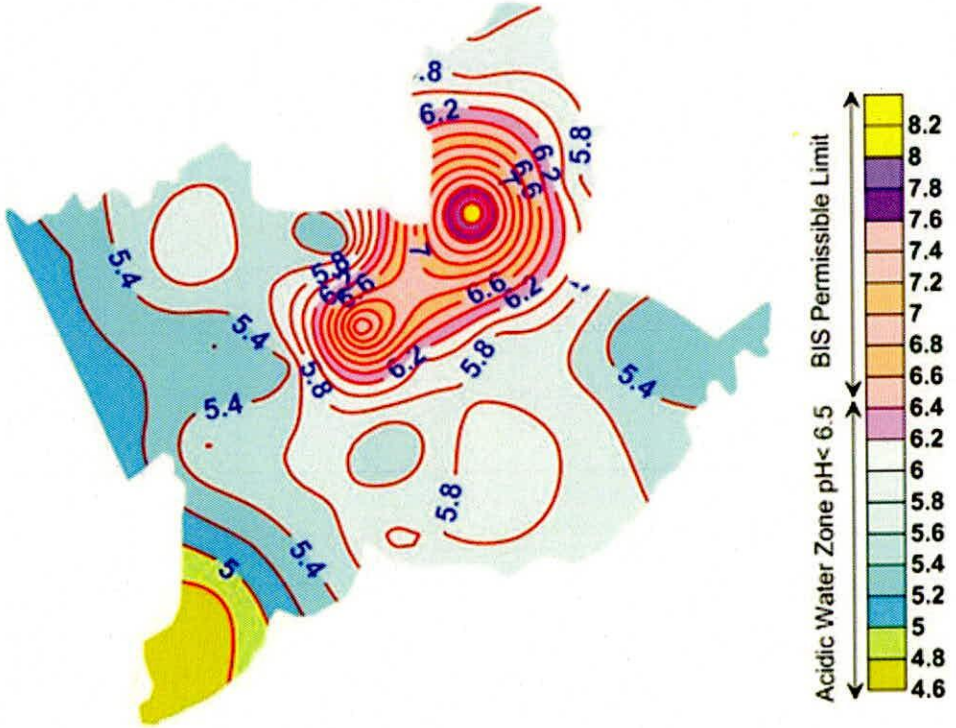


Fig. 5.49 : Variation of pH in ground water of Agartala through thematic map

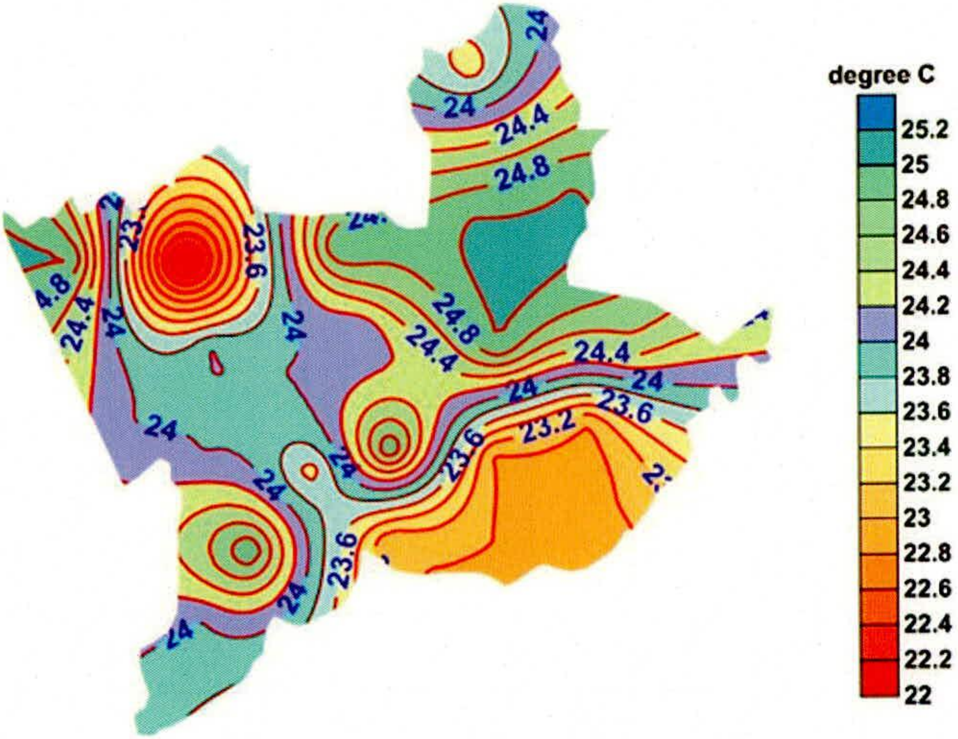


Fig. 5.50 : Variation of temperature in ground water of Agartala through thematic map

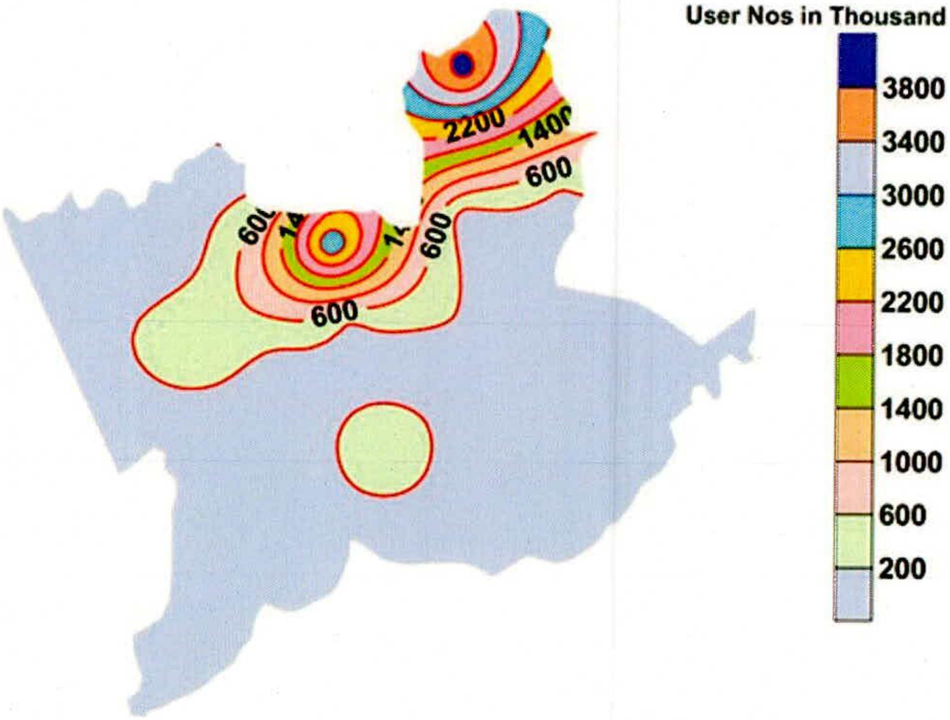


Fig. 5.51 : Variation of user nos. from each tube well of Agartala through thematic map

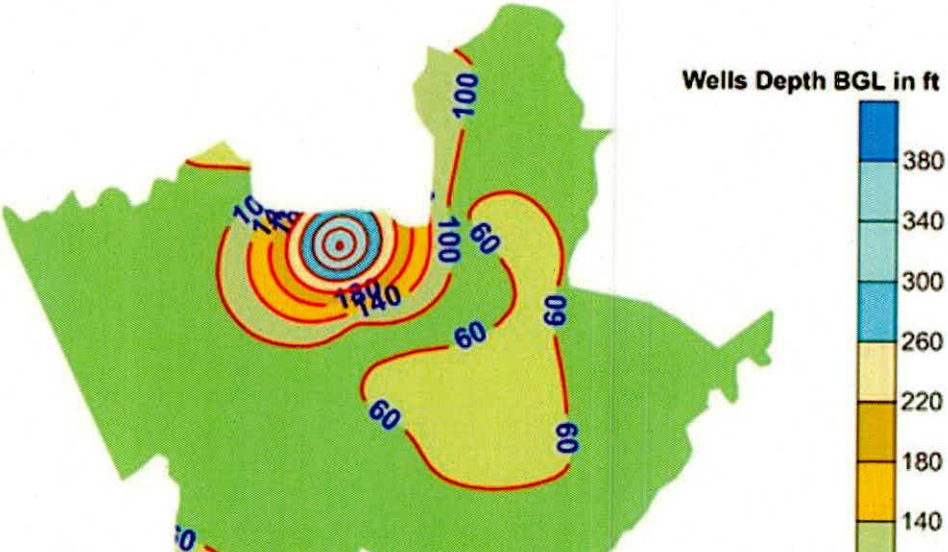


Fig. 5.52 : Variation of area wise depth of sampling wells in Agartala through thematic map

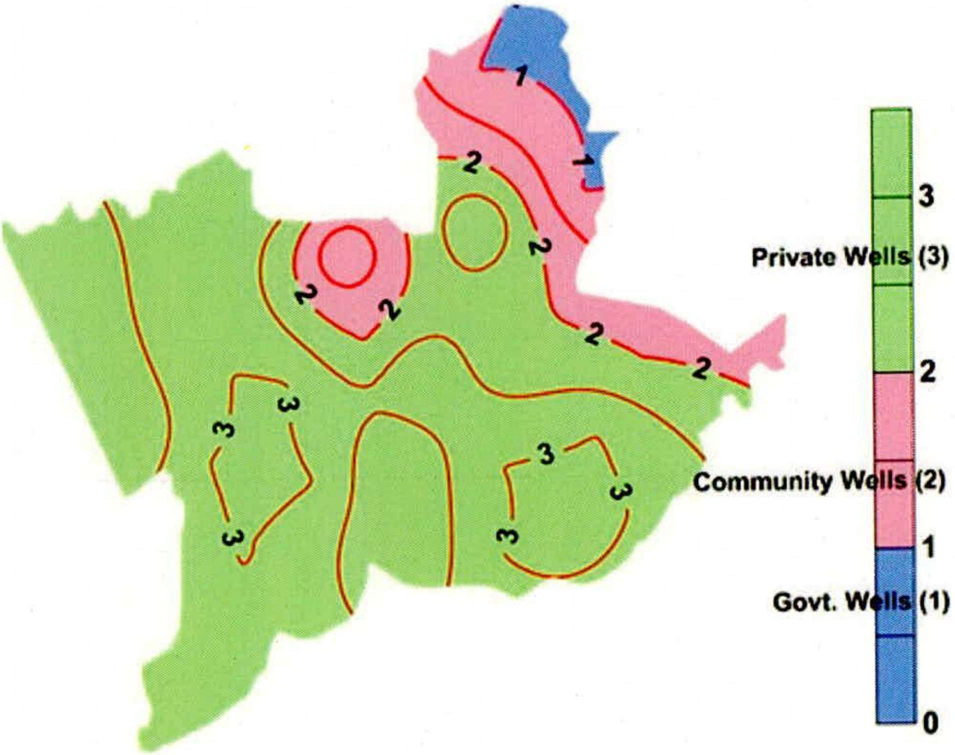


Fig. 5.53 : Variation of ownership of tube wells in Agartala through thematic map

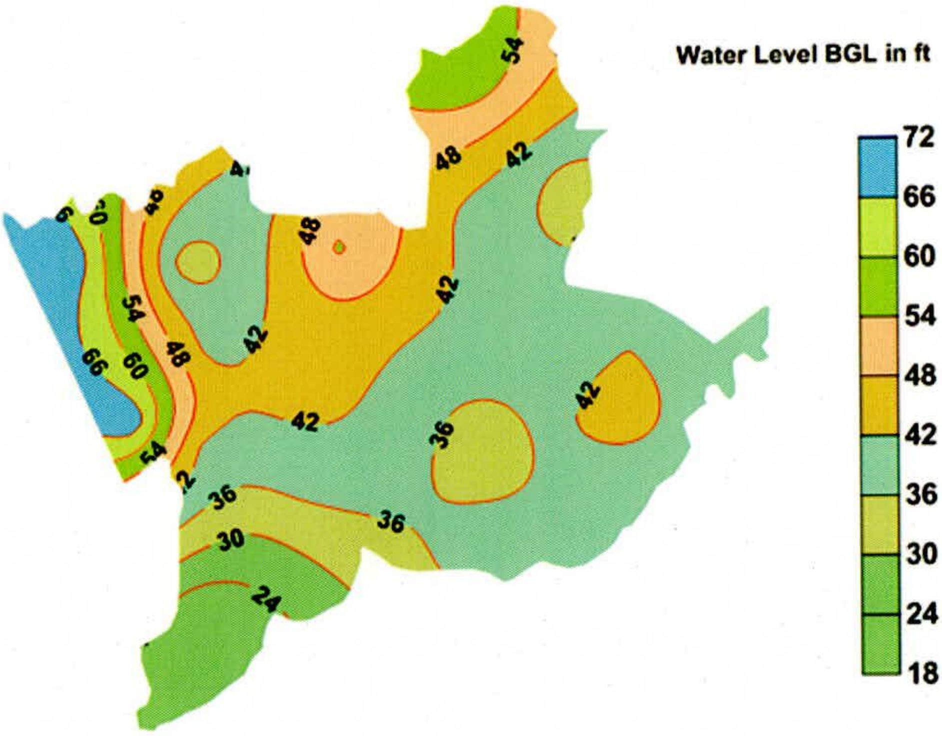


Fig. 5.54 : Variation of water level of ground water in Agartala through thematic map

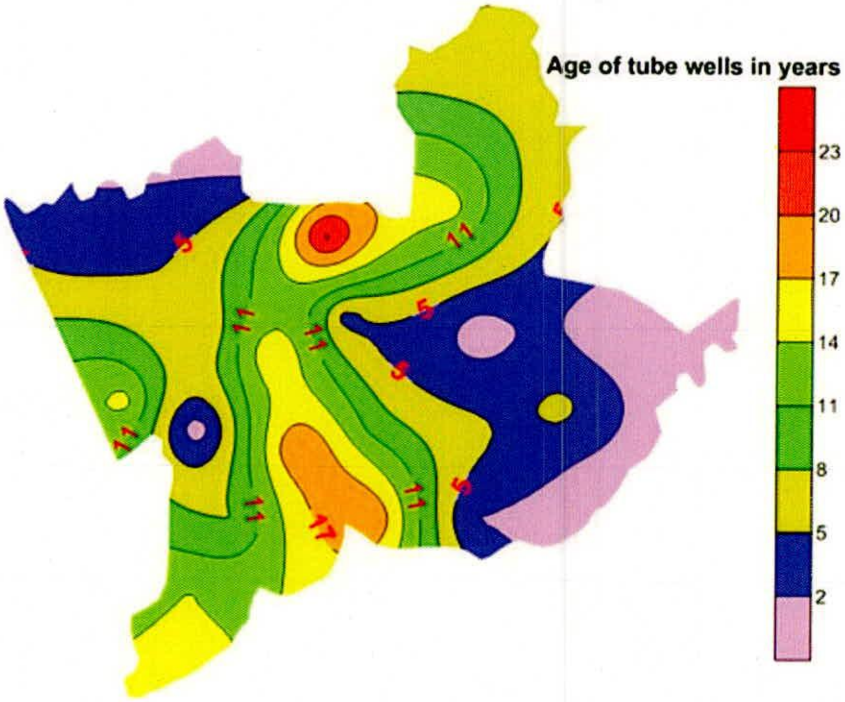


Fig. 5.55 : Variation of area wise age of tube wells in Agartala through thematic map

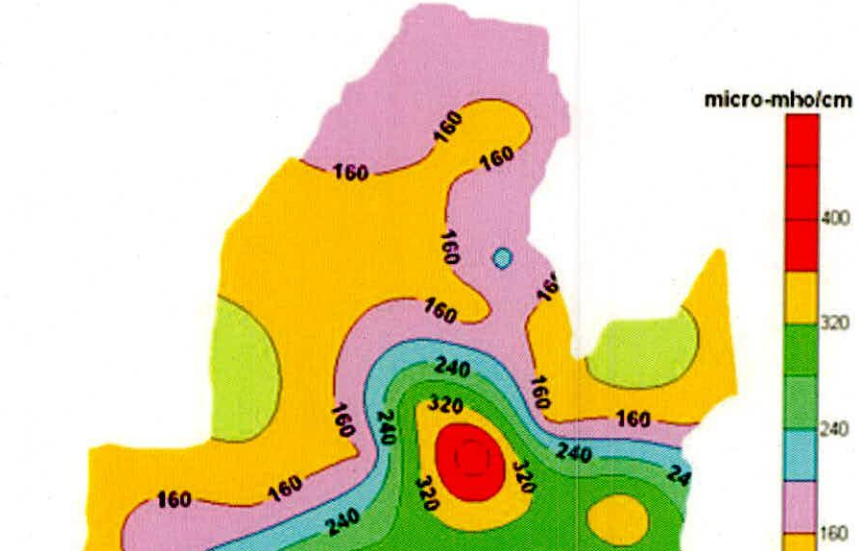


Fig. 5.56 : Variation of conductivity in ground water of Tezpur through thematic map

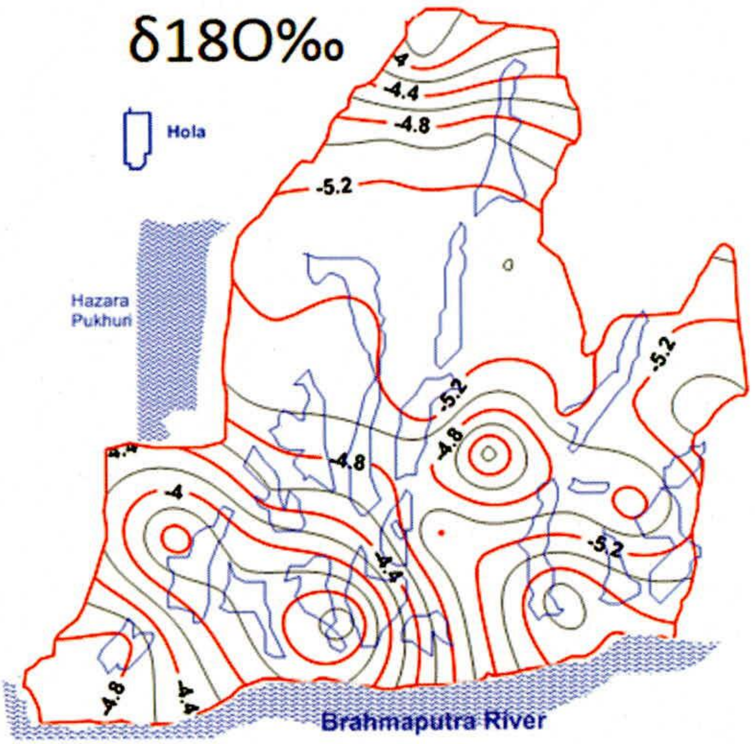


Fig. 5.57 : Variation of oxygen isotope in ground water of Tezpur through thematic map

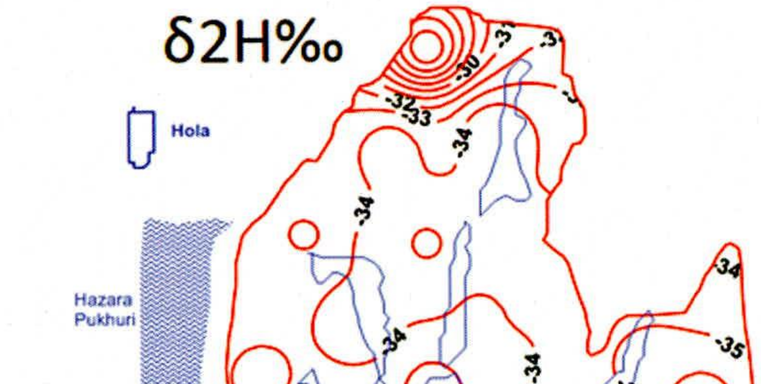


Fig. 5.58 : Variation of hydrogen isotope in ground water of Tezpur through thematic map

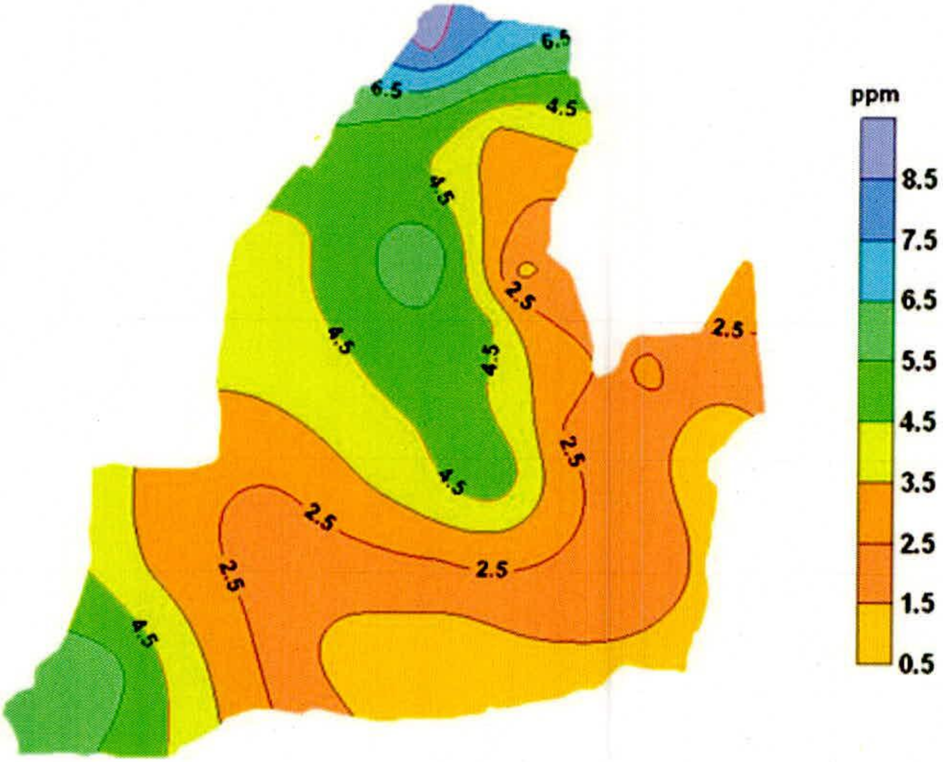


Fig. 5.59 : Variation of dissolved oxygen in ground water of Tezpur through thematic map

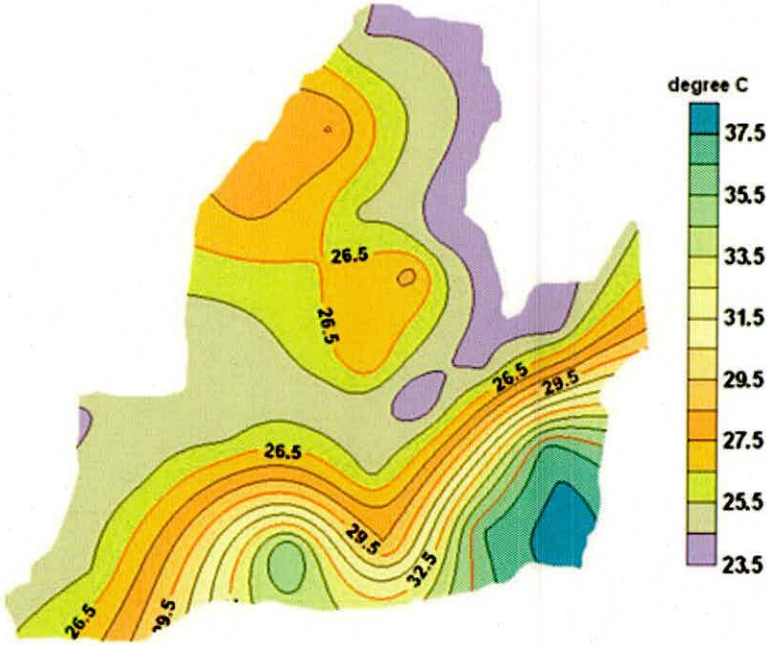


Fig. 5.60 : Variation of temperature in ground water of Tezpur through thematic map

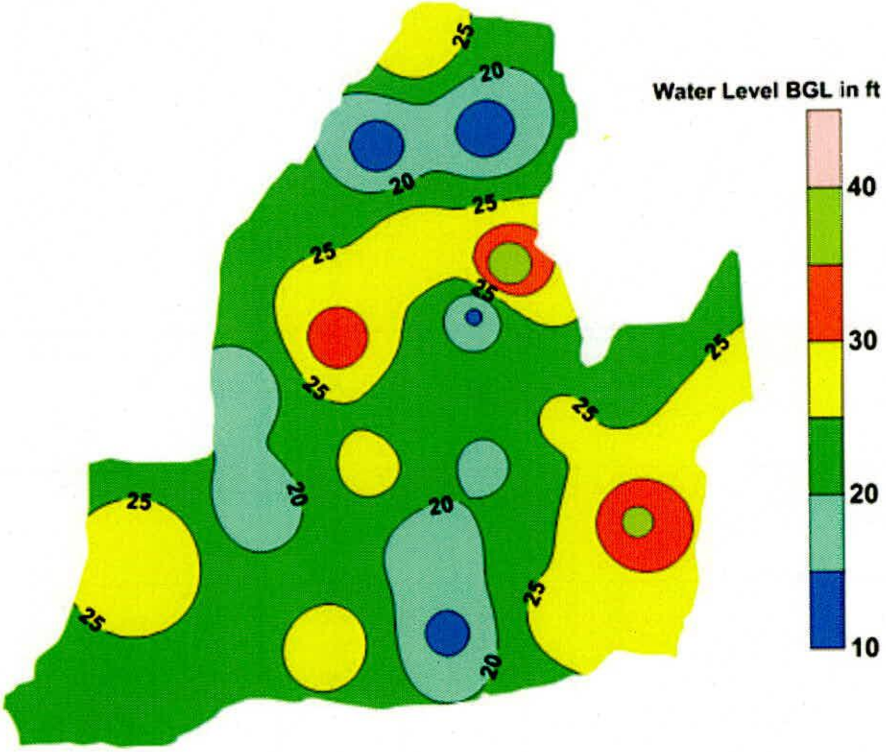


Fig. 5.61 : Variation of ground water level in Tezpur through thematic map

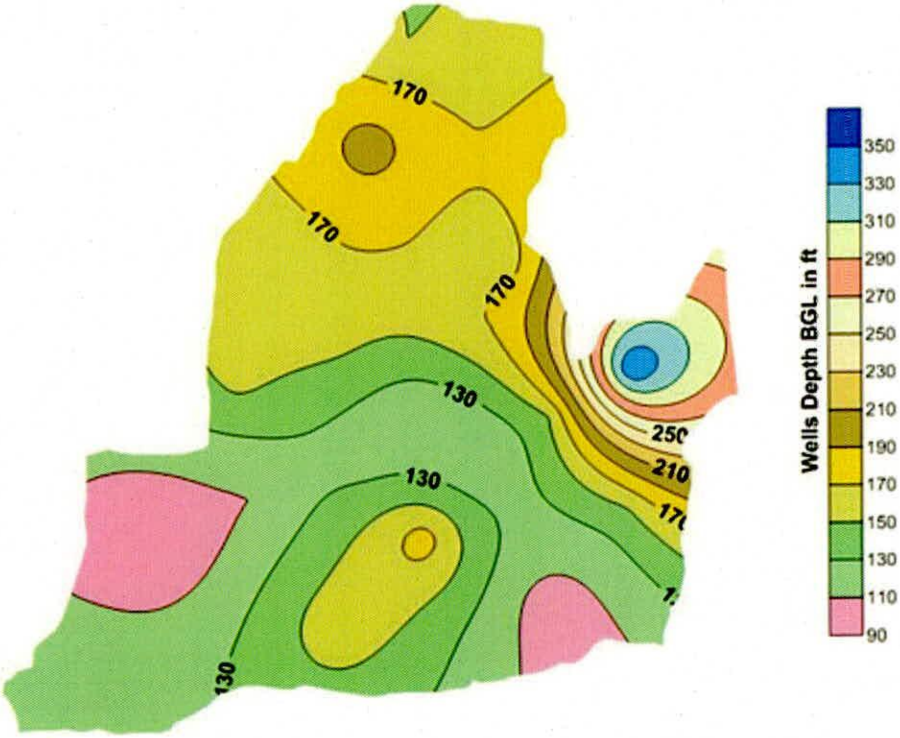


Fig. 5.62 : Variation of area wise well depth in Tezpur through thematic map

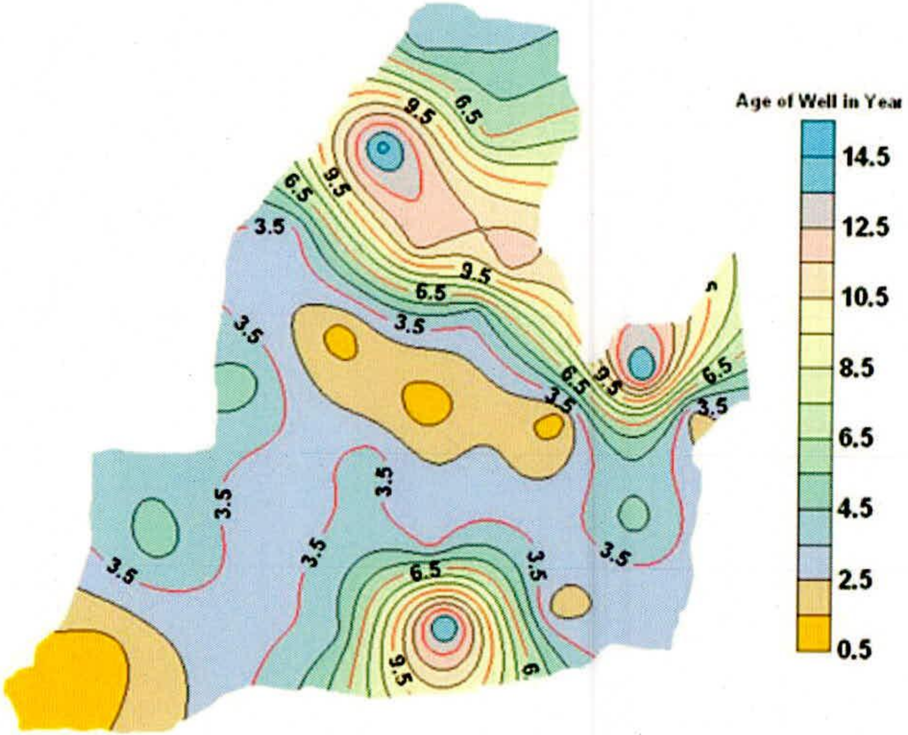


Fig. 5.63 : Variation of area wise age of tube wells in Tezpur through thematic map

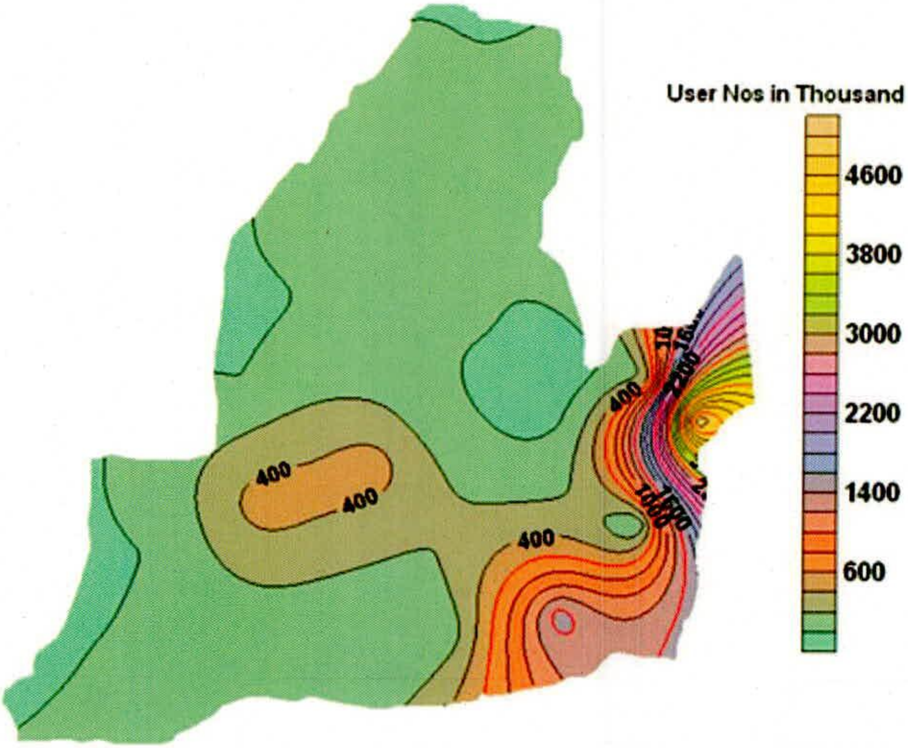
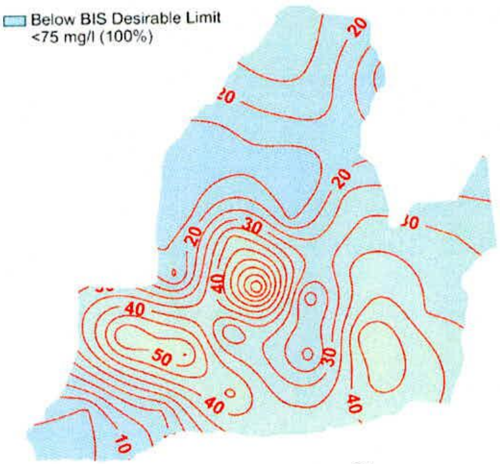
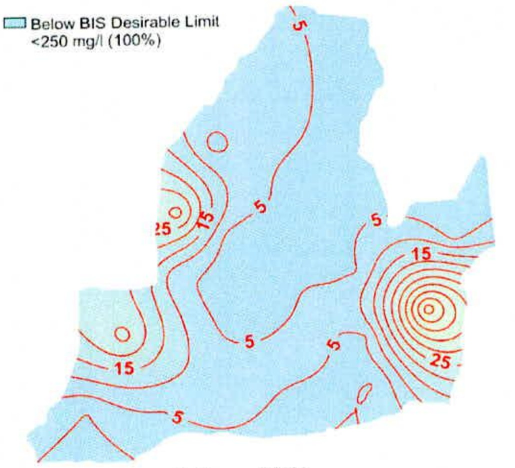


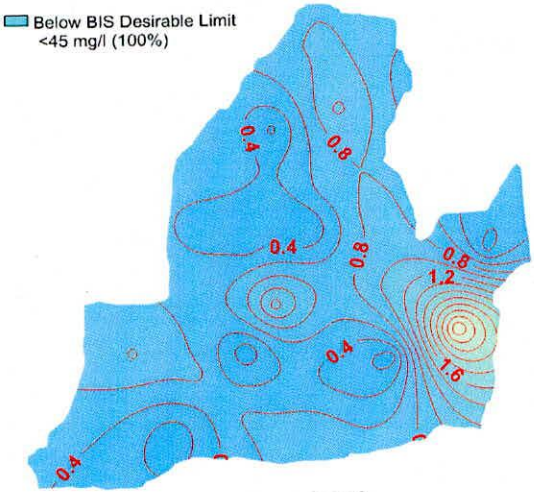
Fig. 5.64 : Variation of ownership of tube wells in Tezpur through thematic map



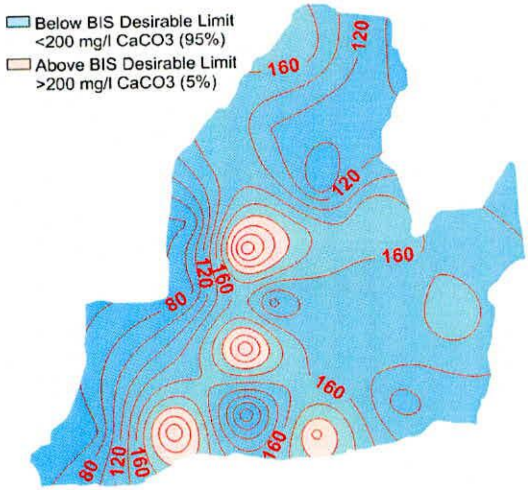
variation of Ca^{2+}



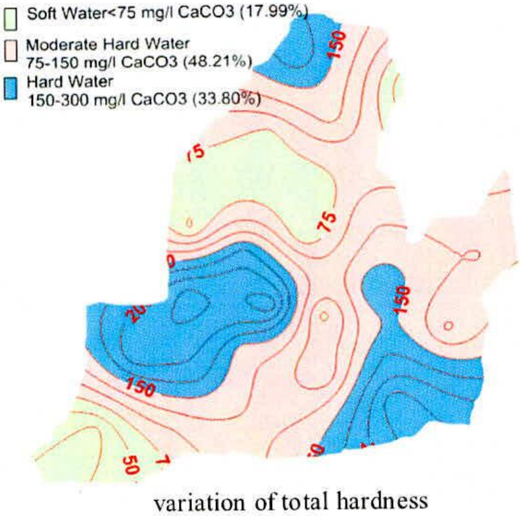
variation of Cl^-



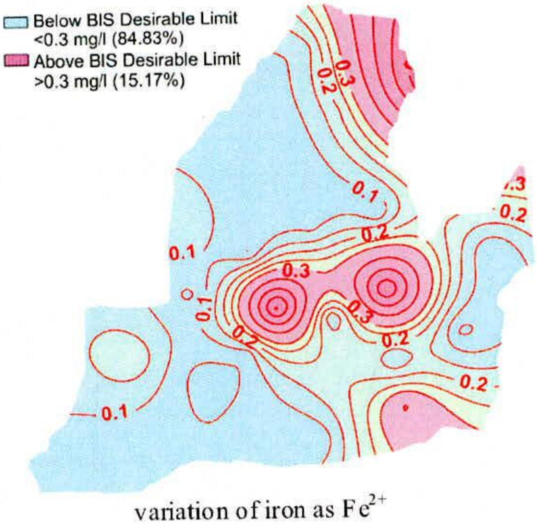
variation of NO^{2-}_3



variation of total alkalinity



variation of total hardness



variation of iron as Fe^{2+}

Fig. 5.65 : Spatial Variation of Ca^{2+}, Cl^-, NO^{2-}_3, Alkalinity, Hardness and Fe^{2+} in Gr. Water of Tezpur

6.0 CONCLUDING REMARKS AND RECOMMENDATIONS

The study is focused on the variation of ground water quality in the area and the following points emerged from the analysis of the ground water samples of Agartala and Tezpur.

1. As per the stiff classification, most of the samples were found to be of either Mg^{2+}-HCO_3^- type or Na^+ HCO_3^- type.

2. According to the USSL Classification of irrigation water, samples fall under water type C1 S1 (low salinity and low SAR) and C2 S1 type (medium salinity and low SAR). Few samples fall under C2 S3 and C2-S4 type (medium salinity and medium to high SAR).

3. According to Doneen's classification most of the samples are class II and class-III type.

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

5. Durov's trilinear classification shows that in cation type, majority of the samples are Mg^{2+}, Na^+ and intermediate type while, in anion type, samples fall in HCO_3^- 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 Agartala and Tezpur.

7. Based on the low pH value (< 6.5) of the Agartala area, it may be concluded that well waters of Agartala are skewed towards corrosive in nature. Acidic water quality also contributes to corrosiveness and corrodes concrete and metallic pipes of water distribution system and hand pumps. Corrosion in a water distribution system can cause three distinct but related problems. First, pipe mass is lost through oxidization to soluble iron species or iron-bearing scale. Second, the scale can accumulate as large tubercles that increase head loss and decrease water capacity. Finally, the release of soluble or particulate iron corrosion-byproducts to the water decreases its aesthetic quality and often leads to consumer complaints of *"red water"* at the tap.

Using plastic and CPVC pipes in the house and non-corrosive fixtures may eliminate corrosion related problems in water distribution system. Corrosion control options include pretreatment systems, installation of non-conductive unions, reducing hot water temperature, and replacing metal pipes with CPVC. Pretreatment systems include neutralizing tank filters and caustic liquid treatment. These systems change the pH, hardness, and/or alkalinity to achieve less corrosive water quality.

In waters with a pH of 4.0 to 6.8 lime or soda ash (sodium carbonate) is typically used to increase the pH value. The lime or soda ash is usually feed into the system at a rate to produce a resultant pH of approximately 7.5. When the raw water pH is less than 4.0, a caustic soda (sodium hydroxide) solution is used. In general, treatment of ground water can be accomplished by adding some hardness or alkalinity, or both, and raising the pH to slightly increase the scale-forming tendency

8. Based on the total solids, which is less than 1000 ppm in all the sites, ground water of the Agartala and Tezpur could be classified as fresh water.

9. Most of the ground water samples of Agartala and Tezpur are soft in nature.

10. 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.

11. Except Mg^{2+} hazard, ground water of Agartala and Tezpur is found suitable for irrigation purpose. For magnesium sensitive crops, suitable measures are to be taken to avoid Mg^{2+} hazard.

12. The plots between Na^{+}+K^{+} and HCO^{-}_{3} fall at the left hand side of the Durov's square, indicate the fresh water characteristics i.e. absence of salt water intrusion while right hand side fall indicate saline water characteristics which need to be verified further because Na^{-} and K^{+} cations were calculated from the ionic balance formula.

13 The iron, cadmium, copper, lead, nickel, manganese and zinc were detected at elevated levels in some pockets of ground water in Agartala. These metals destroy ecosystem in which they enter. ground water, which contains higher amount of trace elements, affects public health to a great extent if it is used for drinking and domestic purposes. Prolonged use of such waters is dangerous for health.

14. The use of water for irrigation, which invariably contains high iron content, may further increase the iron content in the soil. Soil, being a porous media, allows the deposited iron to move down to the root zone of the crop and is likely to affect the balance of plant nutrients and their availability to plants. Intake of Iron above the permissible level appears to be largely manifested as a pronounced malformation as well as malfunction of the root system. The reason attributed to these observations may be due to the fact that plants grown in iron rich soils often show phosphorus and potassium deficiency. This leads to serious nutritional imbalance and the crop may succumb in extreme cases. Rice plants more frequently suffer from Iron toxicity known as "browning" and ultimately the whole plant die.

15. Iron in excess of desirable limit is objectionable constituent in water supplies for either drinking or industrial use. Earlier many researchers have reported that iron in the ground water of NE region is in the form of ferrous ion hence it can be easily converted to ferric on oxidation and since $Fe(OH)_3$ has quit low solubility, the removal of excessive ferrous iron can easily be

accomplished by spraying the ground water on beds of gravel or sand and on coke beds, settling the precipitated ferric hydroxide and draining off of the supernatant clear water. Marble or calcite beds may also be used and are likely to be more efficient as the pH of the water will also be increased, which will lead to faster precipitation of ferric hydroxide. The time required for ferrous iron to undergo oxidation to the ferric state is dependent on many factors, the dominant being: pH; temperature; dissolved oxygen level; and the presence of other soluble ions. The lower the pH and temperature the longer the time required for completion of the oxidation reaction. Increasing dissolved oxygen decreases the time required for oxidation ***(www.rcre.rutgers.edu):***

- At pH 7.0, 90% Fe^{+2} oxidation requires 1 hour at 21°C and 10 hours at 5°C.
- At pH 8.0, 90% Fe^{+2} oxidation occurs in 30 seconds.
- At pH 6.0 it requires 100 hours.
- The critical dissolved oxygen concentration is 2 ppm. Below that ferrous iron oxidation occurs very slowly.

16. Time series data is necessary for monitoring the quality of ground water to protect it from possible sources of contamination.

17. Hydrochemical analysis in association with isotopic cross correlation is useful in identifying the origin of ground water composition, time of contact between rocks-water and to develop the water quality of the ground water system. Ground water is characterized as Ca^{2+}-Mg^{2+}-HCO^{-}_{3} type representing dissolution of dolomite ($CaMg(CO_3)_2$) or dissolution of admixture of calcite or aragonite ($CaCO_3$) with magnesite ($MgCO_3$) under typical recharge conditions. Alkalinity and ionic concentration is mainly controlled by bicarbonate concentration.

18. Isotopes, when used in ground water hydrology give a direct insight into the movement and distribution processes within aquifers. Ground water, in its natural state, contains environmental isotopes and conclusions may be drawn from their abundance variation. The use of isotope techniques which complement hydrochemical and hydrogeological studies should be encouraged in both surface water and ground water resource development.

19. Isotope study provides complementary information on the type, origin and age of ground water. If the isotope content does not change within the aquifer, it will reflect the origin of the water, particularly the location, period and processes of recharge. If the isotope content changes along ground water paths, this will reflect the history of the water, particularly the mixing, salinization and discharge processes.

20. One of the main aim of this study was to describe the development of a local meteoric water line for Agartala and Tezpur. δ^2H ‰ and $\delta^{18}O$ ‰ of the ground waters of Agartala and Tezpur plot along an evaporative trend that deviates from the global meteoric water line.

21. Stable isotopes of oxygen and hydrogen are naturally occurring tracers that can provide quantitative information about surface-water/ground-water interactions.

22. In ground water related study, environmental tracers, such as T, D, ^{18}O, ^{14}C, SF_6 and CFCs have been widely used successfully in many fields since 1950s. Many problems including dating, renewability and recharging origin of ground water, as well as other related processes can be solved using these techniques, among which D and ^{18}O played an important role.

23. Isotope techniques can effectively be used in carrying out various hydrological studies. Specifically, the Isotope can be used for tracing the source, movement, and pollution of ground water. Moreover, findings of the isotope and hydrogeochemical investigation are expected to enable planners and decision makers to properly manage and protect the ground water resources through a better assessment of the effects of anthropogenic activities on water resources.

24. Applications of isotopes in hydrology and water resources are relatively a new subject, but its importance has been felt more in recent years. This is due to tremendous increase of problems in water sector, particularly depleting ground water quantity, deterioration in water quality and many other unpredictable natural events that affect the hydrological cycle. The conventional methods often fail to provide insight to these problems, while isotope techniques provide a clear picture and helps in finding a suitable solution.

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Table 4.1- Ground and Lake Water Sampling Site Details for Environmental Isotopes in Agartala

Site No.	Ward No.	Site Name	Well/ water body Type	Ownership/ Control	User's No. (approx. persons)	Age of well (year)	Total depth of well (feet)	Use of well / water body
AG-1	3	Chandmari village	TW with motor	State Govt.	4000	6	100	D&D, cooking, cloths washing, bathing
AG-2	5	Madhya Banmalipur	HTW	Community	200	1/2	70	D&D
AG-3	4	Dholeshwer	HTW	Community	50	15	75	D&D
AG-4	9	Hotel Sukh-Shanti	HTW	Private	500	5	75	D&D, cooking, bathing
AG-5	11	Badarghat Sripalli	DW	Private	10	14	27	D&D, cooking, cloths washing, bathing
AG-6	12	Borduali Madhyapara	HTW	Private	20	8	70	D&D
AG-7	10	South Ramnagar	HTW	Community	100	15	85	D&D
AG-8	8	Sanmura	HTW	Community	200	3	90	D&D, religious function
AG-9	7	Krishnanagar Kadamtala	HTW	Private	16	17	75	D&D, bathing, cloths washing
AG-10	14	Durgabari Temple	HTW	Community	500	10	70	D&D, bathing, in hotels
AG-11	6	Madhyamic Dropout Girl's Hostel	HTW	Community	100	4	80	Domestic, bathing
AG-12	1	Purva Narayanpur (Airport)	HTW	Private	15	1	60	D&D, bathing
AG-13	1	Bhati Abhoynagar	TW with motor	PHE Sub Div-3	3000	24	400 (casing)	D&D, in hotels, bathing, cloths washing
AG-14	2	Abhoynagar	HTW	Private	25	15	50	D&D
AG-15	9	Joynagar	HTW	Private	10	3 days old	80	Domestic only
AG-16	13	Melarmath	HTW	Private	15	20	70	Domestic only
AG-17	13	Jaikali Ashram	HTW	Community	50	20	65	D&D, bathing
AG-18	15	Jogindranagar	HTW	Private	10	2	90	D&D, bathing
AG-19	16	Banmalipur	HTW	Private	16	6	40	Domestic only
AG-20	14	Indirapalli (Palace compound)	HTW	Private	15	4	50	Domestic only
AG-21	17	East Shivnagar (college tilla)	HTW (plastic pipes)	Private	25	7month	60	D&D, cloths washing, bathing
AG-22	17	East Shivnagar Kalitala	HTW	Private	10	6	65	Domestic and washing
AG-23	3	Jagatpur Abhoynagar	HTW	State Govt.	200	6	70	Domestic, in hotels
AG-24	8	Rampur Road No.-11	HTW	Private	6	5	70	D&D, bathing, cloths washing
AG-25	-	Rudra Sagar National Lake (NeerMahal)	Lake	National Lake	3000	Migratory birds seen		D&D, Fishing. boating, in bricks kiln, tourism, Agri., bathing etc.
AG-26	-	SepahiJala Wild Life Sanctuary Lake	Lake	Forest Dept.	1000	Migratory birds seen		
AG-27	-	Elephanta Falls on UMDIENGPUN River, Shillong	Water Fall	State Govt.	-	-		Tourism

Note : DW - Dug Well, HTW - Hand Tube Well, TW - Tube Well, D&D - Drinking and Domestic

Table 4.2 - Ground water Sampling Site Details for Environmental Isotopes in Tezpur

Site No.	Ward No.	Site Name	Well/ water body Type	Ownership/ Control	User's No. (approx. persons)	Age of well (year)	Total depth of well (feet)		Use of well / water body
TZ-1	11	Kalibari, B.S. Road	TWM	Private	10	5	144	shallow	D&D, cooking, cloths washing, bathing, Gardening
TZ-2	8	Tezpur College Campus	TWM	College	1500	2	100	shallow	D&D, bathing, cloths washing
TZ-3	1	Cotton Road Side	TWM	Private	16	4	160	shallow	D&D, bathing, cloths washing
TZ-4	12	Dolabari, NERIWALM	Boring	NERIWALM	250	15	350	deep	D&D, cooking, cloths washing, bathing, Irrigation
TZ-5	19	Jyotiban Chandmari	TWM	Private	12	5	90	shallow	D&D, cloths washing, bathing
TZ-6	2	Kumargaon Nimna Buniyadi Vidyalaya	HTW	School	500	2&1/2	110	shallow	Drinking purpose for students
TZ-7	19	Sahid Bhupen Deka Path	TWM	Private	10	1	120	shallow	D&D, cooking, cloths washing, bathing, Gardening
TZ-8	18	Bishwajit Bora Path	TWM	Private	10	5	155	shallow	D&D, cooking, cloths washing, bathing, Gardening
TZ-9	3	Govt. Girl's H.S. & Multipurpose School	HTW	School	500	4	120	shallow	D&D, bathing
TZ-10	5	Hotel Luit	TWM	Hotel	200	3	180	deep	D&D, bathing, washing in hotel
TZ-11	9	Hotel Madhuban	TWM	Hotel	100	3	110	shallow	D&D, bathing, washing in hotel
TZ-12	9	Ex Police Line	TWM	Private	10	1	150	shallow	D&D, bathing, cloths washing
TZ-13	-	Tezpur University (outside of map boundary)	Boring	University	2000	10	300	deep	D&D, cooking, cloths washing, bathing, Gardening
TZ-14	-	Assam Valley School (outside of map boundary)	Boring	School	1500	16	300	deep	D&D, cooking, cloths washing, bathing, gardening, swimming
TZ-15	-	Tezpur Airport (outside of map boundary)	Boring	Airport	500	6	300	deep	D&D, cooking, cloths washing, bathing, gardening, swimming
TZ-16	-	Army Cantonment Area (near DRL) (outside of map boundary)	Boring	Army	5000	25	300	deep	D&D, cooking, cloths washing, bathing, Irrigation, swimming
TZ-17	15	Padmini Cloths Store (Darrang college)	TWM	Private	10	6	100	shallow	D&D, cloths washing, bathing
TZ-18	7	Bara Holia	TWM	Private	15	12	170	deep	D&D, cloths washing, bathing
TZ-19	16	Study Home Boys Hostel	TWM	Private	20	4	150	shallow	D&D, cloths washing, bathing
TZ-20	14	Garwan Patti	HTW	Private	35	12	150	shallow	D&D, cloths washing, bathing
TZ-21	-	Nameri National Park (Eco Camp) (outside of map boundary)	DW	Forest Dept.	100	10	20	shallow	D&D, cloths washing, bathing
TZ-22	6	Hatibil Khana	HTW	PHED	100	1	115	shallow	D&D, cloths washing, bathing
TZ-23	4	Suvemrekha Path (DMS, LGBRIMH)	TWM	Private	20	1	160	shallow	D&D, cloths washing, bathing
TZ-24	17	Bishnu Rava Path	TWM	Private	20	3	160	shallow	D&D, bathing, cloths washing
TZ-25	10	Anand Medical	TWM	Private	35	4	170	deep	D&D, bathing, cloths washing
TZ-26	16	Lalit Bora's House	TWM	Private	20	15	200	deep	D&D, bathing, cloths washing
TZ-27	5	Circuit House	TWM	State Govt.	50	15	140	shallow	D&D, bathing, cloths washing
TZ-28	12	LGBRIMH	Boring	Hospital	5000	2	280	deep	D&D, bathing, cloths washing

Note : DW - Dug Well, HTW - Hand Tube Well, TWM - Tube Well with Motor, D&D - Drinking and Domestic

Table 5.1 - pH, Temp., Oxygen and Hydrogen Isotopes in Ground/Lake Waters of Agartala

Site and Ward No.		Site Name	Well/ Water Body Type	Oxygen Isotope (for ground water)	Hydrogen Isotope (for ground water)	Oxygen Isotope (for Lake water)	Hydrogen Isotope (for Lake water)	pH	Temp $^{\circ}C$
				$\delta^{18}O$‰	$\delta^{2}H$‰	$\delta^{18}O$‰	$\delta^{2}H$‰		
AG-1	3	Chandmari village	TW with motor	-4.66	-30.17	-	-	5.65	23.5
AG-2	5	Madhya Banmalipur	HTW	-4.52	-22.57	-	-	5.7	25.0
AG-3	4	Dholeshwer	HTW	-4.69	-25.24	-	-	5.24	24.5
AG-4	9	Hotel Sukh-Shanti	HTW	-4.58	-27.71	-	-	5.19	24.0
AG-5	11	Badarghat Sripalli	DW	-4.54	-29.55	-	-	4.65	24.0
AG-6	12	Borduali Madhyapara	HTW	-3.78	-21.00	-	-	5.21	25.0
AG-7	10	South Ramnagar	HTW	-4.56	-25.98	-	-	5.15	24.0
AG-8	8	Sanmura	HTW	-4.59	-30.09	-	-	5.21	25.0
AG-9	7	Krishnanagar Kadamtala	HTW	-4.47	-28.14	-	-	5.33	24.0
AG-10	14	Durgabari Temple	HTW	-4.44	-22.27	-	-	5.37	25.0
AG-11	6	Madhyamic Dropout Hostel	HTW	-3.78	-25.18	-	-	7.64	24.0
AG-12	1	Purva Narayanpur (Airport)	HTW	-4.35	-26.52	-	-	5.57	24.0
AG-13	1	Bhati Abhoynagar	TW with motor	-4.59	-24.53	-	-	5.15	25.0
AG-14	2	Abhoynagar	HTW	-4.19	-25.53	-	-	8.25	25.0
AG-15	9	Joynagar	HTW	-4.30	-26.76	-	-	5.62	24.0
AG-16	13	Melarmath	HTW	-4.37	-27.69	-	-	5.68	23.5
AG-17	13	Jaikali Ashram	HTW	-4.58	-31.17	-	-	5.83	23.0
AG-18	15	Jogindranagar	HTW	-4.73	-28.09	-	-	5.81	23.0
AG-19	16	Banmalipur	HTW	-4.85	-28.05	-	-	6.01	23.0
AG-20	14	Indirapalli (Palace compound)	HTW	-3.65	-21.38	-	-	6.01	24.2
AG-21	17	East Shivnagar (college tilla)	HTW (plastic pipes)	-4.60	-27.83	-	-	5.65	23.0
AG-22	17	East Shivnagar Kalitala	HTW	-4.35	-27.45	-	-	5.7	23.0
AG-23	3	Jagatpur Abhoynagar	HTW	-3.43	-21.18	-	-	5.85	25.0
AG-24	8	Rampur Road No.-11	HTW	-4.49	-32.99	-	-	5.81	22.0
AG-25	-	Rudra Sagar (NeerMahal) National Lake-Ramasar site	Lake	-	-	-3.35	-21.66	5.52	25.5
AG-26	-	SepahiJala Sanctuary Lake	Lake	-	-	-2.20	-21.35	5.85	26.0
AG-27	-	Elephanta Falls on UmdiengpunRiver (Shillong)	Water Fall	-	-	-6.61	-48.29	-	-
			Max	-3.43	-21.00	-	-	8.25	26.00
			Min	-4.85	-32.99	-	-	4.65	22.00
			Avg	-4.38	-26.54	-	-	5.72	24.12
			StDev	0.37	3.23	-	-	0.73	0.95
			Var	0.14	10.40	-	-	0.54	0.91

Note : DW - Dug Well, HTW - Hand Tube Well, TW - Tube Well

Table 5.2(a) - Status of Oxygen & Hydrogen Isotopes in Ground Water of Tezpur

**Site No		Sample No.	Ward No.	Well Type	Oxygen Isotope in Shallow Well Water	Hydrogen Isotope in Shallow Well Water	Oxygen Isotope in Deep Tube Well Water	Hydrogen Isotope in Deep Tube Well Water
					$\delta^{18}O$‰	$\delta^{2}H$‰	$\delta^{18}O$‰	$\delta^{2}H$‰
TZ-	1	1(a)	11	TWM	-4.67	-27.90	-	-
		1(b)		DW	-5.04	-28.34	-	-
TZ-	2	2(a)	8	TWM	-5.95	-37.22	-	-
		2(b)		DW	-4.05	-22.33	-	-
TZ-	3	3(a)	1	TWM	-3.24	-25.33	-	-
		3(b)		DW	-5.21	-31.93	-	-
TZ-	4	4	12	Boring	-	-	-5.12	-35.64
TZ-	5	5(a)	19	TWM	-3.46	-24.97	-	-
		5(b)		DW	-4.87	-28.32	-	-
TZ-	6	6	2	HTW	-4.60	-31.42	-	-
TZ-	7	7(a)	19	TWM	-4.88	-31.39	-	-
		7(b)		DW	-5.20	-30.24	-	-
TZ-	8	8(a)	18	TWM	-5.15	-34.57	-	-
		8(b)		DW	-4.92	-26.74	-	-
TZ-	9	9(a)	3	HTW	-4.84	-32.83	-	-
		9(b)		DW	-5.21	-31.59	-	-
TZ-	10	10	5	TWM	-	-	-5.23	-35.51
TZ-	11	11	9	TWM	-4.07	-30.56	-	-
TZ-	12	12	9	TWM	-5.23	-35.05	-	-
TZ-	13	13(a)	-	Boring	-	-	-5.47	-36.21
		13(b)	-	DW	-5.01	-30.39	-	-
TZ-	14	14(a)	-	Boring	-	-	-5.55	-33.77
		14(b)	-	DW	-5.22	-31.78	-	-
TZ-	15	15	-	Boring	-	-	-3.29	-25.24
TZ-	16	16(a)	-	Boring	-	-	-4.93	-34.03
		16(b)	-	DW	-5.88	-36.69	-	-
TZ-	17	17	15	TWM	-5.01	-34.94	-	-
TZ-	18	18	7	TWM	-	-	-5.24	-35.21
TZ-	19	19	16	TWM	-3.70	-25.27	-	-
TZ-	20	20	14	HTW	-5.41	-34.99	-	-
TZ-	21	21	-	DW	-5.73	-36.53	-	-
TZ-	22	22	6	HTW	-5.39	-34.89	-	-
TZ-	23	23	4	TWM	-5.09	-34.48	-	-
TZ-	24	24	17	TWM	-5.33	-34.04	-	-
TZ-	25	25	10	TWM	-	-	-5.34	-33.89
TZ-	26	26	16	TWM	-	-	-5.11	-34.51
TZ-	27	27	5	TWM	-4.89	-31.78	-	-
TZ-	28	28	12	Boring	-	-	-5.55	-37.36
				Max	-3.24	-22.33	-3.29	-25.24
				Min	-5.95	-37.22	-5.55	-37.36
				Avg	-4.90	-31.30	-5.08	-34.14
				StDev	0.66	3.95	0.66	3.33
				Var	0.44	15.62	0.44	11.06

Note: DW-Dug Well, HTW-Hand Tube Well, TWM -Motor Tube Well (* for site name Table 4.1)

Table 5.2(b) - Status of Physical Parameters in Ground Water of Tezpur

Site and No.		Ward	Well Type	Temp	Conductivity	DO
				°C	micro-mho/cm	ppm
TZ-	1	11	TWM	37.2	360	1.8
TZ-	2	8	TWM	36.4	210	1.6
TZ-	3	1	TWM	35.7	390	1.2
TZ-	4	12	Boring	24	100	2.6
TZ-	5	19	TWM	25.1	190	3.2
TZ-	6	2	HTW	25.1	140	2.1
TZ-	7	19	TWM	25.4	90	6
TZ-	8	18	TWM	24.8	100	3.5
TZ-	9	3	HTW	24.9	160	3.8
TZ-	10	5	TWM	25.3	300	2.5
TZ-	11	9	TWM	23.5	440	5.4
TZ-	12	9	TWM	24.4	140	2.2
TZ-	13	-	Boring	24.8	150	5.7
TZ-	14	-	Boring	24.2	140	3.2
TZ-	15	-	Boring	22.6	190	8.9
TZ-	16	-	Boring	25.3	210	8.2
TZ-	17	15	TWM	25.2	330	3.2
TZ-	18	7	TWM	25.3	150	6.4
TZ-	19	16	TWM	24.5	150	8.8
TZ-	20	14	HTW	23.9	140	1.3
TZ-	21	-	DW	23.7	170	6
TZ-	22	6	HTW	27.5	250	4.6
TZ-	23	4	TWM	26.1	140	4.5
TZ-	24	17	TWM	27.9	360	4.3
TZ-	25	10	TWM	27.8	210	4.82
TZ-	26	16	TWM	28.6	390	4.6
TZ-	27	5	TWM	28.5	100	1
TZ-	28	12	Boring	37.2	190	1.8
			Max	37.2	440.0	8.9
			Min	22.6	90.0	1.0
			Avg	26.6	210.4	4.1
			StDev	3.9	101.5	2.3
			Var	14.9	10299.9	5.1

Note : DW-Dug Well, HTW-Hand Tube Well, TWM-Tube Well with Motor
(** for corresponding site name refer table 4.1)

Table 5.3 - Status of Physico-chemical and trace elements of ground water samples in Agartala

Nature of Tube Well/ Lake	Site Name	Data Source	Data Site Index	Ward No	pH	Total Alkalinity ($CaCO_3$)	Cl^-	SO^{2-}_4	NO_3^-	PO^{2-}_4	HCO_3^-	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$ (by ionic balance)	Fe^{2+}	lead	nickle	cad-mium	copper	man-ganese	zinc	Conductivity, micro-mho/cm	DO ppm	TDS, ppm
						ppm						ppm				ppm								
Deep	Kunjban	CPCB	A 1	3	5.76	15.40	7.40	7.40	0.51	0.00	18.79	10.70	22.90	21.40	1.94	-	-	-	-	-	-	150.0	-	134
Deep	A.D.Nagar		A 2	11	6.52	38.50	2.50	11.10	0.03	-	46.97	17.80	21.60	15.20	0.01	-	-	-	-	-	-	70.0	-	130
Deep	Shibnagar		A 3	17	6.41	76.90	2.50	8.20	0.03	0.00	93.82	24.90	10.40	15.10	5.92	-	-	-	-	-	-	166.0	-	142
Deep	Gandhigram		A 4	3	6.55	50.00	4.90	12.20	0.02	0.10	61.00	23.20	7.30	15.30	0.56	-	-	-	-	-	-	175.0	-	166
Deep	G.B. Pant Hospital	TSPCB	A 5		6.17	55.86	2.45	7.50	-	0.00	68.15	8.04	4.87	16.45	1.30	-	-	-	-	-	-	81.0	4.27	259
Deep	I.G.M. Hospital		A 6	13	6.79	83.22	2.45	7.70	-	0.00	101.53	11.05	5.48	19.09	2.60	-	-	-	-	-	-	114.0	6.09	218
Deep	Rajiv Gandhi Cancer Hospital		A 7	3	6.30	52.44	7.30	8.80	-	0.00	63.98	6.03	3.65	15.87	3.40	-	-	-	-	-	-	89.0	2.82	196
Deep	Dr. B.R. Ambedkar Hospital		A 8	10	6.38	58.14	2.45	7.10	-	0.03	70.93	6.99	5.51	16.45	1.10	-	-	-	-	-	-	83.0	6.33	232
Deep	ICAR Lamburcherra	NERIWALM	A 9	3	6.80	160.04	-	20.84	0.04	0.00	195.25	1.86	0.45	75.83	5.83	-	-	-	-	-	-	320.0	0.90	240
Deep	Gandhigram		A 10		6.50	160.04	-	36.13	0.09	0.00	195.25	0.59	0.20	74.02	19.28	-	-	-	-	-	-	280.0	0.20	250
Deep	Salbagan (Mohanpur Block)		A 11		4.30	60.02	-	19.45	0.41	0.00	73.22	0.96	0.23	33.33	2.79	0.141	0.011	0.057	0.027	0.448	0.020	570.0	2.10	440
Deep	Kunjaban		A 12		7.20	160.04	-	30.57	0.04	0.01	195.25	12.17	7.48	58.45	2.07	0.003	0.078	0.001	0.012	0.204	0.078	330.0	1.60	300
Deep	Banamalipur		A 13	16	7.10	80.02	-	83.37	0.04	0.00	97.63	17.72	9.38	38.47	0.23	0.001	0.024	0.001	0.000	0.231	0.186	450.0	3.90	400
Mark-II	South Barjala Jr. Basic School	TSPCB	A 14	1	6.79	112.68	7.35	9.18	-	-	137.47	19.84	6.95	19.79	6.40	0.061	0.093	0.096	0.096	7.476	1.737	220.0	1.07	152
Deep	Bitarban, Bhati Abhoynagar		A 15		6.38	86.68	4.90	9.79	-	-	105.75	9.92	3.47	24.18	6.80	0.692	0.425	0.027	0.030	9.378	5.713	159.0	1.56	100
Shallow	Bitarban, Bhati Abhoynagar		A 16		6.05	82.35	9.80	8.78	-	-	100.47	13.89	8.11	14.52	3.20	-	-	-	-	-	-	162.0	0.78	128
Shallow	Bitarban, Bhati Abhoynagar		A 17		6.25	78.01	12.25	10.61	-	-	95.17	11.90	2.32	24.93	7.20	-	-	-	-	-	-	151.0	0.29	140
Shallow	Bitarban, Mailakhalla		A 18		6.12	91.01	24.50	7.76	-	-	111.03	23.81	6.95	20.35	0.78	-	-	-	-	-	-	210.0	0.98	116
Mark-II	Kalibari, Bhati Abhoynagar		A 19		6.43	78.01	4.90	8.57	-	-	95.17	7.94	2.32	14.86	18.00	-	-	-	-	-	-	172.0	0.88	144
Shallow	Rishi Colony, Bitarban		A 20		6.08	69.34	7.35	9.59	-	-	84.59	5.95	1.16	30.32	2.30	-	-	-	-	-	-	125.0	Nil	88
Lake	Rudrasagar, Sonumura	CPCB	A 21		7.72	19.20	9.80	15.30	0.20	0.10	23.42	10.90	18.70	1.00	1.43	-	-	-	-	-	-	272.0	-	168
				Max	7.72	160.04	24.50	83.37	0.51	0.10	195.25	24.90	22.90	75.83	19.28	0.692	0.425	0.096	0.096	9.378	5.713	570.0	6.33	440
				Min	4.30	15.40	2.45	7.10	0.02	0.00	18.79	0.59	0.20	1.00	0.01	0.001	0.011	0.001	0.000	0.204	0.020	70.0	0.20	88
				Average	6.41	79.42	7.05	16.19	0.14	0.02	96.90	11.72	7.12	26.90	4.43	0.180	0.126	0.036	0.033	3.547	1.547	207.1	2.25	197
				StDev	0.66	40.81	3.57	17.27	0.18	0.04	49.79	7.26	6.58	19.64	5.23	0.292	0.171	0.041	0.037	4.506	2.436	127.0	2.01	94
				Var	0.43	1665.28	31.05	298.3	0.03	0.00	2478.6	52.68	43.35	385.68	27.32	0.085	0.029	0.002	0.001	20.30	5.933	16120.5	4.0	8751

Table 5.4 - Physico-chemical status of ground water samples of Tezpur and surrounding areas

Site no.	Ward no.	pH	$Na^+ + K^+$ from ionic balance	Ca^{2+}	Mg^{2+} from total hardness	PO^{2-}_4	Cl^-	SO^{2-}_4	HCO^-_3 from total alkalinity	NO^-_3	BOD_5	Total alkalinity as $CaCO_3$	TDS
			(ppm)									ppm	ppm
TZ-1	11	6.7	75.07	34.21	2.32	1.37	53.17	8.5	207.29	2.8	0.8	170	241
TZ-2	8	6.9	7.80	30.53	6.48	0.486	nil	8.3	134.13	0.62	0.5	110	141
TZ-3	1	6.6	20.37	2.28	6.18	0.774	8.86	1.2	73.16	0.64	0.6	60	188
TZ-5	19	6.3	14.63	19.32	15.60	1.35	26.58	3.85	121.93	0.82	0.9	100	147
TZ-7	19	6.5	14.51	1.72	4.41	1.08	nil	1.9	60.97	0.43	1.2	50	74
TZ-8	18	6.8	31.42	10.13	5.12	0.432	31.9	8.4	73.16	0.34	0.6	60	181
TZ-9	3	6.9	22.83	15.62	6.61	0.5	nil	3.9	134.13	1.3	0.8	110	134
TZ-13	-	7.1	4.31	18.42	10.20	0.9	nil	5.2	109.74	0.67	0.1	90	147
TZ-14	-	7.3	19.41	0.00	0.07	0.324	nil	1.8	48.77	0.21	0.1	40	40
TZ-15	-	7.2	22.11	0.14	0.68	0.63	nil	nil	60.97	0.31	0.2	50	94
TZ-16	-	7.4	35.74	3.71	0.99	0.54	nil	nil	109.74	0.31	0.1	90	101
	Max	7.30	75.07	34.21	15.60	1.37	53.17	8.50	207.29	2.80	1.20	170.00	241
	Min	6.30	4.31	0.00	0.07	0.32	8.86	1.20	48.77	0.21	0.10	40.00	40
	Avg	6.82	23.25	13.24	5.77	0.78	30.13	4.78	102.43	0.81	0.58	84.00	135
	Var	0.10	391.63	157.51	21.13	0.14	333.00	8.89	2385.53	0.58	0.13	1604.44	57
	StDev	0.31	19.79	12.55	4.60	0.38	18.25	2.98	48.84	0.76	0.36	40.06	3212

Table 5.5 - Status of Trace Elements in ground water samples of Tezpur and surrounding areas

Site no.	Ward no	Lead	Nickel	Cadmium	Iron
		(ppm)			
TZ-1	11	Nil	nil	0.001	0.037
TZ-2	8	Nil	0.001	nil	0.409
TZ-3	1	0.04	nil	0.003	0.073
TZ-5	19	Nil	0.003	0.004	0.194
TZ-7	19	Nil	nil	0.002	0.075
TZ-8	18	Nil	nil	nil	0.144
TZ-9	3	Nil	nil	0.003	0.732
TZ-13	-	nil	nil	0.01	0.652
TZ-14	-	nil	nil	0.003	0.301
TZ-15	-	0.045	nil	0.002	5.729
TZ-16	-	nil	nil	0.001	0.798
			Max	0.01	5.73
			Min	0.001	0.04
			Avg	0.0035	0.83
			Var	7.71E-06	3.02
			StDev	0.0028	1.74

Table 5.6 - Different Classifications of Ground Water

Site	Different Classifications						
	Stiff	USSL	Piper Trilianear	After Back	Gibbs	Durov's classification on the basis of	
						Cation Type	Anion Type
For Tezpur							
TZ- 1	Na^{+}-HCO_3^{-}	C2-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
TZ- 2	Ca^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}- HCO_3^{-}	RD	Ca^{2+} Type	HCO_3^{-} Type
TZ- 3	Mg^{2+}-HCO_3^{-}	C2-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Mg^{2+} Type	HCO_3^{-} Type
TZ- 5	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
TZ- 7	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}- HCO_3^{-}	RD	Mg^{2+} Type	HCO_3^{-} Type
TZ- 8	Mg^{2+}-HCO_3^{-}	C2-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Mg^{2+} Type	HCO_3^{-} Type
TZ- 9	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}- HCO_3^{-}	RD	Mg^{2+} Type	HCO_3^{-} Type
TZ- 13	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}- HCO_3^{-}	RD	Mg^{2+} Type	HCO_3^{-} Type
TZ- 14	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}	RD	Mg^{2+} Type	HCO_3^{-} Type
TZ- 15	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}	RD	Mg^{2+} Type	HCO_3^{-} Type
TZ- 16	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}	RD	Mg^{2+} Type	HCO_3^{-} Type
For Agartala							
A- 1	Mg^{2+}-HCO_3^{-}	C1-S1	Mixed	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Mg^{2+} Type	Intermediate
A- 2	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Mg^{2+} Type	HCO_3^{-} Type
A- 3	Ca^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 4	Ca^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 5	Na^{+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 6	Na^{+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 7	Na^{+}-HCO_3^{-}	C1-S1	Mixed	Na^{+}-Ca^{2+}-Mg^{2+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 8	Na^{+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 9	Na^{+}-HCO_3^{-}	C2-S3	Na^{+}+K^{+}-HCO_3^{-}	Na^{+}-K^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 10	Na^{+}-HCO_3^{-}	C2-S4	Na^{+}+K^{+}-HCO_3^{-}	Na^{+}-K^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 11	Na^{+}-HCO_3^{-}	C2-S2	Na^{+}+K^{+}-HCO_3^{-}	Na^{+}-K^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 12	Na^{+}-HCO_3^{-}	C2-S1	Na^{+}+K^{+}-HCO_3^{-}	Na^{+}-Ca^{2+}-Mg^{2+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 13	Na^{+}-SO_4^{2-}+PO_4^{2-}	C2-S1	Mixed	Na^{+}-Ca^{2+}-Mg^{2+}- Cl^{-}-SO_4^{2-}-HCO_3^{-}	RD	Intermediate	Intermediate
A- 14	Ca^{2+}-HCO_3^{-}	C2-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 15	Na^{+}-HCO_3^{-}	C1-S1	Mixed	Na^{+}-Ca^{2+}-Mg^{2+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 16	Mg^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 17	Na^{+}-HCO_3^{-}	C1-S1	Mixed	Na^{+}-Ca^{2+}-Mg^{2+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 18	Ca^{2+}-HCO_3^{-}	C1-S1	Ca^{2+}+Mg^{2+}-HCO_3^{-}	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Intermediate	HCO_3^{-} Type
A- 19	Na^{+}-HCO_3^{-}	C1-S1	Mixed	Ca^{2+}-Mg^{2+}-Na^{+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 20	Na^{+}-HCO_3^{-}	C1-S1	Na^{+}+K^{+}-HCO_3^{-}	Na^{+}-Ca^{2+}-Mg^{2+}- HCO_3^{-}-Cl^{-}-SO_4^{2-}	RD	Na^{+} Type	HCO_3^{-} Type
A- 21	Mg^{2+}-SO_4^{2-}+PO_4^{2-}	C1-S1	Ca^{2+}+Mg^{2+}-Cl^{-}	Ca^{2+}-Mg^{2+}- Cl^{-}-SO_4^{2-}-HCO_3^{-}	RD	Mg^{2+} Type	Intermediate

** USSL- US Salinity Laboratory   RD - Rock Dominance

Table 5.7 - Different Criteria for Suitability of Ground Water for Agricultural Use

Site No.	SAR	Adjusted SAR	Na^+ (%)	Doneen's Permeability Index	Mg^{2-} Hazards	Kelley's Ratio	Residual Sodium Carbonate	Doneen's Classification	Wilcox classification on the basis of Na^+%	
									Na^+%	Conductivity
For Tezpur										
TZ- 1	1.81	3.38	42.70	78.39	42.31	0.75	0.44	Class-I	Permissible	Good
TZ- 2	0.01	0.02	0.52	62.34	36.14	0.01	-0.19	Class-II	Excellent	Excellent
TZ- 3	0.03	0.03	1.42	71.78	92.88	0.01	-0.30	Class-II	Excellent	Good
TZ- 5	0.45	0.72	17.08	66.06	59.71	0.21	-0.39	Class-II	Excellent	Excellent
TZ- 7	0.06	0.06	4.23	96.55	91.72	0.04	-0.04	Class-III	Excellent	Excellent
TZ- 8	0.04	0.05	1.59	49.15	78.89	0.02	-1.06	Class-I	Excellent	Good
TZ- 9	0.18	0.29	8.06	71.95	63.47	0.09	0.06	Class-II	Excellent	Excellent
TZ- 13	0.07	0.11	3.39	70.73	53.50	0.04	-0.08	Class-II	Excellent	Excellent
TZ- 14	0.81	0.46	45.44	149.44	100.00	0.83	0.33	Class-III	Permissible	Excellent
TZ- 15	0.30	0.27	18.68	116.11	99.18	0.23	0.16	Class-III	Excellent	Excellent
TZ- 16	0.20	0.29	10.01	83.11	88.79	0.11	0.15	Class-II	Excellent	Excellent
Max	1.81	3.38	45.44	149.44	100.00	0.83	0.44			
Min	0.01	0.02	0.52	49.15	36.14	0.01	-1.06			
Avg	0.36	0.52	13.92	83.24	73.33	0.21	-0.08			
Var	0.29	0.95	259.67	797.27	539.09	0.09	0.17			
StDev	0.54	0.98	16.11	28.24	23.22	0.30	0.41			
For Agartala										
A- 1	0.85	0.65	27.80	44.37	77.92	0.38	-2.11	Class-II	Good	Excellent
A- 2	0.57	0.69	19.88	46.25	66.67	0.25	-1.90	Class-II	Excellent	Excellent
A- 3	0.64	0.91	23.84	68.85	40.78	0.31	-0.56	Class-II	Good	Excellent
A- 4	0.71	0.83	27.46	68.71	34.16	0.38	-0.76	Class-II	Good	Excellent
A- 5	1.13	1.03	47.16	116.80	49.97	0.89	0.32	Class-III	Permissible	Excellent
A- 6	1.17	1.37	45.31	115.70	44.98	0.83	0.66	Class-III	Permissible	Excellent
A- 7	1.26	0.97	53.45	132.74	49.95	1.15	0.45	Class-III	Permissible	Excellent
A- 8	1.13	1.05	47.15	118.19	56.51	0.89	0.36	Class-III	Permissible	Excellent
A- 9	12.94	6.67	96.21	148.39	28.38	25.40	3.07	Class-III	Unsuitable	Good
A- 10	21.23	1.46	98.59	153.36	36.47	69.96	3.15	Class-III	Unsuitable	Good
A- 11	7.93	-1.08	95.59	167.82	28.40	21.66	1.13	Class-III	Unsuitable	Good
A- 12	3.25	4.82	67.53	115.05	50.32	2.08	1.98	Class-III	Doubtful	Good
A- 13	1.84	2.43	50.26	88.26	46.60	1.01	-0.06	Class-II	Permissible	Good
A- 14	0.97	1.43	35.54	97.49	36.61	0.55	0.69	Class-III	Good	Excellent
A- 15	1.68	1.81	57.40	129.26	36.58	1.35	0.95	Class-III	Permissible	Excellent
A- 16	0.77	0.99	31.70	96.13	49.05	0.46	0.29	Class-III	Good	Excellent
A- 17	1.73	1.78	58.01	124.84	24.32	1.38	0.78	Class-III	Permissible	Excellent
A- 18	0.94	1.34	33.46	84.46	32.49	0.50	0.06	Class-II	Good	Excellent
A- 19	1.19	1.12	52.40	153.66	32.51	1.10	0.97	Class-III	Permissible	Excellent
A- 20	2.98	2.04	77.07	145.88	24.32	3.36	0.99	Class-III	Doubtful	Excellent
A- 21	0.04	0.04	2.05	31.19	73.88	0.02	-1.70	Class-II	Excellent	Good
Max	21.23	6.67	98.59	167.82	77.92	69.96	3.15			
Min	0.04	-1.08	2.05	31.19	24.32	0.02	-2.11			
Avg	3.09	1.54	49.90	107.02	43.85	6.38	0.42			
Var	26.00	2.56	675.01	1521.93	232.87	259.05	1.88			
StDev	5.10	1.60	25.98	39.01	15.26	16.10	1.37			

Table 5.8 - Hardness (as $CaCO_3$) and corrosivity ratio in ground water of Agartala and Tezpur

Site No.	Calcium Hardness (ppm)	Magnesium Hardness (ppm)	Carbonate Hardness (ppm)	Non-Carbonate Hardness (ppm)	Total Hardness (ppm)	Larson-Skold Corrosivity Ratio
For Tezpur						
TZ- 1	85.50	62.43	148.00	0.00	148.00 (Hard)	0.49 (Non corrosive)
TZ- 2	76.31	42.96	110.00	10.00	120.00 (Moderate Hard)	0.08 (Non corrosive)
TZ- 3	5.70	74.17	65.00	15.00	80.00 (Moderate Hard)	0.21 (Non corrosive)
TZ- 5	48.29	71.36	100.00	20.00	120.00 (Moderate Hard)	0.42 (Non corrosive)
TZ- 7	4.30	47.57	50.00	2.00	52.00 (Soft)	0.04 (Non corrosive)
TZ- 8	25.32	94.42	67.00	53.00	120.00 (Moderate Hard)	0.80 (Non corrosive)
TZ- 9	39.04	67.65	108.00	0.00	108.00 (Moderate Hard)	0.04 (Non corrosive)
TZ- 13	46.04	52.79	95.00	5.00	100.00 (Moderate Hard)	0.06 (Non corrosive)
TZ- 14	0.00	23.46	24.00	0.00	24.00 (Soft)	0.05 (Non corrosive)
TZ- 15	0.34	41.39	50.00	2.00	52.00 (Soft)	0.00 (Non corrosive)
TZ- 16	9.27	73.30	84.00	0.00	84.00 (Moderate Hard)	0.00 (Non corrosive)
Max.	85.50	94.42	148.00	53.00	148.00	0.80
Min.	0.00	23.46	24.00	0.00	24.00	0.00
Avg.	30.92	59.23	81.91	9.73	91.64	0.20
Var	937.13	392.79	1223.89	252.62	1383.85	0.07
StDev	30.61	19.82	34.98	15.89	37.20	0.26
For Agartala						
A- 1	26.68	94.24	15.40	109.00	124.40 (Hard)	1.18 (Moderate corrosive)
A- 2	44.39	88.89	38.50	94.80	133.30 (Hard)	0.39 (Non corrosive)
A- 3	62.09	42.80	76.90	38.60	115.50 (Moderate Hard)	0.16 (Non corrosive)
A- 4	57.86	30.04	50.00	38.90	88.90 (Moderate Hard)	0.39 (Non corrosive)
A- 5	20.05	20.04	40.10	0.00	40.10 (Soft)	0.20 (Non corrosive)
A- 6	27.56	22.55	50.13	0.00	50.13 (Soft)	0.14 (Non corrosive)
A- 7	15.04	15.02	30.08	0.00	30.08 (Soft)	0.37 (Non corrosive)
A- 8	17.43	22.67	40.10	0.00	40.10 (Soft)	0.19 (Non corrosive)
A- 9	4.65	1.84	17.78	0.00	17.78 (Soft)	0.14 (Non corrosive)
A- 10	1.46	0.84	37.35	0.00	37.35 (Soft)	0.24 (Non corrosive)
A- 11	2.39	0.95	9.04	0.00	9.04 (Soft)	0.34 (Non corrosive)
A- 12	30.34	30.77	81.08	0.00	81.08 (Moderate Hard)	0.20 (Non corrosive)
A- 13	44.19	38.59	80.02	28.97	109.00 (Moderate Hard)	1.09 (Moderate corrosive)
A- 14	49.48	28.60	79.20	0.00	79.20 (Moderate Hard)	0.18 (Non corrosive)
A- 15	24.74	14.28	39.60	0.00	39.60 (Soft)	0.20 (Non corrosive)
A- 16	34.64	33.37	69.30	0.00	69.30 (Moderate Hard)	0.28 (Non corrosive)
A- 17	29.68	9.55	39.60	0.00	39.60 (Soft)	0.36 (Non corrosive)
A- 18	59.38	28.60	89.10	0.00	89.10 (Moderate Hard)	0.47 (Non corrosive)
A- 19	19.80	9.55	29.70	0.00	29.70 (Soft)	0.20 (Non corrosive)
A- 20	14.84	4.77	19.80	0.00	19.80 (Soft)	0.29 (Non corrosive)
A- 21	27.18	76.95	19.20	87.50	106.70 (Moderate Hard)	1.55 (Highly corrosive)
Max.	62.09	94.24	89.10	109.00	133.30	1.55
Min.	1.46	0.84	9.04	0.00	9.04	0.14
Avg.	29.23	29.28	45.33	18.94	64.27	0.41
Var	327.63	734.09	608.71	1241.62	1471.15	0.15
StDev	18.10	27.09	24.67	35.24	38.36	0.38

Table 5.9 - Oxygen and Hydrogen Isotopes in Rain Waters at Guwahati Network Station

Period	Oxygen Isotope (for Rain water)	Hydrogen Isotope (for Rain water)	Mean Total Rainfall mm
	weighted mean monthly		
	δ^{18}O‰	δ^{2}H‰	
July-2003	-8.4	-58.3	-
Aug-2003	-8.9	-64.3	-
Sep-2003	-0.2	-3.6	-
Mar-2005	-4.2	-36.3	143.1
Apr-2005	-4.0	-37.3	174.5
May-2005	-9.4	-76.9	261.9
Jun-2005	-7.5	-62.4	168.5
Jul-2005	-8.0	-65.6	205.9
Aug-2005	-8.3	-65.6	520.2
Sep-2005	-8.2	-66.1	92.3
Oct-2005	-8.4	-58.3	145.1
Max	-0.20	-3.60	520.20
Min	-9.40	-76.90	92.30
Avg	-6.71	-53.64	213.94
StDev	2.94	21.77	133.27

Table 5.10 - Local Water Lines Developed using Ground, Surface and Rain Waters

S. No.	Local Water Line between δ^{2}H‰ and δ^{18}O‰	R^2	Std. Dev.	No. of samples taken for relation	Std. Error	Ref. of related fig. no. for looking trend line nature	Remarks / by considering the samples of
1	δ^{2}H‰ = 5.67 * (δ^{18}O‰) - 1.73	0.32	3.02	23	0.63	5.36	All ground water sample data of Agartala
2	δ^{2}H‰ = 6.56 * (δ^{18}O‰) - 3.84	0.942	12.63	3	7.29	5.37	Lake and River water only
3	δ^{2}H‰ = 5.714 * (δ^{18}H‰) - 3.196	0.696	5.07	65	0.63	5.38	Agartala and Tezpur (all data of ground water, lake water and river water)
4	δ^{2}H‰ = 4.6 * (δ^{18}O‰) – 10.29	0.87	3.15	10	1.0	5.39	Tezpur all deep ground water samples
5	δ^{2}H‰ = 4.91 * (δ^{18}O‰) – 7.2	0.68	3.95	28	0.75	5.40	All shallow ground water sample data from Tezpur
6	δ^{2}H‰ = 5.02 * (δ^{18}O‰) -7.202	0.698	3.91	38	0.63	5.41	Tezpur all data of ground water shallow and deep
7	δ^{2}H‰ = 5.69 * (δ^{18}O‰) - 3.12	0.648	4.39	62	0.56	5.42	For all ground water samples from Agartala and Tezpur shallow and deep
8	δ^{18}O‰ = -0.002 * (altitude-m) – 3.65	0.616	1.49	5	0.67	5.43(a)	From ground and surface water
9	δ^{2}H‰ = -0.016* (altitude-m) – 24.73	0.873	9.92	5	4.44	5.43(a)	From ground and surface water
10	δ^{18}O‰ = -0.0026 * (altitude-m) – 2.69	0.944	1.87	3	1.08	5.43(b)	From surface water
11	δ^{2}H‰ = -0.0182 *(altitude-m) – 20.99	0.99998	12.63	3	7.29	5.43(b)	From surface water
12	δ^{18}O‰ = -0.002 * (altitude-m) – 4.24	0.29	1.63	6	0.67	5.43(c)	From Gr., surface and Rain water
13	δ^{2}H‰ = -0.01* (altitude-m) – 30.43	0.28	12.65	6	5.16	5.43(c)	From Gr., surface and Rain water
14	δ^{2}H‰ = 7.28 * (δ^{18}O‰) – 4.81	0.968	20.65	10	6.53	4.44(a)	From Rainfall samples of NE region (all are below GMWL)
15	δ^{2}H‰ = 7.95 * (δ^{18}O‰) +6.31	0.87	11.98	75	1.38	4.44(b)	With all data of RAIN, Ground, Lake and River waters
16	Slope = 0.216 * (D-excess) + 5.523	0.742	4.06	22	0.87	4.44(c)	For ground water , lake water, surface water and Rain water only

Table 5.11 - Pearson's correlation's matrix for different parameters in ground water of Agartala

	$\delta^{18}O$‰	δ^2H‰	Cl^-	SO^{2-}_4	NO^-_3	$PO^{2-}4$	HCO^-_3	Ca^{2+}	Mg^{2+}	Na^++K^+	Fe^{2+}	lead	nickel	cadmium	copper	mangnese	zinc	Total Hardness	Temperature	Conductivity	DO	pH	TDS
$\delta^{18}O$‰	1.00																						
δ^2H‰	0.61	1.00																					
Cl^-	-0.10	0.44	1.00																				
SO^{2-}_4	-0.63	-0.24	-0.05	1.00																			
NO^-_3	-0.01	-0.35	0.87	-0.27	1.00																		
$PO^{2-}4$	0.00	-0.01	0.03	-0.17	-0.29	1.00																	
HCO^-_3	0.02	-0.05	0.31	0.32	-0.48	-0.23	1.00																
Ca^{2+}	0.16	0.20	0.30	-0.02	-0.41	0.45	-0.21	1.00															
Mg^{2+}	0.01	-0.22	-0.11	-0.04	0.22	0.02	-0.50	0.51	1.00														
Na^++K^+	-0.35	-0.38	0.29	0.51	-0.19	-0.27	0.81	-0.49	-0.36	1.00													
Fe^{2+}	0.07	0.16	-0.08	0.01	-0.09	-0.26	0.45	-0.37	-0.42	0.34	1.00												
lead	0.16	0.73	-1.00	-0.48	1.00	-0.49	-0.31	-0.30	-0.48	-0.48	0.66	1.00											
nickel	0.24	0.81	-1.00	-0.46	-0.65	0.98	-0.02	-0.04	-0.22	-0.39	0.71	0.94	1.00										
cadmium	0.84	0.23	1.00	-0.64	1.00	-0.50	-0.22	0.04	-0.36	-0.73	0.64	0.00	-0.07	1.00									
copper	0.95	0.40	1.00	-0.65	0.90	-0.06	0.08	0.34	-0.07	-0.68	0.74	0.02	0.08	0.92	1.00								
mangnese	0.69	0.92	-1.00	-0.62	0.99	-0.58	-0.06	0.25	-0.14	-0.76	0.94	0.73	0.80	0.48	0.64	1.00							
zinc	0.35	0.90	-1.00	-0.48	-0.77	-0.17	-0.14	0.02	-0.23	-0.57	0.79	0.94	0.98	0.10	0.23	0.89	1.00						
Total Hardness	-0.05	-0.15	0.05	0.17	-0.12	0.16	-0.27	0.78	0.88	-0.27	-0.37	-0.51	-0.26	-0.34	-0.08	-0.17	-0.26	1.00					
Temperature	-0.25	0.01	0.35	0.29	0.42	0.05	0.35	0.09	0.11	0.46	0.28	-0.63	-0.75	-0.07	-0.27	-0.82	-0.82	0.22	1.00				
Conductivity	-0.44	-0.28	0.54	0.65	0.22	-0.19	0.39	-0.19	-0.27	0.56	0.06	-0.54	-0.76	-0.16	-0.47	-0.85	-0.77	-0.12	0.55	1.00			
DO	0.10	-0.24	-0.54	0.06	0.06	0.47	-0.42	0.01	0.36	-0.33	-0.46	-0.30	-0.38	-0.57	-0.69	-0.58	-0.39	0.10	-0.77	-0.18	1.00		
pH	0.08	0.02	-0.39	0.32	-0.79	0.11	0.45	0.32	0.09	0.22	0.07	-0.17	0.14	-0.38	-0.02	0.14	0.09	0.30	-0.08	-0.25	0.12	1.00	
TDS	-0.46	-0.54	-0.43	0.66	0.14	-0.28	0.21	-0.35	-0.24	0.43	-0.11	-0.62	-0.80	-0.31	-0.58	-0.93	-0.83	-0.19	0.00	0.77	0.39	-0.15	1.00

Colour Index

🟨 **Correlation between 50-70 % both +ve & -ve**

🟦 **Correlation between 71-100 % both +ve & -ve**

Table 5.12 - Pearson's correlation's matrix for different parameters in ground water of Tezpur

	δ18O‰	δ^2H‰	Temperature	Conductivity	DO	pH	PO^{2-}_4	Cl^-	NO^-_3	SO^{2-}_4	HCO^-_3	Ca^{2+}	Mg^{2+}	Na^++K^+	BOD5	lead	nickel	cadmium	Fe^{2+}	Total Hardness	Depth from sample taken	Age of Well	Well Depth
δ18O‰	1.00																						
δ^2H‰	0.90	1.00																					
Temperature	0.15	0.29	1.00																				
Conductivity	-0.03	0.23	0.55	1.00																			
DO	0.16	-0.05	-0.58	-0.38	1.00																		
pH	0.03	-0.27	-0.24	-0.47	0.40	1.00																	
PO^{2-}_4	-0.07	0.05	0.17	0.45	-0.39	-0.71	1.00																
Cl^-	-0.08	0.21	0.30	0.76	-0.26	-0.47	0.56	1.00															
NO^-_3	-0.10	0.08	0.46	0.70	-0.42	-0.32	0.59	0.70	1.00														
SO^{2-}_4	0.11	0.57	0.30	0.65	-0.26	-0.32	0.16	0.60	0.51	1.00													
HCO^-_3	-0.11	0.12	0.40	0.72	-0.47	-0.23	0.48	0.59	0.88	0.62	1.00												
Ca^{2+}	0.12	0.46	0.40	0.66	-0.53	-0.32	0.41	0.53	0.72	0.83	0.90	1.00											
Mg^{2+}	-0.36	-0.18	-0.01	0.63	0.10	-0.36	0.14	0.49	0.16	0.26	0.27	0.12	1.00										
Na^++K^+	-0.08	0.04	0.38	0.53	-0.35	-0.16	0.58	0.78	0.89	0.38	0.72	0.56	0.00	1.00									
BOD5	-0.11	0.18	0.18	0.29	-0.15	-0.86	0.57	0.39	0.39	0.26	0.23	0.25	0.29	0.21	1.00								
lead	0.51	0.13	0.31	0.02	0.12	0.07	-0.09	-0.18	-0.20	-0.50	-0.38	-0.45	-0.06	-0.18	-0.19	1.00							
nickel	0.15	0.29	-0.10	0.08	-0.49	-0.54	0.44	0.21	0.00	0.14	0.19	0.34	0.11	0.02	0.30	-0.19	1.00						
cadmium	-0.12	-0.24	-0.37	-0.06	-0.16	-0.02	0.24	-0.26	-0.06	-0.14	-0.04	-0.01	-0.17	-0.16	-0.27	-0.03	0.06	1.00					
Fe^{2+}	0.74	0.29	-0.18	-0.29	0.52	0.42	-0.19	-0.29	-0.24	-0.43	-0.30	-0.33	-0.30	-0.14	-0.38	0.67	-0.15	-0.02	1.00				
Total Hardness	-0.03	0.30	0.31	0.85	-0.34	-0.42	0.40	0.67	0.66	0.78	0.86	0.86	0.61	0.45	0.33	-0.35	0.33	-0.10	-0.35	1.00			
Depth from sample taken	0.09	-0.31	-0.31	-0.65	0.39	0.80	-0.47	-0.39	-0.43	-0.65	-0.46	-0.59	-0.42	-0.10	-0.68	0.27	-0.26	-0.16	0.56	-0.67	1.00		
Age of Well	0.46	0.01	-0.32	-0.45	0.40	0.67	-0.31	-0.28	-0.32	-0.50	-0.41	-0.46	-0.46	-0.05	-0.70	0.50	-0.22	0.15	0.82	-0.55	0.81	1.00	
Well Depth	0.09	-0.32	-0.32	-0.67	0.39	0.80	-0.48	-0.40	-0.45	-0.67	-0.47	-0.61	-0.42	-0.12	-0.67	0.27	-0.25	-0.16	0.56	-0.68	1.00	0.81	1.00

Colour Index

🟨	**Correlation between 50-70 % both +ve & -ve**
🟩	**Correlation between 71-100 % both +ve & -ve**