HYDRO GEOCHEMICAL QUALITY ASSESSMENT OF GROUNDWATER – A GENERAL PERSPECTIVE

Thesis Submitted to the

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the requirements for the award of the Degree of

DOCTOR OF PHILOSOPHY

In

Environmental Hydrochemistry

Under the Faculty of Marine Sciences

By

SUMANGALA K. N.

DEPARTMENT OF CHEMICAL OCEANOGRAPHY

SCHOOL OF MARINE SCIENCES

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

COCHIN-682016

DECEMBER 2011

"The Secret of progress is obedience. True obedience comes only with love. The highest expression of love is the ability to sacrifice. When we become love, whatever comes within the orbit of that influence gets that love, feels that love, perceives that love, and is inspired by that love. Love's reward is the beloved"

Babuji,

Founder – SRCM

DECLARATION

I hereby declare that the thesis entitled, **"Hydro Geochemical Quality Assessment of Groundwater – A General Perspective"** is an authentic record of research work carried out by me under the supervision and guidance of **Dr. Sujatha C.H**, Department of Chemical Oceanography, Cochin University of Science and Technology, in partial fulfillment of the requirements for the Ph.D. degree of Cochin University of Science and Technology under the faculty of Marine Sciences and no part thereof has been presented for the award of any degree in any University/Institute.

Kochi -16 **Sumangala.K.N.**

December 2011

ACKNOWLEDGEMENT

I wish to express my heartfelt and deep sense of gratitude to my affectionate Research Supervisor, Dr. Sujatha C.H., Asst. Professor, Department of Chemical Oceanography, Cochin University of Science and Technology, for guiding the research programme, constant encouragement, valuable suggestions and for the continuous support throughout the course of this thesis work. She sharpened my thinking and inspired me to enlighten the horizon of knowledge. This work would not have been completed without her timely help and guidance.

I take this opportunity to convey my earnest thanks to the Head (Prof) Dr.N.Chandramohanakumar, Department of Chemical Oceanography for his support, valuable advice and giving permission to do the research work and continuous encouragement throughout the course of my work.

I acknowledge with special thanks to the facilities provided to me by the Director, School of Marine Sciences, CUSAT.

I would like to record my gratitude and honest recognition to my teachers Dr. (Prof) Jacob Chacko and Dr. S. Muraleedharan Nair, Associate Professor, Dept. of Chemical Oceanography, CUSAT for their timely suggestions.

I express my profound gratitude to Sri.G.Balagangadharan Nair, former Director, Ground Water Department, Trivandrum for his in-depth valuable suggestions, moral support and positive encouragement throughout the course of this work.

My sincere gratitude to Dr. (Prof).R.Damodharan, former Dean, School of Marine Sciences, CUSAT for introducing me to the erstwhile University.

I thank Sri.P.S.Harikumar, Head, CWAL, CWRDM, Kozhikode for his valuable advice and help during the research work.

My sincere thanks to Mr. Kurian.C. Kunnath, Director, Chemical division, Geological Survey of India, Trivandrum for the knowledge provided by him in the chemical analysis.

I am greatly indebted to the State Ground Water Department, Kerala, Indian Meteorological Department and IDRB, Trivandrum, for providing data for this thesis work.

There are no words to convey and express my sincere thanks to Mr.Akhil.P.Soman, Junior Research Fellow, Department of Chemical Oceanography, CUSAT, who sincerely dedicated his valuable time for the technical fulfillment of the thesis work in a speedy and time bound manner.

I record my thanks to Sri J.Pradeep Kukkillaya and Sri. V.P. Radhakrishna Pillai, Former directors, State Ground Water Department for giving permission to use the data of the department for this work.

I extend my thanks to Sri. M.R. Ramesh, Director, State Ground Water Department for supporting me with sufficient training in Ground water quality analysis.

I am grateful to all staff of the analytical wing of the State Ground Water Department with special reference to Ms. M.S. Sreekala, Junior Chemist and Mrs. S. Sylaja, Surveyor.

I am grateful to Sri. K. K. Kartha, Senoir Chemist, Geological Survey of India, Kerala region for helping me in the Trace metal analysis.

My sincere thanks to Sri.P.N.Ajithkumar, District Officer, State Ground Water Department for his advice and timely suggestions.

I thank Dr. Babu.N, Department of Marine Geology and Geophysics, for providing valuable information regarding geochemistry.

I thank Dr.N.S.Kalesh, Section-in-charge, Chemistry, Inter Field laboratories, Kochi-5 , for analyzing the sample for pesticides.

My sincere thanks to Ms.Shiji, Technical Assistant and Ms.Dr.Resmi, Scientist, CWAL, CWRDM, Calicut for the help in analysis work.

I express my sincere thanks to Mr. Jose Mathew and his mother for providing hospitality in the final stages of the thesis writing.

I am grateful to all the Office staff, Department of Chemical Oceanography and Librarian, School of Marine Sciences Library for the co operation extended during my tenure.

My special thanks to Mr.Pramod Lal for his help in GIS map preparation.

The field support given to me by Saju, Lascar, State Ground Water Department is gratefully acknowledged.

I record my thankfulness to my Supervising guide's husband, Mr.P.V.Sathyachandran and children, Jithu.S. and Aishwarya.S for their help and peaceful bearing mind. My special thanks to Jithu.S for the preparation of sketch for this thesis.

My special thanks to Mr.Shyju. P, Technical Assistant, Department of Chemical Oceanography, CUSAT for providing immense help in the laboratory.

My sincere thanks to Ms.Renjitha.R, Mr.DeepuLal.P.M., Mrs. Dayala V.T, Ms.Manju.P.Nair, Mr.Jyothish Kumar.T and all other Research scholars in the Department of Chemical Oceanography,CUSAT. I would like to thank for whoever being with me in all times of need and helping me in keeping my spirits up.

I am greatly indebted to my late beloved parents for their whole-hearted divine blessings.

This work would not have been feasible but for the keen interest, love , affection and help in data entry by my beloved younger son Vishnu.S, studying in XI STD (Loyola School, Trivandrum). I am greatly indebted to my husband, Sri.K.Sureshkumar and elder son, Mr.Hemanth.S and other family members who stood behind me in the ups and downs and gave me immense help for the successful completion of this work.

Above all, I thank the Almighty without whom not a sand grain move or not a leaf quivers.

Sumangala.K.N

PREFACE

People in several parts of the world as well in India countenance an immense confront to meet the basic needs of water. The crisis is not due to lack of fresh water but its availability in adequate superiority. Environmental quality objectives should be developed in order to define acceptable loads on the terrain. There has been a number of initiatives in water quality monitoring but the next step towards improving its quality hasn't taken the required pace. Today, there is a growing need to create awareness among citizens on the different technologies available for improving the water quality. Monitoring facilitate to apprehend how land and water use distress the quality of water and assist in estimating the extent of pollution. Once these issues are recognized, people can work towards local solutions to manage the indispensable resource effectively. Ground waters are extremely precious resources and in many countries together with India they represent the most important drinking water supply. They are generally microbiologically pure and, in most cases, they do not need any treatment. This communiqué is intended to act as a channel on the various paraphernalia and techniques accessible for groundwater quality assessment and suggesting the assured precautionary measures to embark on environment management. This learning is imperative considering that groundwater as the exclusive source of drinking water in the region which not makes situation alarming but also calls for immediate attention.

The scope of this work is somewhat vast. Water quality in Ernakulam district is getting deteriorated due to the fast growth of urbanization. The closure of several water bodies due to land development and construction prevents infiltration of rainwater into the ground and hence recharge the aquifers. Most of the aquifers are getting polluted from the industrial effluents and chemicals and fertilizers used in agriculture. Such serious issues require proper monitoring of groundwater and steps are to be taken for remedial measures. This study helps in the total protection of the rich resource of groundwater and its sustainability. Socio-economic aspect covered could be used for conducting further individual case studies and to suggest remedial measures on a scientific basis. The specific study taken up for 15 sites can be further extended to the sources of pollution, especially industrial and agriculture.

Major Objectives of the present investigation are summarized as:-

1. To study the hydro-geochemical characteristics of sedimentary and crystalline geologic formations of Ernakulam district.
2. To investigate the effect of precipitation on groundwater level and water quality of shallow and deeper aquifers.
3. To evaluate the water quality of open wells in sedimentary and crystalline formations.
4. To observe water quality fluctuation during pre-monsoon, monsoon and post-monsoon seasons during the study period (2006-2008).
5. To classify the water type and irrigation suitability.
6. Mapping of selected water quality parameters in Ernakulam district.
7. To investigate the presence of trace metals and pesticides in the groundwater of 15 selected stations.
8. To study on the socio economic effect of water quality in the dug-cum-bore wells of Anchalpetty in Pampakuda panchayat.

The thesis is divided into 6 chapters.

Chapter I gives a general introduction, Indian scenario, hydrologic cycle, significant water quality parameters related to groundwater, selected groundwater structures, and objectives and scope of the study.

Chapter II (Materials and Methods) This chapter deals with the general features of the study area. Description includes both general study and specific study. Site selection criteria is discussed. Details of observation sites, sampling, instrumental methods and analytical procedures adopted for the analyses of various physic-chemical parameters are included. Administrative map, geological map, geomorphological map, location maps etc., are incorporated.

Description of the study area. (General and Special)

The study area is Ernakulam district. Both sedimentary and crystalline formations are selected for the study. Under the general geochemical study 8 open wells in the sedimentary formation, 31 open wells in the phreatic crystalline formation and 12 bore wells in the deeper crystalline have been chosen. Locations under sedimentary formations cover Paravur and Cochin taluks and those under crystalline formation cover taluks of Aluva, Kanayannur, Kothamangalam, Kunnathunad and Muvattupuzha. Under sedimentary area, the stations selected are Paravur, Pallippuram, Njarakkal, Mattanchery, Ernakulam South (Ravipuram), Chellanam, Kumbalangi, and Edacochin. For the purpose of study the selected stations of phreatic crystalline formation are Aluva, Angamaly, Kalady, Manjapra, Nedumbassery, AluvaEast, Ambaloor, Thiruvankulam, Trikkakkara, Pothanikkad, Keerampara, Eramalloor, Pindimana, Kuttamangalam, Neryamangalam, Ramamangalam, Vengola, Pattimattom, Kunnathunad, Rayamangalam, Kunnathunadsouth, Perumbavur, Kizhakkambalam, Piravom, Elanji, Kuthattukulam, Thirumaradi, Kakkur, Memuri, Muvattupuzha, and Eranellur.

The locations of bore wells are Kunnukara, MookkannurWard-I, Kadungallur (Edayar), Vadavukode, Pattimattom, Rayamangalam, Vengoor, Muvattupuzha, Onakkur, Piravom, Pindimana and Neryamangalam. Collected rainfall data for 3 years from January 2006 to December 2008 for different stations covering all the sites. Monthly water level data was also collected during the study period of January 2006 to September 2008. Water samples were collected during pre-monsoon, monsoon and post-monsoon seasons of 2006 to 2008 and analyzed for various physic-chemical parameters. Analytical methodology for the present study was selected as per the recommendations given by Standard Methods for the Examination of Water and Wastewater, APHA 19th Edition, Methods of Seawater

Analysis, Grasshoff, et al., 3rd Edn, 1999. Under specific study, a total of 15 wells at Ernakulam district (12 open wells and 3 bore wells) were selected in order to assess the possible contamination due to pesticides and trace metals from the neighbouring environment. Analysed the sample for general parameters, Phosphate, Nitrite, Silica, Trace metals as Pb, Cd, Cu, Zn , Mn and As and Pesticides. Measured water levels and water quality during September 2007, January 2008 and May 2008. Studied the seasonal variation of water quality parameters.

Chapter III

This chapter deals with item no 1 to 4 of the objectives and scope of the work. This chapter explains the study of hydrogeochemical characteristics of natural waters and groundwater chemistry, groundwater quality in various geological formations, hydrological and geochemical parameters, major ions in groundwater etc. It details data validation of all the wells selected and includes station-wise correlation.

This chapter explains the study of hydro-geochemical characteristics of sedimentary and crystalline formations of Ernakulam district by selecting phreatic and deeper aquifers. Whenever the rate of precipitation varies there is a change in the ground water quality. The study throws light on the effect of precipitation on water level and water quality of shallow and deeper aquifers.

The open wells in the sedimentary and crystalline formations have different water quality parameters. This chapter also deals with the comparison of water quality of open wells in sedimentary and crystalline formations. This will give an idea on how the ground water movement affects the water quality parameters. The velocity of movement of ground water in sedimentary and crystalline formations also varies. Field observations are made on three seasons pre-monsoon, monsoon, post-monsoon, in order to study the seasonal fluctuation of ground water quality. This will give clear information on the basic characteristics of the aquifer on water quality with reference to the seasonal variation. This study would give way to determine the quantity of abstraction of ground water at a suitable season when the water quality parameters are well within the limits. These seasonal studies could be further extended for aquaculture, agriculture etc., in addition to the water marketing. In order to view the results easily, a set of hydrographs are also generated.

Chapter IV

This chapter consists of items 5 and 6 of the objectives and scope of the work. Water quality interpretation for groundwater samples are done by using Piper diagram. On this diagram the relative concentrations of the major ions in percent are plotted on cation anion triangles and the locations are projected to the point on a quadrilateral representing both cations and anions. The water types for different well water samples were obtained by putting the analytical data into AQUACHEM software. The nature of groundwater is related to the soluble products of rock weathering, decomposition and changes with respect to time and space. The concentration of an ion in water depends upon the nature of the rock minerals, its solubility and weather ability in fresh or carbonated water (due to dissolution of atmospheric CO_2 in rain water), climate and local topography. Groundwater has been classified based on irrigation quality parameters such as Percent Sodium, Residual Sodium Carbonate, Sodium Adsorption Ratio, Residual Magnesium/Calcium ratio and Kelly's Ratio. In this chapter classification of groundwater quality and irrigation suitability have been represented as correlation matrix for future reference. Water quality of Ernakulam district has been mapped with respect to the study period. The seasonal water quality changes have been mapped. Such representation will reveal the effect of each water quality parameter in the groundwater occurrence.

Chapter V

This chapter deals with item no 7 and 8 of the objectives and scope of the work. 15 stations were selected where possibility of pollution was anticipated. Presence of pesticides and trace metals were analysed and included. A very important aspect of socio-economic effect of the water quality in dug-cum-bore wells of two case studies has been incorporated. For this purpose 2 dug-cum-bore wells in Anchalpetty in Pampakuda panchayat were selected. The sites are located on both sides of Piravom-Koothattukulam road. The effect of water quality in one of the dug-cum-bore wells has directly affected the people with the result of lack of hygiene, loss in agriculture and other economic aspects of life. The water quality would affect the general health of the public and water borne diseases are common which requires special attention.

Chapter VI deals with remedial measures and summary of overall objectives.

Chapter 6 shows the overall summary of the work and reveals the interrelation of various factors such as rainfall and water levels of deeper and shallow aquifer, the influence of dilution and other items on the water quality of the aquifers etc., with respect to time. The effect of precipitation on the deeper aquifer is a time consuming exercise. This study throws light on the quality variation of aquifer with respect to time by which the precipitation has contributed to the effect. The effect of precipitation on hydro-chemical water quality of deeper aquifer of Ernakulam has been well established by this study.

CONTENTS

Cochin University of Science and Technology
DEPARTMENT OF CHEMICAL OCEANOGRAPHY
Dr: Sujatha C.H.
Assistant Professor

Fine Arts Avenue
Cochin-682016,India
Tel:91-484-2382131(0)
Mob:9995991778
Fax:91-484-2374164
E-mail:drchsujatha@yahoo.co.in

CERTIFICATE

This is to certify that this thesis entitled, **"Hydro Geochemical Quality Assessment of Groundwater – A General Perspective"** is an authentic record of the research work carried out by **Mrs. Sumangala K.N.** under my supervision and guidance in the Department of Chemical Oceanography, Cochin University of Science and Technology, in partial fulfillment of the requirements for the Ph.D Degree of Cochin University of Science and Technology under the faculty of Marine Sciences and no part thereof has been presented for the award of any degree in any University/Institute.

Kochi-16
December 2011

Dr. Sujatha C.H
Supervising guide

Chapter - I

GENERAL INTRODUCTION

Chapter - I

GENERAL INTRODUCTION

1.1 INTRODUCTION

Water is the most important natural resource which forms the core of the ecological system. Over the few decades, competition for economic development associated with rapid growth in population and urbanization has brought in significant changes in land use, resulting in more demand of water for drinking, domestic, agriculture and industrial activities. Global water consumption is increasing at twice the rate of population growth, though only 1% of the earth's water is available for human use (CGWB 2009). Water is very vital for nature and can be a limiting resource to human and other living beings. Without a well functioning water supply system it is difficult to imagine productive human activity in the field of agriculture and livestock. To meet this escalating demand for potable water, there has been indiscriminate exploitation of groundwater resources particularly in areas where the surface water potential is negligible (Banerjee et al. 2008). It has been estimated that the requirement of the groundwater in 2050 will be about more than three times the present level due to the population explosion (Gupta and Deshpande 2004). In addition, the quality of groundwater is as important as its quantity, owing to the sustainability and intended use for various purposes, because the variation in its quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Bhagavathi and Thamarai 2008; Subramani et al. 2005; Tatawat and Chandel 2008). The poor quality of water can also adversely affect the plant growth and human health (Wilcox 1948; US Salinity Laboratory Staff 1954; Holden 1971; ISI 1983; WHO 1984; Hem 1991; Karanth 1997).

Groundwater is the main source of irrigation in arid and semi-arid regions in the world. The quality of water is of utmost importance to quantity in any water supply planning and its quality is influenced by natural and anthropogenic effects including local climate, geology and irrigation practices. The quality of any groundwater is a function of the physical, chemical and biological parameters, and could be subjective, since it depends on a particular intended use (Tatawat and Chandel, 2008). Over the few decades, competition for economic development, associated with rapid growth in population and urbanization, has brought in significant changes in land use, resulting in more demand of water for agriculture, domestic and industrial activities. Irrigated lands contribute significantly to the world agriculture output and food supply. India is one of the agriculture based countries. Water used for irrigation can vary greatly in quality depending upon the type and quantity of dissolved salts. Salts present in irrigation water are relatively small but significant amounts, usually originate from dissolution or weathering of rocks and soil, including dissolution of lime, gypsum and other soil minerals. These salts are carried with the water that flows through it. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop. In irrigated agriculture, the hazard of salt water is a constant threat. Besides affecting crop yield and soil physical conditions, irrigation water quality affects fertility needs, irrigation system performance and longevity and how the water can be applied (Ayers and Westcot 1994). Due to inadequate availability of surface water to meet the requirement of human activities, groundwater remains the only option to supplement the ever-increasing demand of water. The quality of the groundwater has also been affected by over-abstraction (Wang et al. 1999; Tang and Zhang 2001; Ding and Zhang 2002). Hence, the suitability of groundwater for agricultural, municipal, industrial and domestic water supplies can be determined by evaluation and graphical representation of physico-chemical water quality parameters.

India with a geographical area of 3.29 million square kilometers receives annual precipitation of about 4000 cubic kilometers. Average annual rainfall can be treated as 114 cm for the study purpose. Rainfall in India is dependent on South-West and North-East monsoon. Shallow cyclonic depressions and disturbances, violent local storms, cool humid winds from the sea etc; have also been observed resulting in additional rainfall. The long term average annual rainfall for the country is 116 cm. It is also observed that great variations, unequal seasonal distribution, and geographic distribution etc; creates frequent departure from the normal.

According to National Commission for Integrated Water Resources Development, the basin-wise average annual flow in the Indian river systems has 1953 km^3 and the utilizable annual surface water for the country is 690 km^3. The total replenishable ground water resource of India is assessed as 431.89 km^3. The annual potential of natural groundwater recharge from rainfall in India is about 344.43 km^3 which is about 8.56% of the total annual rainfall of the country. The annual potential groundwater recharge from canal irrigation system is about 89.46 km^3. India traditionally has been an agriculture-based country. Industrial growth and urbanization include additional aspects. Agriculture being the major basis of economy, irrigation and development of water resources became two important dependant factors.

Irrigation was based on surface water for a long time. Rain dependent cropping pattern became uneconomical. Irrigation potential developed from surface water was then supplemented by development of ground water. The recent trend is to have conjunctive use of surface water and ground water. This makes the role of groundwater as essential commodity. Quality assessment and monitoring, resource management etc; became relevant factors. Various conservation and management strategies have been formulated for optimum use of available water resource to maximize the benefits.

Water conservation, rainwater harvesting, groundwater recharge and management etc; are various recent developments. In the Indian economy, ground water quality assessment plays an important role for industrial development and fast track urbanization, sustainability of agriculture etc; which requires proper water quality management. Without proper water quality data, such management is not possible.

Groundwater is superior to surface water as it serves as a naturally occurring reservoir with less susceptibility to evaporation losses, climate variability and anthropogenic activities. These advantages impart a significant quantity of groundwater which is being used for domestic, agricultural, industrial and land-use-related activities. Monitoring of water quality is one of the important steps in water resource management. Water quality monitoring has been given the highest preference in health protection by World Health Organization (WHO 2006) and also for environmental protection policies (Robins 2002; Kruawal et al. 2005). The routine monitoring of groundwater can assure the populace about the quality of their drinking water and helps in recommending remedial action to check whether further deterioration in quality takes place (Mor et al. 2007; Ravindra and Garg 2007). The chemical characteristics of water govern its suitability for various activities, such as domestic, irrigation and industrial use (Wen and Chen 2006). Water chemistry is very complex because of the association of a large number of measured valuable information variables (Ravindra et al. 2003) and extraction of these from huge data sets makes a difficult task.

In India, the water quality monitoring helps to realize how land and water use affects the quality of water and give a pathway in estimating the extent of pollution. Once these issues are recognized, people can work towards local solutions and manage the indispensable resource effectively. Removal of high concentration of hardness, faecal bacteria, fluoride, iron, turbidity, nitrate, arsenic and pesticides from water require the application of various tools and modern techniques. Water quality management has become a part of socio-economic development of the society as mankind has wide range of water utility activity. Average intake of water by individual is 3.1% of body weight. Life sustains on water as one of the major components. Therefore qualitatively safe and adequate volume of aesthetically acceptable water should be made available. Availability of water in various water bodies in the universe is shown in **Table 1.1**

Table 1.1

Water availability in the universe in terms of Percentage

Water bodies	Percentage
Oceans	97.000
Fresh water	2.9
Potable water	0.1

Surveillance of drinking water quality from the public health point of view involves organization, management and number of other activities including follow up action to keep a constant vigil on the safety and acceptability of drinking water supply. Water Quality programmes need to be tagged with surveillance. The absence of water quality surveillance may lead to catastrophes due to contamination of water. Such situation may cause break of waterborne and water related diseases. In India, 1.5 million children below 5 years age die from diarrhoeal diseases every year (Handbook on drinking water quality monitoring and management). Water borne diseases are a heavy burden for all governments in the developing countries. Water quality standards in the country were formulated as early 1940 and the standards were modified later from time to time. Although there are at least three standards formulated by ICMR, BIS and CPHEEO, the one recommended by Bureau of Indian Standards (BIS) is being widely adopted, which has been used in this study. The presence of F^- in groundwater at higher than the prescribed permissible limit significantly affects human health and may lead to fluorosis, an endemic disease (BIS 1991; Ripa 1993; WHO 1997).

The present study is significant due to the annual depletion of groundwater in India specifically in the Metropolitan city, Kochi. It becomes the need of the humanity to sustain and protect the rich resource under the surface of the earth. Aim of this work is to achieve such a surveillance programme which in future will lead to the remedial and preventive action. Sustainability of safe water supply will help the community in general with special benefit to the rural areas. Proper water quality surveillance will be a safe guard of general public and also will avoid unnecessary capital cost on infrastructure.

1.2 HYDROLOGIC CYCLE

This study on geochemical quality assessment of groundwater in Ernakulam district will not be complete without mentioning the term Hydrologic cycle, as the entire programme depends on the groundwater received from precipitation. The cycle is applied to the general circulation of water from the sea to the atmosphere, to the ground and back to the sea again. It has no beginning or end, but undergoes various complicated processes such as evaporation, precipitation, interception, transpiration, infiltration, percolation, storage and run off. The hydrologic cycle is driven by the energy of the sun and the gravity of the earth and proceeds endlessly with or without human intervention. Groundwater constitutes one portion of the hydrologic cycle and depicted in **Figure1. 1**. The water bearing formation of the earth's crust act as conduits for transmission and as reservoirs for storage of water.

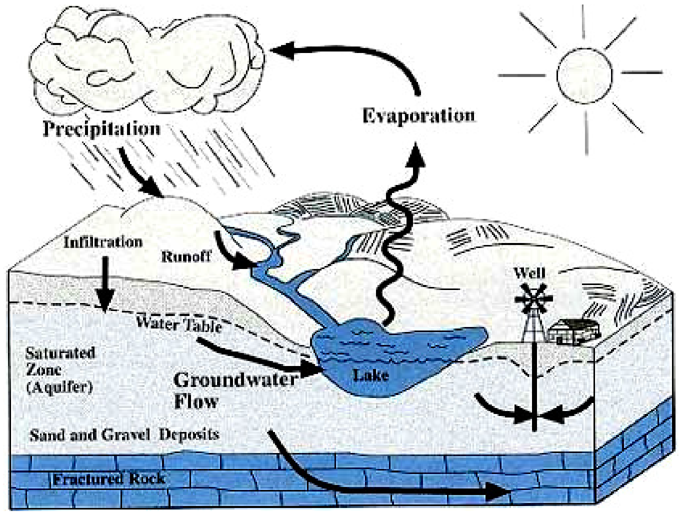


Figure 1.1

Hydrologic cycle

The storage capacity of groundwater reservoirs combined with small flow rates provide large, extensively distributed sources of water supply. Groundwater emerging into surface stream channels aids in sustaining stream flow when surface runoff is low or nonexistent. Similarly water pumped from wells represents the sole water sources in many regions during much of every year. Practically all groundwater originates as surface water. Principal sources of natural recharge include precipitation, stream flow, lakes and reservoirs. Other contributions known as artificial recharge occur from excess irrigation, seepage from canals and water applied to augment groundwater supplies. Water within the ground moves downwards through unsaturated zones under the action of gravity, whereas in the saturated zone it moves in a direction determined by the surrounding hydraulic situation. Thus the infiltrated water may percolate to deeper zones to be stored as groundwater, which may later flow out as springs or seep into streams (as base flow) and finally evaporate in to atmosphere to complete the hydrologic cycle.

All waters that occur naturally beneath the surface of the earth's surface, including saturated and unsaturated zones, called subsurface water. The zone in which soil water occurs is called unsaturated zone or vadose zone or zone of aeration and the zone in which groundwater occurs is the saturated zone. The two zones are fundamentally different because of the way water occurs in them. Vadose zone, in which soil, air and water are in contact with each other and may react with each other, vary in depth by zero to tens of meters. Downward movement of water in this zone is very slow and at the rate of less than 10 meter per annum or even less than 1 meter per annum. Residence time of water in this zone depends on the thickness of the zone.

The surface separating the zone of aeration and zone of saturation is called the water table or the phreatic surface and it is described as a surface along which the fluid pressure is equal to atmospheric pressure (**Figure1.2**).

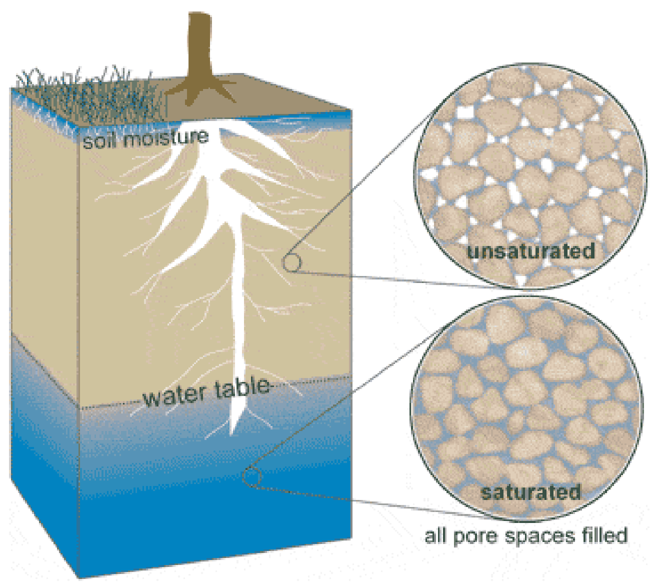


Figure 1.2

Water Table

The region between ground surface and water table is known as zone of aeration in which there is a free exchange of air and moisture. In this zone, some pores contain water, some are partially filled and some are empty. The space not occupied by water is filled with air. This zone act as a reservoir containing water for vegetation growth, and act as a conduit for water moving down to recharge groundwater. Below the zone of aeration is the groundwater or zone of saturation. In the groundwater zone, all the rock pores and soil are completely filled with water. The lower limit of zone of saturation extends to depths at which the interconnected openings filled with water are so little that they have no practical significance. The width of zone of saturation varies from a few meters to several thousands of meters.

In an area, the hydrological framework may consist of one or several rock units having distinct permeability and storage capacities. The rock units, based on their permeability, storage capacities, and their water yielding capacities are classified as aquifers. Aquifers are geological formations which are sufficiently porous to store large quantities of water and permeable enough to transmit it in quantities that can be economically exploited. Aquicludes are low permeability formations which contain water but incapable to transmit in significant quantities. Aquitard is a low permeability geologic formation, which contains water and can transmit it slowly from one aquifer to another. Aquifuge is an impermeable unit which neither contains nor transmits water.

According to geological setting and hydrogeologic regime, aquifers are classified in to confined aquifer and unconfined aquifer. The source of groundwater in the unconfined aquifer is precipitation and infiltration. They are like underground lakes in porous materials. There is no clay or other restricting material at the top of the groundwater so that groundwater levels are free to rise or fall. In an unconfined aquifer the upper limit of zone of saturation i.e., water table is at atmospheric pressure. Any point below it shows a water pressure greater than atmospheric pressure.

Confined aquifers are completely filled with groundwater and they do not have a water table. They usually occur at depths and relatively protected from contamination. In this, the water-bearing material is sandwiched between two layers of much less pervious material like a sandy layer between two clay layers, or sandstone between layers of shale or solid lime stone. The water pressure in this aquifer is greater than atmosphere and the effective aquifer thickness extends between two impermeable layers. If a well is drilled in such an aquifer, water will rise in the well until the water column balances the pressure in this aquifer. For example a bore well drilled up to a depth of 60 m will have the static water level at 5 mbgl.

The present study area comprises of both phreatic aquifer known as unconfined aquifer and deeper aquifer. The detailed description is given in **Chapter-II**. The aquifer occurring at depth consists of porous materials such as sands and gravel which are sandwiched between two formations of low permeability. Mostly such formations are protected from contamination.

The study has intended to observe water levels in the observation wells/piezometers pertaining a confining aquifer. They are the hydrostatic pressure levels of the water in the aquifer at the observation points. An imaginary surface joining the water levels in many wells in a confined aquifer is called potentiometric surface. If the pressure in a confined aquifer is such that the potentiometric surface comes above ground level, the well will overflow and is said to be artesian. Different types of aquifer and their conditions are given in **Table 1.2**.

Table 1.2

Aquifer Types and Conditions

Aquifer type	Conditions
Unconfined	Upper limit is water table, water exists in the atmospheric pressure, and its static level is water table
Semi confined	Upper limit is Aquicludes/Aquitard. Water exists in the hydrostatic pressure, and its static level is piezometric head.
Confined, unpressured	Upper and lower layers are impermeable strata. Water exists in the hydrostatic pressure, and its static level is potentiometric surface.
Confined, pressured/Artesian	Piezometric level is above ground surface
Perched aquifer	Unconfined, local extension, piezometric level is above main water table

For a phreatic aquifer, (the first unconfined aquifer to be formed from land surface) the potentiometric surface is the water table found in wells and boreholes.

1.3 SIGNIFICANT WATER QUALITY PARAMETERS RELATED TO GROUNDWATER

Groundwater denotes all water below the water table which is the upper surface of the completely saturated ground. Above the water table, lies the zone of unsaturated soil or zone of aeration which extends up to the ground surface. At some places, there might be localized zone of saturation within zone of aeration which forms perched water table. Groundwater occurs only close to the earth's surface. There must be space between the rock particles for groundwater to occur and the earth materials become denser with more depth. Essentially the weight of the rocks above condenses the rocks below and squeeze out the open pore spaces deeper in the earth. This makes groundwater to find within a few kilometers of the earth's surface. The movement of groundwater is due to gravitational force of the earth. The direction of flow depends on the hydraulic gradient, geologic formation and geomorphology of the subsurface. The occurrence, movement, storage and its development is related to soil science, hydraulic conductivity, storativity etc. Almost all groundwater can be thought of as a part of the hydrologic cycle including surface and atmospheric water. Relatively minor amounts of groundwater may enter this cycle from other origin.

The alarming rate of population growth, evolving industrial society, advances in technology, and the existing trend of depletion of water resources has raised some serious environmental problems. The quality of drinking water has increasingly been questioned from health point of view from last many decades. In countries like India, where the majority of population lives in villages with bare infrastructure facilities, lack of awareness levels, poor sanitation and hygiene, the concept of safe potable water assumes greater significance. However, common problems of drinking water include exposure to toxic inorganic substances, heavy metals, bacterial and other pathogens, increased nitrogen concentrations and other trace chemicals and micronutrients in drinking water resources. The chemical contaminations are often considered a low priority than microbial contamination, because adverse health effects from chemical contaminations are generally associated with long-term exposure, whereas effects from microbial contaminations are usually immediate. The chemicals in water supplies can cause very serious health problems, whether the chemicals are naturally occurring or derived from source of pollution. According to WHO (2006) at global scale, fluoride and arsenic are the most significant chemicals which can be important contaminants of drinking water under specific local conditions. According to WHO (2007) guidelines there are two main criteria for identifying specific chemicals of concern to public health: high probability of consumer exposure from drinking water and, significant hazard to health. Chemicals judged to be more likely to occur and to be highly hazardous to human health should be given greater priority for risk assessment than those judged less likely to occur in drinking water and to have lower health hazard.

Fluoride in water derives mainly from dissolution of natural minerals in the rocks and soils through which it passes. The most common fluorine-bearing minerals are fluorite, apatite, and micas and fluoride problems tend to occur where these elements are most abundant in the host rocks. High fluoride concentrations can build up in ground waters that have long residence times in the host aquifers.

Surface waters usually have low concentration as do most shallow ground waters from hand dug wells as they represent young recently in filtered, rainwater. High fluoride content is also a feature of arid climatic conditions where groundwater flow is slow and reaction times between water and rocks are enhanced. Fluoride build up is less pronounced in the humid tropics because of high rainfall inputs and their diluting effect on ground water chemical composition. In developing countries, groundwater is extracted without responsible management as well as without due attention to quality issues (Ravindra and Garg 2007). In many parts of India, fluoride (F^-) is one of the most undesired elements present in underground water extracted for drinking purposes.

Nitrate is one of the most commonly identified groundwater pollutants. It rarely originates from rocks, but indicates pollution from human activities. Nitrate is the main form in which nitrogen occurs in groundwater although dissolved nitrogen also can be present as nitrite, NH_4, N_2O and organic N. The chemical form of N in groundwater is controlled by the presence or absence of oxygen in the water. In aerobic water, nitrogen occurs as nitrate ions. Nitrate is stable over a considerable range of conditions and is very mobile in water. Concentration of nitrate in groundwater typically ranges from 0 to 15 mg/L NO_3^- compared to guideline value of 45 mg/L.

Increased use of nitrogen fertilizers pollutes surface water runoff or drainage, or leach from the store of nitrogen in the soil to underlying aquifers and pollutes groundwater. High rates of nitrogen leaching from soil can be anticipated in areas where soils are permeable and aerobic, and nitrogen applications are made to relatively short duration crops, e.g. vegetables or wheat. High nitrogen leaching can occur from soils where irrigation is excessive and not carefully controlled. Areas of livestock concentration can also be a source of groundwater pollution by discharge of effluents, leaching from manure heaps, leaking slurry storage pits, and slurry or manure spreading. Sewage and wastewater disposal is also a major source of nitrate in groundwater. Nitrogen is produced in sewage in a range of reduced and organic forms such as ammonia and urea. Unsewered sanitation units such as septic tanks, cesspits and latrines act as major pollution sources in both rural and urban areas. Leachate from solid waste disposal is a high mixture of inorganic and organic compounds. Leachate is generally anaerobic and may contain high concentration of ammoniacal nitrogen. Such nitrogen is readily absorbed to clay minerals in the aquifer and may not migrate for large distances, but oxidized to nitrate. The ratio of nitrate to Cl^- in groundwater affected by unsewered sanitation is often about 2:1 while groundwater affected by nitrate leached from agriculture, the ratio is as high as 8:1 (Developing Groundwater 2005). A strong positive correlation between high nitrate and microbial pollution is an indicator of pollution from sanitation waste disposal. The potential sources of nitrate contamination can be estimated by nitrogen isotopes.

High concentrations of iron (Fe) and manganese (Mn) in groundwater are a widespread constraint on rural water supply. When iron changes from Fe^{2+} to Fe^{3+}, on contact with air, a colour is developed which will stain clothes, utensils, food and may also taste bitter. Therefore the WHO has suggested a concentration of 0.3 mg/l for Fe and 0.1 mg/L for Mn. Fe and Mn are in dissolved conditions in groundwater under reducing (anaerobic) conditions . Solubility also increases at low pH groundwaters. As the water is drawn to the surface it may be completely clear but on exposure to the atmosphere, dissolved iron is oxidized to produce an objectionable reddish brown color and with time a precipitate forms. Iron concentration in water drawn from boreholes with a high concentration of iron may increase with time even if an analysis at the time of construction indicated an acceptable concentration. Boreholes with PVC casing and plastic pump components produced water with significantly lower iron concentration than their equivalents mild steel and galvanized iron and galvanized iron in the same hydro-chemical environment (CESS 1984). Corrosion of steel casing and cast iron pump components is a major problem in areas of aggressive groundwater with low pH, reducing conditions or high salinity, and has a major impact on borehole life, hand pump performance and maintenance costs.

Heavy metals are natural constituents of groundwater originating from the weathering and solutions of numerous minerals. Natural concentrations are typically low (Developing Groundwater 2005).

Copper 10-20 µg/l, Nickel <10 µg/l, Lead <5 µg/l, Cd and Cr<1 µg/l

However, concentrations can be more than the above guideline values locally in the groundwater from rocks containing metal-bearing ores. Metal concentrations increase by mining, mineral processing, metal smelting and finishing, waste disposal in spoil heaps and tailings ponds and by other industrial processes and waste disposal. The leather-processing industry is a well-documented source of Cr pollution in groundwater. Acidification of soils and rainfall by air pollution lowers pH and encourages the mobilization of heavy metals.

The heavy metals for which there are health based guidelines includes Cadmium, Lead, Nickel, Chromium and Copper. High concentrations of As can produce cardiovascular problems, hypertension, heart diseases, Raynaud's syndrome, black foot disease, gangrene, neurological, respiratory, renal and hepatitic diseases as well as diabetes mellitus, internal cancers, lung cancer, bladder, liver, prostate and kidney cancer have been linked with Arsenic in drinking water (Smith et al 2000). Arsenic is mobilized in the environment by a combination of natural process such as weathering rocks, biological activity and volcanic emissions as well as through a range of human activities including mining, industry, agriculture and use of arsenical pesticides. The occurrence of Arsenic in groundwater is complex. Groundwaters are generally more vulnerable to accumulation of high Arsenic concentration than surface water because of the increased contact between water and rocks.

Groundwaters usually have Arsenic content below 10 microgram/L, but they may exceed to 1 mg/L in some conditions (Kinniburgh and Smedley 2001). Arsenic occurs in two oxidation states in water. In reduced (no oxygen, anaerobic) condition, it is dominated by the reduced from, Arsenite As (III) and in oxidizing conditions by the oxidized form, Arsenate As (V). Arsenate is strongly absorbed and is therefore less mobile than Arsenite.

Cadmium is notorious for its high renal toxicity due to its irreversible accumulation in the kidney. Lead is a strong neurotoxin in unborn and young children, leading to irreversible impairment of intelligence. Lead easily crosses the placenta. The threshold of neurotoxic effect has decreased over the last 20 years and drinking water standards and guidelines for lead have been revised accordingly to their present 10 µg/L. Nickel has high allergic potential. Cr is found in the environment in two states Cr^{3+} and Cr^{4+}. The latter is toxic and originates only from human activities. Copper is an essential trace element with an optimum daily oral intake of 1-2 mg/person and above 2 mg/L leads to liver cirrhosis in babies if water of this concentration is used to prepare bottle-feeding formulas (Developing Groundwater 2005).

For many years the likelihood of contamination of ground water by synthetic organic chemicals was largely ignored. The assumption that the soil profile always serves as an efficient purifying filter led to the conclusion that extensive penetration of pollutants into ground water was unlikely. Recent reports on ground water contamination, however, aroused public and government concern about a potential threat to the quality of drinking water. In contrast to previous assumptions, ground water quality may be affected by human activities, particularly by the widespread use of organic chemicals. Under certain soil and climatic conditions, some organic compounds exhibit sufficient soil mobility and persistence to allow them to reach ground water; the recent discovery of aldicarb and other carbamates, as well as some halogenated hydrocarbons and triazines, in some ground water has been confirmed. The extent of occurrence of pesticides in ground water is still unknown, however, and the magnitude of the problem has to be defined. Preliminary findings indicate a need for detailed monitoring, to determine the extent of the problem and interdisciplinary research to elucidate the processes governing the transport and fate of organic chemicals in subsoil and ground water. When the pollutants, once enter the groundwater it takes a long time to get it removed from it. This is true in the case of synthetic organic chemicals. In the case of surface water occasional flooding will remove the major pollutants, but in groundwater such a faster turbulent flow is absent. Hence geochemical groundwater quality monitoring is very significant.

1.4 GROUNDWATER STRUCTURES SELECTED FOR THE STUDY

The collection of ground water is accomplished primarily through the construction of wells. From ancient times, Indians use well for both drinking and irrigation purposes. It is economical as compared to any other method for tapping water. The quality of water thus driven out also improves its acceptability (Deepa G.D.1998; Mamta Tomar. 1999).

The quality of water obtainable from a well depends on:

- The intake area
- The annual rainfall percolation
- The preciousness of the ground
- The storage capacity of the ground
- Type of the well
- The distance from pollution source.
- The hydrogeology of the area.
- The slope of the location.
- The presence of flora and fauna.
- And many other factors.

Wells are classified into three types viz; shallow well (dug well), deep well (bore well) and artesian well and are made by digging or drilling holes through the zone of saturation where all the openings in the well, filling into the levels of water table. If wells extract water from an aquifer over a period of time at a rate such that the aquifer will become depleted, under these conditions, salt water encroachment may occur where wells are located near the seashore or underground saline waters.

Dug wells are one of the oldest water supply technologies available. It may be lined with brick, stone or concrete. Most dug wells do not penetrate much below the water table because of their shallow penetration into the zone of saturation. Many dug wells fail, in time of drought and the water level recedes large quantities of water are pumped from the well. However, dug wells have the highest risk of becoming contaminated because they are shallow (Burkart M.R, Kolpin D.W and James D.E.1997).

Bored wells are commonly constructed with earth aquifer formed either by hand or by power equipment. Such wells are usually regarded as practical at depths less than 30 m, when the water requirement is low and the material overlying the water bearing formation has concaving properties and contain few large boulders (Bouwer.H, 1978). Power equipment can drill wells of more than 30 m depth, but limitations are many.

A groundwater structure is a man made construction to develop groundwater and to transfer the same from confined aquifer to the earth's surface. The surface water undergoes percolation to form groundwater where as the groundwater development aims at bringing the groundwater to the surface for various application of agriculture, drinking water, animal husbandry, industries and for recharge of groundwater. While extracting groundwater care must be taken to limit the extraction within safe limits.

This study covers both phreatic and deeper zones of crystalline formations and the sedimentary formations of Ernakulam district. The area of the district is 2408 km^2. Groundwater structures such as open wells and bore wells have been included in the study. Open wells are tapping the phreatic aquifer, whereas bore wells are tapping the confined aquifer.

The monthly rainfall data, groundwater levels and samples for water quality parameters from 39 open wells and 12 bore wells were collected for the period from January 2006 to September 2008 representing the three prominent seasons of the study area. These samples were marked with identification numbers and subjected to detailed analytical methods (given in **Chapter II**) following the Bureau of Indian Standards. Different multivariate techniques were applied to understand the groundwater chemistry of the aquifer. The data thus generated have been validated and analyzed. The results are established by representing in charts and graphs and correlating between various quality parameters which influence the hydraulic and hydrologic parameters, precipitation (rainfall), water level changes, and are incorporated in **Chapters III & IV**.

In addition to the above, a special study by selecting 12 numbers of open wells and 3 numbers of bore wells have also been conducted seasonally for one year

(September 2007-May 2008) and analyzed for pesticides and trace metals and is detailed in **Chapter V**. The results are scientifically interpreted for future planning and execution. General remedial measures adopted are also incorporated and featured in **Chapter VI**.

1.5 OBJECTIVES AND SCOPE OF THE WORK

Objectives and scope of the work are summarized as follows:-

1. To study the hydro-geochemical characteristics of sedimentary and crystalline geologic formations of Ernakulam district.
2. To investigate the effect of precipitation on groundwater level and water quality of shallow and deeper aquifers.
3. To evaluate the water quality of open wells in sedimentary and crystalline formations.
4. To observe water quality fluctuation during pre-monsoon, monsoon and post-monsoon seasons during the study period (2006-2008).
5. To classify the water type and irrigation suitability.
6. Mapping of selected water quality parameters in Ernakulam district.
7. To investigate the presence of trace metals and pesticides in the groundwater of 15 selected stations.
8. To study on the socio economic effect of water quality in the dug-cum-bore wells of Anchalpetty in Pampakuda panchayat.

The scope of this work is somewhat vast. Water quality in Ernakulam district is getting deteriorated due to the fast growth of urbanization. The closure of several water bodies due to land development and building works prevents percolation of rain water to the aquifers. Most of the aquifers are getting polluted from the industrial effluents and chemicals and fertilizers are used in agriculture. Such serious issues require proper monitoring and steps are to be taken for remedial measures. The water quality maps can be used to plan future suitable water source identification in that area can be done. The study helps in the total protection of the rich resource of groundwater and its sustainability. Socio-economic aspect covered could be used for conducting further individual case study and to suggest remedial measures on a scientific basis. The special study taken up for 15 sites can be further extended to the sources of pollution, especially industrial and agriculture. As a net outcome of this study, certain relationships of precipitation and water level at the stations under study have been obtained. These water levels play an important role in the water quality changes of certain parameters.

Chapter - II

MATERIALS AND METHODS

Chapter - II

MATERIALS AND METHODS

2.1 INTRODUCTION

Kerala State lies as a narrow strip of land along the South-West corner of India and is located between North latitudes $8^0 18'$ and 12^0 48′ and East longitudes 74^0 52′ and 77^0 22′. Kerala, the God's own country was considered to be very much rich in ground water resources with significant rainfall received over two monsoon seasons. But however recent studies indicate that the water resource position of Kerala is not safe as in the past years. The average annual rainfall of Kerala is around 3000 mm and there is a considerable variation both in time and space. Major portion of rainfall is spread over a period of about 6 months due to undulating topography and good network of rivers in the State, the water is drained into the sea quite fast. The aquifer thickness forming the water table aquifer is also less in Kerala compared to other states with even topography. Fast urbanization, abandoning of water bodies, concreting of courtyards and roads, reduce the recharge of groundwater. The water resources are over-exploited due to the ever increasing demand of water for agricultural, industrial and domestic purposes. Contamination of groundwater resources due to geogenic and anthropogenic causes have become a serious concern now (CGWB 2009). Water marketing is also a new trend, for which quality and quantity play equal role. Groundwater is the major source for meeting the domestic needs of more than 80% of rural and 50% of urban population of Kerala (CGWB 2009). It caters to the need of around 50% of irrigated agriculture in the State.

The annual replenishable groundwater resource has been assessed as 6841.33 Million Cubic Metres (MCM) and the net annual groundwater availability as 6229.55 MCM (CGWB 2004). The annual groundwater draft for irrigation, domestic and industrial uses is 2920.01 MCM leaving a balance of 3309.54 MCM for future development (CGWB 2009). Groundwater serves as a naturally occurring reservoir having less susceptibility to evaporation losses, climate variability and anthropogenic activities. Because of these advantages and uses, a significant quantity of groundwater is being used for domestic, agricultural, industrial and land-use-related activities. In Kerala, the most water quality problems due to urbanization are present in the Ernakulam District which is an industrial hub of the State. This study, therefore, focused on the district with selected types of groundwater structures both in sedimentary and crystalline geologic formations, which require monitoring of water quality and quantity.

2.2 DESCRIPTION OF THE STUDY AREA

The study area Ernakulam, lies between north latitudes 9^0 42′ and 10^0 18′ East longitudes 76^0 09′ and 77^0 02′ having a geographical area of 2408 km^2 (**Figure 2.1**).The district is situated in the northern side of Kerala State bound by Trichur district on the north, Idukki on the East, Kottayam and Alleppy districts on the South and Lakshadweep sea on the West. There are 2 revenue divisions, 7 taluks, 15 community development blocks, 86 village panchayats, 8 municipalities and 1 corporation.

Physiographically, the district is divided into 3 main divisions as follows:

- The coastal plains in the west with an area of 1126 km^2 and elevation less than 7.6 m above Mean Sea Level.
- The midland region in the centre over an area of 1218 km^2, with elevation ranging from 7.6 to 76 m above Mean Sea Level.
- Hill ranges in the north east over a small area of 64 km^2.

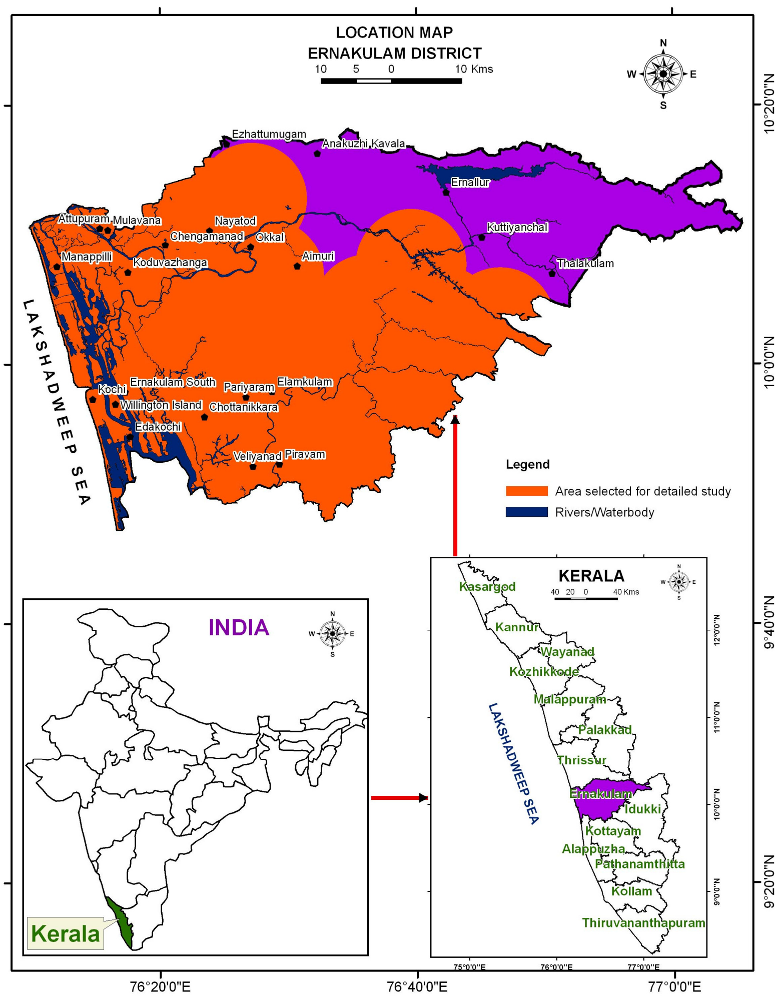


Figure 2.1

Location of the study area (Ernakulam district)

2.2.1 DRAINAGE CHARACTERISTICS

The District is drained by Periyar and its tributaries on the north and Muvattupuzha and its tributaries in the southern part. Periyar the longest river of Kerala originates from the Cardamom hills of the Western Ghats and enters the District at Neryamangalam and near Bhuthathankettu, it is joined by major tributaries. At Aluva, the river bifurcates in to Marthandam branch and Mangalapuzha branch. The Mangalapuzha branch flows through a northwesterly course and is joined by Chalakudy river, and after this, expands to a large water body and drains into Lakshadweep sea. The Marthandam branch flows southward and drains in to the Vembanad lake.

The confluence of three rivers, i.e., Thodupuzha, Kaliyar and Kothamangalam forms the Muvattupuzha river and flows in a westerly direction and drains in to Vembanad lake through a series of channels. The drainage characteristics show that both rivers have a trellis and sub-trellis type drainage pattern. Towards the lower portion, this pattern changes into dendritic pattern. The river basins of the District are the Periyar basin and the Muvattupuzha basin and the sub basins are Periyar and Thodupuzha, Kaliyar and Kothamangalam. The major irrigation projects of the District are the Periyar valley irrigation project, the Edamalayar irrigation project and the Muvattupuzha river valley project, and 93 lift irrigation schemes. Through the major, medium and minor irrigation schemes, an area of 50366 ha is irrigated.

2.2.2 IRRIGATION AND CROPPING PATTERN

About 83% of the total area of the District is cultivable and nearly 10% of the area is under forest cover including reserve forest plantation. Water bodies constitute 5.3% and built-up area is nearly 2%. An area of 505 km^2 is under irrigation in the district. The major crops under irrigation are paddy, coconut, rubber, banana and arecanut. The gross area under irrigation is higher than the net as more than one crop of paddy is cultivated under irrigation. Coconut is the major single crop in the District followed by paddy and rubber. Spices and vegetables are also cultivated.

2.2.3 RAINFALL AND CLIMATE

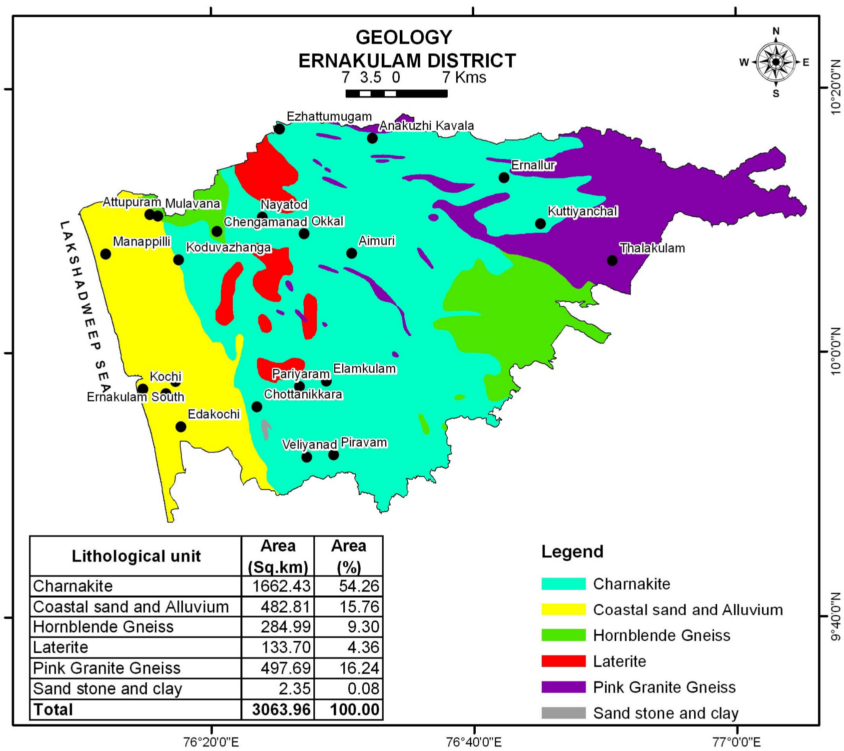
Ernakulam District has monsoon type of climate. The district experiences heavy rainfall during south west monsoon season followed by north east monsoon. During the other months rainfall is considerably less. March, April, and May are the hottest. December to February are the coldest. The annual rainfall ranges from 3233 to 3456 mm at different places of the District. The district receives on average 3359.2 mm of rainfall annually. The rainfall is less in the western part and increases towards the east. Rainfall during the south west monsoon contributes nearly 67.4% of the total rainfall of the year, followed by north east monsoon which contributes nearly 16.6% and the balance of 16% is received during the month of January to May as summer/pre-monsoon showers (CGWB 2008).

The monthly rainfall data for 2006 to 2008 of different stations of Ernakulam district is given in **Table 2.1 (Annexure).**

For the district, the recharge from rainfall during monsoon is 308.12 MCM**;** recharge from non-monsoon is 171.15 MCM and the recharge from other sources during non-monsoon season is 139.14 MCM, thereby the total annual recharge is 618.42 MCM. Natural discharge during non-monsoon season was considered as 50.59 MCM. Thus, the net annual groundwater availability is 567.83 MCM (CGWB 2008) (**Table 2.2 Annexure**).

2.2.4 GEOLOGY OF **ERNAKULAM DISTRICT**

Archean gneissic complex and Charnockite formations form the hard rock of the area, and laterite formations of the sub recent age and unconsolidated alluvium of the recent formation with sand and clays form the geological setup. The Archean formations comprise the charnockites and pyroxene granulites, hornblende biotite gneiss and garnet biotite gneiss. These cover an area of about 1100 km^2. Of these Charnockite is the most predominant, covering an area of 840 km^2. The hornblende biotite gneiss, biotite gneiss and garnet sillimanite gneiss occur in the eastern part of Kothamangalam block. The intrusives are the basic dykes of gabbro and dolerite. The presence of a major gabbro dyke trending NNW-SSE, of 300 m wide, extending for about 37 km is a major feature of the District. The tertiaries occur in the costal belt, and comprise of Warkallais, Quilons and the Vaikom beds, overlain by residual laterite and by unconsolidated recent sediments. The laterite thickness varies from 20 m on the western side to 2 to 3 m on the eastern side. The recent sediments include the sediments of backwaters and black clay, quartzitic sand and silty sands. The thickness of alluvial sediments varies from 20 to 56 m. The general foliation trend of the crystalline rock is NW-SE and there are a number of joints and fracture systems, which control the drainage of the area. **Figure 2.2** displays the different geological formations in the Ernakulam district.



Lithological unit	Area (Sq.km)	Area (%)
Charnakite	1662.43	54.26
Coastal sand and Alluvium	482.81	15.76
Hornblende Gneiss	284.99	9.30
Laterite	133.70	4.36
Pink Granite Gneiss	497.69	16.24
Sand stone and clay	2.35	0.08
Total	**3063.96**	**100.00**

Figure 2.2

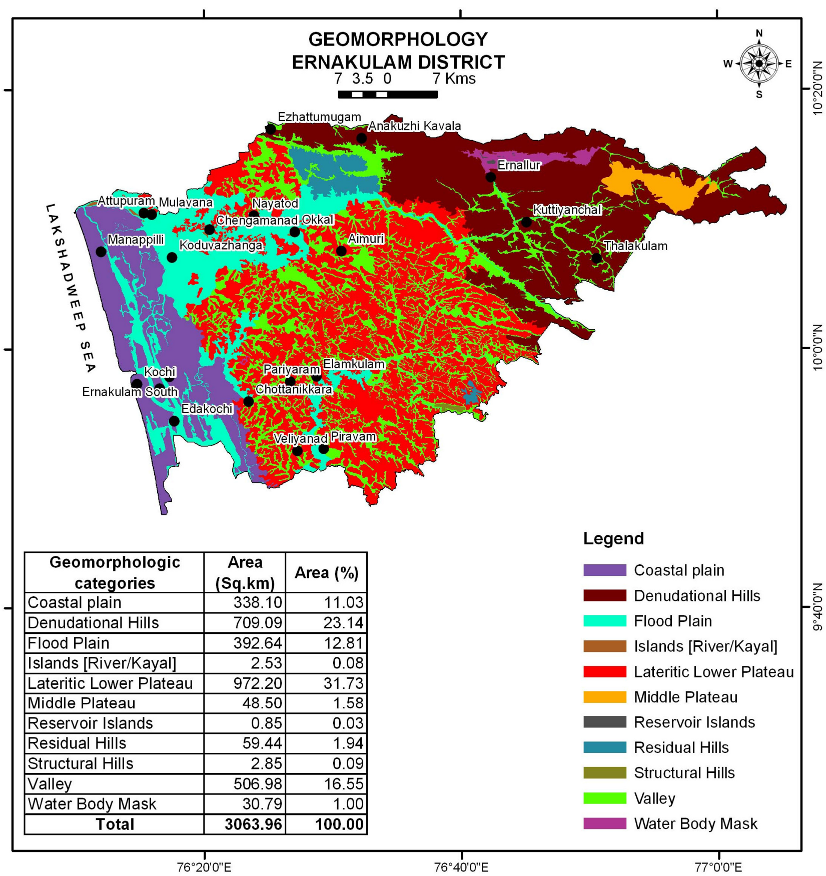
Geological map of Ernakulam District

2.2.5 GROUNDWATER SCENARIO

Groundwater occurs under phreatic conditions in weathered and fractured crystalline rocks, laterites and unconsolidated coastal sediments. It occurs under semi-confined to confined conditions in the deep seated fractured aquifer in the crystallines and tertiary rocks. The weathered zone in the crystallines below water table acts as a good storage for groundwater. Fractures have been developed during tectonic movements and opened up due to weathering and subsequent erosional processes. The semi consolidated tertiary sediments occurring below the alluvium form potential aquifers and are represented by the Warkallais, Quilons and the Vaikom beds. The tertiaries give different qualities of water at different beds and the Vaikom beds approximately below 90 m give fresh water.

2.2.6 SOIL TYPES

Based on the morphological and physico-chemical properties, the soils of the District have been classified as lateritic, hydromorphic saline, brown hydromorphic, riverine alluvium, and coastal alluvium. **Figure 2.3** displays the different geomorphic units of the study area.



Geomorphologic categories	Area (Sq.km)	Area (%)
Coastal plain	338.10	11.03
Denudational Hills	709.09	23.14
Flood Plain	392.64	12.81
Islands [River/Kayal]	2.53	0.08
Lateritic Lower Plateau	972.20	31.73
Middle Plateau	48.50	1.58
Reservoir Islands	0.85	0.03
Residual Hills	59.44	1.94
Structural Hills	2.85	0.09
Valley	506.98	16.55
Water Body Mask	30.79	1.00
Total	**3063.96**	**100.00**

Figure 2.3

Map showing geomorphic units of the study area.

a. Lateritic soil

Laterites form the predominant soil in the midland region is well drained and low in plant nutrients and organic matters. The fertility of the soil is generally poor with low available nitrogen, phosphorous, potash and organic contents. They are generally acidic with pH ranging from 5 to 6.2.

b. Hydromorphic saline soil

Very small patches of hydromorphic saline soil are found in Ernakulam District in coastal tract adjoining the alluvium. They are brownish, imperfectly drained, showing wide variations in texture. The network of back waters and estuaries bordering the coast serves as inlet for tidal waters to flow into these areas which cause salinity. Wide fluctuations in intensity of salinity have been observed in these soils. The pH of the soil ranges between 3 and 7.5.

c. Brown hydromorphic soil

The second prominent soil group found in the District is the brown hydromorphic soils. These soils are confined to valley bottoms of undulating topography in the mid land area. They have been formed as a result of transportation and sedimentation of material from the adjoining hills and slopes and also through the deposition by rivers. The soil is usually enriched in clay content. They are moderately supplied with organic matter, nitrogen and potash, deficient in lime and phosphate. The pH value ranges between 5.2 and 6.4 and are acidic in character.

d. Riverine alluvium

These soils occur mostly along the banks of rivers and their tributaries and show wide variations in their chemical properties depending on the nature of alluvium. These soils are usually well drained and have a moderate supply of organic matter. The texture ranges from sandy loam to clay loam.

e. Coastal alluvium

These are seen all along the coastal tracts and have been developed from recent marine and estuarine deposits. The soil is mainly composed of sand and clay with dominance of sand fraction. They are excessively drained with very high permeability. The pH value ranges between 5.2 and 6.6. The water table is generally high in the low-lying areas. Water-holding capacity of these soils is low since organic matter and clay content is very less. The pH value ranges between 5.2 and 6.6. This type of soil is good for groundwater recharge.

Ernakulam district is having major groundwater quality problems. It is imperative to monitor the water quality of Ernakulam as the faster growth of urbanization on one side and salinity problem due to the proximity of oceans on the other side. Salinity problems exist in the coastal sedimentary due to intrusion from the west sea. Industrial pollution has contributed to the water quality deterioration due to the untreated or partially treated effluent discharges from the factories or industries around Eloor, Alwaye, Ambalamugal etc. Agricultural activity using fertilizers and pesticides are the major contributors. Pollution from water transport affects the openwells in the nearby area. Fishing industry is polluting the water bodies and thereby polluting the phreatic aquifer. The sites chosen for the study were based on the water quality problems and its location fixed based on the typical groundwater structures. The observations from such complicated groundwater structures are essential to know the behavior of the deeper aquifer. The study area has thus been selected by considering all such prerequisites.

Geologically, the study area has both sedimentary and crystalline formations which lead to the complexity of groundwater problems, its occurrence, movement and the quality changes during its movement. Sedimentaries are the basic data generating points as far as the phreatic aquifer is concerned. Various surface water bodies (canals, ponds, etc) with seasonal water quality variation is present in the study area. Groundwater structures such as open wells and bore wells have been included in the study. Open wells are tapping the phreatic aquifer and bore wells are tapping the confined aquifer.

The study has been subdivided into two separate entities as given below:

- Groundwater structures selected for the study of seasonal water quality variation and its impact on both sedimentary and crystalline wells.
- To monitor the concentration of heavy metals and pesticides in groundwater in fifteen selected wells.

Both the analyses are time dependent, and hence the data has been generated by actual field work combined with lab work and finally consolidated by applying software packages such as AQUACHEM 6.0, ARCGIS 10.0, GWDES 4.0

and SPSS. The data processing and other interpretations have been done by adopting different multivariate techniques to establish the ground water chemistry of Ernakulam district.

2.3 NETWORKING

Study for a network design in groundwater monitoring, four different design phases have been adopted. They are initial phase, juvenile phase, mature phase and optimisation phase. The initial phase of a new network based solely on the deterministic "hydrogeological approach of collecting and evaluating information". Existing wells are adopted for monitoring purposes and new piezometers are designed in the hydrogeological units. Juvenile phase in which some information about the groundwater level fluctuation is available. In this phase groundwater level data is used to confirm the ideas developed during the hydro geological approach. Mature phase uses time series of groundwater level measurements and information about the represented activity of the spatial distribution of the observation wells. The observation from the wells can be used to correlate the precipitation and subsequent change in the water quality parameters. A well defined correlation cannot be arrived without the field work of monitoring the water levels followed by sample collection.

Water quality monitoring with a proper network design is necessary in order to obtain the actual scenario. These network designs are partly for the data users with a required frequency. The observation stations are chosen to measure the water levels and to collect water samples for systematic analysis. Water quality monitoring has been given due consideration in the study.

Contour maps, evaluation and optimization of the existing network, inventory of available information, evaluation are the major components in the research programme. Network for monitoring salinity ingress is for determining the relation between the intrusions for saline water and declining hydraulic heads due to extensive aquifer developments. Large groundwater withdrawals results in regional cones of depression, which if not checked can lower potentiometric surfaces of aquifers to below sea levels. The natural flow direction then gets reversed and saline water can migrate towards pumping wells. If saline water enters an aquifer it takes long period to reverse the situation.

Water level data is one of the chief contributing parameter in groundwater quality issues. Long-term water level measurements are often needed to develop an understanding of how groundwater contaminants migrate from their sources through the groundwater system. There is a relation between the occurrence of event related or seasonal changes in ground water recharge and fluctuation in the groundwater contaminant concentrations.

2.4 SITE SELECTION CRITERIA

The location information such as hydrogeology, geology, aquifer system, was prepared. The water quality parameters were never observed uniform throughout the seasons. The sites are chosen for the study based on the complexity of the water quality in the District of Ernakulam. Under the general geochemical study, 39 numbers of open wells (31 in crystalline and 8 in sedimentary) and 12 bore wells in the deeper crystalline formation were incorporated. The detailed well descriptions are given in **Table 2.3** and the location maps are shown in **Figure 2.4 and 2.4a.**

Monthly rainfall data was collected for 3 years from January 2006 to December 2008 for different stations, covering all the selected sites in Ernakulam district. Monthly water level data was collected for the study period of January 2006 to September 2008 (GWD, Kerala). Water samples were collected during pre-monsoon, monsoon and post-monsoon seasons of 2006 to 2008 and analyzed for various physico-chemical parameters.

Under specific study, a total of 15 wells at Ernakulam district (12 open wells and 3 bore wells) were selected in order to assess the possible contamination due to pesticides and trace metals from the neighbouring environment. Analysed the sample for general water quality parameters and additional parameters as phosphate, nitrite, dissolved oxygen, silica **(Table 2.4)**, trace metals as Pb, Cd, Cu, Zn, Mn, As **(Table 2.5)** and pesticides by adopting standard methods. Measured water level and water quality during September 2007, January 2008 and May 2008.

Detailed well descriptions are given in **Table 2.6,** and the location map is shown in **Figure 2.5**.

Table 2.3

Well ID and location for general hydro-geochemical study are follows:

I. Sedimentary formation – 8 Openwells

Well ID	Location
ESOW-01	Paravur

ESOW-02	Pallippuram
ESOW-03	Njarakkal
ESOW-04	Mattanchery
ESOW-05	Ernakulam
ESOW-06	Chellanam
ESOW-07	Kumbalangi
ESOW-08	Edacochi

II. Crystalline formation – 31 Openwells

Well ID	Location
ECOW-01	Aluva
ECOW-02	Ankamaly
ECOW-03	Kalady
ECOW-04	Manjapra
ECOW-05	Nedumbasseri
ECOW-06	Aluva East
ECOW-07	Amballoor
ECOW-08	Thiruvankulam
ECOW-09	Thrikkakkara
ECOW-10	Pothanikkadu
ECOW-11	Keerampara
ECOW-12	Eramalloor
ECOW-13	Pindimana

ECOW-14	Kuttamangalam
ECOW-15	Neryamangalam
ECOW-16	Ramamangalam
ECOW-17	Vengola
ECOW-18	Kunnathunadu (Pattimattom)
ECOW-19	Kunnathunadu (Pallikkara)
ECOW-20	Rayamangalam
ECOW-21	Kunnathunadu south
ECOW-22	Perumbavoor
ECOW-23	Kizhakkambalam
ECOW-24	Piravom
ECOW-25	Elanji
ECOW-26	Kuthattukulam
ECOW-27	Thirumaradi (Mannathore)
ECOW-28	Thirumaradi (Kakkur)
ECOW-29	Memuri
ECOW-30	Muvattupuzha
ECOW-31	Eranellur

III. Crystalline formation - Borewells – 12 Nos.

Well ID	Location
ECBW-01	Kunnukara
ECBW-02	Mookkannoor Ward-1

ECBW-03	Kadungalloor (Edayar)
ECBW-04	Vadavukode
ECBW-05	Pattimattom
ECBW-06	Rayamangalam
ECBW-07	Vengoor
ECBW-08	Muvattupuzha
ECBW-09	Onakkur
ECBW-10	Piravom
ECBW-11	Pindimana
ECBW-12	Neryamangalam

The following water quality parameters were analyzed for the seasonal study from the period 2006 to 2008 by using appropriate analytical methods as summarised in **Table 2.4**

Table 2.4

Analytical methods used for water quality parameters

SI. No.	Parameter	Analytical Method	Equipment	Unit	IS 10500:1991 (2003-09) Limits
1	pH	Electrometric	pH Meter		6.5-8.5
2	Electrical Conductivity (EC)	Electrometric	Conductivity meter	µmho /cm	-
3	Total Dissolved Solids (TDS)	By calculation EC	-	mg/L	2000
4	Total Hardness (as $CaCO_3$)	EDTA titration	-	mg/L	600
5	Total alkalinity (as $CaCO_3$)	Acid Titration	-	mg/L	600
6	Sodium (as Na+)	Flame photometry	Flame emission	mg/L	-
7	Potassium (as K+)	Flame photometry	Flame emission	mg/L	-

8	Calcium (as Ca^{2+})	EDTA titration	-	mg/L	200
9	Magnesium (as Mg^{2+})	TH-Ca	-	mg/L	100
10	Carbonate (CO_3^-)	Acid titration	-	mg/L	-
11	Bicarbonate (HCO_3^-)	Acid titration	-	mg/L	-
12	Chloride (Cl^-)	Argentometric titration	-	mg/L	1000
13	Sulfate (as SO_4^{2-})	Turbidimetric method	UV-Visible Spectrophotometer/ Turbidimeter	mg/L	400
14	Nitrate (as NO_3^- N)	UV screening& Eectrometry	UV-Visible Spectrophotometer /Ion Selective Electrode	mg/L	10
15	Phosphate (as PO_4^{3-}P)	Moybdophosphoric acid method	UV-Visible Spectrophotometer	µg/L	-
16	Fluoride (as F^-)	SPADNS/ISE	UV-Visible Spectrophotometer& Ion Meter	mg/L	1.5
17	Iron	1,10 phenathroline method	UV-Visible Spectrophotometer	mg/L	1.0
18	Dissolved Oxygen	Winklers method	-	mg/L	-
19	Nitrite-N	Sulphanilamide method	UV-Visible Spectrophotometer	µg/L	-
20	Silica	Molybdate Yellow Method	UV-Visible Spectrophotometer	mg/L	-
21	Turbidity	Nephelometry	Nephelometric Turbidity Meter	NTU	10

Table 2.5

Methods used for trace metal analysis

SI. No.	Parameter	Analytical Method	Equipment	Unit	IS 10500:1991 (2003-09) (Desirable) Limits	IS 10500:1991 (2003-09) (Permissible) Limits
1	Lead	Atomic Absorption	AAS	µg/L or mg/L	0.05	No relaxation
2	Copper	Atomic Absorption	AAS	µg/L or mg/L	0.05	1.5
3	Zinc	Atomic Absorption	AAS	µg/L or mg/L	5	15

4	Manganese	Atomic Absorption	AAS	µg/L or mg/L	0.1	0.3
5	Cadmium	Atomic Absorption	AAS	µg/L or mg/L	0.01	No relaxation
6	Arsenic	Atomic Absorption-Hydride Generation	AAS-HGA	µg/L or mg/L	0.01	No relaxation

Note: AAS: - Atomic Absorption Spectrophotometer

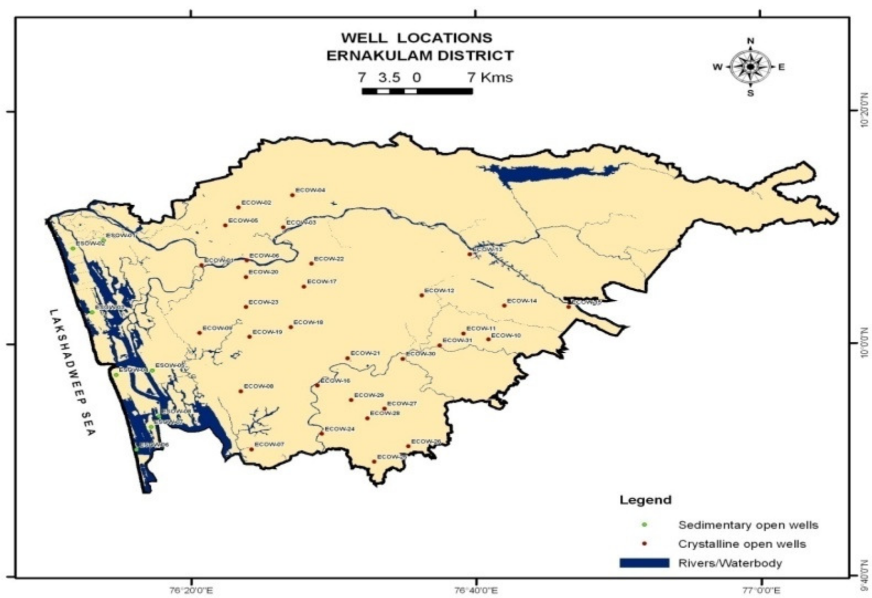


Figure 2.4

Map showing Openwell locations in the Ernakulam district

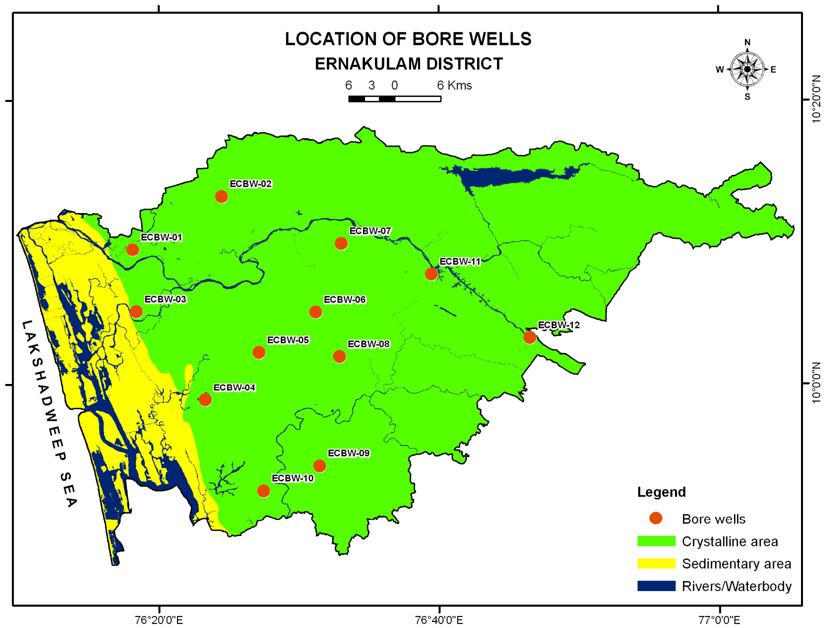


Figure 2.4a

Map showing Borewell locations in the Ernakulam district

Table 2.6

Well ID and Location for the Specific Study

Well ID	Location
TMPOW-01	District Agriculture Farm, Neryamangalam
TMPOW-02	Coconut Development Board, Neryamangalam
TMPOW-03	H/OPKBaby, Anchalpetty,Puthusserippady,Pampakuda
TMPBW-04	H/OPKBaby,Anchalpetty,Puthusserippady,Pampakuda
TMPOW-05	H/O Azhakan,Manakkalkadavu, Pampakkuda
TMPOW-06	H/O Biju Kurien,Manakkalkara, Pallikkara
TMPOW-07	Pookattupady, Kizhakkambalam

TMPOW-08	Binanipuram Hospital Compound, Edayar
TMPOW-09	Keezhillam, Mazhuvannur Panchayath
TMPBW-10	State Seed Farm, Okkal
TMPOW-11	Medical Plant Research Station , Odakkali
TMPBW-12	Medical Plant Research Station, Odakkali
TMPOW-13	Pallippuram, Cherai
TMPOW-14	Njarakkal, Ward 3
TMP OW-15	Mattancherry, Vypin
TMP CHK- 16	Check sample ,Kakkanad

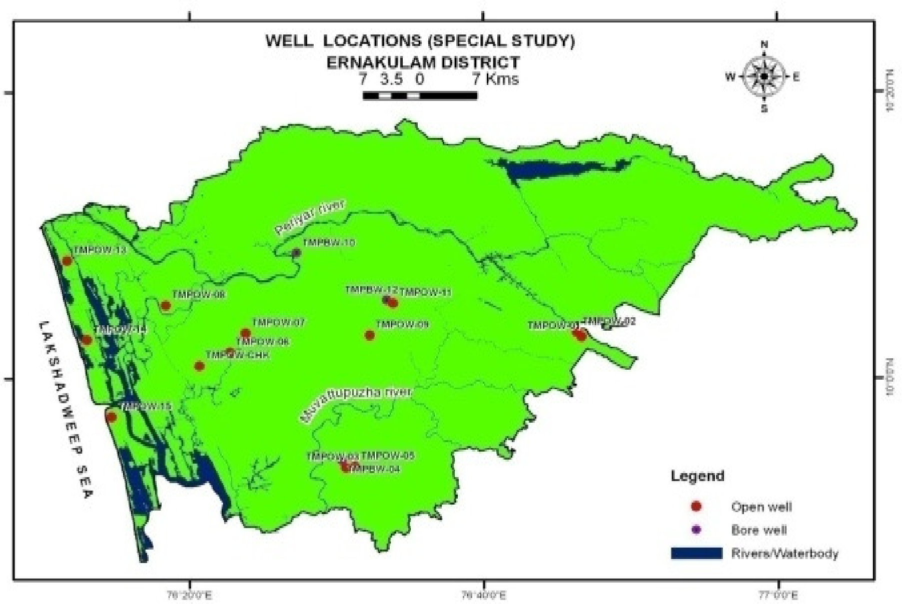


Figure 2.5

Map showing well locations in specific study

2.5 SAMPLING PROCEDURES

Water samples were collected from open wells and bore wells of selected stations as illustrated previously during the month January, May and September of 2006, 2007 and 2008**.**

Samples were collected from open dug wells using a clean, weighted sampling can with a plastic rope attached to its handle. This pre washed can was carefully lowered down the well so that it does not touch the sides or bottom of the well. Samples were collected from 30 cm below the surface. Samples from borewells were collected after pumping the wells for 10 minutes. Samples were immediately transferred to the analytical laboratory for analyzing the water quality parameters.

The analysis of water samples starts from the point of its collection and the accuracy of analytical data depends on to a considerable extent upon the precautions taken at the time of collection of the sample. The selection of container for water sample is of prime importance as analysis is generally intended to reveal composition of water at the time or over the period of sampling. Bottles which were used for collecting samples were thoroughly washed and before filling rinsed 2-3 times with the sample being collected. Sample bottles for pesticide analysis were well washed and rinsed with hexane prior to use. The sample bottle filled up to the top (so that no air left inside) stoppered tightly kept in icebox and brought to the lab and stored in a refrigerator. Containers used for collecting samples for trace metal analysis were soaked in 10% Nitric acid for 48 hours and thoroughly cleaned and rinsed several times with de- ionized water.

Samples for dissolved oxygen were collected from open wells by using dissolved oxygen sampler. Inserted the BOD bottles in to the DO sampler, submerged into the water column so that water enters BOD bottle directly by means of a dip tube thus displacing all air from the bottle. Retrieved the s ampler after it is full. Special precautions were taken for obtaining borewell samples for DO analysis. Samples were taken by inserting a plastic tube in to the discharge pipe and placing the other end at the bottom of the 300 ml BOD bottle with a ground glass stopper. Water was allowed to flow in to the bottle until the volume of the bottle has been displaced at least 3 times. Care was taken to ensure that no air bubbles are introduced into the sample bottle.

Temperature was measured at site. Colour and odour was noted in the field. Samples for DO measurements were fixed soon after sampling by adding 1 ml Manganese Sulphate solution and 1 ml of alkaline lodide – Azide solution to the sample collected in the BOD bottle and analyzed by Winkler method. Sample for dissolved metal analysis was filtered using on 0.45 µm membrane filter and preserved by acidifying to pH<2 with concentrated ultrapure nitric acid. Samples for phosphate were taken in glass bottles cleaned with dilute hydrochloric acid. pH and EC measurements were conducted soon after reaching the laboratory. The water quality parameters were done by standard methods (APHA 1998).

2.6 INSTRUMENTATION AND ANALYTICAL TECHNIQUES

All glassware used in the analysis were washed thoroughly and soaked in appropriate wash solutions for 48 hours, and rinsed several times with de-ionised water finally rinsed with double distilled water. Reagents used were analytical grade and standard solutions were prepared using milli-Q water. A Chemito make "Model UV 2600" spectrophotometer was used for colourimetric determination. Ion meter "Orion" make was used for electrometry. Perkin Elmer (Model 100) Atomic Absorption Spectrophotometer with Graphite Furnace and Hydride Generation Unit was used for analysis of trace metals. Pesticide analysis was conducted using AGILANT make GC-MS 6890-5975 and the method followed is USEPA 525.2 solid phase extraction.

2.6.1 DISSOLVED TRACE METALS

The samples were filtered using 0.45 µm cellulose nitrate filter paper and preserved by adding ultrapure HNO_3 to a pH <2. Analysed the samples with AAS as per Standard Analytical Procedures (APHA 1998).

Samples for Arsenic were pre-reduced by adding to 10 ml sample, 1ml 5M HCl and 1ml 20% KI solution in a pyrex test tube and heated in a water bath to 80 ºC for 30 minutes. Hydride generation was effected using HCl and Sodium Borohydride. The Arsine gas (AsH_3) so produced was analysed (Hydride Generation Technique) with the AAS.

2.6.2 EXTRACTION PROCEDURE FOR PESTICIDES

The pesticides analyzed during the study were classified under 3 parent groups such as: Organo chlorine pesticides, Organo phosphorus pesticides, Other Miscellaneous pesticides used commercially. The method followed is 525.2 solid phase extraction and preconcentration and briefly discussed as: 1 litre water sample was passed through a Solid Phase Extraction (SPE) cartridge (C18 Octadecyl group-non polar liquid coated on silica). The pesticides in the sample get absorbed on the cartridge. It is then eluted with 5 ml methylene chloride and 5 ml ethyl acetate. The solvents were evaporated using nitrogen evaporator. Made up to 1 ml in HPLC grade acetone. (1000 times concentration). Injected 3 microlitre of this sample into a columns DB5 (HP-5-MS). Temperature ramp programming was 50 ^{0}C to 300 ^{0}C of rise 10 ^{0}C up to 300 ^{0}C 5 minutes holding capillary column of 30 m length and internal diameter 0.25 mm coated with 5% Trimethyl Silane. The concentration were reported in µg/L. Standard addition was conducted with 1.13 ppm alpha-HCH, 1.565 ppm gamma-HCH, 0.8695 ppm B-HCH, 1.3043 ppm p-p' DDT and 1.2174 ppm p-p' DDE to check the accuracy of the analysis.

2.6.3 LIST OF EACH TYPE OF PESTICIDES INVESTIGATED

2.6.3a ORGANOCHLORINE PESTICIDES: 30 Nos

1	alpha – HCH	16	Cis-Chlordane
2	beta – HCH	17	Trans – Chlordane
3	gamma - HCH (Lindane)	18	Heptachlor
4	delta - HCH	19	Heptachlor Epoxide
5	o, p^1 – DDT	20	Butachlor
6	p, p^1 – DDT	21	Alachlor
7	o, p^1 – DDE	22	Methoxychlor
8	p, p^1 – DDE	23	Endosulfan Sulfate
9	o, p^1 – DDD	24	Endrin Aldehyde
10	p, p^1 – DDD	25	Endrin Ketone

11	Endosulfan – Alpha	26	Chlorthalonil
12	Endosulfan – Beta	27	Dichlofluanid
13	Aldrin	28	Dicofol (Kelthane)
14	Endrin	29	Vinclozolin
15	Dieldrin	30	Chlorbenzilate

2.6.3b ORGANOPHOSPHOROUS PESTICIDES: 35 Nos.

1.	Acephate	19	Mathamindophos
2	Azinphos – methyl	20	Mevinphos
3	Chlorfenvinphos	21	Omethoate
4	Chlorpyriphos	22	Methyl Paraoxon
5	Chlorpyriphos – methyl	23	Parathion – ethyl
6	Coumaphos	24	Parathion – methyl
7	Dichlorvos	25	Prothiofos
8	Diazinon	26	Phorate
9	Dimethoate	27	Phorate sulfone
10	Disulfoton	28	Phorate sulfoxide
11	Ethoprophos	29	Profenfos
12	Ethion	30	Phosalone
13	Fenchlorphos	31	Phosphamidon
14	Fenitrothion	32	Quinalphos
15	Iprobenphos	33	Triazophos
16	Monocrotophos	34	Tridimefon
17	Malathion	35	Propargite

18 Malaoxon

2.6.3c OTHER COMMERCIALLY USED PESTICIDES: 30 Nos.

1	Cypermethrin	16	Fenarimol
2	Cyfluthrin	17	Fipronil
3	Cyhalothrin – Lambda	18	Cyromazine
4	Deltamethrin	19	Difenoconazole
5	Fenvalarate	20	Flusilazole
6	Esfenvalerate	21	Hexaconazole
7	Fluvalinate	22	Penconazole
8	Flumethrin	23	Propiconazole
9	Permethrin	24	Myclobutanil
10	Fenpropathrin	25	Bitertanol
11	Amitraz	26	Isoproturon
12	Atrazine	27	Benalaxyl
13	Captan	28	Metalaxyl
14	Captafol	29	Bromopropylate
15	Iprodione	30	Dimethomorphe

Chapter - III

HYDROGEOCHEMICAL ASSESSMENT IN SEDIMENTARY AND CRYSTALLINE WELLS

Chapter - III

HYDROGEOCHEMICAL ASSESSMENT IN SEDIMENTARY AND CRYSTALLINE WELLS

3.1 INTRODUCTION

The World Health Organization (WHO) has repeatedly insisted that the single major factor adversely influencing the general health and life expectancy of a population in many developing countries is lack of ready access to clean drinking water (Nash and McCall 1995). Groundwater is important for human water supply and in Asia alone about 1 billion people are directly dependent upon this resource (Foster 1995). However, many groundwater exploitation schemes in developing countries are designed without due attention to quality issues. In recent years, in many parts of India especially in the arid- and semi-arid regions, due to the vagaries of monsoon and scarcity of surface water, dependence on groundwater has increased tremendously. India supports more than 16% of the world's population with only 4% of the world's fresh water resources (Singh 2003). The total area cultivated in India using groundwater has increased from 6.5 million hectare in 1951 to 35.38 million hectare in 1993 (GWREC 1997). In India, several studies have reported groundwater contamination by nitrate due to agricultural activities (Singh 1983; Hem 1985; Datta et al. 1997; Prasad 1998; Kumar et al. 2006a, b). Soil contamination due to irrigation water quality has also been reported (Palaniswami and Ramulu 1994; Datta et al. 2000; Patel et al. 2004; Marechal et al.

2006, Zeman et al. 2006, Manish Kumar et al. 2007, Raju 2007, Umar et al. 2009, Sanjay Kumar et al. 2009, Subba Rao et al. 2011).

3.2 CHARACTERISTICS OF NATURAL WATERS

Water has the ability to dissolve a wide range of materials, so that in its natural state it is never pure. Always it contains a variety of soluble inorganic and organic compounds. In addition to these, water can carry large amounts of insoluble materials that are held in suspension. Both the amounts and types of impurities found in natural water vary from place to place and by time of year. Their characteristics determine the quality of water.

Natural groundwater and surface water contain many chemical species in the dissolved state. The occurrence of these constituents results from many physical and chemical weathering processes on geological formations and from many chemical reactions in the atmosphere. The nature of these constituents is a function of the type of geology, the distribution of this geology and the physical and chemical constraints of the many weathering processes. Consequently these natural waters achieve definite concentrations of the several dissolved substances that are controlled by equilibrium conditions of the weathering processes.

3.3 GROUNDWATER CHEMISTRY

Most groundwater abstracted for domestic, industrial or agricultural use is meteoric water that is, groundwater derived from rainfall and infiltration within the normal hydrologic cycle. The chemistry of meteoric groundwater changes during the passage through rocks, the changes depending on such factors as the minerals with which it comes into contact, the temperature and pressure conditions, and the time available for water and minerals to react. The modification of meteoric groundwater in its passage into and through the ground is one of the evolutionary sequences of groundwater chemistry (Developing Groundwater 2005).

A brief description about the major parameters related to groundwater quality is provided below.

3.3.1 PHYSICAL PARAMETERS

Colour : Colour in groundwater mainly result from degradation process in the natural environment. It may occur due to the presence of humic acid, fulvic acids, metallic ions such as iron and manganese, suspended matter, industrial wastes etc. Colour is expressed in terms of Hazen standard unit which is defined as the colour produced by 1mg/L of platinum in the form of chloroplatinic acid in the presence of 2 mg/L of cobaltous chloride hexahydrate.

Odour and Taste: The odours and tastes are present mainly due to dissolved impurities often organic in nature. The odour may be of natural origin, caused by living and decaying aquatic organisms and accumulation of gases like ammonia, hydrogen sulphide etc. Many algae also impart taste and odours to water. Sometimes reagents added to water supply systems may also produce odour and tastes. The objectionable tastes and odours are sometimes rejected on the ground of aesthetic values. Some organic substance imparting taste and odours may also be toxic. The tastes and odours in the water are also not suitable in food, pharmaceuticals and beverage industries.

Temperature: Variations in solar energy received at the earth's surface create periodicities, both diurnal and annual in temperature below ground water surface. In marked contrast to the large seasonal variation of surface water temperature tend to remain relatively constant.

Below the zone of surface, influence of groundwater temperatures increases approximately 2.9 ^{0}C for each 100 m of depth in accordance with the geothermal gradient of the earth's crust. Temperature must be measured immediately after collecting the sample. It is basically important for its effect on the chemistry and biological reactions on the organisms in water. A rise in temperature of the water leads to the speeding up to the solubility of gases and amplifies the taste and odours. Water in the temperature range of 7 to 11 ^{0}C has pleasant taste and is refreshing (Trivedi and Goel 1986). At higher temperatures with less dissolved gases the water become tasteless. Temperature is also important in the determination of various parameters such as pH, conductivity, saturation level of gases and alkalinity.

Turbidity: Turbidity in water is caused by the substances like clay, silt, organic matter, phytoplankton and other microscopic organisms. It is actually the expression of optical property. Turbidity makes the water unfit for domestic purposes and some industries; however it is usually negligible in groundwater. Sometimes turbidity is measured to evaluate the performance of water treatment plants (Ghosh and Sharma 2006).

3.3.2 CHEMICAL PARAMETERS

pH: pH is the measure of the intensity of acidity or alkalinity and measures the concentration of hydrogen ion in water. Most groundwater has pH values between 5.8 and 8.0.Very high pH values above 8.5 are usually associated with sodium carbonate/bicarbonate waters; moderately high pH values are commonly associated with waters high in bicarbonates; very low pH values may be associated with small amounts of mineral acids from sulphide sources or with organic acids (Ghosh and Sharma 2006). A low value of pH below 4 will produce sour taste and higher value above 8.5 an alkaline taste. Low pH of drinking water will affect the mucous membrane of intestine. It affects aquatic life, causes corrosion and, toxicity of many substances increases with increase in pH. High pH causes scaling and product blackening of cooking.

Electrical Conductivity (EC) and Total Dissolved Solids (TDS): Conductivity is the measure of capacity of a substance or solution to conduct electric current. As most of the salts in water are present in ionic forms and capable of conducting current, conductivity is a good and rapid measure of the total dissolved solids. As the dissolved solids in the highly mineralized waters are usually more than 65% conductivity, the value of dissolved solids, as a general rule can be obtained by multiplying it by a factor of 0.65. However it is difficult to get accurate values by this calculation, as capacity to conduct the current depends on number and kinds of ions present, their relative charge and freedom of ions to act as conductors. Electrical conductivity is expressed as mhos per centimeter. It is such a large unit that most natural water has a value much less than one unit. For convenience these values can be reported as milli mhos or micro mhos at 25 ^{0}C.

Total dissolved solids denote mainly various kinds of minerals present in the water. In natural waters dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron, manganese etc. Concentration of dissolved solids is an important parameter in drinking water and other water quality standards. They give a particular taste to the water at higher concentration and also reduce palatability.

Dissolved Oxygen (DO): Dissolved oxygen is one of the most important parameters in water quality assessment and reflects the physical and biological processes prevailing in water. Its presence is essential to maintain the higher forms of biological life in the water. Low oxygen in water can kill fish and other organisms present in water. Low oxygen concentrations are generally associated with heavy contamination by organic matter.

Alkalinity: The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural waters is due to the salts of carbonates, bicarbonates, borate, silicates and phosphates along with the hydroxyl ions in the free state. However, the major portion of alkalinity in natural water is caused by hydroxide, carbonate and bicarbonates which may be ranked in order of their association with high pH values. Alkalinity values provide guidance in applying proper doses of chemicals in water and waste water treatment processes, particularly in coagulation softening and operational control of anaerobic digestion. The ratio of alkalinity to that of alkaline earth metals is a good parameter determining the suitability of irrigation waters.

Acidity: Acidity of water is its capacity to neutralize a strong base and is mostly due to the presence of strong mineral acids, weak acids (carbonic, acetic acids) and the salts of strong acids and weak bases (ferrous sulphate, aluminium sulphate, etc). These salts on hydrolysis produce strong acid and metal hydroxides, which are sparingly soluble thus producing the acidity. However, in natural waters, most of the acidity is present due to the dissolution of carbon dioxide which forms carbonic acid. Determination of acidity is significant as it causes corrosion and influences the chemical and biochemical reactions.

Phosphates: The major sources of phosphorous are domestic sewage, detergents, agricultural effluents with fertilizers and industrial waste waters. The prime concern of phosphorous lies in the ability to increase the nuisance algae and eutrophication.

Sulphate: Sulphate is naturally occurring anion in all kinds of natural waters. It is an important constituent of hardness with calcium and magnesium. Sulphate produces an objectionable taste at 300-400 mg/L above 500 mg/L a bitter taste is produced in the water. At concentrations around 1000 mg/L, it is laxative (Trivedi and Goel 1986).

Chloride: Chlorides occur naturally in all types of waters. The most important source of chlorides in the water is the discharge of domestic sewage.

3.3.3 HEALTH RELATED INORGANIC CONSTITUENTS

Arsenic: Arsenic minerals are widely distributed and small amounts of the free element have also been found. Common minerals include two sulphides, realgar and orpiment and the oxidized form arsenolite. Many arsenic compounds are water soluble and thus contamination of water can occur. Most of the arsenic found in water derives from industrial discharges. Arsenic is present in most food stuffs. The gastro intestinal tract, nervous system, the respiratory tract and skin can be severely affected.

Fluoride: Fluoride is an essential element for some animal species. The three most important fluorine bearing minerals are fluorite, cryolite and fluorapatite. In little quantities, it can reduce dental caries. Once fluoride is incorporated into teeth, it reduces the solubility of the enamel under acidic conditions and thereby provides protection against dental caries. Long term consumption of water containing 1 mg of fluoride per litre may lead to mottling. Skeletal fluorosis has been observed in persons when water contains more than 3-6 mg of fluoride per litre. In high doses, fluoride is actually toxic to man. Pathological changes include hemorrhagic, gastroenteritis, acute toxic nephritis and various degrees of injury to the liver and heart muscle.

Hardness: Hardness of water is the property attributable to the presence of alkaline earths. The major alkaline earth elements present in most natural waters are Ca and Mg. Other elements such as Sr, Ba (also alkaline earths), Fe, Mn and Al are normally not present in waters in sufficient amount to affect a test for hardness. The degree of hardness in water is commonly based on the following classification: Water hardness is primarily the result of interaction between water and the geological formations containing it, or over which the water flows. There is some suggestive evidence that drinking extremely hard water might lead to an increased incidence of urolithiasis.

Iron: Iron is an abundant element in the crust by weight and is a major constituent in pyroxenes, amphiboles, micas (silicates), pyrite and chalco-pyrite (sulphides) and magnetite and hematite (oxides). Iron is an essential element in human nutrition. Iron ingestion in large quantities results in a condition of haemochromatosis (normal regulatory mechanisms do not operate effectively).Iron bearing water often tastes unpalatable and stains laundry and plumbing fixtures.

Cadmium: Cadmium is found as greenockite. But the commercially important source is found in zinc ores. Drinking water normally contains very low concentrations of cadmium. Most food stuffs contains traces of cadmium. Higher levels of cadmium in tap water are associated with plated plumbing fittings, silver base solders and galvanized iron piping material. Acute effects have been seen where food has been contaminated by cadmium from plated vessels. Health effects have been demonstrated in industrial workers having been exposed to cadmium oxide fuels and dust. The renal cortex is generally accepted to be the critical organ for cadmium accumulation in man. A guideline value of 0.01 mg of cadmium per litre is recommended.

Lead: The most important lead ore is galena. Other ore minerals are anglesite, cerussite, pyromorphite and mimetestite. Lead in high doses is a cumulative general metabolic poison. Some of the symptoms of acute poisoning are tiredness, lassitude, slight abdominal discomfort, irritability, anemia and, in the case of children, behavioral changes. A guideline value of 0.05 mg of lead per litre is recommended.

Nitrate and Nitrite: Nitrates are present widely in substantial quantities in soil, in most waters and in plants including vegetables. Water supplies containing high levels of nitrate is responsible for infantile metheamoglobinaemia and death. This problem does not arise in adults.

Sodium: Sodium is present mainly in rock salts. This ion is ubiquitous in water owing to the high solubility. In general, sodium salts are not acutely toxic substances because of the efficiency with which mature kidneys excrete sodium. Excessive intake of sodium chloride causes vomiting and the elimination of much of salts. Acute effects may include convulsions, muscular twitching and rigidity and cerebral and pulmonary oedema. Acute effects and death have been reported in the case of children.

Zinc: The major source of zinc is sphalerite, smithsonite, hemimorphite and franklinite. Zinc is an essential element for both animals and man and is necessary for the functioning of various enzyme systems. Symptoms of zinc toxicity in humans include vomiting, dehydration, electrolyte imbalance, abdominal pain, nausea, dizziness, lethargy and lack of muscular co-ordination. Acute renal failure caused by zinc chloride has been reported.

Pesticides: Pesticides are synthetic organic chemicals used to control weeds in fields and lawns, and unwanted or harmful pests, such as insects and mites that feed on crops. Pesticides may cause acute and delayed health effects in those who are exposed. Usage of pesticides in India is increasing at 2 to 5% per annum and is about 3% of total pesticide used in the world. India thus needs to urgently take a tough measure in the indiscriminate and careless use of pesticides.

3.4 GROUNDWATER QUALITY IN CLIMATICALLY CLASSIFIED AREAS

Meteoric water was once precipitation. Although rain is nature's distilled water, it contains between 10 and 20 mg/L of dissolved materials (Michael Price

1985). Near coastlines, the concentration of NaCl is increased and downwind of industrial areas sulphur and nitrogen compounds are more. The presence of these compounds turns the rain into dilute acid, creating serious environmental problem. When the precipitation infiltrates the soil, the most important natural change is the dissolution of carbon dioxide from the soil to water. The weak carbonic acid so formed is then able to dissolve calcium carbonate present in the underlying rocks. The soil organisms also consume much of the oxygen that was dissolved in the precipitation in its passage through the atmosphere.

In temporate and humid climates where recharge is a regular process and the annual surplus of precipitation exceeds evapotranspiration, water is usually moving relatively rapidly through the outcrop area of an aquifer and hence its contact time with the rocks may be limited. Any highly soluble materials such as NaCl, will have been flushed from the system long ago, and there will be insufficient time for poorly soluble minerals to be taken into solution in significant amounts. Thus the outcrop areas of such aquifers are having low dissolved solids unless the aquifer is a limestone or sandstone with $CaCO_3$ cement in which the ground water will contain calcium and bicarbonates as the dominant ions.

Sulphates and Nitrates will be present in small quantities. Nitrates are usually derived from the soil where it may originate from the fixation of atmosphere nitrogen by leguminous plants or from the oxidation of organic materials by bacteria. Besides this, large quantities of nitrates are leached from agricultural fertilizers. Sulphate ions are commonly produced in the out crop areas by the oxidation of metallic sulphides that are present in many rocks. The oxidising agent is atmospheric oxygen which was dissolved by precipitation. Sulphate minerals as gypsum and anhydrite are readily soluble and usually flushed from the outcrop area readily.

If the aquifer drops below a confining bed, the conditions prevalent at the outcrop may continue for some way below the imperishable cover. Dissolution is still the dominant process and in aquifers containing $CaCO_3$, the amounts of calcium and bicarbonate in solution typically rise to their highest levels in this part of the aquifer. With increasing distance from the outcrop, the dominant process changes from dissolution to ion exchange. Most aquifers contain some clay minerals.

The small size of clay particles means that although the clay may be present in only small quantities, it presents a relatively large surface area to the percolating groundwater. Ions absorbed on the clay surfaces tend to exchange with ions in solution. This principally involves cations the trend being for the cation in the water to come in to equilibrium with those on the clay particles in the aquifer. A major effect is that calcium and magnesium ions in solution are replaced by sodium ions which are frequently concentrated on clay surfaces when rocks are deposited. The removal of Ca ions from the water can lead to further solution of $CaCO_3$, but the end product tend to be a sodium – bicarbonate water. Since it is calcium and magnesium ions that cause hardness, ion exchange leads to softer water.

Fine textured formation like clay or shale aquitard behave like semi permeable membranes, retarding movement of charged ionic species but allowing relatively unrestricted movement of neutral substances. Molecules with high dipole moments like H_2O will be retarded relative to those with low dipole moments like organic compounds. This behavior is caused by the negatively charged surfaces of clay particles which absorb cation from the surrounding soil solution. Some anions get trapped in the absorbed layers of ions. When the fine textured material is very dense, the pores between the clay particles are so small that they are entirely influenced by the absorbed layers and water and ions no longer move freely in the pores. The clay layer then behaves like a semi permeable membrane which can produce osmotic pressure differences, salt sieving or ultra filtration and electrical potential differences.

Salt sieving and osmotic effects can explain certain salinity and piezometric properties of water in sedimentary rock that cannot be readily explained by simple solution chemistry or gravity flow. The high salt content of certain ground waters that have not been in contact with evaporites may be due to salt sieving as water left the formation through a semi permeable membrane that did not pass the salts. At greater distances from the aquifer media there is typically less natural movement of water because there is generally no outlet for the water as the strata dip downward, except leakage through the confining beds. The slower movement means that there is more opportunity for less soluble minerals to be dissolved. The reduced through flow also means that soluble minerals such as gypsum may not have been flushed from the aquifer. With even greater distance from the outcrop and greater depth of burial, this will even be true of NaCl. Then there is a change from bicarbonate water to sulphate water and finally to chloride water, with cations correspondingly changing from Ca and Mg to Na.

A complete typical sequence of the evolution of meteoric ground water starts with water in which the main anions are bicarbonates. As the water move deeper, sulphate ions increase and become prominent. If this system is deep enough, chloride becomes dominant. The amount of material in solution also increases with time and depth. The sequence in which the various cations become important is complicated by the effects of ion exchange. As the ground water becomes older and deeper the dominant cations change from Ca and Mg to Na.

The above explained typical sequence is subject to many variations in water quality. The water may not stay in an aquifer long enough or move deep enough to reach the typical end product of a Na-Cl brine. Conversely, if water exceptionally infiltrates an arid region where evaporate deposits are still present, it may reach the Na-Cl stage almost immediately. Another significant change that occurs with increasing distance from out crop is the change from oxidizing to reducing condition. Ground water at the out crop will generally contain oxygen derived from the atmosphere, and sulphate from the soil and aquifer media. As the water containing dissolved oxygen, nitrates and sulphate moves away from the out crop, oxygen is used up in oxidizing organic matter and other material such as ferrous iron. Dissolved Oxygen is used first and then nitrates and finally sulphate are reduced as their oxygen is used up. Like the evolution of major ion chemistry, the time and distance taken for these changes will vary from one aquifer and place to another. Aquifers containing large amounts of organic material will rapidly deplete the oxidizing capacity of the ground water. In many aquifers the presence of reducing condition results in the presence of H_2S gas. This is evident from the lithology of the deeper aquifers of the sedimentary of Kerala state. When deep tube wells are drilled in the coastal belt of Kerala, H_2S smell is observed at a particular zone.

In arid and semi arid areas, evaporation and evapotranspiration generally exceeds rainfall for most or all of the year, the aquifer out crop may be a zone of concentration rather than dissolution. Unless soluble minerals have been leached from the aquifer in the past, the ground water may be saline. If the water table is sufficiently close to the ground surface for ground water to be lost either by capillary action and direct evaporation or by transpiration, there is likely to be a concentration of salts within the soil and subsoil, as water is evaporated or transpired and the solutes are left behind. As a result a crust or 'hardpan' can form at or near the surface. In such cases, irrigation aggravates the problem. If ground water is used for irrigation in arid areas, then the high rates of evaporation mean that soluble material in this ground water will be deposited in this soil. Any occasional natural recharge or excess of irrigation water is liable to dissolve these minerals and carry them down to the water table, thereby increasing the salinity of the ground water.

The limited recharge in the arid and semi-arid region often means that ground water has either migrated from outside the area or infiltered a long time ago. Either alternative implies long residence times and possibly incomplete flushing of soluble minerals from the aquifer. Sodium chloride water is relatively common. This is observed in the fresh water saline water zones of the coastal belt and in the backwaters of Kerala.

Sedimentary rock generally yields good-quality ground water. The water from sandstones may be high in Na and HCO_3. Shales may produce slightly acid water high in Fe, SO_4, and F. Limestones yield water that is slightly alkaline and contains Ca and Mg. Water from alluvial deposits in tectonic basins and valleys may have a relatively high salt content, if the basin was closed and or the water came from deeper aquifers where it was in contact with evaporites or connate water. Water with a lower salt content normally is obtained where there is some outlet for the ground water and the older ground water and connate water have been replaced by more recent meteoric water. If there is sedimentary rock in the alluvial fill, the ground water may contain Ca, Mg, HCO_3, and SO_4. Na and Cl, depending on how much leaching and concentration took place in the surface soil. Material of igneous and volcanic origin may contribute SiO_2 to the water. Alluvial river valleys normally yield ground water with a relatively low salt content, depending on the material. If it contains carbonate rock, the water will contain Ca, Mg and HCO_3 while gypsum and anhydrite contribute Ca and SO_4. In some valleys, salty water from the bedrock seeps in to the aquifers and causes local increases in the salt concentration of the ground water. Upper aquifers in coastal-plain sediments normally yield good ground water with low salt content and with Na, Ca, and HCO_3 as principal ions. Deeper aquifers (100 to 300 m depth) tend to yield water with more Na and HCO_3 and less Ca and SO_4. Below this level, aquifers are generally contaminated with marine or salty connate water. If the water has moved along long distances through aquifers or if it has been stagnant, like between aquicludes, the salt content may be relatively high. Hard water is yielded where the aquifers contain calcite or dolomite.

3.5 MAJOR CATIONS AND ANIONS IN GROUNDWATER

The concentrations of major dissolved ions in groundwater must be measured to understand the geochemical system because these ions are the primary contributors to solution ionic strength, which impacts the effective concentrations of all dissolved species. Also, the major ions may form strong solution complexes with each other and the trace constituents, thereby affecting their mobility and reactivity.

3.5a MAJOR IONS IN GROUNDWATER

Of the many constituents present in groundwater, only a few are present at concentrations greater than 1mg/l under typical natural conditions. These are generally called major ions and some of the major ions occur more frequently and at greater concentrations than others (**Table 3.1** and **3.2**).

Table 3.1

Major and secondary constituents of groundwater (HP manual 2003)

Major Constituents (1 to 1000 mg/L)	Secondary Constituents (0.01 to 10 mg/L)
Sodium	Iron
Calcium	Strontium
Magnesium	Potassium
Bicarbonate	Carbonate

Sulphate	Nitrate
Chloride	Fluoride
Silica	Boron

Table 3.2

Major cations and anions in natural water (HP manual 2003)

Cations	Anions
Sodium	Bicarbonate/carbonate
Potassium	Sulphate
Calcium	Chloride
Magnesium	

Rain water, as it passes through the air and over the land, dissolves many chemical species. Passing through the atmosphere, it dissolves the gases which constitute air including nitrogen, oxygen and carbon dioxide. The fact that it dissolves carbon dioxide from the air is important because when carbon dioxide is present in water, it forms carbonic acid and this acid enhances water's ability to dissolve chemical species (salts) contained in rocks and soil. In passing through polluted atmosphere it also dissolves gases associated with pollution such as sulphur and nitrogen oxides. Some of these gases can also make the water acidic, further adding to the water's ability to dissolve salts. By the time that rain water has passed over the land to become groundwater or surface water it has normally acquired many dissolved chemical species. Clearly, the precise chemical composition of the water will depend upon the types of rocks and soils with which the water has been in contact and this can be used to characterize particular water by determining its chemical make-up as shown in **Table 3.3**.

Table 3.3

Major ions and their sources (HP manual 2003)

Major ions	Primary Sources
Calcium	Amphiboles, feldspars, gypsum, pyroxenes, aragonite, calcite, dolomite, clay minerals
Magnesium	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals
Sodium	Feldspars, clay minerals, halite, mirabilite, industrial wastes
Potassium	Feldspars, feldspathoids, some micas, clay minerals
Bicarbonate/Carbonate	Limestone, dolomite
Sulphate	Oxidation of sulphide ores, gypsum, anhydrite
Chloride	Sedimentary rock, igneous rock

3.5b WATER QUALITY CONSEQUENCES OF MAJOR IONS

Calcium and magnesium ions are common in natural waters and both are essential elements for all organisms. Calcium and magnesium when combined with bicarbonate, carbonate, sulphate and other species, contribute to the hardness of natural waters. The effect of this hardness can be seen as deposited scale when such waters are heated. Normally hardness due to calcium predominates although in certain regions magnesium hardness can be high. Classification of degree of hardness in water (Vinayan, 2009) shown in **Table 3.4**.

Table 3.4

Classification of degree of hardness in water (HP manual 2003)

Hardness (mg/L as $CaCO_3$)	**Classification**
0-75	Soft
75-150	Moderately hard
150-300	Hard
Over 300	Very hard

In natural waters, calcium concentrations are normally below 15mg/L although this can rise to 100 mg/L where waters are associated with carbonate rich rocks. Magnesium concentrations also vary widely and can be from 1 to over 50 mg/L depending upon the rock types within the catchment. All natural waters contain sodium ions as the element is one of the most abundant on the planet. High concentrations in inland waters are normally associated with pollution from industrial discharges or sewage effluent or, in coastal areas, sea water intrusion. Normally, sodium concentrations are below 200 mg/L. Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. When high sodium water is applied to soil, the number of sodium ions combined with the soil increases, while an equivalent quantity of calcium or other ions is displaced. These reactions change the soil characteristics, causing deflocculation and reduction of permeability. The ion exchange occurs in the opposite direction when calcium is added. Thus, adding gypsum ($CaSO_4$) to a soil creates a flocculated and more permeable soil, improving soil texture and drainability. The concentration of potassium ions in natural fresh waters is generally low (normally less than 10 mg/L, HP manual 2003). Sea water and brines contain much higher concentrations. Bicarbonate concentrations in natural waters range from less than 25 mg/L in areas of non carbonate rocks to over 400 mg/L where carbonate rocks are present. Carbonate concentrations in natural waters are generally low and nearly always less than 10 mg/L. Sulphate is present in all waters as it arises from rocks and sea water. High concentrations of sulphate is problematic as they make the water corrosive to building materials and are capable of being reduced to toxic, foul-smelling hydrogen sulphide gas in anaerobic conditions. Sulphate concentrations in natural waters are between 2 and 80 mg/L (HP manual 2003). Chlorides in natural fresh waters generally come from rocks, sea, sewage and agricultural and industrial effluents. Fresh water concentrations of chloride are normally less than 40 mg/L and can be as low as 2 mg/L in unpolluted waters(HP manual 2003). Chloride concentrations over 100 mg/L give the water a salty taste. High concentrations of nitrate are present when municipal waste water or leachate from garbage dumps has contaminated the ground water (HP manual 2003). Excessive concentrations of nitrate in drinking water causes methaemoglobinaemia in bottle-fed infants.

3.6 DATA VALIDATION

Water quality data validation consists of a series of checks to see if errors have been made in water sampling, sample analysis or data entry. The following steps have been adopted for the validation procedure for the present study programme.

3.7 ANION-CATION BALANCE

Anion-Cation balance check is the most important validation test to be conducted when a water quality sample has been analysed for the major ionic species. The principle of electro neutrality requires that the sum of the cations must equal the sum of anions. If significant errors in any of the major ion analyses have been made, there will be an error in the cation – anion balance. If this error is too large (>10%), it indicates that there has been an error made in at least one of the major ion analyses.

$$\% \text{ of balance error} = \left(\frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \right) \text{X } 100 \qquad (3.1)$$

$$\text{Cations} = Na^{+} + Ca^{2+} + Mg^{2+} + K^{+} \qquad (3.2)$$

$$\text{Anions} = Cl^{-} + HCO_3^{-} + SO_4^{2-} + NO_3^{-} \qquad (3.3)$$

By applying the above formula in each observation where ever the % error is > 10% the observed readings were rejected and new analysis has been adapted. It is also noted that an accurate ion balance does not necessarily mean that the analysis is correct. There may be more than one error and these may cancel each other out. Check accuracy (% balance error) is referred in “Major ions in water doc” version 25/10/1999 of HP Training module; Data Validation and analysis – Villars. In order to have uniform pattern in the data storage system of the country, the I.S.I has introduced the standard with modification from time to time. An error committed at the sampling point, or cleaning of bottles etc., can cause ionic imbalance.

3.8 HYDROGEOCHEMICAL CHARACTERISTICS OF SHALLOW SEDIMENTARY AQUIFER

The coastal plains of Ernakulam district covering an area of 1126 km^2, has an elevation less than 7.6 m amsl and occurs parallel to the sea coast. The width of the coastal plains generally ranges from 10-15 km. The area parallel to the coast dominated by the presence of a number of back water channel part of it is covered by coastal alluvial soil which is mainly composed of sand and clay with dominance of sand fraction. They are excessively drained with very high permeability. The water table is generally high in the low-lying areas. The low content of organic matter and clay has resulted in low cation exchange capacity of the soil (CGWB 1993). A significant portion of the western part of Greater Cochin area is covered by Vembanad back waters. A thin strip of land along the sea coast separates the back waters from the sea. The Vembanad back waters are connected to the sea at two places viz., at Cochin and at Kodungallur at the northern boarder of the district.

A systematic hydrogeochemical study was carried out to assess the groundwater quality of sedimentary formation of Ernakulam district, based on BIS criteria, during the period January 2006 to September 2008. The study area covers the entire taluk of Kochi and Paravur. In Cochin taluk and western parts of Paravur and Aluva taluk, coastal alluvium is encountered and is composed of sand, silt and clay of lagoonal and backwater deposits and beach deposits. The thickness of coastal alluvium ranges from less than 1 m to 54 m. Small patches of hydromorphic saline soil, which is brownish and imperfectly drained, occurs in the coastal tracts of Kanayannur and Cochin taluks. The network of back waters and estuaries boardering the coast serve as inlet for tidal waters to flow into the coastal areas causing salinity. Wide fluctuation in the intensity of salinity has been observed in these soils (CGWB 1993). During the monsoon period, these areas are flooded and most of the salt is leached out.

3.8a HYDROGEOLOGY OF THE AREA

Ground water occurs under phreatic condition in the unconsolidated coastal sediments and occurs under semi confined to confined conditions in the tertiary sediments. The alluvial formation is excessively drained with very high permeability and hence forms potential phreatic aquifer. The water table is generally high in the low lying areas. In this formation, wells are tapped to meet domestic and other needs. Eight open wells were selected for the study in sedimentary phreatic aquifer. The general well information is shown in **Table 3.5(a)** and lithology is shown in **Table 3.5(b).**

Table 3.5(a)

General well information

Tahsil/Taluk	Village	Well ID	Latitude	Longitude	Geology
Paravur	Paravur	ESOW-01	10°08'53"	76°13'52"	Alluvium

Cochin	Pallippuram	ESOW-02	10°08'13"	76°11'43"	Alluvium
Cochin	Njarakkal	ESOW-03	10°02'43"	76°13'04"	Alluvium
Cochin	Mattanchery	ESOW-04	09°57'19"	76°14'45"	Alluvium
Cochin	Ernakulam	ESOW-05	09°57'42"	76°17'18"	Alluvium
Cochin	Chellanam	ESOW-06	09°50'54"	76°16'11"	Alluvium
Cochin	Kumbalangi	ESOW-07	09°52'51"	76°17'12"	Alluvium
Cochin	Edacochin	ESOW-08	09°53'45"	76°17'45"	Alluvium

Table 3.5(b)

Lithologic information of wells

Well ID	Depth to (m)	Lithology	Texture
ESOW-01	4.81	Alluvial soil	Fine to medium
ESOW-02	1	Topsoil	Fine to medium
	3.5	Sand	Fine to medium
ESOW-03	2.36	Alluvial soil	Fine to medium
ESOW-04	2.27	Sandy clay	Fine to medium
ESOW-05	3.15	Alluvial soil	Medium
ESOW-06	1.5	Alluvium	Medium to coarse
	1.85	Clay	Fine
ESOW-07	2	Sandy soil	Medium to coarse
	3.45	Clay	Fine
ESOW-08	1	Lateritic soil	Fine
	3.6	Laterite	Medium

As explained in **Chapter II**, water level was monitored monthly. The depth to water level varied from 0 to 3.07 mbgl during the study period. The monthly water level data are given in the **Table 3.6** (**Annexure).** Minimum, maximum and average water levels of open wells in sedimentary formation of Ernakulam district during 2006-2008 were given in **Table 3.7.** The long term behavior of water level in dugwells was mainly controlled by the rainfall recharge received and also the return seepage due to canal flow and irrigation. The pre-monsoon water level variations reflect the trend of ground water development, the post-monsoon water level trend brings out the actual rise or fall in the area. The water quality parameters have been analysed and presented in the **Table 3.8** (**Annexure**).

Table 3.7

Minimum, Maximum and Average Water Levels (Jan-2006 to Sep-2008)

Village	Well ID	Minimum (mbgl)	Maximum (mbgl)	Average (mbgl)
Paravur	ESOW-01	1.10	3.07	2.21
Pallippuram	ESOW-02	0.03	1.92	0.78
Njarakkal	ESOW-03	0.13	1.93	0.84
Mattanchery	ESOW-04	0.11	1.90	0.81
Ernakulam	ESOW-05	0.00	1.82	0.67
Chellanam	ESOW-06	0.00	1.20	0.40
Kumbalangi	ESOW-07	0.47	2.65	1.43
Edacochin	ESOW-08	0.17	1.73	0.86

Out of the eight wells in the study area, the well at Chellanam ESOW-06, which is about 200 m away from sea, shows minimum water level fluctuation during the study period 2006-2008. The maximum rise in water level was up to ground level (July, August and September 2007) and the maximum lowering in water level was 1.2 m bgl during January 2007 (**Figure 3.1**).

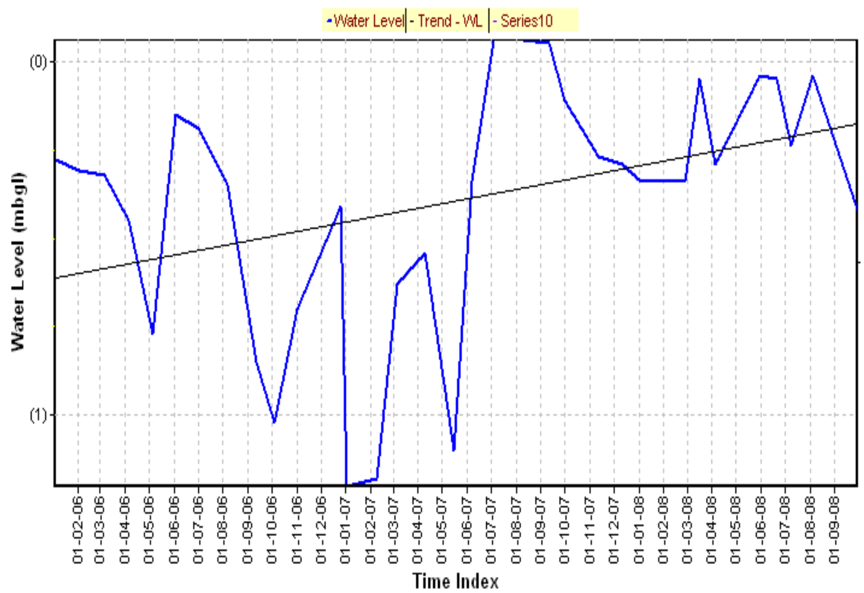


Figure 3.1

Hydrograph of ESOW-06

Compared the water level fluctuation with the monthly rainfall (Data received from IMD, Trivandrum). It can be seen that the rainfall received in this location (IMD rainfall station at Naval Air Station, Kochi) during June to August 2007 was maximum. This supports the maximum rise in the groundwater level occurred during July, August and September of 2007. Similarly, there was no rainfall in the months of December 2006 and January 2007 and hence there was maximum lowering in groundwater level during January 2007. Analysis of water quality data for 2006-2008 shows that this well is having a maximum water quality fluctuation throughout the study period. pH of the station varies from 8.5 to 8.9, which was above the permissible limit (BIS 1998).

Electrical conductivity values showed marked wide fluctuation from 1920 to 7460 µmhos/cm (**Figure 3.2**). The lowest EC value was 1920 µmhos/cm during monsoon 2007 and maximum during post-monsoon 2007 for which the water level fall was maximum and no rainfall was received in this station.

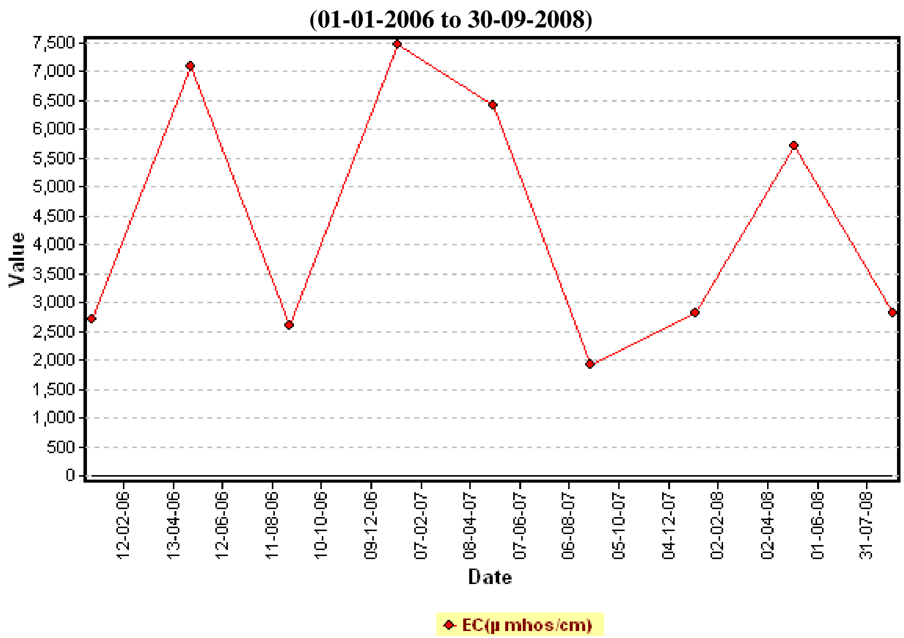


Figure 3.2

Time Series plot of EC for ESOW-06

The maximum electrical conductivity during January 2007 was contributed by high sodium and chloride concentration. It was also noted that the pre-monsoon values of electrical conductivity was comparatively higher than other seasons. The chloride concentration ranges from 466 mg/L (September 2007) to 2320 mg/L (January 2007). From the time series graph **Figure 3.3** showing variation in EC, TH, TA, Na and Chloride, it is clear that the major contributing factor for EC variation was mainly due to Na and Cl and the variation in concentration of Na and Cl was sharp or pointed for this station. It was inferred that during drought period, when water level lowering occurs, saline intrusion taking place in the well.

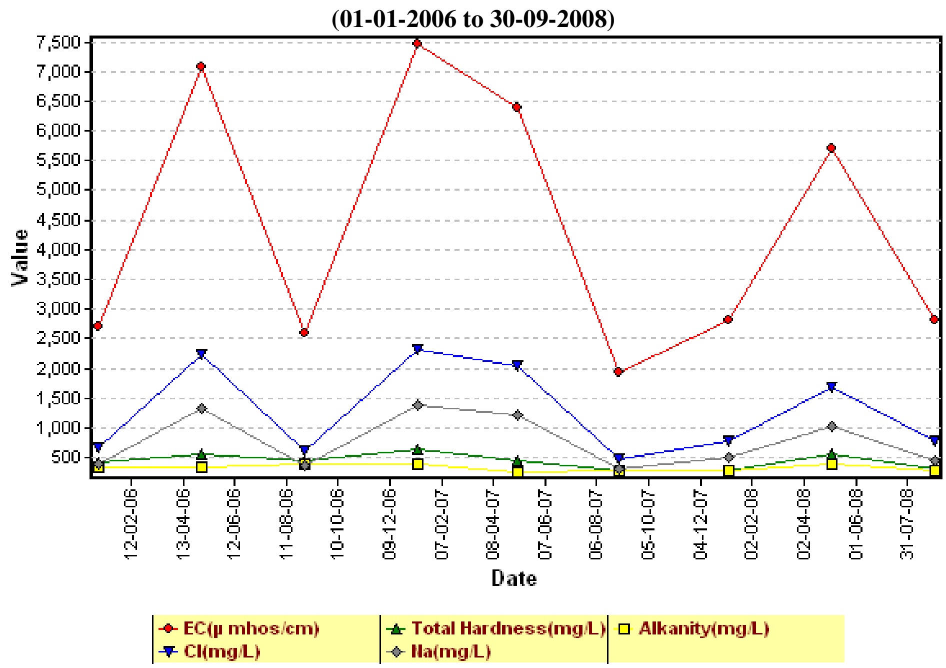


Figure 3.3

Time series graph (ESOW - 06)

Flouride concentration ranges from 0.03 to 1.16 mg/L. Concentration of iron reached its maximum value of 3.4 mg/L during May 2006 and lowest value of 0.16 mg/L during September 2007. The post-monsoon values of iron were lower while the pre-monsoon values exceeds the maximum permissible limits. Values for nitrate-Nitrogen varies from 0 (September 2006) to 4 mg/L (May2006). During January 2007 and September 2007, total hardness, chloride, sodium, potassium and carbonate also reache its maximum and minimum, respectively.

Alkalinity exceeds the drinking water desirable limit of 200 mg/L (as $CaCO_3$) and the concentration of carbonates and bicarbonates were higher for this station as compared to other stations of the sedimentary formation. Hardness exceeds drinking water BIS limits throughout the study period except during September 2007 and January 2008. Chloride exceeds the BIS desirable limit (250mg/L) of drinking water throughout the study period. Whenever there were high values of sodium and chloride, magnesium, potassium concentrations also reaches a higher value. During the entire study period, the total hardness exceeds the total alkalinity and this difference reaches its maximum during pre-monsoon season and minimum during post-monsoon. This is because, the permanent hardness become higher in summer season. Even though the well remains alkaline and saline intrusion was a marked observation, the sodium/chloride ratio remains well within the range of 0.8 to 1.2 for natural water, and it was always less than 1. The highest Na/Cl ratio noted was 0.99 during September 2007 for which water level was the maximum. The noticeable seasonal variation of the well was due to the geological features of the location. The well is subjected to saline water intrusion due to proximity to sea.

The well showing maximum fluctuation in water level during the study period is ESOW-07 at Kumbalangi. Up to 2 m from ground level, medium to coarse textured sandy soil and up to 3.45 m, occurs a clay layer of fine texture. Studied the water level fluctuation of this well correlating to the rainfall data. The maximum water level rise was 0.47 mbgl during July 2007 which can be explained by the maximum rainfall received in this station during June and July 2007. Out of the 8 wells in the sedimentary area, this well shows the maximum lowering in water level (2.65 mbgl) during February 2007, which is clearly supported by the rainfall data. Hydrograph of this station is given in **Figure 3.4**.

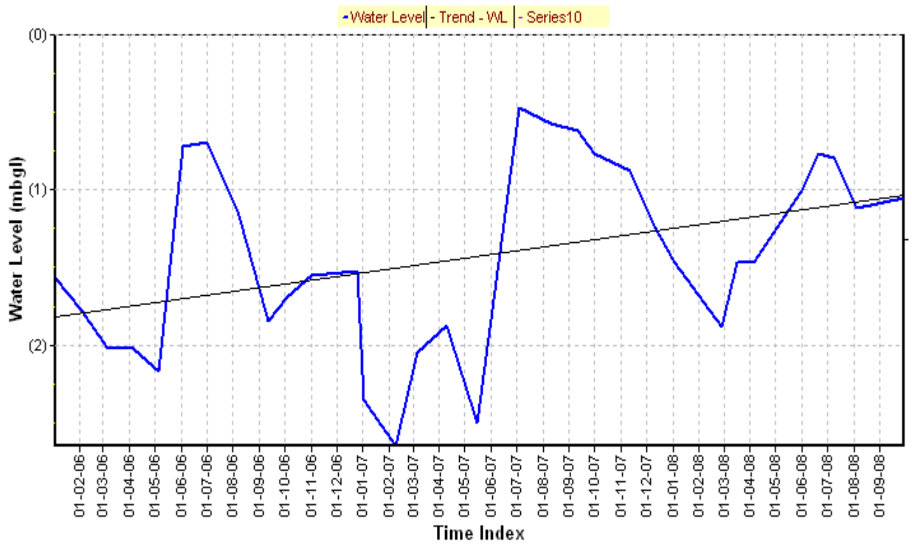


Figure 3.4

Well Hydrograph of ESOW-07

Even though the fluctuation in water level was maximum for this well, corresponding water quality fluctuation was not observed. pH of the well varies from 8.3 to 8.7. Electrical conductivity value reached its maximum of 365 µmho/cm during January 2006 and the lowest value noticed was 210 µmho/cm during September 2008. Electrical conductivity, total hardness, total alkalinity, sodium, potassium chloride, nitrate-N etc., having lower values, as compared to other wells at this study sites and are well-within the desirable limits of BIS. Time series graph of ESOW-07 is given in **Figure 3.5**

(01-01-2006 to 30-09-2008)

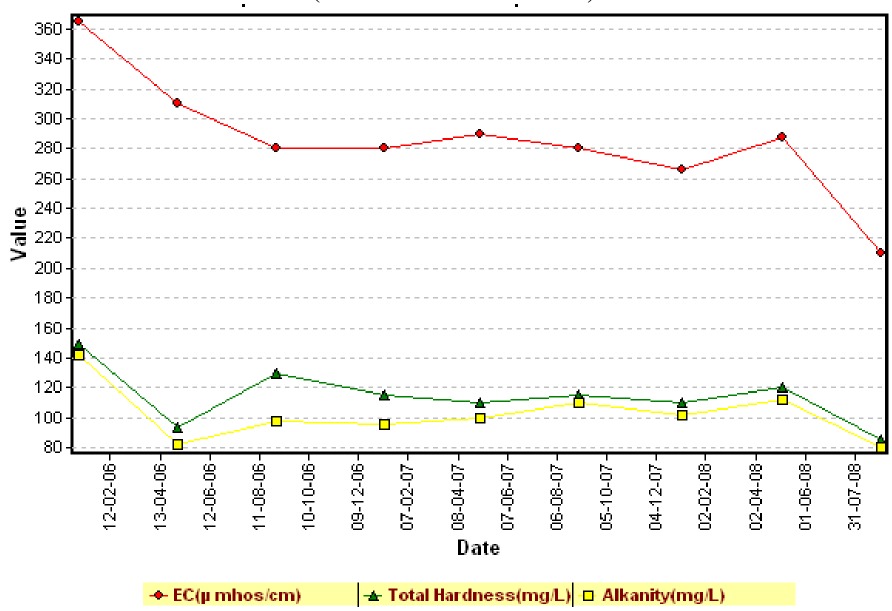


Figure 3.5

Time series plots of EC, TH and TA for ESOW-07

The total hardness always exceeds total alkalinity during the study period. Na/Cl ratio was well within the permissible range of 0.8 to 1.2 during all seasons. But during post monsoon season, it always exceeds 1. Fluoride ranges from 0.03 to 0.64 mg/L where as iron concentration ranges from 0.12 (September 2006) to 3.2 mg/L (May 2006). Analysis of the water quality data reveals that the contribution towards electrical conductivity was mainly due to hardness causing ions and not by Na-Cl.

As described in the lithology of the well, a clay layer with fine texture having thickness 1.45 m was acting as a preventive barrier to the contaminants entering in the well. It was also noted that this is the only well in the study area, having nitrate-N value zero (except the negligible concentrations in May 2008 and September 2008).

Three wells in the sedimentary area tapping the alluvial soil formation of fine to medium texture are ESOW-05 Ernakulam, ESOW-03 Njarakkal and ESOW-01 Paravur. The difference in minimum and maximum water levels is almost equal for these wells, even though the water table for ESOW-05 Ernakulam is high while that of ESOW-01 at Paravur is comparatively lower (**Figure 3.6**).

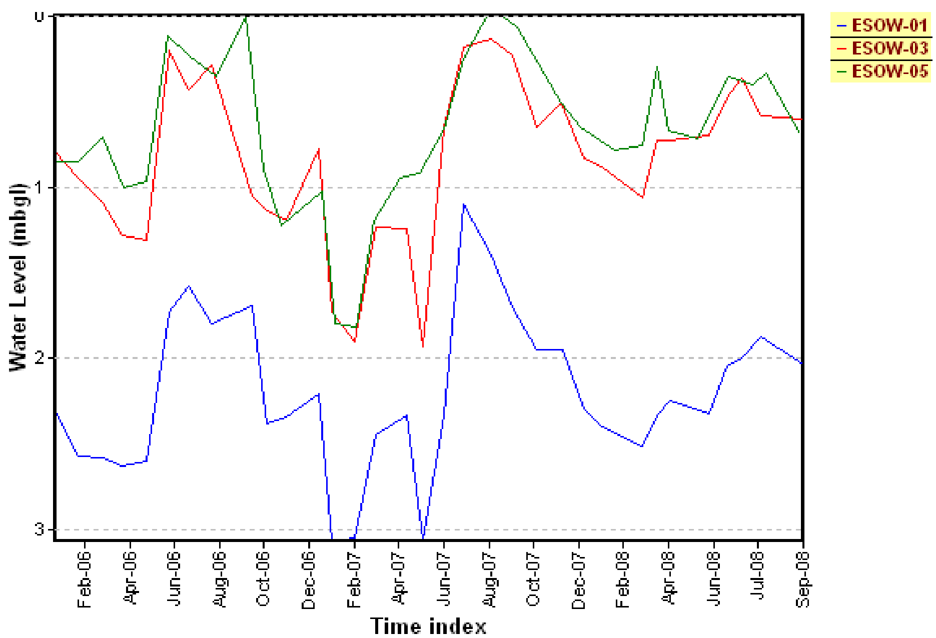


Figure 3.6

Well Hydrograph for ESOW-01, 03, 05

Rainfall data supports the above inference. For ESOW-05 Ernakulam (Ravipuram), there was no rain received during December 2006 to February 2007. As a result, the water level has gone down to its maximum depth of 1.82 mbgl during January 2007. A corresponding hike in water quality parameters were also observed during January 2007. Electrical conductivity, total hardness, sodium and chloride showed maximum values during January 2007 while pH, calcium, alkalinity, carbonates, and sulphate reached maximum values during January 2008. Similarly the maximum rainfall received during July and August 2007 (Rainfall station of IMD-Naval Air Station, Kochi) causes maximum rise up to ground level. It was observed that the pre-monsoon value of water quality parameters were comparatively lower than that of the post-monsoon period. Leaching of minerals due to rain was prominent than dilution effect in this study area.

pH of this station was above 8.5 throughout the study period. The maximum fluctuation of pH was within the range of 8.5 and 8.9. EC value varies from 440 µmho/cm (May 2008) to 770 µmho/cm (January 2007). Abnormal hike in NO_3-N concentration was observed during January 2007 and May 2007. It was also observed that the sulphate value was maximum when calcium value was maximum. Fluoride values varies from 0 to 0.78 mg/L and iron concentration ranges from 0.15 to 3.11 mg/L. Throughout the study period, the total hardness exceeds total alkalinity indicating slight permanent hardness in the water. But the difference between total hardness and total alkalinity values reaches its maximum during the drought period. The Na/Cl ratio lies between that of natural water (0.8 to 1.2) during the entire study period. The time series graph of this station showing variation in EC, TH, TA, Na and Cl is depicted in **Figure 3.7.**

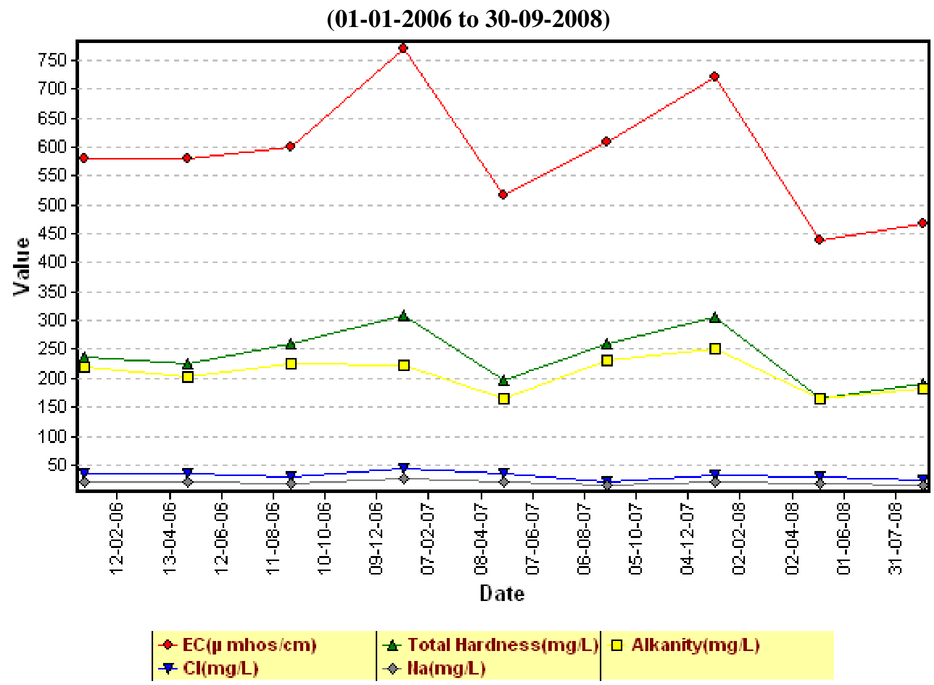


Figure 3.7

Time series plots of EC, TH, TA, Cl and Na for ESOW-05

In the case of open well at Njarakkal, ESOW-03, the rainfall data supports water level variation. In this period of maximum rise in water level, there was a corresponding dilution in water quality parameters as EC, total hardness, total alkalinity, chloride, sodium, nitrate-N, iron and fluoride. The well shows comparatively lower EC values. All other parameters except pH lies within the permissible limit of the BIS guideline values.

The well at Paravur ESOW-01 for which the water table was lowered to a maximum of 3.07 mbgl during January 2007 and 3.06 mbgl during May 2007. This is clearly supported by rainfall data. For the period from December 2006 to

February 2007, no rainfall was received in this station. But the maximum rainfall received was during June and July 2007 which raised the water level up to a maximum of 1.1mbgl during July 2007. This brought about a dilution effect in the water quality parameters. EC, TH, TA, chloride, sodium, fluoride, nitrate-N and iron had a minimum value during January 2007. On the contrary, the maximum lowering of water level during January 2007 (3.07 mbgl) reflected in water quality parameters also. Values for EC, TH, TA, chloride, sulphate, calcium and sodium were highest during January 2007. Time series graph of this station reveals that the variation in EC was almost equally contributed by TH, TA, sodium and chloride. (**Figure 3.8**). But due to the minor amount of rainfall received during April 2007, the water quality parameters shifted to slight lower values during May 2007 than values for Jan 2007.

(01-01-2006 to 30-09-2008)

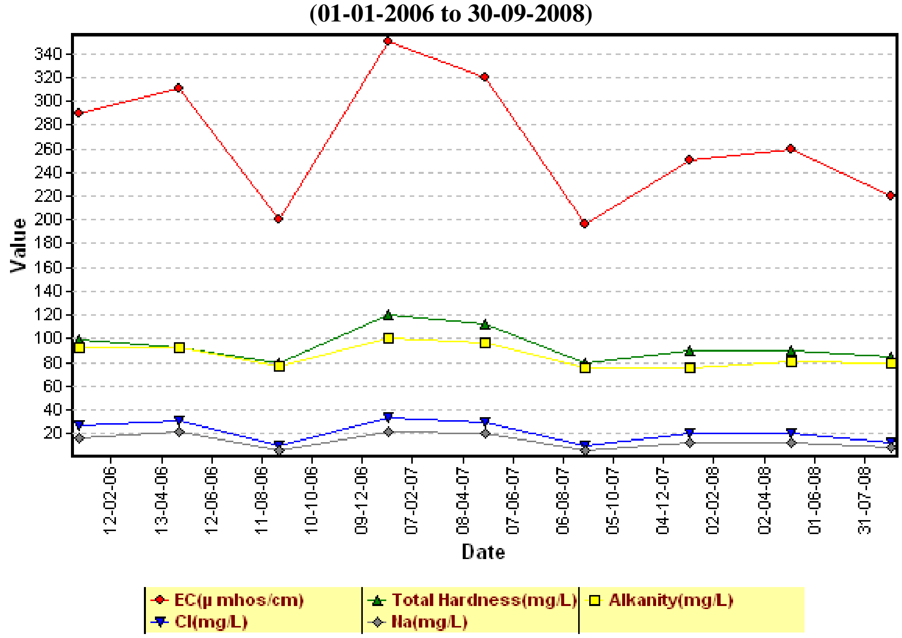


Figure 3.8

Time series plots of EC, TH, TA, Cl and Na for ESOW-01

pH value of this well varies from 7.9 to 8.5 and EC 196 (Sept 2007) to 350 (Jan 2007) µmho/cm. Total hardness exceeds total alkalinity almost throughout the study period. The pre-monsoon values are higher for total alkalinity. The Na/Cl ratio was within 0.8-1.2. It was observed that during pre-monsoon season, bicarbonate, calcium and sulphate concentrations reached its maximum. For this station, except iron, all parameters were within the drinking water permissible limit of BIS. Concentration of iron exceeds BIS permissible limit and a maximum value of 11.62 mg/L was reached during January 2007.

For the well ESOW-03, Njarakkal, the maximum water level rise of 0.13 mbgl was during August 2007 because of the maximum rainfall received in this station during July 2007**.** As a result, there was a considerable dilution in water quality parameters observed during Sept 2007 as shown by values of EC, total hardness, total alkalinity, calcium and sodium. Concentration of iron was maximum (4.7 mg/L) during the monsoon seasons. No rainfall was received during Jan 2007 to March 2007 and scanty rain fall in April 2007. As a consequence the water level has lowered to its maximum depth (1.93 mbgl) during May 2007. This was reflected in the electrical conductivity, TH, TA, carbonate, bicarbonate, nitrate-N, calcium and magnesium values. A dilution effect in concentration of water quality parameters is noticed due to the water level rise of 0.13 mbgl during Aug 2007. Maximum rainfall was received in this station (1040.7 mm) during July 2007. Observed minimum values for EC, TH, TA, HCO_3, NO_3-N, Ca, Mg, Na, and K and maximum Iron concentration during Sept 2007. It was inferred that due to the plenty of rainfall during July 2007, aquifer flushing was maximum and hence the minimum values for the water quality parameters.

The monsoon received during May to August 2008 was not as much as that in previous years of the study period and the water level fluctuation occurred was not prominent during that period. Owing to the moderate rainfall received during this period, the aquifer was getting recharged from February 2008 onwards and hence no severe drought was felt during May 2008.

For ESOW-04, 06 and 08 having high variation in water quality was observed. ESOW-05 Ernakulam (Ravipuram) and ESOW-06 Chellanam showed a pH value greater than 8.5 throughout the study period. Wells at Paravur, Njarakkal and Kumbalangi showed an EC less than 500 µmho/cm throughout the study period. Wells showing high conductivity values were prone to saline intrusion during the pre-monsoon period. Wells at Mattanchery, Edacochi and Chellanam showed prominent fluctuation in the water quality parameters. The difference between pre-monsoon and post-monsoon values were high because of the seawater intrusion into the aquifer during pre-monsoon period. The difference between total hardness and total alkalinity were also higher during this period. ESOW-06 Chellanam showed maximum water quality fluctuation during the study period.

Wells in which no saline intrusion occurred were the following: ESOW-01 Paravur, ESOW-02 Pallippuram, ESOW-03 Njarakkal, ESOW-05 Ernakulam, ESOW-07 Kumbalangi. Station ESOW-01 and ESOW-05 having almost similar trend throughout the study period. It was observed that for all the wells the total hardness exceed to that of total alkalinity. For ESOW-01 Paravur and ESOW-02

Pallippuram, the concentration of iron was less than1mg/L which lies on the maximum permissible limit of BIS. All wells except ESOW-01 (Paravur) exceeded the BIS pH limit of 8.5. ESOW-01 and ESOW-07 shows EC values within 500 µmho/cm.

3.9 HYDROGEOCHEMICAL CHARACTERISTICS OF PHREATIC CRYSTALLINE AQUIFER

Physiographically Ernakulam district is divided into 3 units viz., (1) Low lands/Coastal plains, the general elevation of which is less than 7.6 m above mean sea level (amsl), (2) midlands having general elevation between 7.6 m amsl and 76m amsl and (3) high lands having general elevation above 76 m with the maximum of 504 m amsl as in Malayattoor Reserve forest. The midland region with an area of 1218 km^2 rises gently from the coastal plain in the west to an elevation of 76 m amsl in the east. This region is covered by rugged topography comprising small flat topped low mounds and broad valleys. This region has a maximum width of about 45 km and is partly covered by laterite on the west and has exposures of crystalline rocks in the east. Aluva, Kothamangalam, Muvattupuzha, parts of Kanayannur and Kunnathunadu taluks fall under the midland region. The laterites which occupy vast area over the midland region of this district are derived due to the lateralization of the crystalline formation. This soil is well drained with low organic matter and plant nutrients. The laterites contribute a potential aquifer by virtue of its highly porous and permeable nature (CGWB 2009). The fractured rocks just below the weathered mantle of the crystalline formation also contribute potential phreatic shallow aquifer. In this zone, fractures have been developed during tectonic movements and opened up due to weathering and subsequent erosion processes. In areas where weathering and lateralization are negligible, occurrence and movement of groundwater is mainly controlled by joints and fissures in the aquifer. In the valley bottoms of undulating topography in the midland areas of the district, brown hydromorphic soil is encountered. They have been formed as a result of transportation and sedimentation of materials from adjoining hills and slopes and also through deposition by rivers. The soil is enriched in clay content. They are moderately supplied with organic matter, nitrogen and potash and deficient in lime and phosphates (CGWB 1993).

In the midland area, ground water in laterite is extensively developed by dug wells for domestic needs. Wells located in the valleys are used for irrigation to a limited extent. In some of the areas the wells are used for collecting water in tankers for city supply to flats and hotels. Unscientific water marketing is a dangerous action. Water quality analysis plays an important role in water marketing but it is being neglected due to either ignorance or due to lack of implementation of water act.

3.9a HYDROGEOLOGY OF THE AREA

Study was carried out to assess the hydro-geochemical characterization of phreatic crystalline formation of Ernakulam district during the period of 2006-2008. For this, 31 open wells were selected to assess the ground water quality. The general well information and lithology are given in **Tables 3** and **3.9a (Annexure)**

Table 3.9

General Well Information

Well ID	Tahsil/Taluk	Village	Latitude	Longitude	Geology
ECOW-01	Aluva	Aluva	10°06'45"	76°20'45"	Laterite
ECOW-02	Aluva	Ankamaly	10°11'43"	76°23'21"	Laterite
ECOW-03	Aluva	Kalady	10°10'00"	76°26'30"	Laterite
ECOW-04	Aluva	Manjapra	10°12'47"	76°27'09"	Laterite
ECOW-05	Aluva	Nedumbassery	10°10'11"	76°22'26"	Laterite
ECOW-06	Aluva	Aluva East	10°07'10"	76°23'55"	Laterite
ECOW-07	Kanayannur	Amballur	09°50'55"	76°24'15"	Laterite
ECOW-08	Kanayannur	Thiruvankulam	09°55'55"	76°23'30"	Laterite
ECOW-09	Kanayannur	Thrikkakara	10°00'56"	76°20'37"	Laterite
ECOW-10	Kothamangalam	Pothanikkadu	10°00'21"	76°40'52"	Alluvium
ECOW-11	Kothamangalam	Keerampara	10°00'52"	76°39'08"	Laterite
ECOW-12	Kothamangalam	Eramallur	10°04'08"	76°36'12"	Laterite
ECOW-13	Kothamangalam	Pindimana	10°07'40"	76°39'35"	Laterite
ECOW-14	Kothamangalam	Kuttamangalam	10°03'15"	76°42'00"	Laterite
ECOW-15	Kothamangalam	Neriyamangalam	10°03'07"	76°46'31"	Charnockite
ECOW-16	Kunnathunad	Ramamangalam	09°56'24"	76°28'53"	Laterite
ECOW-17	Kunnathunad	Vengola	10°04'55"	76°27'57"	Laterite
ECOW-18	Kunnathunad	Kunnathunadu (Pattimattom)	10°01'25"	76°27'00"	Laterite
ECOW-19	Kunnathunad	Kunnathunadu	10°00'36"	76°24'07"	Laterite
ECOW-20	Kunnathunad	Rayamangalam	10°05'45"	76°23'52"	Charnockite
ECOW-21	Kunnathunad	Kunnathunadu South	09°58'45"	76°31'00"	Charnockite
ECOW-22	Kunnathunad	Perumbavoor	10°06'53"	76°28'28"	Laterite
ECOW-23	Kunnathunad	Kizhakambalam	10°03'10"	76°23'52"	Charnockite
ECOW-24	Muvattupuzha	Piravom	09°52'15"	76°29'11"	Laterite
ECOW-25	Muvattupuzha	Elanji	09°49'51"	76°32'51"	Laterite
ECOW-26	Muvattupuzha	Koothattukulam	09°51'10"	76°35'15"	Laterite
ECOW-27	Muvattupuzha	Thirumaradi	09°54'25"	76°33'34"	Laterite
ECOW-28	Muvattupuzha	Thirumaradi	09°53'35"	76°32'22"	Laterite
ECOW-29	Muvattupuzha	Memuri	09°55'09"	76°31'15"	Laterite
ECOW-30	Muvattupuzha	Muvattupuzha	09°58'41"	76°34'52"	Alluvium
ECOW-31	Muvattupuzha	Eranellur	09°59'51"	76°37'28"	Laterite

Monthly water level variation in the phreatic crystalline formation during study period are shown in **Table 3.10 (Annexure).** The average depth to water level varies from 1.41 to 8.46 mbgl. Minimum, maximum and average water level is shown in **Table 3.11.** The depth of water table shows a wide variation on account of the distinct physiographical units in which the wells are located and undulating terrain in the midland. The thickness of aquifer also varies.

Table 3.11

Minimum, Maximum and Average Water Levels

Village	Well ID	Minimum(mbgl)	Maximum(mbgl)	Average (mbgl)
Aluva	ECOW-01	1.00	4.65	3.29
Ankamaly	ECOW-02	1.30	8.45	6.45
Kalady	ECOW-03	0.35	7.00	5.09
Manjapra	ECOW-04	0.90	4.74	3.41
Nedumbassery	ECOW-05	2.10	8.80	6.73
Aluva East	ECOW-06	5.10	7.42	6.53
Amballur	ECOW-07	3.55	9.20	7.02
Thiruvankulam	ECOW-08	2.35	6.15	4.33
Thrikkakara	ECOW-09	3.40	9.60	7.71
Pothanikkadu	ECOW-10	0.17	5.55	3.38
Keerampara	ECOW-11	0.70	3.00	1.41
Eramallur	ECOW-12	0.00	5.27	2.43
Pindimana	ECOW-13	0.00	6.52	3.19
Kuttamangalam	ECOW-14	1.30	4.30	2.81
Neriyamangalam	ECOW-15	2.29	9.20	6.29
Ramamangalam	ECOW-16	1.59	5.27	3.81
Vengola	ECOW-17	4.01	8.57	6.58
Pattimattom	ECOW-18	4.03	9.05	7.17
Kunnathunadu	ECOW-19	2.78	8.90	6.50

Rayamangalam	ECOW-20	0.63	5.38	3.60
Kunnathunadu South	ECOW-21	3.43	8.20	6.70
Perumbavoor	ECOW-22	1.70	10.05	6.94
Kizhakambalam	ECOW-23	4.90	11.13	8.24
Piravom	ECOW-24	3.99	12.63	8.46
Elanji	ECOW-25	0.12	7.90	4.54
Koothattukulam	ECOW-26	1.80	4.95	3.78
Thirumaradi	ECOW-27	2.05	5.30	3.76
Thirumaradi	ECOW-28	1.25	3.55	2.29
Memuri	ECOW-29	3.20	6.75	5.50
Muvattupuzha	ECOW-30	3.07	8.92	6.69
Eranellur	ECOW-31	3.48	8.90	5.92

Water quality monitoring were conducted during the post-monsoon (January), pre-monsoon (May) and monsoon (September) season of the study period 2006-2008 and is detailed in **Table 3.12 (Annexure).**

Most of the wells in the study area are tapping the lateritic formation. As per lithology, 6 open wells, ECOW (20 to 24) and ECOW-26 were having a clay layer after the lateritic zone. For the other two wells ECOW-10 and ECOW-30, alluvium is followed by compact soil.

Based on the values of average water levels, the wells are categorized into three types.

1. Stations for which average water level is within 2 m - 1No.
2. Station for which average water level is between 2 to 5 m - 13 Nos.
3. Station for which average water level is above 5 m - 17 Nos.

ECOW-11 Keerampara of Kothamangalam taluk comes under category I for which the maximum rise in depth to water level was 0.7m during July 2007, while the maximum drawdown occurred was 3 mbgl during January 2007. The average water level for this station was 1.41 m. This is supported by the rainfall data of Keerampara. The water table in this station was high during the study period due to the shallow depth of well drilled in a highly potential zone. Analysed the water quality data of this station. The pH varies from 7.4 to 8.1 and EC ranges from 64 (May 2007) to 157 µmhos/cm (May 2008).Total hardness showed a corresponding variation of 19 to 65 mg/L, highest value for Calcium is 15 mg/L and Bicarbonate 57.3 mg/L are shown during May 2006. For this station, Total Hardness exceeds Total Alkalinity indicating that the water is having permanent hardness. The maximum drought was noted in January 2007 during which Nitrate-N (4.34 mg/L) and Fluoride (0.98 mg/L) level reached its maximum but within the desirable limits prescribed by BIS. Even though the well is located in the laterite formation, concentration of Iron is below 0.3 mg/L; except during post-monsoon and pre-monsoon 2007 wherein it exceeds the maximum permissible limit of 1.0 mg/L.

All other parameters analysed for this station is well within the BIS maximum permissible limits of BIS. No marked effect of monsoon is observed at this station. For station ECOW-12 Eramallur, water level overflows the parapet. The maximum rainfall received in this station is 1272 mm during July 2007 and a rise up to ground level reached during June 2006 because of the continuous rainfall received during May and June 2006. For ECOW-13 Pindimana is a dug well in the catchment area of Bhoothathankettu dam, a water level rise above ground level occured during June 2006.This can be explained by the high rainfall of 731.3 mm during the second half of May 2006. Influence of the dam keeps the aquifer saturated. Hydrograph of the two stations showing water level fluctuation is given in **Figure 3.9.**

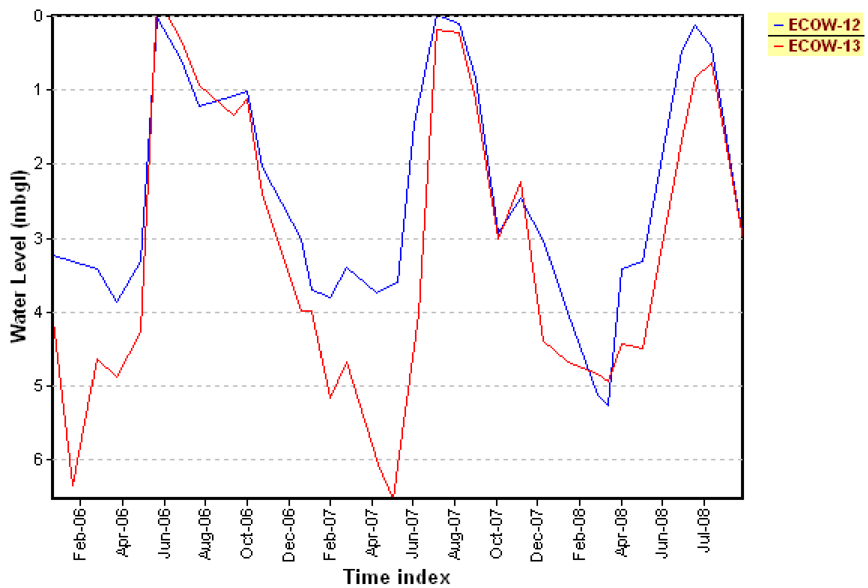


Figure 3.9

Well Hydrographs of wells ECOW-12 and ECOW-13.

A pre-monsoon hike in water quality parameters as EC, TH and TA was observed for station ECOW-12**.** Potassium concentration exceeds sodium concentration during the study period**.** All parameters except iron, for which no regular pattern of variation in concentration was observed, fall well within the range of BIS guideline values.

For ECOW-24 Piravom, the maximum draw-down occurred was 12.63 mbgl during June 2008 which is having the maximum depth to water level in the crystalline area. The average water level was 8.46 mbgl. Topsoil up to 1m, followed by laterite till 11 mbgl. A clay layer of 0.68 m thickness is the lithology. During May 2008 the depth of the well was increased further and erected concrete rings. Thereafter the water level is lowered to 12.63 mbgl. The maximum rainfall received in this station is 1417.5 mm during July 2007 but this is not reflected in the water level. The water level not showed considerable increase because of the clay content which has low permeability. Estimated the water quality of the well. It was observed that the pH of the station varies from 7.1 to 7.8 and EC from 70 to 200 μmhos/cm. Total hardness always exceeds total alkalinity which shows that the hardness is non-carbonate hardness. Hydrographs of wells ECOW-11 and ECOW-24 having average water levels of 1.41(min) and 8.46 mbgl (max), respectively are shown in **Figure 3.10**.

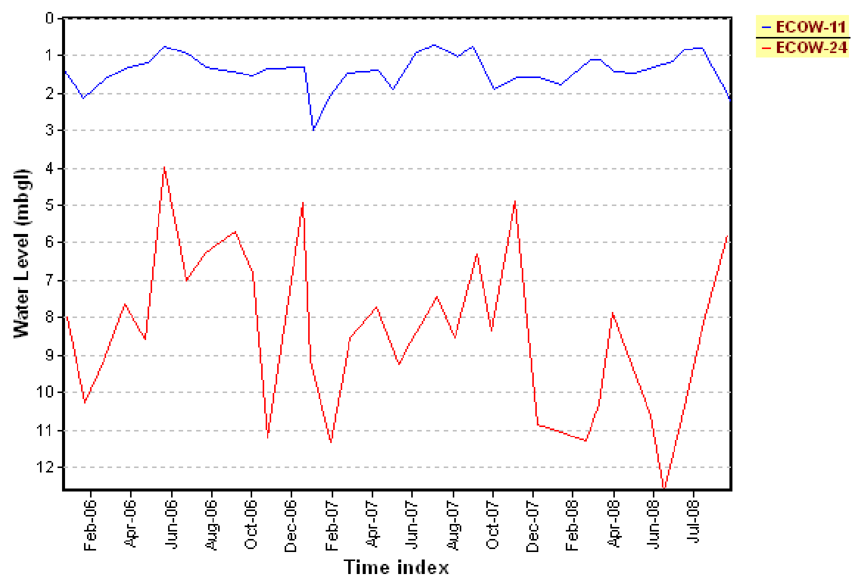


Figure 3.10

Well Hydrographs of wells ECOW-11 and ECOW-24

Among the open wells at the shallow crystalline aquifer, ECOW-08 at Thiruvankulam shows slightly higher concentrations in water quality parameters pH, K, SO_4 and Iron. pH was slightly alkaline and varies from 7.4 to 8.3. Electrical conductivity values were within the range of 280 to 500 µmhos/cm with a corresponding variation for total hardness, 60 mg/L during Sept 2008 and 170 mg/L during Jan 2007 respectively. During Jan 2007 water quality parameters pH, EC, TH, TA, CO_3, HCO_3, Cl, Ca and Mg showed maximum values. This can be explained as follows. During December 2006 no rainfall received at this station and no dilution occurred in the water quality parameters, and hence TH exceeds TA. It was observed that the chloride value in this station was comparatively higher than other wells of the shallow crystalline formations. But the corresponding sodium values were not high. Na/Cl ratio was between 0.17 and 0.88. During monsoon period, Na/Cl ratio becomes lower. Throughout the study period, the total anion exceeds total cation. Concentration of potassium lies between 14.80 to 28 mg/L which was higher than other openwells in the study area. Concentration of iron ranges up to 9 mg/L during May 2008. The concentration of iron during pre-monsoon was higher than the post-monsoon period. Iron exceeds the maximum permissible limit of BIS. The well was very near to Chottanikkara pilgrim centre and external pollution was observed in this well. The lithology of the well is 1m top soil and up to 11.5 m laterite formation.

The station ECOW-23, Kizhakkambalam shows high fluctuation in water levels during the study period. The effect of drought on water column was observed. During the month of May 2007, the draw-down in water level becomes maximum which was 11.13 mbgl during May 2007. There was no rainfall during January, February and March 2007 and very scarce rainfall obtained during April and May 2007.

pH of the station varies from 4.1(January 2008) to 5.4 (September 2006) and it is out of the permissible range of BIS. Electrical conductivity ranges from 59 (September 2007) to 155 µmhos/cm (May 2008). Total hardness exceeds total alkalinity throughout the study period. The water was acidic in all seasons. The monsoon values for nitrate-N are lower. Similar pattern of results was observed for fluoride and iron. Concentration of iron never exceeds the permissible limit of BIS.

Time series graph of electrical conductivity of two open wells in the laterite formation (ECOW-12 Eramallur and ECOW-29 Memuri) and two other open wells in the alluvium (ECOW-10 Pothanikkadu and ECOW-30 Muvattupuzha) is shown in **Figure 3.11**. It was observed that the lateritic wells showed variation in electrical conductivity in a similar manner. The wells, ECOW 10, (Periyar river passes through the eastern side) and ESOW-30 (Kaliyar passes through southern part) show different pattern of EC variation. This is due to the fact that the soil type is different. ECOW-10 is dug in alluvial soil followed by laterite while ECOW-30 dug in alluvium followed by compact soil. The general observation of the study is that two different wells near the stream /river need not show the same behavior either in quality or in quantity if the geology is different. At the same time two different wells in the laterite viewed similar pattern of change with respect to time in the case of EC, TH, Ca, and Cl.

(01-01-2006 to 30-09-2008)

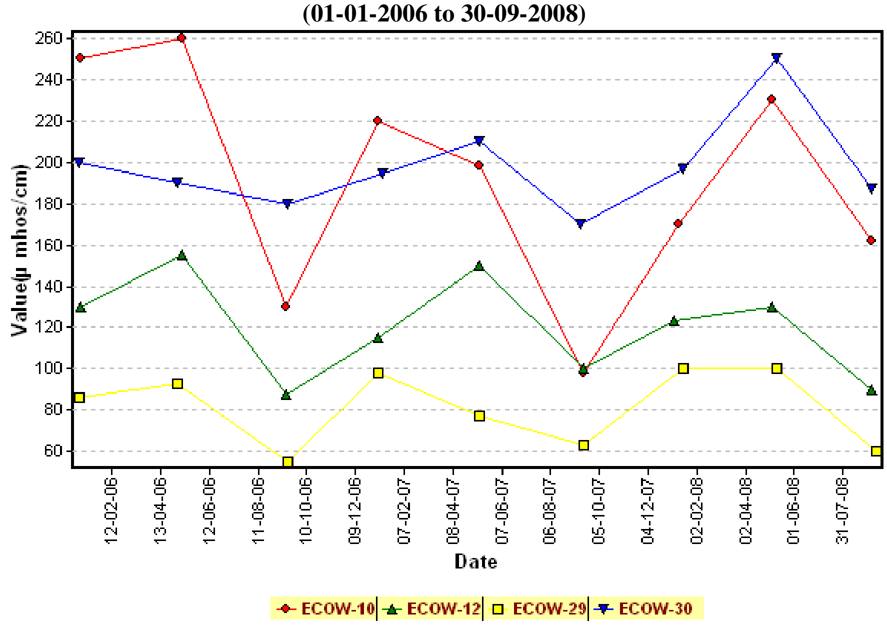


Figure 3.11

Time series plots of EC

The field observations made on three seasons have helped to determine the basic characteristics of the aquifer with reference to the seasonal variation. This study has facilitated to determine the quantity of abstraction on groundwater at the appropriate season when the water quality parameters are well within the limits. These studies can be extended for aquaculture, agriculture and water marketing.

3.10 HYDROGEOCHEMICAL CHARACTERISTICS OF DEEPER CRYSTALLINE AQUIFER

The study area covers the physiographical units of the midland region in the centre covering an area of 1218 km^2 and highlands in north-east and south-east parts occupies a small area of 64 km^2 of Ernakulam district. The general elevation of the midlands is between 7.6 and 76 m amsl. The highlands are having the general elevation above 76 m with the maximum of around 504 m above as in Malayattoor

Reserve forests. Aluva, Kothamangalam, Muvattupuzha, south-west parts of Kunnathunadu taluk and some parts of Paravoor fall in the midland area of Ernakulam district. The only high land belt of the district is Malayattoor reserve forest of Koovappady block which covers about 9% of the area of the district (CGWB 2008). The predominant soil type of the district is lateritic soil. These soils are well drained, low in organic matter and plant nutrients, brown hydromorphic soil is the second most soil type of the district and they are encountered in the valley bottom. This soil is enriched in clay content and plant nutrients. Reverine alluvium is restricted to banks of rivers and their tributaries. They are composed of sand to clayey loam and enriched with plant nutrients (CGWB 2008).

3.10a HYDROGEOLOGY OF THE AREA

Groundwater occurs under phreatic condition in weathered and fractured crystalline rocks and laterites. It occurs under semi confined to confined condition in the deep seated fractured aquifer of the crystalline rocks. The weathered zone in the crystalline below acts as good storage for groundwater. The hardrock formation in general lack primary porosity. The water is stored in the secondary pores developed as a consequence of weathering of fractures, fissures and joints. The movement of groundwater is controlled by the extent of interconnections of the fractures (CGWB 2008).

Among the 12 borewells selected for the study, 9 were tapped in the charnockite formation and 2 borewells one at Kunnukara of Paravur taluk and the other at Pindimana of Kothamangalam taluk were drilled in the gneissic formation. General well information is given in **Table 3.13**.

Table 3.13

General Information of the Wells

Well ID	Tahsil/Taluk	Village	Latitude	Longitude	Geology
ECBW-01	**Paravur**	Kunnukara	10°09'30"	76°18'10"	Gneiss
ECBW-02	**Auva**	Mookkannur ward I	10°13'15"	76°24'30"	Charnockite
ECBW-03	**Auva**	Kadungalloor	10°05'07"	76°18'25"	Charnockite
ECBW-04	**Kunnathunad**	Vadavukode	09°58'54"	76°23'20"	Charnockite
ECBW-05	**Kunnathunad**	Pattimattom	10°02'15"	76°27'10"	Charnockite
ECBW-06	**Kunnathunad**	Rayamangalam	10°05'05"	76°31'13"	Charnockite
ECBW-07	**Kunnathunad**	Vengoor	10°09'56"	76°33'04"	Charnockite
ECBW-08	**Muvattupuzha**	Muvattupuzha	10°01'58"	76°32'56"	Charnockite
ECBW-09	**Muvattupuzha**	Onakkur	09°54'15"	76°31'30"	Charnockite
ECBW-10	**Muvattupuzha**	Piravom	09°52'30"	76°27'30"	Charnockite
ECBW-11	**Kothamangalam**	Pindimana	10°07'45"	76°39'30"	Charnockite
ECBW-12	**Kothamangalam**	Neryamangalam	10°03'16"	76°46'32"	Charnockite

Systematic hydro-geochemical study was carried out for the period of January 2006 to September 2008 for 12 selected borewells of the deeper crystalline formation of Ernakulam district. The area spread into 5 taluks as Aluva, Kothamangalam, Kunnathunad, Muvattupuzha and some parts of Paravur. The description of sites with pedology and hydrogeology of the area were discussed in **Chapter II**. Lithology of the bore wells collected from GWD, Kerala (**Table 3.14 Annexure).**

ECBW-07 at Vengoor in Kunnathunadu taluk is drilled in the gneissic charnockite formation. Scrutinized the monthly water level data of these bore wells obtained from State Ground Water Department, Kerala **Table 3.15 (Annexure**). It was observed that among the 12 borewells in the study area the borewell ECBW-01 at Kunnukara, Paravur taluk tapping the gneissic formation has got a maximum rise in water level (1.85 m bgl). Minimum, maximum and average water levels are detailed in **Table 3.16**.

Table 3.16

Minimum, Maximum and Average water levels

Village	Well ID	Minimum (mbgl)	Maximum (mbgl)	Average (mbgl)
Kunnukara	ECBW-01	1.85	3.38	2.87
Mookkannur ward I	ECBW-02	2.57	7.97	6.40
Kadungalloor	ECBW-03	5.17	10.21	8.86
Vadavukode	ECBW-04	6.99	11.90	10.14
Pattimattom	ECBW-05	3.92	6.35	5.56
Rayamangalam	ECBW-06	5.37	8.80	6.57
Vengoor	ECBW-07	3.26	7.25	6.34
Muvattupuzha	ECBW-08	3.54	5.53	4.83
Onakkur	ECBW-09	3.53	4.26	3.86
Piravom	ECBW-10	5.04	6.93	6.24
Pindimana	ECBW-11	4.39	7.88	6.60
Neriyamangalam	ECBW-12	2.65	10.69	6.78

The maximum depth to which the water level was lowered was 3.38 m bgl. The average water level was 2.87 mbgl. The month of maximum rise in water level was July 2007 and maximum fall was January 2007. It was seen that availability of maximum rainfall in this station was during June and July 2007. Hence the water levels rise during July 2007. No rainfall received during December

2006 and January 2007. This substantiates the maximum drawdown of water level during January 2007.

From the lithology of the borewell ECBW-01 at Kunnukara, it was seen that up to 2 m depth from ground, lateritic soil followed by laterite up to 5 m depth bgl occurs. After that a 2 m thick clay layer of fine texture of impermeable nature, which acts as a protective barrier to the contaminants entering into the well. From 7 to 8 m depth, weathered rock with alternate biotite gneiss and fractured gneiss formation unto the drilled depth of 60 m forms the lithological set up. The alternate fractured rock zones act as potential aquifers and explain the raised water level condition of the well. Water quality data **Table 3.17(Annexure**) were supported by the water level fluctuation. pH of the station varies from 7.6 to 8.4 and electrical conductivity (EC) varies from 230 to 352 µmhos/cm.

These are well within the limits of BIS guideline values for drinking water. The maximum values for pH, EC, TH, TA, calcium and bicarbonate were observed during the pre-monsoon season. A dilution effect was observed during the monsoon season. Maximum EC value of 352 µmhos/cm was noticed during pre-monsoon of 2008 which was a drought period and minimum EC value of 230 µmhos/cm was monsoon 2007. The maximum rainfall noted in this station was during June and July 2007 and the aquifer acquired a saturated condition. Total hardness, Ca, Na and Cl showed maximum values during the pre-monsoon 2008. Total hardness, total alkalinity, Ca, Mg and bicarbonate are minimum during monsoon 2007. Nitrate-N reaches a maximum value during monsoon 2006. Concentration of fluoride ranges from 0.08 (pre-monsoon 2008) and 0.81 (post-monsoon 2006) mg/L. Higher concentration of F was noticed during post-monsoon season of the study period. Concentration of iron lies between non detectable (monsoon 2007) to 2.58 mg/L (post-monsoon 2006). Concentration of iron during monsoon season was lowest during 2006 and 2007; but this pattern was not observed during 2008.

The total hardness exceeds total alkalinity**.** The Na/Cl ratio for natural waters lies between 0.8 and 1.2 and for this location, the value was between 0.74 (pre-monsoon 2006) and 1.14 (pre-monsoon 2007). During the study period, Na and Cl concentration shows an increasing trend. No monsoon effect was noted in iron concentration because of the geological formation that contributes iron. The total cations does not differ much from total anions. An increasing trend was noted for EC , Na, K, Cl and Ca concentration while a decreasing trend for nitrate, sulphate , bicarbonate, fluoride, Fe and Mg. The trend remains the same throughout the study period in the case of total hardness. Another borewell, ECBW-11 in Pindimana of Kothamangalam taluk is tapping the gneissic formation. From the lithology, it was seen that up to 3 m depth from ground, lateritic soil followed by lateritic clay up to 6 mbgl occurs. After that weathered gneiss zone occurs at a thickness of 3 m and biotite gneiss extends up to a depth of 42.4 m. Again a weathered zone of 0.7 m thickness followed by biotite gneiss up to the drilled depth of 60 m forms the lithological set up. The alternate weathered zones act as potential aquifers and explain the raised water level condition of the well. The maximum rise in water level occurred is 4.39 mbgl during June 2006 while the maximum depth to which the water level is lowered is only 6.6 mbgl during April 2007. The average water level is 6.6 mbgl.

The maximum lowering in piezometric head was supported by the scarce rainfall received during the period of December 2006 to March 2007. Maximum rainfall in this station was during June and July 2007. pH of the station varies from 7.4 during post-monsoon 2007 to 8.2 during monsoon 2008. Electrical conductivity varies from 92 during monsoon 2007 to 170 μmhos/cm during post-monsoon 2007. These are well within the limits of BIS guideline values (6.5-8.5) for drinking water. The maximum values for EC, total hardness, Mg, Cl, SO_4, NO_3-N and iron were observed during the pre-monsoon season of 2007 and minimum value for EC, TH, Ca, Na, K, TA, HCO_3, Cl, NO_3-N, F^- and iron during the monsoon season of 2007. A dilution effect was observed during the monsoon season due to the continuous recharging of the aquifer. Water quality parameters as pH, Na, K, TA, HCO_3, SO_4, and F^- are having maximum concentrations during monsoon 2008. The total hardness always exceeds total alkalinity for this well. The Na/Cl ratio for natural waters lies between 0.8 and 1.2 and for this location, the value is between 0.55 (Jan 2007) and 1.17 (Sept 2008). An increasing trend was noted for EC, Na, K, Cl and Ca concentration while a decreasing trend for nitrate, sulphate, bicarbonate, fluoride, Fe and Mg. For total hardness, the trend remains the same throughout the study period.

The borewell at Onakkur ECBW-09, the water level fluctuation was minimum. The maximum rise occurred was 3.53 m (June 2006) and maximum draw-down occurred is 4.26 mbgl (March 2006). The level difference is within 0.73

m. Similar but lesser drought was experienced during March 2007 and March 2008 also. Very high rainfall of 810 mm was received in this station during May 2006 which is much higher than the same season of other years. This reflects in the water level to reach the maximum of 3.53 mbgl. During February 2006, no rainfall has been received and a corresponding maximum lowering occurs in water level during March 2006. The lithology of the well is as follows. Up to 7.5 m fine textured laterite followed by medium textured charnockite formation up to 32 m depth and a medium to coarse fractured zone of 0.3 m thickness followed by charnockite formation till the drilled depth of 45 m. No clay layer was seen in this aquifer**.** The aquifer act as a saturated aquifer. Hence the water level fluctuation is minimum. This well shows an alkaline character during the entire study period. pH of the station varies from 8.2-8.7. EC ranges between 270 and 360 µmho/cm. The total alkalinity exceeds total hardness throughout the study period. The sodium values are higher. The Na/Cl ratio is far above than that for natural water. It comes between the range of 3.24 to 6.93. Fluoride concentration ranges from non-detectable to 1.05 mg/L and nitrate-N concentration is less than 1 mg/L throughout the study period. The minimum pH 8.2 was shown in January 2007. It can be explained as: There was no rainfall during December 2006 and dissolution of carbonates/ leaching of CO_2 rich in water flows into the aquifer is minimum during that time causing a nil value for CO_3^- ion. The alkalinity value is minimum 105 mg/L for January 2008 and a maximum value of 154 mg/L during May 2007. Hardness was minimum during May 2006 (80 mg/L) and maximum for January 2006 and 2007 (120mg/L). The lowest value of pH 8.2 (corresponding bicarbonate concentration is 170.8 mg/L) and 8.4 (bicarbonate concentration 178 mg/L) are during January 2008 and May 2007 respectively. The concentration of iron is maximum during January 2007 (1.29 mg/L) and May 2007 (2.12 mg/L) respectively. There exist no anion-cation balance and the anion cation concentration does not match with EC values. In the study area the maximum water level lowering is noted for the borewell at Vadavukode (ECBW-04). The maximum rise in water level is 6.99 mbgl during May 2006 and a lowering up to 11.9 mbgl during May 2007. This is supported by the rainfall data of Aluva. The lithology of the well is as follows. After topsoil zone for a depth of 3 mbgl, 1.3 m thick laterite formation of fine to medium texture occurs. Thereafter at a thickness of 7.73 m clay layer which is a non permeable layer, followed by weathered charnockite formation extending up to 22.25 m. The fractured zone which is the productive potential zone starts from 20.73 to 22.25 m only. Followed by alternate charnockite and fractured charnockite of medium to coarse texture up to the drilled depth of 60 m. The water yielding capacity of the 7.73 m thick clay layer is low due to minimum porosity in this formation. The fractured charnockite will act as storage for groundwater and the quantity depends on the extent and depth with hydraulic gradient. Regarding water quality the lowest pH observed for the station is 7.6 during January 2007 and the maximum pH attained was 8.5 during May 2008. The pH remains 8.3 and above during the monsoon season. The electrical conductivity reached its maximum of 225 µmhos/cm during May 2008 and a corresponding high values for total hardness, total alkalinity, carbonate, bicarbonate and calcium. There is an increase in temporary hardness during May 2008. This is because of the dissolution of hardness contributing minerals as calcium and bicarbonates of the aquifer due to the rainfall during the previous months. The EC value recorded its minimum of 138 µmhos/cm during September 2006 and 2007. The concentration of iron is very high except during September 2007. Highest iron value reached was 7.9 mg/L during January 2006. Fluoride ranges from 0.11 (May 2007) to 0.8 mg/L (January 2008). The Na/Cl ratio ranges from 0.82 to 3.8. It is observed that even though the maximum drawdown was during May 2007, the hike in water quality parameters was during May 2008. It can be explained by the fact that the geological formation is contributing to the hike even though the water level fluctuation in the low water table well is not a contributing factor.

Another well showing similar trend is ECBW-03, Edayar. Out of the 12 bore wells, the well showing maximum fluctuation in water level is ECBW-12 Neryamangalam. The maximum rise recorded is 2.65 m while maximum drawdown is 10.69 mbgl. The difference in minimum-maximum of water level is 8.04 m. The lithology of the well is as below. Up to 3 m, fine to medium topsoil followed by fine laterite of 6 m thickness. From 6 to 9 m, there occurs a fine clay formation which is impermeable and act as a protective layer. Charnockite follows up to 12.8 m depth while the fractured charnockite is only up to 13.4 m (0.6 m thick). From 24 m up to the drilled depth of 31.5 m, pegmatite vein of medium to coarse texture occurs. It is seen that the uncased portion of the formation is from 12.8 to 31.5 m covering the upper and clayey formation. The maximum water level rise observed was 2.65 mbgl during June 2006 and the maximum water level lowering occurred was 10.69 mbgl during February 2008. Neryamangalam station receives the maximum rainfall in Ernakulam district, the rainfall being less in the western parts and an increase towards the east. This station received annual rainfall around 5883 mm (CGWB 2008). During May 2006 the total rainfall received is 751.8 mm and hence a rise of 2.65 mbgl during June 2006. While for May 2007 it is 373 mm and for May 2008 the rain fall is 282.6 mm.

The maximum rainfall received in this station is 1244 mm during July 2007. The rainfall received during previous month of June 2007 is 923.6 mm which is also high. But a corresponding rise in water level is not observed during this period. This may be due to the over pumping in the nearby borewells. Hence the fluctuation in water levels even though it is a high recharge area. pH of the station varies from 7.8 to 8.5 and EC 140-210 μmhos/cm. TH exceeds TA. Sulphate values are lesser as compared to other borewells(1-5 mg/L). Nitrate and potassium concentration also showed similar trend. Concentration of iron ranges from 0.22 to a maximum value of 4.2 mg/L. Even though significant fluctuation occurs in water levels corresponding prominent concentration changes are not observed in the water quality parameters. Being a recharge area flushing of the aquifer during the rainy season may be the reason. The borewell at Piravom showed a minimum water level fluctuation during the study period. The maximum water level lowering is 6.93 mbgl during April 2007. This can be explained by the scarcity of rainfall during the previous month of December 2006 to March 2007. The water level rise was maximum during July 2007 (5.04 m) which is well explained by the maximum rainfall received during June and July 2007. The minimum pH observed was 7.9 during September 2006 and maximum of 8.5 during September 2007. Electrical conductivity values varies from 720 µmhos/cm (September 2008) to 900 µmhos/cm (May 2008). The total hardness was much higher than the total alkalinity values during all seasons. The water comes under the category of "very hard water" except the monsoon season of 2007 and 2008. (TH> 300 mg/L as $CaCO_3$). Total cation always exceeds total anions and not obeys validation rules for normal ground water. Also the Na/Cl ratio is much lower (always<0.8) Na/Cl ratio for natural ground water should be between 0.8 and 1.2. The low ratio is because of the high chloride concentration. Increased concentration of sulphate and chloride contribute permanent hardness to this water. During May 2008, the well showed the maximum values for bicarbonate, chloride and sodium. Flouride ranges from non-detectatable (September 2007) to 0.74 mg/L (January 2006) and concentration Iron is maximum (2.54 mg/L during May 2007). Lithology of the well is given in Table 3.14. Up to 10 m depth, fine textured topsoil and laterite followed by medium grained weathered rock until 20 m depth from 20 m to 65 m depth grayish charnockite formation followed by fractured charnockite of only 0.7m thickness and finally up to the drilled depth of 72 m, grayish charnockite formation of fine texture occurs. The piezometric head is not much affected by monsoon. Among the 12 bore wells, ECBW-04 Vadavukode shows a maximum average water level.

From the hydro-geochemical studies, the following findings were obtained:

Water is alkaline in nature in the shallow sedimentary area. The minimum pH occurred is 7.8 in ESOW-01 at Kunnukara of Paravur taluk and maximum pH of 8.9 is observed in ESOW-06 at Chellanam. The high pH is mainly due to the carbonates and bicarbonates.

In the phreatic crystalline formation almost all wells showed a pH well within the permissible limit of BIS, with few exceptions as ECOW-23 Kizhakkambalam for which minimum pH is 4.1. In the case of deeper crystalline formation the minimum pH observed is 7.1 (ECOW-01, Kunnukara) and maximum of 8.8 is shown by ECOW-02, Mookkannoor, Ward-1). The high pH is due to the carbonates and bicarbonates associated with sodium (ECOW-09, ECOW-05) were also showed a high bicarbonate concentration and hence high pH.

Wells in the shallow sedimentary formation shows very high temporal and spatial variation in EC values. Values ranges from 196 (ESOW-01) to 7460 µmhos/cm (ESOW-06). The high EC values where contributed mainly by ions causing alkalinity and hardness. For locations were saline intrusion were occurred sodium and chloride also contributes a greater extent. Stations like ESOW-04 and 08 also show a high EC values above 750 µmhos/cm.

In the phreatic crystalline area, the minimum EC of 38 µmhos/cm was shown by ECOW-15 at Neryamangalam, which is the high recharge area due to the maximum rain fall. ECOW-09, 13,25 21,27,29 and 31 are some stations of low EC values. The maximum value of EC 500 µmhos/cm is shown by ECOW-08, Thiruvankulam. Both temporary and permanent hardness, alkalinity, sodium, chloride ions contributes to high EC value .

In deeper crystalline formation the lowest value of EC (92 µmhos/cm) was shown by ECBW-11 Pindimana. The maximum EC of 900 µmhos/cm was shown by ECBW-10 Piravom due to the permanent hardness and high chloride. The high EC in ECBW-02 and 05 is due to the high carbonate and bicarbonate concentration, whereas in stations ECBW-07 and 09 high hardness causing ions contribute to high EC.

Concentration of iron ranges from 0.11 to 11.62 mg/L (ESOW-01, Paravur) of sedimentary area, 0 to 9 mg/L (ECOW-08, Thiruvankulam) of phreatic crystalline and non-detectable to 8.57 mg/L in (ECBW-05, Pattimattom) of deeper crystalline formation. 60% of the stations in the sedimentary and 50% of the stations in the phreatic crystalline formations are having iron concentration above 1.0 mg/L whereas all the deeper crystalline formation are having a concentration of Iron greater than 1.0 mg/L

From the hydro-geochemical studies of the sedimentary and the crystalline, it is revealed that the water quality status of crystalline phreatic formation was much better than the sedimentary formation.

Chapter - IV

CLASSIFICATION-WATER TYPE-MAPPING

4.1 Geochemical Characterization of Groundwater of the Study Area.

4.2 Graphical Representation of Major Ion Concentration

4.3 Water Quality Assessment for Irrigation Purpose

- 4.3a Salinity
- 4.3b Sodium Adsorption Ratio
- 4.3c Percent Sodium
- 4.3d Residual Sodium Carbonate
- 4.3e Kelly's Ratio
- 4.3f Chloride - Bicarbonate Ratio of Groundwater

4.4 Assessment of Irrigation Quality

- 4.4a Percent Sodium
- 4.4b Residual Sodium Carbonate
- 4.4c Sodium Adsorption Ratio
- 4.4d Residual Mg / Ca Ratio
- 4.4e Kelly's Ratio

4.5 Mapping of Selected water quality parameters

Chapter - IV
CLASSIFICATION-WATER TYPE-MAPPING

4.1 GEOCHEMICAL CHARACTERIZATION OF GROUNDWATER IN THE STUDY AREA

The observation points chosen for the study was 39 open wells (31 Nos. in the crystalline area and 8 Nos. in the sedimentary area) and 12 bore wells in the deeper crystalline formation. The major ion composition is used to classify groundwater into various types. Hence to assess the water type of the study area, samples were analysed for major ions in epm (equivalent per million). Water type classification was done using AQUACHEM 6.0 software. The quality of groundwater can be classified into various hydro-geochemical facies, on the basis of geochemical parameters, which explains the distribution and genesis of principal groundwater types along the water flow paths taking the ionic percentage in the relative decreasing order of their abundances (CWRDM 2009). Ions less than 5% of the total concentration are neglected. The groundwater types derived from the data for sedimentary area, phreatic crystalline area and deeper crystalline formation during pre-monsoon, monsoon and post-monsoon seasons of 2007 are given in **Tables 4.1, 4.2** and **4.3**, respectively.

Table 4.1

Water type of open wells in sedimentary area during Pre-monsoon, Monsoon and Post-monsoon 2007

Well ID	Location	PRE-MONSOON	MONSOON	POST-MONSOON
ESOW-01	Paravoor	Ca-Na-Mg-HCO_3-Cl	Ca-Mg-HCO_3	Ca-Na-HCO_3-Cl
ESOW-02	Pallippuram	Ca-Mg-HCO_3	Ca-Mg-HCO_3	Ca-Mg-HCO_3-CO_3
ESOW-03	Njarakkal	Ca-Mg-HCO_3	Ca-Mg-HCO_3	Ca-Mg-HCO_3
ESOW-04	Mattanchery	Ca-Mg-HCO_3	Ca-Mg-HCO_3	Na-Ca-Cl
ESOW-05	Ernakulam	Ca-Mg-HCO_3-Cl	Ca-Mg-HCO_3	Ca-Mg-HCO_3
ESOW-06	Chellanam	Na-Cl	Na-Cl-HCO_3	Na-Cl
ESOW-07	Kumbalangi	Ca-Na-HCO_3-Cl	Ca-Mg-HCO_3	Ca-Mg-HCO_3
ESOW-08	Edacochin	Na-Cl	Ca-Mg-HCO_3	Na-Ca-Mg-Cl-HCO_3

It is observed that the dominant form of water type during the three seasons of 2007 in the sedimentary area is Ca-Mg-HCO_3. For station ESOW-03 at Njarakkal, the ground water type remains the same in the pre-monsoon, monsoon and post-monsoon seasons of 2007. The source of Ca-Mg-HCO_3 is generally calcareous sedimentary rocks such as calcite, dolomite, or magnesite (CWRDM, 2009).

Table 4.2

Water type of open wells in crystalline area during Pre-monsoon, Monsoon and Post-monsoon 2007

Well ID	Location	PRE-MONSOON	MONSOON	POST-MONSOON
ECOW-01	Aluva	Ca-Mg-HCO_3	Ca-Mg-HCO_3	Ca-Mg-HCO_3
ECOW-02	Angamaly	Na-Ca-Mg-Cl-NO_3-HCO_3	Na-Ca-Mg-Cl-NO_3	Na-Ca-Mg-Cl-HCO_3
ECOW-03	Kalady	Ca-Na-Mg-HCO_3-Cl	Na-Ca-Mg-Cl-HCO_3	Ca-Na-Mg-HCO_3-Cl
ECOW-04	Manjapra	Ca-Na-Mg-Cl-HCO_3	Na-Ca-Cl-HCO_3	Ca-Mg-Na-Cl-NO_3
ECOW-05	Nedumbassery	Na-Ca-HCO_3-Cl	Na-Ca-Mg-Cl-NO_3	Na-Ca-Mg-Cl
ECOW-06	Aluva East	Ca-Mg-Na-HCO_3-Cl	Ca-Na-Mg-HCO_3	Ca-Na-Mg-HCO_3
ECOW-07	Amballoor	Ca-Mg-HCO_3	Na-Ca-Cl	Ca-Mg-HCO_3
ECOW-08	Thiruvankulam	Ca-Mg-Cl-HCO_3	Ca-Na-Mg-Cl-HCO_3	Ca-Mg-Cl-HCO_3
ECOW-09	Trikkakkara	Ca-Na-Mg-Cl-HCO_3	Na-Ca-Cl-NO_3	Ca-Na-Mg-Cl-HCO_3
ECOW-10	Pothanikkad	Ca-Na-Mg-Cl-HCO_3	Na-Ca-Cl-HCO_3-NO_3	Ca-Na-Mg-Cl-HCO_3-NO_3
ECOW-11	Keerampara	Ca-Na-Mg-HCO_3-Cl-NO_3	Ca-Mg-Na-HCO_3-Cl	Ca-Mg-HCO_3-NO_3-Cl
ECOW-12	Eramalloor	Ca-Mg-HCO_3	Ca-Mg-HCO_3	Ca-Mg-HCO_3-Cl
ECOW-13	Pindimana	Ca-Mg-Na-HCO_3-Cl	Ca-Mg-Na-HCO_3-Cl-SO_4	Na-Ca-Mg-NO_3-Cl-HCO_3
ECOW-14	Kuttamangalam	Ca-Mg-HCO_3-Cl-NO_3	Ca-Na-K-Mg-Cl-HCO_3-SO_4	Ca-Na-Mg-K-Cl
ECOW-15	Neryamangalam	Ca-Na-Mg-HCO_3-Cl	Na-Ca-Mg-Cl-HCO_3	Ca-Mg-Na-Cl-HCO_3
ECOW-16	Ramamangalam	Na-Ca-Mg-Cl-HCO_3-NO_3	Na-Ca-Cl-NO_3-HCO_3	Ca-Mg-Na-HCO_3-Cl
ECOW-17	Vengola	Ca-Mg-Na-HCO_3-NO_3	Ca-Mg-Na-HCO_3-Cl	Ca-Mg-HCO_3
ECOW-18	Kunnathunad	Na-Ca-Cl-HCO_3	Na-Ca-Cl-NO_3	Na-Ca-Cl-HCO_3-NO_3
ECOW-19	Kunnathunad	Ca-Na-Mg-Cl	Na-Ca-Mg-Cl-NO_3	Ca-Na-Mg-HCO_3-Cl
ECOW-20	Rayamangalam	Ca-Na-Mg-NO_3-Cl-HCO_3	Na-Ca-Cl-NO_3-HCO_3	Ca-Mg-Na-HCO_3-Cl
ECOW-21	Kunnathunad South	Ca-Na-NO3-Cl-HCO_3	Ca-Na-Mg-Cl-NO_3-HCO_3	Ca-Na-Mg-Cl-HCO_3-NO_3
ECOW-22	Perumbavur	Ca-Na-Mg-HCO3-NO_3-Cl	Na-Ca-Mg-Cl-HCO_3	Na-Ca-NO_3-Cl
ECOW-23	Kizhakkambalam	Na-Ca-Mg-Cl-NO_3	Na-Cl-NO_3	Na-Ca-Mg-Cl-NO_3
ECOW-24	Piravom	Ca-Na-Mg-Cl-NO_3-HCO_3-SO_4	Ca-Na-Mg-Cl-NO_3-HCO_3	Ca-Mg-Na-Cl-HCO_3
ECOW-25	Elanji	Na-Ca-Cl-HCO_3	Ca-Na-Mg-Cl-HCO_3	Na-Ca-Cl-HCO_3
ECOW-26	Kuthattukulam	Ca-Na-Mg-Cl-HCO_3	Ca-Na-K-Mg-Cl-HCO_3-NO_3	Ca-Na-Mg-Cl-HCO_3
ECOW-27	Thirumaradi	Ca-Na-Mg-Cl-HCO_3	Na-Ca-HCO_3-Cl	Ca-Mg-HCO_3-Cl
ECOW-28	Thirumaradi	Na-Ca-HCO_3-Cl	Ca-Na-Mg-HCO_3-Cl	Na-Ca-Cl-HCO_3
ECOW-29	Memuri	Ca-Na-Mg-HCO_3-Cl	Ca-HCO_3-Cl	Ca-Mg-Cl-HCO_3
ECOW-30	Muvattupuzha	Na-Ca-Cl-HCO_3	Na-Ca-Mg-Cl-HCO_3-SO_4	Ca-Na-Mg-Cl-NO_3-HCO_3
ECOW-31	Eranellur	Ca-Na-Mg-HCO_3-Cl	Na-Ca-Cl-HCO_3	Na-Ca-Mg-Cl-HCO_3

It is observed that a major grouping is not possible as it contains different water types for each observation stations. This may be due to different dilution and ion liberating effect of the aquifer. For station at Aluva ECOW-01 the ground water type remains the same in all the three seasons.

Table 4.3

Water type of bore wells in deeper crystalline aquifer during Pre-monsoon, Monsoon and Post-monsoon 2007

Well ID	Location	PRE-MONSOON	MONSOON	POST-MONSOON
ECBW-01	Kunnukara	Na-Ca-HCO_3-Cl	Na-Ca-Cl-HCO_3	Na-Ca-Cl-HCO_3
ECBW-02	Mookkannoor Ward - I	Na-HCO_3	Na-HCO_3	Na-HCO_3
ECBW-03	Kadungalloor (Edayar)	Ca-Na-Mg-HCO_3	Ca-Mg-Na-HCO3	Ca-Na-Mg-HCO_3-Cl
ECBW-04	Vadavukode	Ca-Mg-Na-HCO_3	Ca-Na-Mg-HCO_3	Ca-Na-Mg-HCO_3
ECBW-05	Pattimattom	Ca-Mg-Na-HCO_3	Ca-Mg-Na-HCO_3	Ca-Na-Mg-HCO_3-CO_3
ECBW-06	Rayamangalam	Ca-Mg-HCO_3-Cl	Ca-Mg-HCO_3-Cl	Ca-Mg-HCO_3-Cl
ECBW-07	Vengoor	Ca-Mg-HCO_3-SO_4	Ca-Mg-HCO_3	Ca-Mg-HCO_3-SO_4
ECBW-08	Muvattupuzha	Ca-Mg-HCO_3	Ca-Mg-Na-HCO_3-Cl	Ca-Mg-HCO_3-Cl
ECBW-09	Onakkur	Ca-Na-Mg-HCO_3	Na-Ca-Mg-HCO_3	Ca-Na-Mg-HCO_3
ECBW-10	Piravom	Ca-Mg-Na-Cl	Ca-Mg-Na-Cl-HCO_3	Ca-Mg-Na-Cl
ECBW-11	Pindimana	Ca-Mg-HCO_3	Ca-Mg-HCO_3-SO_4	Ca-Mg-HCO_3-SO_4
ECBW-12	Neryamangalam	Ca-Mg-HCO_3	Ca-Mg-HCO_3-Cl	Ca-Mg-HCO_3

In deeper crystalline formation of the study area, for bore wells ECBW-02 Mookkannoor Ward-1 and for ECBW-06 Rayamangalam the water types are Na-HCO_3 and Ca-Mg-HCO_3-Cl respectively and it remains unchanged during the three seasons. The above observation shows that these two wells are not affected by the precipitation. It can reason out for a) pocketed entrapped groundwater aquifer which does not react with the precipitation; b) there is no possibility of any dilution or concentration for this aquifer. All other wells show different water types during different seasons. The above classification indicates that the water quality parameter has direct relation with the precipitation and seasonal changes, i.e., pre-monsoon parameter and water type are different from monsoon and post-monsoon parameters. Its explanation is provided below.

The nature of groundwater is related to the soluble products of rock weathering, soil, decomposition and changes with respect to precipitation, time and space. The concentration of ions in water depends upon the nature of rock mineral, its solubility and weatherability in fresh or carbonated water (due to dissolution of atmospheric carbon dioxide in rain water, i.e., pH dependent),climate and local topography. The main rock minerals forming the earth's surface are oxides of Silica(quartz), Aluminium, Iron (Magnetite), Sulphides (Chlorite and Pyrites), Carbonates (Magnesite and Dolomite) etc. These minerals on weathered character release simple radicals or ions such as Na, K, Ca, Mg, HCO_3, SO_4, NO_3, PO_4^{3-},H^+, Cl^-, etc. A mineral in contact with ground water represents a geochemical system consisting of solid phase and solution phase. If the solution does not initially contain any of the minerals, an inequilibrium exists between the phases and some of the minerals will dissolve to provide their component to the solution (CWRDM, 2009).

It is thus inferred that in an unpolluted environment groundwater quality can be correlated with the minerals present in the bed rock or aquifer. A very significant inference of this study is that the quality of bed rock or aquifer can be determined to some extent by interpreting the water type of phreatic crystalline/deeper aquifers. The source of Ca-Mg-HCO_3 is generally calcarious sedimentary rocks such as Calcite, Dolomite or Magnesite. Weathering of igneous silicate rocks may also be responsible for the water type because it introduces appreciate concentration of Ca, Mg and Na. Some inland rocks could be responsible for the contribution of NaCl to the groundwater. The case of ESOW-06, Chellanam is different, as it is near to sea with saline water intrusion.

This study establishes the fact that not only the water level is affected by the seasonal change but also the water quality. Micro-level studies can realize the extent of inter relation between the precipitation and the water type. Much scope for such studies is emphasized in future in problematic areas.

4.2 GRAPHICAL REPRESENTATION OF MAJOR ION CONCENTRATION

The composition of dominant ions can be displayed graphically by several methods. A more useful summary presentation used in this study is the Piper-Hill diagram (Piper 1944). It is used to infer hydrogeochemical facies. On this diagram the relative concentrations of the major ions in percent meq/L are plotted on cation and anion triangles. The cation and anion fields are combined to show a single point in a diamond shaped field, from which inference is drawn on the basis of hydrogeochemical facies concept. The tri linear diagrams are useful in bringing out chemical relationships among ground water samples in more definite terms rather than with other possible plotting methods (Avin et al. 2002, Laluraj et al. 2005, Rajendra Prasad et al. 2009, Ravikumar et al. 2010, Ravikumar and

Somashekar 2010). The concept of hydrochemical facies was developed in order to understand and identify the water composition in different classes. Facies are recognizable parts of different characters belonging to any genetically related system. Hydrochemical facies are distinct zones that possess cation and anion categories. The evolution of water and relationship between rock types and water composition can be evaluated by the Piper Trilinear diagram. The trends in water quality variations can also be brought out by this diagram (**Figure 4.1**).

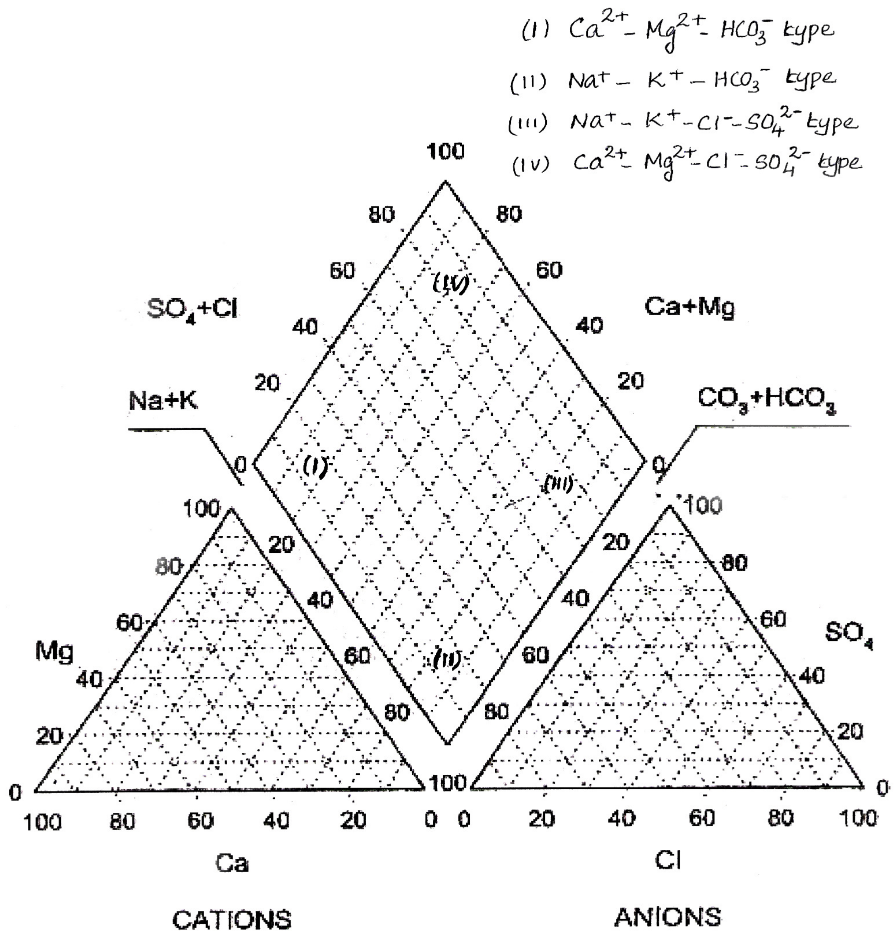


Figure 4.1

Piper-Hill diagram

Piper plots for the sedimentary phreatic crystalline, and deeper crystalline formation were plotted for pre-monsoon, monsoon and post-monsoon seasons of 2007 (**Figure 4.2** to **4.10**).

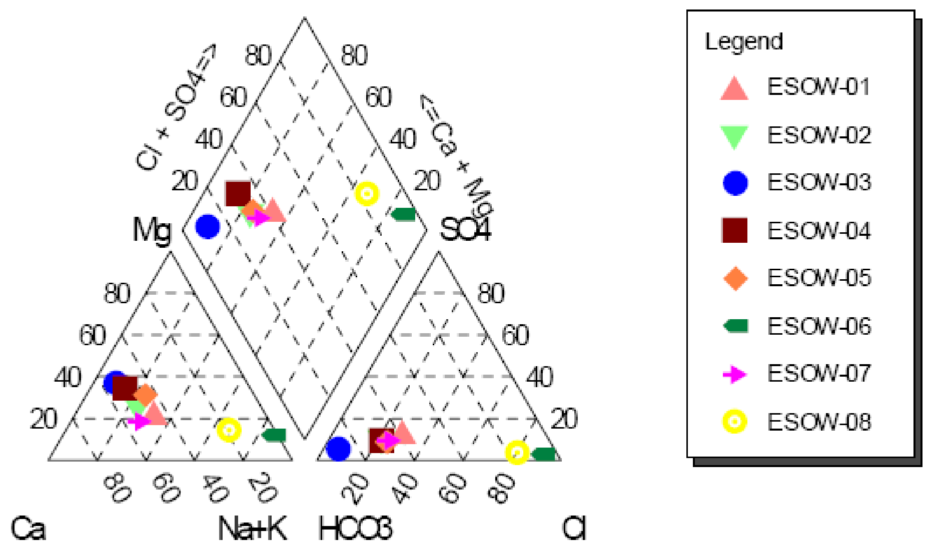


Figure 4.2
Piper Plot for the Shallow Sedimentary Area (Pre-monsoon 2007)

In the study it is observed that almost all samples fall under Type I (Ca-Mg-HCO_3) except two open wells ESOW-06 (Chellanam) and ESOW-08 (Edakochi) which fall under Type III (Na-K-Cl-SO_4).Typical sea water intrusion is a possibility and hence for future groundwater development such areas are unsuitable. ESOW-08 (Edakochi) which falls under Type-III. The shift of the well is not a typical one as in the case of ESOW-06.

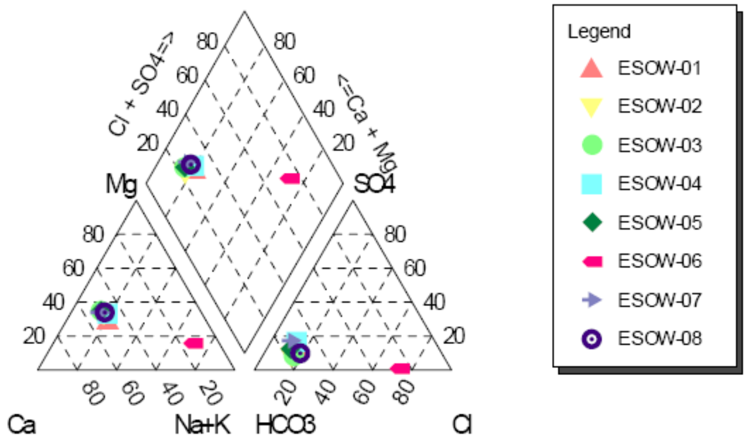


Figure 4.3

Piper Plot for the Shallow Sedimentary Area (Monsoon 2007)

All wells are under type1 except ESOW-06 (Chellanam) which falls under Type III. The reason being that it is a typical coastal well. ESOW-08 (Edakochi) which fall under Type III (Na-K-Cl-SO_4), changed to Type I due to the effect of monsoon.

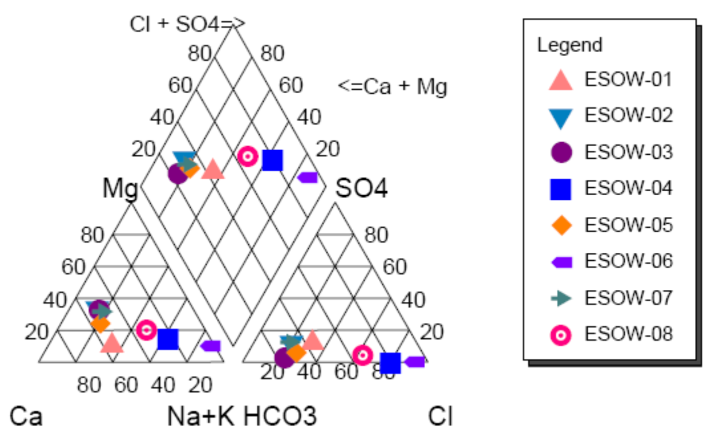


Figure 4.4

Piper Plot for the Shallow Sedimentary Area (Post-monsoon 2007)

In this case, ESOW-06 (Chellanam) remains in Type III. ESOW-04 has shifted from Type-I to Type-III. ESOW-08 has shifted from type III to mixed type shows the effect of saline water intrusion and dilution effect due to monsoon. In ESOW-08 (Edakochi), a corresponding decrease in the values of TH, Ca, Mg, Na, K, Cl and SO_4 was noted and clearly establishes the inter relationship of the parameters with respect to seasonal change i.e., precipitation effect.

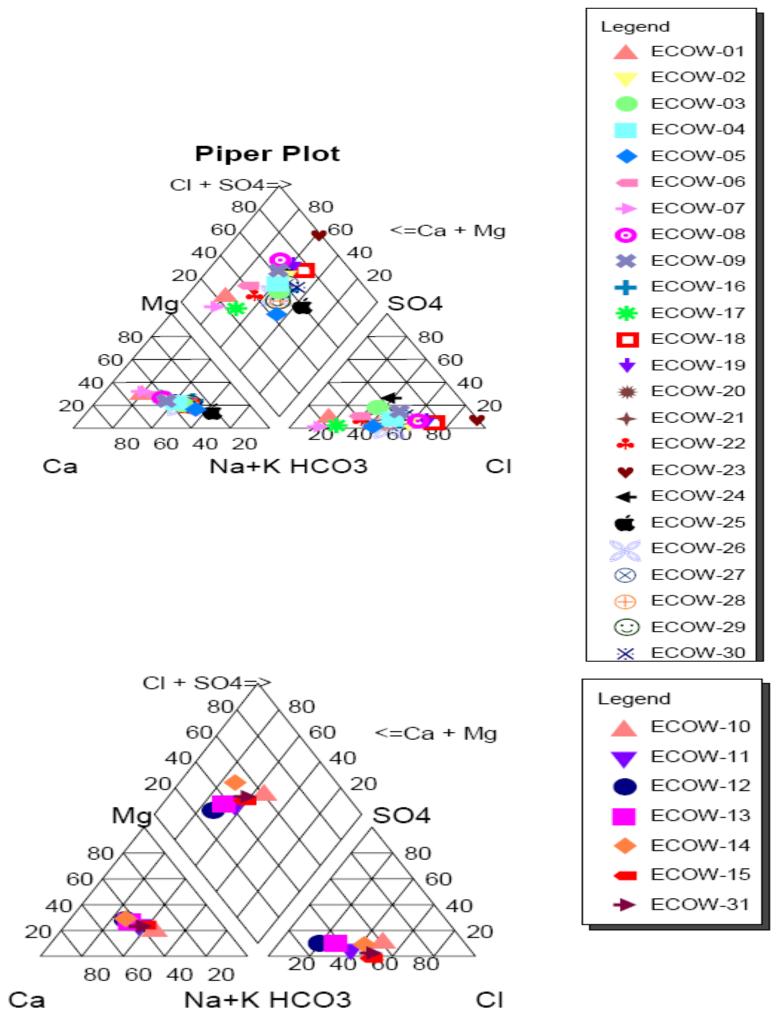


Figure 4.5

Piper plot for the Phreatic Crystalline Area (pre-monsoon 2007)

The following are the observations.

The six wells ECOW-01, ECOW-07, ECOW-11, ECOW-12, ECOW-13 and ECOW-17 belongs to Type-I. (Aluva, Amballoor, Keerampara, Eramalloor, Pindimana, Vengola). Other stations come under mixed type water.

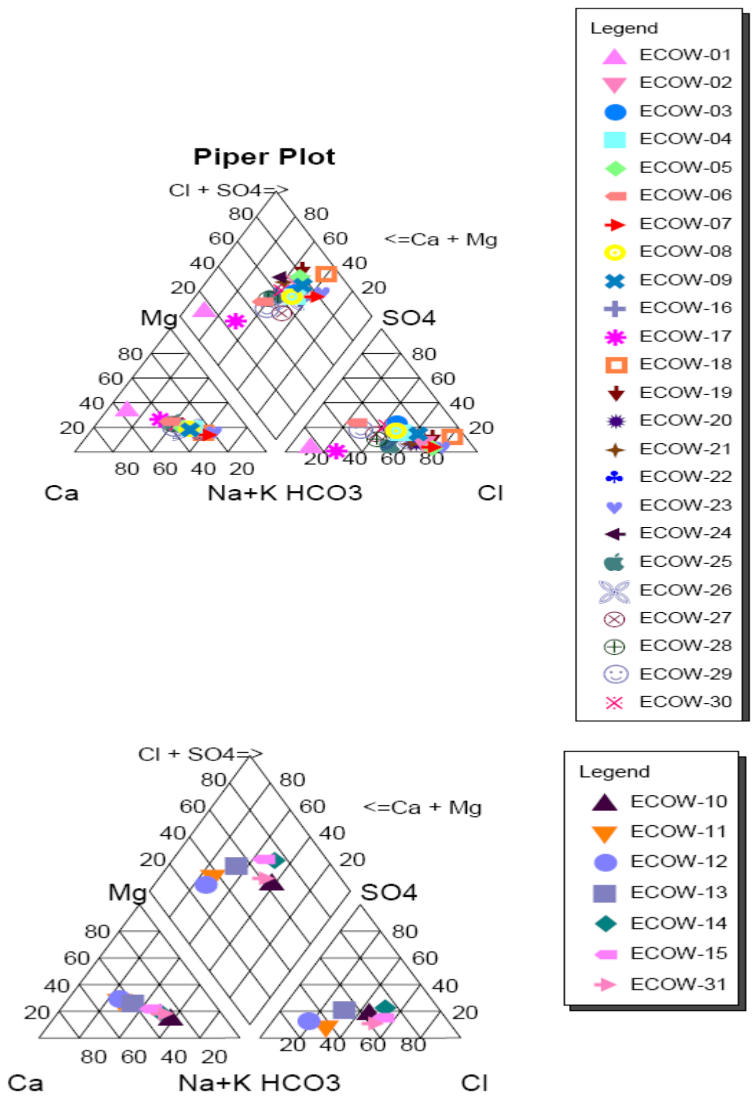


Figure 4.6

Piper Plot for the Phreatic Crystalline Area (Monsoon 2007)

The monsoon data were also plotted. It was observed that the wells ECOW-01 Aluva, ECOW-17 Vengola, ECOW-11 Keerampara, ECOW-12 Eramalloor come under Type I. Two wells ECOW-18 Kunnathunadu and ECOW-19 Pattimattom comes under Type III and all others are classified as mixed type.

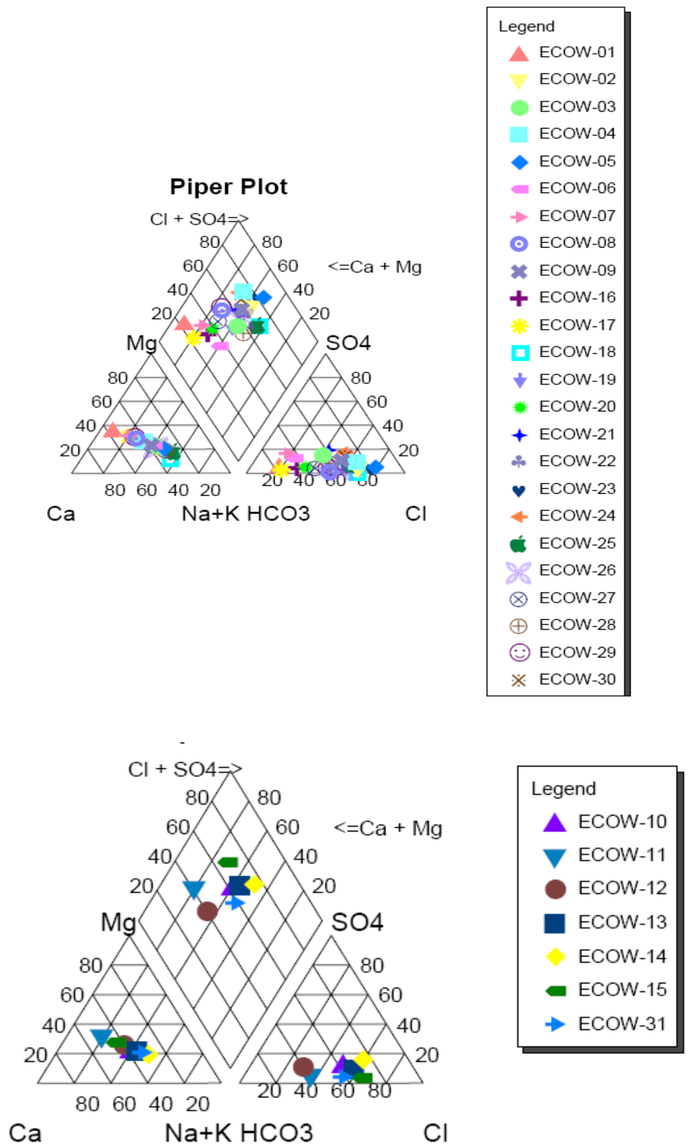


Figure 4.7

Piper Plot for the Phreatic Crystalline Area (Post-monsoon 2007)

The post-monsoon results show that ECOW-01 Aluva, ECOW-07 Amballoor, ECOW-11 Keerampara, ECOW-12 Eramalloor, ECOW-16 Ramamangalam and ECOW-17 Vengola are in Type I. Only one well ECOW-05 Nedumbasserry is under Type III. ECOW-04 Manjapra, ECOW-15 Neryamangalam, ECOW-23 Kizhakkambalam, ECOW- 24 Piravom belong to Type IV.

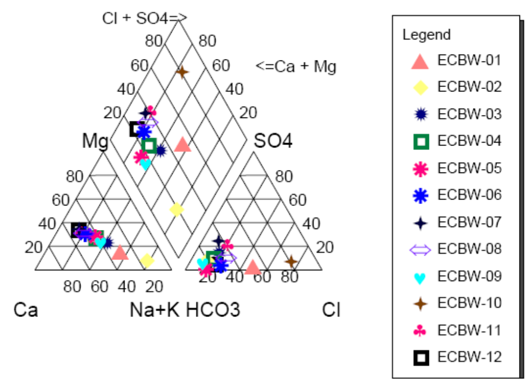


Figure 4.8

Piper Plot for the Deeper Crystalline formation (Pre-monsoon 2007)

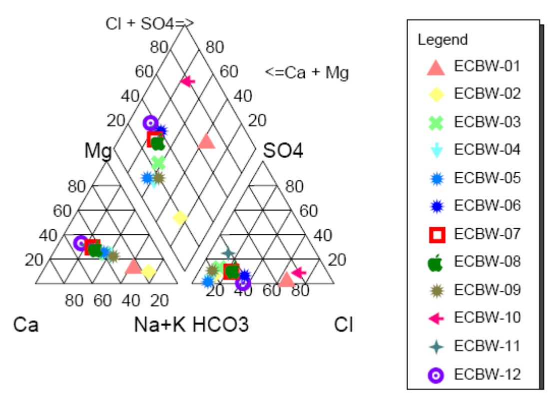


Figure 4.9

Piper Plot for the Deeper Crystalline Formation (Monsoon 2007)

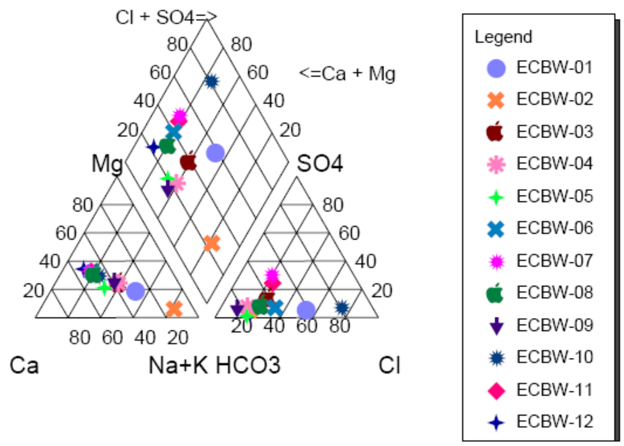


Figure 4.10

Piper Plot for the Deeper Crystalline Formation (Post-monsoon 2007)

All the bore wells selected in the crystalline formation have been classified based on major ions. It is observed that (ECBW-02) Mookkannoor comes under Type II and ECBW-10 Piravom comes under Type IV during pre-monsoon, monsoon and post-monsoon periods. The above observation shows that these two wells are not affected by the precipitation. It can reason out for a) pocketed entrapped groundwater aquifer which does not react with the precipitation; b) One more reason may be that there is no possibility of any dilution or concentration for its aquifer. ECBW-01 remains in the mixed type facies during pre-monsoon and monsoon but changed to Type II in post-monsoon. The well is a high yielding and all types of dilution effects are possible. This observation can be further used for deciding production wells in that area for drinking water supply. Economic structures are possible so as to survive the drought situations. A few production wells in that area can act as storage to overcome the dry seasons. All other wells are under Type I during monsoon, pre-monsoon and post-monsoon period. All other observation stations fall under Type I.

4.3 WATER QUALITY ASSESSMENT FOR IRRIGATION PURPOSE

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. A good quality water has the potential to cause maximum yield under good soil and water management practices. However, the quality of irrigation water depends primarily on its silt and salt content. Water used for irrigation always contains measurable quantities of dissolved substances, called salts. They include relatively small but significant amounts of dissolved solids originating from dissolution or weathering of the rocks and soils, lime, gypsum and other salt sources as water passes over or percolates through them. Whatever may be the source of irrigation water, viz, river, canal ,tank, open well or tube well, some soluble salts are always dissolved in it. The nature and quality of dissolved salts depends upon the source of water and its course before use and determine the quality of irrigation water. No problems affecting productivity when good quality water used. However, with poor quality water, various soil and cropping problems can be expected to develop. Special management practices may then be required to maintain full crop productivity. Of the several factors influencing irrigation water quality, the generally accepted criteria for judging the quality are:

4.3a Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discolouration and even leaf burns at margin or top.

4.3b Sodium Adsorption Ratio (SAR)

Soils containing a large proportion of sodium, with carbonate as the predominant anion are termed alkali soils. Soils with chloride or sulphate as the predominant anion are termed saline soils. Ordinarily, either type of sodium-saturated soil will support little or no plant growth. The Sodium Adsorption Ratio (SAR) is one common water quality index indicating sodium content and the suitability of water for irrigation.

The SAR is calculated from the major ions in water as:

$$SAR = \frac{Na^{+}}{\sqrt{\left(Ca^{2+} + Mg^{2+}\right)/2}}$$

where all the concentrations are in milliequivalents per liter.

The suitability of the water for irrigation decreases with increasing SAR value. Specifically, the sodium reacts with the soil and reduce its permeability. In international standards, the following classification scale is used.

- SAR < 3 : Suitable for irrigation
- SAR = 3 - 9 : Use may be restricted
- SAR > 9 : Unsuitable for irrigation

However in India, higher values of SAR are tolerated, because the annual flushing from monsoon rains prevents sodium accumulation in the soils. The following classifications are used (Ghosh and Sharma 2006):

- SAR < 10 : Excellent
- SAR = 10 – 18 : Good
- SAR = 18-26 : Doubtful
- SAR > 26 : Poor

A high salt concentration in water leads to the formation of a saline soil and high sodium leads to the development of an alkali soil. 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 in terms of Sodium Adsorption Ratio (SAR). If the proportion of the sodium is high, the alkali hazard is high; if calcium and magnesium predominate, the hazard is less. There is significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles.

4.3c Percent Sodium (%Na)

Methods of Wilcox (1995) and Richards (1954) have been used to classify and understand the basic character of the chemical composition of water, since the suitability of the water for irrigation depends on the mineralization of water and its effect on plants and soil. Percent Sodium can be determined using the following formula. Sodium can also be calculated as Percent Sodium (%Na) to indicate the suitability of water for irrigation:

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

where all concentrations are in mill equivalents per liter.

The results based on Wilcox (1995) classification of water sample with respect to percent sodium are represented. Based on Eaton's 1950 classification all the samples belong to the safe category when %Na is less than 60.

The following classifications are generally used:

- %Na < 20 : Excellent
- %Na = 20 – 40 : Good
- %Na = 40 – 60 : Permissible
- %Na = 60 – 80 : Doubtful
- %Na > 80 : Unsuitable

4.3d Residual Sodium Carbonate (RSC)

In waters where bicarbonate content is high, there is a tendency for Ca and Mg to precipitate as carbonates, thus increasing SAR. The sodium hazard to soils is also increased if the water contains high concentrations of bicarbonate ions. The bicarbonate values are conveniently expressed in terms of 'Residual Sodium Carbonate' (RSC) as follows:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

where all concentrations are in milliequivalents per liter.

The following classification scale is used (Ghosh and Sharma 2006):

- RSC < 1.25 meq/l : Suitable for irrigation
- RSC = 1.25 – 2.5 meq/l : Marginal
- RSC > 2.5 meq/l : Unsuitable for irrigation

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) where all ionic concentrations are expressed in epm. Groundwater containing high concentration of carbonate and bicarbonate ions precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicates that the water is safe for irrigation.

4.3e Kelly's Ratio

Based on Kelly' Index (KI) waters are classified for irrigation. Sodium measured against calcium and magnesium was considered by Kelly (1940) and Paliwal (1967) to calculate this parameter. A Kelly's Index of more than one indicates an excess level of sodium in waters. Therefore, waters with a Kelly's Index less than one are suitable for irrigation, while those with a ratio more than one are unsuitable.

4.3f Chloride – bicarbonate ratio of groundwater

The chloride – bicarbonate ratio is used to indicate sea water intrusion into groundwater. Chloride is the dominant ion of sea water and normally occurs in only small amounts in groundwater. Additionally, bicarbonate is usually the most abundant negative ion in groundwater. Often an increase in the chloride - bicarbonate ratio, as well as total salinity can be seen near the coast.

$$Chloride - Bicarbonate\ Ratio = \frac{Cl^-}{CO_3^{2-} + HCO_3^-}$$

where all concentrations are in milliequivalents per liter.

4.4 ASSESSMENT OF IRRIGATION QUALITY

Irrigation suitability of groundwater in the study area was determined for the study period of 2006-2008, by using irrigation water quality parameters as %Na, RSC, SAR, Residual Mg/Ca Ratio, and Kelly's Ratio. All are briefly represented in **Table 4.4**.

4.4a Percent Sodium (%Na)

Selected eight numbers of open wells in the shallow sedimentary area of Ernakulam district were studied for irrigation suitability in terms calculating the Percent Sodium (%Na). It is observed that as per %Na after Wilcox (1995), one open well, ESOW-06 at Chellanam, fall in the “Unsuitable “category during the pre-monsoon 2006 and 2007, pre and post-monsoon 2006. During other seasons of the study period, the well approaches to “Doubtful” category (% Na below 60 and 80). Besides, examined the water quality data of this well for 2006-2008. The water is alkaline, with pH > 8.5. Total Hardness is much higher than total alkalinity and Na/Cl ratio falls in the range of natural water. The water is having permanent hardness (non-carbonate hardness) may be due to increased concentration in chlorides, sulphates etc. The water type is Na-Cl type, the major cation is Sodium and anion is Chloride. Saline intrusion is higher during premonsoon periods. The increased concentration of Na^+ makes the water in the well unsuitable for irrigation. ESOW-04 Mattanchery during post monsoon2007 fall under “Doubtful” category and shows alkaline character (pH between 8.3 and 8.7) and total hardness exceeds total alkalinity with a Na/Cl ratio ranging from 0.24 to 1.45. During post monsoon season of 2007, the water type changes to Na-Ca-Cl type, the maximum concentration of sodium ion leads the water to fall in the “Doubtful “category.

ESOW-08 Edacochi also appear under doubtful category which is alkaline with pH always higher than 8.5. As per Eaton’s 1950 classification it can be generalized that, out of the 8 selected wells, 7 numbers come under “Safe” category (%Na<60) except the pre-monsoon or dry period of 2006 and 2007. During the dry periods, the six number of wells fall under "Safe" category.

In phreatic crystalline aquifer, selected thirty one numbers of open wells and assessed the suitability for irrigation. As per the Wilcox (1995) classification, no wells included in the "Unsuitable" category during the pre-monsoon, post-monsoon and monsoon periods of 2006-2008. As per Eaton's Classification, the following wells come under the "Unsafe" category, at least during one season of the study period.

1. ECOW-10 Pothanikkad
2. ECOW-14 Kuttamangalam
3. ECOW-19 Kunnathunad (Pattimattom)
4. ECOW-25 Elanji
5. ECOW-23 Kizhakkambalam
6. ECOW-14 Kuttamangalam
7. ESOW-07 Amballor

The water quality data of these wells were analysed. For these wells, the alkali metals (Na and K) are the predominant ions as compared to alkaline earth (Ca and Mg) metals. The effect of precipitation and water level fluctuation in the open wells causes water quality fluctuation during the pre-monsoon, post-monsoon and monsoon season and may be one of the reason for this phenomena.

Among the twelve numbers of bore wells in the deeper crystalline formation, only one well at Mookkannoor Ward-I (ECBW-02) comes under the "Unsuitable" category (% Na>80) during the study period (pre-monsoon 2006 and

2008 and post-monsoon 2007). It remains under “Doubtful” category (% Na between 60-80) during the remaining season of the study period.

On examining the water quality data, it is observed that the pH of the well remains alkaline (above 8.5) during the pre-monsoon, monsoon and post-monsoon periods of 2006-2008. The Total Alkalinity of this station exceeds the Total Hardness throughout the study period which reveals that the water is having temporary hardness (i.e., carbonate hardness). The concentration of sodium is about four times the concentration of chloride. The Na/Cl ratio for natural waters should be between 0.8 and 1.2. A deviation from this indicates the salt water intrusion, anthropogenic activities or geogenic contribution in the environment. The Na/Cl ratio more than 1, shows that the water is of non-marine origin (Hem 1991). The water type of this station is Na-HCO_3 type (Piper Plot also supports this) during the pre-monsoon, monsoon and post-monsoon season of 2007. The predominating cation is and this causes the water to account in the “Unsuitable” category.

In pre-monsoon season, the concentration effect is high and due to the dilution effect of monsoon, a change from “Unsuitable” to “doubtful” category occurs. As per Eaton’s 1950 classification also, this station comes under the “Unsafe” (%Na >60) category, throughout the study period. All other wells in the deeper crystalline formation fall in the “Safe” category, in terms of Percent Sodium.

4.4b Residual Sodium Carbonate (RSC)

In order to explain the suitability of water for irrigation, a relation between carbonate concentration and alkaline earth’s metal concentration was adopted. Calculated the Residual Sodium Carbonate (RSC) after Rechard (1954) values for different types of wells under the study area. All the thirty one open wells in the phreatic crystallines fall under the "Good" category (RSC <1.25). In the shallow sedimentary wells, the total hardness exceeds total alkalinity and there exists no residual (excess) carbonates. Out of the twelve bore wells in the deeper aquifer, only one well ECBW-02 at Mookkannoor ward-I, comes under the "Doubtful" category (RSC between 1.25 and 2.5) for Irrigation suitability. The dominating anion is bicarbonate. The Total Alkalinity is much higher than the Total Hardness and the water type remain in Na-HCO_3 type for all throughout the seasons. This is the reason why the RSC(which is having excess alkalinity) of the station fall in the "Doubtful" category. All other stations are in "Good" category.

4.4c Sodium Absorption Ratio (SAR)

SAR is a better measure of sodium (alkali) hazard in irrigation, as this is directly related to the adsorption of sodium by soil. Excessive sodium content relative to the Calcium and Magnesium may deteriorate the soil characteristics, thereby reduce the soil permeability and thus inhibits the supply of water needed for the crops. Determined the SAR for different types of wells in the study area. All the stations under the phreatic crystalline and deeper crystalline formation are under the "Excellent" category. Most of the wells in the shallow sedimentary area of "Excellent" category with an exception, ESOW-06 at Chellanam which shows SAR value at the "Doubtful" category, during the pre-monsoon seasons. The water is Na-Cl type. High concentration of sodium during pre-monsoon season may be due to saline intrusion, due to proximity to sea. Owing to the increased concentration of sodium, the SAR value includes the "Doubtful" category.

4.4d Residual Mg/Ca ratio

Determined the Mg/Ca ratio of all wells in the sedimentary and crystalline areas. All stations in the phreatic crystalline and deeper crystalline formation fall under the "Safe" category. Only one open well in the sedimentary area ESOW-06 Chellanam falls in the "Marginal" classification during the pre-monsoon and post-monsoon seasons of the study period. Summing up, groundwater in the phreatic crystalline areas are suitable for irrigation. Wells at the sedimentary area are also "Safe" except the station ESOW-06 Chellanam. Owing to the high concentration of sodium and bicarbonate, station at Mookkannoor Ward-1 of deeper crystalline formation turns "Unsuitable" for irrigation.

4.4e Kelly's Ratio

Assessed irrigation suitability of various types of wells in the study area in terms of Kelly's Ratio. In the shallow sedimentary area only one station, ESOW-06 Chellanam, comes under the "Marginal" classification, during all seasons.

As per Kelly's ratio, the phreatic aquifer is almost safe even though some exceptions are noted. No stations fall under the "Unsafe" class. The deeper aquifer is also "Suitable" except the station at Mookkannoor Ward-1, which comes under the "Marginal" classification in terms of Kelly's Ratio.

From the assessment of hydrochemical classification, the following findings are inferred:

The type of water that predominates in the shallow sedimentary formation is Ca-Mg-HCO_3. A major grouping is not possible in the case of crystalline aquifer(phreatic and deeper) during the study period. The suitability of groundwater for irrigation was evaluated based on the irrigation quality parameters like %Na, RSC , SAR, Residual Mg/Ca ratio and Kelly's Ratio (**Table 4.4**). Based on % Na majority of the samples in sedimentary, deeper crystalline formation were "Excellent/Good". ESOW-06 and ECBW-02 fall in the unsuitable category. Groundwater in the phreatic crystalline formation comes under "Suitable" category as per RSC. Groundwater in the shallow sedimentary and phreatic crystalline formation are classified as "Good". In deeper crystalline formation, all stations are classified as "Good" except ECBW-02. All stations in the study area are "Excellent" for irrigation except the coastal well which is in the "Doubtful" category in terms of SAR. Groundwater in the crystalline formation (both phreatic and deeper) is in the "Safe" class as per evaluation using Residual Mg/Ca ratio. But ESOW-06 comes in the "Moderate" class. Groundwater in the study area comes under "Suitable" category based on Kelly's Ratio with a few exceptions.

4.5 MAPPING OF SELECTED WATER QUALITY PARAMETERS

During the study period, analysed the water samples from the selected locations. The location map of these observation stations (open wells of sedimentary and crystalline aquifers) is given in **Figure 2.4**. The parameters chosen for the water quality mapping are pH, EC, TH and Iron. The mapping was done on the basis of BIS desirable limits for drinking water.

The following are the findings.

The variations in pH during the pre-monsoon, monsoon and post-monsoon seasons of the study period 2006-2008 is shown in **Figures 4.11,4.11a and 4.11b**. It is observed that in all the three years the number of wells having pH between 6.5 and 8.5 remains almost the same. The desirable drinking water limit has been taken as the basis.

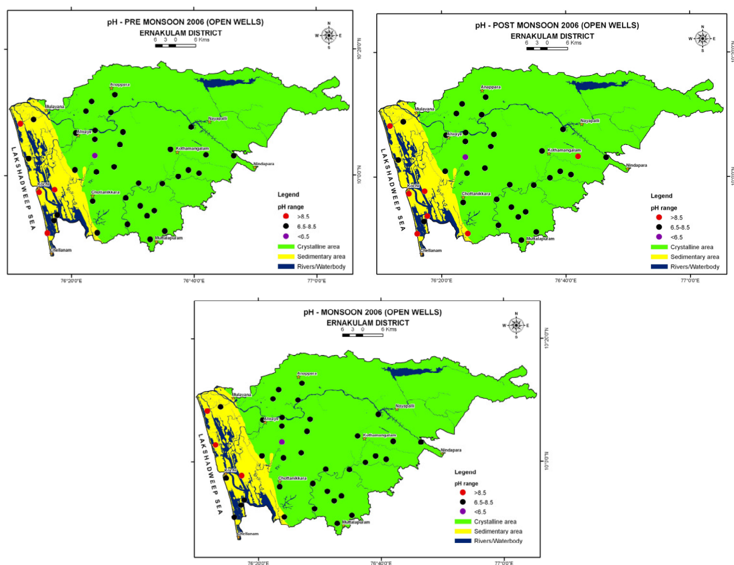


Figure 4.11
Seasonal pH during 2006

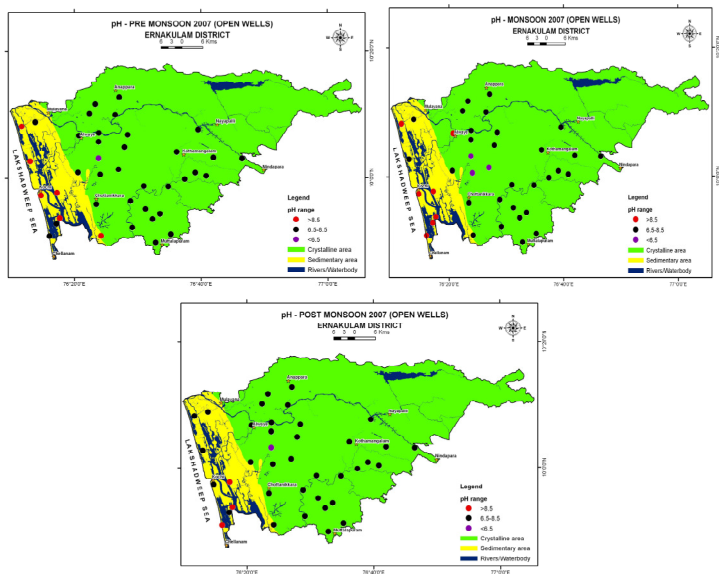


Figure 4.11a

Seasonal pH during 2007

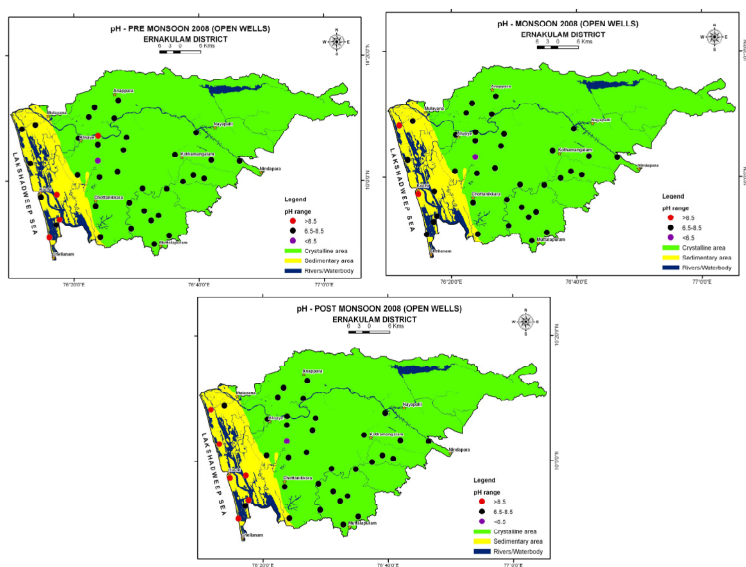


Figure 4.11b

Seasonal pH during -2008

EC has been shown in **Figures 4.12, 4.12a** and **4.12b.**

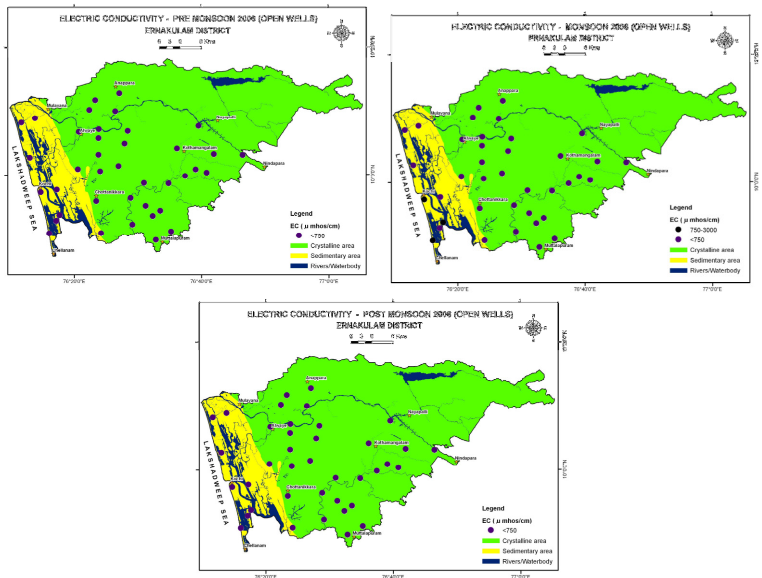


Figure 4.12

Seasonal EC during 2006

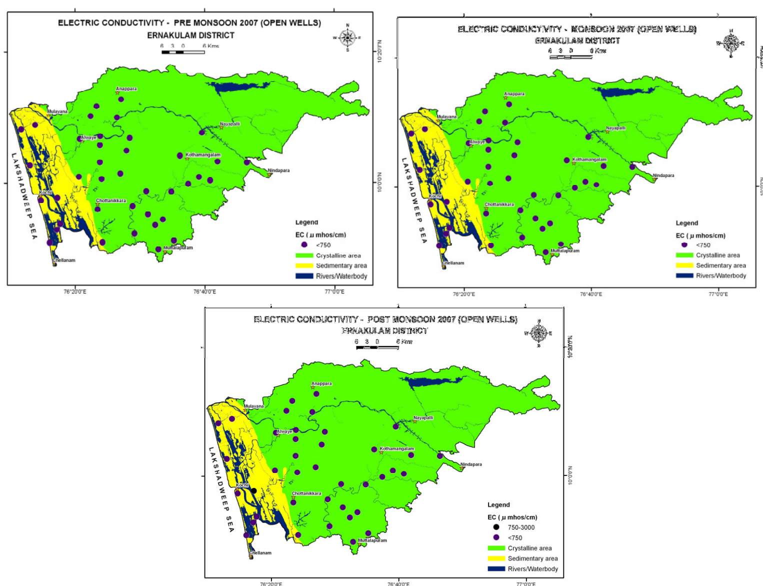


Figure 4.12a

Seasonal EC during 2007

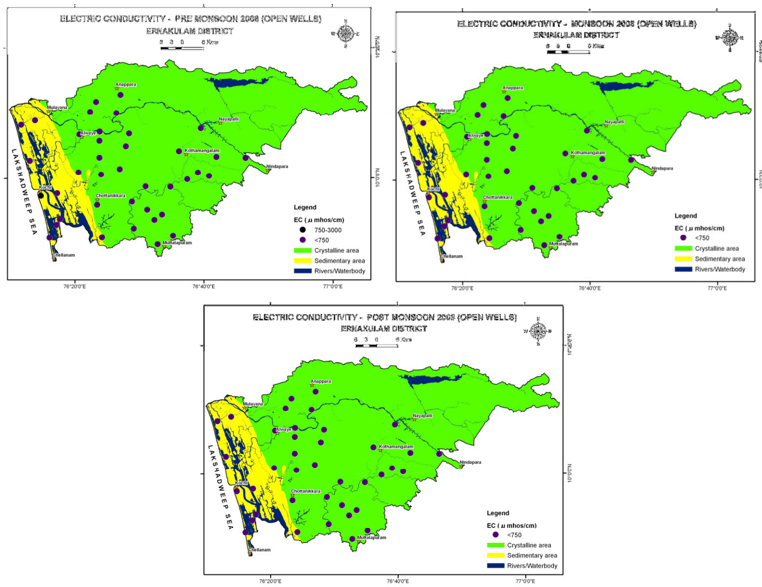


Figure 4.12b

Seasonal EC during 2008

Total Hardness has been mapped in **Figures 4.13, 4.13a** and **4.13b** by adopting two categories.TH< 300 and TH > 300 mg/L which is the desirable limit as per the BIS guidelines.

It is observed that in the phreatic aquifer, major wells fall under category of TH <300 mg/L in all the three seasons of the study period. Only two wells in the sedimentary show TH above the permissible limits.

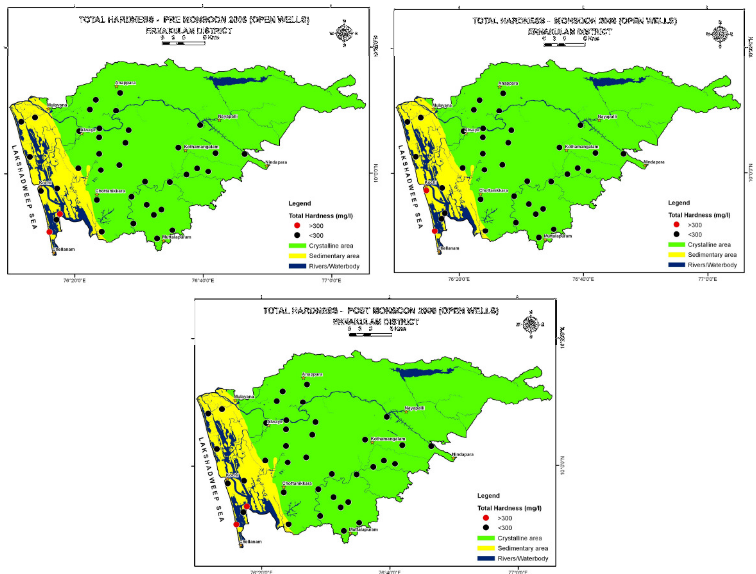


Figure 4.13

Seasonal TH during 2006

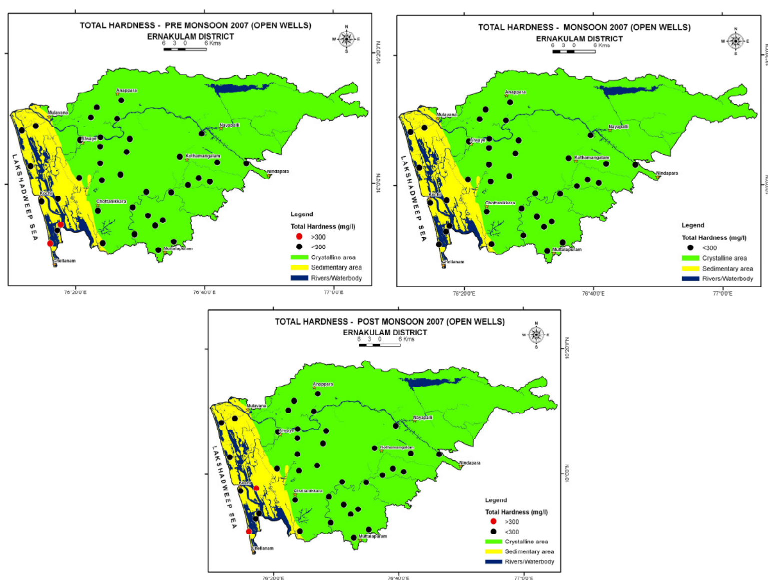


Figure 4.13a

Seasonal TH during 2007

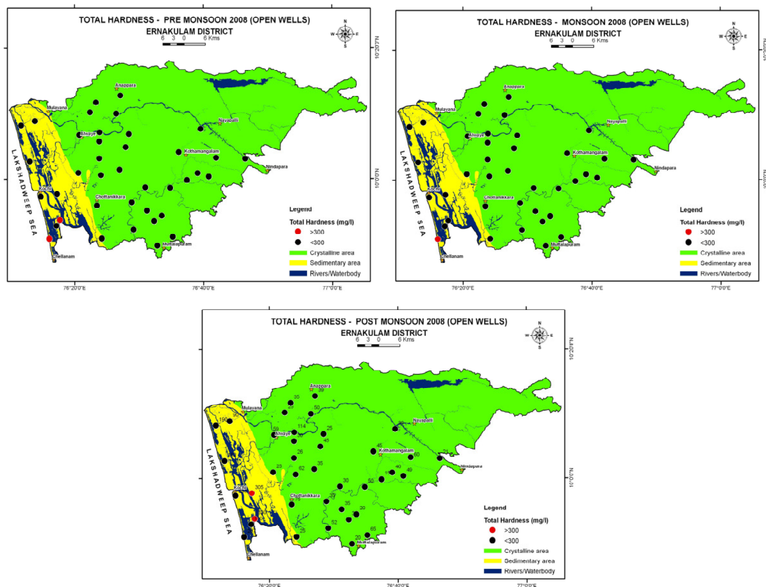


Figure 4.13b

Seasonal TH during 2008

In the case of iron, the stations of Fe> 0.3 and Fe < 0.3 mg/L were mapped for the pre-monsoon, monsoon and post-monsoon seasons were shown in **Figures 4.14, 4.14a** and **4.14b**. Out of the 39 observation stations, major number of observation stations fall under the category of Iron > 0.3 mg/L. It was observed that during pre and post-monsoon seasons, the number of observation stations follow almost the same pattern. That is, the number of wells having Fe> 0.3 mg/L is 69% (pre-monsoon) and 74% (post-monsoon) during the period 2006, 97% (pre-monsoon) and 82% (post-monsoon) during the period 2007 and 56% (pre-monsoon) and 82% (post-monsoon) during 2008.The values of Iron in monsoon season shows just the opposite pattern. That is, Fe>0.3 is 69% of the wells during 2006, 71% during 2007 and 53% during 2008.

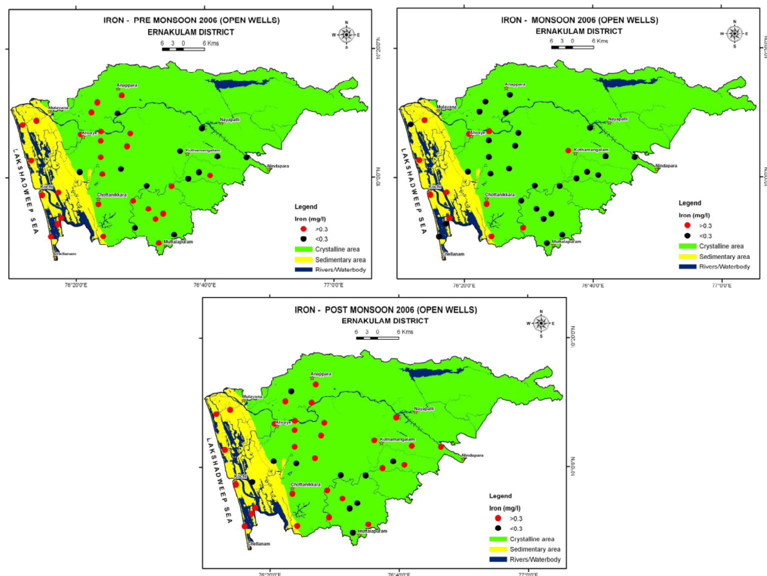


Figure 4.14

Seasonal Iron concentration during 2006

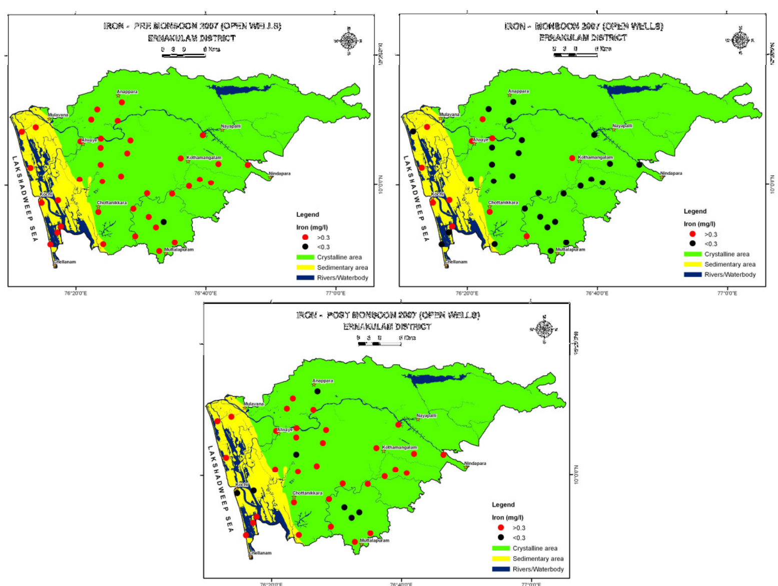


Figure 4.14a
Seasonal Iron concentration during 2007

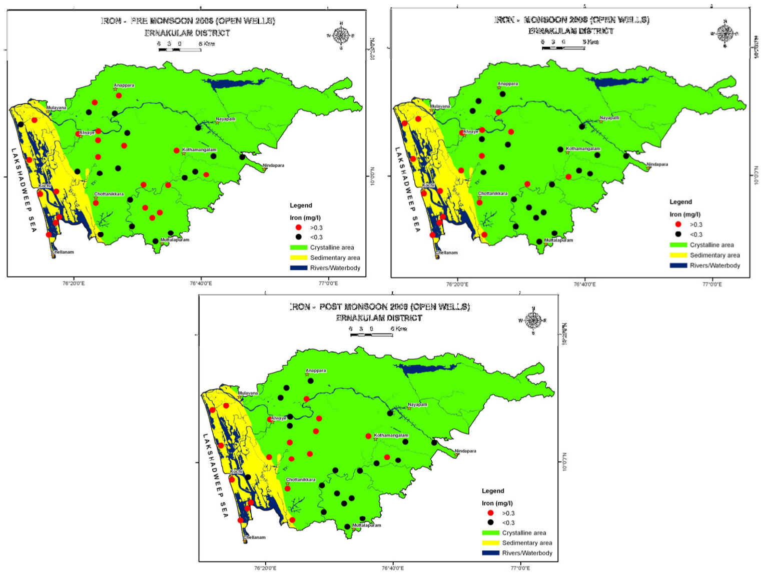


Figure 4.14b
Seasonal Iron concentration during 2008

This above findings clearly shows the monsoon effect/dilution effect, in the phreatic aquifer. The relation between precipitation and water quality parameters has been well established by this study. The water quality maps can be used to plan future water works and suitable source identification.

Chapter - V

HYDROGEOCHEMICAL ASSESSMENT OF SPECIFICALLY SELECTED WELLS

Chapter - V

HYDROGEOCHEMICAL ASSESSMENT OF SPECIFICALLY SELECTED WELLS

5.1 INTRODUCTION

The phenomenal human population growth has intensified pressure on each and every natural resource to produce adequate food and raw materials to meet the proportional demand (Smil 1999). With the advent of green revolution technologies, India has increased the consumption of fertilizer from 0.3 million metric tons in 1961–18.7 million metric tons in 2000, which resulted in a 170% increase in cereal production during the same period where as the population nearly got doubled (FAO 1996). During the next three decades, world population will increase by another 2 billion demanding a higher production of food. The food security can be achieved only through improvements in crop yields, which would require a 30% increase in fertilizer use. This increased fertilizer requirement has to be balanced against the environmental and human health concerns stemming from intensive fertilizer applications, particularly in fast developing and industrialized countries. The World Health Organization (WHO) has repeatedly insisted that the single major factor adversely influencing the general health and life expectancy of a population in many developing countries is lack of ready access to clean drinking water (Nash and McCall 1995).

India draws out an estimated 231 billion cubic metres of water from the ground annually, the largest amount in the world. The recent report on Groundwater Management and Ownership (2010*)* prepared by an expert group set up by the

Planning Commission takes explicit cognizance of the fact that there are clear indications that the groundwater resource in the country is under severe stress. Moreover, depletion of groundwater is closely associated with worsening water quality, as indicated by the rising levels of fluoride, arsenic and iron. There is no doubt then that groundwater management is a matter of high priority. Groundwater is an invisible, non-stationary, fugitive resource, which does not respect boundaries set by landholdings. Ground water is inevitable water supply source worldwide. It is the major source of drinking water in both developed and under developed areas in India.

Water quality assessment is inevitable for monitoring the environmental quality and a number of studies were also carried out in different parts of the country (Subba Rao et al.1998, Elango et al.2003). The natural quality of groundwater is controlled by the geochemistry of the lithosphere, the solid portion of the earth, and the hydrochemistry of the hydrosphere, the aqueous portion of the earth. Therefore knowledge on ground water characteristics is one of the essential requirements to understand the subsurface hydrology. Groundwater chemistry provides information on identification of different aquifers as well as the dominant hydrological processes. Pure siliceous sands or sandstones without soluble cement also contain ground water with very low total dissolved solids (Mathess 1982). Sulphate may also be produced by the oxidation of metallic sulphides, which are present in small amounts in many rock types. The presence of soluble cement may produce increased concentrations of the major ions. Groundwater in carbonate rocks has pH values above 7, and mineral contents usually dominated by bicarbonate and calcium. Naturally, ground water contains mineral ions and these ions slowly derived from soil particles, sediments, and rocks as the water travels along mineral surfaces in the pores or fractures of the unsaturated zone and the aquifer may have been originated in the precipitation water or river water that recharges the aquifer. It is divided into three groups: major constituents, minor constituents, and trace elements. The naturally occurring dissolved solids are inorganic constituents, minerals, nutrients, and trace elements, including trace metals. In most cases, trace elements occur in such low concentrations that they are not a threat to human health. In fact, many of the trace elements are considered essential for the human metabolism. Mineral exploration and exploitation, although are indispensable for development of any country. Release of major and trace elements, especially the so-called heavy metals, which contaminate our natural environment due to their toxicity, persistence and bioaccumulation bring problems. Increased anthropogenic inputs of major and trace metals in terrestrial environments have also caused considerable concern relative to their impact on groundwater contamination. Although most major and trace metals are generally considered to be relatively immobile in the short term, their mobility under certain chemical conditions may exceed ordinary rates and pose a significant threat to groundwater quality (Scokart et al. 1983). A range of groundwater contamination problems can be associated with mining activities. Coal mining is one of the core industries in India, which plays a positive role in the economic development of the country. Mining activity releases the major and trace elements, especially the so-called heavy metals, which pollute our natural environment. Their occurrence in water resource and biota indicate the presence of natural or anthropogenic sources (Fang and Hong 1999; Klavins et al. 2000; Tam and Wong 2000). The nature of contamination depends on the materials being extracted and the post-extraction process. Coal, salt, potash, phosphate and uranium mines are major polluters. Metalliferous mineral extraction is also important, but stone, sand and gravel quarries, although more numerous and widespread, are much less important chemically. Both surface and underground mines usually extend below the water table and often major dewatering facilities are required to allow mining to proceed. The water pumped, either directly from the mine or from specially constructed boreholes, may be highly mineralised and its usual characteristics include low pH (down to pH 3) and high levels of iron, aluminium and sulphate. The contamination of groundwater can also result from the leaching of mine tailings and from settling ponds and can, therefore, be associated with both present and past mining activity. High concentrations of major and trace metals can also be recorded in the ground water near contaminated sources posing serious health threats. Some trace constituents that are associated with industrial pollution may also occur in completely pristine ground water at concentrations that are high enough to make the water unsuitable for drinking purposes. The total area cultivated in India using groundwater has increased from 6.5 million hectare in 1951 to 35.38 million hectare in 1993 (GWREC 1997). In India, several studies have reported groundwater contamination by nitrate due to agricultural activities (Singh 1983; Hem 1985; Datta et al. 1997; Prasad 1998; Kumar et al. 2006a, b). Soil contamination due to irrigation water quality has also been reported (Palaniswami and Ramulu 1994; Datta et al. 2000; Patel et al. 2004; Marechal et al.

2006). However, previous reports illustrates uncontrolled extraction without commensurate recharge and heavy leaching of pollutants from pesticides and fertilizers to the aquifers has resulted in pollution of groundwater (Rajmohan and Elango 2005). Increased industrialization, urbanization and agricultural activities during the last few decades have deteriorated the surface water and groundwater quality of Kerala, the southernmost State of India (Nageswara Rao and Ramadurai, 1970; CGWB, 2002). In general, colour and taste of the water are the two basic criteria for a consumer to decide the suitability of a given water for drinking without considering other lethal chemical contaminations due to arsenic, nitrate, fluoride, heavy metals and pesticides.

It is therefore becomes essential to determine the present status of groundwater on the basis of its quality and thus its suitability for two major purposes viz., drinking and irrigation. Understanding the spacial distribution of pH, electrical conductivity (EC), total dissolved solids (TDS), fluoride and total iron content will help to identify the quality of groundwater. Groundwater contamination can often have serious ill effects on human health. Groundwater with low pH values can cause gastrointestinal disorders, such as hyperacidity, ulcers, stomach pain and burning sensation. pH values below 6.5 cause corrosion of metal pipes, resulting in the release of toxic metals such as Zn, Pb, Cd, Cu etc. (Trivedy and Goel, 1986). Electrical Conductivity (EC) of groundwater is considered as an important parameter for irrigation and industrial purposes. Total dissolved solids help to identify the potability of groundwater. Total iron content may not have direct effects on human health but is of importance due to aesthetic reasons. The excess presence of iron in groundwater causes stains to cloths and fixtures and has a bad taste and odour. These problems arise when iron concentration approaches more than 0.3 mg/L in groundwater. High concentration of fluoride in drinking water are also linked with cancer (Smedly, 1992).

5.2 MAJOR POLLUTANTS

Trace metals and other potentially toxic elements are the most serious soil pollutants in sewage. Sewage sludge contains trace metals and, if applied repeatedly or in large amounts, the treated soil may accumulate trace metals and consequently become more polluted. Soil pollution can lead to ground water pollution if toxic chemicals, pesticides and trace metals leach into groundwater. Recently Akhila, B (2011) studied the soil chemistry in Ernakulam district.

5.2a TRACE METALS

Trace metals are metals in extremely small quantities that reside in or are present in animal and plant cells and tissue. They are ubiquitous, persistent ions and toxic at certain concentrations. Some metals are essential for health whereas others have no biological function and have toxic effects. Trace metals include iron, magnesium, lithium, zinc, copper, chromium, nickel, cobalt, vanadium, arsenic, molybdenum, manganese, lead, cadmium and selenium. Trace metals are depleted through the expenditure of energy by a living organism. They are replenished in animals by eating plants, and replenished in plants through the uptake of nutrients from the soil in which the plant grows.

Cadmium is notorious for its high renal toxicity due to its irreversible accumulation in the kidney. Lead is a strong neurotoxin in unborn and young children, leading to irreversible impairment of intelligence. Lead easily crosses the placenta. The threshold of neurotoxic effect has decreased over the last 20 years and drinking water standards and guidelines for lead have been revised accordingly to their present 10 µg/L. Nickel has high allergic potential. Cr is found in the environment in two states Cr^{3+} and Cr^{4+}. The latter is toxic and originates only from human activities. Copper is an essential trace element with an optimum daily oral intake of 1-2 mg/person. Above 2 mg/L leads to liver cirrhosis in babies if water of this concentration is used to prepare bottle-feeding formulas. Trace metals are natural constituents of groundwater originating from the weathering and solutions of numerous minerals. Natural concentrations are typically low.

Metal concentrations can be increased by mining, mineral processing, metal smelting and finishing, waste disposal in spoil heaps and tailings ponds and by other industrial processes and waste disposal. The leather-processing industry is a well-documented source of Cr pollution in groundwater. Acidification of soils and rainfall by air pollution lowers pH and encourages the mobilization of trace metals. Beneath the soil zone, where organic matter is less abundant and less reactive, it is likely that metal oxides of Fe and Mn play the greatest role in the adsorption of Pb. Although Pb itself is not redox sensitive in the natural environment, its mobility may be affected by the redox state of the system. Because Pb is adsorbed onto naturally occurring metal (Fe and Mn) oxyhydroxides, the presence and stability of these solids will effect Pb movement. The adsorption of Pb onto these solids will retard the movement of Pb compared with the groundwater flow velocity, unless contamination produces reducing conditions in which case ferric hydroxide and/or manganese oxide/oxyhydroxide may dissolve and release adsorbed lead. If the groundwater becomes reoxidized, the Fe/Mn solids will precipitate and scavenge Pb from solution. Waste products from the industries can be a source of chromium contamination to the environment. Releases to the atmosphere in the form of particulates generated by electric arc furnaces used in ferrochrome and refractory brick production provide the largest total amount of chromium released by human activity. Disposal of fly-ash from coal combustion provides the largest single input to soils. Another widespread source of chromium to soils is the application of sewage sludge to the land surface as a disposal method. Sludges from tanneries or plating facilities can produce locally high concentrations of chromium. In some locations chromate-bearing slag from the processing of chromate ore has been used as general fill material that may pose a human health or environmental hazard. Disposal of this industrial waste to the rivers is a real threat to the groundwater.

5.2b PESTICIDES AS ORGANIC POLLUTANTS

Pesticides are synthetic organic chemicals used to control weeds in fields and lawns, and unwanted or harmful pests, such as insects and mites that feed on crops. Pesticides are divided into categories according to the target organisms, they are designed to control target organisms (e.g., insecticides control insects). Herbicides are by far the most commonly used pesticides. The toxicity level of a pesticide depends on the deadliness of the chemical, the dose, the length of exposure, and the route of entry or absorption by the body. Pesticide degradation in soil generally results in a reduction in toxicity; however, some pesticides have breakdown products (metabolites) that are more toxic than the parent compound.

Pesticides may cause acute and delayed health effects in those who are exposed. Pesticide exposure can cause a variety of adverse health effects. These effects can range from simple irritation of the skin and eyes to more severe effects such as affecting the nervous system, mimicking hormones causing reproductive problems, and also causing cancer. Toxicity studies found that most studies on non-Hodgkin lymphoma and leukemia showed positive associations with pesticide exposure and thus concluded that cosmetic use of pesticides should be decreased. Strong evidence also exists for other negative outcomes from pesticide exposure including neurological, birth defects, fatal death and neuro developmental disorder.

Most of the developed countries have banned or restricted the production and usage of many organochlorines during 1970s and 1980s. But these chemicals are still being used in some developing nations for agricultural and aqua cultural purposes (Tanabe et al. 2001). Some of the chemicals are still being manufactured in the Asian developing region. Usage of pesticides in India is increasing at 2 to 5% per annum and is about 3% of total pesticide used in the world (Nigam and Moorthy, 2000). India thus needs to urgently take a tough measure in the indiscriminate and careless use of pesticides. Approximately 125 companies manufacture more than 60 technical grade pesticides in India including organochlorine and organophosphorous. The annual production of these pesticides in India is approximately 91000 million tons. A broad spectrum of pesticide is used in India for agricultural as well as vector control program. An estimated 380000 tons of pesticides and other halogenated hydrocarbon are used each year of which approximately 55000 tons are used in agricultural activities. The total annual consumption of DDT and its isomers is 107000 tons per year. After green revolution started in India, the usage of pesticides jumped hundred fold from 154 million tons in 1954 to 88000 million tons in 2001.

Groundwater is one among the Nation's most important natural resources. It is one of the major sources for drinking water, agriculture, industry, as well as to the health of rivers, wetlands, and estuaries throughout the country. Large-scale development of groundwater resources with accompanying declines in groundwater levels and pollution has led to concerns about the future availability of groundwater to meet domestic, agricultural and industrial needs.

A study of water quality is fundamental to understand the water resources, as it gives insight in to the benefits to be gained from water management and consequences of mismanagement. The present study involves the assessment of ground water quality by analyzing the water from specifically considered areas in Ernakulum district. As Ernakulum being the industrial capital of Kerala, inherent industrial pollution is on a higher side in this district. A number of major industries are placed in this area. Because of the dumping of industrial wastes and effluents, the environment, including the soil, river system and groundwater, is highly polluted.

Thus, this chapter highlights the spatial and temporal variations in the groundwater quality in 15 pristine areas where groundwater was extensively used in this district and evaluates the suitability of groundwater for irrigation and drinking purpose for a sustainable agriculture and basic human needs (**Figure 5.1**). An effort has also been made to investigate relationship between perceived water qualities with trace pollutants like pesticides and trace metals. Considering these facts and also least studied the soil chemistry as compared to other districts in Kerala State, Ernakulam district is the ideal location for assessing the ground water quality in terms of:

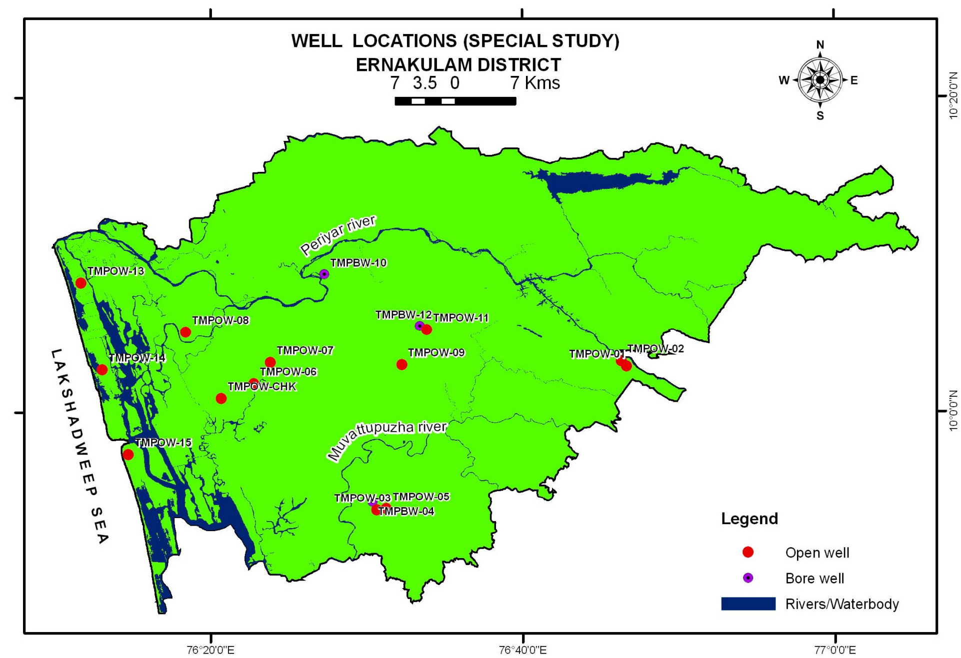


Figure 5.1

Location Map of the study area

- Hydro-chemical quality parameters
- Drinking water suitability
- Irrigation suitability
- Trace metal distribution
- Pesticide distribution

Detailed procedure is documented in **Chapter II** and the specific studied well details are given in **Table 5.1**. The physical parameters considered were colour, odour, turbidity and temperature. Water levels were also measured. Chemical parameters accounted were the hydrogen ion concentration, electrical conductivity, total dissolved solids (TDS), total hardness, total alkalinity, fluoride, iron, nutrients, silica and concentrations of all major cations and anions along with special importance to trace elements and pesticides and the results are given in **Tables 5.2a, 5.2b** and **5.2c (Annexure)**. This hydro-geochemical analysis enables assessment of the groundwater quality and its suitability for domestic and irrigational purposes. Chemical analyses were carried out as per the procedures stipulated by American Public Health Association (APHA 1998) as explained in **Chapter II**.

Table - 5.1

WELL DETAILS OF THE SPECIFIC STUDY

Location	Well ID	Type of Well	Latitude N	Longitude E	Depth (mbgl)	Diameter (m)	Water yielding formation	Height of Measuring point (m)
District Agricultural Farm, Neryamangalam	TMPOW-01	OW	$10^0$03' 15"	$76^0$46' 21"	9	3.5	Laterite	0.6
Coconut Development Board, Neryamangalam	TMPOW-02	OW	$10^0$03' 15"	$76^0$46' 21"	12.6	1.8	Laterite	0.6
H/O PKBaby, Anchalpetty, Puthuserippady	TMPOW-03	OW	$9^0$54' 15"	$76^0$30'46"	7.5	3.2	Laterite	0.6
H/O PKBaby, Anchalpetty, Puthuserippady	TMPBW-04	BW	$9^0$54' 15"	$76^0$30'46"	20	0.6	Fractured rock	-
H/O Azhakan, Manakkalkara, Pampakuda Panchayath	TMPOW-05	OW	$9^0$54' 8"	$76^0$30' 51"	6.7	2.12	Laterite	0.75
H/O Biju Kurien, Manakkalkadavu, Pallikkara	TMPOW-06	OW	$10^0$01' 49"	$76^0$22' 47"	13.8	2.57	Laterite	0.77

Pookattupady, Kizhakkambalam	TMPOW-07	OW	$10^0$03' 10"	$76^0$23' 52"	12.5	2.2	Clay,soft	0.9
Binanipuram HospitalCompound, Edayar	TMPOW-08	OW	$10^0$05' 07"	$76^0$18' 25"	16	4	Charnokite	0.78
Keezhillam, Mazhuvannoor Panchayat	TMPOW-09	OW	$10^0$03' 01"	$76^0$32' 17"	4	1.65	Laterite	0.75
District Seed Farm, Okkal, (Chelamattam)	TMPBW-10	BW	$10^0$08' 47"	$76^0$27' 19"	54	0.15	Charnokite	0
MPRS, Odakkali (Assamannoor)	TMPOW-11	OW	$10^0$05' 30"	$76^0$33' 30"	6.2	3.25	Laterite	0.65
MPRS, Odakkali (Assamannoor)	TMPBW-12	BW	$10^0$05' 30"	$76^0$33' 30"	66	0.15	Charnokite	0.6
Pallippuram, Cherai	TMPOW-13	OW	$10^0$08' 13"	$76^0$11' 43"	3.5	2.1	Sand	0.91
Njarakkal, Ward 3, Panchayat Office	TMPOW-14	OW	$10^0$02' 43"	$76^0$13' 04"	2.4	2.56	Alluvium	0.77
Mattancherry, Vypin	TMPOW-15	OW	$9^0$57' 19"	$76^0$14' 45"	2.27	1.3	Alluvium	0.69
Check Sample, Kakkanad	TMPCHK-16	OW	10^0 01' 19"	76^0 21' 30"	25	6	Charnokite	0.78

5.3 BRIEF DESCRIPTION OF THE SPECIFIC STATIONS

1. TMPOW-01

The observation station is situated in the District Agriculture Farm (DAF), Neryamangalam, in Kothamangalam taluk. Area of the farm is approximately 300 Acres. The well is located at the valley portion, about 100 m towards 45 ˚W of the farm. It is a pumping open well for domestic purpose. This station gets the maximum rainfall in Kerala. Periyar flows 150 m away from the site. The water yielding formation is laterite. The area is provided with thick vegetation, mainly arecanut. There is a very small west-flowing nalah 10 m away from the well. Planting materials available in the farm are coconut seedlings, pepper cuttings, cashew graft, arecanut seedlings, guava layer, sappotta graft, Jack graft, mango graft, clove seedlings, nut graft, ginger, turmeric, cinnamon, banana suckers etc. The farm is using various pesticides as Metacid, Ekalux, Carbaryl, Xevin, Furidan (Carbofuran), Phorate (not in use now), Gram X, Glycid, Phytolan etc. The commonly used weedicides are Paraquote (Gramaxone) and Gycid (SAFAL) and fungicide used is Phytolan. For general weed control, 41%S IPA salt solution of Glyphosate is used. The significance of selecting the observation well was that several types of pesticides are being used in the farm and the area is a potentially recharging one with possibility of contamination and or effect of dilution due to presence of flowing water near the well.

2. TMPOW-02

This observation well is located 30 m south of Coconut Development Board (CDB), Neryamangalam. This well is located on a slope beside the valley portion in the laterite formation. It is a pumping open well, exclusively used for drinking and domestic purpose. This station gets the maximum rainfall in Kerala. The water is slightly acidic. The planting materials available in the farm is only coconut seedlings. The farm is using pesticides as Monocrotophos (Novacron, Monocid), Chlorpyriphos (Quinalphos, Thimet), Phorate Granules, Glyphosate etc., and fungicides as Diuron, Endophil (Mancozeb), Glyphosate etc. Therefore, this station is included as one of the specific stations.

3.TMPOW-03

The well is located in the private property of Mr.P.K.Baby, Poonkottukuzhiyil House, Anchalpetty, Pampakkuda (Piravom-Koothattukulam Road) (**Photo 5.1**). It is an open well with water availability during rainy season only. Hence a bore well is drilled inside the open well. Water is available during all seasons in this bore well. During rainy season, water is clear but in summer season an oily layer appears on the surface. There is a rubber plantation nearby where only biofertilizers are being used. The water yielding formation is laterite.

Photo 5.1
Sampling Station-Pampakkuda

4. TMPBW-04

The well and address is the same as above but it is the bore well drilled inside the open well TMPOW-04. It is a pumping bore well, exclusively used for drinking and domestic purpose. The water yielding formation is charnockite. The bore well is drilled piercing the fractured zone in the charnockite and is yielding sufficient quantity of water but with quality problem. The water is having H_2S smell during pre and post-monsoon periods. The presence of iron and manganese in this well water creates socio-economic problems. Since this is a typical well structure combining an open well and a deep bore well, the site was selected for the study.

5. TMPOW-05

The open well is located in the plot of Mr.Azhakan, Manakkalkara House, Anchalpetty, Pampakkuda.(Piravom-KoothattukulamRoad) (**Photo 5.2**). They have drilled a bore well of 45 m depth inside the well TMPOW-05 due to the lack of water in the open well. But there was no sufficient water both in the open well or in the bore well. Later on, a flowing canal from Muvattupuzha project was constructed at a distance of 10 m from the well at a higher elevation. Thereafter the open well started yielding sufficient good quality water. This well was selected for the study due to its dual nature of construction and presence of another surface water body nearby.

Photo 5.2
Sampling Station- Pampakkuda

6. TMPOW-06

This well is located at Kayyalath house, Manakkalkadavu, Pallikkara, of Mr.Biju Kurien. This station is located in a laterite area with no pollution sources nearby. Water table goes down during summer. Influence of monsoon is very high. The significant observation is that this well shows high water level fluctuation. The well is located in the laterite formation which becomes highly saturated during monsoon due to the good permeability. The lowering in water table during the pre-monsoon season is due to the high slope of the location.

7. TMPOW-07

This well is located in a private land owned by Mr.Neelakantan, Puthenkudy house, Pookkattupadi, Kizhakkambalam near the road. The topsoil is covering the laterite followed by soft clay content. The water is acidic in nature and water table is low.

8. TMPOW-08

This well is located near the industrial hub inside the Binanipuram Hospital Compound, Edayar. This openwell is deep and is constructed at charnockite formation. There is a fine textured clay layer yellow in colour occurs at 6m thickness. The difference in water level is minimum. Due to the reduced permeability of the clay layer the water level fluctuation is very less in this well. The well was selected for the study due to the industrial hub and thick clay layer.

9. TMPOW-09

This open well is located in the property of Mr. James John, Neerunthanathu house, Keezhilam, Mazhuvannoor Panchayat. The well is used for drinking purpose and is located very near to a paddy field. An irrigation canal passes through the location at a distance of 7 m. In all the seasons the water table is shallow. This may be due to the effect of the canal. The well was chosen due to the presence of agriculture land and due to the presence of surface water body.

10. TMPBW-10

The location of the bore well having a depth of 54 m below ground level is in the middle of a paddy field owned by the District Seed Farm, Okkal. The paddy field is using several pesticides. The water table is only 0.6 m below ground where as the water level in the bore well was below 2 m. It is a typical bore well unaffected by the surface water around and hence chosen for the study.

11. TMPOW-11

The observation well is a large diameter open well located in the Medicinal and Aromatic Plant Research Station at Odakkali, Assamannoor (**Photo 5.3**). Previously it was dry. But due to the construction of a sub- surface dyke, the water level rise was significant and there was sufficient water all through the seasons. The well was chosen due to the presence of a sub-surface dyke of 20 m length and 6-8 m depth provided with separate piezometers in the upstream and downstream of the dyke to assess the leakage of the subsurface dyke. The sub-surface dyke is acting as a barrier to the run off of groundwater between the layers of laterite and the bed rock. This is a significant water conservation structure to have sustainable water in the well.

Photo 5.3

Sampling Station- Odakkali

12. TMPBW-12 Medicinal Plant Research Station, Odakkali

This observation station is a bore well very near to (5 m) the observation station TMPOW-11 as given previously. The influence of the sub-surface dyke makes the bore well overflow during the rainy seasons. The water level in this well is high during all seasons.

13. TMPOW-13

This observation well is located at the house compound of Mr. P.P.Varghese, Puthussery, Pallippuram Village, Cherai junction. The water yielding formation is sand which act as a good aquifer and hence the water table is at a raised level, just below the parapet. Two sides of the well is surrounded by kayal. The well was selected for the study due to the presence of surface water body, and due to its ideal location in an ideal potential aquifer.

14. TMPOW-14

This open well is located in the compound of Panchayat office, Njarakkal Ward 3, North Paravur located in the sedimentary area, nearer to the westerly flowing Arabian Sea. Water table is at a raised condition. Quality problem exists due to coastal effect.

15. TMPOW-15

This well is located in the sedimentary area, north of Siva temple and opposite to TDHS, Mattanchery. The water table is at a raised condition and water quality problem exists due to the influence of coastal inputs. The station was preferred due to the above reasons.

Thus total 15 wells including twelve open wells and three bore wells were chosen for the study. The study period was from September 2007 to May 2008. Samples were collected during September 2007, January 2008 and May-June 2008.Water levels were measured for September 2007, January 2008 and May-June 2008.

5.4 WATER LEVEL VARIATION IN THE SELECTED WELLS

The depth of the wells in the study area varies from 2.27 to 16 m for open wells and 20 to 66 m for bore wells. Diameter of open wells ranges from 1.3 to 4.0 m for open wells. The maximum rise of above ground level was observed during monsoon 2007 for bore well TMPBW-12 in the Medicinal and Aromatic Plants Research Station at Odakkali drilled to a depth of 66 m and tapped in the charnockite formation. The water level lowering is minimum for this well as compared to other wells of the study area. The raised piezometric head of this station can be explained as follows. A subsurface dyke having 20 m length is constructed at 5 m distance away from this bore well. This sub-surface dyke acts as a barrier to the run off of groundwater between the layers of laterite and the bed rock. Hence during all seasons the water level is high. The open well, TMPOW-11 at this station also shows a raised water level. The max rise observed being 0.8 m below ground level.

TMPOW-06, Pallikkara the maximum rise in water level occurred was 1.45 m during monsoon 2007 while the max depth to water level reached was 13m below ground level during the pre-monsoon 2008.This can be explained by the aquifer characteristics of the location. The well is tapping in the laterite formation which becomes saturated at a high rate during monsoon. Water levels for specific study area shown in **Table 5.3**.

Table 5.3

WATER LEVELS OF WELLS

Well ID	Month	Water level, mbgl
TMPBW-04	9/2007	4.34
	1/2008	4.95
	6/2008	5.00
TMPBW-10	9/2007	1.00
	1/2008	4.07
	5/2008	1.02
TMPBW-12	9/2007	-0.21
	1/2008	0.71
	9/2007	0.36
TMPOW-01	1/2008	1.85
	6/2008	3.25
	9/2007	5.40
TMPOW-02	1/2008	10.25
	6/2008	11.90
	9/2007	12.30
TMPOW-03	1/2008	7.20
	6/2008	7.20
TMPOW-05	9/2007	4.67
	1/2008	3.57
	6/2008	6.45
TMPOW-06	9/2007	1.45
	1/2008	11.20
	6/2008	13.00
TMPOW-07	9/2007	6.80

	1/2008	8.66
	6/2008	10.00
TMPOW-08	9/2007	9.00
	1/2008	10.44
	6/2008	9.80
TMPOW-09	9/2007	2.45
	1/2008	3.15
	6/2008	3.05
TMPOW-11	9/2007	0.84
	1/2008	1.27
	6/2008	2.90
TMPOW-13	9/2007	0.97
	1/2008	1.75
	6/2008	1.45
TMPOW-14	9/2007	1.00
	1/2008	1.65
	6/2008	1.00
TMPOW-15	9/2007	1.54
	1/2008	0.95
	6/2008	1.00
TMPOW-CHK	6/2008	10.50

5.5 WATER QUALITY VARIATION

Water quality analysis was carried out to determine the overall chemical constituents of the groundwater in the selected locations in the monsoon 2007 and in the pre-monsoon and post-monsoon seasons of 2008.The results are discussed in subsequent sub-sections.

TMPOW-01

The well is located at the valley portion of the District Agricultural Farm, Neryamangalam. Analysed the various water quality parameters to assess suitability for drinking and irrigation. The maximum water level rise observed for this well was 1.85 m below ground level (mbgl) during monsoon 2007 and water level lowered to a maximum depth of 5.4 mbgl during the pre-monsoon 2008 (**Photo**

5.5). The minimum temperature measured was 29.5 ^{o}C for monsoon 2007 while the maximum being 30 ^{o}C for pre-monsoon 2008. pH lies within the range of 5.36 to 6.91. Electrical conductivity value was 41 µmho/cm during the post-monsoon 2008 while the maximum value observed was 53 µmho/cm during monsoon 2007. Total hardness lies between 10 and 15 mg/L and alkalinity between 9.8 and 14.6 mg/L. Concentration of sodium ranges from 4.3 to 7 mg/L while potassium lies between 1.48 and 1.85 mg/L. Sulphate and nitrate were having very low values and the range observed as 0 to 2 mg/L and 0.26 and 1.7 mg/L respectively. The minimum fluoride value observed was 0 and maximum value was 0.23 mg/L. Even though the well is located at the laterite formation, no iron content is observed. The total hardness always exceeds total alkalinity and sodium/chloride ratio is less than 1 during the study period. All parameters analyzed were within the permissible limits for drinking water, as per BIS. There is no marked change observed in the water quality parameters during the pre-monsoon, monsoon and post-monsoon periods.

Photo 5.5

Sampling Station- Neryamangalam

TMPOW-02

This open well is located inside the compound of Coconut Development Board, Neryamangalam. The maximum water level rise observed was 10.25 mbgl during monsoon 2007 and the water level lowering was 12.3 mbgl during May 2008.The water table was at a lowered condition in this area. The temperature of this station was 30 ^{0}C.The minimum pH was 5.29 (pre-monsoon 2008). The sample was acidic in nature and the pH remains out of the permissible range during this season. Electrical Conductivity value ranges from 39 to 45 µmho/cm ; total hardness 10-15 mg/L and bicarbonate alkalinity 2.9-9.8 mg/L. The well showed a minimum sodium value of 2.6 mg/L (monsoon 2007) and maximum value of 6.87 mg/L (pre-monsoon 2008) while for chloride, the minimum observed value was 4.9 mg/l and maximum 11.7 mg/L. The concentration of potassium ranges from 0.96-1.1 mg/L. For sulphate, very low values (max being 0.83 mg/L)and the nitrate-N concentration was minimum, 0.67 mg/L during the post-monsoon 2008 and maximum (3.3 mg/L) during monsoon 2007.Fluoride and iron concentration are negligible. The total hardness exceeds total alkalinity and Na/Cl ratio was within the range of 0.8-1.2. The water quality parameters except pH lie within the range of drinking water during the three seasons. Influence of monsoon is minimum for this well both in the case of water level and in the concentration of water quality parameters.

TMPOW-03

This open well placed in the premises of Poonkottukuzhiyil House, Anchalpetty, Puthusserippady. The monsoon water level rise was up to 4.2 mbgl while during pre-monsoon period, the well dries up. The temperature of sample during monsoon was 30 ^{0}C and at post-monsoon it was 29 ^{0}C. The pH of this well was around 7. The concentration of water quality parameters was lower during the monsoon season of 2007 as compared to the values in post-monsoon season. During monsoon 2007, a dilution effect was observed for the concentration of parameters such as total hardness, calcium ,sodium, potassium, bicarbonate alkalinity, chloride, sulphate, fluoride, iron etc., but an increase in concentration of magnesium and nitrate-N. Water was clear during rainy season. On the onset of summer, oily layer appears on the surface of this water.

TMPBW-04

This is a bore well built in the fractured charnockite formation inside the open well TMPOW-03. During monsoon, the water was odorless, but having a H_2S smell during the pre monsoon and post monsoon period. pH of the station ranges from 6.81 during monsoon 2007 to 8.12 post-monsoon 2008. Electrical conductivity value was lowest (111 µmho/cm) during the monsoon of 2007 and maximum, (192 µmho/cm) for pre monsoon 2008. Similar trend was observed for total hardness, total alkalinity, calcium, magnesium, sodium and potassium. During monsoon season, total hardness, calcium, magnesium, bicarbonate and sulphate ions are much lower in concentration as compared to other seasons. But variations in concentrations of sodium, potassium and chloride were not much prominent. Concentration of NO_3-N was maximum (4.58 mg/L) during the monsoon 2007. This may be due to the leaching of nitrates into the well during the rainy season. Fluoride values ranges from 0 in post-monsoon 2008 to 0.14 mg/L in pre-monsoon

2008. The concentration of iron during post-monsoon was 0 while during pre-monsoon it was 2.85 mg/L. Total alkalinity exceeds total hardness in the three seasons. During monsoon, the Na/Cl ratio comes below the range of 0.8 to 1.2. The open well TMPOW-03 and bore well TMPBW-04 having maximum concentration for NO3-N during monsoon season. This is due to the leaching of nitrates. The smell of H_2S in the bore well sample during pre-monsoon and post-monsoon season may be due to the reduction of sulphur bearing rocks/sulphates within the borewell under anaerobic conditions. In the case of the above two wells, the mixing of water from the phreatic zone and deeper zone results in similar values and trends in water quality parameters also. Depth of open well and bore well being 7.5 m and 20 m respectively.

TMPBW-05

This well located within the compound of Manakkalkara house, Pampakuda Panchayat, Anchalpetty. The water level varies from 3.57 mbgl during post-monsoon 2008 and 6.45 mbgl during pre-monsoon 2008 (depth of well is 6.7 m). Due to the seepage from the unlined canal, the phreatic aquifer becomes saturated throughout and the open well remains full throughout the year. Bore well constructed within the open well is dry since the deeper aquifer has no connection with the phreatic aquifer.

The pH of the well varies from 6.24 during pre-monsoon 2008 and 7.19 monsoon 2007and EC ranges between 40 during post-monsoon 2008 and 48 μmho/cm during monsoon 2007. Total hardness during monsoon 2007 was 15 mg/L and post-monsoon and pre-monsoon 2008 was 10 mg/L. Same trend was observed for bicarbonate alkalinity. The values being 17.1 mg/L monsoon 2007 and 12.2 mg/L for post and pre-monsoon of 2008. The sodium value ranges from 7.5 mg/L monsoon 2007 to 3.1 pre-monsoon 2008. The concentration of potassium ranges from 5.4 mg/L monsoon 2007 and 2.2 mg/L during pre-monsoon 2008. The chloride and sulphate concentration varies slightly during the entire period and concentration of nitrate-nitrogen was very negligible. Concentration of fluoride was 0.3 mg/L during monsoon 2007 and 0.13 mg/L during post-monsoon 2008. Values of Iron varies from 0.2 mg/L during monsoon 2007 and 0.65 mg/L during pre-monsoon 2008. The values for electrical conductivity, bicarbonate, total hardness, calcium, sodium and potassium during monsoon 2007 were higher than the values at pre-monsoon 2008 but concentration of Mg, Cl and fluoride were higher during the monsoon period. Leaching of ions as calcium, bicarbonate, sodium and potassium in to the well during monsoon may be one of the reasons for this. It was also observed that there was no profound variation in the pre-monsoon and post-monsoon values of water quality parameters, since the source of water was continuous seepage from the canal. The monsoon values were higher than these values due to the subsurface leaching of water quality components during the rainy season. The total hardness exceeds total alkalinity during the monsoon season only. On the contrary, the Na/Cl ratio is well within the range of 0.8-1.2 during monsoon and post-monsoon, but it was far below the range during pre-monsoon period.

TMPOW-06

This open well is located at the premises of Kayyalath house, Manakkalkadavu, Pallikara. The water level varies from 1.45 mbgl during monsoon

2007 and 13 mbgl during pre-monsoon 2008.The water level fluctuation was very high for this well. This can be explained by the aquifer characteristics of the location. The well is located in the laterite formation which become highly saturated by monsoon owing to the aquifer permeability. The water table lowers during pre-monsoon season due to high slope of the location. pH of the well ranges between 6.82 (May 2008) and 7.69 (May 2007). This is well within the range of pH 6.5-8.5 prescribed by BIS. EC value ranges from 84 (September 2008) to 200 µmho/cm (May 2008). Total hardness varies from 85 (May 2008) to 30 mg/L (September 2007) while, bicarbonate alkalinity varies from 41.50 (September 2008) to 87.8 mg/L (May 2007). Concentration of sodium and potassium were 7.2 mg/L and 5.70 mg/L during the pre-monsoon and 3.9 and 1.49 mg/L respectively during monsoon. Concentration of sodium having the same trend of chloride. Sulphate varies from 16.36 (May 2007) to 2.7 mg/L (January 2008) while nitrate-N is 2.7 mg/L during pre-monsoon 2008 and 0 during monsoon 2007. Concentration of fluoride is below the permissible limit 0.46 mg/L during pre-monsoon and 0 mg/L during monsoon. Concentration of Iron exceeded the desirable range of the BIS guidelines, but it is well within the maximum permissible limit. The total alkalinity exceeds the total hardness and Na/Cl ratio was within the range of natural water.

TMPOW-07

This open well, exclusively used for domestic purpose is located at Puthenkudy house, Pookattupady, Kizhakkambalam Panchayat. The water table of the well was in the lowered condition during September 2007 to May 2008. The water level was 7.64 mbgl during monsoon 2007 and 11.24 mbgl during pre-monsoon 2008. During the entire season, the total hardness exceeds the total alkalinity and Na/Cl ratio falls well within the range of 2.8-1.2 for natural water. The lowest pH of 4.06 was observed during post-monsoon 2008 and the maximum pH 5.53 was reached during monsoon 2007. This may be due to the slight dissolution of bicarbonates into the water. The conductivity during monsoon was 59 µmho/cm and the pre-monsoon value reach up to141 µmho/cm. The total hardness value for monsoon, 2007 was 10 mg/L and the maximum value of 20 mg/L is reached during post-monsoon 2008. The maximum sodium and chloride concentrations were 4.4 mg/L and 5.9 mg/L respectively during monsoon 2009 and 10.5 mg/L and 19.4 mg/L respectively during pre-monsoon 2008. The minimum potassium concentration was 1.03 during January 2008 and maximum concentration of 2 mg/L is observed during May 2008. Sulphate value ranges from 4.6 mg/L (May 2008) and 1.67 mg/L during January 2008 while concentration of nitrate ranges from 1.8 (September 2007) to 7.8 mg/L during May 2008. Fluride and iron concentration estimated were negligible for this location.

TMPOW-08

The well located at the Binanipuram Hospital Compound, Edayar has a depth of 16 m, dug into the charnockite formation. The maximum rise in water level was 9 m during the monsoon 2007 and maximum lowering in pre-monsoon 2008 was 10.44 m. It was observed that the difference in water level during monsoon and pre-monsoon is not very much. This can be explained by the lithology of the well. Topsoil covers up to 3 m, up to 8.5 m reddish brown laterite and till 14.6 m depth, yellow coloured fine textured clay exists. The depth of the well is 16 m and up to that, grey colored charnockite exists. Due to reduced permeability of the clay layer, the water level fluctuation was very less. pH of the well varies from 4.76 (during monsoon) and 6.58 (during post-monsoon). Electrical conductivity varies from 31 during September 2007 to 45 µmho/cm during May 2008. Total hardness remains the same throughout the study period. During pre-monsoon season there was only a slight increase in the concentration for all parameters. But the nitrate value is maximum during the monsoon period. This can be explained as: The result of monsoon rainfall, the nitrate in the soil column leaches into the well. The corresponding anion absorbed in the soil/clay column. The total hardness exceeds total alkalinity during monsoon 2007. This increase may be contributed by the nitrate anion leached into the well. The Na/Cl ratio was far below the range for natural water. This may be due to the absorption of sodium ions in the clay layer. Concentration of iron ranges from 0.1 during September 2007 while the pre-monsoon value was 1.72 mg/L. During post-monsoon and pre-monsoon, iron concentration exceeds the BIS permissible limits.

TMPOW- 09

The depth of the well is 4 m. The water level variation in the well was minimum. The water level during monsoon was 2.45 while in pre-monsoon, the water level was 3.25 mbgl. The well never dries up due to the water in the nearby canal. Hardness and alkalinity were higher during the monsoon season. This may be due to the dissolution of hardness causing minerals by the slightly acidic water. The pH value ranges from 5.54 during pre-monsoon 2008 and 7.03 during post-monsoon 2008. EC value was minimum 36 µmho/cm during post-monsoon and maximum50 µmho/cm during monsoon. TH during monsoon was 20 mbgl and for pre-monsoon was 10 mbgl. The calcium concentration shows a decreasing trend while the Mg concentration remains constant during the entire study period. The post-monsoon values for EC, Na, Cl and Nitrate-N were lower than the pre-monsoon values. pH, sulphate, TH, Ca, K, F and Fe were higher than the pre-monsoon period. The fluoride and iron concentration were well below the drinking water permissible limits of BIS. During the 3 seasons, the TH was less than TA and Na/Cl ratio was less than 0.8-1.2. The sodium concentration may be adsorbed on the soil strata.

TMPBW-10

pH of the station varies from 7.43 (pre-monsoon 2008) to 8.72 (post-monsoon 2008). EC was in between 310 to 340 µmho/cm. Total hardness remain the same throughout the study period. But the concentrations of Ca, Mg and HCO_3 varies in each season. Na and K do not vary much. Chloride ranged from 13.7 to 25 mg/L during monsoon and post-monsoon respectively. During monsoon 2007, nitrate-N concentration was zero while it was 1.3 mg/L during pre-monsoon 2008. Concentration of iron during post-monsoon was 1.94 mg/L. TA exceeds TH and Na/Cl ratio is much higher than that of natural water.

TMPOW-11

The depth of the well is 6.2 mbgl. The water level during monsoon was 0.84 mbgl and during pre-monsoon it was 2.9 mbgl. Water level never falls below 2.9 m even though the depth of the well is 6.2 m. The raised water table in this station was constructed 20 m long at a distance of 5 m away from the well. The pH of this station was 5.7 during monsoon 2007 and 7.19 during the post-monsoon 2008 period. EC values were very low as compared to other wells and ranges from 34 (January 2008) to 49 (September 2007) µmho/cm. The increased Electrical conductivity was due to the increased values of Ca, TH, Na, K, and Cl during monsoon period. The pre-monsoon values of Ca, TH, Na, and sulphate were lower than the values during monsoon period. Nitrate concentration was not detected during the entire study period. F-concentration ranges from 0.14 (May 2008) to 0.25 (January 2008) and Fe concentration was the lowest during monsoon while maximum (1.0 mg/L) during pre-monsoon period. The TH exceeds the TA during the three seasons. Na/Cl ratio was within the range (0.8-1.2) for natural water. There was no severe water level fluctuation and water quality variation.

TMPBW-12

This station having a pH above 8.3 during all seasons and EC remains the same throughout the study period. The variations in EC, TH, TA, SO_4 are minimum. Concentration of NO_3-N was negligible whereas concentration of sodium and bicarbonate were high. Iron content is always below the desirable limit of BIS. Concentration F was comparatively higher (0.97 mg/L) during post-monsoon 07. Total alkalinity is much higher than total hardness during all seasons. Water type is Na-HCO_3.

TMPOW 13

The total depth of the well is 3.5m and the formation is sand. The maximum rise in water level was 0.97 mbgl during monsoon 2007 and an extreme lowering of 1.75 m was viewed during post-monsoon 2008. The water level fluctuation was not prominent and throughout the year there was no water scarcity. This is due to the fact that the aquifer is a potential one at lower elevation. The minimum pH observed was 8.29 during pre-monsoon and the maximum pH reached 9.0 during post-monsoon 2008. The water was alkaline throughout the study period. The alkalinity values also support this. The dissolution of carbonate minerals makes the water more alkaline in the post-monsoon. The minimum electrical conductivity observed was 370 µmho/cm during September 2007 and maximum 470 µmho/cm was reached during January 2008. The maximum hardness was 220 mg/L during January 2008. All parameters except fluoride reached maximum concentration during January 2008. The water level was lowest during post-monsoon 2008 and maximum concentrations in water quality parameters were reached in this period. Due to this dissolution of carbonate minerals, there is a corresponding increase in hardness and alkalinity also. TA exceeds the TH and the Na/Cl ratio was within the permissible range of natural water.

TMPOW 14

The water level rise during monsoon 2007 was 1 mbgl and the maximum depth of water level lowering was 2.4 mbgl during pre-monsoon 2008. The minimum pH was 8.37 during post-monsoon and maximum pH of 8.7 was reached during monsoon. Electrical conductivity ranges from 300 during January 2008 to 400 µmho/cm during monsoon period.TH, Ca, Mg, TA, HCO_3 etc., were highest during monsoon 2007.This is due to the dissolution of carbonate minerals by rain. Minimum values of EC, Na, Cl and sulphate were observed during post-monsoon 2007. Maximum values of EC, Na, Cl and sulphate were observed during pre-monsoon 2008; but K, F and Fe were maximum during post-monsoon 2008. Nitrate was not detected during the entire study period. The station received minimum rainfall during December 2007 and January 2008 (Naval Air Station, Kochi). The TH exceeded TA and NaCl ratio was less than the range for natural water (0.8-1.2).

TMPOW 15

The water level during monsoon was 1.0 mbgl and during post-monsoon 2008, it goes up to 1.8 mbgl. The minimum pH observed was 8.23 during monsoon 2007 and 8.5 during post-monsoon. The alkalinity values strongly support this inference. Electrical conductivity ranged from 700 µmho/cm during post-monsoon 2008 and 500 µmho/cm during monsoon 2007.The high electrical conductivity during post-monsoon was due to the increased values of Na, K, Cl and sulphate. The electrical conductivity value was the lowest during monsoon 2007 with a corresponding lowest values for Na, K, Cl, F, Fe but maximum values for TH, Mg, TA and HCO_3. The highest values of EC, Na, K, Cl, SO_4, Nitrate-N, F and Fe during post-monsoon, 2008 was due to the concentration of the parameters since no dilution was experienced due to scarce rainfall during December 2007 and no rainfall during January 2008. The TH exceeds TA and the difference is maximum during pre-monsoon 2008. The Na/Cl ratio is significantly higher than that for natural waters.

5.6 HYDROGEOCHEMICAL ASSESSMENT OF SPECIFIC STUDY WELLS

Tables 5.2d, 5.2e and **5.2f (Annexure)** represents the major ion constituents. All water samples collected were colourless. Most of the samples in the sedimentary area and borewells were alkaline in nature. The overall high pH values were due to the high bicarbonate concentration of geological origin. The desirable limit of pH prescribed for drinking water by BIS and WHO (1984) is 6.5–8.5. Conductivity values in the study area ranged between 31 and 700 µmhos/cm, with the minimum concentration accounted in sample TMPOW-08 during monsoon 2008 and maximum EC value was observed in sample TMPOW-15 during post-monsoon 2008. All the EC values were within the prescribed limits of 3000 µmhos/cm (BIS). A total dissolved solid (TDS) is a measure of the dissolved solids present in the water. The TDS values range between 20.4 and 420 mg/L. Usually unconfined aquifer system has relatively low TDS (Langmuir.1997). The hydro-geological properties of rocks will have a strong influence on the extent of water/rock reaction. Zones with high groundwater-flow velocities usually will have relatively low dissolved solids because of the shorter groundwater-rock contact time and high water/rock ratios, and vice-versa (Langmuir, 1997). The low TDS values could be attributed to the prevailing of high rainfall, which causes significant dilution. All the TDS values were within the permissible limit 2000 mg/l (BIS 1998). Dissolved oxygen (DO) is one of the most important parameters in water quality assessment and reflects the physical and biological processes prevailing in the water. The observed DO values were in the range of 0.56 and 5.04 mg/l. Minimum and maximum value for dissolved oxygen was observed for sampleTMPOW-05 and TMPOW-15 during monsoon 2008. Total hardness was found to be in the range of 10 to 220 mg/L. All the samples showed Total Hardness well within the prescribed limit of 600 mg/L (BIS 1998). An alkalinity value ranged between 0 and 238 mg/L and is within the prescribed limits of 600 mg/L (BIS

1998). The concentration of Fe in the study area varies from 0.01 to 2.85 mg/L. Majority of the water samples were within the prescribed limits (BIS 1998). The maximum value of Fe was noted in sample TMPOW-04 during pre-monsoon 2008. This is due to the passage of groundwater through the strata liberating iron.

Na values ranged from 2.3 to 118 mg/L while K values ranges from 0.44 to 13.2 mg/L. The natural source of potassium in water is usually from the chemical weathering and subsequent dissolution of minerals in local igneous rocks such as feldspars (orthoclase and microcline), mica and sedimentary rocks as well as silicate and clay minerals (Howari and Banat 2002). Low concentration of K may be due to greater resistance of K mineral to weathering and its fixation in the formation of clay minerals (Sarin et al. 1989).

Fluoride concentration is an important criteria in hydro-geochemical quality due to its impact on human health. Low fluoride content (<0.6 mg/L) causes dental caries, whereas high fluoride levels(>1.50 mg/L) results in fluorosis. Hence it is essential to have a safe limit of fluoride concentration between 0.60 and 1.50 mg/L in drinking water. In this study majority of the water samples were below the permissible limit. The nitrate-N values ranged from 0 and 7.8 mg/L. All the samples showed nitrate-N values within the permissible limit (10 mg/L). The sulphate concentration ranged between 0 and 112.8 mg/L and lies within the permissible limit of 400 mg/L (BIS 1998). The lowest sulphate concentration of 0 mg/L was found in the sample TMPOW-01 and 02 during pre-monsoon 2008 and highest (112.8 mg/L) has been observed in sample TMPOW-15 in post-monsoon 2008. Phosphate values varied from 0 to 7.91 ppb during the study period. Chloride concentrations vary from 3.9 to 42 mg/L and were well within the permissible limit of 1000 mg/L.

5.7 RESULTS OF TRACE METALS AND PESTICIDES

The samples from these selected stations of the study area were also analyzed for trace metals and pesticides. Trace metals includes lead, copper, zinc, manganese, cadmium and arsenic. Pesticides include organochlorines, organo phosphorous, carbamates and other commonly used pesticides as synthetic pyrethroids were analysed in the Interfield Laboratories, Cochin. The analytical techniques used and procedures adopted were given in **Chapter II.**

Concentration of lead, zinc, cadmium and arsenic were below the permissible limits as per BIS (1991). For TMPOW-02 concentration of copper was above the desirable limits but it was below the permissible limit during the monsoon and post monsoon periods. Concentration of manganese was above the permissible limit for TMPBW-04 (1797µg/L). For TMPBW-10 concentration of manganese was 907 µg/L during monsoon 2007 and 887 µg/L during post-monsoon 2008 (**Tables 5.4, 5.4a** and **5.4b**).

Table 5.4

Concentration of Trace metals and Pesticides in Groundwater during Monsoon 2007

Sl. No.	Well ID		Pb ppb	Cu ppb	Zn ppb	Mn ppb	Cd ppb	As ppb	Pesticides
Desirable limit (BIS)			**50**	**50**	**5000**	**100**	**10**	**10**	**Absent**
Permissible limit (BIS)			**50**	**1500**	**15000**	**300**	**10**	**10**	**0.001**
1	TMPOW-01	OW	7.09	ND	7.3	28.49	ND	ND	ND
2	TMPOW-02	OW	23	96.75	10.7	21.32	ND	ND	ND
3	TMPOW-03	OW	ND	ND	8.9	ND	ND	ND	ND

4	TMPBW-04	BW	16.74	30.49	416.8	15.8	ND	ND	ND
5	TMPOW-05	OW	ND	ND	9.8	13.84	ND	ND	ND
6	TMPOW-06	OW	ND	ND	10	ND	ND	ND	ND
7	TMPOW-07	OW	5.37	ND	8.5	18.72	ND	ND	ND
8	TMPOW-08	OW	8.52	ND	12	39.8	ND	ND	ND
9	TMPOW-09	OW	ND	ND	ND	ND	ND	ND	ND
10	TMPBW-10	BW	6.29	ND	ND	907	ND	ND	ND
11	TMPOW-11	OW	8.15	ND	ND	ND	ND	ND	ND
12	TMPBW-12	BW	8.46	ND	6.4	ND	ND	ND	ND
13	TMPOW-13	OW	ND	ND	10	ND	ND	ND	ND
14	TMPOW-14	OW	ND	ND	11.7	10	ND	ND	ND
15	TMPOW-15	OW	ND	ND	8.4	17	ND	ND	ND

Table 5.4a

Concentration of Trace metals and

Pesticides in groundwater during Post-monsoon 2008

Sl. No.	Well ID	Type of Well	Pb ppb	Cu ppb	Zn ppb	Mn ppb	Cd ppb	As ppb	Pesticides
Desirable limit (BIS)			**50**	**50**	**5000**	**100**	**10**	**10**	**Absent**
Permissible limit (BIS)			**50**	**1500**	**15000**	**300**	**10**	**10**	**0.001**
1	TMPOW-01	OW	ND	ND	ND	ND	ND	ND	ND
2	TMPOW-02	OW	16.3	57	11	24.6	ND	ND	ND
3	TMPOW-03	OW	ND	ND	11.6	ND	ND	ND	ND
4	TMPBW-04	BW	13	69	382.7	1797	ND	ND	ND
5	TMPOW-05	OW	ND	ND	11.3	437	ND	ND	ND
6	TMPOW-06	OW	6.3	ND	17.6	34.3	ND	ND	ND
7	TMPOW-07	OW	ND	ND	9.5	16.4	ND	ND	ND
8	TMPOW-08	OW	5.2	ND	27.3	45.5	ND	ND	ND
9	TMPOW-09	OW	ND	ND	9.4	ND	ND	ND	ND
10	TMPBW-10	BW	15	69.7	20	877	ND	ND	ND
11	TMPOW-11	OW	ND	ND	9	11.1	ND	ND	ND
12	TMPBW-12	BW	ND	ND	59	41	ND	ND	ND
13	TMPOW-13	OW	ND	ND	41	54	ND	ND	ND
14	TMPOW-14	OW	ND	ND	6	15.3	ND	ND	ND
15	TMPOW-15	OW	ND	ND	5.6	39.5	ND	ND	ND

Table 5.4b

Concentration of Trace metals and Pesticides in groundwater

Pre-monsoon 2008

Sl. No.	Well ID	Type of Well	Pb ppb	Cu ppb	Zn ppb	Mn ppb	Cd ppb	As ppb	Pesticides
Desirable limit (BIS)			**50**	**50**	**5000**	**100**	**10**	**10**	**Absent**
Permissible limit (BIS)			**50**	**1500**	**15000**	**300**	**10**	**10**	**0.001**
1	TMPOW-01	OW	ND	ND	6	14.5	ND	ND	ND
2	TMPOW-02	OW	ND	ND	12.4	16.8	ND	ND	ND
3	TMPOW-03	OW	Dry						
4	TMPBW-04	BW	ND	ND	44.4	353	ND	ND	ND
5	TMPOW-05	OW	ND	ND	6.4	10	ND	ND	ND
6	TMPOW-06	OW	ND	ND	6.5	33.66	ND	ND	ND
7	TMPOW-07	OW	ND	ND	13.5	84.55	ND	ND	ND
8	TMPOW-08	OW	ND	ND	70.8	85.76	ND	ND	ND
9	TMPOW-09	OW	ND	ND	ND	ND	ND	ND	ND
10	TMPBW-10	BW	ND	ND	12.6	185	ND	ND	ND
11	TMPOW-11	OW	ND	ND	ND	24.25	ND	ND	ND
12	TMPBW-12	BW	ND	ND	47.7	13.84	ND	ND	ND
13	TMPOW-13	OW	ND	ND	ND	15.43	ND	ND	ND
14	TMPOW-14	OW	ND	ND	ND	12.48	ND	ND	ND
15	TMPOW-15	OW	ND	ND	ND	32.94	ND	ND	ND
16	TMP CHK-16	OW	ND	ND	ND	51.4	ND	ND	ND

All pesticides analysed were below the detectable limit. Pesticide standard addition was also conducted to find out the accuracy of the analysis. Analysis was performed on a check sample also (TMP CHK-16) during the pre-monsoon 2008. This sample was used by a large community for drinking as well as all purpose aesthetic activities.

5.8 WATER TYPE OF SPECIFIC STUDY WELLS

From the major ion composition, calculated the water type by making use of AQUACHEM (**Table 5.5**) and piper diagrams shown in **Figure 5.2, 5.3** and **5.4**.

Table 5.5

WATER TYPE OF SPECIFIC STUDY WELLS

Well ID	Location	MONSOON 2007	POST-MONSOON 2008	PRE-MONSOON 2008
TMPBW-04	H/O PKBaby, Anchalpetty, Puthusserippady	Ca-Na-Cl-HCO_3-NO_3	Mg-Ca-HCO_3-Cl	Mg-Ca-HCO_3
TMPBW-10	District Seed Farm, Okkal, (Chelamattam)	Ca-Na-HCO_3	Ca-Na-Mg-HCO_3	Ca-Mg-Na-HCO_3
TMPBW-12	MPRS, Odakkali (Assamannoor)	Na-HCO_3	Na-HCO_3	Na-HCO_3
TMPOW-01	District Agricultural Farm, Neryamangalam	Na-Ca-Cl-HCO_3	Mg-Na-HCO_3-Cl	Na-Mg-Cl-HCO_3
TMPOW-02	Coconut Development Board, Neryamangalam	Na-Ca-Mg-NO_3-Cl-HCO_3	Mg-Na-Ca-Cl-HCO_3-NO3	Mg-Cl-NO_3-HCO_3
TMPOW-03	H/O PKBaby, Anchalpetty, Puthusserippady	Mg-Na-Ca-Cl-NO3-HCO_3	Ca-Na-HCO_3-Cl	-
TMPOW-05	H/O Azhakan, Manakkalkara, Pampakuda Panchayat	Na-Ca-HCO_3-Cl	Ca-Na-Cl-HCO_3	Mg-Na-Cl-HCO_3

TMPOW-06	H/O Biju Kurien, Manakkalkadavu, Pallikkara	$Ca-HCO_3$	$Ca-HCO_3-Cl$	$Mg-Ca-HCO_3-Cl$
TMPOW-07	Pookattupady, Kizhakkambalam	$Na-Ca-Mg-Cl-NO_3-HCO_3$	$Na-Ca-Mg-Cl-SO_4$	$Na-Cl-NO_3$
TMPOW-08	BHC, Edayar	$Ca-Mg-Na-Cl-NO_3-HCO_3$	$Na-Ca-Mg-HCO_3-Cl$	$Mg-Na-HCO_3-Cl$
TMPOW-09	Keezhillam, Mazhuvannoor Panchayat	$Ca-Mg-Na-HCO_3-Cl$	$Mg-HCO_3-Cl$	$Mg-Na-HCO_3-Cl$
TMPOW-11	MPRS, Odakkali (Assamannoor)	$Mg-Na-Ca-HCO_3-Cl$	$Na-Ca-Mg-HCO_3-Cl$	$Mg-Na-HCO_3-Cl$
TMPOW-13	Pallippuram, Cherai	$Ca-HCO_3$	$Na-Ca-HCO_3$	$Ca-HCO_3$
TMPOW-14	Njarakkal, Ward 3, Panchayat Office	$Ca-HCO_3$	$Ca-HCO_3$	$Ca-HCO_3$
TMPOW-15	Mattancherry, Vypin	$Ca-Mg-HCO_3$	$Ca-Na-HCO_3-SO_4$	$Ca-Na-HCO_3-Cl$
TMPOW CHK-16		-	-	$Na-Cl-NO_3$

The water type of bore well TMPBW-12 is $Na-HCO_3$ type and it remains the same throughout the study period. No variation in water types for the coastal wells viz., Pallippuram, Njarakkal Ward 3 and Mattancherry.

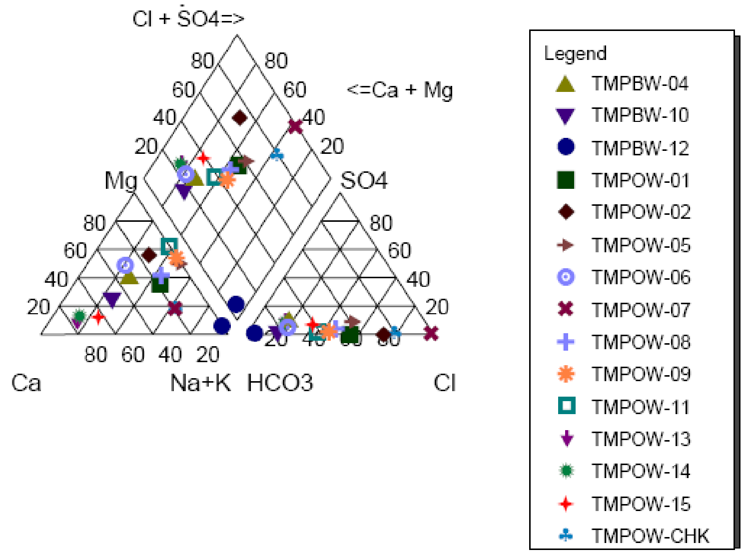


Figure 5.2

PIPER PLOT OF SPECIFIC STUDY WELLS (MONSOON 2007)

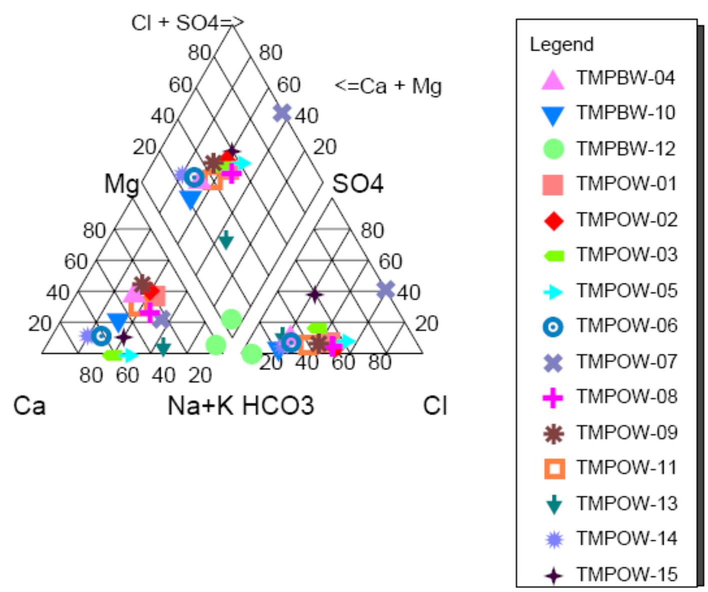


Figure 5.3

PIPER PLOT OF SPECIFIC STUDY WELLS (POST-MONSOON 2008)

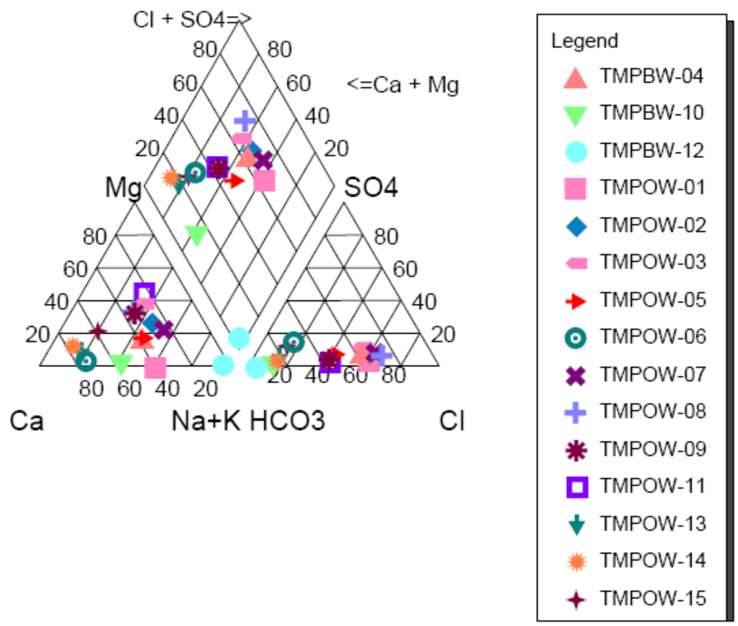


Figure 5.4

PIPER PLOT OF SPECIFIC STUDY WELLS (PRE-MONSOON 2008)

5.9 ASSESSMENT OF IRRIGATION QUALITY

Based on the physic-chemical analysis, irrigation quality parameters : % Na, Sodium Adsorption Ratio, RSC, KR and Residual Mg/Ca ratio were calculated and represented in **Table 5.6**.

According to the classification of water samples with respect to SAR all the samples belongs to "Safe" category except TMPBW-12 at Odakkali. Based on the Residual Mg/Ca ratio, the groundwater samples can be classified as "Suitable" or "Unsuitable" for irrigation. In this study, all samples are under "Safe" category except TMPBW-12 at Odakkali which falls in moderate class. As per % Na, RSC and KR classification TMPBW-12 at Odakkali comes under the "Unsuitable" category.

Irrigation suitability for these specifically studied 15 wells was determined. The irrigation water quality parameters analyzed were Percent Sodium (%Na), Sodium Adsorption Ratio (SAR), Residual Mg/Ca Ratio, Residual Sodium Carbonate (RSC) and Kelly's Ratio. TMPBW-12 at Odakkali records %Na and RSC and KR in the "Unsuitable" category while SAR and Mg/Ca ratio in the Good/Moderate class. This can be explained as: The station having alkalinity above 8.3 during the three seasons. The sodium and bicarbonate concentration were also high. The water type was Na-HCO_3 type. Piper classification also justifies the above inference. Due to the high alkalinity and sodium concentration the water falls under the "Unsafe" category of irrigation quality. In terms of Kelly's Ratio, TMPOW-10 is classified as "Marginal".

Table 5.6

Classification based on Irrigation Quality Parameters

Parameters	Range	Water Class	Number of Wells		
			JAN 2008	MAY 2008	SEP 2007
%Na (Wilcox 1995)	<20	Excellent	2	2	3
	20-40	Good	8	6	5
	40-60	Permissible	4	4	6
	60-80	Doubtful		1	
	>80	Unsuitable	1	1	1
%Na (Eaton 1950)	<60	Safe	14	13	14
	>60	Unsafe	1	2	1
Alkalinity hazard (SAR) (Richard 1954)	<10	Excellent	15	14	14

	10-18	Good		1	1
	18-26	Doubtful			
	>26	Unsuitable			
Residual Mg/Ca ratio	<1.5	Safe	14	13	15
	1.5-3.0	Moderate	1	2	
	>3.0	Unsafe			
RSC (Richard 1954)	<1.25	Good	14	14	13
	1.25-2.50	Doubtful			1
	>2.5	Unsuitable	1	1	1
KR(1940, 1951., Paliwal 1967)	<1	Suitable	13	12	13
	1--2	Marginal	1	2	1
	>2	Unsuitable	1	1	1

5.10 CORRELATION ANALYSIS

The correlation coefficient values exhibiting +1 or -1 between the variables reveal that there exist strong correlation and the value at zero indicates no relationship between them. In general, the geochemical parameters showing correlation coefficients greater than 0.7 are considered to be strongly correlated, whereas value between 0.5 and 0.7 shows moderate correlation. The correlation coefficients among the water quality parameters pH, EC, TDS, DO, nitrite, nitrate, phosphate, sulphate, iron, fluoride, silica, chloride, Na, K, alkalinity, total hardness, carbonate, HCO_3 , Mg and Ca were calculated for correlation analysis. The correlation matrix **(Tables 5.7, 5.8** and **5.9 Annexure)** shows significant positive and negative correlations.

Chapter-VI

OVERALL SUMMARY AND REMEDIAL MEASURES FOR REMARKED WELLS

6.1 Introduction

6.2 Physical and Chemical Aspects

6.3 Chemical Causing Water Related Diseases

6.4 Water Quality Standards

6.5 Traditional Methods of Purification

6.6 Socio-Economic Effect of Water Quality in the Dug-Cum-Bore Wells of Anchalpetty in Pampakkuda

Chapter-VI

OVERALL SUMMARY AND REMEDIAL MEASURES FOR REMARKED WELLS

6.1 INTRODUCTION

In the environment although water is commonly thought of as simply H_2O, many other substances are dissolved in it. Most of these substances occur naturally and many are present in water only in small quantities. The term “Water Chemistry” (or water quality) refers to the presence of these substances or solutes in a water sample making its chemical composition. The water chemistry of a ground water sample can be thought of as a chemical signature that reflects the sum total of all physical processes and chemical reactions that affected the water from the time it began as: dilute rainfall, infiltrated the soil above the water table, passed into the aquifer (ground water recharge) and travelled, sometimes over great distances and depth to the point of sample collection or discharge from the aquifer. Water acquires very small quantities of some solutes from dust and gases when it falls through the atmosphere as precipitation but water typically acquires the majority of its solutes once.

Water is an elixir of life. The parameter of socio-economical development of the society is average consumption of water for all-purpose per person. The mankind has wide range of water utility activity but direct intake of water for sustenance of life is of prime importance. Average intake of water by individual is 3.1% of body weight. Water is one of the most important media for transmission of diseases. The life sustains on water as one of the elements.

Therefore qualitatively safe and adequate volume of acceptable water should be made available. More than 1.1 billion people in the world have no access to safe drinking water and double the number do not have access to sanitation. Estimated amount of fresh water potentially available for human use including groundwater, fresh water lakes and rivers is 0.629%. However, in the present context, the water availability has diminished considerably and whatever little that is available to us is getting polluted day by day. Organizations like government, non-governmental, bilateral, multilateral agencies and many more are striving their best to combat the grim situation. They are so committed to provide access to safe drinking water and adequate water supply to every individual in both rural and urban areas. Lack of proper planning, management and deficient funds are the reasons for the short of progress in this area.

In the Indian context, Government of India and all State Government departments are committed to provide safe drinking water and adequate water supply to every individual in rural areas. The Department of Drinking Water Supply, Ministry of Rural Development, and Government of India has taken this issue as a national mission. According to the current policy the Department of Drinking Water Supply emphasizing on the need of community involvement as well as participation and capacity development of all stakeholders in maintaining sustainable safe water supply system. In this context the Department of Drinking Water Supply in association with different State Governments has taken up sector reform programme wherein special thrust is being given on community based management programme on rural water supply. Such thrust includes capacity building and training at different levels from policy makers, administrators, implementers, caretakers and community as a whole. The organizational set up, effective and smooth functioning of routine water quality monitoring should match the objectives set forth to ensure supply of safe and protected water supply to the community in urban, peri-urban and rural areas.

Poor environmental sanitation and unsafe drinking water have been one of the major health problems in India. Water and sanitation related infections and the diseases of the alimentary tract constitute 60% - 80% of the illness. Many of them, such as diarrhea, dysentery, typhoid fevers, intestinal helminthiasis, jaundice, cholera are endemic in scientific India, particularly in the rural areas. In spite of significant progress and technical fields there is no significant change in the situation since attainment of independence. While the rural areas continue to be in sanitary, rapid industrialization and associated growth of the urban population during the last 25 years to 30 years have adversely affected the environmental sanitation of the major cities. The diseases related to water supply and sanitation are numerous and the relationships are sometimes complex. Our water resources are not only getting depleted but also getting contaminated due to increased pressure of various human activities. Different human activities that may contaminate water are: open defecation, bathing, washing, disposal of cremation wastes in and around water source, untreated sewage, industrial and nuclear wastes, leaching of chemicals like fertilizers and pesticides, acid rain, thermal pollution, soil erosion etc. Availability of fresh water in ample quantity and awareness to the public on general neatness will prevent spreading of large number of water bore diseases.

Besides, physicochemical components also contribute for the water quality to a large extent.

6.2 PHYSICAL AND CHEMICAL ASPECTS

Although the great majority of water quality problem are related to bacteriological or other biological contamination, a significant number of very serious problems may occur, even in rural areas, as a result of chemical contamination of water sources, such contamination may arise from certain agro-based industries, mining etc., or from agricultural practices or malpractice (e.g. use and misuse of nitrates as fertilizer) or from natural sources (e.g. iron, manganese, fluoride and arsenic etc). In order to establish such problems, a selected number of physico-chemical parameters may be measured.

In case there are chemical constituents of local significance (arsenic, iron, manganese and fluoride), the levels must be measured and results evaluated in the light of the guideline values. There are a few indicating parameters of practical importance, which can provide useful guidance in assessing water quality.

Turbidity

High levels of turbidity can shield and protect bacteria from the action of disinfecting agents, stimulate growth of the bacteria and exert significant chlorine demand. Hence, water should be of low turbidity. The recommended guideline value as per BIS is 5 NTU, but levels should be below 1 NTU when disinfection is practiced. Turbidity in excess of 10 NTU constitutes ground for rejection.

Colour

Colour in drinking water may be due to the presence of organic matter as humus substances, metals such as iron and manganese or highly coloured industrial waste waters. Drinking water should be colourless so that it should be aesthetically pleasing.

Taste and Odour

Odour in water is mainly due to the presence of organic substances. Increased biological activity may also be the cause of certain types of odour. Others may have their origin in industrial pollution. The possible and existing sources of odour should always be investigated and eliminated by taking corrective measures. The combined perception of substances detected by the senses of taste and smell is often termed as 'Taste' and the problem of taste in drinking water supplies represent the largest single class of consumer complaints. Generally, the taste buds in the oral cavity specially detect inorganic compounds of metals like magnesium, calcium, sodium, copper, iron and zinc. Changes in the normal taste of a public water supply may signal changes in the water quality of raw water sources or deficiencies in the treatment process. Since water should be free from objectionable taste and odour for the large majority of consumers, the guideline criterion is not offensive to most of the consumers.

6.3 CHEMICALS CAUSING WATER RELATED DISEASES

The chemical contaminants like fluoride, nitrate and arsenic require immediate attention once detected in water.

Fluoride

As per BIS (IS 10500:1991), the maximum permissible limit of fluoride in drinking water is 1.5 mg/L. Fluoride occurs naturally in water. Though most waters contain below 1 mg of fluoride per litre, there are areas that are rich in fluoride containing minerals, where fluoride content of water can be very high. However, long term consumption of water above the permissible level can give rise to dental fluorosis, manifested by mottling of teeth and higher exposures can give rise to skeletal fluorosis, crippling diseases in which bone structure is affected. Contamination of ground water with fluoride is severe in Rajasthan, Andhra Pradesh, Gujarat, Haryana and certain parts of Orissa, Tamil Nadu, Delhi, and Kerala. In Kerala concentration of fluoride above 1.5 mg/L is reported in deeper aquifers of Alappuzha and some parts of Palakkad. Recently fluoride concentration beyond permissible limit have also been reported from some parts of Assam and West Bengal. The fluoride problem may be tackled by adopting a well planned systematic approach to identify and use safe alternative sources or treat fluoride containing waters using proven treatment technologies. The problem of excessive fluoride in drinking water can be dealt by the following alternative courses of action:

- Supplying fluoride free water from distance sources
- Installation of defluoridation plants at water sources
- Recharging the ground water and hence diluting the concentrations of fluoride in water

- Limiting the depth of wells (deeper zones have higher concentration of fluoride)
- By diluting the water supply with fresh water.

Nitrate in drinking water

As per BIS (IS 10500:1991), the maximum permissible limit of nitrate in drinking water is 45 mg/L. Increase in nitrate levels in surface and groundwater is primarily due to agricultural fertilizers and manure, animal dung and other sources of nitrogenous materials in the environment. Excessive nitrates combine with various amines in the gastrointestinal tract to form nitrosamines (particularly in low acidity conditions) some of which are carcinogenic in nature. Nitrate (NO_3) is the primary source of nitrogen (N) for plants; it is a nutrient they cannot live without. Nitrates are naturally occurring in soil and water. Extensive farming can rob the soil of its natural nitrogen source, so farmers often add nitrate fertilizers. Properly managed, nitrogen does not endanger health and can increase crop production. However, when more nitrogen is added to the soil than the plants can use, excess nitrate can leach into groundwater supplies and contaminate wells. On-site sewage systems (such as septic tanks and lagoons) also can be a source of nitrate pollution. Because nitrate is converted to a very toxic substance (nitrite) in the digestive systems of human infants and some livestock, nitrate-contaminated water is a serious problem.

Human babies are extremely susceptible to acute nitrate poisoning because of certain bacteria that may live in their digestive system during the first few months of life. These bacteria change nitrate into toxic nitrite (NO_2). The nitrite reacts with haemoglobin (which carries oxygen to all parts of the body) to form methemoglobin, which does not carry oxygen. The level of oxygen being carried throughout the body decreases in proportion to the amount of haemoglobin converted to methemoglobin. As the oxygen level decreases, the baby is suffocated. This condition is called methemoglobinemia. The most obvious symptom of nitrate poisoning is a bluish colour of the skin, particularly around the eyes and mouth is called cyanosis.

In India, Gujarat, Rajasthan, Haryana, Punjab, Andhra Pradesh, Madhya Pradesh, Tamil Nadu and Karnataka are affected by nitrate problem. Nitrate contamination occurs when there is more nitrate in the soil than plants can use and when water can move easily through the soil and underlying rock. The excess nitrate is carried through the soil into groundwater supplies by irrigation and rainwater. This occurs particularly where the soil is sandy, gravelly or shallow over porous limestone bedrock. Excess nitrate can accumulate in the soil if applying more nitrate fertilizer to the soil than a crop can use will build up high levels of nitrate. Manure and sewage contain both ammonia and organic forms of nitrogen. Organic nitrogen may be converted to ammonia in the soil. This ammonia, along with any ammonia fertilizer that is applied, is converted to nitrate by soil bacteria in a process called nitrification. Nitrification is important because plants can only use nitrogen in the nitrate form. However, when more ammonia is nitrified than plants can use, the unused nitrate will accumulate in the soil.

Arsenic

The sources of arsenic in soil are mainly the parent materials from which it is derived. The symptoms of chronic arsenic poisoning include various types of dermatological lesions, muscular weakness, and liver disorder. Arsenic is a potential carcinogen and skin cancer can occur after prolonged exposure. Arsenicosis, a disease caused by drinking arsenic contaminated water, may lead to a very painful death. The killing strength of arsenic has made history. As per BIS (IS 10500:1991), the maximum permissible limit of arsenic in drinking water is 0.01mg/L. The sources of arsenic contamination in water are generally industrial wastes, contaminating water bodies, either directly or by leaching through soil and also some agricultural insecticides. Though rare, natural arsenic pollution can occur in groundwater from arsiniferous belts in specific geomorphological conditions, as has been found in some areas of West Bengal. The symptoms of chronic arsenic poisoning include various types of dermatological lesions, muscular weakness, paralysis of lower limbs, etc. Arsenic is a potential carcinogen and skin and lung cancer occur after exposure. Techniques available for removal of excess arsenic are oxidation of arsenic (III) to arsenic (V) by adding suitable oxidizing agents followed by coagulation, sedimentation and filtration (co-precipitation), adsorption through $A1_2O_3$, iron filings (zerovalent iron) hydrated iron oxide, ion-exchange through suitable cation and anion exchanger and osmosis or electrodialysis (membrane filter).

Iron

Iron is a common metallic element found in the earth's crust. Water percolating through soil and rock can dissolve minerals containing iron and hold it in solution. Occasionally, iron pipes also may be a source of iron in water. Permissible limit of iron in water is 0.3 mg/L**.** Iron in drinking water may not be a health hazard but it causes a lot of problems as it gives unpleasant colour and odour to the drinking water. Iron is generally divided into two main categories. Soluble iron is the most common form and the one that creates the most complaints by water users. Insoluble iron can create serious taste and appearance problems for the water users. Because iron combines with different naturally occurring acids, it may also exist as an organic complex. A combination of acid and iron, or organic iron, can be found in shallow wells and surface water. Although this kind of iron can be colorless, it is usually yellow or brown. In deep wells, where oxygen content is low, the iron-bearing water is clear and colourless (the iron and manganese are in dissolved state). On exposure to air, iron is oxidized and changes from colourless, dissolved form to coloured solid form.

Oxidation of dissolved iron particles in water changes the iron to white, then yellow and finally to red-brown solid particles that settle out of the water. Iron that does not form particles large enough to settle out and that remains suspended (colloidal iron) leaves the water with a red tint. These precipitates or sediments may be severe enough to plug water pipes. Iron in drinking water causes tissue damage, constipation, hair loss and loss of apetite. Iron can affect the flavour and colour of water. It may react with tannins in coffee, tea and some alcoholic beverages to produce a black sludge, which affects both taste and appearance. It causes reddish-brown staining of laundry, porcelain dishes, utensils and even glassware. Detergents do not remove these stains. Iron will build up in pipelines, pressure tanks, water heaters and water softeners. This reduces the available quantity and pressure of the water supply. Iron accumulations become an economic problem when water supply or water softening equipment must be replaced. A problem that frequently results from iron is iron bacteria. These non-pathogenic (not health threatening) bacteria occur in soil, shallow aquifers and some surface waters. The bacteria feed on iron in water. These bacteria form red-brown (iron) slime in toilet tanks and can clog water systems.

Pesticides

Toxins like pesticides can cause a wide range of harmful effect on organisms. They include cancer, infertility, birth defects, blood disorders, genetic damage and nervous disorders. The toxin intake can result in either bioaccumulation or biomagnifications. Pesticides are one of the most difficult parameters that can be tackled in water. Surface run-off carrying pesticides/insecticides may cause pollution of surface water sources. The ubiquitous presence of DDT and HCH in the general population and reported risk of breast cancer among women. As per BIS (IS 10500:1991), the maximum permissible limit of pesticides in drinking water is 0.001 mg/L.

Several technologies are available to bring down the level of pesticides in water. Pesticide removal from drinking water may be technically feasible, but requires advanced treatment technologies. Also, a technology that effectively removes one pesticide, may not necessarily remove another. There are certain pesticide reduction technologies available. They are chemical coagulation, adsorption using powdered activated carbon or granular activated carbon, membrane filtration - nano filtration etc.

Water supply agencies should conduct study to monitor presence of insecticides in surface water sources through research institutions. Indiscriminate disposal of hazardous and toxic chemicals and heavy metals into water and soil is causing serious contamination of surface and ground water sources.The periodic reports on contamination of water sources with chromium, cadmium, lead, mercury, etc., are of grave public health concern. It is estimated that in India alone, 1.5 million children below 5 years age die from diarrheal diseases every year. Despite tremendous advances in medical knowledge and practice, morbidity and mortality due to water and excreta related communicable diseases continue to remain a heavy burden for all governments in the developing countries. Water and sanitation has been accepted today, as priority issue in health sector. But, it is also clear that the health impact cannot be achieved by a simple policy of supplying clean water. Only carefully designed programmes that integrate water quality improvements with improvement in water availability, sanitation and hygiene education, will achieve substantial reductions in the transmission of water and excreta related infections.

Table 6.1

The preventive strategies appropriate to the water-based issues

Parameters	Sources	Sphere-most Affected	Effects
Nitrate	Industrial waste, domestic sewage, run-off from agricultural fields	• Water, Food	• Methamoglobinemia, also called blue baby disease, which causes the skin of infants to become blue due to decreased efficiency of hemoglobin to combine with oxygen.
Fluoride	Naturally from rock and minerals, fluoridation of water supplies (as a public health measure), industrial discharges, etc.	• Water	• Fluoride may be kept as low as possible. • High fluoride may cause dental Fluorosis • Fluoride in larger quantities approx. 20-80 mg/day taken over a period of 10-20 years results in crippling and severe bone damage. • People exposed to more fluoride have less hemoglobin, more red blood corpuscles • Fluoride causes wide spread digestive disorders, skin diseases, dental problems.
Iron	Natural sources (iron ore mines) corrosion of pipes, pumps, etc	• Water	• Discoloration of water • Bitter, metallic, astringent taste • Brown colour deposition on utensils and clothes during washing or cooking • Odour, frothing • A dose of 1500 mg/L has a poisoning effect on a child, it can damage the blood tissues • Iron causes digestive disorders, skin diseases and dental problems.
Residual Chlorine	Municipal authorities add chlorine for disinfection	• Water	• Excessive chlorine concentration is known to cause learning impairment and neurological disorders. • Excessive chlorine intensifies the taste and odour of water. • Chloramines are found to be carcinogenic. • Excessive chlorine can cause thyroid and liver problems.
Chloride	Discharges of effluents from chemical industries, sewage, irrigation, leacheates and sea water intrusion in coastal areas are some	• Water	• High chloride content has deleterious effects on metallic pipes and structures as well as on agricultural crops. • It can also corrode concrete by extracting calcium in the form of

	vital sources of excess chloride levels.		calcite.
Hardness	Natural sources: Principally limestone, which are dissolved by percolating rainwater (made acidic by dissolved carbon dioxide). Industrial and discharges form operating and abandoned mines.	• Water	• Hardness has no known adverse effects on health. However, some evidence has been given to indicate its role in heart disease. • It is undesirable due to the formation of scales in boilers and other heat exchange equipment. • Hard water is also unsuitable for domestic use in washing, cleaning and laundering. • Hard water is also known to clog the skin pores due to deposition and hence result in scaling of skin and hair loss.
Pesticides	Agricultural run off	• Food, water, soil and animal products	• Workers exposed to pesticides through inhalation develop abnormal number of cells which weakens their immune system and may lead to increase in tumour formation
Arsenic	Fertilizers, combustion of coal, ore smelting, refining, pesticides, geological	• Air, water	• Carcinogenic, affects liver and heart • Respiratory problems • Abdominal pains, vomiting, diarrhoea • Pain in the extremities and skin and weakness with flushing of skin

Other contaminants like mercury (from automobile parts manufacturing factories), lead (paint factories), chromium, cadmium, nickel, (battery units) when discharged in rivers, cause harm when consumed either through drinking water or on eating fish which have accumulated it from the contaminated water. When such contaminated water is used regularly for bathing and washing, it can cause skin diseases. Similarly the application of contaminated water on fields results in the transmission and build-up of the contaminants in the crops, from where it is passed on to the consumers, resulting eventually in serious illness.

The quality of water required, need not be the same for carrying out the various activities. The purest form of water is required for drinking, while lesser quality water could be used for other purposes like washing, gardening etc. The water quality guideline values for drinking water, represents the level of a constituent that ensures aesthetically pleasing water and does not result in any significant risk to the health of the consumer. The quality of water defined by the guideline values is such that it is suitable for human consumption and for all usual domestic purposes, including personal hygiene. Whenever a guideline value is exceeded, the cause needs to be investigated in order to take corrective measures. The amount by which, and the duration for which any guideline value can be exceeded without any adverse effect on public health will depend on the specific constituent or characteristic involved.

6.4 WATER QUALITY STANDARDS

In India water quality standards were formulated as early 1940 and the standards were modified later from time to time. Although there are at least three standards formulated by ICMR, BIS and CPHEEO, the one recommended by Bureau of Indian Standards (BIS) is being widely adopted. Water quality is dynamic and its changing parameters demand water technologies to be in constant touch with many segments of scientific world. The products of population explosion and industrial expansion are immensely reflected in the deterioration of water quality in the different parts of the world which were otherwise unaffected in past. It is thus obvious that in future, water utilizers will be forced to accept water of inferior quality. Consequently, water quality acquired greater significance and man must define in more exacting terms those parameters which for most part have been quite subjective during the earlier period of our social development. Taste and odour are useful indicators of the quality of drinking water, suitability in terms of public health is determined by microbiological, physical, chemical and radiological characteristics; of these the most important is microbiological quality. Also a number of chemical contaminants (both inorganic and organic) are found in water. These cause health problems in the course of time.

The drinking water thus should be free from pathogenic (disease causing) organisms, clear, not saline, free from offensive taste or smell, free from compounds that may have adverse effects on human health(harmful in the long term) and free from chemicals that may cause corrosion of water supply system or stain clothes.

The chemical and physical make-up of natural water tends to be very site-specific. It reflects the geology and or topography as modified by human activities such as housing, agriculture and industry. It is very difficult to generalize raw water constituents. By the same token, there is no single water treatment scheme that will fit all kinds of water. Hence there are certain primary treatment methods which can be applied to all kinds of water while secondary treatment is used for specific contaminants. Hence for an effective treatment, monitoring the quality of water is essential as it helps in identifying the problem and thereby selecting the appropriate treatment method. Modern water treatment plants are available for individual use, when the quantity of water to be treated is less.

6.5 TRADITIONAL METHODS OF PURIFICATION

Traditionally purification of water has been carried out by simple process, like physical, chemical or biological treatment. Nature itself purifies water. The sun, living and non-living things in water help in purification. Various traditional methods are a fine blend of natural way of purification and various scientific techniques are evolved by man.

There are several traditional methods of purification which have been in practice for some time. Some of them are: "Kataka seeds" (Strychnos potatorum) are natural coagulants for the purification of muddy water. These can be used as effective coagulants and in a dose of 1.5 mg/L of water, where the ripe seed extract is prepared from thick paste of crushed seeds. The water is also treated with alum (10-15 mg/L). To purify the drinking water, seeds of Kataka can also be rubbed on the inside of the vessel, which causes precipitation or coagulation-flocculation of the microbes and the turbidity in water. Moringa olifera (drumstick), the use of its seed as coagulant is a Sudanese discovery. After the coat and wings of the seed are removed, the white kernel is crushed in a mortar and the powder mixed with a small amount of already purified water in a glass and stirred fast with spoon for five minutes. The suspension is poured through a tea strainer into the turbid water and slowly stirred by a wooden twirling stick for ten minutes. The dose for a jar of 40 litres is thirty seeds. Vetiveria zizanoides (khus) are laid in a clay jar which has a few tiny holes in its bottom. Water filtered through this layer of roots is not only clear but also has a pleasant smell. Dusting of water with plant ashes, earth from termite hills, paddy husks or crushed seed coats from elaichi (Elettaria Cardamom) improves clarity of water. Use of sun rays to disinfect water has been used since times immemorial. Also water stored in copper as well as brass vessels has been known to be purified of bacteria.

Table 6.2 is a summary of water quality problems encountered during the study. Suitable remedial measures are also suggested. This will be very useful for the public if proper awareness is given to them.

Table 6.2

WATER QUALITY PROBLEMS AND REMEDIAL MEASURES

SL No	Well ID	Location	WQ problem	Remedial Measures
1	ECOW-23	Kizhakkambalam	low pH	Lime addition
2	TMPOW-02	CDB,Neryamangalam	low pH	Lime addition
3	TMPOW-08	BHC,Edayar	low pH	Lime addition
4	ESOW-04	Chellanam	High pH	Alum coagulation followed by flocculation, sedimentation and filtration
5	ESOW-06	Mattanchery	High pH	do
6	ESOW-08	Edacochin	High pH	do
7	ECBW-02	Mookkannoor Ward-I	High pH	do
8	TMPBW-12	Odakkali	High pH	do
9	ESOW-04	Chellanam	High salinity	Desalination,Eletrodialysis, Reverse osmosis
10	ESOW-06	Mattanchery	High EC,TH,TA,Cl	Lime soda process/ Ion exchange(Zeolite) process/ Demineralisation
11	ESOW-08	Edacochin	High EC,TH,TA,Cl	do
12	ECBW-10	Piravom	High EC,TH,TA,Cl	do
13	ESOW-05	Ernakulam South	High nitrate content	Ion-exchange process
14	ESOW-01	Paravoor	High iron content	Aeration/Chemical oxidation followed by filtration/Zeolite Ion Exchange
15	ESOW-03	Njarakkal	High iron content	do
16	ESOW-08	Edacochin	High iron content	do

17	ECOW-04	Vadavukode	High iron content	do
18	ECOW-05	Pattimattom	High iron content	do
19	ECOW-08	Thiruvankulam	High iron content	do
20	TMPBW-04	Pampakkuda	Smell of H_2S,Turbidity and Colour on standing,High Iron and Manganese concentration	Aeration and/Chemical oxidation followed by filtration/Zeolite Ion Exchange

As an overall summary of the work done the following points are noted:

In the case of iron, detailed analysis of the samples of the sedimentary and phreatic crystalline formations reveal that 60% of the stations in the sedimentary and 50% of the stations in the phreatic crystalline are having iron concentration more than 1mg/L whereas all the deeper crystalline aquifer having iron concentration more than 1mg/L. From the hydro-geochemical studies of both, it is revealed that the water quality status of phreatic crystalline formation was much better than the sedimentary formation. The study also revealed the monsoon effect/dilution effect in the phreatic aquifer.

Water types of 8 wells in the sedimentary area and 31 wells in the crystalline area were worked out. It was found that the dominant form of water type during the three seasons in the sedimentary area is Ca-Mg-HCO_3 type. In the case of crystalline, major grouping was not possible.

All the ions analysed were represented in Piper-Hill diagram. It was observed that in the sedimentary almost all wells fall under Type I. Dilution effect of monsoon was established in the phreatic aquifer by the field sample collection and lab analysis data. Na-HCO_3 type was detected on Mookannoor Ward-I which was unsuitable for irrigation. Bore well at Piravom comes under Type IV with quality problem (high chloride and permanent hardness). High yielding wells were identified with no quality problem. Such areas can be further developed for the construction of production wells. Percent Na shows that no wells can be included in the "Unsuitable" category in terms of SAR. It was observed that the precipitation has direct effect on the Iron in the aquifer.

Na-HCO_3 type water is encountered in the bore well at Odakkali (TMPBW-12). This well gets maximum recharge due to the construction of a sub-surface dyke of 20 m length and 6-8 m width. The effect of subsurface dyke was well established by the study. Quantity problem was nil due to the storage in the aquifer during rainy season due to the dyke.

A socio-economic study was also conducted at Pampakuda which revealed the direct impact of poor water quality in the social life and economic status of the public.

Trace metals and pesticides were also analysed. All samples with respect to SAR belong to "Safe" category except bore well at Odakkali. As per % Na, RSC and KR classification the bore well at Odakkali comes under "Unsuitable" category. In terms of Kelly's ratio TMPOW-10 is classified as marginal. The health hazards due to NO_3, Fe, F, Cl, hardness, pesticides and trace metals have been tabulated and remedial measures suggested. The study has revealed that there is ample scope for more and more water quality sectors in order to identify such socio economic problem which is left unnoticed now and to solve them.

6.6 SOCIO-ECONOMIC EFFECT OF WATER QUALITY IN THE DUG-CUM-BORE WELLS OF ANCHALPETTY IN PAMPAKUDA

As a part of the water quality study the impact of water quality on the socio economic life of people were also looked into. For this purpose two dug cum borewells were selected in Anchalpetty, Pampakkuda. The sites are located on both sides of Piravom-Koothattukulam road. The wells TMPOW- 03 and TMPBW- 04 located in the plot of Mr. Baby, Poonkottukuzhiyil house is on the right side of the Piravom-Koothattukulam road and the well TMPOW- 05 located in the plot of Mr. Azhakan, Manakkalkkara house is on the left side of the road. The former well is at a lower elevation of -10 m with respect to the road level and the latter is at a height of +10 m with reference to the road level. The distance between the two stations is approximately 300 m. A schematic representation of the two dug-cum-bore wells are represented in **Figure 6.1** for both monsoon and pre-monsoon seasons.

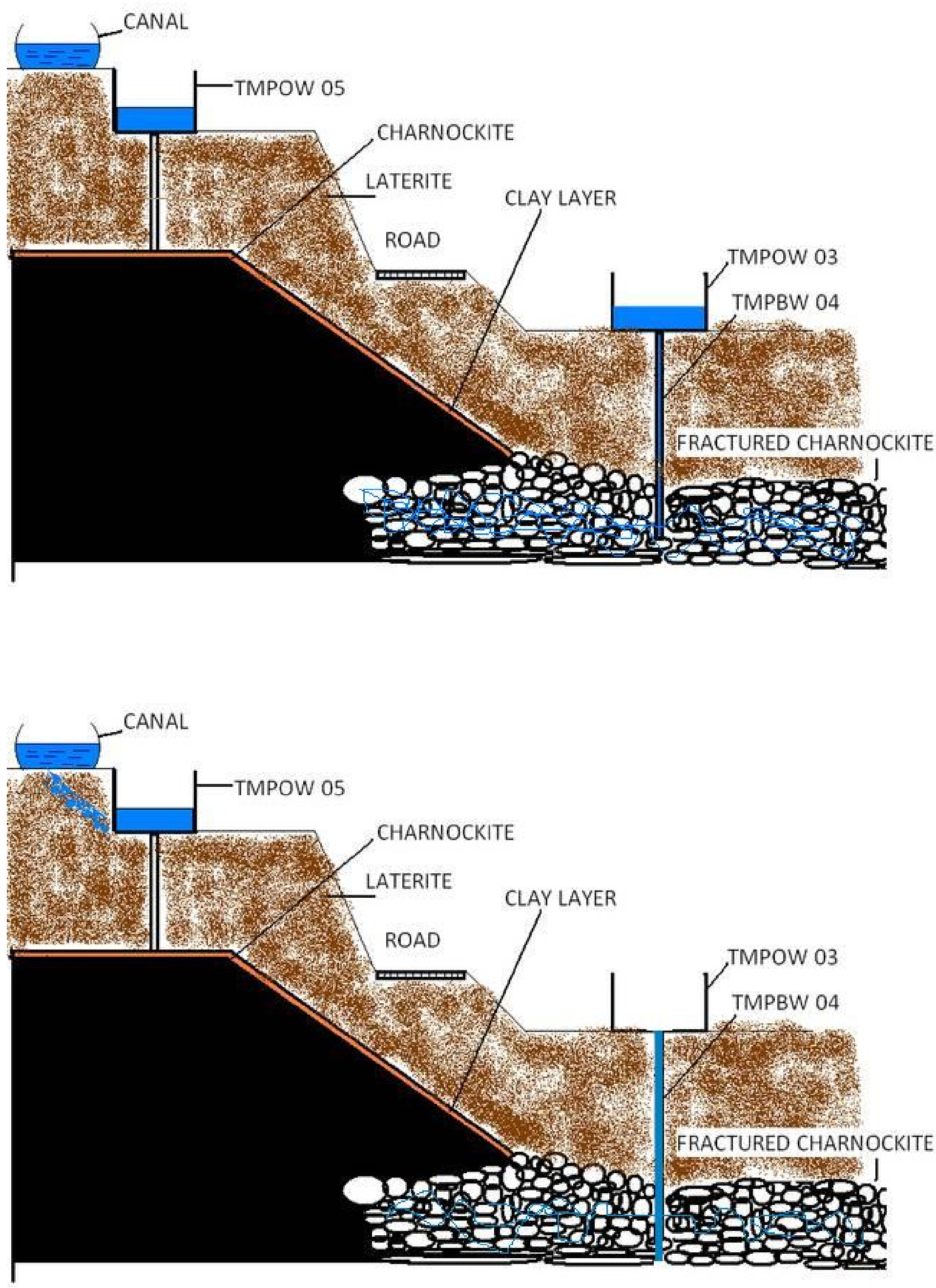


Figure 6.1

Schematic representation of Dug-cum-Bore wells

(TMPOW-03, TMPBW-04 and TMPOW-05)

These are two groundwater structures which combines an open well and a drilled well inside the open well. When a dug well is made and the water is not sufficient or dry, a bore is drilled inside the dug well to pierce the fractured zone in the rock (charnokite). On a comparison of the water quality of these stations, it is observed that TMPOW-03/TMPBW-04 is much inferior to TMPOW-05 (**Table 6.3**). In TMPBW-04, the water is odourless during monsoon but during pre and post monsoon periods, having hydrogen sulfide smell. The parameters EC, Ca, Mg.TH, SO_4, Cl and HCO_3 are higher for TMPOW-05.

Table 6.3 Data on the water quality analysis

	pH	EC	TH	Ca	Mg	Na	K	TA	HCO_3	Cl	SO_4	NO_3-N	F	Fe	Mn
TMPOW-03 (monsoon)	7	114	34	5.6	4.9	6.8	1.72	12	14.6	12.7	4.17	4.9	0	0.05	ND
TMPOW-03 (post monsoon)	7.17	147	45	18	0	8.2	6.7	36	43.6	15.7	11.9	1.41	0.07	0.11	ND
TMPBW-04 (monsoon)	6.8	111	30	8	2.4	7.3	6	14	17.1	14.7	3.54	4.6	0.27	0.3	ND
TMPBW-04 (post monsoon)	8.12	171	60	10	8.5	7.7	6.6	62	75.6	12.7	17.3	0	0	0	1.797
TMPOW-05 (monsoon)	7.19	48	15	4	1.2	4.8	5.4	14	17.1	8.8	2.3	0	0.03	0.2	ND
TMPOW-05 (postmonsoon)	7.24	40	10	4	0	3.4	1.21	10	12.2	9.8	2.6	0.22	0	0.07	ND

During pre-monsoon season, in TMPBW-04, concentration of iron and manganese are 2.85 and 0.353 mg/L respectively. Thus, in the case of TMPOW-03/TMPBW-04 quality problem exists in deeper aquifer due to H_2S smell, high iron and manganese concentrations. In the case of TMPOW-05 there is no quality problem where as quantity problem exist in the deeper aquifer. This is a typical case where the TMPOW-03/TMPBW-04 is affecting the life of the people. They cannot properly take bath every day, cannot cook food properly, and even wash the clothes leading routine life problematic. They use this water for agriculture to some extent. For drinking water they have to depend on others and the life itself is not smooth.

In the case of open well of TMPOW-05, no quantity or quality problem exists. But the deep strata are dry. Due to a canal which is flowing adjacent, the phreatic aquifer is saturated and due to dilution effect there is no quality problem. The general hygiene is good. The observation is that water quality will definitely affect the human life, social status and economy of the public. There is ample scope for more and more water quality sectors in order to identify such grave reality and to eradicate such social problems now left unnoticed.

The study also throws light on the fact that similar micro level water quality assessment is highly essential to keep the socio-economic status of the public by opening them constructive vistas on the subject.

ABBREVIATION

amsl	-	Above mean sea level
bmsl	-	Below mean sea level
mbgl	-	Meter below ground level
MCM	-	Million Cubic Meter
BCM	-	Billion Cubic Meter
km^2	-	Square Kilometer
bgl	-	Below ground level
ppb	-	Parts per billion
ppm	-	Parts per million
mg/L	-	Milligram per liter
epm	-	Equivalent per million
BW	-	Bore Well
OW	-	Open Well
DCBW	-	Dug-Cum-Bore Well
ESOW	-	Ernakulam Sedimentary Open Well
ECOW	-	Ernakulam Crystalline Open Well
ECBW	-	Ernakulam Crystalline Bore Well
TMPOW	-	Trace Metal Pesticide/ Open Well
TMPBW	-	Trace Metal Pesticide/ Bore Well
WL	-	Water Level
WQ	-	Water Quality
Cl	-	Chloride

Na	-	Sodium
K	-	Potassium
SO_4	-	Sulphate
NO_3-N	-	Nitrate-Nitrogen
NO_3	-	Nitrate
EC	-	Electrical Conductivity
TDS	-	Total Dissolved Solids
TH	-	Total Hardness
TA	-	Total Alkalinity
Ca	-	Calcium
Mg	-	Magnesium
F	-	Fluoride
Fe	-	Iron
Pb	-	Lead
Cd	-	Cadmium
Zn	-	Zinc
Cu	-	Copper
Mn	-	Manganese
As	-	Arsenic

Appendix - A

STANDARD ADDITION RESULT

Interfield Laboratories

XIII / 1208, Interprint House, Kochi - 682 005, Kerala, India.
TEL : 91-484-221-0915, 221-1838 FAX : 91-484-221-2465 mail@interfieldlaboratories.com
Web site : www.interfieldlaboratories.com

CERTIFICATE OF ANALYSIS

CLIENT NAME & ADDRESS :
K.N. SUMANGALA
RESEARCH SCHOLAR
DEPT. OF CHEMICAL OCEANOGRAPHY
CUSAT, COCHIN

CERTIFICATE NO. A: 18761 DATE OF ISSUE : 28/08/08
SAMPLE RECEIPT: 19/07/08 SAMPLE CODE : C 28928
SAMPLE NAME : WATER
SAMPLE DESCRIPTION : COLOURLESS LIQUID
ANALYSIS START : 19/07/08 ANALYSIS COMPLETION : 30/07/08

Page 1 of 2

SL. NO.	PARAMETERS TESTED	RESULTS	DETECTION LIMIT	TEST METHOD
1)	ORGANOCHLORINE PESTICIDES *			USEPA 525.2
	α - BHC	0.37 μg/l		
	β - BHC	9.81 μg/l		
	LINDANE	1.51 μg/l		
	p,p' - DDE	3.75 μg/l		
	p,p' - DDT	2.93 μg/l		
	OTHER PESTICIDES	NOT DETECTED	0.05 μg/l	
2)	ORGANOPHOSPHOROUS PESTICIDES *	NOT DETECTED	0.05 μg/l	,,
3)	OTHER PESTICIDES *	NOT DETECTED	0.05 μg/l	,,

ORIGINAL

SAMPLE ID : 24
LOCATION : CK NERYAMANGALAM
TYPE OF WELL : OW
QUANTITY : 1 Litre

REMARKS : Contd...

* List of tested pesticides attached.

FOR AND ON BEHALF OF
Interfield Laboratories
N.S. KALESH, Ph.D.
SECTION-IN-CHARGE (CHEMISTRY)
28/08/08
Authorised Signatory

SAMPLE SUBMITTED BY CUSTOMER

Approved by Export Inspection Council
Ministry of Commerce and Industry, Government of India

ANNEXURE

Table 2.1

Monthly Rainfall Data (In mm)

Perumbavur (Lat: 10° 05' Long: 76° 25' E)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	9.0	0.0	68.0	39.0	288.5	561.0	617.0	465.0	593.0	410.0	473.0	12.0
2007	0.0	0.0	0.0	128.5	122.0	664.0	1158.9	554.0	598.9	405.1	35.0	0.0
2008	18.0	25.0	342.0	174.0	53.0	407.7	457.8	369.3	705.0	324.9	14.0	37.0

Naval Air Station, Kochi (Lat: 9° 57' Long: 76° 16' E)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	4.7	0.0	87.9	52.7	576.4	671.8	596.8	475.5	449.8	545.5	198.6	0.0
2007	0.0	2.4	0.9	156.7	216.5	719.5	894.9	363.3	733.6	423.3	114.8	11.8
2008	0.0	28.0	287.4	174.7	199.0	396.3	507.1	218.9	541.3	300.0	13.7	25.2

Piravom (Lat: 9° 48' Long: 76° 28' E)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	29.4	0.0	82.9	44.0	809.9	771.6	812.5	658.7	427.5	486.5	400.4	0.0
2007	10.9	4.6	28.8	145.4	210.3	1000.8	1417.5	451.4	752.7	557.7	124.7	5.4
2008	0.0	56.4	409.8	92.1	112.6	539.9	829.5	416.9	526.6	319.3	118.0	69.9

Paravur (Lat: 10^o 09' Long: 76^o 13' E)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	0.6	0.0	51.2	82.8	658.3	687.4	450.1	474.2	534.9	549.1	383.1	0.0
2007	0.0	0.0	13.0	152.6	156.0	926.8	1130.8	480.7	689.4	735.9	94.4	8.9
2008	0.0	65.4	225.0	91.6	265.0	517.7	555.0	277.9	435.2	306.6	-	-

Aluva (Lat: 10^o 07' Long: 76^o 21' E)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	19.0	0.0	57.4	28.8	556.0	594.8	468.3	500.4	519.3	448.0	511.2	6.0
2007	0.0	0.0	0.0	99.0	168.1	801.7	1040.7	433.7	667.1	441.8	20.4	14.0
2008	0.0	5.8	353.5	100.8	145.0	470.3	463.9	316.2	602.4	226.7	6.3	4.0

Airport Cochin (Lat: 10^o 09' Long: 76^o 24' E)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	13.7	0.0	24.9	9.9	580.5	646.6	557.1	415.6	531.6	430.8	400.5	0.6
2007	0.3	1.0	12.9	157.3	244.5	767.2	1156.8	599.7	560.7	567.3	8.9	18.8
2008	0.0	4.3	302.3	142.0	52.3	397.7	418.0	357.3	481.2	352.8	40.8	48.8

Neryamangalam Lat 10°03'41'' Long 76°47'0''

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Rainfall
2006	13.2	0.0	228.6	212.6	751.8	599.0	882.2	612.0	670.6	428.2	675.0	0.0	5073.2
2007	1.0	19.0	25.0	270.8	373.0	923.6	1244.0	675.4	751.0	584.2	78.2	29.0	4974.2
2008	0.0	34.8	115.0	207.0	282.6	704.8	900.2	627.4	429.7	393.2	103.0	25.0	3822.7

Keeramapara Lat 10°09'0'' Long 76°45'0''

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Rainfall
2006	58.8	0.0	47.4	217.0	775.5	488.2	787.1	570.3	616.9	702.4	521.2	0.0	4784.8
2007	1.4	12.1	48.1	193.2	290.9	855.7	1187.2	632.0	851.7	641.0	141.3	31.1	4885.7
2008	0.5	62.8	167.6	174.6	167.3	549.3	725.6	657.4	284.4	448.9	53.3	38.6	3330.3

Boothathankettu Lat 10°09'33'' Long 76°36'59''

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Rainfall
2006	77.5	0.0	95.1	151.3	731.3	484.7	847.9	531.2	540.3	439.2	408.6	37.4	4344.5
2007	0.0	2.1	3.2	226.5	316.0	845.4	1271.9	675.2	782.0	624.4	132.9	33.5	4913.1
2008	0.0	63.7	204.0	108.3	217.3	520.8	797.7	742.1	362.1	349.3	40.2	18.2	3423.7

Table2.2

Block Wise Net Ground Water Availability as on March 2004 in MCM

Sl No.	Assessment Unit/Block	Recharge from rainfall during monsoon season	Recharge from other sources during monsoon season	Recharge from rainfall during non monsoon season	Recharge from other sources during non monsoon season	Total Annual Groundwater Recharge (3+4+5+6)	Natural discharge during nonmonsoon season	Net annual groundwater availability (7-8)
1	2	3	4	5	6	7	8	9
1	Alangadu	10.49	Nil	5.37	8.1	23.96	2.34	21.62
2	Angamaly	36.83	Nil	15.36	17.5	69.69	3.25	66.44
3	Edapalli	8.03	Nil	4.21	11.16	23.41	2.31	21.10
4	Koovapady	57.46	Nil	29.53	25.9	112.89	5.22	107.67
5	Kothamangalam	31.92	Nil	20.81	5.0	57.73	5.77	51.96
6	Mulanthuruthy	17.5	Nil	9.19	Nil	26.69	2.67	24.02
7	Moovattupuzha	25.71	Nil	16.77	4.0	46.48	4.68	41.8
8	Palluruthy	5.6	Nil	3.67	Nil	9.27	0.91	8.36
9	Pampakuda	20.39	Nil	13.3	12.4	46.09	4.43	41.66
10	Parakadavu	16.63	Nil	6.14	Nil	22.77	1.66	21.11
11	Paravoor	10.6	Nil	5.82	0.05	16.47	1.85	14.62
12	Vadavukode	28.6	Nil	18.65	27.8	75.05	6.9	68.15
13	Vazhakulam	17.12	Nil	8.98	27.1	53.2	5.27	47.93
14	Vypin	14.75	Nil	9.68	0.13	24.56	2.42	22.14
15	Vytilla	6.49	Nil	3.67	Nil	10.16	0.91	9.25
16	**TOTAL**	**308.12**	**Nil**	**171.15**	**139.14**	**618.42**	**50.59**	**567.83**

Table 3.6

WATER LEVEL DATA OF OPEN WELLS IN SEDIMENTARY FORMATION

2006-2008

ESOW-01 Paravoor

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	2.31	2.57	2.58	2.63	2.60	1.73	1.58	1.80	1.69	2.38	2.34	2.21
2007	3.07	3.05	2.45	2.33	3.06	2.33	1.10	1.40	1.70	1.95	1.95	2.30
2008	2.40	2.52	2.33	2.25	2.32	2.05	2.00	1.87	2.04			

ESOW-02 Pallippuram

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.84	0.89	0.71	0.97	0.99	0.12	0.34	0.54	1.14	1.33	1.17	0.87
2007	1.86	1.92	1.05	0.89	1.70	0.54	0.04	0.03	0.06	0.69	0.59	0.79
2008	0.84	0.89	0.64	0.54	0.79	0.39	0.49	0.49	0.69			

ESOW-03 Njarakkal

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.79	0.95	1.09	1.28	1.31	0.20	0.43	0.29	1.05	1.14	1.20	0.77
2007	1.73	1.90	1.23	1.24	1.93	0.65	0.18	0.13	0.23	0.65	0.51	0.83
2008	0.88	1.06	0.73	0.73	0.70	0.48	0.36	0.58	0.60			

ESOW-04 Mattanchery

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.78	1.01	0.99	1.24	1.36	0.31	0.66	0.87	0.56	0.66	1.26	1.03
2007	1.73	1.90	1.27	1.25	1.64	0.71	0.21	0.11	0.26	0.41	0.49	0.68
2008	0.85	1.04	0.33	0.79	0.26	0.52	0.41	0.71	0.52			

ESOW-05 Ernakulam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.85	0.85	0.71	1.00	0.97	0.11	0.23	0.35	0.00	0.90	1.22	1.02
2007	1.80	1.82	1.20	0.95	0.92	0.66	0.25	0.00	0.07	0.28	0.51	0.65
2008	0.78	0.76	0.30	0.67	0.72	0.35	0.40	0.33	0.69			

ESOW-06 Chellanam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.28	0.31	0.32	0.45	0.77	0.15	0.19	0.35	0.85	1.02	0.70	0.41
2007	1.20	1.18	0.63	0.54	1.10	0.34	0.00	0.00	0.00	0.11	0.27	0.29
2008	0.34	0.34	0.05	0.29	0.04	0.05	0.24	0.04	0.42			

ESOW-07 Kumbalangi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	1.57	1.77	2.02	2.02	2.17	0.72	0.69	1.14	1.85	1.69	1.55	1.52
2007	2.35	2.65	2.05	1.87	2.50	1.52	0.47	0.57	0.62	0.77	0.88	1.25
2008	1.47	1.88	1.47	1.47	1.02	0.77	0.79	1.12	1.05			

ESOW-08 Edacochin

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.85	1.12	1.06	1.10	1.17	0.50	0.52	0.77	1.40	0.82	1.14	1.02
2007	1.35	1.73	1.14	0.97	1.57	0.87	0.20	0.17	0.37	0.57	0.67	0.88
2008	0.85	0.83	0.58	0.82	1.53	0.49	0.62	0.62	0.62			

Table 3.8
Water Quality Data (Shallow Sedimentary)

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO_3	HCO_3	Cl	SO4	NO_3-N	F	Fe
			µmhos/cm	mg/L	mg/L (as $CaCO_3$)	mg/L	mg/L	mg/L	mg/L	mg/L(as $CaCO_3$)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ESOW-01	Jan/05/2006	8.4	290	174	99	23.8	9.7	17	11.3	92	9.6	92.7	27	2	1.24	0.03	1.5
ESOW-01	May/05/2006	8.5	310	186	92	22.1	9	22	8.2	92.5	4.8	103	31	22	0.62	0.01	3.8
ESOW-01	Sep/01/2006	7.9	200	120	80	19.2	7.8	6	5.1	76.5	0	93.3	10	6	0.62	0.5	1.5
ESOW-01	Jan/10/2007	8.5	350	210	120	38	6.1	22	6.3	100	7.2	107	33	24	0.1	0.12	11.62
ESOW-01	May/05/2007	8.4	320	192	112	30	9	20	7	96	4.8	107	30	20	0.6	0.23	3.4
ESOW-01	Sep/01/2007	8.3	196	118	80	20	7.3	6	6	75	7.2	76.8	10	11	0	0	1.25
ESOW-01	Jan/05/2008	8	250	150	90	32	2.4	12	5.4	76	0	92.7	20	12	2.4	0.08	4.73
ESOW-01	May/05/2008	8.5	260	156	90	21.6	8.8	13	6	81	12	74.4	21	9	2	0.26	3
ESOW-01	Sep/01/2008	8.3	220	132	85	32	1.2	9	5.6	80	2.4	92.7	12	16	0.42	0	1.83
ESOW-02	Jan/05/2006	8.9	560	336	250	60.6	24	11	6.2	217	21.6	220.8	34	5	1.86	0.4	0.32
ESOW-02	May/05/2006	8.7	450	270	157.5	37.8	15.4	17	7.4	160	16.5	161.6	27	25	1.24	0.56	0.4
ESOW-02	Sep/01/2006	8.7	458	275	190	45.6	18.5	6	6.2	188	11.7	205.6	18	14	0	1.04	0.16
ESOW-02	Jan/10/2007	8.4	560	336	235	56.4	22.9	14	5.5	210	36	183	30	28	2.4	0.34	0.55
ESOW-02	May/05/2007	8.7	420	252	155	42	13	19	6	150	14	154.5	28	18	1.2	0.55	0.5
ESOW-02	Sep/01/2007	8.6	400	240	170	40.8	16.6	12	6.2	160	24	146.4	16	13	1.86	0.35	0.21
ESOW-02	Jan/05/2008	8.7	490	294	190	68	4.9	21	8.5	148	14.4	151.3	34	23	6.3	0.62	0.3
ESOW-02	May/05/2008	8.4	400	240	155	56	3.7	14	6.2	150	12	158.6	21	16	1	0.26	0.28
ESOW-02	Sep/01/2008	8.7	520	312	215	68	11	13	3.4	206	31.2	187.9	21	20	0.65	0.22	0.73
ESOW-03	Jan/05/2006	8.4	280	168	120	24	14.6	7	5	110	9.6	114.6	14	12	0	0.67	0.37
ESOW-03	May/05/2006	8.5	278	167	110	25.5	11.3	8	6.2	112	7.2	122	14	6	0.62	0.18	1.8
ESOW-03	Sep/01/2006	8.6	405	243	180	43.2	17.6	7	3.5	168	14	176.5	14	8	0	0.62	0.42

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO_3	HCO_3	Cl	SO4	NO_3-N	F	Fe
			µmhos/cm	mg/L	mg/L (as $CaCO_3$)	mg/L	mg/L	mg/L	mg/L	mg/L(as $CaCO_3$)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ESOW-03	May/05/2007	8.8	515	309	227	54.6	22.2	8	4	230	24	231.8	9	10	1.24	0.45	2.77
ESOW-03	Sep/01/2007	8.5	220	132	95	22.8	9.27	6	2.3	94	7.2	100	12	8	0	0.54	4.7
ESOW-03	May/05/2008	8.5	340	204	150	40.4	12	7	3.8	142	14	145	14	8	0.62	0.36	2.6
ESOW-03	Sep/01/2008	8.5	320	192	138	35.5	12	7	3.9	132	12	136.6	12	8	0	0.58	0.96
ESOW-04	Jan/05/2006	8.6	500	300	223	53.5	21.8	8	6.2	160	18.6	157.4	24	24	1.86	1.11	0.39
ESOW-04	May/05/2006	8.6	665	399	286	68.6	27.9	16	9	186	26.4	173.2	31	19	1.24	0.35	0.39
ESOW-04	Sep/01/2006	8.4	944	566	400	96	39	23	16	262	21	277	146	2	0	0.38	0.49
ESOW-04	Jan/10/2007	8.3	1090	654	205	49.2	20	138	21.4	122	12	124.4	277	4	3.6	0.31	0.11
ESOW-04	May/05/2007	8.7	1300	780	290	66	26.8	162	22	268	16.8	292.8	290	29	1.4	0.61	0.92
ESOW-04	Sep/01/2007	8.7	540	324	220	52.8	21.5	20	5.8	194	19.2	197.6	21	36	0	0.16	0.62
ESOW-04	Jan/05/2008	8.7	690	414	233	56	22.7	50	14.8	213	43	172	76	5	3.7	0.3	4.8
ESOW-04	May/05/2008	8.4	905	543	295	106	7.3	64	14	296	16.8	327	74	33	5	0.04	0.81
ESOW-04	Sep/01/2008	8.6	700	420	230	78	8.4	40	12.4	220	45.6	175.7	73	17	6.14	0.4	0.74
ESOW-05	Jan/05/2006	8.7	580	348	237	57	23	20	12	219	16.2	234.2	36	21	0	0.26	0.16
ESOW-05	May/05/2006	8.8	580	348	224	53	22.3	22	13.7	202	33	179	35	31	1.86	0	0.83
ESOW-05	Sep/01/2006	8.6	600	360	260	62.4	25.4	19	8.2	226	7.2	261	28	26	0.62	0.78	1.2
ESOW-05	Jan/10/2007	8.8	770	462	308	83.6	24.1	26	12	223	28.8	213.5	44	19	21.7	0.24	0.29
ESOW-05	May/05/2007	8.7	515	309	197	47.3	19.2	22	11	164	12	175.7	36	18	24.8	0.71	3.11
ESOW-05	Sep/01/2007	8.8	610	366	260	62.4	25.4	15	8.6	232	21.6	239.1	21	30	3.1	0	0.41
ESOW-05	Jan/05/2008	8.9	720	432	305	104	11	20	10	252	31.2	244	33	37	0.3	0.34	0.15
ESOW-05	May/05/2008	8.6	440	264	165	66	2.4	18	8.3	166	14.4	173.2	28	16	0.1	0.2	0.36
ESOW-05	Sep/01/2008	8.5	468	281	190	68	4.9	16	6	182	21.6	178	24	16	0.43	0.42	0.32
ESOW-06	Jan/05/2006	8.9	2710	1626	426	35.4	82.4	390	40	338	45.6	319.6	670	30	3.8	1.16	0.33
ESOW-06	May/05/2006	8.7	7070	4242	550	42	108.6	1330	54.2	326	61.2	273.3	2231	31	4	0.24	3.4

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO_3	HCO_3	Cl	SO4	NO_3-N	F	Fe
			µmhos/ cm	mg/L	mg/L (as $CaCO_3$)	mg/L	mg/L	mg/L	mg/L	mg/ L(as $CaCO_3$)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ESOW-06	Jan/10/2007	8.9	7460	4536	630	38.4	104	1368	68	390	62	349.7	2320	42	3.1	1	3.3
ESOW-06	Sep/01/2007	8.9	1920	1152	280	54	35.4	300	23	270	19.2	290.3	466	8	3.6	0	0.16
ESOW-06	Jan/05/2008	8.9	2800	1680	287	88	16.3	492	38	286	28.8	290.3	786	4	0.8	0.28	1.1
ESOW-06	May/05/2008	8.8	5700	3420	550	42	108.6	1020	56	396	14.4	453.8	1678	70	1	0.2	3
ESOW-06	Sep/01/2008	8.5	2800	1680	315	54	43.9	460	26	290	12	329.4	768	26	1.87	0.03	0.96
ESOW-07	Jan/05/2006	8.3	365	219	149	35.8	14.4	8	12.5	142	7.2	158.6	11	23	0	0.03	0.33
ESOW-07	May/05/2006	8.5	310	186	93	23.8	8.1	18	13.3	82	7.2	85.4	27	33	0	0.15	3.2
ESOW-07	Sep/01/2006	8.5	280	168	130	31.2	12.7	8	6.3	98	7.2	104.9	14	22	0	0.64	0.12
ESOW-07	Jan/10/2007	8.4	280	168	115	27.6	11.2	8	4.8	95	12	91.5	14	15	0	0.31	1.5
ESOW-07	May/05/2007	8.4	290	174	110	33	6.7	15	8	100	7.2	107.4	23	12	0	0.54	2.96
ESOW-07	Sep/01/2007	8.7	280	168	115	27.6	11	6	4.7	110	12	109.8	9	20	0	0.58	0.13
ESOW-07	Jan/05/2008	8.5	266	160	110	40	2.4	9	3	102	7.2	109.8	14	11	0	0.4	0.53
ESOW-07	May/05/2008	8.4	288	173	120	42	3.6	9	4.5	112	7.2	122	14	10	0.3	0.04	1.6
ESOW-07	Sep/01/2008	8.3	210	126	85	34	0	6	5.6	80	2.4	92.7	8	11	0.64	0.05	0.32
ESOW-08	Jan/05/2006	8.7	1080	648	335	75	36	83	16	234	26.4	231.8	165	24	4.34	0.48	0.44
ESOW-08	May/05/2006	8.5	2100	1260	345	82.8	33.6	287	22.2	160	19	155.3	546	46	3.72	0.02	0.62
ESOW-08	Sep/01/2006	8.4	820	492	280	72	24.4	66	3.12	220	12	244	116	24	0.4	0.4	0.96
ESOW-08	Jan/10/2007	8.6	1060	636	298	71.5	29	110	17.2	208	38.4	175.7	190	26	4.44	0.36	1.21
ESOW-08	May/05/2007	8.7	2600	1560	425	98	44	382	22	242	26.2	242	693	46	7	0.6	0.52
ESOW-08	Sep/01/2007	8.7	405	243	165	39.6	16.1	14	2.73	150	12	158.6	23	17	0.62	0	0.57
ESOW-08	Jan/05/2008	8.6	1060	636	330	70	37.8	78	14.3	228	24	229.4	152	25	4	0.21	0.54
ESOW-08	May/05/2008	8.7	1080	648	345	86	31.7	83	16	234	26.4	232	165	42	4.34	0.06	0.44
ESOW-08	Sep/01/2008	8.5	380	228	165	60	3.7	6	1.7	154	7.2	173.2	10	18	0.22	0	0.93

Table 3.9a
Lithology (Phreatic Crystalline)

Well ID	Depth To (M)	Lithology	Texture
ECOW-01	3.35	Sandy soil	medium to coarse
	6.75	Laterite	medium to coarse
ECOW-02	1.70	Topsoil	medium to coarse
	9.00	Laterite	medium to coarse
	10.37	Weathered Rock	fine to medium
ECOW-03	1.50	Topsoil	fine to medium
	7.16	Laterite	medium to coarse
ECOW-04	1.00	lateritic soil	fine
	7.30	Laterite	medium
ECOW-05	1.00	lateritic soil	fine
	10.30	Laterite	medium
ECOW-06	1.00	lateritic soil	fine
	8.90	Laterite	medium to coarse
ECOW-07	1.00	Topsoil	
	11.50	Laterite	
ECOW-08	1.00	Topsoil	
	11.50	Laterite	
ECOW-09	1.00	Topsoil	fine
	15.30	Laterite	medium to coarse

ECOW-10	2.65	Topsoil	coarse
	7.00	Laterite	medium to coarse
ECOW-11	1.00	Topsoil	
	4.00	Laterite	
ECOW-12	1.00	Topsoil	
	6.60	Laterite	
ECOW-13	1.40	Topsoil	medium to coarse
	3.40	Laterite	medium to coarse
	8.40	Weathered rock	fine to medium
ECOW-14	1.00	lateritic soil	fine
	5.90	Laterite	medium to coarse
ECOW-15	1.00	Topsoil	coarse to very coarse
	5.00	Laterite	medium to coarse
	6.00	Weathered Gneiss	fine to medium
	11.67	Charnokite	
ECOW-16	1.00	Topsoil	fine to medium
	8.40	Laterite	fine to medium
ECOW-17	1.00	Topsoil	fine to medium
	8.60	Laterite	fine to medium
ECOW-18	1.00	Topsoil	fine to medium
	10.30	Laterite	
ECOW-19	1.00	Topsoil	

	9.20	Laterite	
ECOW-20	0.20	Topsoil	medium to coarse
	5.00	Laterite verigated / wuggy	medium to coarse
	6.63	Clay	fine
	7.90	Charnokite	
ECOW-21	2.90	Topsoil	medium to coarse
	7.00	Laterite verigated / wuggy	medium to coarse
	8.20	Clay	fine
	10.39	Charnokite	
ECOW-22	1.00	Topsoil	medium to coarse
	9.00	Laterite	medium to coarse
	10.75	Clay	fine
ECOW-23	1.00	Topsoil	medium to coarse
	7.00	Laterite verigated / wuggy	medium to coarse
	10.75	Clay soft	fine
	12.50	Charnokite	
ECOW-24	1.00	Topsoil	medium to coarse
	11.00	Laterite	medium to coarse
	11.68	Clay	fine
ECOW-25	1.00	Topsoil	fine to medium
	9.40	Laterite	medium to coarse
ECOW-26	1.00	Topsoil	coarse

	6.50	Laterite	medium to coarse
	7.62	Clay	fine
ECOW-27	1.00	Lateritic soil	medium to coarse
	7.9	Laterite	medium to coarse
ECOW-28	1.00	Topsoil	
	6.20	Laterite	
ECOW-29	1.00	Topsoil	
	9.40	Laterite	
ECOW-30	2.28	Alluvium	
	9.40	Compact Soil	
ECOW-31	1.00	Topsoil	fine to medium
	8.90	Laterite	medium to coarse

Table 3.10

WATER LEVEL DATA OF OPEN WELLS IN PHREATIC CRYSTALLINE FORMATION

ECOW-01 Aluva

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.04	3.10	2.66	3.00	3.00	2.08	2.70	3.50	4.65	3.75	4.18	4.34
2007	3.66	4.06	3.26	2.97	3.83	3.57	1.00	3.02	2.97	3.12	3.33	3.75
2008	3.56	3.30	2.90	3.10	3.25	2.75	3.69	3.20	3.18			

ECOW-02 Ankamaly

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.70	7.20	7.63	7.50	7.65	4.97	4.20	5.34	5.98	6.20	6.90	7.04
2007	8.07	8.45	7.64	7.69	7.78	6.93	1.30	2.60	5.93	5.93	6.26	6.90
2008	7.20	7.44	6.98	6.67	7.26	6.74	5.90	5.85	5.92			

ECOW-03 Kalady

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.78	6.90	6.00	6.70	6.72	3.77	2.53	2.70	5.15	3.77	4.40	6.25
2007	6.82	6.90	6.12	5.97	6.95	6.70	0.35	4.50	3.80	4.60	3.82	6.50
2008	6.45	5.12	3.64	5.20	7.00	6.11	4.20	1.20	3.58			

ECOW-04 Manjapra

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	3.05	3.95	3.43	3.35	3.77	1.80	2.88	3.00	4.04	3.25	4.00	2.99
2007	4.16	4.74	3.29	2.95	3.82	3.60	0.90	3.28	3.25	3.65	3.50	3.95
2008	3.68	3.55	3.61	3.60	3.80	3.60	3.41	3.35	3.49			

ECOW-05 Nedumbassery

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.41	7.75	7.90	8.16	8.42	4.86	4.40	5.24	6.84	5.50	6.75	7.10
2007	8.02	8.35	7.74	8.07	8.80	7.82	2.10	4.25	5.38	5.68	5.84	7.13
2008	7.50	7.85	7.94	7.17	7.75	7.60	5.75	5.34	5.55			

ECOW-06 Aluva East

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.47	6.60	5.54	6.55	6.60	6.75	6.06	6.65	7.10	6.35	6.90	6.71
2007	7.42	7.32	6.45	7.20	7.04	6.91	5.10	6.32	6.10	6.62	6.48	6.72
2008	6.42	6.75	6.57	6.39	6.25	5.74	6.49	6.55	6.24			

ECOW-07 Amballur

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.85	8.01	8.32	8.55	8.90	3.75	4.84	5.41	6.74	5.82	6.30	7.68
2007	8.76	8.86	8.26	8.49	9.20	8.25	3.55	4.75	4.26	5.43	5.98	7.63
2008	7.95	8.32	8.55	8.00	8.13	8.05	6.25	5.45	5.45			

ECOW-08 Thiruvankulam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.15	4.60	4.78	5.05	4.45	2.50	4.26	4.02	2.36	4.60	4.60	4.10
2007	5.10	5.05	4.60	5.69	5.85	4.80	2.80	3.25	2.97	4.00	3.20	4.75
2008	4.80	5.65	5.35	4.77	4.80	3.95	3.70	2.35	4.05			

ECOW-09 Thrikkakara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.75	8.20	8.13	9.05	8.40	6.70	6.86	7.63	7.00	7.15	8.35	7.70
2007	8.35	8.90	8.50	7.46	8.90	6.30	3.40	6.45	5.97	7.07	7.32	7.70
2008	7.80	8.95	9.60	9.30	9.10	8.00	7.27	7.50	7.39			

ECOW-10 Pothanikkadu

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.67	4.97	4.67	4.54	4.42	0.17	1.04	1.89	1.62	2.45	2.75	4.48
2007	5.40	5.55	4.87	4.31	5.20	3.47	0.42	0.92	1.92	3.24	2.99	4.52
2008	4.67	4.67	4.59	4.55	4.22	3.62	0.62	1.12	3.09			

ECOW-11 Keerampara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	1.39	2.13	1.63	1.34	1.20	0.76	0.93	1.30	1.44	1.53	1.35	1.30
2007	3.00	2.05	1.46	1.36	1.88	0.90	0.70	1.01	0.75	1.90	1.57	1.56
2008	1.79	1.12	1.12	1.43	1.45	1.15	0.82	0.80	2.25			

ECOW-12 Eramallur

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	3.22	3.32	3.42	3.85	3.32	0.02	0.59	1.22	1.08	1.02	2.03	3.00
2007	3.70	3.80	3.40	3.74	3.60	1.47	0.00	0.11	0.84	2.92	2.46	3.02
2008	4.01	5.12	5.27	3.42	3.32	0.47	0.12	0.42	3.02			

ECOW-13 Pindimana

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.10	6.33	4.63	4.88	4.26	0.00	0.33	0.93	1.35	1.12	2.40	3.98
2007	3.98	5.15	4.68	6.05	6.52	4.03	0.18	0.23	1.13	3.00	2.23	4.38
2008	4.68	4.83	4.93	4.43	4.48	1.68	0.83	0.63	3.03			

ECOW-14 Kuttamangalam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	3.10	3.40	4.18	4.10	3.26	1.30	2.08	2.24	2.92	2.28	2.90	2.56
2007	4.00	4.30	3.45	3.70	4.20	2.05	1.50	1.85	1.95	2.38	2.35	2.66
2008	3.31	3.61	3.94	3.00	2.40	1.62	1.86	1.75	2.40			

ECOW-15 Neryamangalam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.47	8.65	8.40	8.05	7.67	2.29	4.25	6.07	4.30	4.83	2.78	6.98
2007	7.16	8.60	9.20	8.74	7.12	6.24	3.15	3.99	5.07	6.59	6.50	7.88
2008	8.72	-	-	9.01	7.80	3.40	3.85	3.36	6.80			

ECOW-16 Ramamangalam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	3.90	4.21	4.56	4.59	4.70	1.94	3.16	3.19	3.97	3.84	3.75	3.92
2007	4.60	4.70	4.52	4.56	5.27	4.12	2.44	2.72	3.32	3.54	3.67	3.90
2008	3.86	4.12	4.54	4.04	4.49	3.42	3.44	1.59	2.99			

ECOW-17 Vengola

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.77	7.05	7.15	7.88	8.07	6.20	4.88	5.96	6.00	5.24	6.64	6.55
2007	7.68	7.90	7.45	7.55	8.57	7.52	4.01	4.81	5.01	6.22	6.16	6.47
2008	6.83	7.17	7.45	7.00	6.25	6.55	6.09	5.71	6.25			

ECOW-18 Kunnathunadu (Pattimattom)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.56	7.93	8.03	8.03	8.49	5.63	5.51	6.58	7.12	4.70	7.60	7.58
2007	8.35	9.05	8.28	8.27	8.85	7.38	4.03	5.15	5.53	7.20	6.54	7.47
2008	7.73	8.27	8.38	7.33	7.68	7.13	6.78	5.65	6.83			

ECOW-19 Kunnathunadu

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.76	6.95	7.08	7.40	7.70	3.86	4.97	5.67	5.82	6.34	6.60	6.66
2007	8.16	8.90	7.85	8.16	8.72	7.40	3.45	2.78	4.80	5.87	5.59	6.64
2008	7.47	7.50	7.45	7.55	7.60	6.60	5.70	5.25	5.14			

ECOW-20 Rayamangalam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.49	4.43	4.29	3.03	4.51	0.99	2.73	3.13	2.50	2.80	3.28	4.67
2007	5.38	4.88	3.18	4.42	4.40	4.53	0.63	1.97	2.23	4.24	3.56	4.86
2008	4.33	3.86	3.08	4.43	4.13	3.93	2.65	3.28	4.13			

ECOW-21 Kunnathunadu South

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.85	7.35	7.70	7.90	7.80	3.80	3.43	6.05	7.72	6.2	5.97	6.70
2007	7.01	7.20	7.80	7.52	7.10	6.90	4.60	4.57	6.91	6.51	6.10	6.80
2008	7.32	8.20	8.18	7.94	8.05	7.53	4.77	5.58	6.10			

ECOW-22 Perumbavoor

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.83	8.00	8.17	8.80	8.05	2.42	4.52	5.70	5.74	5.33	7.04	7.91
2007	9.16	10.05	8.25	7.69	9.23	7.70	1.70	4.29	4.60	7.16	6.31	7.69
2008	8.20	8.69	7.15	7.23	8.20	8.20	4.73	6.60	6.75			

ECOW-23 Kizhakkambalam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	8.20	8.75	9.34	9.80	10.10	8.50	5.80	6.50	7.75	4.90	7.15	8.06
2007	9.24	10.10	9.38	9.86	11.13	10.25	4.90	4.91	6.74	6.90	6.50	7.84
2008	8.66	9.12	9.62	9.77	10.34	9.94	8.50	7.38	6.08			

ECOW-24 Piravom

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.99	10.25	9.14	7.62	8.59	3.99	7.02	6.24	5.70	6.82	11.20	4.90
2007	9.12	11.34	8.52	7.73	9.26	8.64	7.42	8.55	6.30	8.34	4.89	10.84
2008	10.96	11.28	10.30	7.88	10.62	12.63	11.06	8.26	5.77			

ECOW-25 Elanji

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.69	6.90	7.00	6.95	6.90	0.12	0.75	1.75	3.45	1.35	1.75	6.55
2007	7.60	7.61	6.97	6.86	7.90	6.80	0.15	0.40	1.40	2.05	1.03	6.65
2008	6.80	6.75	6.95	6.50	6.75	6.19	1.23	0.77	2.41			

ECOW-26 Koothattukulam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	3.94	4.12	4.18	4.23	4.16	1.80	3.24	3.34	3.26	4.20	4.06	4.01
2007	4.90	4.95	4.18	4.12	4.75	3.96	2.56	2.91	2.56	3.66	3.41	4.01
2008	4.11	4.22	4.31	4.02	3.76	3.92	3.66	2.71	3.56			

ECOW-27 Thirumaradi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.10	4.53	3.95	4.00	3.97	2.05	3.10	3.22	3.54	3.50	3.95	4.35
2007	5.12	5.30	4.65	4.41	4.72	3.70	2.20	2.55	2.75	3.60	3.42	4.34
2008	3.77	4.09	4.23	4.15	4.02	3.30	3.67	2.25	3.55			

ECOW-28 Thirumaradi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	2.50	2.87	3.08	2.92	3.00	1.25	1.33	1.55	2.00	2.20	2.56	2.30
2007	3.12	3.55	3.00	3.08	3.34	2.45	1.35	1.25	1.37	2.00	1.73	2.32
2008	2.40	2.82	2.85	2.36	2.20	2.05	1.90	1.25	1.75			

ECOW-29 Memuri

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.35	6.75	6.25	6.25	6.11	3.70	4.22	4.24	5.43	5.05	5.96	5.83
2007	6.51	6.60	6.07	6.07	6.64	6.05	3.75	4.10	4.89	5.22	5.47	5.88
2008	5.96	6.10	6.11	5.82	5.60	5.70	5.50	3.20	4.22			

ECOW-30 Muvattupuzha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	8.92	8.46	7.90	8.62	8.76	7.22	7.90	8.19	6.58	6.22	6.34	7.66
2007	7.60	7.26	7.77	8.16	8.77	3.72	3.07	4.15	7.02	7.97	7.04	7.46
2008	7.30	5.26	6.96	7.46	4.52	3.37	3.27	3.47	6.35			

ECOW-31 Eranellur

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	5.77	6.13	6.46	6.90	7.16	4.70	4.56	4.80	5.45	5.42	5.45	5.66
2007	6.55	6.80	6.50	7.04	8.90	7.20	4.30	4.43	3.48	5.07	5.04	5.60
2008	5.95	6.28	6.54	6.66	6.20	5.60	4.58	4.60	4.92			

Table 3.12
WATER QUALITY DATA OF OPEN WELLS IN CRYSTALLINE FORMATIONS

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-01	Jan/06/2006	8.50	300.00	180.00	130.00	31.20	12.20	6.00	6.20	110.00	12.00	109.80	8.00	20.00	2.48	0.90	0.93
ECOW-01	May/06/2006	7.90	103.00	62.00	35.00	8.40	3.40	5.00	1.20	32.00	0.00	39.00	9.00	7.00	0.00	0.23	0.30
ECOW-01	Sep/17/2006	8.40	250.00	150.00	120.00	28.80	11.71	4.30	2.70	102.00	4.80	114.70	9.00	5.00	0.62	0.52	0.77
ECOW-01	Jan/05/2007	8.30	250.00	150.00	110.00	26.40	10.74	3.00	0.78	96.00	12.00	92.70	11.40	7.68	1.86	0.17	2.92
ECOW-01	May/07/2007	7.90	110.00	66.00	50.00	12.00	4.90	4.00	1.60	48.00	0.00	58.60	6.00	8.00	1.86	0.46	4.42
ECOW-01	Sep/14/2007	8.60	220.00	132.00	100.00	24.00	9.80	3.00	2.00	100.00	4.80	112.20	7.00	7.00	0.62	0.43	0.48
ECOW-01	Jan/08/2008	8.40	160.00	96.00	59.00	21.70	1.20	5.00	2.50	60.00	6.00	61.00	7.00	0.90	1.24	0.84	0.40
ECOW-01	May/09/2008	8.30	190.00	114.00	90.00	33.60	1.50	5.00	3.40	62.00	10.20	55.00	8.00	5.00	4.94	0.01	0.70
ECOW-01	Sep/12/2008	8.40	240.00	144.00	98.00	37.20	1.20	6.00	3.60	88.00	19.50	67.70	10.00	6.00	2.96	0.08	0.72
ECOW-02	Jan/06/2006	7.30	105.00	63.00	42.00	10.00	4.10	8.00	2.00	8.00	0.00	9.80	15.00	10.00	3.10	0.89	0.25
ECOW-02	May/06/2006	7.90	102.00	61.00	30.00	7.20	2.90	7.00	1.60	14.00	0.00	17.00	17.00	5.00	1.24	0.17	0.40
ECOW-02	Sep/17/2006	7.20	95.00	57.00	30.00	7.20	2.90	8.00	1.20	10.00	0.00	12.20	14.00	5.00	3.60	0.64	0.20
ECOW-02	Jan/05/2007	7.60	137.00	82.00	40.00	9.60	3.90	12.00	2.00	15.00	0.00	18.30	26.00	3.00	3.20	0.21	0.50
ECOW-02	May/07/2007	7.40	140.00	84.00	40.00	9.40	4.00	11.00	2.00	16.00	0.00	19.50	18.00	3.00	6.30	0.15	1.25
ECOW-02	Sep/14/2007	7.30	94.00	56.00	25.00	6.00	2.40	9.00	1.20	8.00	0.00	9.80	16.00	3.00	3.50	0.15	0.10
ECOW-02	Jan/08/2008	7.50	115.00	69.00	35.00	8.00	3.70	9.00	1.70	24.00	0.00	29.00	19.00	3.00	4.10	0.39	0.11
ECOW-02	May/09/2008	8.10	170.00	102.00	50.00	10.00	6.10	14.00	3.20	38.00	0.00	46.40	23.00	4.00	4.50	0.06	0.91
ECOW-02	Sep/12/2008	7.60	153.00	92.00	50.00	12.00	4.90	12.00	3.70	34.00	0.00	41.50	21.00	7.00	5.20	0.52	0.28
ECOW-03	Jan/06/2006	8.10	260.00	156.00	90.00	21.60	8.80	13.00	8.20	62.00	0.00	75.60	21.00	6.00	4.96	0.35	0.81
ECOW-03	May/06/2006	7.90	200.00	120.00	60.00	14.28	5.90	12.00	11.70	34.00	0.00	41.50	19.00	20.00	5.58	0.00	0.22
ECOW-03	Sep/17/2006	7.80	290.00	174.00	100.00	24.00	9.80	14.00	14.40	48.00	0.00	58.60	33.00	18.00	7.44	0.44	0.07
ECOW-03	Jan/05/2007	7.50	240.00	144.00	75.00	18.00	7.30	14.00	17.20	42.00	0.00	51.20	26.00	15.00	8.40	0.16	0.96
ECOW-03	May/07/2007	8.00	170.00	102.00	45.00	11.00	4.30	10.00	10.10	30.00	0.00	36.60	16.00	12.00	3.72	0.43	1.32

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-03	Sep/14/2007	7.70	290.00	174.00	75.00	18.00	7.30	22.00	18.00	34.00	0.00	41.50	35.00	26.00	7.40	0.12	0.07
ECOW-03	Jan/08/2008	7.60	160.00	96.00	50.00	12.00	4.90	10.00	9.80	38.00	0.00	46.40	18.00	13.00	4.10	0.85	1.86
ECOW-03	May/09/2008	7.80	150.00	90.00	40.00	10.00	3.70	9.00	9.10	22.00	0.00	27.00	14.00	12.00	3.50	0.00	0.22
ECOW-03	Sep/12/2008	7.90	220.00	132.00	60.00	14.00	6.10	23.00	16.30	34.00	0.00	41.50	45.00	21.00	6.23	0.29	0.30
ECOW-04	Jan/03/2006	7.80	140.00	84.00	38.00	9.00	3.80	12.00	6.20	22.00	0.00	26.80	24.00	5.00	4.34	0.19	0.35
ECOW-04	May/04/2006	7.30	110.00	66.00	35.00	8.40	3.40	7.00	4.70	12.00	0.00	14.60	19.00	7.00	3.10	0.07	0.62
ECOW-04	Sep/16/2006	7.40	120.00	72.00	35.00	8.40	3.40	8.00	4.30	15.00	0.00	18.30	18.00	8.00	2.48	0.18	0.10
ECOW-04	Jan/07/2007	7.30	167.00	100.00	55.00	13.20	5.40	9.00	3.90	15.00	0.00	18.30	26.00	6.00	7.82	0.18	0.14
ECOW-04	May/09/2007	7.50	94.00	56.00	26.00	6.30	2.50	6.00	3.20	18.00	0.00	22.00	14.00	4.00	1.24	0.15	0.43
ECOW-04	Sep/16/2007	7.30	100.00	60.00	22.00	5.20	2.20	8.00	3.90	16.00	0.00	19.50	18.00	8.00	0.00	0.38	0.05
ECOW-04	Jan/16/2008	7.50	126.00	76.00	39.00	9.40	3.80	8.00	4.30	24.00	0.00	29.30	14.00	6.00	3.70	0.12	0.12
ECOW-04	May/10/2008	7.70	110.00	66.00	42.00	16.80	0.10	5.00	3.00	26.00	0.00	32.00	10.00	5.00	2.10	0.18	0.31
ECOW-04	Sep/10/2008	7.60	169.00	101.00	40.00	8.00	4.90	11.00	1.70	22.00	0.00	26.80	24.00	10.00	4.63	0.10	0.13
ECOW-05	Jan/03/2006	7.10	100.00	60.00	24.00	5.80	2.30	9.00	1.60	16.00	0.00	19.50	17.00	1.00	3.72	0.72	0.30
ECOW-05	May/04/2006	7.80	126.00	76.00	35.00	8.40	3.40	11.00	2.00	30.00	0.00	36.60	14.00	5.00	2.48	0.19	0.62
ECOW-05	Sep/16/2006	7.00	80.00	48.00	20.00	4.70	2.00	7.00	0.80	6.00	0.00	7.30	18.00	2.00	1.86	0.36	0.26
ECOW-05	Jan/06/2007	6.80	79.00	47.00	20.00	4.70	2.00	7.00	1.20	6.00	0.00	7.30	20.00	2.40	1.86	0.14	0.50
ECOW-05	May/09/2007	7.40	107.00	64.00	25.00	6.00	2.20	11.00	1.60	23.00	0.00	34.20	14.00	1.40	2.48	0.40	0.80
ECOW-05	Sep/16/2007	6.80	77.00	46.00	20.00	4.90	1.90	7.00	0.80	6.00	0.00	7.30	14.00	1.20	3.10	0.00	0.70
ECOW-05	Jan/16/2008	7.00	80.00	48.00	25.00	7.90	1.20	8.00	0.90	5.00	0.00	6.10	15.00	2.00	2.30	0.59	0.03
ECOW-05	May/10/2008	7.90	100.00	60.00	37.00	13.00	1.10	7.00	1.10	26.00	0.00	31.70	12.00	3.60	2.06	0.00	0.10
ECOW-05	Sep/10/2008	7.00	70.00	42.00	15.00	4.00	1.20	8.00	0.60	14.00	0.00	17.00	15.00	6.00	1.76	0.78	0.10
ECOW-06	Jan/06/2006	8.40	230.00	138.00	92.00	22.20	9.00	8.00	6.00	66.00	4.80	70.70	17.00	11.00	3.72	0.85	1.21
ECOW-06	May/06/2006	8.30	200.00	120.00	69.00	16.68	6.70	13.00	5.00	57.00	2.40	64.70	19.00	12.00	1.86	0.20	1.50
ECOW-06	Sep/17/2006	8.30	260.00	156.00	100.00	24.00	9.70	14.00	3.50	75.00	7.20	76.80	18.00	13.00	3.72	0.39	0.80

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-06	Jan/05/2007	7.70	240.00	144.00	75.00	18.00	7.30	19.00	3.50	57.00	0.00	69.50	14.00	12.00	8.00	0.33	1.46
ECOW-06	May/07/2007	7.80	200.00	120.00	71.00	17.00	6.90	9.00	3.10	52.00	0.00	63.40	18.00	10.00	4.34	0.20	0.53
ECOW-06	Sep/14/2007	8.30	245.00	147.00	80.00	19.20	7.80	18.00	3.50	52.00	4.80	53.70	14.00	21.00	5.58	0.40	0.60
ECOW-06	Jan/08/2008	8.50	320.00	192.00	114.00	33.20	7.60	23.00	4.30	76.00	18.40	55.30	21.00	17.00	4.80	0.70	0.00
ECOW-06	May/09/2008	8.60	290.00	174.00	122.00	31.60	10.50	12.00	3.80	93.00	20.50	71.70	16.00	11.00	3.54	0.20	1.50
ECOW-06	Sep/12/2008	7.80	300.00	180.00	93.00	21.60	9.60	20.00	3.90	68.00	0.00	83.00	26.00	16.00	4.71	0.75	0.80
ECOW-07	Jan/06/2006	8.60	137.00	82.00	43.00	10.30	4.20	9.00	5.00	42.00	2.40	46.40	14.00	2.00	1.86	0.90	0.62
ECOW-07	May/06/2006	7.70	140.00	84.00	50.00	12.00	4.90	7.00	5.50	49.00	0.00	59.80	9.00	6.00	0.00	0.00	2.20
ECOW-07	Sep/17/2006	7.40	99.00	59.00	20.00	4.80	2.00	8.00	2.70	20.00	0.00	24.40	14.00	3.40	1.86	0.40	0.32
ECOW-07	Jan/05/2007	7.70	166.00	100.00	80.00	19.20	7.80	7.00	2.70	53.00	0.00	64.70	9.00	14.00	2.48	0.15	1.80
ECOW-07	May/07/2007	8.60	250.00	150.00	91.00	21.80	8.90	6.00	4.70	96.00	4.80	107.40	9.00	3.00	3.72	0.45	2.42
ECOW-07	Sep/14/2007	7.60	73.00	44.00	15.00	3.60	1.40	9.00	2.30	6.00	0.00	7.30	14.00	1.40	2.48	0.21	0.25
ECOW-07	Jan/08/2008	7.60	110.00	66.00	25.00	9.90	0.00	10.00	3.70	20.00	0.00	24.40	15.00	7.00	1.64	0.70	0.60
ECOW-07	May/09/2008	8.00	134.00	80.00	48.00	16.80	1.40	6.00	5.20	41.00	0.00	50.00	10.00	4.00	1.12	0.00	0.13
ECOW-07	Sep/12/2008	8.30	90.00	54.00	20.00	8.00	0.00	9.00	2.30	14.00	0.00	17.00	17.00	5.00	2.20	0.69	0.37
ECOW-08	Jan/05/2006	7.80	280.00	168.00	73.00	17.50	7.10	24.00	14.80	14.00	0.00	17.10	83.00	2.40	4.34	0.75	1.56
ECOW-08	May/10/2006	8.30	380.00	228.00	98.00	23.50	9.60	31.00	16.40	82.00	7.20	86.00	76.00	21.00	4.96	0.45	3.40
ECOW-08	Sep/15/2006	7.40	340.00	204.00	70.00	16.80	6.80	30.00	24.20	76.00	0.00	92.70	53.00	14.00	1.24	0.44	2.13
ECOW-08	Jan/06/2007	8.30	500.00	330.00	170.00	40.80	16.60	14.00	20.30	134.00	16.80	129.30	80.00	4.30	1.86	0.26	2.13
ECOW-08	May/10/2007	7.60	370.00	222.00	126.00	30.00	12.40	9.00	28.00	56.00	0.00	68.30	78.00	14.00	1.24	0.40	8.12
ECOW-08	Sep/15/2007	7.80	295.00	177.00	70.00	16.80	6.83	18.00	21.50	44.00	0.00	53.70	44.00	24.00	4.34	0.34	3.70
ECOW-08	Jan/10/2008	7.60	330.00	198.00	75.00	24.00	3.70	20.00	22.00	44.00	0.00	53.70	53.00	27.00	4.40	0.24	7.88
ECOW-08	May/05/2008	7.50	350.00	210.00	85.00	22.00	7.30	27.00	20.50	38.00	0.00	46.40	60.00	18.00	3.60	0.30	9.00
ECOW-08	Sep/05/2008	7.90	280.00	168.00	60.00	18.00	3.70	26.00	25.00	38.00	0.00	46.40	44.00	29.00	4.80	0.26	4.60
ECOW-09	Jan/06/2006	8.00	80.00	48.00	25.00	6.20	2.30	6.00	1.20	14.00	0.00	17.00	10.00	3.40	1.86	0.82	0.20

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-09	May/06/2006	7.40	85.00	51.00	30.00	7.20	2.90	5.00	1.20	10.00	0.00	12.20	14.00	9.00	0.00	0.89	0.20
ECOW-09	Sep/17/2006	7.30	80.00	48.00	25.00	6.00	2.40	5.00	1.20	12.00	0.00	14.60	14.00	2.40	1.86	0.52	0.10
ECOW-09	Jan/05/2007	7.10	75.00	45.00	25.00	6.00	2.40	6.00	1.20	12.00	0.00	14.60	13.00	4.00	0.62	2.00	0.30
ECOW-09	May/07/2007	7.40	80.00	48.00	25.00	6.20	2.30	5.00	1.60	12.00	0.00	14.60	11.00	5.00	0.62	0.20	0.80
ECOW-09	Sep/14/2007	6.80	60.00	36.00	15.00	3.60	1.40	6.00	1.20	6.00	0.00	7.30	11.00	4.00	3.10	0.00	0.10
ECOW-09	Jan/08/2008	8.10	140.00	84.00	25.00	6.00	2.40	7.00	1.80	12.00	0.00	14.60	13.00	4.00	1.60	0.00	0.40
ECOW-09	May/09/2008	7.40	120.00	72.00	40.00	16.00	0.00	6.00	1.60	18.00	0.00	22.00	17.00	6.00	4.20	0.00	0.00
ECOW-09	Sep/12/2008	7.10	70.00	42.00	26.00	6.40	2.60	4.00	1.30	10.20	0.00	12.40	9.00	3.00	1.70	0.06	0.40
ECOW-10	Jan/05/2006	7.90	250.00	150.00	88.00	21.10	8.60	18.00	13.00	32.00	0.00	39.00	28.00	10.00	8.68	1.00	0.53
ECOW-10	May/10/2006	7.90	260.00	156.00	45.00	10.80	4.39	26.00	13.60	34.00	0.00	41.50	41.00	9.00	9.30	0.10	0.30
ECOW-10	Sep/15/2006	7.70	130.00	78.00	40.00	9.60	3.90	9.00	7.00	30.00	0.00	36.60	17.00	6.00	4.34	0.58	0.15
ECOW-10	Jan/06/2007	7.50	220.00	132.00	70.00	16.80	6.80	15.00	7.80	30.00	0.00	36.60	28.00	12.00	10.00	0.09	2.92
ECOW-10	May/10/2007	7.50	198.00	119.00	56.00	13.30	5.50	14.00	9.00	34.00	0.00	41.50	30.00	12.00	6.82	0.00	2.77
ECOW-10	Sep/15/2007	7.40	98.00	59.00	20.00	4.80	1.95	9.00	4.70	14.00	0.00	17.00	12.00	8.00	4.34	0.00	0.07
ECOW-10	Jan/10/2008	7.70	170.00	102.00	49.00	11.80	4.80	10.00	11.70	30.00	0.00	36.60	16.00	8.00	8.90	0.17	0.20
ECOW-10	May/05/2008	7.90	230.00	138.00	60.00	20.00	2.40	14.00	12.30	31.00	0.00	37.80	22.00	10.00	8.70	0.00	2.00
ECOW-10	Sep/05/2008	7.70	162.00	97.00	50.00	12.00	4.90	10.00	8.00	30.00	0.00	36.60	18.00	8.00	5.60	0.48	0.02
ECOW-11	Jan/05/2006	7.90	80.00	48.00	30.00	7.30	2.80	5.00	1.20	22.00	0.00	26.80	9.00	1.00	1.24	0.46	0.22
ECOW-11	May/10/2006	7.80	127.00	76.00	64.00	15.00	6.50	4.00	1.20	47.00	0.00	57.30	9.00	4.00	0.62	0.00	0.25
ECOW-11	Sep/15/2006	7.70	100.00	60.00	40.00	9.60	3.90	3.00	0.80	25.00	0.00	30.50	9.00	4.00	0.00	0.46	0.10
ECOW-11	Jan/06/2007	7.40	82.00	49.00	35.00	8.40	3.40	3.00	0.80	19.00	0.00	23.20	8.00	2.00	4.34	0.98	0.53
ECOW-11	May/10/2007	7.90	64.00	38.00	19.00	4.60	1.80	4.00	0.80	18.00	0.00	22.00	8.00	2.00	2.48	0.00	0.91
ECOW-11	Sep/15/2007	7.80	79.00	47.00	30.00	7.20	2.90	4.00	0.80	26.00	0.00	31.70	8.00	4.00	0.00	0.28	0.13
ECOW-11	Jan/10/2008	7.40	100.00	60.00	40.00	8.00	4.90	5.00	1.10	28.00	0.00	34.20	14.00	2.00	0.70	0.60	0.30
ECOW-11	May/05/2008	7.80	157.00	94.00	65.00	12.00	8.50	4.00	0.70	44.00	0.00	53.70	14.00	1.50	0.20	0.00	0.25

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-11	Sep/05/2008	8.10	125.00	75.00	50.00	10.00	6.10	8.00	1.00	36.00	0.00	44.00	14.00	9.00	0.70	0.51	0.24
ECOW-12	Jan/05/2006	7.50	130.00	78.00	43.00	10.30	4.20	6.00	8.60	36.00	0.00	43.90	10.00	7.00	0.62	0.14	1.40
ECOW-12	May/10/2006	7.30	155.00	93.00	54.00	13.00	5.20	8.00	8.20	41.00	0.00	50.00	12.00	9.00	0.00	0.10	0.20
ECOW-12	Sep/15/2006	7.70	88.00	53.00	30.00	7.20	2.90	4.00	3.10	25.00	0.00	30.50	9.00	7.00	0.00	0.38	0.42
ECOW-12	Jan/06/2007	7.50	115.00	69.00	35.00	8.40	3.40	5.00	4.70	34.00	0.00	41.50	11.00	7.00	0.62	0.17	1.70
ECOW-12	May/10/2007	7.20	150.00	90.00	55.00	13.30	5.30	5.00	6.00	50.00	0.00	61.00	9.00	8.00	1.24	0.55	0.60
ECOW-12	Sep/15/2007	8.00	100.00	60.00	35.00	8.40	3.40	3.00	3.50	36.00	0.00	43.90	6.00	7.00	0.62	0.36	3.60
ECOW-12	Jan/05/2008	7.60	123.00	74.00	45.00	12.00	3.70	5.00	6.30	46.00	0.00	56.10	12.00	11.00	0.00	0.49	0.57
ECOW-12	May/05/2008	8.00	130.00	78.00	63.00	12.40	7.80	5.00	8.80	36.00	0.00	44.00	10.00	5.00	2.74	0.00	0.80
ECOW-12	Sep/05/2008	6.90	90.00	54.00	29.00	8.00	2.40	5.00	5.20	24.00	0.00	29.30	9.00	14.00	0.62	0.53	0.20
ECOW-13	Jan/03/2006	7.80	90.00	54.00	32.00	7.70	3.10	5.00	2.00	17.00	0.00	20.70	10.00	5.00	1.24	0.26	0.31
ECOW-13	May/04/2006	7.50	76.00	46.00	25.00	6.00	2.40	4.00	2.00	14.00	0.00	17.00	12.00	2.40	1.24	0.00	0.17
ECOW-13	Sep/16/2006	7.60	91.00	55.00	35.00	8.40	3.40	6.00	2.30	20.00	0.00	24.40	10.00	9.00	1.24	0.48	0.12
ECOW-13	Jan/07/2007	7.30	70.00	42.00	25.00	6.00	2.40	7.00	2.00	10.00	0.00	12.20	12.00	3.00	6.20	0.26	0.46
ECOW-13	May/09/2007	8.00	92.00	55.00	40.00	9.70	3.80	6.00	2.00	34.00	0.00	41.50	10.00	6.00	0.62	0.23	0.64
ECOW-13	Sep/16/2007	7.50	90.00	54.00	30.00	7.20	2.90	5.00	2.70	20.00	0.00	24.40	9.00	9.00	1.86	0.00	0.11
ECOW-13	Jan/16/2008	7.70	60.00	36.00	36.00	10.40	2.50	5.00	1.40	10.00	0.00	12.20	8.00	4.00	0.70	0.00	0.11
ECOW-13	May/10/2008	7.80	100.00	60.00	37.00	10.50	2.60	5.00	1.60	26.00	0.00	31.70	9.00	3.60	4.10	0.00	0.17
ECOW-13	Sep/10/2008	7.70	92.00	55.00	29.00	8.00	2.40	6.00	3.20	15.00	0.00	18.30	11.00	4.00	3.60	0.17	0.10
ECOW-14	Jan/05/2006	8.70	325.00	195.00	98.00	23.50	9.60	14.00	26.50	90.00	7.20	95.16	32.00	12.00	8.68	0.66	0.62
ECOW-14	May/10/2006	7.70	180.00	108.00	24.00	5.64	2.20	16.00	23.00	23.00	0.00	28.00	22.00	13.00	7.44	0.51	0.18
ECOW-14	Sep/15/2006	7.60	156.00	94.00	45.00	10.68	4.30	6.00	16.40	21.00	0.00	25.60	18.00	14.00	4.34	0.70	0.14
ECOW-14	Jan/06/2007	7.40	210.00	126.00	55.00	13.20	5.40	15.00	15.60	19.00	0.00	23.20	31.00	13.00	3.70	0.21	0.40
ECOW-14	May/10/2007	7.90	140.00	84.00	50.00	12.00	4.90	3.00	7.80	28.00	0.00	34.20	16.00	6.00	5.58	0.40	0.46
ECOW-14	Sep/15/2007	7.70	160.00	96.00	45.00	10.80	4.40	10.00	16.80	20.00	0.00	24.40	26.00	17.00	1.86	0.83	0.05

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-14	Jan/10/2008	7.80	250.00	150.00	60.00	13.80	6.00	15.00	27.40	25.00	0.00	30.50	28.00	9.00	8.90	0.93	0.10
ECOW-14	May/05/2008	7.50	300.00	180.00	85.00	20.00	8.50	17.00	20.00	54.00	0.00	65.80	38.00	8.00	8.00	0.00	0.11
ECOW-14	Sep/05/2008	7.90	180.00	108.00	34.00	10.00	2.40	13.00	21.00	19.00	0.00	23.20	24.00	18.00	5.14	0.86	0.14
ECOW-15	Jan/05/2006	7.40	130.00	78.00	54.00	13.00	5.20	4.00	1.20	44.00	0.00	53.70	6.80	0.00	3.10	0.75	0.42
ECOW-15	May/10/2006	7.00	60.00	36.00	15.00	3.60	1.40	6.00	1.20	4.50	0.00	5.50	12.00	2.00	2.48	0.06	0.11
ECOW-15	Sep/15/2006	7.10	49.00	29.00	15.00	3.60	1.50	4.00	0.80	8.00	0.00	9.80	11.00	1.40	1.86	0.26	0.24
ECOW-15	Jan/06/2007	7.00	80.00	48.00	30.00	7.20	2.90	5.00	0.00	10.00	0.00	12.20	14.00	1.40	1.24	0.19	0.86
ECOW-15	May/10/2007	7.00	51.00	31.00	15.00	3.60	1.50	3.00	1.60	12.00	0.00	14.60	8.00	0.00	0.00	0.29	0.42
ECOW-15	Sep/15/2007	7.10	38.00	23.00	10.00	2.40	0.98	3.00	0.80	6.00	0.00	7.30	7.00	3.00	0.00	0.36	0.03
ECOW-15	Jan/10/2008	6.80	70.00	42.00	21.00	8.40	0.00	5.00	1.00	10.00	0.00	12.20	8.00	5.00	2.90	0.30	0.01
ECOW-15	May/05/2008	6.60	70.00	42.00	20.00	5.90	1.20	5.00	1.00	10.00	0.00	12.20	11.00	0.00	3.10	0.63	0.20
ECOW-15	Sep/05/2008	7.50	58.00	35.00	20.00	6.00	1.20	4.50	0.80	5.00	0.00	6.00	8.00	0.80	2.62	0.40	0.18
ECOW-16	Jan/03/2006	8.30	200.00	120.00	64.00	15.30	6.30	11.00	4.30	64.00	4.80	68.30	22.00	2.40	3.10	0.81	0.36
ECOW-16	May/04/2006	7.40	160.00	96.00	45.00	10.80	4.40	15.00	3.90	27.00	0.00	33.00	27.00	6.00	1.86	0.00	0.50
ECOW-16	Sep/16/2006	7.10	90.00	54.00	30.00	7.20	2.90	7.00	2.30	10.00	0.00	12.20	17.00	5.00	1.86	0.50	0.16
ECOW-16	Jan/06/2007	7.70	220.00	132.00	85.00	20.30	8.30	11.00	4.30	76.00	0.00	92.70	23.00	6.00	3.10	0.28	0.30
ECOW-16	May/10/2007	7.80	140.00	84.00	35.00	7.30	4.00	12.00	4.30	22.00	0.00	26.80	20.00	4.00	5.58	0.11	0.48
ECOW-16	Sep/16/2007	7.10	90.00	54.00	20.00	4.70	2.00	9.00	3.10	12.00	0.00	14.60	16.00	5.00	4.34	0.00	0.13
ECOW-16	Jan/16/2008	7.40	135.00	81.00	35.00	11.00	1.80	12.00	5.20	20.00	0.00	24.40	21.00	4.00	4.02	0.43	0.10
ECOW-16	May/10/2008	7.80	125.00	75.00	37.00	12.80	1.20	10.00	4.00	26.00	0.00	31.70	17.00	4.00	3.90	0.00	0.07
ECOW-16	Sep/10/2008	7.10	100.00	60.00	25.00	8.00	1.20	9.50	3.40	9.80	0.00	12.00	18.00	2.00	3.66	0.75	0.08
ECOW-17	Jan/03/2006	7.80	160.00	96.00	66.00	15.80	6.40	7.00	3.12	61.00	0.00	74.40	9.60	1.44	1.24	0.98	0.63
ECOW-17	May/04/2006	7.30	110.00	66.00	40.00	9.60	3.90	6.00	2.00	41.00	0.00	50.00	9.00	2.40	0.62	0.14	0.62
ECOW-17	Sep/16/2006	7.80	150.00	90.00	65.00	15.60	6.30	5.00	1.60	53.00	0.00	64.60	9.00	2.00	1.24	0.54	0.15
ECOW-17	Jan/07/2007	7.60	135.00	81.00	55.00	13.20	5.30	5.00	1.20	51.00	0.00	62.20	9.00	2.40	0.62	0.06	0.96

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-17	May/09/2007	7.40	101.00	61.00	35.00	8.50	3.50	6.00	1.20	40.00	0.00	48.80	8.00	2.00	4.34	0.40	1.34
ECOW-17	Sep/16/2007	7.90	103.00	62.00	35.00	8.40	3.40	6.00	1.20	38.00	0.00	46.40	9.00	1.00	1.86	0.28	0.13
ECOW-17	Jan/16/2008	7.70	102.00	61.00	45.00	10.00	4.90	4.00	1.00	34.00	0.00	41.50	11.00	1.00	1.80	0.00	0.90
ECOW-17	May/10/2008	8.10	125.00	75.00	58.00	18.80	2.70	4.00	0.70	46.00	0.00	56.00	6.00	3.30	0.80	0.03	0.60
ECOW-17	Sep/10/2008	7.00	60.00	36.00	15.00	4.00	1.20	6.00	1.30	14.00	0.00	17.00	9.00	2.40	2.10	0.10	0.10
ECOW-18	Jan/03/2006	7.60	130.00	78.00	42.00	10.20	4.00	15.00	2.30	8.00	0.00	9.80	34.00	1.40	8.68	0.33	0.30
ECOW-18	May/04/2006	7.50	120.00	72.00	35.00	8.40	3.40	12.00	1.60	12.00	0.00	14.60	24.00	4.00	5.58	0.02	0.18
ECOW-18	Sep/16/2006	6.50	110.00	66.00	30.00	7.20	2.90	13.00	2.00	6.00	0.00	7.30	26.00	5.00	7.44	0.52	0.20
ECOW-18	Jan/07/2007	7.20	120.00	72.00	30.00	7.30	2.80	16.00	1.60	6.00	0.00	7.30	32.00	1.40	4.34	0.09	0.30
ECOW-18	May/09/2007	7.80	110.00	66.00	31.00	7.40	3.00	11.00	2.30	14.00	0.00	17.10	28.00	3.40	4.34	0.00	0.60
ECOW-18	Sep/16/2007	5.90	130.00	78.00	30.00	7.20	2.90	17.00	2.00	4.00	0.00	4.90	29.00	7.00	6.20	0.23	0.20
ECOW-18	Jan/17/2008	7.00	168.00	101.00	35.00	10.00	2.40	18.00	2.00	20.00	0.00	24.40	31.00	1.00	6.80	0.80	0.40
ECOW-18	May/10/2008	7.70	200.00	120.00	50.00	18.00	8.50	16.00	1.70	42.00	0.00	51.20	28.00	8.00	5.90	0.00	0.00
ECOW-18	Sep/10/2008	7.40	160.00	96.00	29.00	8.00	2.40	16.00	1.70	5.00	0.00	6.10	26.00	5.00	7.16	0.10	0.10
ECOW-19	Jan/03/2006	7.20	120.00	72.00	33.00	7.90	3.20	10.00	4.70	6.00	0.00	7.32	27.00	1.00	8.68	0.85	0.23
ECOW-19	May/04/2006	7.30	100.00	60.00	14.00	3.20	1.40	15.00	5.00	14.00	0.00	17.00	17.00	6.00	6.82	0.04	1.50
ECOW-19	Sep/16/2006	7.00	125.00	75.00	40.00	9.60	3.90	9.00	2.00	28.00	0.00	34.20	18.00	5.00	4.96	0.34	0.10
ECOW-19	Jan/07/2007	7.00	171.00	102.00	50.00	12.00	4.90	12.00	3.90	38.00	0.00	46.40	26.00	3.00	3.72	0.04	1.21
ECOW-19	May/09/2007	7.60	197.00	118.00	60.00	14.50	5.80	15.00	3.90	16.00	0.00	19.50	27.00	4.30	3.72	0.65	1.29
ECOW-19	Sep/16/2007	6.20	119.00	71.00	30.00	7.20	2.90	9.00	2.30	6.00	0.00	7.30	16.00	4.00	4.96	0.15	0.10
ECOW-19	Jan/16/2008	7.00	240.00	144.00	62.00	20.80	2.50	20.00	4.80	5.00	0.00	6.10	33.00	4.00	9.40	0.00	2.70
ECOW-19	May/10/2008	6.70	280.00	168.00	74.00	21.00	5.30	23.00	5.10	5.10	0.00	6.20	39.00	3.50	8.70	0.22	0.10
ECOW-19	Sep/10/2008	7.00	180.00	108.00	39.00	10.00	3.40	14.00	2.80	10.00	0.00	12.20	26.00	8.00	7.20	0.16	0.10
ECOW-20	Jan/03/2006	7.80	100.00	60.00	26.00	6.20	2.50	9.00	2.70	16.00	0.00	19.50	18.00	5.00	1.86	0.79	0.60
ECOW-20	May/04/2006	6.90	90.00	54.00	25.00	6.00	2.40	9.00	0.80	12.00	0.00	14.60	16.00	3.00	3.10	0.02	0.97

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-20	Sep/16/2006	7.30	89.00	53.40	25.00	6.00	2.40	7.00	2.30	8.00	0.00	9.76	9.00	3.40	3.10	0.38	0.10
ECOW-20	Jan/07/2007	7.50	147.00	88.20	60.00	14.40	5.80	8.00	2.70	42.00	0.00	51.20	16.00	4.00	4.36	0.12	0.80
ECOW-20	May/09/2007	6.90	100.00	60.00	30.00	7.30	2.80	7.00	2.70	14.00	0.00	17.00	12.00	5.00	6.20	0.20	1.86
ECOW-20	Sep/16/2007	6.80	68.00	41.00	15.00	3.60	1.50	6.00	2.00	8.00	0.00	9.70	12.00	2.00	3.10	0.00	0.11
ECOW-20	Jan/16/2008	7.30	111.00	66.00	30.00	8.00	2.40	10.00	3.40	10.00	0.00	12.20	20.00	5.00	4.00	0.53	0.18
ECOW-20	May/10/2008	6.50	90.00	54.00	25.00	8.00	1.20	8.00	2.40	10.00	0.00	12.20	18.00	3.00	2.90	0.00	0.35
ECOW-20	Sep/10/2008	7.00	100.00	60.00	25.00	6.00	2.40	4.00	1.80	12.00	0.00	14.60	18.00	5.00	3.60	0.10	0.10
ECOW-21	Jan/03/2006	7.30	60.00	36.00	21.00	5.00	2.00	4.00	1.20	14.00	0.00	17.10	7.00	6.00	1.86	0.57	0.21
ECOW-21	May/04/2006	7.30	65.00	39.00	20.00	4.70	2.00	6.00	1.60	10.00	0.00	12.20	10.00	3.00	1.86	0.10	0.24
ECOW-21	Sep/16/2006	7.20	54.00	32.00	20.00	4.70	2.00	4.00	0.80	8.00	0.00	9.70	6.00	3.00	1.86	0.34	0.11
ECOW-21	Jan/07/2007	7.10	59.00	35.00	20.00	4.70	2.00	4.00	1.20	8.00	0.00	9.70	6.00	4.00	2.44	0.30	1.82
ECOW-21	May/09/2007	7.00	58.00	35.00	15.00	3.60	1.50	4.00	2.00	10.00	0.00	12.20	8.00	2.40	5.58	0.20	1.21
ECOW-21	Sep/16/2007	6.70	51.00	31.00	15.00	3.60	1.50	4.00	0.80	6.00	0.00	7.30	8.00	1.40	2.48	0.14	0.05
ECOW-21	Jan/16/2008	6.80	92.00	55.00	30.00	4.00	4.90	6.00	1.40	10.00	0.00	12.20	9.00	3.00	1.70	0.60	0.11
ECOW-21	May/10/2008	7.00	60.00	36.00	20.00	2.00	3.70	4.00	1.00	10.00	0.00	12.20	9.00	4.00	2.40	0.40	0.54
ECOW-21	Sep/10/2008	6.70	56.00	34.00	15.00	3.80	1.30	4.00	0.80	10.00	0.00	12.20	7.00	2.60	1.60	0.73	0.30
ECOW-22	Jan/05/2006	7.70	145.00	87.00	42.00	10.00	4.10	14.00	2.00	16.00	0.00	19.50	22.00	12.00	4.34	1.03	0.30
ECOW-22	May/10/2006	7.50	170.00	102.00	46.00	12.00	3.90	15.00	1.70	26.00	0.00	31.70	25.00	9.00	4.96	0.11	0.41
ECOW-22	Sep/16/2006	7.30	100.00	60.00	35.00	8.40	3.40	8.00	0.80	9.00	0.00	11.00	14.00	3.00	4.96	0.18	0.20
ECOW-22	Jan/06/2007	7.40	150.00	90.00	40.00	10.40	3.40	12.00	1.60	18.00	0.00	22.00	22.00	2.00	3.22	0.18	0.86
ECOW-22	May/10/2007	7.70	90.00	54.00	30.00	7.00	3.00	5.90	1.70	26.00	0.00	31.70	10.00	3.40	5.58	0.43	1.07
ECOW-22	Sep/15/2007	7.30	95.00	57.00	25.00	6.00	2.40	10.00	1.20	10.00	0.00	12.20	16.00	5.00	1.24	0.15	0.12
ECOW-22	Jan/10/2008	7.00	105.00	63.00	25.00	6.00	2.40	10.00	1.70	6.00	0.00	7.50	20.00	9.00	3.90	0.20	1.50
ECOW-22	May/05/2008	7.50	90.00	54.00	25.00	6.00	2.40	8.00	1.30	16.00	0.00	19.50	14.00	6.00	3.20	0.00	0.02
ECOW-22	Sep/05/2008	7.00	80.00	48.00	25.00	6.00	2.40	6.00	1.40	15.00	0.00	18.30	10.00	5.00	4.50	0.33	1.00

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-23	Jan/05/2006	4.60	80.00	48.00	14.00	3.50	1.30	10.00	1.60	0.00	0.00	0.00	18.00	1.40	8.68	38.45	0.75
ECOW-23	May/10/2006	4.30	115.00	69.00	25.00	6.70	2.00	12.00	2.00	0.00	0.00	0.00	22.00	1.40	7.44	32.96	0.00
ECOW-23	Sep/15/2006	5.40	100.00	60.00	30.00	7.20	2.90	7.00	0.40	8.00	0.00	9.80	20.00	2.00	2.48	10.99	0.34
ECOW-23	Jan/06/2007	5.00	140.00	84.00	40.00	9.60	3.90	12.00	2.30	8.00	0.00	9.70	22.00	2.40	7.00	31.01	0.24
ECOW-23	May/10/2007	4.20	155.00	93.00	45.00	10.20	4.80	12.00	2.70	0.00	0.00	0.00	22.00	3.00	6.20	27.47	0.61
ECOW-23	Sep/15/2007	5.30	59.00	35.00	10.00	2.10	1.30	8.00	0.40	4.00	0.00	4.90	14.00	1.40	2.48	10.99	0.00
ECOW-23	Jan/10/2008	4.10	110.00	66.00	32.00	10.40	1.50	10.00	1.00	0.00	0.00	0.00	16.70	3.70	6.90	30.57	0.30
ECOW-23	May/05/2008	4.30	141.00	85.00	42.00	12.00	2.90	12.00	2.00	0.00	0.00	0.00	20.00	3.60	7.80	34.55	0.20
ECOW-23	Sep/05/2008	5.30	83.00	50.00	20.00	5.00	1.80	8.00	2.00	4.00	0.00	4.90	18.00	3.20	3.52	15.59	0.00
ECOW-24	Jan/03/2006	7.60	150.00	90.00	52.00	12.50	5.00	10.00	3.10	16.00	0.00	19.52	24.00	11.00	6.20	0.55	0.44
ECOW-24	May/04/2006	7.50	200.00	120.00	45.00	10.80	4.40	20.00	5.00	14.00	0.00	17.10	31.00	18.00	4.34	0.51	0.12
ECOW-24	Sep/16/2006	7.20	90.00	54.00	35.00	8.40	3.40	7.00	2.70	10.00	0.00	12.20	16.00	8.00	3.72	0.26	0.54
ECOW-24	Jan/06/2007	7.30	138.00	83.00	50.00	12.00	4.90	7.00	3.50	16.00	0.00	19.50	20.00	10.00	4.50	0.31	0.96
ECOW-24	May/10/2007	7.60	70.00	42.00	20.00	4.70	2.00	4.00	2.00	12.00	0.00	14.60	9.00	9.00	4.34	0.07	2.50
ECOW-24	Sep/16/2007	7.30	130.00	78.00	40.00	9.60	3.90	8.00	3.90	16.00	0.00	19.50	17.00	11.00	6.00	0.03	0.41
ECOW-24	Jan/16/2008	7.60	200.00	120.00	52.00	16.20	2.80	17.00	4.40	26.00	0.00	31.70	30.00	10.00	6.60	0.70	0.13
ECOW-24	May/10/2008	7.80	200.00	120.00	53.00	21.20	0.00	18.00	4.50	26.00	0.00	31.70	26.00	12.00	4.38	0.00	0.12
ECOW-24	Sep/10/2008	7.10	120.00	72.00	50.00	18.00	1.20	9.00	1.60	46.00	0.00	56.00	12.00	5.00	0.72	0.74	0.02
ECOW-25	Jan/03/2006	7.00	54.00	32.00	13.00	3.10	1.30	5.00	1.20	10.00	0.00	12.20	8.00	0.00	1.86	0.58	0.20
ECOW-25	May/04/2006	7.30	59.00	35.00	16.00	3.84	1.60	5.00	4.00	8.00	0.00	9.70	9.00	1.50	1.50	0.00	0.30
ECOW-25	Sep/16/2006	7.00	55.00	33.00	20.00	6.00	1.20	6.00	0.80	6.00	0.00	7.30	10.00	1.30	1.62	0.14	0.20
ECOW-25	Jan/07/2007	7.00	51.00	31.00	11.00	2.40	1.00	5.00	0.80	8.00	0.00	9.80	11.00	2.00	1.24	1.97	0.60
ECOW-25	May/09/2007	7.00	57.00	34.00	10.00	2.40	1.00	6.00	3.20	10.00	0.00	12.20	9.00	2.40	1.24	0.15	0.40
ECOW-25	Sep/16/2007	7.00	55.00	33.00	15.00	3.60	1.46	4.00	0.80	12.00	0.00	14.60	10.00	2.00	1.24	0.15	0.10
ECOW-25	Jan/16/2008	6.90	62.00	37.00	20.00	5.90	1.20	4.00	1.60	10.00	0.00	12.20	8.00	3.00	1.82	0.76	0.10

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-25	May/10/2008	7.30	65.00	39.00	20.00	6.40	0.00	5.00	1.00	10.00	0.00	12.20	9.00	4.00	1.60	0.00	0.20
ECOW-25	Sep/10/2008	6.90	60.00	36.00	15.00	2.00	2.40	6.00	1.10	6.00	0.00	7.30	10.00	4.00	1.30	0.32	0.20
ECOW-26	Jan/03/2006	7.70	240.00	144.00	78.00	18.70	7.60	15.00	21.00	46.00	0.00	56.10	36.00	10.00	8.68	0.74	0.34
ECOW-26	May/04/2006	8.30	270.00	162.00	55.00	13.00	5.50	22.00	21.00	54.00	0.00	66.00	36.00	9.00	6.20	0.00	0.27
ECOW-26	Sep/16/2006	7.60	180.00	108.00	60.00	14.40	5.86	9.00	13.00	28.00	0.00	34.10	34.00	10.00	5.58	0.14	0.12
ECOW-26	Jan/06/2007	7.40	250.00	150.00	80.00	19.20	7.81	15.00	17.00	34.00	0.00	41.50	36.00	5.00	7.82	0.21	0.46
ECOW-26	May/10/2007	7.90	330.00	198.00	91.00	21.80	8.90	20.00	22.20	62.00	0.00	75.60	45.00	4.00	9.80	0.05	0.64
ECOW-26	Sep/15/2007	7.60	197.00	118.00	50.00	12.00	4.90	11.00	17.60	26.00	0.00	31.70	26.00	10.00	8.06	0.36	0.08
ECOW-26	Jan/16/2008	7.30	250.00	150.00	65.00	18.00	4.90	16.00	21.00	32.00	0.00	56.00	39.00	7.00	5.80	0.15	0.10
ECOW-26	May/10/2008	8.00	270.00	162.00	70.00	22.00	3.70	17.00	20.30	52.00	0.00	63.40	38.00	8.00	5.60	0.00	0.13
ECOW-26	Sep/05/2008	7.70	191.00	115.00	45.00	8.00	6.10	20.00	17.00	24.00	0.00	29.30	27.00	12.00	4.84	0.60	0.04
ECOW-27	Jan/03/2006	7.20	70.00	42.00	22.00	5.40	2.00	5.00	0.40	12.00	0.00	14.60	11.00	0.50	1.86	0.55	0.20
ECOW-27	May/04/2006	7.30	76.00	46.00	20.00	4.80	2.00	6.00	4.70	10.00	0.00	12.20	13.00	3.40	1.86	0.22	0.30
ECOW-27	Sep/16/2006	7.20	66.00	40.00	20.00	4.80	2.00	3.00	3.90	13.00	0.00	15.80	7.00	2.40	1.24	0.26	0.10
ECOW-27	Jan/07/2007	7.30	87.00	52.00	35.00	8.40	3.40	4.00	3.50	21.00	0.00	25.60	11.00	2.00	1.24	1.56	0.20
ECOW-27	May/09/2007	7.60	74.00	44.00	20.00	4.80	2.00	5.00	4.30	12.00	0.00	14.64	12.00	3.40	1.24	0.90	0.20
ECOW-27	Sep/16/2007	7.20	47.00	28.00	10.00	2.40	1.00	3.00	3.00	10.00	0.00	12.20	6.00	3.40	1.24	0.00	0.10
ECOW-27	Jan/16/2008	7.20	66.00	40.00	20.00	4.00	2.40	5.00	3.20	10.00	0.00	12.20	12.00	1.50	1.80	0.85	0.10
ECOW-27	May/10/2008	7.30	86.00	52.00	25.00	4.00	3.70	6.00	4.00	16.00	0.00	19.50	13.00	1.30	1.90	0.00	0.40
ECOW-27	Sep/10/2008	7.20	65.00	39.00	25.00	4.00	3.70	3.00	0.60	10.00	0.00	12.20	8.00	6.00	2.10	0.11	0.10
ECOW-28	Jan/03/2006	7.90	100.00	60.00	29.00	7.00	2.80	7.00	6.60	16.00	0.00	19.50	16.00	3.00	2.48	0.29	0.19
ECOW-28	May/04/2006	7.60	120.00	72.00	30.00	7.00	3.00	9.00	6.60	20.00	0.00	24.40	19.00	8.00	1.86	0.23	0.32
ECOW-28	Sep/16/2006	7.50	120.00	72.00	31.00	7.40	3.00	9.00	4.70	24.00	0.00	29.30	15.00	5.00	1.86	0.58	0.06
ECOW-28	Jan/07/2007	7.30	119.00	71.00	25.00	6.00	2.40	7.00	6.20	22.00	0.00	26.80	17.00	5.00	1.86	0.09	0.29
ECOW-28	May/09/2007	7.70	90.00	54.00	26.00	6.20	2.50	8.00	5.50	32.00	0.00	39.00	21.00	4.00	1.86	0.45	1.39

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-28	Sep/16/2007	7.50	116.00	70.00	35.00	8.40	3.40	7.00	4.70	24.00	0.00	29.30	15.00	6.00	2.48	0.11	0.14
ECOW-28	Jan/16/2008	7.40	130.00	78.00	39.00	9.90	3.60	10.00	4.80	28.00	0.00	34.20	20.00	6.00	2.10	0.71	0.13
ECOW-28	May/10/2008	7.50	148.00	88.00	53.00	14.80	3.90	8.00	5.90	15.00	0.00	18.30	14.00	5.00	6.40	0.43	1.87
ECOW-28	Sep/10/2008	7.70	130.00	78.00	34.00	10.00	2.40	8.00	6.60	12.00	0.00	14.60	15.00	7.00	3.60	0.96	0.06
ECOW-29	Jan/03/2006	7.30	86.00	52.00	24.00	5.80	2.30	6.00	7.40	18.00	0.00	22.00	12.00	0.50	1.86	0.35	0.30
ECOW-29	May/04/2006	7.70	93.00	56.00	30.00	7.20	2.93	6.00	5.50	19.50	0.00	23.20	13.00	4.00	0.66	0.00	0.40
ECOW-29	Sep/16/2006	7.20	55.00	33.00	15.00	3.60	1.50	3.00	4.70	10.00	0.00	12.20	9.00	3.00	0.62	0.56	0.10
ECOW-29	Jan/06/2007	7.30	98.00	58.00	40.00	9.60	3.90	3.00	4.30	20.00	0.00	24.00	14.00	2.00	3.00	0.02	0.14
ECOW-29	May/10/2007	7.70	77.00	46.00	20.00	4.80	2.00	5.00	5.50	19.00	0.00	23.20	10.00	4.00	0.56	0.15	0.40
ECOW-29	Sep/16/2007	7.30	63.00	38.00	18.00	4.80	1.50	3.00	4.70	18.00	0.00	22.00	7.00	6.00	0.62	0.13	0.10
ECOW-29	Jan/16/2008	7.50	100.00	60.00	35.00	7.90	3.60	8.00	7.80	15.00	0.00	18.30	14.00	4.00	2.90	0.00	0.10
ECOW-29	May/10/2008	7.60	100.00	60.00	32.00	10.40	1.40	7.50	6.20	17.00	0.00	20.70	14.00	4.00	2.50	0.00	0.40
ECOW-29	Sep/10/2008	7.50	60.00	36.00	15.00	6.00	0.00	6.00	5.30	12.00	0.00	14.60	11.00	4.00	1.62	0.79	0.10
ECOW-30	Jan/03/2006	7.50	200.00	120.00	51.00	12.20	5.00	18.00	5.80	18.00	0.00	22.00	28.00	16.00	8.68	0.43	0.22
ECOW-30	May/04/2006	7.60	190.00	114.00	45.00	10.80	4.40	20.00	5.40	15.50	0.00	18.90	31.00	16.00	4.90	0.00	0.80
ECOW-30	Sep/16/2006	7.70	180.00	108.00	60.00	14.40	5.80	10.00	5.80	34.00	0.00	41.50	20.00	13.00	5.58	0.42	0.17
ECOW-30	Jan/11/2007	7.30	195.00	117.00	70.00	16.80	6.80	13.00	4.70	20.00	0.00	24.40	25.00	10.00	10.00	0.11	1.00
ECOW-30	May/10/2007	7.70	210.00	126.00	46.00	11.00	4.50	20.00	4.30	28.00	0.00	34.20	30.00	10.00	6.30	0.15	1.26
ECOW-30	Sep/12/2007	7.70	170.00	102.00	50.00	12.00	4.88	14.00	3.50	28.00	0.00	34.10	22.00	17.00	4.96	0.05	0.13
ECOW-30	Jan/16/2008	7.90	197.00	118.00	50.00	14.00	3.70	20.00	3.70	22.00	0.00	26.80	33.00	18.00	3.20	0.73	0.25
ECOW-30	May/10/2008	7.70	250.00	150.00	70.00	20.00	4.90	24.80	4.00	38.00	0.00	46.36	35.00	24.00	3.50	0.28	0.36
ECOW-30	Sep/05/2008	7.80	187.00	112.00	50.00	10.00	6.10	16.00	3.50	20.00	0.00	24.40	22.00	26.00	5.94	0.84	0.04
ECOW-31	Jan/03/2006	7.60	57.00	34.00	16.00	3.80	1.60	5.00	1.20	8.00	0.00	9.80	10.00	0.00	0.62	0.54	0.30
ECOW-31	May/04/2006	7.30	100.00	60.00	32.00	8.80	2.40	7.00	1.60	15.00	0.00	18.30	15.00	3.00	3.10	0.30	0.10
ECOW-31	Sep/16/2006	7.33	60.00	36.00	15.00	3.60	1.50	5.00	1.20	15.00	0.00	18.30	10.00	1.40	0.00	0.30	0.15

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3-N	F	Fe
ECOW-31	Jan/11/2007	7.20	57.00	34.00	15.00	3.60	1.50	5.00	1.20	10.00	0.00	12.20	9.00	1.40	1.24	0.18	0.50
ECOW-31	May/10/2007	7.30	80.00	48.00	25.00	6.20	2.30	5.00	2.00	18.00	0.00	22.00	12.00	1.40	0.62	0.40	0.40
ECOW-31	Sep/12/2007	7.00	50.00	30.00	10.00	2.40	1.00	4.00	1.20	10.00	0.00	12.20	9.00	3.00	0.62	0.00	0.10
ECOW-31	Jan/16/2008	7.10	48.00	30.00	15.00	2.00	2.40	4.00	1.10	14.00	0.00	17.00	10.00	2.00	0.70	0.36	0.20
ECOW-31	May/10/2008	7.40	84.00	50.00	30.00	10.00	1.20	5.00	1.60	20.00	0.00	24.40	11.00	3.50	1.50	0.08	0.10
ECOW-31	Sep/05/2008	7.20	50.00	30.00	15.00	2.00	2.40	3.00	2.10	6.00	0.00	7.30	8.00	4.00	1.20	0.00	0.30

Table 3.14
Lithology (Deeper Crystalline Formation)

Well ID	Depth To	Lithology	Texture	Colour	Shape
ECBW-01	2	Lateritic soil	coarse	reddish brown	subangular-subrounded
	5	Laterite	coarse	yellowish red	subangular-subrounded
	7	Clay	fine	yellowish brown	rounded
	8	weathered rock	medium to fine	brownish grey	subangular
	15	Biotite gneiss	medium to coarse	grey	subangular to angular
	15.6	Gneiss fractured	medium to coarse	greyish black	subangular
	18	Biotite gneiss	medium to fine	greyish black	subangular to angular
	32	Biotite gneiss	medium to coarse	grey	subangular to angular
	32.8	Gneiss fractured	medium to coarse	greyish black	subangular to angular
	45	Biotite gneiss	medium	greyish black	subangular to angular
	60	Biotite gneiss	medium to fine	greyish black	subangular to angular
ECBW-02	3	Topsoil and laterite	fine	reddish brown	
	6	Laterite and litomarge			
	9	Lithomarge and weathered rock			
	12	Weathered to crystalline rock			
	17	Charnokite	fine to medium	grey	subangular
	17.3	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	60	Charnokite	fine	greenish	

ECBW-03	3	Topsoil	fine to medium	reddish brown	
	8.5	Laterite	fine to medium	reddish brown	
	14.6	Clay	fine	yellow	
	21	Charnokite	fine to medium	grey	
	22.7	Charnokite	medium	greyish black	subangular
	23.7	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	34.6	Charnokite	medium	grey	subangular
	35.6	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	60	Charnokite	fine to medium	greyish black	
ECBW-04	3	Topsoil	fine to medium	reddish brown	
	13	Laterite	fine to medium	reddish brown	
	20.73	Clay	fine	pale yellowish	
	22.25	Wheathered rock and charnockit	fine	grey	
	23.7	Charnokite	medium to coarse	grey	subangular
	24.7	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	30	Charnokite	medium to coarse	grey	
	35.9	Charnokite	medium to coarse	grey	subangular
	36.4	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	48	Charnokite	fine to medium	greyish black	
	57.9	Charnokite	medium to coarse	grey	subangular
	58.4	Charnokite fractured	medium to coarse	greyish black	subangular to angular

	60	Charnokite	medium to coarse	greyish black	
ECBW-05	3	Lateritic soil	coarse to very coarse	reddish brown	rounded
	8	Laterite	coarse	yellowish red	Subangular,subrounded
	10	Sandy clay	fine	yellowish brown	rounded
	18	Sand	medium	brown	rounded
	22	Charnokite - weathered	medium	light brown	subangular-subrounded
	40	Charnokite	medium	greyish black	subangular
	49	Charnokite	medium to coarse	greyish black	subangular to angular
	50	Charnokite	medium to coarse	grey	subangular
	50.9	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	54	Charnokite	medium to coarse	greyish black	subangular to angular
	60	Charnokite	medium to coarse	grey	subangular
	60.6	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	66	Charnokite	coarse to very coarse	greyish black	subangular to angular
	73	Charnokite	medium to coarse	greyish black	subangular to angular
ECBW-06	2.43	Topsoil	fine to medium	reddish brown	subangular-subrounded
	6	lateritic clay	fine to medium	reddish brown	subangular-subrounded
	9	Charnokite	medium to coarse	grey	subangular to angular
	11	Charnokite	medium	grey	subangular
	12	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	14	Charnokite	medium to coarse	grey	subangular

	15	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	25	Charnokite	medium to coarse	dull brown	subangular to angular
	26	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	30	Charnokite	coarse	dull brown	angular
ECBW-07	4	Topsoil and laterite	Fine to medium	Reddish brown	subangular-subrounded
	7	Clay	fine	Reddish brown	rounded
	9	Gnessic charnockite	medium to coarse	Grey	subangular
	36	Gneissic charnockite	fine to medium	Grey	subangular
	42	Gneissic charnockite	fine	Grey	angular
	47	Gneissic charnockite	medium to coarse	greyish black	subangular to angular
	47.3	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	48	Gneissic charnockite	fine to medium	Grey	subangular to angular
	51	Gneissic charnockite	fine to coarse	Grey	subangular-subrounded
	60	Gneissic charnockite	medium to coarse	Grey	subangular to angular
ECBW-08	3	Topsoil	fine to medium	reddish brown	rounded
	6	Laterite	fine to medium	yellowish brown	subangular-subrounded
	7.6	Clay	fine to medium	yellowish brown	rounded
	9	Charnokite	fine to medium	grey	subangular
	12	Charnokite	fine to medium	grey	subangular
	15	Charnokite	fine to medium	grey	subangular
	18	Charnokite	fine to medium	grey	subangular

	21	Charnokite	fine to medium	grey	subangular
	24	Charnokite	medium to coarse	grey	subangular
	27	Charnokite	fine to medium	grey	subangular
	33	Charnokite	fine to medium	grey	subangular
	39	Charnokite	medium to coarse	grey	subangular
	42	Charnokite	medium to coarse	grey	subangular
	44.9	Charnokite	medium to coarse	grey	subangular
	45	Charnokite	medium to coarse	grey	subangular
	45.7	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	46.5	Charnokite	medium to coarse	grey	subangular
ECBW-09	0.5	Topsoil	medium	reddish brown	
	7.5	Laterite	fine	reddish brown	
	32	Charnokite	medium	dull brown	
	32.3	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	45	Charnokite	Medium	Grey	
ECBW-10	10	Topsoil, laterite	Fine	reddish brown	
	20	Weathered rock	Medium	greyish white	
	33	Charnokite	fine to medium	grey	
	65	Charnokite	medium	grey	subangular
	65.7	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	72	Charnokite	fine	grey	

ECBW-11	3	lateritic soil	reddish brown		
	6	lateritic clay	yellow		
	9	weathered gneiss	dull yellow		
	42.4	biotite gneiss	medium to coarse	greyish black	subangular to angular
	43.1	Gneiss fractured	medium to coarse	greyish black	subangular to angular
	60	biotite gneiss	medium	greyish black	subangular
ECBW-12	3	Topsoil, laterite	Fine to medium	Reddish brown	
	6	Laterite, clay	Fine	Reddish brown	
	9	Clay	Fine	Reddish yellow	
	12.8	Charnokite	medium	greyish black	subangular
	13.4	Charnokite fractured	medium to coarse	greyish black	subangular to angular
	21	Charnokite	Medium to coarse	Greyish black	
	24	Pegmatite vein	Fine to medium	Yellowish pink	
	31.5	Pegmatite vein	Medium to coarse	Yellowish pink	

Table 3.15

WATER LEVEL DATA OF BORE WELLS IN DEEPER CRYSTALLINE FORMATION

ECBW-01 Kunnukara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	3.11	3.12	3.12	3.16	3.13	2.45	2.40	2.65	2.54	2.49	2.64	3.15
2007	3.38	3.20	3.12	3.15	3.16	3.33	1.85	2.06	2.58	2.90	2.70	3.02
2008	3.18	3.14	2.94	2.97	3.22	2.93	2.69	2.58	2.73			

ECBW-02 Mookkannoor ward I

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.81	7.14	5.71	6.0	7.85	3.79	5.60	5.59	6.55	5.83	6.55	7.45
2007	6.20	6.11	7.77	7.20	7.46	7.14	2.57	5.87	5.68	7.34	6.70	5.49
2008	6.57	6.28	7.25	7.64	7.97	6.76	7.02	6.51	6.94			

ECBW-03 Kadungallur

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	9.53	9.77	9.90	10.21	10.12	7.05	7.59	7.87	8.00	8.06	8.80	9.28
2007	9.44	9.61	9.92	10.01	9.96	9.82	5.17	7.97	7.06	8.75	8.88	9.26
2008	9.46	9.27	10.04	9.49	10.08	8.46	6.45	8.09	8.90			

ECBW-04 Vadavukode

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	10.42	10.54	10.65	10.55	10.90	6.99	9.56	9.00	8.61	10.00	8.68	10.74
2007	10.80	11.02	11.14	11.85	11.90	11.58	7.61	8.95	8.26	10.15	10.20	10.57
2008	10.53	10.97	11.11	11.18	11.29	10.71	10.18	8.03	10.06			

ECBW-05 Pattimattom

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.07	5.82	5.77	6.22	6.35	5.38	4.36	5.23	5.45	4.09	4.76	5.86
2007	5.75	6.23	5.94	6.26	6.27	6.33	3.92	4.38	4.73	5.65	4.95	5.94
2008	5.91	6.15	6.15	6.08	6.08	6.18	4.98	4.63	5.46			

ECBW-06 Rayamangalam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.36	6.30	6.20	6.43	6.53	5.41	6.32	6.35	6.09	5.86	6.08	6.09
2007	6.21	6.63	6.46	6.80	7.06	7.01	5.37	5.95	6.34	8.44	7.43	8.80
2008	6.53	6.52	6.13	6.13	6.93	7.28	6.20	6.05	8.38			

ECBW-07 Vengoor

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.22	7.15	7.20	7.14	6.90	3.92	4.66	6.02	6.08	5.24	6.55	7.07
2007	7.07	7.20	7.21	7.25	7.18	7.09	3.26	5.49	5.36	6.68	6.10	7.12
2008	6.71	7.19	6.22	6.72	6.54	6.54	5.49	5.58	6.42			

ECBW-08 Muvattupuzha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	5.36	4.97	5.04	5.32	5.53	3.97	3.99	4.41	4.72	4.41	4.58	5.14
2007	5.35	5.38	5.28	5.31	5.41	5.14	3.54	3.87	4.29	4.92	4.69	5.36
2008	5.11	4.88	5.17	5.05	5.35	5.07	4.28	4.21	4.38			

ECBW-09 Onakkur

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	3.90	4.19	4.26	3.96	3.90	3.53	3.72	3.73	3.76	3.75	3.80	4.01
2007	3.93	4.06	4.17	4.00	3.92	3.85	3.61	3.63	3.76	3.79	3.80	3.89
2008	3.84	3.98	4.12	3.93	3.87	3.76	3.77	3.61	3.72			

ECBW-10 Piravom

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	6.75	6.73	6.79	6.39	6.53	5.30	5.35	5.74	6.18	5.77	6.25	6.65
2007	6.70	6.64	6.91	6.93	6.66	6.54	5.04	5.63	6.12	5.72	5.63	6.01
2008	6.24	6.50	6.47	6.53	6.78	6.65	6.11	5.78	5.78			

ECBW-11 Pindimana

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.34	7.43	7.09	7.35	7.44	4.39	5.54	6.15	5.90	5.67	5.91	7.24
2007	7.40	7.29	7.58	7.88	7.30	7.06	5.00	5.62	5.71	6.65	6.27	7.29
2008	7.47	7.53	7.43	7.50	7.22	5.19	5.35	4.84	6.79			

ECBW-12 Neriyamangalam

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	7.15	8.28	7.15	6.87	7.83	2.65	4.72	6.50	5.14	5.92	4.44	7.60
2007	7.83	8.15	8.58	8.23	7.14	5.77	4.59	4.69	6.14	7.15	6.48	8.61
2008	8.43	10.69	10.34	9.63	6.27	3.96	5.18	4.60	6.90			

Table 3.17
WATER QUALITY DATA (BORE WELLS IN DEEPER CRYSTALLINE FORMATION)

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO_3	HCO_3	Cl	SO_4	NO_3-N	NO_3	F	Fe
			µmhos/cm	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ECBW-01	Jan/06/2006	7.60	290.00	174.00	61.00	14.60	6.00	38.00	5.00	52.00	0.00	63.40	55.00	7.00	1.86	8.24	0.81	2.58
ECBW-01	May/06/2006	7.90	310.00	186.00	80.00	20.20	7.20	29.00	5.70	56.00	0.00	68.30	60.00	7.00	1.60	7.09	0.24	2.10
ECBW-01	Sep/17/2006	7.80	270.00	162.00	70.00	16.80	6.80	29.00	4.30	50.00	0.00	61.00	50.00	4.00	3.10	13.73	0.34	0.45
ECBW-01	Jan/05/2007	7.60	290.00	174.00	70.00	16.80	6.80	30.00	4.30	59.00	0.00	72.00	51.00	9.00	1.30	5.76	0.59	2.00
ECBW-01	May/07/2007	8.40	300.00	180.00	70.00	18.00	6.10	34.00	4.30	68.00	4.80	83.10	46.00	6.00	1.24	5.49	0.33	1.46
ECBW-01	Sep/14/2007	7.70	230.00	138.00	45.00	10.80	4.40	29.00	4.30	32.00	0.00	39.00	46.00	5.00	1.24	5.49	0.00	0.00
ECBW-01	Jan/08/2008	8.00	330.00	198.00	69.00	15.60	7.20	41.00	5.70	39.00	0.00	47.60	76.00	5.00	1.32	5.85	0.74	0.55
ECBW-01	May/09/2008	8.20	352.00	211.00	85.00	31.60	1.30	42.00	5.50	51.00	0.00	62.50	79.00	5.00	1.26	5.58	0.08	1.30
ECBW-01	Sep/12/2008	8.00	290.00	174.00	59.00	17.00	4.00	36.00	6.40	35.00	0.00	42.70	73.00	4.00	1.28	5.67	0.72	2.10
ECBW-02	Jan/06/2006	8.60	350.00	210.00	40.00	10.00	3.70	60.00	5.10	144.00	9.60	156.20	15.00	10.00	0.00	0.00	0.40	0.72
ECBW-02	May/06/2006	8.70	320.00	192.00	25.00	6.00	2.40	60.00	4.60	134.00	16.50	129.90	17.00	13.00	0.00	0.00	0.07	1.60
ECBW-02	Sep/17/2006	8.60	315.00	189.00	40.00	9.60	3.90	52.00	4.30	136.00	7.20	151.30	18.00	12.00	0.00	0.00	0.30	0.03
ECBW-02	Jan/05/2007	8.80	340.00	204.00	32.00	7.70	3.10	57.00	4.30	136.00	16.80	131.80	18.00	9.00	0.62	2.75	0.29	2.39
ECBW-02	May/07/2007	8.60	333.00	200.00	40.00	9.70	3.80	56.00	3.90	138.00	14.40	139.10	10.00	12.00	1.24	5.49	0.31	3.04
ECBW-02	Sep/14/2007	8.70	330.00	198.00	45.00	10.80	4.40	53.00	3.90	138.00	7.20	153.70	11.00	12.00	0.00	0.00	0.11	0.05
ECBW-02	Jan/08/2008	8.60	330.00	198.00	39.00	9.80	3.50	57.00	4.00	138.00	7.20	153.70	10.00	14.00	0.00	0.00	0.20	0.10
ECBW-02	May/09/2008	8.60	330.00	198.00	37.00	8.40	3.90	68.00	4.00	138.00	51.20	64.20	11.00	17.00	0.34	1.51	0.00	0.17
ECBW-02	Sep/12/2008	8.60	300.00	180.00	44.00	7.80	6.00	50.00	4.10	112.00	29.00	77.70	13.00	18.00	0.22	0.97	0.26	0.10
ECBW-03	Jan/06/2006	7.70	137.00	82.00	52.00	12.40	5.00	4.00	6.60	43.00	0.00	52.50	7.00	11.00	1.24	5.49	0.95	0.72
ECBW-03	May/06/2006	7.90	140.00	84.00	44.00	10.80	4.10	9.00	6.70	42.00	0.00	51.20	8.00	9.00	1.24	5.49	0.32	0.73
ECBW-03	Sep/17/2006	7.90	120.00	72.00	45.00	10.80	4.40	3.00	6.20	43.00	0.00	52.50	5.00	10.00	1.24	5.49	0.40	0.40
ECBW-03	Jan/05/2007	7.40	140.00	84.00	44.00	10.40	4.40	9.00	5.00	42.00	0.00	51.20	12.00	10.00	1.36	6.02	0.60	1.00
ECBW-03	May/07/2007	7.80	148.00	88.00	45.00	10.80	4.40	10.00	5.80	50.00	0.00	61.00	8.00	11.00	0.62	2.75	0.21	2.18
ECBW-03	Sep/14/2007	7.90	145.00	87.00	45.00	10.80	4.40	8.00	5.85	54.00	0.00	65.90	6.00	10.00	0.00	0.00	0.00	0.05
ECBW-03	Jan/08/2008	8.20	120.00	72.00	41.00	12.40	2.50	4.00	5.80	41.00	0.00	50.20	6.00	10.00	0.70	3.10	0.10	0.20
ECBW-03	May/09/2008	8.10	140.00	84.00	53.00	16.80	2.60	4.00	5.60	51.00	0.00	62.20	6.00	8.00	0.68	3.01	0.00	0.41

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO_3	HCO_3	Cl	SO_4	NO_3-N	NO_3	F	Fe
			µmhos/cm	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ECBW-04	Jan/03/2006	7.90	150.00	90.00	62.00	14.90	6.00	4.00	5.00	58.00	0.00	70.80	6.00	5.00	0.62	2.75	0.41	7.90
ECBW-04	Sep/16/2006	7.90	138.00	83.00	45.00	10.80	4.40	9.00	4.30	57.00	0.00	69.50	8.00	3.00	0.62	2.75	0.72	1.20
ECBW-04	Jan/07/2007	7.60	150.00	90.00	50.00	12.00	4.90	11.00	4.30	61.00	0.00	74.40	8.00	7.00	0.00	0.00	0.62	5.00
ECBW-04	May/09/2007	8.30	170.00	102.00	64.00	15.40	6.30	9.00	5.00	65.00	6.00	67.10	7.00	8.00	0.62	2.75	0.11	2.10
ECBW-04	Sep/16/2007	7.80	138.00	83.00	40.00	9.60	3.90	10.00	3.50	58.00	0.00	70.80	4.00	4.00	1.24	5.49	0.26	0.00
ECBW-04	Jan/16/2008	8.40	180.00	108.00	78.00	22.80	5.10	6.00	4.60	72.00	10.20	67.10	8.00	7.00	0.10	0.44	0.80	2.60
ECBW-04	May/10/2008	8.50	225.00	135.00	95.00	34.00	2.60	6.00	4.40	92.00	18.30	75.00	7.00	5.00	1.00	4.43	0.63	0.60
ECBW-04	Sep/10/2008	8.00	150.00	90.00	54.00	19.60	1.20	9.00	1.70	39.00	0.00	47.60	16.00	2.00	3.22	14.26	0.51	2.58
ECBW-05	Jan/03/2006	8.30	190.00	114.00	78.00	18.70	7.60	12.00	6.60	84.00	9.60	83.00	5.00	1.00	0.62	2.75	0.59	4.62
ECBW-05	May/04/2006	8.40	190.00	114.00	60.00	14.00	6.10	15.00	6.20	78.00	7.20	80.50	9.00	2.40	0.00	0.00	0.29	1.28
ECBW-05	Sep/16/2006	8.30	180.00	108.00	60.00	14.40	5.80	9.00	5.00	74.00	0.00	90.30	9.00	3.00	0.62	2.75	0.90	2.00
ECBW-05	Jan/07/2007	8.30	200.00	120.00	70.00	19.20	5.40	11.00	5.00	79.00	12.00	72.00	9.00	2.00	1.24	5.49	0.33	3.40
ECBW-05	May/09/2007	8.40	210.00	126.00	76.00	18.00	7.60	11.00	4.70	84.00	0.00	102.50	9.00	2.00	1.24	5.49	0.43	8.57
ECBW-05	Sep/16/2007	8.60	170.00	102.00	55.00	13.20	5.40	10.00	4.70	80.00	4.80	87.80	5.00	2.00	2.48	10.99	0.00	0.26
ECBW-05	Jan/16/2008	8.50	188.00	113.00	73.00	18.80	6.30	6.00	5.60	82.00	10.00	79.70	8.00	3.00	0.20	0.89	0.50	0.13
ECBW-05	May/10/2008	8.40	170.00	102.00	79.00	25.20	3.90	4.00	5.30	72.00	10.00	67.50	6.00	4.00	0.62	2.75	1.00	0.25
ECBW-05	Sep/10/2008	8.40	160.00	96.00	64.00	13.60	7.20	7.00	5.50	68.00	19.50	43.30	10.00	2.40	0.96	4.25	0.39	3.84
ECBW-06	Jan/03/2006	8.00	118.00	71.00	57.00	13.70	5.50	7.00	2.70	38.00	0.00	46.40	10.00	4.00	0.62	2.75	0.27	0.40
ECBW-06	May/04/2006	8.00	118.00	71.00	57.00	13.70	5.50	7.00	2.70	38.00	0.00	46.40	10.00	4.00	0.62	2.75	0.44	0.39
ECBW-06	Sep/16/2006	8.00	104.00	62.00	40.00	9.60	3.90	3.00	2.30	34.00	0.00	41.50	10.00	5.00	0.00	0.00	0.44	0.28
ECBW-06	Jan/07/2007	7.40	154.00	92.00	62.50	15.00	6.10	5.00	2.00	45.00	0.00	54.90	17.00	6.00	0.62	2.75	0.34	4.57
ECBW-06	May/05/2007	8.00	140.00	84.00	58.00	14.00	5.60	5.00	2.70	51.00	0.00	56.10	10.00	3.30	1.80	7.97	0.00	1.80
ECBW-06	Sep/16/2007	7.80	95.00	57.00	36.00	8.60	3.50	4.00	2.00	32.00	0.00	39.00	12.00	4.00	0.00	0.00	0.00	0.28
ECBW-06	Jan/16/2008	8.20	130.00	78.00	52.00	10.40	6.30	5.00	2.90	46.00	0.00	56.10	8.00	8.00	0.20	0.89	0.02	0.04
ECBW-06	May/10/2008	8.00	110.00	66.00	58.00	19.20	2.60	6.00	2.70	51.00	0.00	62.20	11.00	7.00	2.02	8.95	0.27	1.80
ECBW-06	Sep/10/2008	8.20	120.00	72.00	44.00	8.00	6.00	6.20	2.70	34.00	0.00	41.50	10.00	5.00	0.18	0.80	0.00	1.65
ECBW-07	Jan/03/2006	7.10	200.00	120.00	70.00	16.80	6.80	10.00	3.90	58.00	0.00	70.80	14.00	8.00	4.96	21.97	0.75	0.61
ECBW-07	May/04/2006	7.90	214.00	128.40	80.00	19.08	7.90	10.00	4.30	51.00	0.00	62.20	16.00	10.00	6.00	26.58	0.38	0.68

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO_3	HCO_3	Cl	SO_4	NO_3-N	NO_3	F	Fe
			µmhos/ cm	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/ L	mg/ L
ECBW-07	Jan/07/2007	8.30	430.00	258.00	180.00	43.20	17.60	13.00	2.30	112.00	19.20	97.60	20.00	48.00	8.06	35.71	0.30	1.46
ECBW-07	May/09/2007	8.50	380.00	228.00	155.00	36.40	15.70	9.00	3.10	112.00	9.60	117.10	11.00	38.00	3.72	16.48	0.85	4.72
ECBW-07	Sep/16/2007	7.90	192.00	115.20	63.00	15.10	6.20	7.00	2.70	56.00	0.00	68.30	12.00	9.00	2.48	10.99	0.17	0.12
ECBW-07	Sep/10/2008	8.50	320.00	192.00	147.00	37.20	13.20	8.00	3.00	98.00	19.50	79.90	14.00	24.00	2.92	12.94	0.41	0.64
ECBW-08	Jan/03/2006	8.40	240.00	144.00	120.00	28.80	11.70	10.00	4.70	86.00	9.60	85.40	15.00	13.00	1.24	5.49	0.54	0.79
ECBW-08	May/04/2006	8.50	260.00	156.00	92.00	22.00	9.00	10.00	5.00	98.00	9.30	100.60	16.00	13.00	0.62	2.75	0.13	0.46
ECBW-08	Sep/16/2006	8.20	200.00	120.00	90.00	21.60	8.80	7.00	3.90	66.00	0.00	80.50	14.00	12.00	0.62	2.75	0.26	0.34
ECBW-08	Jan/11/2007	8.20	270.00	162.00	105.00	25.20	10.30	9.00	3.90	82.00	0.00	100.00	19.00	12.00	4.34	19.23	0.16	1.79
ECBW-08	May/10/2007	8.40	265.00	159.00	106.00	25.40	10.30	9.00	3.50	76.00	7.20	78.00	16.00	11.00	6.20	27.47	0.49	2.42
ECBW-08	Sep/12/2007	8.30	191.00	114.00	70.00	16.80	6.80	10.00	3.50	62.00	2.40	70.80	14.00	10.00	0.00	0.00	0.00	0.07
ECBW-08	Jan/16/2008	8.50	250.00	150.00	119.00	29.20	11.40	8.00	4.50	87.00	20.50	64.50	14.00	11.00	0.70	3.10	0.80	0.20
ECBW-08	May/10/2008	8.50	260.00	156.00	116.00	29.60	10.30	8.00	4.30	87.00	20.50	64.50	14.00	12.00	0.64	2.84	0.00	0.60
ECBW-08	Sep/05/2008	8.10	160.00	96.00	59.00	11.60	7.20	10.00	4.00	44.00	0.00	53.70	18.00	12.00	0.62	2.75	0.11	0.32
ECBW-09	Jan/03/2006	8.70	360.00	216.00	120.00	28.00	12.20	27.00	4.30	152.00	16.80	151.28	8.00	12.00	0.62	2.75	1.00	0.60
ECBW-09	May/04/2006	8.70	300.00	180.00	80.00	19.00	7.90	26.00	3.10	134.00	14.00	135.00	12.00	15.00	0.00	0.00	0.35	0.20
ECBW-09	Sep/16/2006	8.60	310.00	186.00	110.00	26.40	10.70	22.00	3.50	153.00	7.20	172.00	9.00	12.00	0.62	2.75	0.52	0.18
ECBW-09	Jan/11/2007	8.20	330.00	198.00	120.00	28.80	11.70	26.00	3.10	140.00	0.00	170.80	10.00	12.00	0.62	2.75	0.28	1.29
ECBW-09	May/10/2007	8.40	330.00	198.00	122.00	30.00	11.50	28.00	3.10	154.00	4.80	178.10	10.00	13.00	0.62	2.75	0.25	2.12
ECBW-09	Sep/12/2007	8.70	270.00	162.00	85.00	20.40	8.30	26.00	3.10	126.00	7.20	139.00	7.00	16.00	0.62	2.75	0.38	0.16
ECBW-09	Jan/16/2008	8.50	280.00	168.00	94.00	23.70	8.40	26.00	4.20	105.00	12.00	103.70	8.00	12.00	0.32	1.42	0.90	0.07
ECBW-09	May/10/2008	8.50	270.00	162.00	101.00	29.70	6.50	24.00	3.60	128.00	30.00	95.10	6.00	11.00	0.76	3.37	0.00	0.04
ECBW-09	Sep/05/2008	8.50	290.00	174.00	103.00	27.40	8.40	22.00	3.40	112.00	19.50	97.00	10.00	12.00	0.28	1.24	0.72	0.30
ECBW-10	Jan/03/2006	8.40	890.00	534.00	442.00	106.00	43.20	40.00	7.40	80.00	7.20	83.00	203.00	32.00	1.86	8.24	0.74	0.56
ECBW-10	May/04/2006	8.30	850.00	510.00	346.00	82.90	33.80	38.00	6.60	74.00	4.80	80.50	212.00	37.00	1.86	8.24	0.61	0.34
ECBW-10	Sep/16/2006	7.90	880.00	528.00	340.00	81.60	33.20	35.00	5.80	78.00	0.00	95.10	194.00	28.00	0.00	0.00	0.66	0.23
ECBW-10	Jan/06/2007	8.20	820.00	492.00	325.00	78.00	31.70	39.00	6.60	71.00	0.00	86.60	188.00	31.00	1.86	8.24	0.36	1.61
ECBW-10	May/10/2007	8.30	830.00	498.00	318.00	76.00	31.20	39.00	4.70	80.00	4.80	87.80	194.00	32.00	1.24	5.49	0.25	2.54
ECBW-10	Sep/16/2007	8.50	780.00	468.00	290.00	69.60	28.30	36.00	5.00	82.00	4.80	90.28	174.00	34.00	0.00	0.00	0.00	0.08

Well ID	Sampling Date	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO_3	HCO_3	Cl	SO_4	NO_3-N	NO_3	F	Fe
			µmhos/cm	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L(as CaCO3)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ECBW-10	May/10/2008	8.20	900.00	540.00	350.00	72.00	41.50	42.00	6.60	84.00	0.00	102.50	212.00	28.00	1.04	4.61	0.12	0.08
ECBW-10	Sep/10/2008	8.30	720.00	432.00	250.00	47.00	32.30	30.00	6.90	80.00	0.00	97.60	156.00	16.00	1.10	4.87	0.42	0.44
ECBW-11	Jan/03/2006	7.90	130.00	78.00	53.00	12.70	5.20	4.00	3.50	36.00	0.00	43.90	6.00	12.00	1.24	5.49	0.53	0.56
ECBW-11	May/04/2006	7.70	150.00	90.00	64.00	15.00	6.50	5.00	2.70	45.00	0.00	54.90	9.00	20.00	0.62	2.75	0.01	2.80
ECBW-11	Sep/16/2006	7.80	110.00	66.00	45.00	10.80	4.40	3.00	2.30	32.00	0.00	39.00	6.00	11.00	0.62	2.75	0.42	0.31
ECBW-11	May/09/2007	7.90	145.00	87.00	61.00	14.60	6.00	4.00	2.70	34.00	0.00	41.50	8.00	12.00	3.10	13.73	0.40	2.04
ECBW-11	Sep/16/2007	7.70	92.00	55.00	35.00	8.40	3.40	2.50	2.00	30.00	0.00	36.60	4.00	12.00	0.00	0.00	0.05	0.03
ECBW-11	Jan/16/2008	8.00	130.00	78.00	54.00	15.80	3.60	4.00	4.00	35.00	0.00	42.70	7.00	16.00	0.66	2.92	0.58	0.40
ECBW-11	May/10/2008	8.10	150.00	90.00	69.00	21.20	3.90	4.00	3.80	46.00	0.00	56.10	6.00	16.00	0.66	2.92	0.00	2.80
ECBW-11	Sep/10/2008	8.20	120.00	72.00	39.00	8.00	4.80	7.00	4.50	48.00	0.00	58.60	9.00	11.00	0.40	1.77	0.74	0.25
ECBW-12	Jan/05/2006	8.50	210.00	126.00	102.00	24.60	10.00	6.00	0.78	76.00	9.60	73.20	13.00	2.40	0.62	2.75	0.47	3.21
ECBW-12	May/10/2006	7.80	191.00	114.00	80.00	19.00	7.90	5.00	0.78	49.00	0.00	59.80	12.00	3.40	1.58	7.00	0.00	0.26
ECBW-12	Sep/15/2006	7.90	174.00	104.00	80.00	19.20	7.80	5.00	0.40	78.00	0.00	95.10	12.00	1.00	0.00	0.00	0.32	0.40
ECBW-12	Jan/06/2007	8.10	210.00	126.00	100.00	24.00	9.80	5.00	0.80	77.00	0.00	93.90	13.00	4.00	0.62	2.75	0.34	1.70
ECBW-12	May/10/2007	8.30	170.00	102.00	81.00	19.40	7.90	5.00	0.80	80.00	4.80	87.80	12.00	5.00	1.24	5.49	0.35	4.20
ECBW-12	Sep/05/2007	8.50	140.00	84.00	70.00	16.80	6.80	5.00	0.40	42.00	4.80	41.50	13.00	1.00	0.62	2.75	0.00	0.25
ECBW-12	Jan/10/2008	8.30	160.00	96.00	95.00	25.20	7.70	5.00	0.60	81.00	10.20	78.00	8.00	4.00	0.26	1.15	0.07	0.22
ECBW-12	May/10/2008	8.30	160.00	96.00	95.00	25.20	7.70	5.00	0.90	72.00	12.00	63.40	8.00	4.00	0.22	0.97	0.54	0.22
ECBW-12	Sep/05/2008	8.30	160.00	96.00	69.00	17.60	6.00	6.00	1.20	64.00	9.00	59.80	12.00	1.00	0.54	2.39	0.91	0.36

Table 4.4

Irrigation Quality Assessment

Parameters	**Range**	**Water Class**	ECOW 2006			ECOW 2007			ECOW 2008		
			Number of Wells								
			JAN	MAY	SEP	JAN	MAY	SEP	JAN	MAY	SEP
%Na after Wilcox (1995)	<20	Excellent	2	1	3	4	2	1	2	3	1
	20-40	Good	15	10	17	15	17	9	9	13	15
	40-60	Permissible	13	17	11	12	11	19	20	15	14
	60-80	Doubtful	1	3			1	2			1
	>80	Unsuitable									
%Na (Eaton 1950)	<60	Safe	30	28	31	31	30	29	31	31	30
	>60	Unsafe	1	3			1	2			1
Alkalinity hazard (SAR) after Richard (1954)	<10	Excellent	31	31	31	31	31	31	31	31	31
	10-18	Good									
	18-26	Doubtful									
	>26	Unsuitable									
Residual Mg/Ca ratio	<1.5	Safe	31	31	31	31	31	31	31	30	31
	1.5-3.0	Moderate								1	
	>3.0	Unsafe									
RSC after Richard (1954)	<1.25	Good	31	31	31	31	31	31	31	31	31
	1.25-2.50	Doubtful									
	>2.5	Unsuitable									
KR(1940, 1951, Paliwal 1967)	<1	Suitable	30	28	31	29	31	28	29	31	29
	1--2	Marginal	1	3		2		3	2		2
	>2	Unsuitable									

Parameters	Range	Water Class	ESOW 2006			ESOW 2007			ESOW 2008		
			Number of Wells								
			JAN	MAY	SEP	JAN	MAY	SEP	JAN	MAY	SEP
Na% after Wilcox (1995)	<20	Excellent	5	2	6	4	2	6	3	3	5
	20-40	Good	2	4	1	1	4	1	4	4	2
	40-60	Permissible				1					
	60-80	Doubtful	1	1	1	1	1	1	1	1	1
	>80	Unsuitable		1		1	1				
%Na (Eaton 1950)	<60	Safe	7	6	7	6	6	7	7	7	7
	>60	Unsafe	1	2	1	2	2	1	1	1	1
Alkalinity hazard (SAR) after Richard (1954)	<10	Excellent	8	7	8	7	7	8	7	7	7
	10-18	Good							1		1
	18-26	Doubtful		1		1	1			1	
	>26	Unsuitable									
Residual Mg/Ca ratio	<1.5	Safe	7	7	8	7	7	8	8	7	8
	1.5-3.0	Moderate	1	1		1	1			1	
	>3.0	Unsafe									
RSC after Richard (1954)	<1.25	Good	8	8	8	8	8	8	8	8	8
	1.25-2.50	Doubtful									
	>2.5	Unsuitable									
KR(1940, 1951, Paliwal 1967)	<1	Suitable	7	7	7	6	6	7	7	7	7
	1--2	Marginal	1	1	1	2	2	1	1	1	1
	>2	Unsuitable									

Parameters	Range	Water Class	ECBW 2006			ECBW 2007			ECBW 2008		
			Number of Wells								
			JAN	MAY	SEP	JAN	MAY	SEP	JAN	MAY	SEP
Na% after Wilcox (1995)	<20	Excellent	5	2	6	5	5	2	4	6	2
	20-40	Good	5	6	4	5	5	7	6	4	8
	40-60	Permissible	1	3	1	1	1	1	1	1	1
	60-80	Doubtful	1		1		1	2	1		1
	>80	Unsuitable		1		1				1	
%Na (Eaton 1950)	<60	Safe	11	11	11	11	11	10	11	11	11
	>60	Unsafe	1	1	1	1	1	2	1	1	1
Alkalinity hazard (SAR) after Richard (1954)	<10	Excellent	12	12	12	12	12	12	12	12	12
	10-18	Good									
	18-26	Doubtful									
	>26	Unsuitable									
Residual Mg/Ca ratio	<1.5	Safe	12	12	12	12	12	12	12	12	12
	1.5-3.0	Moderate									
	>3.0	Unsafe									
RSC after Richard (1954)	<1.25	Good	11	11	11	11	11	11	11	11	11
	1.25-2.50	Doubtful	1	1	1	1	1	1	1	1	1
	>2.5	Unsuitable									
KR(1940, 1951, Paliwal 1967)	<1	Suitable	10	11	11	11	11	10	10	10	10
	1--2	Marginal	2	1	1	1	1	2	2	2	2
	>2	Unsuitable									

Table 5.2a
CONCENTRATION OF TRACE METALS AND PESTICIDES IN GROUND WATER - MONSOON 2007

Sl No	Well No	Type of well	Pb ppb	Cu ppb	Zn ppb	Mn ppb	Cd ppb	As ppb	Pesticides
Desirable limit (BIS)			**50**	**50**	**5000**	**100**	**10**	**10**	**Absent**
Permissible limit (BIS)			**50**	**1500**	**15000**	**300**	**10**	**10**	**0.001**
1	TMPOW-01	OW	7.09	ND	7.3	28.49	ND	ND	ND
2	TMPOW-02	OW	23	96.75	10.7	21.32	ND	ND	ND
3	TMPOW-03	OW	ND	ND	8.9	ND	ND	ND	ND
4	TMPBW-04	BW	16.74	30.49	416.8	15.8	ND	ND	ND
5	TMPOW-05	OW	ND	ND	9.8	13.84	ND	ND	ND
6	TMPOW-06	OW	ND	ND	10	ND	ND	ND	ND
7	TMPOW-07	OW	5.37	ND	8.5	18.72	ND	ND	ND
8	TMPOW-08	OW	8.52	ND	12	39.8	ND	ND	ND
9	TMPOW-09	OW	ND	ND	ND	ND	ND	ND	ND
10	TMPBW-10	BW	6.29	ND	ND	907	ND	ND	ND
11	TMPOW-11	OW	8.15	ND	ND	ND	ND	ND	ND
12	TMPBW-12	BW	8.46	ND	6.4	ND	ND	ND	ND
13	TMPOW-13	OW	ND	ND	10	ND	ND	ND	ND
14	TMPOW-14	OW	ND	ND	11.7	10	ND	ND	ND
15	TMPOW-15	OW	ND	ND	8.4	17	ND	ND	ND

Table 5.2b

CONCENTRATION OF TRACE METALS AND PESTICIDES IN GROUND WATER - POST MONSOON 2008

Sl No	Well No	Type of Well	Pb ppb	Cu ppb	Zn ppb	Mn ppb	Cd ppb	As ppb	Pesticides
Desirable limit (BIS)			**50**	**50**	**5000**	**100**	**10**	**10**	**Absent**
Permissible limit (BIS)			**50**	**1500**	**15000**	**300**	**10**	**10**	**0.001**
1	TMPOW-01	OW	ND	ND	ND	ND	ND	ND	ND
2	TMPOW-02	OW	16.3	57	11	24.6	ND	ND	ND
3	TMPOW-03	OW	ND	ND	11.6	ND	ND	ND	ND
4	TMPBW-04	BW	13	69	382.7	1797	ND	ND	ND
5	TMPOW-05	OW	ND	ND	11.3	437	ND	ND	ND
6	TMPOW-06	OW	6.3	ND	17.6	34.3	ND	ND	ND
7	TMPOW-07	OW	ND	ND	9.5	16.4	ND	ND	ND
8	TMPOW-08	OW	5.2	ND	27.3	45.5	ND	ND	ND
9	TMPOW-09	OW	ND	ND	9.4	ND	ND	ND	ND
10	TMPBW-10	BW	15	69.7	20	877	ND	ND	ND
11	TMPOW-11	OW	ND	ND	9	11.1	ND	ND	ND
12	TMPBW-12	BW	ND	ND	59	41	ND	ND	ND
13	TMPOW-13	OW	ND	ND	41	54	ND	ND	ND
14	TMPOW-14	OW	ND	ND	6	15.3	ND	ND	ND
15	TMPOW-15	OW	ND	ND	5.6	39.5	ND	ND	ND

Table 5.2c
CONCENTRATION OF TRACE METALS AND PESTICIDES IN GROUND WATER - PRE MONSOON 2008

Sl No	Well No	Type of Well	Pb ppb	Cu ppb	Zn ppb	Mn ppb	Cd ppb	As ppb	Pesticides
Desirable limit (BIS)			**50**	**50**	**5000**	**100**	**10**	**10**	**Absent**
Permissible limit (BIS)			**50**	**1500**	**15000**	**300**	**10**	**10**	**0.001**
1	TMPOW-01	OW	ND	ND	6	14.5	ND	ND	ND
2	TMPOW-02	OW	ND	ND	12.4	16.8	ND	ND	ND
3	TMPOW-03	OW	Dry						
4	TMPBW-04	BW	ND	ND	44.4	353	ND	ND	ND
5	TMPOW-05	OW	ND	ND	6.4	10	ND	ND	ND
6	TMPOW-06	OW	ND	ND	6.5	33.66	ND	ND	ND
7	TMPOW-07	OW	ND	ND	13.5	84.55	ND	ND	ND
8	TMPOW-08	OW	ND	ND	70.8	85.76	ND	ND	ND
9	TMPOW-09	OW	ND	ND	ND	ND	ND	ND	ND
10	TMPBW-10	BW	ND	ND	12.6	185	ND	ND	ND
11	TMPOW-11	OW	ND	ND	ND	24.25	ND	ND	ND
12	TMPBW-12	BW	ND	ND	47.7	13.84	ND	ND	ND
13	TMPOW-13	OW	ND	ND	ND	15.43	ND	ND	ND
14	TMPOW-14	OW	ND	ND	ND	12.48	ND	ND	ND
15	TMPOW-15	OW	ND	ND	ND	32.94	ND	ND	ND
16	TMP CHK-16	OW	ND	ND	ND	51.4	ND	ND	ND

Table 5.2d
WATER QUALITY DATA OF - MONSOON 2007

Sl. No	Well No	Type of Well	pH	EC,micromhos/cm	TDS,mg/L	H(as mgCaCO$_3$/L	Ca,mg/L	Mg,mg/L	Na,mg/L	K,mg/L	A(as mg CaCO$_3$/L	CO$_3$,mg/L	HCO$_3$,mg/L	Cl,mg/L	SO4,mg/L	NO$_3$-N,mg/L	NO$_3$,mg/L	NO$_2$,ppb	PO$_4$,ppb	F,mg/L	SiO$_2$,mg/L	DO,mg/L	Fe,mg/L
Desirable limit (BIS)			**6.5-8.5**	**---**	**500**	**300**	**75**	**30**	**---**	**---**	**200**	**---**	**---**	**250**	**200**	**10**	**45.00**	**30**		**1**			**0.3**
Permissible limit (BIS)			**6.5-8.5**	**---**	**2000**	**600**	**200**	**100**	**---**	**---**	**600**	**---**	**---**	**1000**	**400**					**1.5**			**1**
1	TMPOW-01	OW	6.91	58	34.8	10	4	0	5.8	1.85	8	0	9.8	9.8	1	1.7	7.53	1.56	0.14	0.23	2.89	2.1	ND
2	TMPOW-02	OW	5.37	41	24.6	10	2	1.2	3	1	4	0	4.9	5	1	3.3	14.61	2.5	0.09	0.01	2.6	3.22	0.0035
3	TMPOW-03	OW	7	114	68.4	34	5.6	4.9	6.8	2.3	16	0	14.6	12.7	4.17	4.9	21.70	2.19	3.01	0	4.96	5.04	0.0473
4	TMPBW-04	BW	6.81	111	66.6	30	8	2.4	7.3	6	14	0	17.1	14.7	3.54	4.6	20.37	25.48	0.222	0.27	4.55		0.3
5	TMPOW-05	OW	7.19	54	32.4	15	4	1.2	4.8	1.2	14	0	17.1	7.8	2.29	0	0.00	0	0.1	0.03	5.82	0.56	0.1986
6	TMPOW-06	OW	7.4	84	50.4	30	10	1.2	3.9	1.49	34	0	41.5	7.8	3.8	0	0.00	2	0	ND	6.4	4.48	0.689
7	TMPOW-07	OW	5.53	59	35.4	10	2	1.2	4.4	1.23	4	0	4.9	5.9	1.25	1.8	7.97	2.5	0.32	0	2.15	3.36	0.021
8	TMPOW-08	OW	4.76	31	30.4	10	2	1.2	1.64	0.8	4	0	4.9	6.9	1.04	1.5	6.64	1.47	0	0.14	2.4	3.64	0.1
9	TMPOW-09	OW	6.08	50	36	20	4	2.4	3.2	1.84	16	0	19.5	7.8	1.46	0.3	1.33	2.19	5.53	0.2	5.12		0.089
10	TMPBW-10	BW	8.3	320	192	125	32	11.1	24.4	3.9	154	4.8	178	13.7	4.58	0	0.00	4.06	1.09	0.37	31.72		0.744
11	TMPOW-11	OW	5.7	49	29.4	15	2	2.4	2.7	0.48	14	0	17.1	6.9	0.83	0	0.00	1.56	0.41	0	6.52	1.96	0.039
12	TMPBW-12	BW	8.85	420	252	15	4	1.2	118	1.25	232	4.8	273.3	3.9	1.25	0	0.00	0.94	0.51	0.43	28.19		0.019
13	TMPOW-13	OW	8.53	370	222	180	64	4.9	12.2	5.7	174	9.6	192.8	15.7	11.46	0	0.00	2.35	7.91	0.2	9.02	3.5	0.147
14	TMPOW-14	OW	8.7	330	198	170	58	6.1	6.8	2.4	158	7.2	178.1	13.7	7.64	0	0.00	7.31	0.54	0.28	6.64	2.38	0.192
15	TMPOW-15	OW	8.23	500	300	220	64	14.6	19.8	5.5	196	0	239.1	23.5	33.37	0	0.00	16.06	3.09	0.22	10.33	7	0.259

Table 5.2e
WATER QUALITY DATA OF PRE-MONSOON 2008

Sl. No	Well ID	Type of Well	pH	EC,micromhos/cm	TDS,mg/L	TH(as mg$CaCO_3$/L)	Ca,mg/L	Mg,mg/L	Na,mg/L	K,mg/L	TA(as mg $CaCO_3$/L)	CO_3,mg/L	HCO_3,mg/L	Cl,mg/L	SO4,mg/L	NO_3-N,mg/L	NO_3,mg/L	NO_2,ppb	PO_4,ppb	F,mg/L	SiO_2,mg/L	DO,mg/L	Fe,mg/L
Desirable limit (BIS)	-	-	6.5-8.5	-	500	300	75	30	-	-	200	-	-	250	200	10	45.00	30		1	-	-	0.3
Permissible limit (BIS)	-	-	6.5-8.5	-	2000	600	200	100	-	-	600	-	-	1000	400	-	-	-	-	1.5	-	-	1
1	TMPOW-01	OW	5.36	50	30	15	2	2.4	5	1.5	12	0	14.6	10.7	0	1	4.43	2.5	0	0.19	3.5	-	0.045
2	TMPOW-02	OW	5.29	45	27	15	1	2.5	1.87	1.02	6	0	7.3	11.7	0	2.8	12.40	2	0	0.03	3.2	-	0.021
3	TMPOW-03	OW	-	-	-	-	-	-	-	-	-	-	-	-	-		0.00	-	-	-	-	-	-
4	TMPBW-04	**BW**	8	192	115.2	70	12	9.8	8	6.6	78	0	95.2	13.6	12.1	0	0.00	2	0.11	0.14	9.9	0.98	2.85
5	TMPOW-05	OW	6.24	42	25.2	10	0	2.4	3.1	2.2	10	0	12.2	9.7	2.3	0	0.00	6.5	0.37	0.13	5.7	4.06	0.647
6	TMPOW-06	OW	7.69	200	120	85	32	1.2	7.2	5.7	72	0	87.8	10.8	16.36	2.7	11.96	5.31	4.64	0.46	5.86	3.64	0.028
7	TMPOW-07	OW	4.29	141	84.6	15	3	1.8	10.5	2	0	0	0	19.4	4.6	7.8	34.54	6.5	0.68	0.09	3		0.025
8	TMPOW-08	OW	6.24	45	27	10	1	1.8	2.5	1.72	12	0	14.6	7.8	0.91	0.5	2.21	6.5	0.65	0.22	5.8	2.52	1.72
9	TMPOW-09	OW	5.54	44	26.4	10	0	2.4	2.9	1.43	14	0	17.1	7.8	0.46	0.3	1.33	3.5	0.06	0.15	5.1	2.52	0.078
10	TMPBW-10	**BW**	7.43	340	204	125	42	13.4	23.2	4.5	148	0	180.6	20.4	4.5	1.3	5.76	14	2.5	0.43	30	-	0.12
11	TMPOW-11	OW	6.12	36	21.6	10	0	2.4	2.3	0.64	16	0	19.5	6.8	0.46	0	0.00	2.5	0.25	0.14	6.7	-	1.003
12	TMPBW-12	**BW**	8.33	420	252	15	0	3.7	104	0.94	238	14.4	261.1	6.8	2.3	0	0.00	5	0.7	0.34	27.8	-	0.175
13	TMPOW-13	OW	8.3	400	240	165	56	6.1	15.2	5.8	160	6	183	22.3	18.8	1.3	5.76	6	3.09	0.13	8.3	3.5	0.12
14	TMPOW-14	OW	8.4	400	240	160	54	6.1	10.6	2.4	152	3.6	178.1	22.3	16.5	0	0.00	10	1.68	0.32	7	4.2	0.08
15	TMPOW-15	OW	8.3	540	324	215	72	8.5	28.4	7	122	12	124.4	37.9	12.5	0	0.00	8.5	3.41	0.26	9.1	3.36	0.27
16	TMP CHK-16	OW	5.3	70	42	20	4	2.4	14.1	2.8	8	0	9.8	22.3	0.5	4.67	20.68	2.5	0	0.15	3.14	1.26	0.237

Table 5.2F
WATER QUALITY DATA OF POST-MONSOON 2008

Sl .No	Well No	Type of Well	pH	EC,micromhos/cm	TDS,mg/L	TH(as mgCaCO$_3$/L)	Ca,mg/L	Mg,mg/L	Na,mg/L	K,mg/L	TA(as mg CaCO3/L)	CO$_3$,mg/L	HCO$_3$,mg/L	Cl,mg/L	SO$_4$,mg/L	NO$_3$-N,mg/L	NO$_3$,mg/L	NO$_2$,ppb	PO$_4$,ppb	F,mg/L	SiO$_2$,mg/L	DO,mg/L	Fe,mg/L
Desirable limit (BIS)			**6.5-8.5**	**-**	**500**	**300**	**75**	**30**	**-**	**-**	**200**	**-**	**-**	**250**	**200**	**10**	**45.00**	**30**		**1**			**0.3**
Permissible limit (BIS)			**6.5-8.5**	**-**	**2000**	**600**	**200**	**100**	**-**	**-**	**600**	**-**	**-**	**1000**	**400**					**1.5**			**1**
1	TMPOW-01	OW	6.76	52	31.2	15	2	2.4	4.2	1.48	12	0	14.6	7.8	2	0.26	1.15	5.2	1.1	ND	3	1.96	ND
2	TMPOW-02	OW	6.43	48	28.8	15	2	2.4	3.5	1.1	8	0	9.8	5.9	0.8	1.8	7.97	5	0	ND	3.3	1.68	0.0104
3	TMPOW-03	OW	7.17	147	88.2	45	18	0	8.4	6.7	36	0	43.9	15.7	12	1.41	6.24	8.5	0	ND	8	1.54	ND
4	TMPBW-04	BW	8.12	171	102.6	60	10	8.5	7.7	6.6	62	0	75.6	12.7	12.3	0	0.00	2	0.2	ND	5.6	1.4	0.108
5	TMPOW-05	OW	7.24	40	24	10	4	0	3.4	1.21	10	0	12.2	9.6	2.3	0.22	0.97	2.5	0	ND	4.2	3.08	0.068
6	TMPOW-06	OW	6.82	96	57.6	40	6	6.1	3.9	1.6	42	0	51.2	7.8	2.7	0.1	0.44	8	0	0.23	9.6	3.92	0.5
7	TMPOW-07	OW	4.06	110	66	20	4	2.4	9.9	1.03	0	0	0	16.7	1.67	3	13.28	2	0	ND	6		0.198
8	TMPOW-08	OW	6.58	38	22.8	10	2	1.2	2.8	1.63	10	0	12.2	6.9	1.2	0.75	3.32	2	0	0.35	5.8	1.4	1.076
9	TMPOW-09	OW	7.03	36	21.6	15	2	2.4	2.3	1.45	14	0	17.1	6.9	1.8	0.06	0.27	4.5	0.7	1.3	4.5	2.94	0.115
10	TMPBW-10	BW	8.72	310	186	125	34	9.8	22.6	4.1	156	0	190.3	25	8.7	0.99	4.38	3	0	ND	32.4	1.4	1.94
11	TMPOW-11	OW	7.19	34	20.4	10	2	1.2	2.3	0.44	16	0	19.5	5.9	1.8	0	0.00	4	0	0.25	7	1.96	0.172
12	TMPBW-12	BW	8.84	420	252	20	2	3.7	100	1.09	238	28.8	231.8	5.9	2	0.13	0.58	4.5	0	0.97	28	1.96	0.281
13	TMPOW-13	OW	9	470	282	220	76	7.3	16.8	8.4	204	28.8	190.3	23.5	24	3.61	15.99	2.5	5.2	ND	10.6		0.787
14	TMPOW-14	OW	8.3	300	180	100	34	3.6	8	3.2	102	7.2	103.8	14.7	6.6	0	0.00	3	3.4	0.58	6.8		0.417
15	TMPOW-15	OW	8.5	700	420	185	60	8.5	45	13.2	122	0	148.8	42	112.8	0.73	3.23	2	1.8	1.25	14.5		1.022

Table 5.7

CORRELATION MATRIX

Water Quality Data: Pre Monsoon -2008

	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3N	NO3	NO2	PO4P	F	SiO2	DO	Fe
pH	1																				
EC	.819*	1																			
TDS	.819*	1.000*	1																		
TH	.736*	.852*	.852*	1																	
Ca	.705*	.834*	.834*	.993*	1																
Mg	.588*	.656*	.656*	.690*	.630*	1															
Na	.447	.591*	.591*	.097	.075	.202	1														
K	.612*	.612*	.612*	.771*	.736*	.655*	.005	1													
TA	.859*	.898*	.898*	.631*	.608*	.594*	.757*	.409	1												
CO3	.620*	.794*	.794*	.465	.444	.251	.825*	.235	.772*	1											
HCC	.862*	.885*	.885*	.632*	.610*	.615*	.729*	.417	.998*	.726*	1										
Cl	.316	.694*	.694*	.808*	.791*	.581*	.076	.676*	.361	.391	.347	1									
SO4	.737*	.695*	.695*	.822*	.815*	.427	.024	.778*	.559*	.309	.571*	.543*	1								
NO3	-.596*	-.174	-.174	-.189	-.158	-.241	-.128	-.021	-.321	-.282	-.317	.226	-.070	1							
NO3	-.596*	-.174	-.174	-.189	-.158	-.241	-.128	-.021	-.321	-.282	-.317	.226	-.070	1.000*	1						
NO2	.418	.635*	.635*	.629*	.647*	.638*	.199	.385	.535*	.238	.553*	.559*	.390	-.012	-.012	1					
PO4	.620*	.673*	.673*	.771*	.814*	.359	.120	.715*	.521*	.340	.526*	.519*	.773*	.002	.002	.572*	1				
F	.596*	.572*	.572*	.459	.481	.424	.419	.408	.624*	.306	.642*	.255	.415	-.149	-.149	.671*	.676*	1			
SiO2	.527*	.554*	.554*	.222	.204	.624*	.729*	.125	.758*	.472	.768*	.015	.017	-.304	-.304	.538*	.221	.606*	1		
DO	.385	.400	.400	.421	.499	-.166	.064	-.078	.421	.357	.412	.124	.404	-.338	-.338	.832*	.560	.441	.066	1	
Fe	.156	-.206	-.206	-.144	-.226	.214	-.177	.222	-.144	-.207	-.133	-.235	.012	-.335	-.336	-.260	-.300	-.197	-.039	-.598	1

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Table 5.8

CORRELATION MATRIX

Post Monsoon-2008

	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3N	NO3	NO2	PO4P	F	SiO2	DO	Fe
pH	1																				
EC	.664*	1																			
TDS	.664*	1.000*	1																		
TH	.624*	.836*	.836*	1																	
Ca	.595*	.816*	.816*	.988*	1																
Mg	.554*	.654*	.654*	.727*	.612*	1															
Na	.477	.659*	.659*	.195	.166	.267	1														
K	.513	.781*	.781*	.826*	.817*	.595*	.193	1													
TA	.791*	.815*	.815*	.658*	.624*	.596*	.771*	.425	1												
CO3	.528*	.525*	.525*	.394	.413	.186	.652*	.129	.818*	1											
HCC	.811*	.841*	.841*	.686*	.640*	.669*	.760*	.479	.989*	.723*	1										
Cl	.367	.813*	.813*	.844*	.829*	.633*	.220	.872*	.428	.041	.504	1									
SO4	.357	.779*	.779*	.670*	.661*	.485	.301	.860*	.302	-.009	.367	.865*	1								
NO3	-.232	.208	.208	.416	.459	.092	-.069	.249	.158	.319	.111	.340	.079	1							
NO3	-.232	.208	.208	.416	.459	.092	-.069	.249	.158	.319	.111	.340	.079	1.000*	1						
NO2	-.114	-.300	-.300	-.316	-.298	-.290	-.076	-.199	-.175	-.102	-.182	-.356	-.269	-.168	-.168	1					
PO4	.463	.548*	.548*	.764*	.808*	.318	.008	.486	.482	.553*	.427	.429	.321	.391	.392	-.275	1				
F	.516	.565	.565	.412	.404	.368	.460	.515	.406	.225	.444	.488	.515	.166	.167	-.300	.267	1			
SiO2	.558*	.574*	.574*	.357	.291	.541*	.728*	.179	.779*	.415	.832*	.358	.172	-.021	-.021	-.057	-.061	.323	1		
DO	-.275	-.287	-.287	-.288	-.338	-.110	-.140	-.441	-.209	-.061	-.232	-.351	-.416	-.465	-.465	.354	.087	.027	-.210	1	
Fe	.389	.453	.453	.561*	.520	.588*	.139	.407	.429	.005	.517	.585*	.330	.145	.145	-.226	.148	-.044	.653*	-.340	1

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Table 5.9

CORRELATION MATRIX

Monsoon-2007

	pH	EC	TDS	TH	Ca	Mg	Na	K	TA	CO3	HCO3	Cl	SO4	NO3N	NO3	NO2	PO4P	F	SiO2	DO
pH	1																			
EC	.843*	1																		
TDS	.833*	.999*	1																	
TH	.673*	.817*	.818*	1																
Ca	.680*	.798*	.798*	.989*	1															
Mg	.401	.651*	.652*	.788*	.744*	1														
Na	.515*	.573*	.573*	.001	-.007	-.030	1													
K	.519*	.584*	.581*	.701*	.684*	.560*	-.023	1												
TA	.851*	.977*	.977*	.737*	.731*	.506	.666*	.458	1											
CO3	.612*	.589*	.589*	.539*	.635*	.192	.321	.303	.653*	1										
HCC	.845*	.978*	.978*	.732*	.720*	.511	.672*	.457	.999*	.616*	1									
Cl	.517*	.618*	.616*	.845*	.803*	.823*	-.176	.860*	.458	.192	.462	1								
SO4	.460	.705*	.706*	.823*	.778*	.948*	.011	.641*	.566*	.159	.577*	.851*	1							
NO3	-.406	-.413	-.418	-.379	-.398	-.133	-.242	.102	-.515*	-.342	-.520*	-.013	-.241	1						
NO3	-.406	-.413	-.418	-.379	-.398	-.133	-.242	.102	-.515*	-.342	-.520*	-.013	-.241	1.000*	1					
NO2	.170	.274	.271	.345	.310	.472	-.080	.736*	.133	-.080	.145	.638*	.472	.350	.350	1				
PO4	.282	.358	.363	.491	.511	.404	-.054	.500	.322	.476	.302	.430	.382	-.158	-.158	-.031	1			
F	.685*	.662*	.668*	.379	.375	.079	.624*	.428	.714*	.387	.721*	.275	.184	-.342	-.342	.294	.074	1		
SiO2	.629*	.645*	.644*	.278	.221	-.012	.738*	.190	.724*	.213	.740*	.087	.094	-.402	-.402	-.058	.022	.708*	1	
DO	.194	.528	.535	.464	.386	.693*	.626*	.553	.422	-.103	.445	.619*	.701*	.200	.200	.674*	.366	.171	.371	1
Fe	.390	.187	.183	.291	.248	-.033	-.098	.331	.184	-.153	.204	.319	.154	-.270	-.270	.191	-.136	.522	.420	.244

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

REFERENCES

REFERENCES

Akhila, B. (2011). Geochemical Soil Facies of Ernakulam District: A Tool for Ground Water Quality Assessment. M.Phil. Dissertation submitted to Cochin University of Science and Technology, Kerala, India.

Alan MacDonald, Jeff Davies, Roger Calow and John Chilton. (2005). Developing Groundwater. A Guide for Rural Water Supply. ITDG Publishing. Schumacher Centre for Technology and Development Bourtan Hall, Bourtan-on-Dunsmore, Warwickshire CV 23 902, UK.

Alvin, C.R. (2002). Methods of Multivariate Analysis, Wiley. USA.

APHA (1998). Standard methods for the examination of water and wastewater, 19th edn. American Public Health Association, Washington, D.C., 1467 pp.

Ayers, R.S. and Westcot, D.W. (1994). Water quality for agriculture. FAO Irrigation and Drinage Paper 29, Rev 1: pp. 1-130.

Banerjee, P., Sarwade, D.and Singh, V.S. (2008). Characterization of an island aquifer from tidal response. Environmental Geology, 55, 901-906.

Bhagavathi, P.S. and Thamarai, P. (2008). Ground water quality after tsunami in coastal area of Kanyakumari, South Thamilnadu, India. International Journal Applied Environmental Sciences. 3 (1), 37-55.

BIS (1998). Indian Standard Specification for Drinking Water IS 10500:

1991(2003-2009) Edn. 2-2. Indian Standard Institute

Bouwer, H. (1978). Groundwater Hydrology. McGraw Hill, Newyork.

Bureau of Indian Standards (BIS). (1991). Indian Standard Specification for Drinking Water, IS, 10500, 2–4.

Burkart, M.R., Kolpin, D.W. and James, D.E. (1997). Assessing groundwater vulnerability to agrochemical contamination in Midwest U.S. Water Science and Technology, 39, 103-112.

CESS (1984). Resource Atlas of Kerala. Centre for Earth Science Studies, Kerala, Thiruvanathapuram, India.

CGWB (2002). Groundwater Balance. Mass Awareness Programme in Ernakulam District, January 5, 2002, CGWB, Kerala Region, Thiruvananthapuram, Kerala.

CGWB (2008). Dynamic Ground Water Resources of Kerala 2004. Central Ground Water Board, Kerala Region, Thiruvananthapuram, PP: 1-2, 4-14, 45.

CGWB (2008). Ground Water Information Booklet of Ernakulam District, Kerala State.,CGWB, Kerala Region, Thiruvananthapuram.

CGWB (2009). Workshop Volume on Ground Water Resource and Management in Kerala & Lakshadweep, Retrospect, Perspect and Prospect. CGWB, Kerala Region, Thiruvananthapuram, PP: 4-1.

CWRDM (2009). Report on Environmental Monitoring Programme on Water Quality, Kerala State Council for Science, Technology and Environment, Kerala, India.

Datta, S.P., Biswas, D.R., Saharan, N., Ghosh, S.K. and Rattan, R.K (2000). Effect of long-term application of sewage effluents on organic carbon, bioavailable phosphorus, potassium and heavy metals status of soils and uptake of heavy metals by crops. J Indian Soc Soil Sci, 48: 836–839.

Datta, P.S., Deb, D.L. and Tyagi, S.K. (1997). Assessment of groundwater contamination from fertilizers in the Delhi area based on 18O, NO^{3-} and K^{+} composition. J Conta Hydrol 27:249–262.

Developing Groundwater (2005). A Guide for Rural Water Supply. Alan MacDonald, Jeff Davies, Roger Calow and John Chilton. ITDG Publishing. Schumacher Centre for Technology and Development Bourtan Hall, Bourtan-on-Dunsmore, Warwickshire CV 23 902, UK.

Deepa, G.D. (1998). Water Quality of Selected Open Wells in Cochin Corporation Area. Project Report, School of Environmental Engineering.

Ding, H. and Zhang, J. (2001). The problem of environment caused by groundwater level continuous decline in the inland basins of arid area, Northwest China: an example in middle reaches of Heihe river basin. Hydrogeol Eng.Geol.3:71-75. (in Chineese).

Eaton, F. M. (1950). Significance of Carbonates in Irrigation Waters. Soil Science, 69, 123-133.

Elango, L., Kannan, R. and Senthil Kumar, M. (2003). Major ion chemistry and identification of hydrogeochemical processes of groundwater in a part of Kancheepuram District, Tamil Nadu, India. Environmental Geosciences, 10(4):157–166.

Fang, T. and Hong, E., (1999). Mechanism Influencing the spacial distribution of trace metals in surfacial sediments of Southwestern Taiwan. Mar Pollut Bull :1026-37

FAO (1996). Food, agriculture, and food security: developments since the world food conference and prospects, World Food Summit technical background document.

Foster, S.S.D. (1995).Groundwater for development: an overview of quality constraints. In: Nash H, McCall GJH (eds) Groundwater quality, 17th Special Report. Chapman and Hall, London United, pp 1–3.

Ghosh, N.C. and Sharma, K.D. (2006). Ground Water Modelling and Management. Capital Publishing Company, New Delhi.

Ground Water Resources and Development Potential of Ernakulam District, Kerala, CGWB (1993), Kerala Region, Trivandrum, February, page 24-26.

Ground water Information Booklet of Ernakulam District, CGWB, Kerala Region, July 2008.

Gupta, S.K. and Deshpande, R.D. (2004). Water for India in 2050: First order assessment and available option. Current Science, 86, 1216-1224.

GWREC (1997). Report of ground water resource estimation committee, Ministry of water resources, Government of India, New Delhi.

Hem, J.D. (1985). Study and interpretation of the chemical characteristics of natural water. USGS, Water Supply Paper 2254:264

Hem, J.D. (1991). Study and interpretation of the chemical characteristics of natural waters, book 2254, (3rd ed). Jodhpur: Scientific Publishers.

Holden, W. S. (1971). Water Treatment and Examination. Churchill: London.

Howari, F.M. and Banat, K.M. (2002). Hydrochemical Characteristics of Jordan and Yarmouk River waters: Effect of Natural and Human Activities. Journal of Hydrology and Hydrodynamics 50(1), 50.

Hydrlogical Information System. Ground Water Manual (2003). Volume 7. Water Quality Analysis Design Manual. DHV Consultants and DELFT Hydraulics with HALCROW, TAHAL, CES, ORG and JPS.

ISI (1983). Indian standard specification for drinking water. India: Indian Standards Institution, IS 10500.

Janardhana Raju, N. (2007). Hydrogeochemical parameters for assessment of groundwater quality in the upper Gunjanaeru River basin, Cuddapath

District, Andhra Pradesh, South India. Environmental Geology 52: 1067-1074.

Karanth, K.R. (1997). Groundwater Assessment, Development and Management. Tata McGraw- Hill. New Delhi.

Kelly, W.P. (1940). Permissible composition and concentration of irrigated waters. Proceedings of the ASCF 66:P.607.

Kelley, W.P.(1951). Alkali Soils: their formation properties and reclamations. Reinhold, New York.

Kinniburgh, D.G. and Smedley, P. L.(2001). Arsenic contamination of groundwater in Bangladesh. Volume 1: Summary. BGS Technical Report WC/00/19, British Geological Survey and Development of Public Health Engineering p.15.

Klavins, M., Briede, A., Rodinov, V., Kokorite, I., Parele, E. and Klavina, I. (2000). Heavy metals in River of Letvia. Sci Total Environ. 262, 175-183.

Kruawal, K., Sacher, F., Werner, A., Mu¨ller, J. and Knepper,T.P. (2005). Chemical water quality in Thailand and its impacts on the drinking water production in Thailand. The Science of the Total Environment, 340, 57–70. doi:10.1016/j.scitotenv.2004.08.008.

Kumar, M., Ramanathan, A.L., Rao, M.S. and Kumar, B. (2006a). Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India. Environ Geol 50:1025–1039.

Kumar, M., Sharma, B., Ramanathan, A.L. and Rao, M.S. (2006b). Nutrient chemistry of Groundwater of National Capital Territory (NCT), Delhi, India. In: The conference proceedings of International Groundwater Conference (IGC-2006), New Delhi, India.

Laluraj, C.M., Gopinath, G. and Dineshkumar, P.K. (2005). Groundwater Chemistry of shallow aquifers in the coastal zones of Cochin, India. Applied Ecology and Environmental Research 3(1): 133-139.

Langmuir, D. (1997). Aqueous Environmental Chemistry, Prentice-Hall, Inc., New Jersey, p: 600.

Mamta Tomar.(1999). Quality assessment of water and wastewater. Lewis publishers.

Manish Kumar, Kalpana Kumari, A.L., Ramanathan, and Rajnder Saxena. (2007). A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Panjab, India. Environmental Geology 53: 553-574.

Marechal, J.C., Dewandel, B., Ahmed, S., Galeazzi, L. and Zaidi, F.K. (2006). Combined estimation of specific yield and natural recharge in a semi-arid groundwater basin with irrigated agriculture. J Hydrol 329:281–293.

Matthess, G. (1982). The properties of groundwater (p. 498). New York: Wiley.

Michael Price. (1995). Introducing groundwater. British Geological Survey. George Allen and Unwin (Publishers) Ltd., London WCIA ILU, UK pp: 157

Mor, S., Ravindra, K. and Bishnoi, N.R. (2007). Adsorption of chromium from aqueous solution by activated alumina and activated charcoal. Bioresource Technology, 98, 954–957.

Nash, H. and McCall, GJH (eds). (1995). Groundwater quality. In: 17th Special Report. Chapman and Hall, London.

Nigam, G.L. and Moorthy, K.S. (2000). An optimum use of pesticides in integrated pest management technology. Pesticides Information, 25(1): 6-9.

Piper, A.M. (1944). A graphical procedure in the geochemical interpretation of water analysis: Am Geophys Union Trans 25: 914-928.

Paliwal, K.V. (1967). Effect of gypsum application on the quality of irrigation waters. The Madras Agricultural Journal , 59, 646-647.

Palaniswami, C. and Sree Ramulu, U.S. (1994). Effects of continuous irrigation with paper factory effluent on soil properties. J Indian Soc Soil Sci 42:139–140

Prasad, R. (1998). Fertilizer urea, food security, health and the environments. Curr Sci 75:667–683.

Patel, K.P., Pandya, R.R., Maliwal, G.L., Patel, K.C., Ramani, V.P. and George, V. (2004). Heavy metal content of different effluents and their relative availability in soils irrigated with effluent waters around major industrial cities of Gujarat. J Indian Soc Soil Sci 52:89–94.

Rajendra Prasad, D.S., Sadashivaiah, C., and Ranganna, G. (2009).www.e-journals.net Hydrochemical characteristics and Evaluation of Groundwater Quality of Tumkur Amanikere Lake Watershed, Karnataka, India .

Rajmohan, N. and Elango, L. (2005).Nutrient chemistry of groundwater in an intensively irrigated region of southern India. Environ Geol 47:820–830

Raju, N.J. (2007). Hydrogeochemical parameters for assessment of ground water quality in the upper Gunjanaeru River Basin, Cuddapah District, Andhra Pradesh, South India. Environ Geol 52:1067-1074

Rao, N. and Ramadurai, S. (1970).Systematic geo-hydrological survey of the coastal plains in Malapuram, Trichur and Ernakulam Districts, Kerala state, GSI report.

Rashid Umar., Izrar., Ahmed., Fakhre Alam. and Mohammad Muqtada Khan (2009). Hydrochemical Characteristics and seasonal variations in groundwater quality of an alluvial aquifer in parts of Central Ganga Plain, Western Uttar Pradesh, India. Environmental Geology 58: 1295-1300.

Ravikumar, P., Venkatesharaju, K., Prakash, K.L. and Sumashekar, R..K.(2010). Geochemistry of groundwater and groundwater prospects evaluation. Anekal Taluk, Bangalore Urban District, Karnataka, India. Environmental Monitoring Assessment.

Ravikumar, P. and Somashekar, R.K. (2010). Multivariate Analysis to Evaluate Geochemistry of Groundwater in Varahi River Basin of Udupi in Karnataka, India. Environmental Monitoring Assessment.

Ravindra, K., Ameena, Meenakshi, Rani, Monika and Kaushik,A. (2003). Seasonal variation in physico-chemical characteristics of river Yamuna in Haryana and its ecological best-designated use. Journal of Environmental Monitoring, 5, 419. doi:10.1039/b301723k.

Ravindra, K. and Garg, V. K. (2007). Hydro-chemical survey of groundwater of Hisar city and assessment of defluoridation methods used in India. Environmental Monitoring and Assessment, 132, 33–43. doi:10.1007/s10661-006-9500-6.

Ripa, L.W. (1993). A half-century of Community Water fluoridation in the United States: Review and Commentary. Journal of Public Health Dentistry, 53, 17–44.

Richards, L.A. (1954). Diagnosis and Improvement of Saline Alkali Soils.US Department of Agriculture, Hand Book 60, pp 160

Ripa, L. W. (1993). A Half-century of Community water Fluoridation in the United States: Review and commentary. Journal of Public Health Dentistry, 53: 17–44.

Robins, N. S. (2002). Groundwater quality in Scotland: Major ion chemistry of the key groundwater bodies. The Science of the Total Environment, 294, 41–56, doi:10.1016/S0048-9697(02)00051-7.

Sanjay Kumar Sandaray., Binod., Bihari Nayak, and Dinabandhu Bhatta. (2009). Environmental studies on river water quality with reference to suitability for agriculture purposes: Mahanadi riverine estuarine system. India- A case study. Environmental Monitoring Assessment 155: 227-243.

Sarin, M.M., Krishnaswamy, S.W., Dilli, K., Somayajulu, B.L.K and Moore, W.S. (1989). Major ion Chemistry of the Ganga-Brahmaputra river system: Weathering process and fluxes to the Bay of Bengal. Geochimica Et Cosmochimica Acta 53, 997-1009.

Scokert,P.O., Meeus Verdinne, K. and DeBorger, R. (1983). 'Chemical water quality in Thailand and its impacts on the drinking water production in Thailand". Water, Air and Soil Poll, 20,451.

Singh, A.K. (2003). Water resources and their availability. In: Souvenir, National Symposium on Emerging Trends in Agricultural Physics, Indian Society of Agrophysics, New Delhi, 22–24 April 2003, pp 18–29

Singh, H. (1983). Crop production in India. Agri Situation in India 38:635–639

Smedly, P. L. (1992). Relationship between trace elements in water and health with special reference to developing countries. Interim Report 1992 BGS. Tech., Report WD/92/39, p. 33.

Smil,V. (1999). Long-range perspectives on inorganic fertilizers in global agriculture. Second Travis P. Hignett Memorial Lecture, IFDC Lecture Series LS-2, IFDC, Muscle Shoals, Alabama, USA

Smith, A.H., Lingas, E.O. and Rahman, M. (2000). Contamination of drinking water of arsenic in Bangladesh. A public health emergency. Bull WHO 78:1093–1103

Subramani, T., Elango, L. and Damodarasamy, S.R. (2005). Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India, Environmental Geology, 47,1099-1110.

Subba Rao, N., Gurunadha Rao, V. V. S. and Gupta, C. P. (1998). Groundwater pollution due to discharge of industrial effluents in Venkatapuram area, Visakhapatnam, Andhra Pradesh, India. Environmental Geology, 33(4), 289–294.

Subba Rao, N., Surya Rao, P., Venatram Reddy, G., Nagamani, M., Vidyasagar, G. and Sathyanarayana,N.L.V.(2011).Chemical characteristics of groundwater and assessment of groundwater quality in Varaha River Basin, Visakhapatanam District, Andhra Pradesh, India. Environmental Monitoring Assessment. Published online.

Tanabe, K., Yokota,H., Hironaka, H., Tsusgima, S. and Kubota, Y. (2001). Arsenic pollution of groundwater in Bangladesh. Appl Organometal Chem 15, 241-251.

Tang, Q. and Zhang, J. (2001). Water resources and eco-environment protection in the arid regions in northwest of China (in Chinese). Prog. Geogr. 20(3): 227-233.

Tatawat, R. K. and Chandel, C.P.S.(2008). A hydrochemical profile for assessing the groundwater quality of Jaipur City. Environmental Monitoring and Assessment, 143,337-343.

Thorne, D.W. and Peterson, H.B. (1954). Irrigated soils. London: Constable and Company.

Todd, D. K. (1980). Groundwater Hydrology. John Wiley and Sons. P.535.

Tam, N.F.Y. and Wong, Y.S. (2000). Spatial variation of metals in surface sediments of Hong Kong mangrove Swamps. Environmental Pollution 110, 195-205.

Trivedi, R. K. and Goel, P. K. (1986). Chemical and biological methods for water pollution studies, Environmental Publication.

Tyagi, S.K., Datta, P.S. and Pruthi, N.K. (2008). Hydrochemical appraisal of groundwater and its suitability in the intensive agricultural are of Muzaffarnagar district, Uttar Pradesh, India. Environ Geol,(DO1 10.1007/s00254-008-1190-7).

US Salinity Laboratory Staff (1954). Diagnosis and improvement of saline and alkali soils. US Department of Agricultural Soils. US Department of Agricultural Handbook 60, Washington.

Vinayan, V.B. (2009) Hydrogeology, Stratigraphy and Evolution of the Palaeo-Lagoon (Kole Land Basin) in the Central Kerala Coast, India, Submitted to Cochin University of Science and Technology, Kerala, India.

Wang, G., Cheng, G. and Yang, Z. (1999). The utilization of water resources and its influence on eco-environment in the northwest arid area of China(in Chinese). J. nat. resour.14 (2): 109-116.

Wen, F. and Chen, X. (2006). Evaluation of the impact of groundwater irrigation on streamflow in Nebraska. Journal of Hydrology, 327, 603–617. doi:10.1016/j.jhydrol.2005.12.016.

WHO (1984) Health guidelines for the use of wastewater in agriculture and aquaculture. In: Report of a WHO Scientific Group: technical report series 778, WHO, Geneva, 74 pp.

WHO (1997). Guideline for drinking water quality .Geneva: World Health Organization. Health criteria and other supporting information, Vol. 2, pp. 940–949.

WHO (2006). Fluoride in drinking water. IWA Publishing, London, p 144

WHO (2007). Chemical Safety of drinking water: assessing priorities for risk managements. WHO, Geneva, p 160

Wilcox, L.V. (1955). Classification and use of irrigation waters. USDA, Circular 969, Washington, DC, USA

Wilcox, L.V. (1995). Classification and use of irrigation water, Washington, DC:US Department of Agriculture P:19. Washigton DC.

Workshop volume on Ground Water Resource and Management in Kerala and Lakshadweep, Retrospect, Perspect and Prospect, CGWB Kerala Region, Thiruvananthapuram, March 2009 .

Wilcox, L.V. (1948). The quality water for irrigation use, US Dept. Agricultural Bulletin.

Zeeman, C., Rich, M. and Rose, J. (2006).World Water Resources: Trends, Challenges and Solutions, Reviews in Environmental Science and Bio Technology 5: 333-346.