Neerinru amaiyaathu ulagenin yaaryaarkum
Vaaninru amaiyaathu ozhukku

\textit{Thirukkural 2: 10 (Tamil Poetry)}

\textbf{Meaning:} “Water is life that comes from rain
Sans rain our duties go in vain”

1.1 General

Importance of water in life was explained in above said lines by Thiruvalluvar (the Tamil poet who wrote Thirukkural - 1330 rhyming Tamil language couplets) about 2000 years ago! The existence of water on the earth is highly uneven, since 97.2% of water is confined to the ocean as saline water. Of the balance 2.8% the fresh water in ice caps and glaciers amount to 1.953%, groundwater 0.614%, lakes 0.008%, soil moisture 0.005% and the balance 0.0005% is in rivers, atmosphere and biota (Fetter, 1990). Among these, groundwater is the principal source of drinking and agricultural purposes in both urban and rural India. Other than drinking and irrigation, people use groundwater for cooking, cleaning, bathing and all other types of activities. The demand for water has increased over the years and this has led to water scarcity in many parts of the world. The situation is aggravated by the problem of water pollution or contamination.

The quality of groundwater varies from place to place with the depth of water table. Therefore, groundwater quality assessment studies are equally important as its quantity. Nowadays contamination of groundwater is a serious health and environmental problem in many parts of India and other parts of the
world. This tells us that groundwater is an important source and needs to be taken care of. Water quality is expected to deteriorate even more rapidly if significant control measures are not implemented immediately (Asaf and Saadeh, 2006). In most of the areas on the earth, water quality is affected by human activities. Agriculture has become the most prominent source of pollution of groundwater in some areas.

To maximize the yields of agricultural crops we use fertilizers, pesticides and other chemicals besides improving the inherent quality of the seeds. Though it helps in improving crop yield but the unsustainable path using to maximize the yield will cause some serious concerns like that of groundwater pollution. Pesticides can seep into the groundwater and cause kidney and liver damage and cancer in humans who drink the water. Another major source contributing to pollution problems is disposal of wastes in percolation ponds, on the ground surface, in seepage pits or trenches in dry streambeds, in landfills into disposal wells and into injection wells.

1.2 Groundwater

Groundwater is water that exists within soils and rock cavities underneath the ground. Groundwater is a part of the overall hydrologic cycle. The chief source of groundwater is the downward percolation of rainwater (meteoric water), a process called infiltration. Some groundwater may also be derived from juvenile and connate water. Juvenile water is the term used for magmatic water while the connate water is that water which was entrapped in the sedimentary rocks during their deposition. Permeable rock formations that hold groundwater from which the water can be taken for us to use are called aquifers. Water is taken from the aquifer to the surface using wells and pumps.

The subsurface occurrence of groundwater may be divided into zones of saturation and aeration. In the zone of saturation all interstices are filled with water under hydrostatic pressure. The zone of aeration consists of interstices occupied partially by water and partially by air. Over most of the land masses of the earth, a single zone of aeration overlies a single zone of saturation and extends upward to the ground surface, as shown in Fig 1.1. The saturated zone is bound at the top by either
a limiting surface of saturation or overlying impermeable strata, and extends down to underlying impermeable strata such as clay beds or bedrock. In the absence of overlying impermeable strata, the upper surface of the zone of saturation is the water table, or phreatic surface. This is defined as the surface of atmospheric pressure and would be revealed by the level at which water stands in when penetrating the aquifer. Actually, saturation extends slightly above the water table owing to capillary attraction. However, water is held here at less than atmospheric pressure. The water in the zone of saturation is commonly referred to simply as groundwater. In the zone of aeration, suspended or vadose water occurs. This general zone may be further subdivided into the soil water zone, intermediate zone, and the capillary zone (Todd, 1963).

1.3 Composition of Groundwater

The term pure water is usually referred to the liquid that is pure from any soluble substances. In reality it's impossible to get such water in the lab or noting that in the natural water, therefore a necessary definition to this terminology is needed. The pure water can be defined as the water that has lowest concentrations of chemical substances that never cause any effect on human health (Al Sayed, 2000). A complete chemical analysis of a sample of groundwater includes the determination of the concentrations of all of the inorganic constituents present. Dissolved salts in groundwater occur as dissociated ions; in addition, other minor constituents are present and reported in elemental form only (Todd, 1980). The common anions and cations found in groundwater, together with minor constituents, are listed in (Table 1.1) (Davis and DeWiest, 1966). Properties of groundwater evaluated in a physical analysis include temperature, turbidity, colour and taste.

1.4 Hydrogeochemistry

Hydrogeochemistry is the study of water chemistry. It has been used in understanding the geological environment, source, direction of movement of groundwater, recharge-discharge relationships, influence of climate, presence of
hidden ore bodies and in economic evaluation of mineral rich waters. It deals with the physical, chemical and biological characteristics of water, which determines its usefulness for industry, agriculture and domestic purposes. Recent advances in general geochemistry as well as in analytical techniques, moreover have stimulated research in hydrogeochemistry so that it is one of the most rapidly expanding fields in Earth Sciences.

Hydrogeochemical study helps in determining the water quality. The quality of water is based on two parameters viz., chemical and physical. Water samples collected in the study area have been analyzed for the physical and chemical parameters. Understanding the groundwater quality is important as it is the main factor determining its suitability for drinking, domestic, agricultural, and industrial purposes (Subramani et al., 2005).

1.5 Groundwater Quality

In recent years, it has been recognized that the quality of groundwater is of nearly equal importance to quantity. As greater development and use of groundwater continues, combined with the reuse of water, quality suffers unless consideration is given to protecting it. Pollution is being increased gradually, as the encroachments occur in the required quality of groundwater supply depends upon its purpose; thus, the needs for drinking water, industrial water, and irrigation water vary widely. To establish quality criteria, measures of chemical, physical, and bacterial constituents must be specified, as well as standard methods for reporting results of water analyses. Recommended limits of water quality can then be determined, serving as guides for proper protection and development of groundwater basins (Todd, 1963).

The quality of groundwater depends on various processes and reactions that act on water from the moment it condensed in the atmosphere to the time it is discharged by well or spring. Besides, there are many other sources that contribute contamination to the groundwater zone. Natural water is never pure. They always contain at least small amount of dissolved gases and solids. Water quality is determined by the solutes and gases dissolved in the water, as well as the matter
suspended in water. Water naturally contains a number of different dissolved inorganic constituents.

1.5.1 Calcium (Ca\(^{2+}\))

Subsurface water in contact with sedimentary rocks of marine origin derives most of their calcium from the solution of calcite, aragonite, dolomite, anhydrite, and gypsum. In igneous and metamorphic rocks, weathering also releases calcium from such minerals as apatite, wollastonite, fluorite, various kinds of feldspar, amphibole, and pyroxene groups. In as much as calcium is both abundant in the earth's crust and extremely mobile in the hydrosphere, it is one of the most common ions in the subsurface water. Concentration of calcium in normal potable groundwater is generally between 10 and 100 ppm. Calcium in these concentrations has no known effect on the health of human beings or animals. Indeed, as much as 1000 ppm of calcium may be harmless. The widespread belief that calcium in water causes hardening of the arteries, kidney stones, and liver ailments is without factual support. The most commonly noticed effect of calcium in water is its tendency to react with soap to form a precipitate called soap curd.

1.5.2 Magnesium (Mg\(^{2+}\))

Common sources of magnesium in the hydrosphere are dolomite in sedimentary rocks; Olivine, biotite, hornblende, and augite in igneous rocks; serpentine, talc, diopside and tremolite in metamorphic rocks. Common concentrations of magnesium range from about 1 to 40 ppm. Water from rocks rich in magnesium may have as much as 100 ppm, but concentrations of more than 100 ppm are rarely encountered except the sea water and brine. Exceptionally low values of magnesium and calcium are found in some waters which have undergone natural softening by cation exchange. Most commonly, clay will exchange sodium, if available, for both magnesium and calcium ions.
1.5.3 Sodium (Na$^+$)

Unlike calcium, magnesium, and silica, sodium is not found as an essential constituent of many of the common rock-forming minerals. The primary source of most of the sodium in natural water is from the release of soluble products during the weathering of plagioclase feldspars. In areas of evaporite deposits, the solution of halite is also important. Clay minerals may, under certain conditions, release large quantities of exchangeable sodium. All the natural water contains measurable amounts of sodium. Actual concentrations range is from about 0.2 ppm in some rain and snow to more than 100,000 ppm in brine in contact with salt beds. Areas of igneous and metamorphic rocks that are also in regions of moderate to high rainfall generally have water with 1 to 20 ppm of sodium. Water with total dissolved solids ranging from 1000 to 5000 ppm generally has more than 100 ppm of sodium, except water from gypsum beds and from limestone aquifers.

1.5.4 Potassium (K$^+$)

Common sources of potassium are the products formed by the weathering of orthoclase, microcline, biotite, leucite, and nepheline in igneous and metamorphic rocks. Waters percolating through evaporate deposits may contain very large quantities derived from the dissolution of sylvite and nitrate. All natural water contains measurable amounts of potassium. Some snow and rainwater may contain as little as 0.1 ppm and some brines as much as 100,000 ppm. Most potable groundwater, however, contains less than 10 ppm and commonly ranges between 1.0 and 5.0 ppm. An interesting feature of potassium is that dilute water containing only 20 ppm total dissolved solids may contain about 2 ppm potassium. As the concentrations increase, however, the amount of potassium increases slightly; thus water with a total dissolved solids concentration of 2000 ppm most likely will have less than 20 ppm potassium.
1.5.5 Carbonate and Bicarbonate (HCO₃⁻)

Most carbonate and bicarbonate ions in groundwater are derived from the carbon dioxide in the atmosphere, carbon dioxide in the soil, and solution of carbonate rocks. Some groundwater probably obtains bicarbonate from the carbon dioxide generated by diagenesis of organic compounds. Sodium bicarbonate water can be concentrated by evaporation in soils and desert basins; if it contains much calcium, the bicarbonate will be taken out of the water through precipitation of calcium carbonate.

Groundwater generally contains bicarbonate more than 10 ppm and not less than 800 ppm. Concentrations between 50 and 400 ppm are most common. Groundwater will rarely have pH values of less than 4.5, causing bicarbonate to be converted to carbonic acid or pH values of more than 8.2, so that the bicarbonate ions will dissociate to carbonate ions.

1.5.6 Sulphate (SO₄²⁻)

Despite a relatively large amount of sulfur, mostly in the form of sulfates, in water and in sedimentary rocks, sulfur is only a minor constituent of igneous rocks. Early in the history of the hydrosphere, most sulphate probably originated from the oxidation of sulfides from igneous rocks and volcanic sources, but at present sulphate is largely recycled from the atmosphere and from the solution of sulphate minerals in sedimentary rocks particularly organic shale may also yield large amounts of sulphate through the oxidation of marcasite and pyrite.

Concentrations of sulfate from less than 0.2 ppm to more than 100,000 ppm are found in nature. The lowest concentrations of sulphate are in rainwater, snow, and subsurface waters subject to sulfate reduction. The highest concentrations are in magnesium sulfate brines. Groundwater from igneous and metamorphic rocks or from sediments derived from them generally contains less than 100ppm and may contain less than 1 ppm if sulphate reducing bacteria are active in the soil through which recharge water has percolated.
1.5.7 Chloride (Cl\textsuperscript{-})

Chloride is a minor constituent of the earth's crust, but a major dissolved constituent of natural water. Sodalite and apatite are the only common minerals in igneous and metamorphic rocks which contain chloride as an essential constituent; although mica, hornblende, and natural glass may also contain significant amounts. Most chloride in groundwater comes from four different sources. First, it comes from ancient sea water entrapped in sediments; second, its concentrations are found in natural water between about 0.1 ppm in arctic snow and 150,000 ppm in brine. Continental rain and snow may contain from 1.0 to 3.0 ppm, but probably average less than 1.0 ppm. Shallow groundwater in regions of heavy precipitation generally contains less than 30 ppm of chloride. Concentrations of 1000 ppm or more are common in groundwater from arid regions.

As far as the quality of groundwater is concerned, many states in the country have been identified as endemic to fluorosis due to abundance in naturally occurring fluoride-bearing minerals. These are Andhra Pradesh, Gujarat, Haryana, Orissa, Punjab, Rajasthan, TamilNadu, Uttar Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Bihar, and Delhi. Nearly half a million people in India suffer from ailments due to excess of fluoride in drinking water.

1.5.8 Nitrate (NO\textsubscript{3})

Although igneous rocks contain small amounts of soluble nitrate or ammonia, most of the nitrate in natural water comes from organic sources or from industrial and agricultural chemicals. Nitrate compounds are highly soluble, so nitrate is taken out of natural water only through activity of organisms or through evaporation. Common nitrate concentrations in water range from 0.1 to 0.3 in rainwater to as much as 600 ppm in groundwater from areas influenced by excessive applications of nitrate fertilizer or runoff from barnyards, where normal groundwater contains only 0.1 to 10.0 ppm Nitrate.

Nitrates are chemicals present in most fertilizers. Nitrates can contaminate the groundwater, causing serious illness in young children.
1.5.9 Silica (SiO$_2$)

Silicon is the second most abundant element (after oxygen) of the earth's upper crust. Highest silicon concentration in groundwater is found where the water has been in contact with certain volcanic rocks. Silicon content expressed in mg/l of silica is of the order of 20mg/l for most groundwater.

1.6 Need for Groundwater Quality Studies

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

A vast majority of groundwater quality problems are caused by contamination, over-exploitation, or combination of the two. Most groundwater quality problems are difficult to detect and hard to resolve. The solutions are usually very expensive, time consuming and not always effective. Groundwater quality is slowly but surely declining everywhere. Groundwater pollution is intrinsically difficult to detect, since problem may well be concealed below the surface and monitoring is costly, time consuming and somewhat hit-or-miss by nature.

1.7 Geographical Information System and Remote Sensing

Geographic information system (GIS) is a system designed to capture, manipulate, save, analyze, manage, and present all types of geographical information whereas Remote sensing is the science of obtaining information from a remote platform. Remote sensing data is used in GIS for interpretation. GIS have become a useful and important tool in hydrology. Its use has rapidly become widespread among
hydrologists in recent years due to developed, simple software, availability of data, and the inventions of new applications for which GIS is suited. A very large amount of data from wells is available such as location, depth to water, stratigraphy, water quality and chemistry, aquifer characteristics, and the list goes on. The volume of data can be managed in a GIS platform and manipulated to display spatial characteristics for analysis and water resource planning. Several studies also have utilized GIS and Remote Sensing technique to monitor impacts of Land use/Land cover changes to the hydrologic conditions of watersheds and it is focused on the watershed’s response to future changes of land use/land cover.

1.8 Study Area

In the present study, the upper Pambar watershed was taken for a systematic evaluation of all aspects of hydrogeology. The Study area is located in the northern part of Tamil Nadu State in India (Fig 1.2). It covers Tirupattur, Vaniyambadi taluks of Vellore District and Uthangarai taluk of Krishnagiri District of Tamil Nadu, India (Figs 1.2 & 1.3). 90% of the area lies in Vellore District and only 10% lies in Krishnagiri District. Out of 61 water samples, only 5 were collected from Krishnagiri District. The study area is ellipsoidal in shape and has an aerial extent of about 737 square km and it is stretching from east-west to a width of 33 km and a length of 30 km along north-south. The geographical coordinates of the study area is on 12° 18’ 17”- 12° 38’ 01” North Latitude and 78° 29’ 17” - 78° 48’ 31” East Longitude. The Pambar watershed comes under the main Ponnaiyar river basin. There is no main river as the tributary Pambar River forms the main drainage network in Ponnaiyar basin and the tanks are interconnected to form a drainage network. The catchments for the tanks get water through heavy monsoon rains both within the watershed as well as from the eastern hilly terrain.

A base map appended in Fig1.4 shows the setup of the study area having themes on human settlements, transport network, surface water bodies, drainages and canals and reserve forests.
1.9 Physiography

The major physiographic features (Fig 1.5) of the study area are as follows

- Hills and Reserved forest are present in the northern, western parts
- The top part consists of a highly undulating terrain
- The central to the south-eastern part shows a plain terrain with slightly undulating topography

Considering the total extent of 737 sq.km, majority of the area is covered by wet and dry cultivated lands, apart from the forest cover and residence. There are 162 tanks present in the study area. Tirupattur Eri is a major tank covering an area of 1.11 sq.km. Bargur and Mathur rivers are the major tributaries of the river Pambar which merges with the river Ponnaiyar. Pambar River flows along a NNW-SSE fault zone and joins with Ponnaiyar River along the same alignment.

The watershed is bounded by Javadi hills on the eastern side which consists of many reserved forest, Yelagiri hills on the north and Uthangarai taluk to the south. The maximum and minimum elevations of the study area are 6400 m and 340 m respectively. The slope ranges from 0-80% respectively. The study area is underlain by hard crystalline rocks with its inherent problems regarding development, assessment and evaluation of the groundwater resources.

1.10 General Profile of Vellore District

Vellore is the third most populous district of Tamil Nadu (out of 32), after Chennai and Kanchipuram and had a population of 906,745 as per 2011 census. In terms of urbanisation level, Vellore District ranks 8th place among the other districts in Tamil Nadu. Vellore is a major transit point for travellers, a hub for medical tourism and is emerging as a tourism hot spot. It has an area of 6077 km² and lies between 12° 15’ to 13° 15’ North latitudes and 78° 20’ to 79° 50’ East longitudes in Tamil Nadu State. The district is bound on the northeast by Tiruvallur District, on the southeast by Kanchipuram District, on the south by Tiruvannamalai District, on the southwest
by Krishnagiri District, and on the northwest and north by Andhra Pradesh State. Major towns in the district include Ambur, Arakkonam, Arcot, Jolarpet, Gudiyattam, Melvisharam, Ranipet, Sholinghur, Tirupattur, Vaniyambadi, Vellore, and Walajapet. Kaveripakkam is a panchayat town in Vellore with the second largest lake in Tamil Nadu. The western part of the District has a hilly terrain with undulating topography comprising of a few hill ranges. While the eastern part is gently undulating with isolated hillocks of which the highest elevation is 1339 m above sea level.

Palar River is the major river draining the district and flowing towards east for a distance of about 295 km. It runs parallel to the hill ranges of the Eastern Ghats forming a major part of its course. It has a vast flood plain in the lower reaches, but is dry for major part of the year. Ponnaiyar, Cheyyar, Pambar and Malattar are some of the major tributaries of Palar draining the District.

1.11 Hydrometeorological Characteristics

1.11.1 Rainfall and Climate

The study area receives rainfall from both southwest and northeast monsoons. The annual normal rainfall (1935-2011) for the district is 893 mm. The contribution of southwest monsoon ranges from 45 to 52 percent, whereas it ranges from 30-43 percent due to northeast monsoon.

1.11.2 Rain gauge Stations

The rain gauge stations in and around the study area is given in Table 1.2. Theissen polygon (Fig 1.6) has been created for the following rain gauge stations in and around the study area.

1.11.3 Monsoon and Non-monsoon periods

The study area lies within the tropical monsoon zone. Based on the hydrometeorological features of the basin, the year is divided into 2 periods
(i.e.) 1) Monsoon period spanning from June to December and 2) Non-monsoon period spanning from January to May. The monsoon period is further sub-divided into Southwest monsoon period spanning from June to September (4 months) and Northeast monsoon period spanning from October to December (3 months).

Similarly, the non-monsoon period is further sub-divided into winter period spanning January and February (2 months) and Summer period spanning from March to May (3 months). As the monsoon period brings heavy rainfall, it improves the recharging of groundwater as well as storage of surface water. Hence, the monsoon period is hydrologically significant for water resources analysis. But in the case of non-monsoon, it is insignificant.

The average for southwest, northeast, winter, summer and annual rainfall for all the 10 rain gauge stations have been analysed and are tabulated in Table 1.3. The average rainfall graph (Fig 1.7) and season wise rainfall contour map (Fig 1.8) is presented.

1.11.4 Climate

Vellore is known for its extreme climatic conditions. The District has a tropical climate. The highest temperatures are recorded during May and June. The mean daily minimum and maximum temperature are 18.2 to 36.8° C. The relative humidity ranges from 37 to 85 percent. The climatological stations near the study area are located in Krishnagiri and Melumalai (Table 1.4)

1.11.5 Temperature

Temperature is one of the basic factors under climatological features and it is one of the main parameters to calculate the crop water requirement (i.e. evapotranspiration). The maximum and minimum monthly mean temperature observed in the above two climatological stations are given in Table 1.5
1.11.6 Relative Humidity

The monthly average percentage of relative humidity varies from 60.79% to 75.78% for Krishnagiri and 60.04% to 77.18% for Melumalai.

1.11.7 Wind speed and Sunshine

Wind velocity is an important meteorological parameter which has considerable influences on evaporation and evapotranspiration phenomena. Wind has direct impact on climate and vegetation and is linked with circulation pattern of the monsoon. The average wind velocity in km / hour varies from 1.66 to 6.06 for Krishnagiri and 3.20 to 10.52 for Melumalai. The average sunshine hrs/day varies from 4.63 to 10.25 for Krishnagiri and 4.91 to 9.68 for Melumalai.

1.12 Transportation

The map (Fig 1.5) shows the details about major road networks, important locations, rivers and lakes. There are four state highways and one national highway crossing the study area which is tabulated below (Table 1.6).

Railway network comes under the Southern Railways. There are a total of 28 railway stations and a total of 152 km (94 mi) of rail tracks in the District. Jolarpet Railway Junction in Tirupattur taluk is one of the biggest junctions in the Indian Railways and is the only station in Asia having sixteen tracks. Per day 121 trains pass through Jolarpet Railway Junction. It connects the States of Kerala, Karnataka and Andhra Pradesh.

1.13 Literature Review

1.13.1 International Reviews

Many workers have carried out research on hydrogeology and hydrogeochemistry throughout the world.
Amadi et al. (1989) carried out detailed hydrogeochemical investigations in parts of the Niger Delta, Nigeria, in order to assess the quality of groundwater.

Eaton et al. (1998) carried out hydrogeochemical investigations on the groundwater from Portugal.


Ducci (1999) produced groundwater contamination risk and quality maps by using GIS in Italy.

Fritch et al. (2000) developed an approach to evaluate the susceptibility of groundwater in north-central Texas to contamination.

Evolution of groundwater composition in an alluvial aquifer was studied by Helena et al., (2000).

Drainage basins are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, including the topology of the stream networks, and quantitative description of drainage texture, pattern, shape and relief characteristics (Abrahams 1984).

Multivariate factor analytical technique had been used by Reeder et al. (1972) to identify the likely weathering processes controlling the chemical composition of surface waters of the Mackenzie River drainage basin in Canada. A set of quantitative analytical data from the alluvium of the Pisuerga River, located northeast of Valladolid, Spain, was processed by multivariate statistical techniques in order to investigate the evolution of the groundwater composition between two surveys.

The effect of simulated outliers was studied by Chan and Shi (1997) in application of PCA to climate studies. They showed how the method of projection-pursuit principal component analysis can be applied to analyze regional monthly sea surface temperature and rainfall. Comparisons were made with results derived from the
traditional empirical orthogonal function method. They observed principal component analysis to be much more robust than the empirical orthogonal function method and opined that it should be considered as an alternative in many of the climate studies.

Join et al. (1997) outlined the use of multivariate statistical analysis to trace groundwater circulation in volcanic terrains using PCA based on both structural and hydrochemical parameters of 243 springs of Reunion (Western Indian Ocean). This analysis was consistent with a geological and hydrogeological conceptual model developed from a combined hydrochemical and geological reconnaissance of 27 springs.

Aruga (1997) analyzed which kind of data (normally distributed, standardized, transformed) are the best for a realistic factor analysis in environmental studies and showed effectiveness of factor analysis on the examples of study the causes of Po River pollution in the Piedmont region. A set of quantitative analytical data from the alluvium of the Pisuerga River, located northeast of Valladolid, Spain, was processed by multivariate statistical techniques in order to investigate the evolution of the groundwater composition between two surveys. Varimax rotation allowed to “break up” the “mineralization” principal components into two varimax rotated principal components, assigned respectively to “natural” mineralization and to “saline” man-made contamination (sodium and chloride).

Liu et al. (2003) applied factor analysis to the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Factor analysis was applied to 28 groundwater samples collected from wells in this coastal area and correlations among 13 hydrochemical parameters were statistically examined. They suggested a two-factor model that explained over 77.8% of the total groundwater quality variation.

Syed Munaf Ahmed et al. (2005) used the multivariate factor analytical technique to assess the water quality and source of contamination in an irrigation project at Al-Fadhli, Saudi Arabia.
1.13.2 National Reviews

Hydrogeochemical studies have been carried out by several workers in India. Handa (1981) studied the hydrogeochemistry, water quality and water pollution in Uttar Pradesh.

Rao and Rao (1990) carried out hydrogeochemical studies to ascertain the intensity of pollution of groundwater due to rapid industrialization and urbanization in Visakhapatnam area.

Benbi et al. (1991) carried out hydrogeochemical investigations on the groundwater of Sangrur, Punjab, to assess its suitability for irrigation purpose.

Ozha et al. (1993) studied the nitrate concentration in some Districts of Rajasthan, their health hazards and nitrate removal.

Elango et al. (2003) have reported the influence of rock types with groundwater chemistry in a part of Palar River basin in Tamil Nadu.

Natchimuthu et al. (2008) studied the Scenario on Ground Water Quality of the Bore Wells located at Industrial Premises, Rechaguneri village, Sri Kalahasthi Mandal, Chittoor District, Andhra Pradesh, India.

Seetharam sethupathi (2009) studied the Hydrogeology and Geochemistry of Bargur- Mathur subwatersheds, Ponnaiyar river basin, India.

Geena (2011) carried out the integrated surface water and groundwater studies in Korattalaiyar river basin, Tamil Nadu, India.

GIS has also been found to be one of the most powerful techniques in assessing the suitability of the land (Padmavathy et al. 1993; Sharada et al. 1993).

Elango and Arrikkat (1998) integrated and analyzed various thematic layers related to groundwater recharge using GIS for the identification of recharge sites in parts of Ongur sub-basin, south India.

Natchimuthu et al. (2008) carried out the Water Quality Analysis and Land use Environment using Remote Sensing and GIS. A case study of Vaippar river basin.
The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed (Singh, 1992).

Agarwal (1998) and Obi Reddy et al. (2002) have made detailed study with morphometry and defined that it is a measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms.

Characterization of groundwater contamination using factor analysis was presented by Subba Rao et al. (1996). The effluent contamination of groundwater at two industrial sites at Visakhapatnam, India was studied using factor analysis. The data were subjected to R-mode factor analysis and the factor scores transferred to areal maps.

Srinivasamoorthy et al. (2008) studied the groundwater quality in Mettur taluk of Salem district and identified that NO$_3$ and PO$_4$ were higher in samples and chemical weathering, leaching from secondary salt followed by anthropogenic impact are the major contributors for certain ions in groundwater.

Jeevanandam et al. (2007) utilized the factor analytical tool to substantiate the hydrogeochemistry and groundwater quality assessment study of the lower part of Ponnaiyar River Basin, Cuddalore District, South India.

Jayaprabak et al. (2008) evaluated and characterized the factors affecting the geochemistry of groundwater in Neyveli, Tamil Nadu, India. R-mode factor analysis was applied and the results showed the influence of various factors such as anthropogenic activities, silicate weathering reactions, precipitation and rock-water interaction in the overall chemical budget of water. The seasonal variation in the chemistry of water has also been brought out using the factor analytical technique.
Fig 1.8 Rainfall contour maps of the study area
Fig 1.6 Theissen Polygon
Fig 1.5 Physiographic map of the study area
Fig 1.4 Base map of the study area
Fig 1.3 Major Taluks and the study area
Fig.1.2 Key map of the study area