STUDIES ON SALT WATER INTRUSION IN COASTAL D.K. DISTRICT, KARNATAKA

Final Report Submitted to the

INDIAN NATIONAL COMMITTEE FOR HYDROLOGY (INCOH)

Ministry of Water Resources, Govt. of India

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Senior Research Fellow

September 2008

DEPARTMENT OF APPLIED MECHANICS AND HYDRAULICS

NATIONAL INSTITUTE OF TECHNOLOGY

KARNATAKA, SURATHKAL, MANGALORE- 575 025

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(Research Project Sanctioned by the Ministry of Water Resources, G.O.I. through Indian National Committee for Hydrology- INCOH)

(Sanction Letter No. 23/24/2002 –R & D/2056 dated 16th September, 2004)

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Notation	Description
A_L	Longitudinal Dispersivity
A_T	Transverse Dispersivity
B	The saturated aquifer thickness (m)
C	Solute mass fraction (dimensionless)
D_m	Apparent molecular diffusivity of solutes in solution in porous medium (L^2/T)
e	Void ratio
Gs	Specific gravity at room temperature
g	Acceleration due to gravity(9.81 m/sec^2)
I	Identity tensor (dimensionless)
K	The aquifer hydraulic conductivity (m/day)
k	Solid matrix permeability tensor (L^2)
L	Relation between the length of saltwater intrusion (m)
m	Hydraulic mean radius (m)
p	Fluid pressure ($M/(LT^2)$)
Q	Discharge rate (m^3/day)
S_{op}	Specific pressure storativity (LT^2/M)
S_y	Specific yield
T	Transmissivity (m^2/day)
t	Time (T)
V	Fluid velocity (L/T)
x, y and z	Cartesian coordinate variables (L)
ρ_w	Density of water (= 9774 N/m^3)
α	Porosity (%)

μ	Dynamic viscosity of water (0.00086 N-Sec/m^2)
ρ	Insitu bulk density (gms/cc)
ρ_d	Insitu dry density(gms/cc)
ω	Water content of the soil (%)
β	Fluid compressibility (LT^2/M)
ε	Porosity (dimensionless)
ρ	Fluid density (M/L^3)
ρ_s	Density of sea water (M/L^3)
ρ_f	Density of fresh water (M/L^3)

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3. Title of the Scheme:

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Unspent balance	: Nil

5. Original objectives and methodology as in the sanctioned proposal are mentioned in Chapter 1(page 18) and 3 (page 34-80) respectively.

6. Any changes in the objectives during the operation of the scheme – No

7. All data collected and used in the analysis with sources of data

The data collected in the analysis includes water quality parameters, aquifer parameters, observation well data and others. Most of the data are generated during the investigation. The details of the data and their sources are mentioned in Introduction, Methodology and Results and Discussion chapters.

8. Methodology actually followed- Observations, analysis, results and inferences- detailed in Results and Discussion chapter.

9. Conclusions/Recommendations – Chapter 5 highlights these aspects.

10. How do the conclusions/recommendations compare with current thinking

Currently, no scientific assessment is available on the extent of saltwater intrusion and the vulnerability to saltwater intrusion. The field studies conducted and the vulnerability assessment carried out in the region estimate the areas already contaminated by saltwater intrusion and the most vulnerable areas for saltwater intrusion. Also, a few management scenarios were predicted for higher rates of freshwater pumping. From this, the optimal levels of pumping for long term operation are estimated.

11. Field tests conducted: Pumping test, soil test, geo-resistivity survey, water level and quality analysis on monthly basis for a period of three years. The details of the tests conducted are given in Methodology.

12. Software generated, if any – No

13. Possibilities of any patents/copyrights – The work carried out may not have enough potential for patent. However, following research publications were possible from the investigation:

Research Publications:International Journal

1.Vyshali, Lathashri UA and A.Mahesha, 2008. Characterization and vulnerability assessment of coastal aquifer to saltwater intrusion, J. Hydrologic Engg., ASCE (Communicated).

National Journal

2.Vyshali, Moumita, P. and A.Mahesha, 2007. Simulation of saltwater intrusion in the Pavanje-Gurpur basins of Karnataka, ISH J. Hydraulic Engg. (Accepted).

3.Lathashri, U.A. and A.Mahesha, 2007. Assessment of aquifer vulnerability to saltwater intrusion in the D.K. district, Karnataka, J. Applied Hydrology (Communicated).

Conferences:

4.Vyshali, U.A. Lathashri, P.C. Moumita and A.Mahesha, 2008. Studies on the vulnerability assessment of a coastal aquifer. Proc. International Groundwater Conference on Groundwater Dynamics and Global Change, March 19-22, 2008, University of Rajastan, Jaipur, 143-144.

5.Vyshali , Moumita Palchaudhury and A.Mahesha, 2007. Simulation of saltwater intrusion in the coastal aquifer of Karnataka, Proc. Indian National Conference on Harbour and Ocean Engineering, INCHOE, Dept. of Applied Mechanics & Hydraulics, NITK, Surathkal and NMPT Panambur, Vol I, 34-41.

6.Lathashri.U.A and A. Mahesha, 2007. Assessment of aquifer vulnerability to saltwater in coastal Karnataka, Proc. Indian National Conference on Harbour and Ocean Engineering,

INCHOE, Dept. of Applied Mechanics & Hydraulics, NITK, Surathkal and NMPT Panambur, Vol I, 9-17.

7.Vyshali, Moumitha P.C. and A.Mahesha, 2008. Saltwater intrusion assessment in the coastal D.K. district, Karnataka, Proc. National Conference on Advances in Civil Engg., ACE, Anjuman Engg. College, Bhatkal, 116-119.

14. Suggestions for future work – Listed in Conclusion chapter.

CHAPTER 1
INTRODUCTION

1.1 General

Coastal zones contain some of the most densely populated areas in the world as they generally present the best conditions for productivity. However, these regions face many hydrological problems like flooding due to cyclones, wave surge and drinking water scarcity due to problem of salt water intrusion. The development and management of coastal groundwater aquifers is a very delicate issue. Intrusion of saltwater has become one of the major constraints affecting ground water management. As saltwater intrusion progresses, existing pumping wells, especially close to the coast, become saline and have to be abandoned which reduces the value of the aquifer as a source of freshwater.

The groundwater extraction changes the dynamic balance between the flow of freshwater and the interface so that he interface will move and attain an equilibrium position governed by the quantity extracted and the balance outflow of freshwater to the sea. When the groundwater withdrawals are large from the locations close to the saltwater interface, the saltwater upcoming may rise up to the screened section of wells and turn the water saline.

Under the above circumstance, it is very much essential to consider the effective and optimal utilization of coastal aquifer for fresh water supply. Given that withdrawals from the aquifer system can affect the water levels, water quality, coastal discharge and surface water-ground water interactions, a better understanding of the ground-water flow system of the study area is needed for effective water-resources management.

Dakshina Kannada district which is a coastal district of Karnataka spreads along the west coast of India covering coastal track of about 30 km. The chief occupation of the people here are agriculture and fishing. However, due to the developmental activities and progress in the recent years, mainly in the fields of industry, commerce and trade, the demand for fresh water has enormously increased. The major industrial units such as Mangalore Refinery and Petrochemicals Limited, Mangalore Chemical and Fertilizers and New Mangalore Port Trust are located in the region. Other than these, a thermal power plant, software technology park and other industries are coming up in and around Mangalore. At present, the domestic as well as industrial water requirements are mainly met by Nethravathi river water which is being supplied by Mangalore Municipal Corporation and groundwater. However, in the near future, an alternate source for water supply need to be worked out to meet the ever increasing demand for fresh water.

Under the above circumstance, it is very much essential to consider the effective and optimal utilization of coastal aquifer for fresh water supply. For this, dynamics of coastal aquifers i.e. between fresh water and sea water need to be studied. Based on this, safe withdrawal from coastal aquifers could be worked without aggressive intrusion of salt water into coastal fresh water aquifers. Hence it was decided to study existing salt water intrusion, safe withdrawal of fresh water and control measures if required to check the further advancement of sea water.

Change in groundwater levels with respect to mean sea elevation along the coast largely influences the extent of saltwater intrusion in the fresh water aquifers. The smaller the drop in the groundwater levels, the lesser is the sea water intrusion in the aquifers. In other words, the magnitude of change in sea level would have the identical effect on saltwater intrusion if the groundwater levels were held constant. In the past, sea levels have changed with the changes in natural climatic conditions several times. This happened during the glacial and interglacial periods which are well recorded by coastal sediments in the form of transgressive and regressive sediment types. However, at present, the climate is largely influenced by human interference in the form of air and water pollution.

1.2 STUDY AREA

The present area of study is the coastal basin stretched between the Pavanje and Gurpur rivers of Dakshina Kannada district (Fig.1.1and 1.2). Major industries such as Mangalore Refinery and Petrochemical Ltd (MRPL), Mangalore Chemicals and Fertilizers Ltd (MCF), New Mangalore Port Trust (NMPT) and other smaller units comprising of industrial estate, small scale industries are located in the region. Besides, academic institutes like the National Institute of Technology Karnataka (NITK) are located in the region. The Oil and Natural Gas Corporation (ONGC) is exploring various options for diversification of its activities including setting up of a special economic zones (SEZ) in Mangalore. Even though the fresh water requirement is partially met by surface water supply, greater thrust exists on groundwater resources. Since, the Gurpur and Pavanje rivers are tidal in nature, adjoining aquifers get contaminated by salt water from these rivers for considerable distance upstream during the non-monsoon period. The area is surrounded by the sea on the west and by the Pavanje and Gurpur rivers on the north and south respectively. The study area for the present investigation is as shown in Fig 1.2. The areal extent of the region is about 30 km^2. The wells selected for the investigation includes open wells and ponds. The major groundwater extraction at present is limited to a few locations and the rest are of minor in nature. The extraction was found to be about 1500m^3/day at NITK and about 2000 – 3000 m^3/day at NMPT during the summer months (Moumitha, 2006). This is much more than the extractions in other wells of the region .A total of 39 monitoring wells are considered in the area as shown in fig.1.3 and the details are tabulated (table 1).

This area's freshwater requirement even though partially met by surface water supply, greater thrust at present and in future would be on groundwater resources. Besides, the rivers are being tidal in nature, adjoining aquifers get intruded by salt water from these rivers for considerable distance upstream during the non-monsoon period. In all, the study area may be about 30 km^2 in area with 40 sampling locations. Even though saltwater intrusion is being experienced in the region, scientific assessment is yet to be carried out.

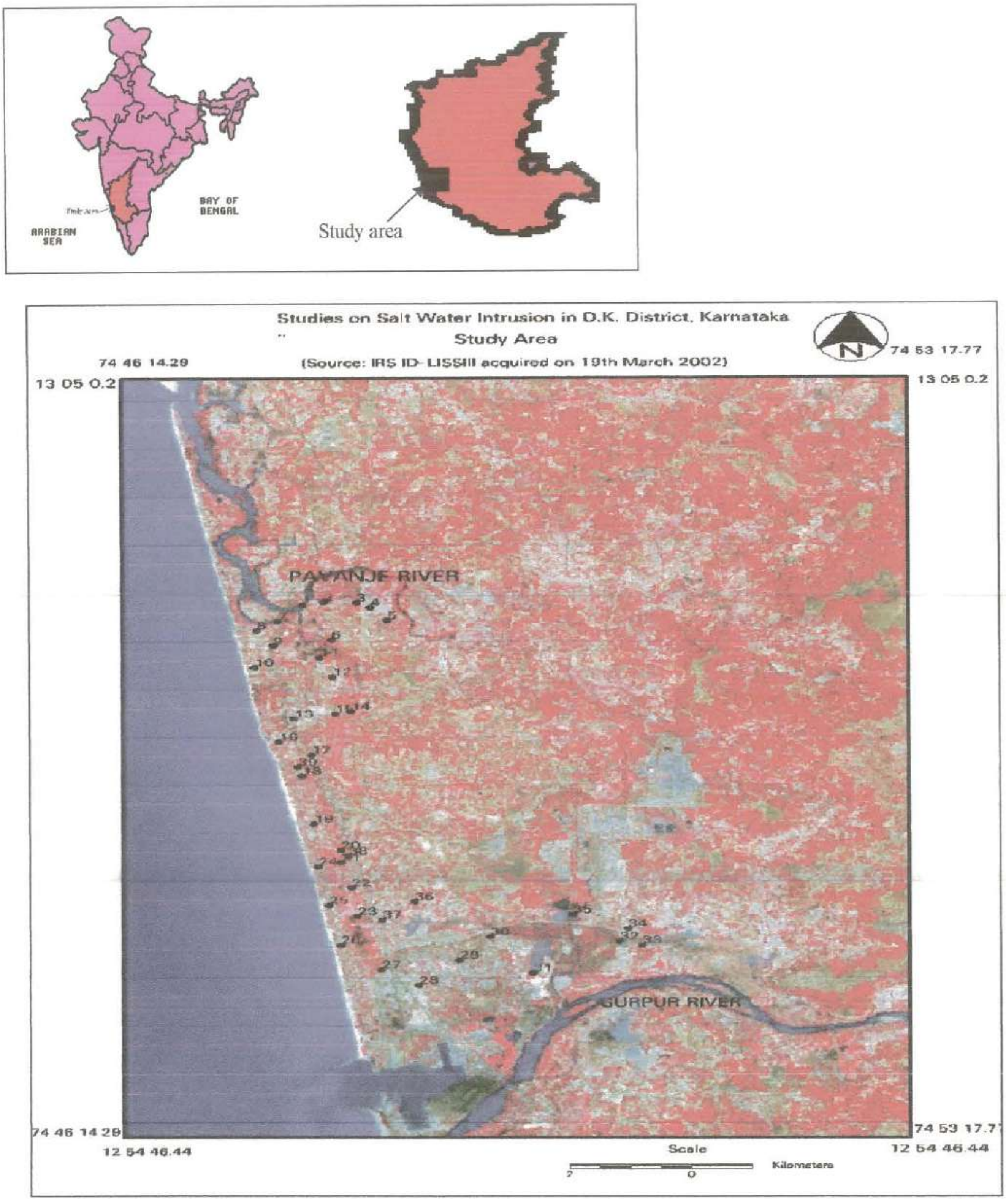


Fig.1.1 Location map of the study area

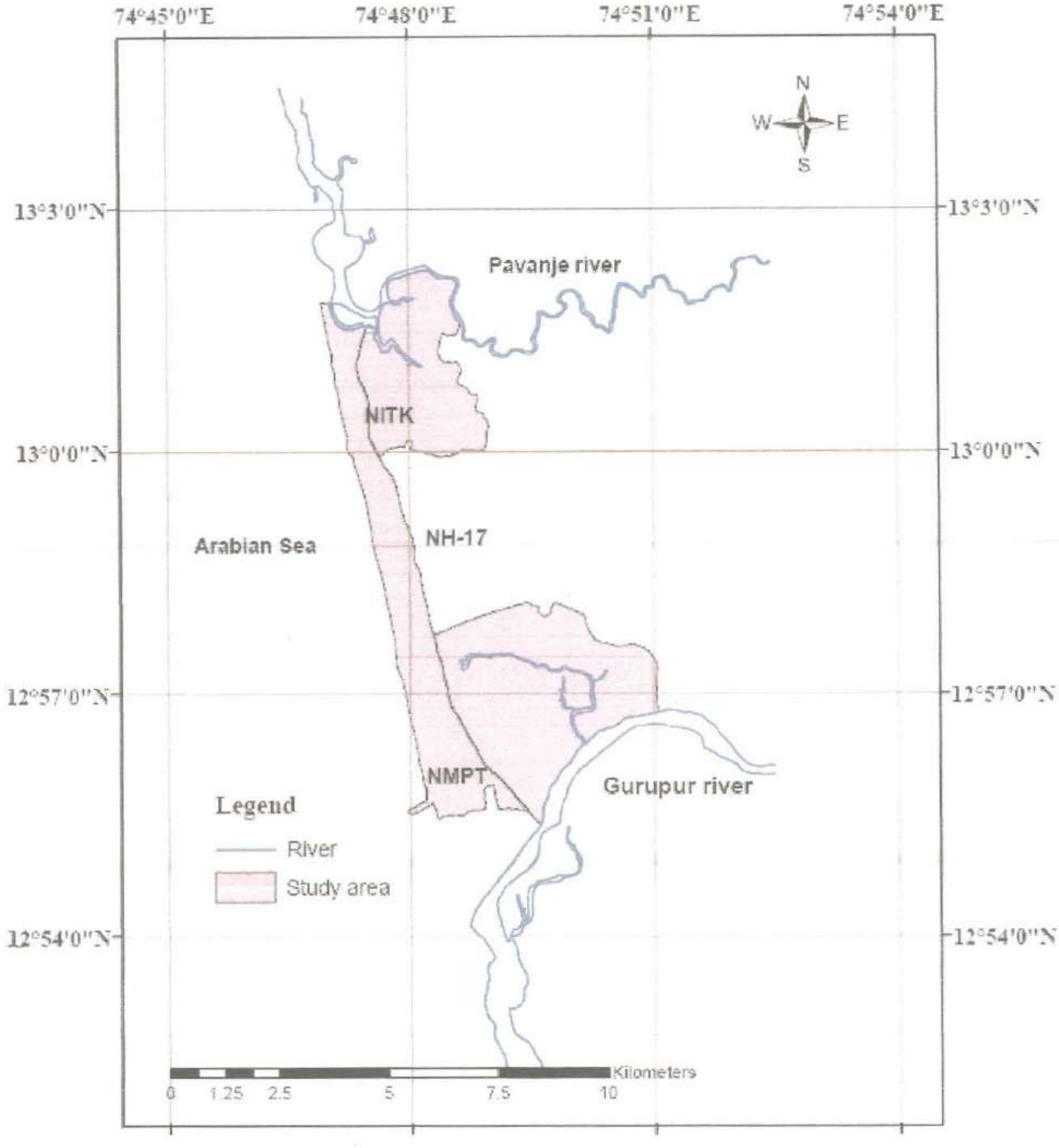


Fig 1.2 Location map of the study area

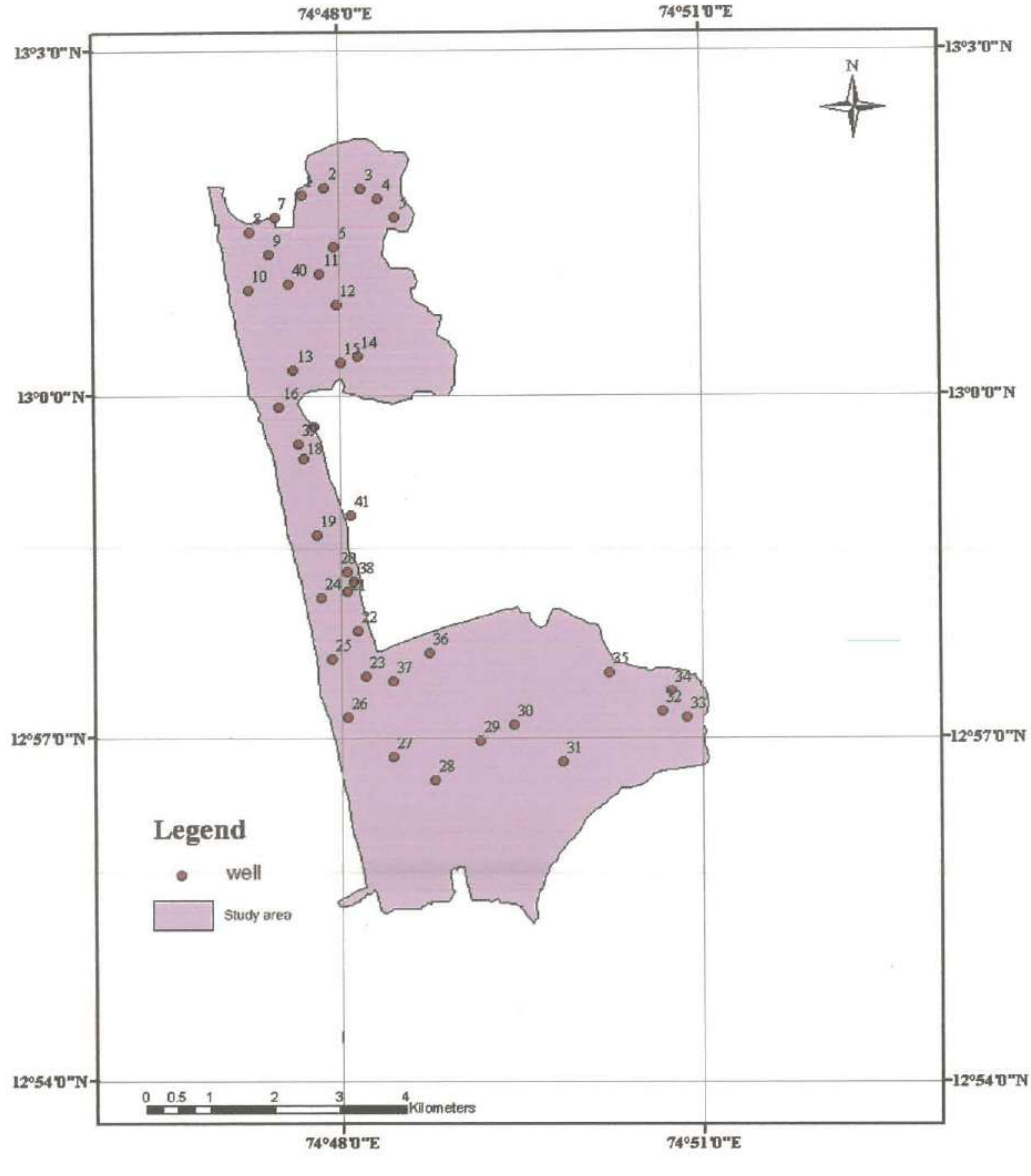


Fig 1.3 Study area with well locations

Table 1.1 Well Inventory

Well No	Address	Latitude /Longitude	Well Depth(m)
1	Shri. K.Vasudev Rao Khandiga, Pavanje Chelaru Post-574 146	13° 1' 57" N (Latitude) and 74° 47' 49.3" E (Longitude)	4.57
2	Shri. Shekar Devadiga Shankarnar House Haleyangadi Post-574 180 Chelaru Village-	13° 1' 59.9" N(Latitude) and 74° 48' 1.2" E(Longitude)	5.90
3	Shri. Basappa Shetty Chelaru Meginaguthu Haleyangadi Post-574 180	13° 1' 58.2" N(Latitude) and 74° 48' 18.7" E(Longitude)	3.0
4	Shri.Venkapp Shetty Periyaguthu house Chelaru Post-574 146	13° 1' 53.9" N (Latitude) and 74° 48' 27.1" E (Longitude	1.80m
5	Smt.Appi Shedthi Padde House Chelaru Village Chelarupadavu Post-574 146	13° 1' 44.3" N(Latitude) and 74° 48' 35.6" E(Longitude)	5.60
6	Shri.Sudhakar Shetty Khandige House Chelaru Post-574 146 Via: Haleyangadi	13° 1' 28.8" N"N (Latitude) and 74° 48' 5.2"E (Longitude)	2.30
7	Shri.Lakshmi das Karkarbail House Mukka Post-575 021	13° 1' 43.4" N (Latitude) and 74° 47' 36"E (Longitude)	2.90
8	Smt.Vasanthi M. Kotiyan Padi House Mukka Post-575 021	13° 1' 36.1" N (Latitude) and 74° 47' 24.2"E (Longitude)	2.05
9	Shri.Devendra Poojari Bhandara Mane House Mukka Post-575 021	13° 1' 23.8"N (Latitude) and 74° 47' 33.4"E (Longitude)	2.07
10	Shri.Rev.Father Jyothi Mandir Mukka Post-575 021	13° 1' 6.2"N (Latitude) and 74° 47' 23.1"E (Longitude)	3.60
11	Shri.Seetharama Shetty Akshaya, Megina Mane, Padre, Post: Srinivasnagar-575 025	13° 1' 14.3"N (Latitude) and 74° 47' 58.8" E (Longitude)	3.15
12	Shri.Vamana Pujari Sithanada Mane, Srinivasnagar-575 025	13° 00' 58.9" N (Latitude) and 74° 48' 5.9"E (Longitude)	3.25

Well No	Address	Latitude /Longitude	Well Depth(m)
13	Shri.The Director N.I.T.K Srinivasnagar-575 025	13° 00' 24.2"N (Latitude) and 74° 47' 44.8"E (Longitude)	6.65
14	Shri.Ramanna Dinda thota. Munchoor, Srinivasnagar Post-575 025	13° 00' 30.9"N (Latitude) and 74° 48' 16.2"E (Longitude)	2.02
15	Smt.Sharadamma Ranganilaya, Kaveribettu Srinivasnagar-575 025	13° 00' 28.7"N (Latitude) and 74° 48' 7.3"Longitude	3.75
16	Shri.Sri Sathya Shankar Bhat Edurkala,Sadashiva Layout Surathkal Post-575 014	13° 00' 5.2" N (Latitude) and 74° 47' 37.4"E (Longitude)	2.80
17	Shri.Vishwanatha Shetty Thadambail Thota House Surathkal-575 014	12° 59' 55.4"N (Latitude) and 74° 47' 55"E (Longitude)	3.10
18	Shri.Ramdas Shriyan Pathith Sadsshiv nagar, I Cross Idya, Surathkal-575 014	12° 59' 38.6" N (Latitude) and 74° 48' 49.4"E (Longitude)	1.70
19	Shri.J.Ishwara Bhat Jatti Nivas, Lecturer's Colony Idya, Surathkal-575 014	12° 58' 59"N (Latitude) and 74° 47' 56" E(Longitude)	3.55
20	Shri.Sanjeeva Devadiga Shrath Sadan,Kulai, Hosabettu Post-574 176	12° 58' 39.4"N (Latitude) and 74° 48' 11.3"E (Longitude)	3.05
21	Shri.B.Karunakara Shetty Savi House,Tavarekola Extension, Kulai, Hosabettu-574 176	12° 58' 28.8" N (Latitude) and 74° 48' 10.7" E (Longitude)	2.40
22	Shri.Ramakrishna Rao Krishnanilaya, Todabali House Kulai, Honnakatte-574 196	12° 58' 7.9" N (Latitude) and 74° 48' 16.8"E (Longitude)	1.85
23	Shri.Dayasagar Shailini 3-136/3,Gokulnagar, Kulai-574 196	12° 57' 44.8"N (Latitude) and 74° 48' 20.3"E (Longitude)	2.30
24	Shri.H.Vaman Puthran Venkateshnilaya, Hosabettu-574 176	12° 58' 25.2"N (Latitude) and 74° 47' 58.7"E (Longitude)	2.40
25	Master Ice Plant Chitrapur, Kuali-574 196	12° 57' 54.2" N (Latitude) and 74° 48' 4.8"E (Longitude)	3.80

Well No	Address	Latitude /Longitude	Well Depth(m)
26	C. Gopalakrishna Acharya House No. 5-23 (Kaggi Mane) Chitrapur, Kuali Post-574 196	12° 57' 22"N (Latitude) and 74° 48' 11.4"E (Longitude)	2.35
27	Swathi Service Station Indian Oil Dealers Panamboor , Mangalore-575 010	12° 57' 2.3" N (Latitude) and 74° 48' 34"E (Longitude)	4.90
28	Swan Laundry Baikampady New Mangalore-575 011	12° 56' 49.4" N (Latitude) and 74° 48' 54.3" E (Longitude)	3.50
29	Achal Industries Baikampady, Mangalore-575 011	12° 57' 10.6"N (Latitude) and 74° 49' 16.4"E (Longitude)	5.15
30	Shri.Naga Baby Shetty Pushpa Nivas, "Plot No.7" Baikampady Post-575 011 Kudumboor	12° 57' 28.9"N (Latitude) and 74° 49' 33.2"E (Longitude)	2.35
31	Near Ruchi Gold Factory Mungaru, Baikampady-575 011	12° 57' 00" N (Latitude) and 74° 49' 57.1" E (Longitude)	3.25
32	Shri.Shekar Kaivali House Kenjar Post-574 173	12° 57' 25.8"N (Latitude) and 74° 50' 44"E(Longitude)	2.30
33	Shri.Ganapathi Bhat Pejavar Matt, Kenjar Post Jokatte-574 173	12° 57' 23" N (Latitude) and 74° 50' 56.1"E (Longitude)	3.40
34	Smt.Kalyani Sankadade House,Jokatte House Kenjar Village-574 173	12° 57' 36.5" N (Latitude) and 74° 50' 48.2"E (Longitude)	3.40
35	Shri.T. Dayanand Alva Tokur Aranthady House Jokatte House-574 173	12° 57' 47.1"N (Latitude) and 74° 50' 18.2"E (Longitude)	4.35
36	Shri.Mahabala T Salian Data House Kulai-574 196	12° 57' 57.3"N (Latitude) and 74° 48' 51.6"E (Longitude)	1.0
37	Shri.Jagannatha Kotian Ganesh kripa, V T U Road Kulai-574 196	12° 57' 42.6" N (Latitude and 74° 48' 34.1"E (Longitude)	2.50
38	Shri.Giridhar Hatwar 2/53, Hatwar House Kulai, Hosabettu -574 176	12° 58' 34.1"N (Latitude) and 74° 48' 15.6"E (Longitude)	2.60
39	Shri.Janardan Shettigar Ermal House,Sadashivnagar II Cross, Surathkal-574 158	12° 59' 45.3"N(Latitude) and 74° 47' 47.2"E(Longitude)	2.85

1.2.1Physical Features of the Study Area

1.2.1.1 Physiography

Coastal region is a narrow elongated belt between the western ghats and the Arabian sea. It runs along the entire length of Dakshina Kannada district and its soil composition mainly includes beach sand, alluvium and laterites. The study area lies between 74° 45' E and 74° 54' E longitude and 12° 50' N and 13° 4' N latitude.

The Gurpur river takes a right angled turn near the coast and flows southwards parallel to the west coast and joins Arabian sea through confluence with the Nethravathi river. The Pavanje river too takes a right angled turn but flows northwards and joins the Mulky river before joining the Arabian sea. Both the river basins have an irregular topography with large undulations typical of the west coast of Karnataka. The topographical lows are good sources of groundwater and fertile land for raising the rice crop. Since the rivers flow through thick vegetation, erosion by these rivers is low as compared to that by east flowing rivers.

1.2.1.2 Geology

The basement rocks of the study area are granitic gneisses of the Archean age, one of the oldest rocks of peninsular India. The laterites are formed in areas which experienced alternate dry and wet seasons with good drainage facilities. The laterites are quite soft in deeper zones. The New Mangalore Port area has large deposits of aluminous laterites overlaid by thick layers of ferruginous laterites. The laterites are often associated with the clay which is normally found in the valley regions. Fine clay is seen in the paddy fields and the swamps. Along the coastal tract, beach sand of uniform size is commonly found. The river basins under study are also found to consist of highly lateritic mounds under laid by a thin bed of clay, granites and gneisses. Both the basins consist of coastal alluvium in the coastal belt. The soil map of the area is digitized using GIS software and the data required is obtained from NBSSCLP (1996). Fig 1.4 shows the soil classification map of the area and the description is given in table 1.2

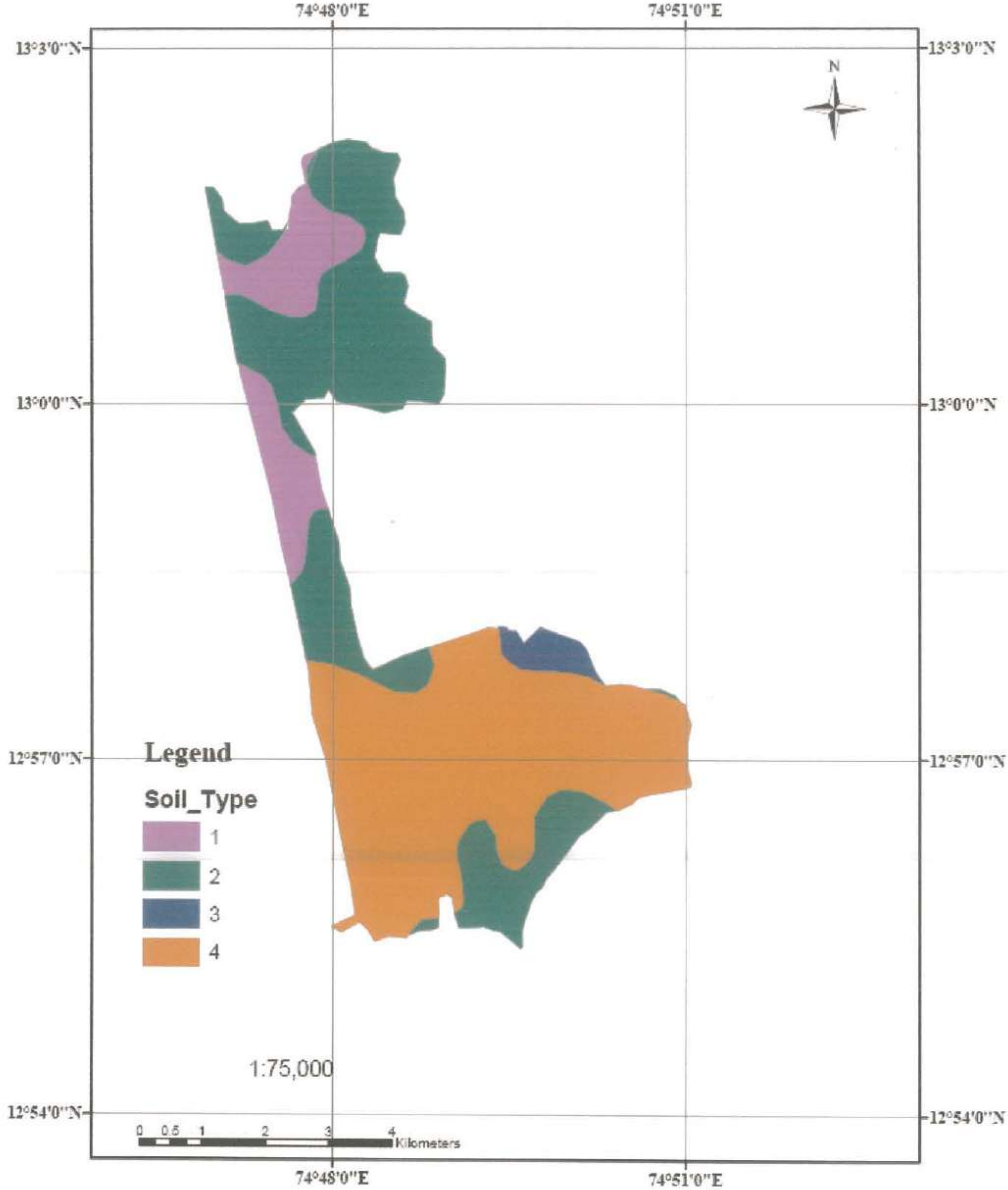


Fig 1.4 Study area soil classification map

Table 1.2 Description of the soil class in the study area

Legend No.	SOIL TYPE
1	Moderately deep, well drained, gravely clay soils with low AWC and surface crusting on undulating uplands, with moderate erosion.
2	Very deep, well drained, gravely clay soils with surface crusting and compaction on undulating uplands, with moderate erosion.
3	Very deep, well drained, gravely clay soils with low AWC on laterite mounds, with slight erosion
4	Deep, imperfectly drained, sandy over loamy soils of valleys with shallow water table

1.2.1.3 Climate

The study area has a hot humid climate. Variations in the climate can be observed between the coastal area and other parts. Coastal belt has almost the same weather throughout the year whereas weather extremities are noticed towards the ghats section. The mean maximum and minimum temperatures in the area are 36°C (May) and 21°C (December) respectively. In the study area, the weather is highly humid all through the year and particularly so during the south west monsoon period. A maximum of 100% humidity is recorded in June and July every year. The winds are strong (up to 60kmph) and are mainly easterly or south-westerly during the south-west monsoon period. During the rest of the year, winds are mainly from north-east direction in the forenoon and easterly during afternoons. The south-west monsoon season is the principal rainy season for the region. In the southwest monsoon period, orographic influence is dominant in the distribution of rainfall and the prevailing wind blows almost at right angles to the western ghats. The coastal region being on the windward side of the ghats, receives heavy oceanographic rainfall. The annual average rainfall in the area is about 3500mm which is mostly confined to June - September. The rainfall distribution for the year 2006-07 observed at the meteorological station at NITK Surathkal is given in fig. 1.5.

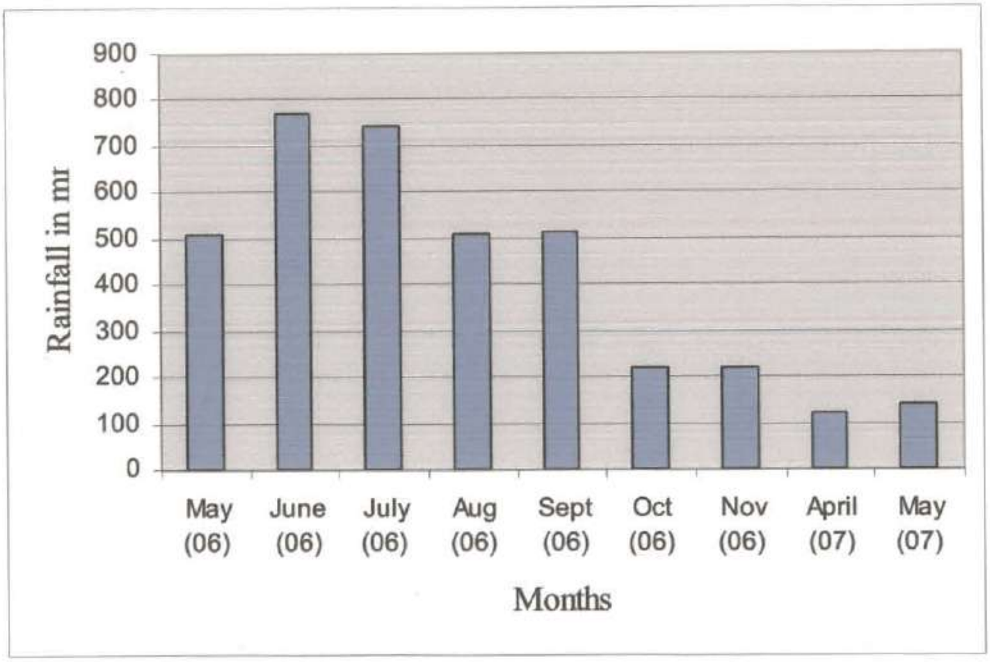


Fig. 1.5 Monthly rainfall at Surathkal (Department of Applied Mechanics, 2006)

1.3 PURPOSE AND SCOPE OF THE PRESENT WORK

Coastal aquifers constitute important sources of fresh water. Utilization of groundwater in the coastal zones need to be carefully expedited due to the problem of saltwater intrusion. This resource, however, is under severe threat from saltwater intrusion and salinization due to both natural (sea level rise) and man-made (overdraft) causes and hence, should be under strict surveillance for the overall sustainable development of coastal region.

It is a well known fact that the west flowing rivers of Karnataka discharge significant portion of the monsoon runoff to the sea. Due to uneven distribution and inadequate storage of the rainfall in the region, there exists a prolonged dry period from Jan-May. The thrust during this period is obviously on groundwater resources which may lead to overdraft conditions resulting in declining groundwater levels and thereby facilitate saltwater intrusion. Hence, proper management of the basin is essential with optimal pumping rate to check further advancement of saltwater.

The focus of the present work is to manage the water resources in the rural coastal areas between the rivers Gurpur and Pavanje. The fresh water requirement of the region is partially met by surface water resources. However, greater thrust would be on groundwater resources. The two rivers are being seasonal and tidal in nature, salt water intrusion into adjoining aquifers during the non- monsoon period is greatly felt up to several kilometers inland along the river courses. Also, salt water intrusion from the sea is also the major cause of groundwater quality degradation in the region.

Past observations on the mean sea level along the Indian coast indicate a long-term rising trend of about 2.5 mm per year on an annual mean basis. The thermal expansion related sea level rise is expected to be between 15 to 38 cm by the middle of the century and between 46 to 59 cm by the end of the century (Lal and Aggarwal, 2000). This simulated rise in the sea level along the Indian coastline is comparable with the projected global mean sea level rise of 50 cm by the end of this century (Lal and Aggarwal, 2000) and may have significant impact on the coastal zones of India. Also the Intergovernmental Panel on Climate Change (IPCC, 2001) predicts that the global seas may rise by an additional 0.2 to 1.0m by 2100, with a best estimate of 0.5m (Masaterson et al, 2006)

The present study also aims to assess the level of threat to the population due to groundwater salinization and to demarcate the salt affected areas using a vulnerability index. Further, the area which is at risk due to the groundwater salinization could be considered for improvisation. Also, an attempt is made to study the impacts of sea level rise on the extent of sea water intrusion into the coastal aquifers.

There has been no methodology for evaluating the spatial distribution of the saltwater intrusion potential, which essentially takes into account hydro-geological factors. The methodology adopted in this study allows saltwater intrusion of coastal hydro-geological settings to be systematically evaluated. It is therefore necessary to adopt a mapping system that is simple to apply using the data generally available, yet capable of making best use of those data in a technically valid and useful way. The adoption of an index has the advantage of eliminating or minimizing subjectivity in the ranking process.

The focus of the present work is to manage the water resources in rural coastal areas between the rivers Gurpur and Pavanje. The fresh water requirement of the region is partially met by surface water resources. However, greater thrust would be on groundwater resources. The two rivers are being seasonal and tidal in nature, salt water intrusion into adjoining aquifers during the non- monsoon period is greatly felt up to several kilometers inland along the river courses. Also,

salt water intrusion into aquifers from the sea is also the major cause of quality degradation in the coastal region.

In order to protect the coastal aquifer from these adverse effects, a proper management strategy is to be evolved in terms of freshwater utilization and its location. Hence the present investigation is taken up with the following objectives.

1.4 OBJECTIVES

The present study is aimed at the assessment of saltwater intrusion in the coastal basin between the rivers Pavanje and Gurpur and has the following objectives

- Field investigation to evaluate the aquifer parameters and assessment of saltwater intrusion.
- Water quality analysis to determine the extent of saltwater intrusion
- Simulation of saltwater intrusion using Saturated Unsaturated Transport (SUTRA) model.
- To predict the future scenario on saltwater intrusion considering the projected demand for groundwater resources.

1.5 ORGANIZATION OF THE REPORT

The chapter wise breakup of the work reported in this thesis is as follows:

Recent available literature on the topic is mentioned in chapter 2. It helps to assess the progress of the related works in the field. In chapter 3, the methodology adopted to study the problem of saltwater intrusion and the various parameters used are discussed. The pumping test data, results obtained from the electrical resistivity survey, soil analysis results, numerical simulation results from SUTRA and the GALDIT analysis outcome are discussed in chapter 4. The chapter 5 highlights the salient conclusions drawn from the work and the scope for further studies.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

Saltwater intrusion into aquifers and groundwater quality degradation by salinization is the most serious threat to coastal fresh groundwater resources, which constitute an essential supply for human needs in the coastal areas Custodio and Galofre (1992).Many models have been developed to represent and to study the problem of saltwater intrusion. In the last five decades, they have advanced from relatively simple analytical solutions to complex numerical models. Since the present investigation deals with the solute transport modeling the relevant literature concerned with this approach is cited in this chapter.

2.2 THEORIES OF SALTWATER INTRUSION

Extensive field investigations were carried out during 1940-1965. Many of these studies are still a basis for understanding the mechanisms of hydrodynamic dispersion and density, and for comparing the results of analytic and numerical approximations. Major work was undertaken in The Netherlands, Israel, and in the United States, on Long Island, N.Y., Florida, California, Hawaii, and the Louisiana-Texas coastal area. Many of the field studies showed importance of the geologic framework and variations in permeability characteristics.

With the theory of Muskat (1937) and Hubbert (1940) as a foundation, and with accurate field descriptions of saltwater –Freshwater behavior in groundwater systems, several basic quantitative relationships were developed during this period. Glover (1959) developed a formula to describe the saltwater-freshwater "sharp" interface in a coastal aquifer that accounts for the movement and discharge of the freshwater, as shown in Fig 2.1 the interface between the freshwater and saltwater can be plotted from the expression

$$y^2 - \frac{2Q}{\gamma K} X - \frac{Q^2}{\gamma^2 K^2} = 0 \qquad (2.1)$$

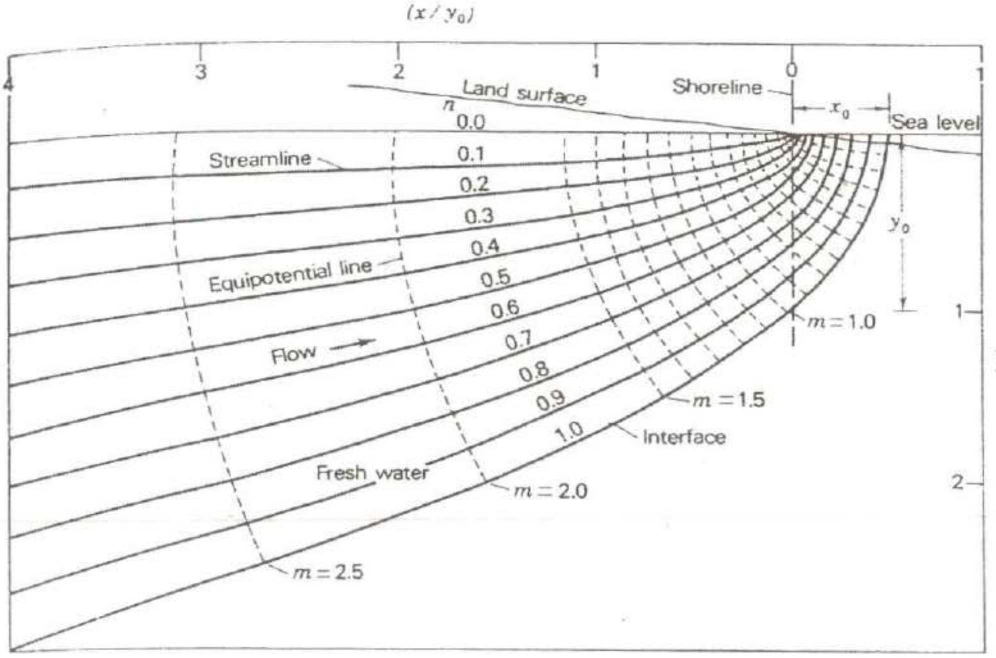


Fig 2.1 Flow pattern near a beach (from Glover, 1959)

Where, Q is freshwater flow per unit length of shore (L^2T^{-1}); K is hydraulic conductivity of the medium (LT^{-1}); $\gamma= (\rho_s-\rho_f)/ \rho_f$ (dimensionless); ρ_s is density of saltwater (ML^{-3}); ρ_f is density of freshwater (ML^{-3}); X is distance from shore (L); and Y is depth from mean sea level (L). As can be observed from Fig 2.1, this differs from the Badon Ghyben-Herzberg formula because it allows for discharge at the shore and balances pressures across the interface, as stated in Hubbert's theory.

Cooper (1959) developed a hypothesis to explain the mixing (or zone of dispersion) and the associated perpetual circulation of saltwater observed in the various field investigations. Included with his qualitative hypothesis, he also attempted to define the amount of mixing attributed to tidal fluctuations in co astal environments.

Bear and others also contributed to the quantification and understanding of saltwater – freshwater dynamics in the early 1960's in papers such as Todd (1960) and Bear and Dagan (1962, 1963, 1964 a, b), which gave insight into dispersion, sharp interfaces, and the movement of interfaces. The analysis of the transient movement of interfaces was first investigated by Bear and Dagan (1964b), although Henry (1962) also investigated transitory movement in a more approximate large–scale system.

Henry (1959) also developed some solutions for determining the sharp interface under various conditions and also made the first attempt to quantitatively determine the effects of dispersion and density –dependent fluid flow on saltwater encroachment in coastal aquifers (Henry, 1964), by investigating a two–dimensional hypothetical cross section. Results of Henry's analysis for his idealized mathematical model are depicted in Fig.2.2.The main significance of Henry's work at this time was that it quantitatively corroborated Cooper's hypothesis and opened a new approach–namely, using the advection-diffusion equation (miscible fluids) instead of the sharp-interface (immiscible fluids) approach.

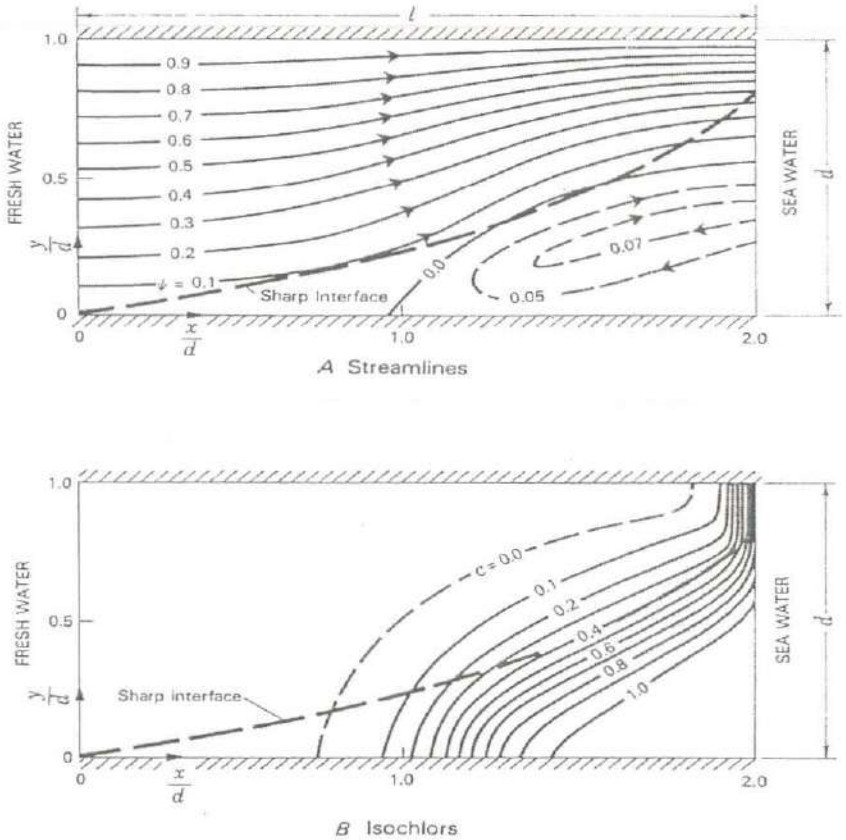


Fig 2.2 Flow and salt concentration patterns in an idealized mathematical model Henry: (A) streamlines; and (B) isochlors (modified from Henry, 1964)

Henry's simulations of the dispersive phenomenon set the stage for future investigations. However, many of the analytical solutions that represented the flow field more accurately than the Badon Ghyben-herzberg formula, such as those developed by Glover. Bear and Dagan became the best available means of investigating simple advection-dominated systems and remain as powerful means of analyzing certain problems.

2.2.1 Two-dimensional cross-sectional analysis

Applications that use two-dimensional cross-sectional analysis account for most of the recent work. One reason is that vertical gradients play an important role in establishing the relationship between the two fluids.

Work on the closed-form analytical solution to various forms (different boundary conditions) of cross-sectional systems continued. Hantush's (1968) work formed a comprehensive view of one class of these groundwater systems. Mualem and Bear (1974) addressed the role and effect of semi-pervious layers with an aquifer system. Van der Veer (1977b) presented a solution accounting for simultaneous flow of fresh and salt groundwater.

Most recent, major advances in understanding saltwater-freshwater relationships have occurred through numerical analysis. Cross-sectional simulations have been made with both the sharp interface approach and the miscible fluid or solute-transport approach (requiring solution of the advection-diffusion equation). Numerical simulations using sharp interface approach were done by Shamir and Dagan (1971), Kashef (1975a, b) and Bear and Kapuler (1981) for example. The solute-transport approach is a more general treatment, in that saline and freshwaters mix producing a continuous solution of the groundwater flow equation and the advection-diffusion (transport) equation because density is a function of concentration. Under the assumption used by Pinder and Cooper (1970) the equation for density –dependent groundwater flow, assuming that release of water from storage has a negligible effect on the movement of the saltwater front is:

$$\nabla \bullet \left(\frac{k}{\mu} \nabla P \right) - g \frac{\partial}{\partial z} \left(\rho \frac{k}{\mu} \right) = 0 \tag{2.2}$$

and the transport of the dissolved salt is described by

$$D \nabla^2 c - \frac{q}{n} \bullet \nabla c = \frac{\partial c}{\partial t} \tag{2.3}$$

where, c is concentration of salt, in mass per unit volume of solution (ML^{-3}); D is dispersion coefficient (L^2T^{-1}); g is gravitational acceleration (LT^{-2}); k is intrinsic permeability (L^2); n is porosity (dimensionless); P is pressure ($ML^{-1}T^{-2}$); q is specific discharge (LT^{-1}); ρ is fluid density (ML^{-3}); and μ is dynamic viscosity ($ML^{-1}T^{-1}$).

This approach or a similar approach solving the two simultaneous partial differential equations was used by Pinder and Cooper (1970), Huyakorn and Taylor (1976), Desai and Contractor (1977), Frind (1982) and Voss (1985).

The second approach accounts for the vertical as well as the horizontal position of the interface. For steady-state conditions, assuming a hydrostatic saltwater system and the Dupuits assumption of no vertical head gradient in the freshwater, Fetter (1972) used an interface procedure similar to the Badon Ghyben-Herzberg formulation to determine the saturated thickness of the aquifer. Burnham et al. (1977), in studying a system from which saltwater was being pumped, used analytical solutions to predict drawdown in the saltwater, a finite-difference model to predict head in the fresh-water, and Hubbert's formula to determine the position of the interface. For transient cases also using the Dupuit assumption, Mercer et al. (1980a) used an approach that simulates the freshwater system and the saltwater system as two different flow systems coupled by the interface boundary which satisfies the Hubbert (1940) equilibrium formulation. This simulation requires a simultaneous solution of the equations describing the flow of freshwater and saltwater. The equation of flow in the freshwater is:

$$S_f \frac{\partial h_f}{\partial t} + \nabla \bullet q_f - Q_f = 0 \qquad (2.4)$$

and for saltwater is:

$$S_s \frac{\partial h_s}{\partial t} + \nabla \bullet q_s - Q_s = 0 \qquad (2.5)$$

where, h is hydraulic head; q is the Darcy velocity (a vector quantity); S is specific storage; Q is a source /sink term (negative for sink); $\nabla = \partial/\partial x i + \partial/\partial y i$ (where i, and j are unit vectors in the x and y directions, respectively); $q_f = -K_f . \nabla h_f$; $q_s = -K_s$; K is hydraulic conductivity (a tensor quantity); and subscripts f and s refer to freshwater and saltwater respectively.

The position of the interface determines the thickness of each flow domain and is calculated using Hubbert's theory by

$$Z = \frac{h_f \rho_f - h_s \rho_s}{\rho_f - \rho_s} \quad (2.6)$$

where Z is the vertical position of the interface

This method is useful, but is applicable only on a regional scale for vertically homogeneous aquifer systems that have small vertical head gradients and relatively thin zones of. dispersion. Thus, the method cannot simulate local effects especially near pumping wells or discharge boundaries where vertical gradients are of major importance.

2.2.2 Three-dimensional analysis

Saltwater-freshwater systems have been studied using three-dimensional analysis. Guswa and LeBlanc (1981), assuming static saltwater with a sharp interface, used a three-dimensional freshwater flow model, and used Hubbert's equation to determine the position of the interface by means of an iterative approach to produce an equilibrium interface position. Weiss (1982) and Kuiper (1983) have used three-dimensional simulations in which fluid density is specified in advance as function of position rather than calculated as a result of solute movement after each time step. This approach is useful in the analysis of steady-state flow systems where the distribution of fresh and saline water is known in advance from field observation.

2.2.3 Upconing analysis

Where the regional saltwater-freshwater system is in equilibrium, a pumping well screened in the freshwater zone can cause a distribution of thus equilibrium. Under certain circumstances a new equilibrium can be attained in which a stable cone develops in the underlying interface or transition zone, and the well still discharges essentially freshwater. Under other conditions, the well induces a greater upcoming of saline water and the well discharge becomes saline to a degree governed by the discharge rate, the duration of pumping and local hydrologic conditions, the phenomenon is of great practical interest because, frequently, the most important objective of hydrologic investigations is to determine conditions ensuring a portable water supply.

If the pumping rate is less than a certain critical value, which is a function of local hydrologic conditions, the cone will eventually stabilize as a saltwater interface or transition zone, with the apex of the cone some distance below the bottom of the well. Freshwater will flow toward the well along the interface, and no flow will occur in the saltwater once the sable interface position has been attained. Successive increase in the pumping rate will procedure higher stable cone positions until the critical pumping rate is reached. At this pumping rate, the apex of the cone is still below the bottom of the well, but the cone is in the highest position at which it can remain stable. If the well discharge is increased, the interface or transition zone will be disrupted, flow will occur within the saline water abs the discharge of the well will become partially saline. This behavior was recognized by Muskat and Wyckoff (1935) in analysis of brine coning beneath oil wells. Their analysis entailed a sharp interface approach, and. As with all such approaches, analysis entailed a sharp interface approach, and as with all such approaches its applicability to water wells is limited by the extent to which the fluids can be considered immiscible.

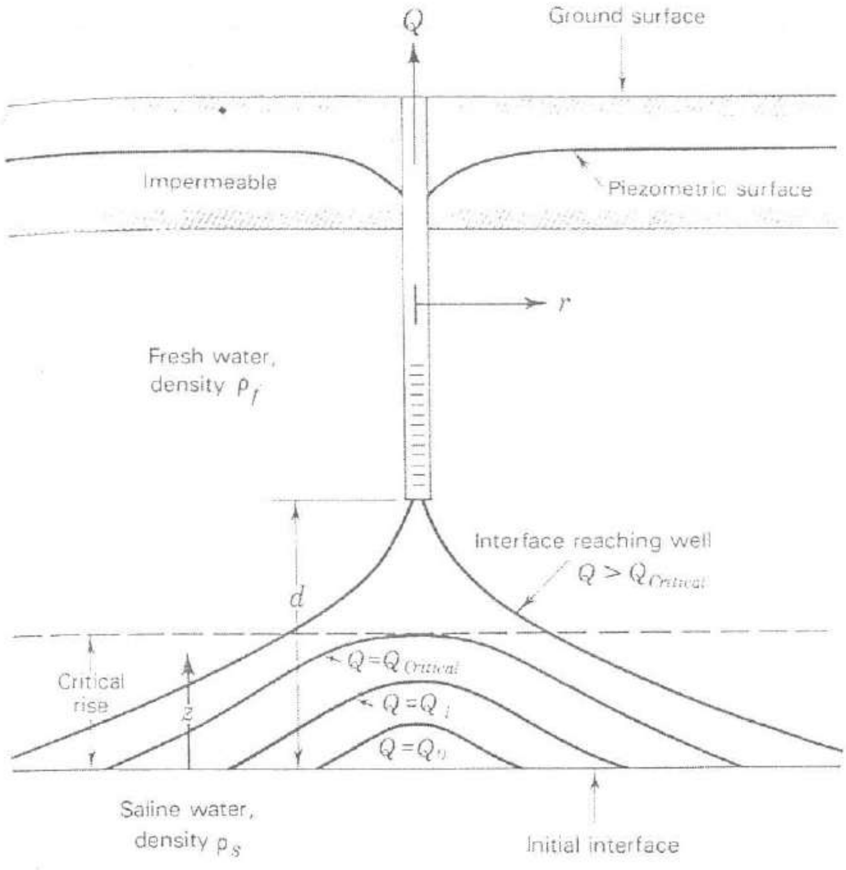


Fig 2.3 Upconing of underlying saline water to a pumping well (modified from Schmorak and Mercado, 1969)

2.3 ESTIMATION OF THE AQUIFER PARAMETERS

Exploration possibility of groundwater resources of an area depends largely on the aquifer characteristics, eg, transmissivity, hydraulic conductivity and storage coefficient. Long duration pumping test is needed in order to estimate these parameters. Pumping test is an expensive process and long duration pump test is rarely carried out. Surface geoelectric measurements provide an alternative approach to estimate some of the aquifer properties.

Several investigators have tried to establish a linear relationship between hydraulic transmisssivity and transverse electrical resistance (Kelly, 1977; Kosinski and Kelly, 1981; Niwas and Singhal, 1981, 1985; Singhal et al., 1998 and Yadav and Abolfazli, 1998). Heigold et al. (1979), however, found an inverse relationship between aquifer resistivity and hydraulic conductivity for sites located in glacial outwash sediments. A total of 42 vertical electrical sounding (VES) were conducted using Schlumberger electrode arrangement with a maximum spread of 250m to 300m in the study area (87°17′30″E, 22°22′N to 87°21′E, 22°24′30″N) which is a part of the Kasai river basin and covers an area of about $35km^2$. The VES curves are interpreted by Evolutionary programming (EP) approach (Shahid et al., 1999).

From the derivations and discussions made in this paper it is obvious that transmissivity of an aquifer can be calculated from a knowledge of transverse resistance obtained through surface geoelectric measurements. Transmissivity can also be computed from knowledge of resistivity formation factor calculated from the surface geoelectric measurements.

Barr (2000) proposed a method for obtaining the permeability of soil from measurable characteristics of soil. It also permits calculating flow of either liquids or gases through porous media. The method is built on the presentations of Kozeny and Carman (Barr, 2000), but there has been little practical application of the Kozeny /Carman studies, probably because of the difficulty of determining the surface area of the usual porous media. A method for estimating the surface area is proposed in their work.

2.4 ASSESSMENT OF SALTWATER INTRUSION

The present study deals with the adoption of an index to assess the level of threat to the population due to groundwater salinization and to map the vulnerability of the aquifer to saltwater intrusion. The method is a weightage driven approach to assess the vulnerability of coastal aquifers using hydro-geological parameters. It has the advantage of, in principle, eliminating or minimizing subjectivity in the ranking process. The relevant literature concerned with this approach is cited in this chapter.

Salinity is a common problem in Greek islands, especially, during the summer period when the saltwater intrusion becomes more severe due to extensive over pumping (Papadopoulou et al., 2005). In this paper, scenarios that suggest artificial recharge of fresh water are presented in order to control the saltwater intrusion by raising the groundwater level and creating a hydraulic gradient towards the sea.

Sustained pumping from the upper Floridian aquifer in the coastal area of Georgia and adjacent low county of South Carolina has resulted in substantial reductions in artesian pressure in the aquifer, which has led to in saltwater intrusion at two locations in the area (Krause and Clarke, 2001).Understanding the conditions under which these types of intrusion occur is of importance to managing the water resources of the coastal area.

Chachadi et al., (2005) have introduced a new method of aquifer vulnerability mapping due to sea water intrusion, *i.e.*GALDIT method .It has been successfully used (Chachadi and Ferreira, 2001) to assess the impact of sea-level rise on the aquifer contamination due to sea water intrusion along the coast of north Goa. The GALDIT scores at each of the 56 groundwater monitoring wells were computed for the Goa study area in Bardez taluk for normal existing sea level and the 0.5 m rise in the sea level. These GALDIT values were used in the SURFER package to draw the vulnerability contour maps. It is seen from these maps that if the sea level rises by 0.5 m from the present level, there will be significant increase in the extent of saltwater intrusion area, particularly along the river creeks of Anjuna, Baga, Chapora and Nerul.

Ferreira et. al, (2005) reported the first application of GALDIT index in Europe in the framework of the EU-India INCO-DEV COASTIN project aiming the assessment of aquifer vulnerability to sea-water intrusion in coastal aquifers. The application of the method is exemplified in the paper for the assessment of aquifer vulnerability to saltwater intrusion in Monte Gordo aquifer of the Portuguese southern Algarve region.

It is found from the studies (Agarwadkar, 2005) that groundwater salinity in the western Gujarat has increased considerably in the last two decades. The drinking water with high chloride content (more than 250 mg / lit) was observed in 55% of the villages in the year 2003 as compared to 38 % in year 1983 and 48 % in 1993. The results also revealed that the satellite images are useful in demarcating the salt affected areas. The study indicated that use of indices and their stacked product with satellite images gives better results for demarcation of salt affected areas. The results from the GALDIT method show that the area under the vulnerability classes "high" and "moderate" have increased considerably in the last two decades.

Hydrogeological conditions and human activities in the vicinity of coasts have significant influence on groundwater quality and supplies. The expansion of agricultural and cattle raising in the central-western Sardinia (Barrocu et al,2006) has caused two major problems, one associated with aquifer pollution caused by fertilizers and animal waste and the other with the salination by saltwater intrusion as the result of groundwater overexploitation by the wells. The vulnerability of the area to saltwater intrusion was assessed on the basis of the GALDIT Index in association with the GIS tools.

An attempt was made by Marella (1999) to understand the saltwater intrusion in coastal aquifer of Oropesa, Spain using hydrochemical analyses of certain minor ions that could help in the characterization process. The coastal aquifer of Oropesa is affected by salinization processes undoubtedly associated with intense groundwater exploitation for agriculture supply. Contact with the sea, in addition to the presence of cultivated soil requiring extreme exploitation of groundwater, the region experiences saltwater intrusion.

The maximum values of Cl^- percentages are found in the coastal zone and especially in the marshland .The percentages of Cl^- and HCO_3^- in this zone are around 30%. The multi-parametric study involving major and minor ions and their comparison with the physicochemical data corresponding to the saltwater–fresh-water mixing, provided useful information on the hydro-chemical features of the aquifer.

A groundwater quality survey has been carried out (Subba Rao et al., 2005) to assess such phenomena along the coast of Visakhapatnam, Andhra Pradesh, India. The brackish groundwater is observed in most of the wells. The rest of the wells show a fresh water environment. The factors responsible for the brackish groundwater quality with respect to the influence of saltwater are assessed using the standard ionic ratios, such as Ca^{+2}:Mg^{+2} and Cl^-:HCO_3^-. Results suggest that the brackish nature in most of the groundwater is not due to the saltwater influence but is caused by the hydro-geochemical processes

Since the investigated area is close to the coast the ratios of Ca^{+2}:Mg^{+2} and Cl^-:HCO_3^- are used to distinguish the factors responsible for the variation of groundwater quality with respect to the influence of saltwater as suggested by Revelle (1941) and Hem (1970).

The samples collected from the southern part as well as from the central part have the Cl^- : HCO^-_3 ratio more than unity. This result infers that the aquifer water is contaminated with saltwater, as Cl^-, the most abundant ion in saltwater, occurs normally in small amounts in groundwater, and HCO^-_3, the most dominant ion in groundwater, occurs generally in small amounts in saltwater.

Because of the conservative nature of Cl, it can be used as an indicator of salinity, which influences groundwater quality in an area. Where no other source of saline contamination exists, higher concentration of Cl in groundwater can be considered as definite proof of salt-water contamination.

2.5 RECENT INVESTIGATIONS ON SALTWATER INTRUSION

Salinity is a common problem in Greek islands, especially, during the summer period when the saltwater intrusion becomes more severe due to extensive over pumping Papadopoulou et al., (2005). In the past few years, the industrial zone of the city of Herakleio in Crete appears to have an increasing water demand as result of the continuous industrial development. The water demand is to be mainly covered from groundwater resources. The karstić nature of the geological formations beneath the industrial zone has a great impact in the overall hydro-geological characterization of the aquifer. Also the expansion of the saltwater front into the aquifer is hard to be determined due to the presence of innumerable cracks, which act as closed conduits of saltwater and the density variation between the saltwater and the fresh water. The industrial zone lies on a karstified limestone with several faults that need to be delineated. Mapping of the area also revealed specific places that were recommended for observation wells. In the future, these wells are planned to be used as injection wells for the restoration of the aquifer. In this paper, scenarios that suggest artificial recharge of fresh water are presented in order to raise the groundwater level and to create a groundwater flow towards the sea.

A conceptual model based on the sharp interface assumption was considered to estimate the change in the freshwater-saltwater interface data in the coastal aquifer in lower part of the Walawe river basin, Sri Lanka Ranjan et al., (2004). The model was used to evaluate the effect of geo-hydrological factors affecting the dynamics of freshwater- saltwater interface. The effect of storage coefficient, porosity and the hydraulic conductivity was mainly evaluated. Since the storage coefficient and the porosity are not much affecting the change of interface, the model was calibrated by adjusting the hydraulic conductivity to match the observed values. The simulation has been carried out for a range of recharge values. The results show that the saltwater intrusion is far more sensitive to recharge than aquifer properties.

Sustained pumping from the upper Floridian aquifer in the coastal area of Georgia and adjacent low country of South Carolina has resulted in substantial reductions in artesian pressure in the aquifer, which has resulted in saltwater intrusion at two locations in the area Krause and Clarke (2001). At Brunswick, Georgia, brine from deeply buried paleokarst zones has intruded the aquifer by migrating upward through solution-enlarged breaks in the confining units. At the northern end of Hilton Head Island, South Carolina, lateral encroachment of saltwater has occurred. Understanding the conditions under which these types of intrusion occur is of importance to managing the water resources of the coastal area.

Das and Datta (2001) present some typical example simulation of 3-D saltwater intrusion process for a specified hypothetical study area. A non-linear optimization based simulation methodology was used in this study. The simulations demonstrate the viability of using a planned strategy of spatially varying withdrawals from the aquifer to manage saltwater. It is demonstrated that series of pumps near the ocean-face boundary induce a hydraulic head distribution that can be effectively used for controlling saltwater intrusion.

Nile Delta aquifer in Egypt is among the largest groundwater reservoirs in the world. The aquifer is subjected to a severe saltwater intrusion problem from the Mediterranean Sea mainly due to its geometric and geological conditions, limited natural recharge and over exploitation of the aquifer. Sherif (1999) presents the saltwater intrusion mechanisms through various numerical simulations for the saltwater intrusion in the vertical and areal views. Several scenarios for ground-water pumping and land use with specific reference to rice cultivation are presented. The study comes out with recommendations for the mitigation of the saltwater intrusion problem in the Nile Delta aquifer.

The movement of saltwater front in coastal aquifers, including the effect of dispersion, can be determined by using numerical methods Pinder and Cooper, Jr. (1970). The method of characteristics is used to solve the solute transport equation, and the alternating direction iterative procedure is used to solve the groundwater flow equation for the two dimensional problem. This approach permits the treatment of transient flow in non-homogeneous aquifers with irregular geometry.

Currently, several solute transport models are commercially available for the simulation of saltwater intrusion. The development and management of fresh groundwater resources in coastal aquifers are seriously constrained by the saltwater intrusion. Under utilization of the available groundwater resource means that valuable fresh water discharges naturally to the sea and is wasted; over- development, on the other hand, mines the resource and will cause a gradual degradation of water quality due to the encroachment of saltwater. Over the years, many models have been developed to represent and study the problem of saltwater intrusion. They range from relatively simple analytical solutions to complex numerical models. Ernakulam is one of the important ports in west coast of India. Due to increase in population, fast urbanisation and land reforms, the district is facing a number of environment problems such as flooding, groundwater pollution due to discharge of industrial effluents, saltwater intrusion etc. There exists an urgent need to study systematically the causes and remedial measures for saltwater intrusion. Bhosale and Kumar (2001) present the simulation of saltwater intrusion in a section of Ernakulam coast through Saturated-Unsaturated TRAnsport (SUTRA) model and examine the impact of increased pumping scenarios on extent of saltwater intrusion.

A numerical model Paniconi et al.,(2001) CODESA-3D, a Coupled variable Density and Saturation 3D finite element model that treats density-dependent variably saturated flow and miscible salt transport was used Gambolati et al. (1999) to investigate the occurrence of saltwater intrusion in the Korba aquifer of the eastern coast of Cap-Bon in northern Tunisia. They examined the interplay between pumping regimes and recharge scenarios and its effect on the saline water distribution. More localized simulations are used to examine, in vertical cross sections, the effects of well location and soil type and the role of the vadose zone in possible remedition actions. The exploratory simulations suggest interesting interactions between the unsaturated zone and the saltwater freshwater interface with possible implications for groundwater exploitation from shallow unconfined coastal aquifers, involving in one case feedback between saltwater intrusion and the high pressure head gradients around the pumping-induced drawdown cone and in another case threshold-like interface displacement for tight soils such as clays. The simulation results support groundwater pumping as the mechanism for and saltwater intrusion as the origin of the salt contamination observed in the soils and subsurface waters of the Korba plain.

To characterize regional ground-water flow and localized encroachment of saltwater into groundwater, the U.S. Geological Survey, in cooperation with the Georgia Department of Natural Resources, is developing regional-scale ground-water flow and local-scale variable-density transport models for coastal Georgia, U.S.A., using MODFLOW2000 and SUTRA version 2D3D.1 Payne et l., (2000). The objectives of these models are to predict the effects of future changes in pumping on 1) the regional ground-water flow system; and 2) localized areas of known and potential saltwater intrusion. Three models are being developed: a regional-scale flow model, using MODFLOW and SUTRA in parallel; and two local-scales, variable-density transport models, both using SUTRA. The parallel development of the regional-scale model is facilitated by the use of a common GIS-based interface and is designed to take advantage of the strengths of the two simulation codes used. MODFLOW is a constant-density flow simulator that is widely used and offers integrated parameter estimation and sensitivity analysis tools that facilitate model calibration. SUTRA is capable of explicitly simulating the effects of variable fluid density, which control the position the saltwater-freshwater interface and local-scale saltwater intrusion. Accordingly, model calibration is performed primarily using the MODFLOW version of the model, while the SUTRA version is used to assess the effects of variable-density flow on the boundary conditions used in the MODFLOW version, particularly the condition used to represent the pre-development, offshore saltwater-freshwater interface. After the regional-scale model is developed and calibrated with sufficient consistency between the two versions, the SUTRA version will be modified by increasing grid density in the area of greatest concern for saltwater intrusion (in the areas of Savannah and Brunswick), and by decreasing grid density outside of this area. The results will be used to conveniently specify boundary conditions for the local-scale transport models.

Global warming could raise sea level by several tens of centimeters in the next fifty years, about one meter in the century, and several meters in the next few centuries by expanding ocean water, by melting glaciers, and by causing ice sheets to melt or slide into the ocean. Such a rise would inundate deltas, coral atoll islands, and other coastal lowlands, erode beaches, exacerbate coastal flooding and threaten water quality in estuaries and aquifers. Saltwater intrusion is a serious environmental problem to coastal subsurface water systems around the world due to climate change. In the development of subsurface water protection and rehabilitation strategies, mathematical models play an important role in coastal areas. A density dependent model (SUTRA) is applied to predict freshwater depth in coastal areas of islands. A case history from a small island, Agatti Island, in the Laccadive Islands of India, is used to illustrate the current modeling methodology and mechanisms of saltwater intrusion due to climate change Ghosh (1998).

A 3D model Faye et al., (1995) using finite element code FEFLOW was used to simulate groundwater and saltwater intrusion in the Dakar (Senegal) confined aquifer. The conceptual model was based on steady state flow and transient solute transport. Steady state flow was calibrated using water level in 1995. Solute transport was calibrated using the salinity observed in control wells near the coastal wedge of the aquifer. A comparison of the computed head and the salinity distribution with the control wells shows that the model was reasonable. Computed flow velocity and flow direction together with isotopic measurements reveal that salt water in the western coastal wedge does not seem to be controlled by dispersion.

CHAPTER 3
METHODOLOGY

3.1 GENERAL

Salt water intrusion becomes a problem in coastal areas where fresh water aquifers are hydraulically connected with saltwater. When large amounts of fresh water are withdrawn from these aquifers, hydraulic gradients encourage the flow of saltwater toward the pumped well or wells. Salt water intrusion is a problem that affects coastal areas around the world. It often results in the degradation of water quality within the aquifer and may ultimately require costly remedial measures. Development of a well-planned pumping strategy can arrest further degradation of the aquifer on water quality, remediate an already contaminated aquifer, and contain the contamination within a certain region of the aquifer. Mathematical modeling of saltwater intrusion plays a key role in the development of such optimal operating strategies. Ideally, these mathematical models should be capable of simulating 3-D saltwater intrusion cases. However, the mathematical models reported in the literature mostly consider two-dimensional cases. In order to develop any simulation or optimization model that necessarily seeks to optimally exploit a coastal aquifer, it is necessary to investigate the coastal aquifer responses to the possible stress scenarios.

3.2 AQUIFER CHARACTERIZATION

The groundwater investigations should necessarily involve in the assessment of the aquifer parameters and the properties of the fluid as well. These parameters in the study area are determined from the pumping tests, vertical electrical sounding (VES) and the soil tests.

3.2.1 Pumping Tests

The hydraulic properties of aquifers can be determined by the pumping test. It involves pumping of water from a well at a controlled rate and observation of water level at the observation well with respect to time. Pumping tests also provide information on the yield and drawdown of wells. The important hydraulic properties of aquifers are the hydraulic conductivity, transmissivity, coefficient of storage, specific yield, porosity and the specific capacity.

3.2.1.1Hydraulic conductivity (K)

The hydraulic conductivity, also known as the permeability is as measure of the ease with which fluid moves through a formation and is defined as the amount of flow per unit cross sectional area under the influence of an unit gradient. It has the dimensions of velocity and is usually expressed as m/day. The hydraulic conductivity depends upon the properties of the fluid as well as the aquifer.

3.2.1.2 Transmissivity (T)

Transmissivity is a hydraulic characteristic of the aquifer which is defined as the rate of flow of water at the prevailing field temperature under an unit hydraulic gradient through a vertical strip of aquifer of unit width and extending through the entire saturated thickness of the aquifer. It is therefore the product of the average hydraulic conductivity and the thickness of the aquifer. Transmissivity is usually expressed in m^2/day.

3.2.1.3 Coefficient of storage (S) and specific yield (S_y)

Each aquifer, whether under the water table or in a confined condition, has the capacity to store water which is expressed as a coefficient. The storage coefficient of an aquifer is defined as the volume of water it releases from or it takes into storage per unit surface area of the aquifer per unit change in the head. In the case of an unconfined aquifer, the concept of storage is analogous to that of specific yield. In confined aquifer, the storage coefficient depends on the compressibility of the aquifer and the expansion of water. Since the unconfined aquifer is not bounded by confining layers, the specific yield or storage coefficient does not depend upon the compressibility of either the aquifer or the fluid. The specific yield for all practical purposes is same as effective porosity or drainable porosity because in the unconfined aquifer the effects of elasticity of the aquifer material or fluid are generally negligible.

3.2.1.4 Specific capacity

It is a measure of both effectiveness of a well and of the aquifer characteristics. It is defined as the ratio of the pumping rate and the drawdown and is usually expressed in liters per minute per meter of drawdown for a specific period of pumping.

The pumping tests were carried out for four wells in the study area to estimate transmissivity and storage coefficient. These wells are fitted with 5 HP pump. Aquifer win32 software based on the Nueman (1972) method is used for pumping test data analysis.

3.2.1.5 Measurement of Discharge and Water Levels

The estimation of discharge of streams, canals and wells forms an integral part of pumping tests. Of the large number of methods available for flow measurements, only a few common, readily adoptable ones are described below.

The commonly used methods of discharge measurements are:

1. Velocity-area method
2. Tracer method
3. Measurements at hydraulic structures
4. Miscellaneous methods

In the miscellaneous methods are included the determination of small flow by using rectangular and V-notches, parshall flumes, orifices, meter gates, discharge pipes and volumetric measurements. These methods are commonly used in farm irrigation practice and groundwater exploitation.

Discharges of wells are usually measured at the well head. Where this is not possible, they can be measured some distance away after ensuring that water is not lost during transit. The methods commonly adopted consist of volumetric measurements by using containers or observing the head of water as it passes through a weir plate or pipe.

Small discharge rates may be measured accurately by noting, with a stop watch, the time required to fill a collecting tank of known volume. The discharge rate Q is

$$Q\ (m^3/sec) = \frac{\text{Volume of container } (m^3)}{\text{Time to fill container (seconds)}} \tag{3.1}$$

A fairly accurate determination of flow from full open horizontal or inclined pipes can be made by measuring the distance, parallel to the pipe, traveled by the trajectory of water Fig. 3.3 for a vertical fall of 30cm, and using the value in conjunction with that of the diameter of the pipe in the formula.

Fig. 3.1 Measurements for determining Discharge: (a) horizontal; and (b) inclined pipe

$$Q = 0.017CP \tag{3.2}$$

Where, Q= flow of water, in m^3/s

C=constant, to be determined from graph (Fig. A)

P= distance traveled by the stream, in m, measured parallel to the pipe for a 30cm vertical drop.

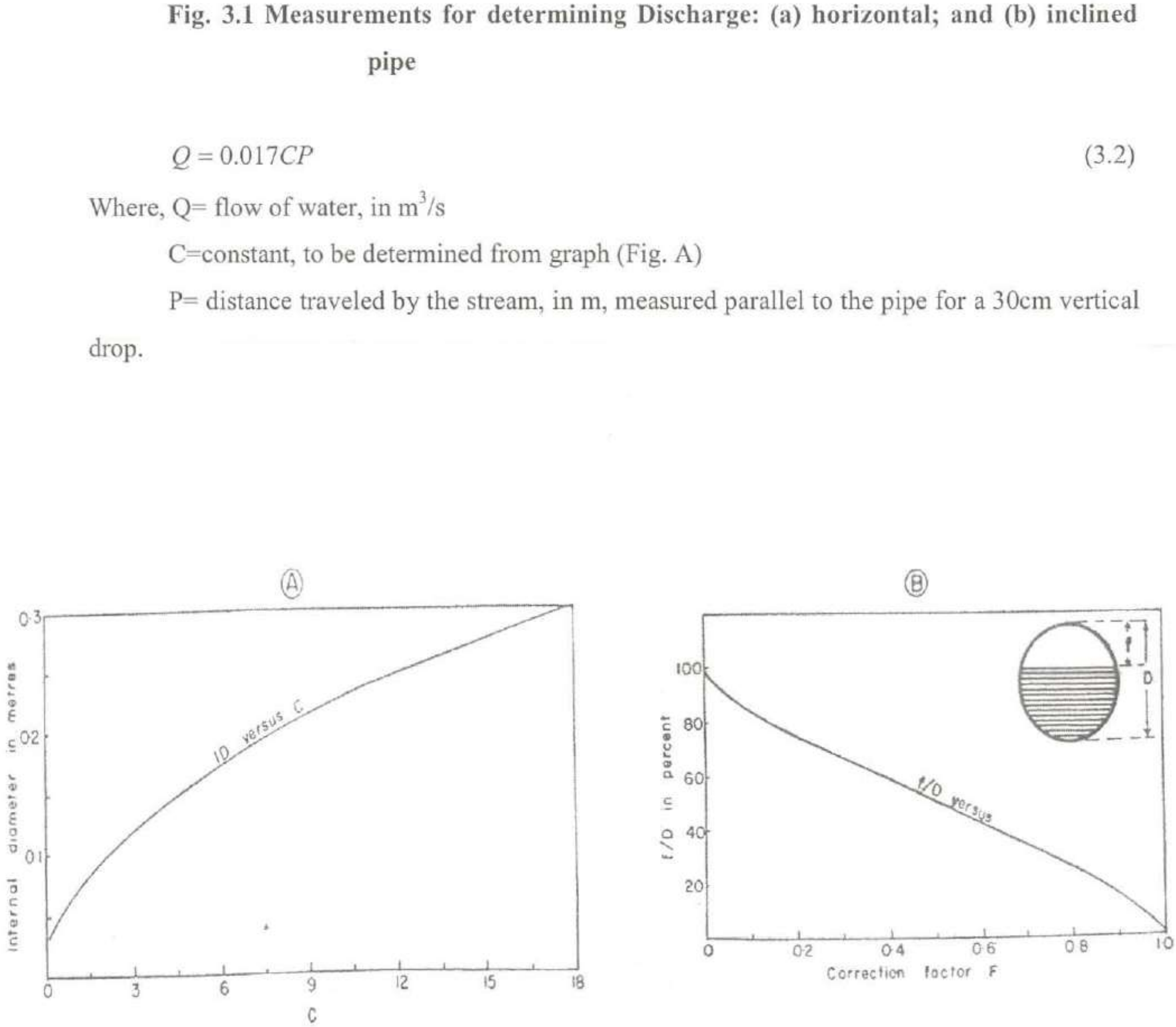


Fig. 3.2 Curves for determining C and F for estimation of flow through inclined and horizontal pipes.

When the pipes are only partially filled, the freeboard (f) and internal diameter (D) are measured and the ratio f/D calculated, as a percentage. The discharge is calculated as in the method for full pipes and a correction factor, to be read from the curve in Fig. B is applied to obtain the appropriate discharge.

Prosonic flow 32 Portable ultrasonic flow measuring system consists of prosonic flow 92 transmitter and prosonic flow W, P and prosonic flow U sensors. It is used for measuring the flow of fluids in closed pipes. In addition to the flow volume of flow, the system measures the sound velocity in the fluid. The sound velocity can be used to distinguish different fluids or as a measure of fluid quality.

For the present study discharge measurements were carried out using V-notch, collecting tank, inclined pipe, ultrasonic flow meter methods. Among these ultrasonic flow meter was found to give a reliable value close to the pumping capacity.

3.2.1.6 Analysis of pumping tests

A frequently used method for estimating hydraulic properties is graphical type-curve analysis of aquifer tests, in which dimensionless type curves derived from an assumed analytical model of ground-water flow to a pumped well are used to analyze time-drawdown measurements of hydraulic head in observation wells and piezometers. These analyses are done to estimate the hydraulic conductivity and specific yield of water-table (unconfined) aquifers. Fig. 3.3 shows two-dimensional, axial-symmetric flow in a water-table aquifer with a partially penetrating pumped well, where z_{pd}, z_{pl}, depth below initial water table to the top and bottom, respectively, of the screened interval of the pumped well; z_1, z_2, depth below initial water table to the top and bottom, respectively, of the screened interval of the observation well; z_p, depth below initial water table to center of piezometer.

When the water table is lowered, the saturated thickness of the aquifer is reduced, this reduction in thickness contrasts with the response of a confined aquifer in which the thickness of the aquifer remains constant during pumping. Furthermore, as the water table is lowered by pumping, water drains from pores at the water table and from the overlying unsaturated zone and flows vertically into the aquifer. The specific yield (S_y) of a water-table aquifer is defined as the volume of pore water that is released from storage per unit surface area of aquifer per unit decline in the water table, Freeze and Cherry (1979). Specific yields of water-table aquifers are much larger than the storativities of confined aquifers because specific yields reflect an actual drainage of the pores in the zone above the water table. In a confined aquifer, on the other hand, water is released from storage only by compression of the aquifer matrix and expansion of the water. A characteristic feature of the drawdown curve that is frequently seen in log-log plots for the water-table aquifer is the inflection in the curve during the intermediate time (between about 1 to 3,000 seconds after the start of pumping in Fig. 3.4). This inflection is caused by vertical drainage from the zone above the water table, which slows the drawdown response in the aquifer. Following the inflection there is an apparent (due to log-scale compression of time) increase in the rate of drawdown as the drainage from the zone above the water table keeps pace with the decline in the free surface and "the time-drawdown curve merges with the Theis non-equilibrium curve associated with the coefficient of storage for water-table conditions" i.e. specific yield Boulton (1963).

Two conceptual approaches have been used to analytically model the release of water from the zone above the water table. In the first approach, developed primarily by Boulton (1954, 1963), drainage from the zone above the water table is assumed to occur gradually in a manner that varies exponentially with time in response to a unit decline in the elevation of the water table. As part of his mathematical treatment of the problem, Boulton introduced an empirical drainage constant. In the second approach, developed by Neuman (1972, 1974), water is assumed to be released instantaneously from the zone above the water table in response to lowering of the water table. Neuman (1974) justified this assumption, in part, based upon numerical models that appeared to show that effects of flow from the unsaturated zone upon drawdown in the saturated zone were negligible.

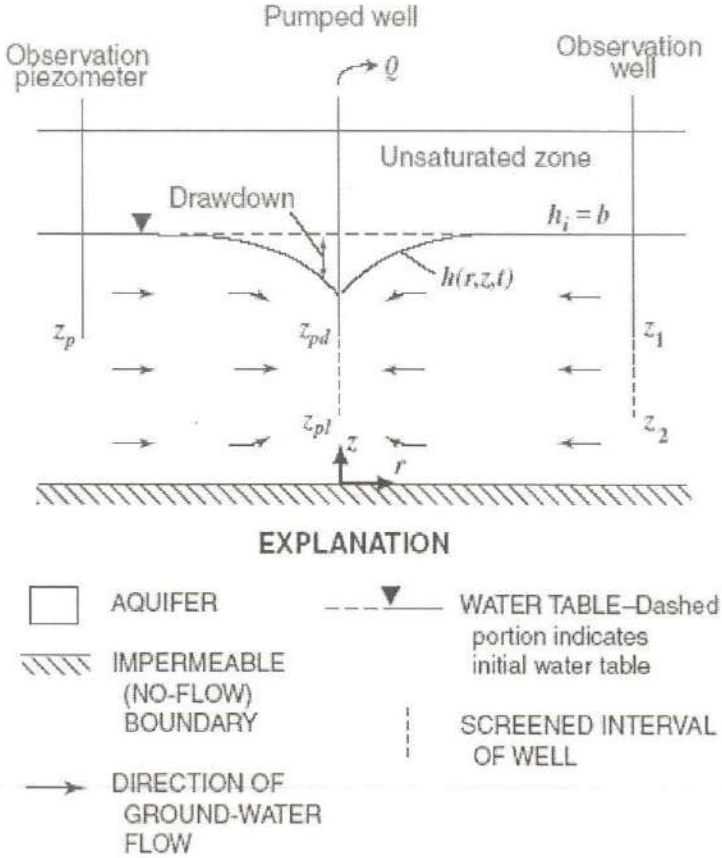


Fig. 3.3 Two-dimensional, axial-symmetric flow in a water-table aquifer with a partially penetrating pumped well

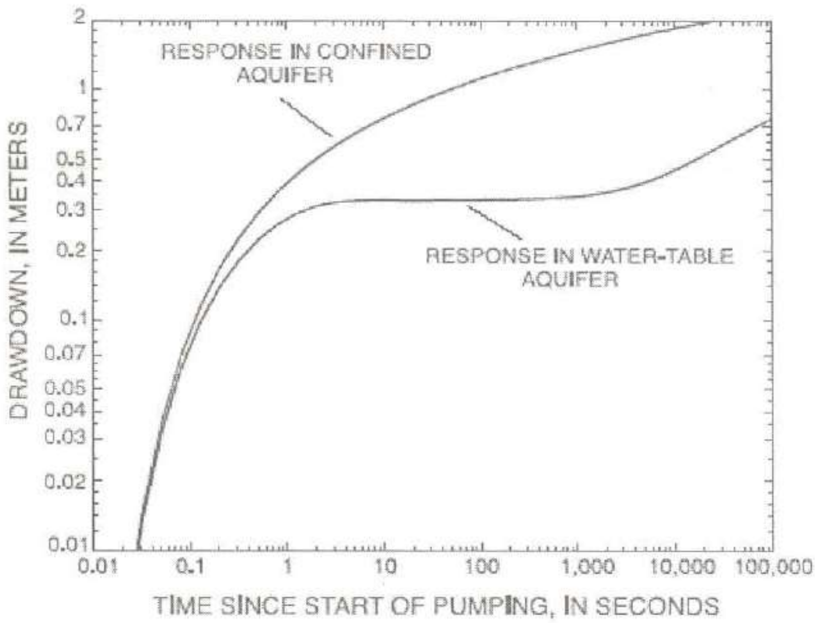


Fig. 3.4 Drawdown at a fully penetrating pumped well in hypothetical confined and water -table aquifers

When the pumping well and the observation well are perforated throughout the entire saturated thickness of the aquifer, the drawdown in the observation well is given by Neuman, 1974,

$$s(r,t)=\frac{Q}{4\pi T}\int_0^\infty 4yJ_0\left(y\beta^{1/2}\right)\left[u_0(y)+\sum_{n=1}^{\infty}u_n(y)\right]dy \tag{3.3}$$

where,

$$u_0(y)=\frac{\left\{1-\exp\left[-t_s\beta\left(y^2-\gamma_0^2\right)\right]\right\}\tanh\left(\gamma_0\right)}{\left\{y^2+(1+\sigma)\gamma_0^2-\left[\left(y^2-\gamma_0^2\right)^2/\sigma\right]\right\}\gamma_0} \tag{3.4}$$

$$u_n(y)=\frac{\left\{1-\exp\left[-t_n\beta\left(y^2+\gamma_n^2\right)\right]\right\}\tanh\left(\gamma_n\right)}{\left\{y^2-(1+\sigma)\gamma_n^2-\left[\left(y^2+\gamma_n^2\right)^2/\sigma\right]\right\}\gamma_n} \tag{3.5}$$

and the terms γ_0 and γ_n are the roots of the equations

$$\begin{aligned}&\sigma\gamma_0\sinh\left(\gamma_0\right)-\left(y^2-\gamma_0^2\right)\cosh\left(\gamma_0\right)=0\\&\gamma_0^2<y^2\end{aligned} \tag{3.6}$$

$$\begin{aligned}&\sigma\gamma_n\sin(\gamma_n)+\left(y^2+\gamma_n^2\right)\cos(\gamma_n)=0\\&(2n-1)(\pi/2)<\gamma_n<n\pi \qquad n\geq 1\end{aligned} \tag{3.7}$$

Equation (3.3) is expressed in terms of three independent dimensionless parameters σ, β *and* t_s *or* t_y , where the dimensionless time parameters are related to each other by $t_y = \sigma t_s$. The curves lying to the left of the values of β in Fig. 3.5 are called type A curves and correspond to the top scale expressed in terms of t_s. The curves lying to the right of the values of β in Fig are called type B curves and correspond to the bottom scale expressed in terms of t_y. The Theis curves with respect to both dimensionless time parameters t_s and t_y have been included in the figure for reference purposes. Type A curves are intended for use with early drawdown data and type B curves with late drawdown data.

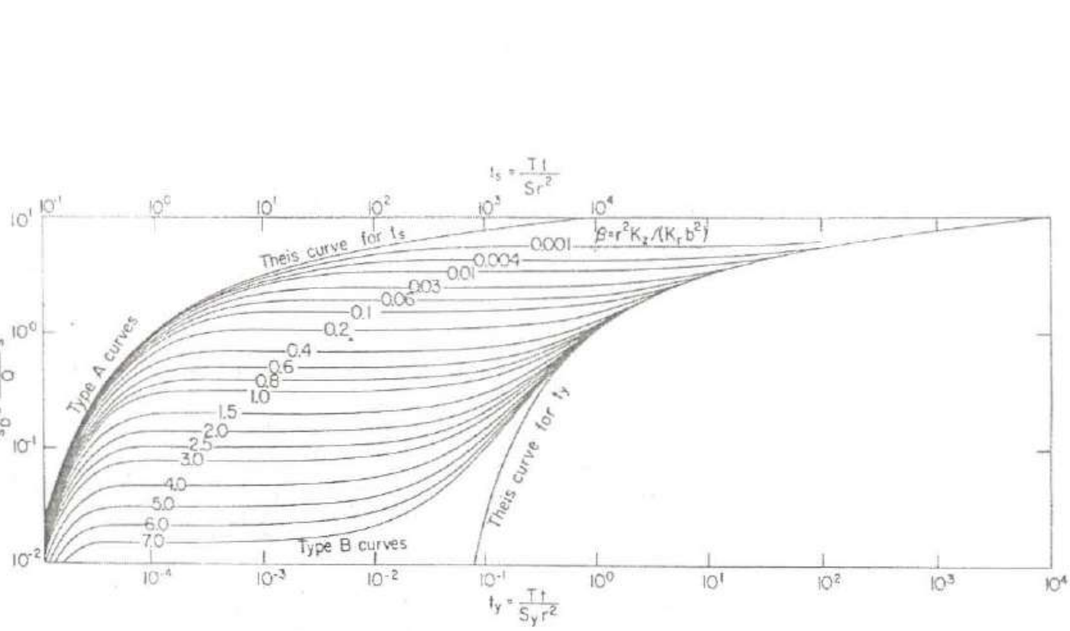


Fig. 3.5 Type curves for fully penetrating wells

The field data, plotted on a logarithmic paper (drawdown s versus time t) is superimposed on the type B curves, keeping the vertical and the horizontal axes of both graphs parallel to each other and matching as much of the latest time-drawdown data to a particular type curve .The value of β corresponding to this type curve is noted, and a match point is chosen anywhere on the overlapping portion of the two sheets of paper. The coordinates of this match point are s* and s_d* along the vertical axis and t* and t_y* along the horizontal axis. Hence, transmissivity

$$T = c_1(Qs_d^* / s^*) \tag{3.8}$$

and the specific yield

$$S_y = c_2(Tt^* / r^2 t_y^*) \tag{3.9}$$

where c_1 and c_2 are constants depending on the units. If a consistent set of units such as cgs is used, $c_1 = 1/4\pi = 0.0796$, and $c_2 = 1.0$.

The transmissivity value is again calculated by superimposing the field data on the type A curve, and its value should be approximately equal to that calculated from the late drawdown data.

Applicability of Jacob's correction scheme

Equation (3.3) was derived by assuming that the decline of the water table remains small in comparison to the saturated thickness of the aquifer. For cases where this is not so, Jacob [1944] recommended that prior to analyzing the pumping test data the drawdown be corrected according to $s_c = s - \left(s^2 / 2b\right)$. This equation was derived by adopting the Dupit assumptions and in particular by assuming that the drawdowns along any vertical are always equal to the drawdown of the water table s_{wt}. The flux across a cylindrical surface of radius r centered around the pumping well is then given by Darcy's law as

$$
\begin{aligned}
q &= 2\pi r k_r (b - s_{wt}) \frac{\partial (b - s_{wt})}{\partial r} = \pi r K_r \frac{\partial (b - s^2)}{\partial r} \frac{2b}{2b} \\
&= -2\pi r b K_r \frac{\partial (s - s^2 / 2b)}{\partial r} = -2\pi r b K_r \frac{\partial s_e}{\partial r}
\end{aligned}
\quad (3.10)
$$

This shows that when the Dupit assumptions hold, the equations that govern radial flow in a confined aquifer are directly applicable to unconfined aquifers provided that s is replaced by s_c.

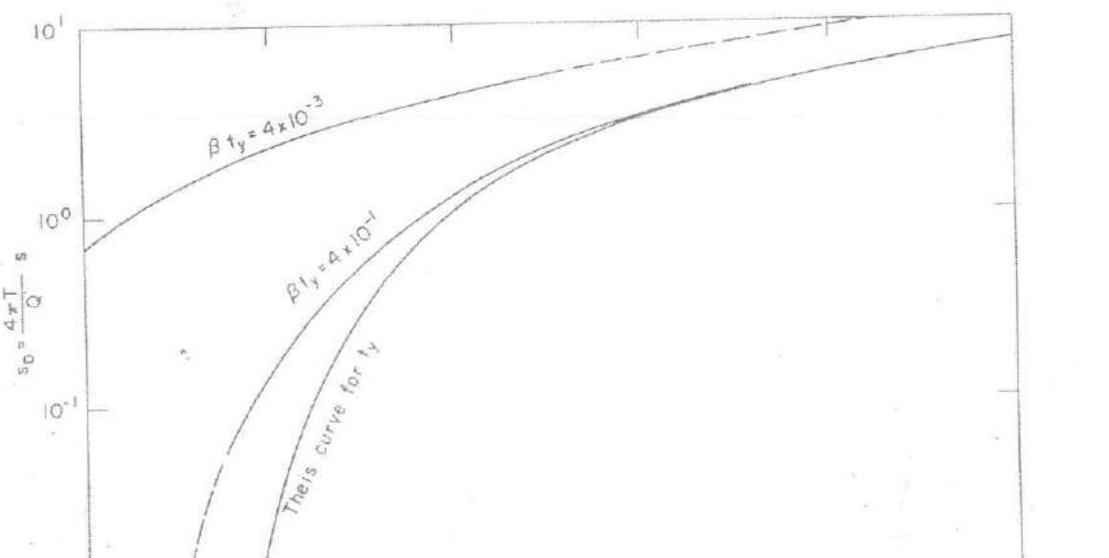


Fig. 3.6 Dimensionless distance-drawdown curves for fully penetrating wells at various values of βt_y=const.

From Fig. 3.5 of Neuman (1972) it is evident that the Dupuit assumptions do not hold in an unconfined aquifer with delayed gravity response as long as the drawdown data do not fall on the late Theis curve. This means that Jacob's correction scheme is strictly applicable only to the late drawdown data and is not applicable to the early and intermediate data. Fig. 3.6 shows two such distance-drawdown curves appears to be similar to that of the Theis curve but substantially different from the shape of the curves in Fig. 3.7 for $\beta t_y = 4x10^{-3}$ and $\beta t_y = 4x10^{-1}$. Thus concluded that one should be cautions in applying distance-drawdown analyses to pumping test data from unconfined aquifers even if these data appears to fall on the Theis curve.

3.2.2 Surface Geoelectric Measurements

The electrical resistivity method involves the measurement of the apparent resistivity of soils and rock as a function of depth or position. The resistivity of soils is a complicated function of porosity, permeability, ionic content of the pore fluids and clay mineralization. The most common electrical method used in hydro-geologic and environmental investigations is the vertical electrical soundings (VES) or resistivity soundings.

During the resistivity surveys, current is passed through a pair of current electrodes located at certain distance apart and the potential difference is measured between a pair of potential electrodes. The current and the potential electrodes are generally arranged in a linear array. Common arrays include the dipole-dipole array, pole-pole array, Schlumberger array and the Wenner array. The apparent resistivity is the bulk average resisitivity of all the soils and rock influencing the current. It is calculated by dividing the measured potential difference by the input current and multiplying by a geometric factor specific to the array being used and electrode spacing.

In a resistivity sounding, the distance between the current electrodes and the potential electrodes is systematically increased, thereby yielding information on subsurface resistivity from successively greater depths. The *apparent resistivity* values (in ohmmeters) are calculated based on VES (vertical electrical sounding) geo-electrical studies using Schlumberger's electrode configuration. The instrument used is *Aquameter CRM 50*, a microprocessor based resistivity meter, designed and manufactured by Anvic Systems,Pune.

A total of 22 vertical electrical soundings are carried out using the Schlumberger electrode arrangement in the study area. The detailed apparent resistivity data for the study area is given in the next chapter.

From the VES data, the aquifer transmissivity is calculated using the following relationship (Nath et al,2000)

$$T=834.4+0.8795T' \qquad (3.11)$$

where T′ = Transverse unit resistance in $\Omega\text{-}m^2$

In hydrogeological investigations, transverse unit resistance has been found to be functionally analogous to hydraulic transmissivity.

3.2.3 Hydraulic Conductivity from Soil Parameters

The coefficient of permeability of a porous media can be determined from the following measurable parameters: the density and viscosity of the permeating fluid, the porosity of the media, the average hydraulic radius of the pores, and the gravitation constant. The hydraulic radius is calculated from the grain size distribution analysis of the porous media assuming spherical particles and a factor to account for the shape of the particles. The shape factor ranges from 1.0 to 1.4 in the extreme but, for common porous media, ranges only from 1.0 to about 1.1. All of the variable except the shape factor; are measurable by the standard test procedures. An important advantage of using this procedure for determining permeability is that the factors can be visualized as part of the physical flow process. The procedure assumes laminar flow and applies equally to liquid or gas fluids.

The equation based on the soil parameters (Barr-2000) for the determination of the hydraulic conductivity K is:

$$K = \rho_w g \alpha m^2 / 5\mu \quad (3.12)$$

where ρ_w - Density of fluid (for water = 9774 N/m^3)

g - Acceleration due to gravity(9.81 m/sec^2)

α - Porosity

μ - Dynamic viscosity of water (0.00086 N-Sec/m^2)

m - Hydraulic mean radius

= Porosity / Surface area

As seen in the equation (3.12), soil and fluid parameters are required for the calculation of hydraulic conductivity of soil. The soil samples are collected from 8 different locations in the study area and various tests are carried out to obtain the required soil parameters.

The basic physical properties of a soil are those required to define its physical state. For the purposes of engineering analysis and design, it is necessary to quantify the three constituent phases (solid, liquid and gas) and to be able to express relationships between them in numerical terms.

The porosity is calculated from the bulk density of the porous media and the specific gravity of the minerals which make up the grains of the material. The quantity referred to as densities provide a measure of the quantity of material related to the amount of space it occupies. The insitu bulk density of the porous media is the ratio of total mass (mass of soil solids + mass of water) to the total volume and is obtained from the traditional core cutter method as:

$$\rho = \frac{W_2 - W_1}{V} \tag{3.13}$$

where, W_1 is the empty weight of the core in grams, W_2 is the weight of the core with wet soil and V is the volume of the core.

The insitu dry density is the ratio of mass of soil solids to the total volume and is given by;

$$\rho_d = \frac{\rho}{1+\omega} \tag{3.14}$$

where, ω is the water content of the soil

The ratio of the mass of a given volume of a material to the mass of the same volume of water is termed as specific gravity. The specific gravity of fine grained soil is calculated using a 50ml specific gravity bottle.

The specific gravity at room temperature, $$G_s = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)} \tag{3.15}$$

where, W_1 = Empty weight of the specific gravity bottle

W_2 = Weight of the specific gravity bottle + soil solids

W_3 = Weight of the specific gravity bottle + soil solids + water

W_4 = Weight of the specific gravity bottle + water

The volume not occupied by soil solids is known as void volume, it may be occupied by either water or air, or by a mixture of these. It is given by ratio of volume of voids to the volume of solids. Another way of expressing the quantity of voids is to relate the void volume to the total volume and it is termed as porosity.

Therefore porosity is given by;

$$\alpha = \frac{e}{1+e} \qquad (3.16)$$

where e is the void ratio given by;

$$e = \frac{G_s \times \rho_w}{\rho_d} - 1 \qquad (3.17)$$

where ρ_w is the density of fluid (for water = 9774 N/m^3)

The hydraulic radius, m, is equal to porosity divided by surface area. Thus it is the surface area, S, which must be determined in order to complete the calculation of the coefficient of permeability, K.

3.2.4 Determining the surface area

The surface area can be calculated from the sieve analysis of the soil also known as grain size distribution analysis or mechanical analysis. The sieve analysis consists of a breakdown of the unconsolidated sample into its various sizes. The soil sample to be analyzed is first air dried. Soil aggregations are then broken by pulverization with a wooden mallet. A representative sample, about 1 kg by weight, is taken for analysis. This sample is passed through the Indian standard sieves of diameter 4.75mm, 2.36mm, 1.18mm, 600 μ, 300 μ, 150 μ, 75 μ and pan. And the grain size is determined by the openings of a given size through which the grains have passed.

It is assumed that the grains are spherical so that the volume and the surface area of each spherical grain can be calculated. The sieve analysis can be divided into increments of sample weight and a grain size selected to represent each increment of sample weight, and its corresponding representative grain size, the volume of each grain will be $4\pi r^3/3$, where r is the radius of the sphere representing each grain.

The mass of the grain is given by $\rho \times 4\pi \frac{r^3}{3}$ (3.18)

where ρ is the density of the granular material.

The number of grains per unit volume of solid material will be

$$n = \frac{\rho}{\frac{4}{3}\pi\rho r^3} = \frac{3}{4\pi r^3} \quad (3.19)$$

The surface area of each such grain will be $4\pi r^2$. The surface of all the grains within that increment will be the area of each grain times the number of grains

$$S_0 = 4\pi r^2 \times n = 4\pi r^2 \times \frac{3}{4\pi r^3} = \frac{3}{r} \quad (3.20)$$

where S_O represents the surface area per unit mass of solid material in that increment.

Since the increments selected for the sieve analysis will represent known portions of a unit weight of sample, the surface area of each portion of the sample will be calculated and then the surface area of each increment is summed up to yield the surface area of unit mass of the sample. In a porous medium, the solid within the bulk volume is represented by $(1-\alpha)$, and the surface area (m^2) is given by

$$S = \frac{3}{r}\ \frac{\text{unit area surface}}{\text{unit volume solid}} \times \frac{(1-\alpha)\ \text{unit volume solid}}{\text{unit volume bulk}} = \frac{3(1-\alpha)}{r}\ \frac{\text{unit area surface}}{\text{unit volume bulk}}$$

3.3 MATHEMATICAL MODELING – SUTRA

The use of field surveys, such as geophysical and geochemical studies, can reveal the present state of saltwater intrusion, and perhaps some insight into its history. It however, cannot make prediction into the future, and particularly cannot be used for the scenario building and impact assessment based on different levels of anthropogenic activities. Mathematical models are needed for these purposes.

In the present study, SUTRA (Saturated –Unsaturated Transport) Voss and Provost (2002), which is a computer program that simulates fluid movement and the transport of either energy or dissolved substance in a subsurface environment have been used. This upgraded version of SUTRA Voss and Provost (2002) adds the capability for three-dimensional (3D) simulation to the former code VOSS (1984), which allowed only two-dimensional (2D) simulation. The code employs a 2D or 3D finite-element and finite-difference method to approximate the governing equations that describe the two interdependent processes that are simulated.

1) Fluid-density-dependent saturated or unsaturated ground-water flow; and either
2) (a) transport of a solute in the groundwater, in which the solute may be subject to equilibrium adsorption on the porous matrix, and both first-order and zero – order production or decay; or

   (b) transport of thermal energy in the groundwater and solid matrix of the aquifer.

SUTRA provides fluid pressures and either solute concentrations or temperatures, as they vary with time, everywhere in the simulated subsurface system.

3.4 SUTRA PROCESSES Voss and Provost (2002)

3.4.1 Properties of fluid within the solid matrix

The total volume of a porous medium is composed of a matrix of solid grains typically of solid earth materials, and of void space, which includes the entire remaining volume that the solid does not fill. The volume of void space may be fully or partly filled with gas or liquid, and is commonly referred to as the pore volume. Porosity is defined as a volume of voids in the soil matrix per total volume of voids plus matrix.

3.4.2 Saturated-unsaturated groundwater flow

Fluid movement in porous media where fluid density varies spatially may be driven by differences either in fluid pressure or by unstable variations in fluid density. Pressure-driven flows, for example, are directed from regions of higher than hydrostatic fluid pressure toward regions of lower than hydrostatic pressure. Density-driven flows occur when gravity forces act on denser regions of fluid causing them to flow downward relative to fluid regions that are less dense. A stable density configuration drives no flow, and is one in which fluid density remains constant or increases with depth.

3.4.3 Solute transport in groundwater

3.4.3.1 Subsurface solute-transport mechanisms

Solute mass is transported through the porous medium by flow of groundwater (solute advection) and by molecular or ionic diffusion, which while small on a field scale, carries solute mass from areas of high to low concentrations. The actual flow velocities of the groundwater from point to point in 3D space of an aquifer may vary considerably about an average velocity, v, which is calculated from Darcy's law. As the true, not-average, velocity field is usually too complex to measure in real systems, an additional transport mechanism approximating the effects of mixing of waters with different concentrations moving both faster and slower than the average velocity, v(x,y[,z],t), is hypothesized. This mechanism, called solute dispersion, is employed in SUTRA as the best currently available, though approximate, description of the mixing process. In the simple dispersion model employed, dispersion, in effect, significantly adds to the molecular diffusivity value of the fluid in particular directions dependent upon the direction of fluid flow. In other words, mixing due to the existence of nonuniform, non-average velocities in three dimensions about the average flow, v is conceptualized as a diffusion-like process with anisotropic diffusivities. The model has been shown, in fact, to describe transport well in purely homogeneous porous media with uniform one-dimensional flows. In heterogeneous field situations with nonuniform flows in, for example, irregular bedding or fractures, the model holds only at the predetermined scale at which dispersivities have been determined and it must be considered as a currently necessary approximation, and be very carefully applied when extrapolating to other scales of transport.

3.4.3.2 Solute and adsorbate mass balances

SUTRA solute-transport simulation accounts for a single species mass stored in fluid solution as well as solute and species mass stored as adsorbate on the surfaces of solid matrix grains. Solute concentration, C, and adsorbate concentration, Cs(x, y [, z], t) [Ms/MG], (where [Ms] denotes units of solute mass, and [MG] denotes units of solid grain mass), are related through equilibrium adsorption isotherms. The species mass stored in solution in a particular volume of solid matrix may change with time due to: ambient water with a different concentration flowing in, well water injected with a different concentration, changes in the total fluid mass in the block, solute diffusion or dispersion in or out of the volume, transfer of dissolved species to adsorbed species (or reverse), or a chemical or biological reaction causing solute production or decay. The species mass stored as adsorbate on the surface of solid grains in a particular block of solid matrix may change with time due to a gain of adsorbed species by transfer of solute from the fluid (or reverse), or a chemical or biological reaction causing adsorbate production or decay.

Simulation using SUTRA is in two or three spatial dimensions. A pseudo-3D quality is provided for 2D, in that the thickness of the 2D region in the third direction may vary from point to point. A 2D simulation may be done either in the areal plane or in a cross sectional view. The 2D spatial coordinate system may be either Cartesian (x, y) or radial-cylindrical (r, z). Areal simulation is usually physically unrealistic for variable-density fluid and for unsaturated flow problems. The 3D spatial coordinate system is Cartesian (x, y, and z). Ground-water flow is simulated through numerical solution of a fluid mass-balance equation. The ground-water system may be either saturated, or partly or completely unsaturated. Fluid density may be constant, or vary as a function of solute concentration or fluid temperature. SUTRA tracks the transport of either solute mass or energy in flowing groundwater through a unified equation, which represents the transport of either solute or energy. Solute transport is simulated through numerical solution of a solute mass-balance equation where solute concentration may affect fluid density. The single solute species may be transported conservatively, or it may undergo equilibrium sorption (through linear, Freundlich, or Langmuir isotherms). In addition, the solute may be produced or decay through first- or zero-order processes. Energy transport is simulated through numerical solution of an energy-balance equation. The solid grains of the aquifer matrix and fluid are locally assumed to have equal temperature, and fluid density and viscosity may be affected by the temperature. Most aquifer material, flow, and transport parameters may vary in value throughout the simulated region. Sources and boundary conditions of fluid, solute and energy may be specified to vary with time or may be constant. SUTRA dispersion processes include diffusion and two types of fluid velocity-dependent dispersion. The standard dispersion model for isotropic media assumes direction-independent values of longitudinal and transverse dispersivity. This process assumes that longitudinal and transverse dispersivities vary depending on the orientation of the flow direction relative to the principal axes of aquifer permeability.

3.5 PHYSICAL-MATHEMATICAL BASIS OF SUTRA SIMULATION

The physical mechanisms that drive thermal energy transport and solute transport in the subsurface environment are described by nearly identical mathematical expressions. SUTRA takes advantage of this similarity, and with a simple program structure provides for simulation of either energy or solute transport. In fact, SUTRA simulation combines two physical models, one to simulate the flow of groundwater, and the second to simulate the movement of either thermal energy or a single solute in the groundwater. SUTRA allows only the transport of either thermal energy or_a single solute to be modeled in a given simulation. Thus, when simulating energy transport, a constant value of solute concentration is assumed in the groundwater. When simulating solute transport, a constant ground-water temperature is assumed. When SUTRA simulation is carried out in two space dimensions, parameters vary only in these two directions (x, y). However, the region of space to be simulated may be defined as 3D, when the assumption is made that all SUTRA parameters and coefficients have a constant_value in the third space direction. A SUTRA simulation may be carried out over a region defined over two space coordinates (x,y) in which the thickness of the region measured in the third coordinate direction (z) varies depending on (x,y) position.

3.5.1 Governing equations

The model simulates saltwater movement by means of two partial differential equations:

$$\frac{\partial(\theta\rho)}{\partial t} = -\nabla(\theta\rho v) + Q_p + T \tag{3.21}$$

$$\frac{\partial(\theta\rho C)}{\partial t} = -\nabla(\theta\rho v C) + \nabla[\theta\rho(D_m I + D)\nabla C] + Q_p C^* \tag{3.22}$$

Where, θ = porosity, r = fluid density, Qp = fluid mass source, v = average fluid velocity,T = solute mass source; Dm = molecular diffusivity, I = the identity tensor, D = the dispersion tensor, C = the fluid solute mass fraction, C* = the solute mass fraction of fluid sources; t = time, and ∇ = a differential operator.

The first equation is written in terms of fluid pressure and is used to describe the flow of variable density fluid (mixture of freshwater and saltwater) in the aquifer. In this way the driving mechanism for flow is described by pressure differences as well as by density variations. In the second equation, the solute transport mechanism is formulated in terms of salt concentrations.

These equations are solved with the use of appropriate boundary conditions and initial conditions by following a specific numerical scheme for the distributions of pressure and concentrations throughout the aquifer. The numerical scheme is based on a hybridization of finite-element and integrated finite-difference methods used in the framework of a method of weighted residuals Voss (1984). The modeling analysis was accomplished in two steps

a) An areal model of groundwater flow was applied, and the head distribution in the region was calculated under steady state conditions (the most suitable boundary conditions and the physical parameters were determined during the steady state calibration runs), and

b) The results were input to a density dependent saltwater intrusion analysis. In these runs, an areal mesh was selected, and the position of the freshwater-saltwater interface was analyzed for steady state and transient conditions.

3.6 SUTRA NUMERICAL METHODS

SUTRA simulation is based on a hybridization of finite-element and integrated-finite-difference methods employed in the framework of a method of weighted residuals. The method is robust and accurate when employed with proper spatial and temporal discretization. Standard finite-element approximations are employed only for terms in the balance equations that describe fluxes of fluid mass, solute mass, and energy. All other nonflux terms are approximated with a finite-element mesh version of the integrated-finite-difference methods. The hybrid method is the simplest and most economical approach that preserves the mathematical elegance and geometric flexibility of finite-element simulation, while taking advantage of finite-difference efficiency.

SUTRA employs a special finite-element method for calculation of fluid velocities in variable density fluids. Fluid velocities, when calculated with standard finite-element methods for systems with variable fluid density, may display spurious numerically generated components within each element. These errors are due to fundamental numerical inconsistencies in spatial and temporal approximations for the pressure gradient and density-gravity terms, which are involved in velocity calculation. Spurious velocities can significantly add to the dispersion of solute or energy. This false dispersion makes accurate simulation of all systems impossible, except those with very low vertical concentration or temperature gradients, even when fine vertical spatial discretization is employed. Velocities as calculated in SUTRA, however, are based on a consistent spatial and temporal discretization Voss and Provost (2002). The consistently evaluated velocities allow stable and accurate transport simulation (even at steady state) for systems with large vertical gradients of concentration or temperature. An example of such a system that SUTRA successfully simulates is a cross sectional regional model of a coastal aquifer wherein the transition zone between horizontally flowing freshwater and deep stagnant saltwater is relatively narrow Voss and Souza (1987). The time discretization used in SUTRA is based on a backwards finite-difference approximation for the time derivatives in the balance equations. Some nonlinear coefficients are evaluated at the new time level of solution by projection, and others are evaluated at the previous time level for noniterative solutions. All coefficients are evaluated at the new time level for iterative solutions. The finite-element method used in SUTRA allows the simulation of irregular regions with irregular internal discretization in 2D and regular (logically rectangular) internal discretization in 3D. This is made possible through use of quadrilateral elements with four corner nodes in 2D and hexahedral elements with eight corner nodes in 3D. Coefficients and properties of the system may vary in value throughout the mesh.

SUTRA includes an optional numerical method, based on asymmetric finite-element weighting functions, that results in "upstream weighting" of advective transport and unsaturated fluid flux terms. Although upstream weighting has been employed to achieve stable, non-oscillatory solutions to transport problems and unsaturated flow problems, the method is not recommended for general use as it merely changes the physical system being simulated by increasing the magnitude of the dispersion process Voss and Provost (2002). A practical use of the method is, however, to provide a simulation of the sharpest concentration or temperature variations possible with a given mesh. This is obtained by specifying a simulation with no physical diffusion or dispersion, and with 50% upstream weighting. The results may be interpreted as the solution with the minimum amount of dispersion possible for a stable result in the particular mesh in use. In general simulation analyses of transport, upstream weighting is discouraged. The normal non-upstream methods provided by SUTRA are based on symmetric weighting functions. These methods are robust and accurate when the finite-element mesh is properly designed for a particular simulation, and should be used for most transport simulations.

3.7 PROGRAM STRUCTURE AND PROGRAM UNIT DESCRIPTIONS

SUTRA is structured in a modular, top-down programming style that allows for code readability, ease in tracing logic, and hopefully, ease in eventual modifications. Each subroutine carries out a primary function that is clearly distinguished from all other program functions. User-required program changes are limited to coding portions of a subroutine that is used to control time-dependent sources and boundary conditions (when they are used) and a subroutine that sets the unsaturated flow functions when unsaturated flow is simulated. The program is commented to aid in tracing logic.

SUTRA is written in FORTRAN-90 and takes advantage of dynamic array allocation; however, few structures are used that are not compatible with FORTRAN-77. The code runs accurately when it employs "double-precision" real variables (64 bit words with 47 bit mantissa) with a precision of about 15 significant figures, and 32 bit word integer variables. Input and output are also somewhat modularized. Input is through three data files consisting of list-directed records. The input first file, called "SUTRA.FIL", contains a list of FORTRAN unit numbers and the names of the remaining input and output files to which the unit numbers are to be assigned. The second input file, typically given the filename extension ".ics", contains only data on initial conditions for P and U at the nodes. The third input file, typically given the filename extension ".inp", contains all other input data required for a simulation. Output is to six data files. The first output file, typically given the filename extension ".rst", receives the result of the final time step in a format equivalent to that of the ".ics" file (with some additional information), for later use as the initial conditions file if the simulation is to be restarted. The second output file, typically given the filename extension ".nod", receives nod wise results (node coordinates, pressures, concentrations, and saturations) at each node for a user-specified sequence of time steps. The third output file, typically given the filename extension ".ele", receives element wise results (element centroid coordinates and velocity components) at each element centroid for a user-specified sequence of time steps. In the ".nod" and ".ele" files, output is arranged in columns to facilitate importing the results into post processing software. The fourth output file, typically given the filename extension ".obs", receives node wise results, called observations, for a set of nodes and a sequence of time steps specified by the user. The fifth output file, typically given the filename extension ".lst". The sixth output file, typically given the filename extension ".smy", summarizes simulation progress, receives convergence and error information; its default name is "SUTRA.SMY"(Appendix).

3.8 THE SALTWATER INTRUSION MODEL

3.8.1 SUTRA applications

SUTRA may be employed in one-, two-, or three-dimensional analyses. Flow and transport simulation may be either steady state, which requires only a single solution step, or transient, which requires a series of time steps in the numerical solution. Single-step steady-state solutions are usually not appropriate for nonlinear problems with variable density, saturation, viscosity or nonlinear sorption Voss and Provost (2003). SUTRA flow simulation may be employed for 2D areal, cross sectional and fully 3D modeling of saturated ground-water flow systems and unsaturated-zone flow. Hydraulic aquifer tests may be analyzed using flow simulation. SUTRA solute-transport simulation may be employed to model natural or man-induced chemical-species transport including processes of solute sorption, production and decay. Such simulation may be used to analyze ground-water contaminant-transport problems and aquifer restoration designs. SUTRA solute-transport simulation may also be used for modeling of variable-density leachate movement, and for cross sectional modeling of saltwater intrusion migration in aquifers at near-well or regional scales with either dispersed or relatively sharp transition zones between freshwater and saltwater. SUTRA energy-transport simulation may be employed to model thermal regimes in aquifers, subsurface heat conduction, aquifer thermal-energy storage systems, geothermal reservoirs, thermal pollution of aquifers, and natural hydrogeologic convection systems. A review of published SUTRA applications is given in Voss (1999).

3.8.2 Data requirement

The most essential types of data required are salinity values in a number of observation wells, hydraulic conductivity and recharge information. Other useful information would include an accurate topographic map, water level data and extraction data.

Table 3.1 Input parameters for SUTRA

Sl.no.	Parameter	Value
1	Fresh water density (ρ) (kg/m^3)	1000
2	Saltwater density (ρs) (kg/m^3)	1025
3	Fluid viscosity (μ) (kg/ms)	$1x10^{-3}$
4	Coefficient of fluid density change with concentration (∂ρ/∂C) (kg/m^3)	700
5	Saltwater concentration (mg/l)	35700
6	Molecular Diffusivity (m^2/sec)	1.5×10^{-9}
7	Porosity	0.25-0.3 (0.3)
8	Longitudinal Dispersivity,α_L (m)	15-150 (30)
9	Transverse Dispersivity,α_T (m)	0.15-1.5 (0.3)
10	Intrinsic Permeability (k) (m^2)	$2.9525x10^{-11}$- $4.72418x10^{-11}$ (4.410^{-11})

3.8.2.1 Porosity

The position of the interface is not affected by the change in the porosity. It leads to the change in the time period to achieve the steady state of the interface. Reduction in porosity accelerates the movement of the interface and it drives the system to steady state over a shorter time period. Theoretically it can be explained as the freshwater heads fall to steady state more rapidly since less water must drain from the pores and the interface change more rapidly. The porosity of laterite formation ranges from 0.25-0.3 (Bhosale and Kumar, 2001).

3.8.2.2 Dispersivity

Dispersion is a pseudo-transport process representing mixing of fluids that actually travel through the solid matrix at velocities different from the average velocity in two or three spatial dimensions, v, calculated from Darcy's law. Differences in longitudinal dispersivity in various flow directions may either be due to a local anisotropy in porous medium or aquifer structure, or to the different sizes of heterogeneities experienced by flows along vertical and horizontal transport reaches in an aquifer system. Regional horizontal flows typically encounter much larger heterogeneities than flows occurring vertically through an aquifer, causing higher longitudinal dispersion for horizontal flows than for vertical flows. Longitudinal dispersivity of laterite formation ranges from 15-150 and transverse dispersivity ranges from 0.15-1.5 (Bhosale and Kumar, 2001).

3.8.2.3 Abstraction Data

Extraction data was collected through local knowledge and survey. As shown in Table 3.2 in well no.13 (near boy's hostel, NITK) and well no. 28 (near NMPT) the extraction was found to be 432m^3/day and 1000m^3/day respectively. This is much more than the extraction in other wells of the region.

Groundwater extraction changes the dynamic balance between the flow of freshwater and the interface so that he interface will move and attain an equilibrium position governed by the quantity extracted and the balance outflow of freshwater to the sea. When groundwater withdrawals are large from points close to the interface, the cone may rise upto the screened section of wells, and turn the water saline. Hence if the pumping rates are low, a new equilibrium may be established with the upconed interface occupying an intermediate position between the original level and the screen, which prevents saltwater from entering into the well.

Table 3.2 Groundwater abstraction data

Well no.	Extraction value in litres/day	Well no.	Extraction value in litres/day	Well no.	Extraction value in litres/day	Well no.	Extraction value in litres/day
1	3000	11	2500	21	2000	31	2000
2	3000	12	2500	22	2000	32	2000
3	2000	13	432000	23	2000	33	2000
4	2000	14	4000	24	2000	34	2000
5	2000	15	4000	25	2000	35	2000
6	2000	16	4000	26	2000	36	2000
7	2000	17	2000	27	2000	37	2000
8	2000	18	4000	28	1000000	38	2000
9	2500	19	4000	29	2000	39	2000
10	2500	20	6000	30	2000		

3.8.2.4 Lateral Flow

The water entering from the adjacent areas into the study area in the present model is termed as lateral boundary flow. It is calculated as shown below,

The free flow of water through soil is governed by Darcy's law.

$$v = ki \tag{3.23}$$

where, k = coefficient of permeability, i = hydraulic gradient.

The velocity of flow is also known as the discharge velocity or the superficial velocity.

$$Q = kiA \tag{3.24}$$

where A is taken as normal to the direction of flow and it includes both solids and voids. The lateral or the boundary flow is divided equally among the nodes as shown in Fig. 3.7.

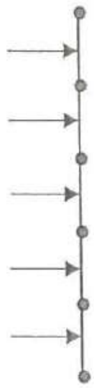


Fig. 3.7 Inflow Q along the boundary

3.8.2.5 Recharge

Owing to increasing demand for water, groundwater maybe subjected to over-exploitation and natural equilibrium is thus disturbed. This results in aggressive saltwater intrusion which may even reach inland aquifers. Efficient design and management of coastal groundwater system necessitates accurate prediction of interface movement owing to groundwater withdrawals and recharge.

The recharge coefficient is crucial factor which determines the amount of seepage reaching the groundwater table due to natural/artificial recharge. It is dependent on the geological and meteorological factors of the region. In view of the available literature, the value of recharge coefficient was found to vary over a range of 5% to 35% depending on the local conditions. In the present work, a recharge coefficient of 0.1 is assumed based on the soil characteristics. Total rainfall during monsoon period from Fig. 3.8 is 2500mm.Total number of nodes in the study area is 230 nodes for an area of 8.625km^2. The uniform recharge rate for the sub basin (I)

$$= \frac{2500 * 0.1 * 46 * 250 * 3 * 250}{1000 * 4 * 30 * 24 * 60 * 60 * 230}$$

$= 0.000863 m^3/sec/node.$

Similarly for sub basin (II) and (III) the value is 0.00062m^3/sec/node and 0.00059m^3/sec/node respectively.

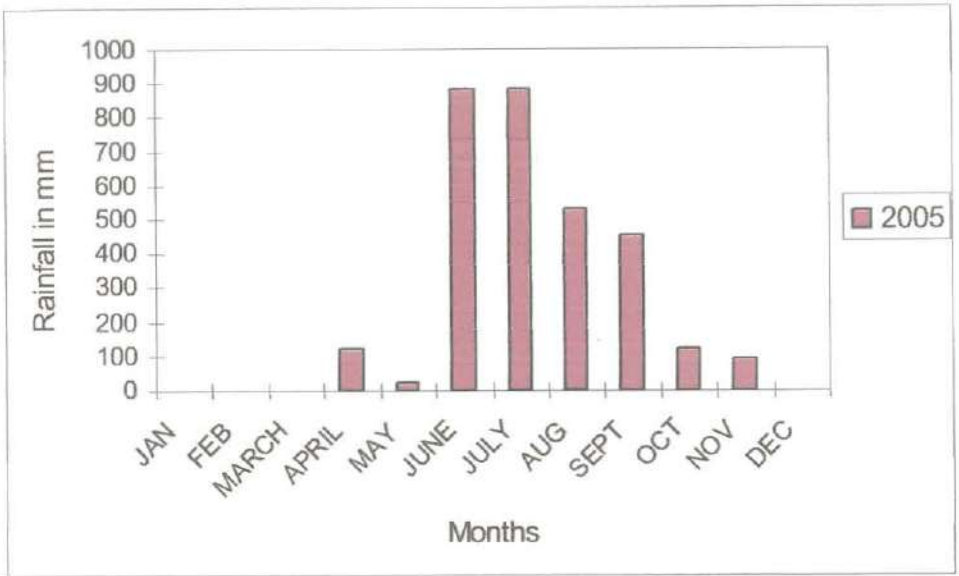


Fig. 3.8 Monthly variations in rainfall at Surathkal (Department of Applied Mechanics,2005)

3.8.2.6 Hydraulic Conductivity

Determination of aquifer hydraulic properties is a basic component of most ground-water supply and contaminant-transport investigations. Pumping tests were carried out to estimate Transmissivity and Storage Coefficient.

3.8.2.7 Permeability

The term intrinsic permeability refers to the inherent permeability character of a transmit fluid, independent of the fluid characteristics (viscosity and density). The intrinsic permeability k is given by:

$$k = Cd^2 \qquad (3.25)$$

Where C is a dimensionless constant or shape factor dependent on the various properties of the medium affecting flow other than the grain diameter d on which the dimensions of the pores depend. The hydraulic conductivity K is related to k as follows:

$$K = \frac{k\gamma}{\mu} = \frac{kg\rho}{\mu} = \frac{kg}{\nu} \qquad (3.26)$$

where γ = specific gravity of fluid

μ = dynamic viscosity of fluid

ν = kinematic viscosity of fluid

ρ = density of fluid

g = acceleration due to gravity

To obtain the intrinsic permeability the above may be suitable substituted in Darcy's law

$$k = \frac{Q}{A}\frac{\mu}{\rho g(dh/dl)} = \frac{Q}{A}\frac{\nu}{d\Phi/dl} \tag{3.27}$$

From which it is seen that intrinsic permeability will be of one unit length squared if it will transmit in unit time a unit volume of fluid of unit kinematic viscosity through a cross section of unit area measured at right angles to the flow direction under a unit potential gradient. If Q/A is measured in meters per second, ν in square meters per second, fluid potential Φ in Joules per kg and l in meters, the unit for k will be in square meters. k is commonly expressed in square micrometers where one square micrometer ($\mu\ m^2$)=$10^{-12}m^2$.In Equation (3.27), if k is expressed in $10^{-12}m^2$ and K in m/day for water at a standard temperature of 60°F (for which ν=1.1296 centistokes) they are related as follows:

$$k = \frac{1.1296\times10^{-2}\,cm^2s^{-1}}{\left(980.665cms^{-2}\right)\left(10^2\,cm\cdot m^{-1}\right)\left(86{,}400s\cdot day^{-1}\right)}K$$

$$= \frac{4}{3}\left(10^{-12}\,m\cdot day\right)K\left(m\cdot day^{-1}\right)$$

Intrinsic permeability of lateritic formation varies from 2.9525e^{-11} - 4.7241e^{-11}(Bhosale and Kumar, 2001).

3.8.3 Simulation of saltwater intrusion in the study area

In coastal regions heavy summer pumping at isolated locations leads to drastic lowering of water table. This results in saltwater intrusion at selected locations which is the cause of concern. During monsoon, rainwater recharge to the surface of the study area raises the water table, flushing out saltwater, and eventually establishing a stable freshwater lens. Hence it is of practical importance to study the dynamics of saltwater-freshwater in the region due to varied levels of stresses on the aquifers at present and in future.

The problem is simulated using both 2D and 3D models. The 3D transient-state solution is compared with the well established 2D solution. In the 2D model, difficulties lie primarily in model conceptualization in that

- boundary conditions used in 2D model allow the movement of saltwater toward the simulated section only from the two ends of the vertical section; and
- simulated pumping rate based on the estimates based on the estimates of the influence radius of each pumping well is difficult to calculate accurately.

3D model can be used to represent the 3D boundary conditions, the physics of the flow system and the response of the saltwater intrusion dynamic in relation to aquifer stresses throughout the aquifer domain.

The simulation is transient in both pressure and concentration. The study involves the assessment of effect of natural recharge and freshwater draft on the dynamics of saltwater and freshwater. In the present work, a time period of four months is selected to suit the pre monsoon (February-May), monsoon (June-September), post monsoon (October-January) periods. The ORTHOMIN solver is used in the work with a convergence tolerance of $1x10^{-03}$ requiring between about 10 and 30 solver iterations for each pressure and concentration solution.

To predict the long term future scenarios steady state 3D simulation is adopted. The simulation predicts the scenario beyond 150 years to establish the equilibrium between saltwater and freshwater. However, the short term responses are of practical importance and hence are also investigated in the analysis. The provision for both steady state and transient simulation is made in the SUTRA program code.

3.8.4 Discretization and boundary conditions

The saturated depth in the study area varies from 15m to 24m. A bore log data is shown in Fig. 3.9 (Department of Applied Mechanics, 1996). The depth of section is taken as 24m below mean sea level.

3.4.1.1 3D model

Coastline study area

- For the simulation of saltwater intrusion in the study area, the section of the aquifer along the line E - E' – 11500m long and 25 m deep, was discretized to 225 rectangular elements and 276 nodes.
- Another section of the aquifer along the line F-F' - 875m long and 25 m deep, was discretized to 20 rectangular elements and 30 nodes.

Therefore, the total number of elements and nodes considered in the 3D simulation are 900 and 1380 respectively with a uniform spacing of 5m along the vertical direction(fig.3.10). The recharge due to rainfall has been specified at the top of the aquifer for the study area. Along the western and the southern boundary of the Coastline study area, a hydrostatic pressure defined by,

$$p = \rho_s g d \tag{3.28}$$

has been imposed. Here, p is the hydrostatic pressure $[ML^{-1}T^{-2}]$, ρ_s is the density of saltwater $[ML^{-3}]$, g is the acceleration due to gravity $[LT^{-2}]$, and d is the depth [L].

The boundary conditions for the transport simulation are dependent on the flow boundary conditions. The total dissolved solids (TDS) of recharge due to rainfall is zero ($C^* = 0$ kg TDS/kg fluid).Any flow out of the mesh, at the specified pressure boundaries, occurs at the ambient concentration of the aquifer fluid. Solute may neither disperse nor advect across the no-flow boundary.

Depth in meters	Description of the layer	Observed N value in the field	Depth of SPT (m)
G.L. 0.0 2.0 GWL 2.7	Brownish yellow fine to medium sand with small percentage of fines	8 8 10	1.0 2.0 3.0
4.0	Brownish sand with lateritic pieces and small percentage of fines	17 7	4.0 5.0
6.0	Silt clay with sand	13	6.5
8.0 10.0	Reddish brown coarse to medium sand with small % of fines (lateritic soil)	17 21 31	8.0 10.0 11.5
12.0	Grayish brown weathered/disintegrated rock	44 >100	13.0 14.5

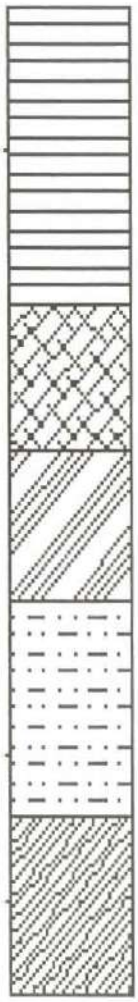
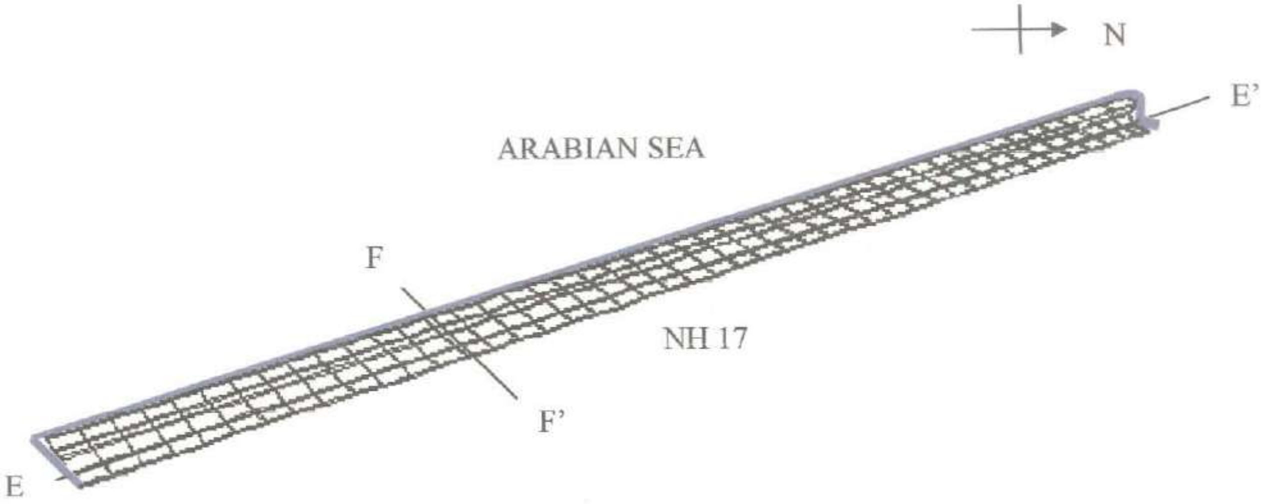
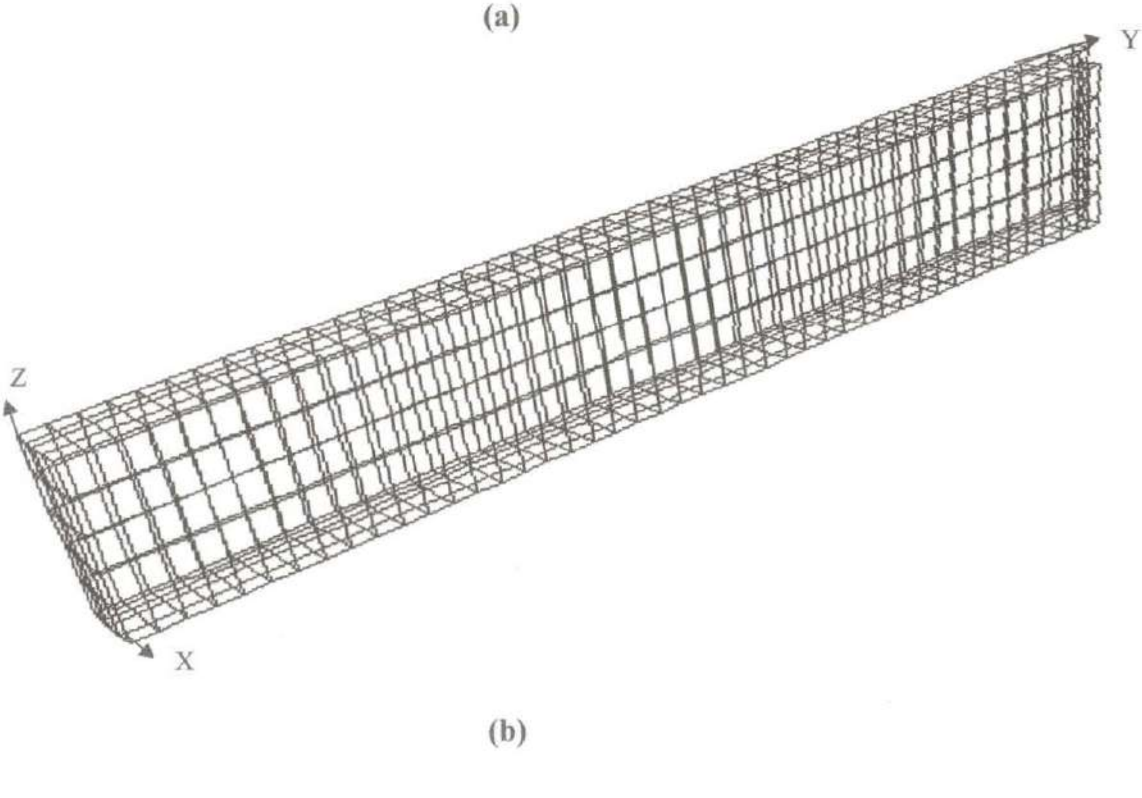


Fig. 3.9 Bore log details (Department of Applied Mechanics, 1996)



(a)



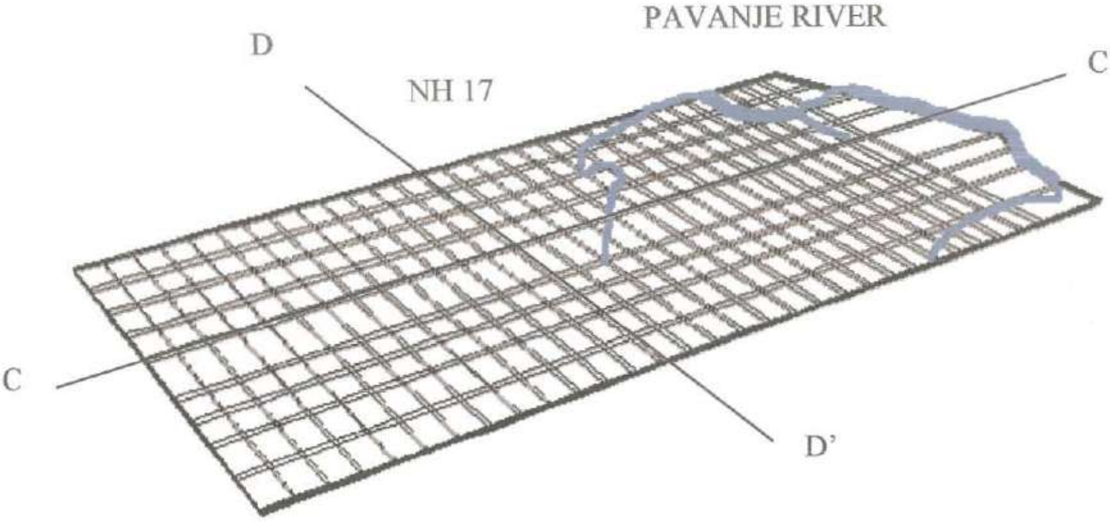
(b)

Fig. 3.10 3D finite element mesh for the coastline study area: (a) Top view; (b) oblique view

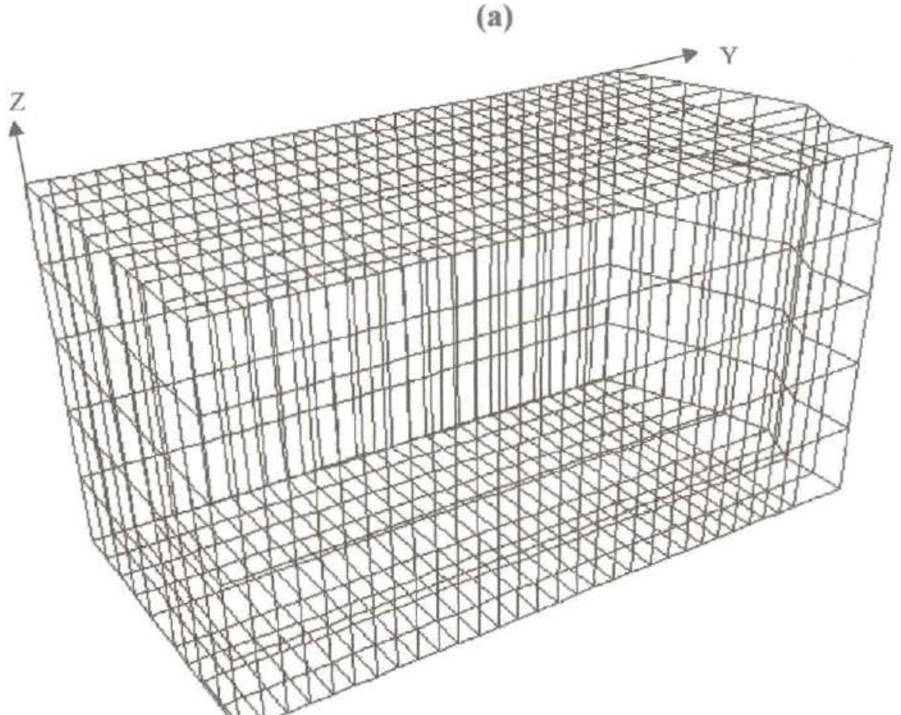
Pavanje study area

- For the simulation of saltwater intrusion in the study area, the section of the aquifer along the line C-C' – 4175 m long and 25 m deep, was discretized to 150 rectangular elements and 186 nodes.
- Another section of the aquifer along the line D-D' - 2000m long and 25 m deep, was discretized to 45 rectangular elements and 60 nodes.

Therefore, the total number of elements and nodes considered in the 3D simulation are 1350 and 1860 respectively(fig.3.11). The vertical spacing here also was kept at 5m from top of the aquifer to the bottom. The recharge due to rainfall has been specified at the top of the aquifer for the study areas. The boundary conditions for the transport simulation are dependent on the flow boundary conditions. The total dissolved solids (TDS) of recharge due to rainfall is zero ($C^* = 0$ kg TDS/kg fluid).Any flow out of the mesh, at the specified pressure boundaries, occurs at the ambient concentration of the aquifer fluid. Solute may neither disperse nor advect across the no-flow boundary.



(a)



(b)

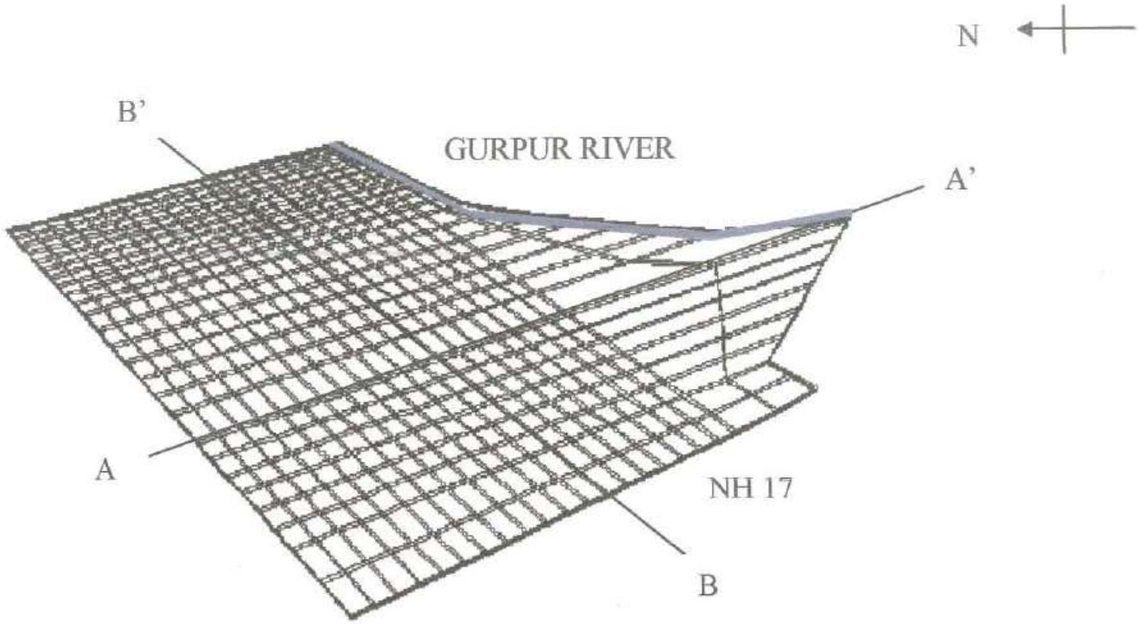
Fig. 3.11 3D finite-element mesh for the Pavanje study area: (a) Top view; and (b) oblique view

Gurpur river basin

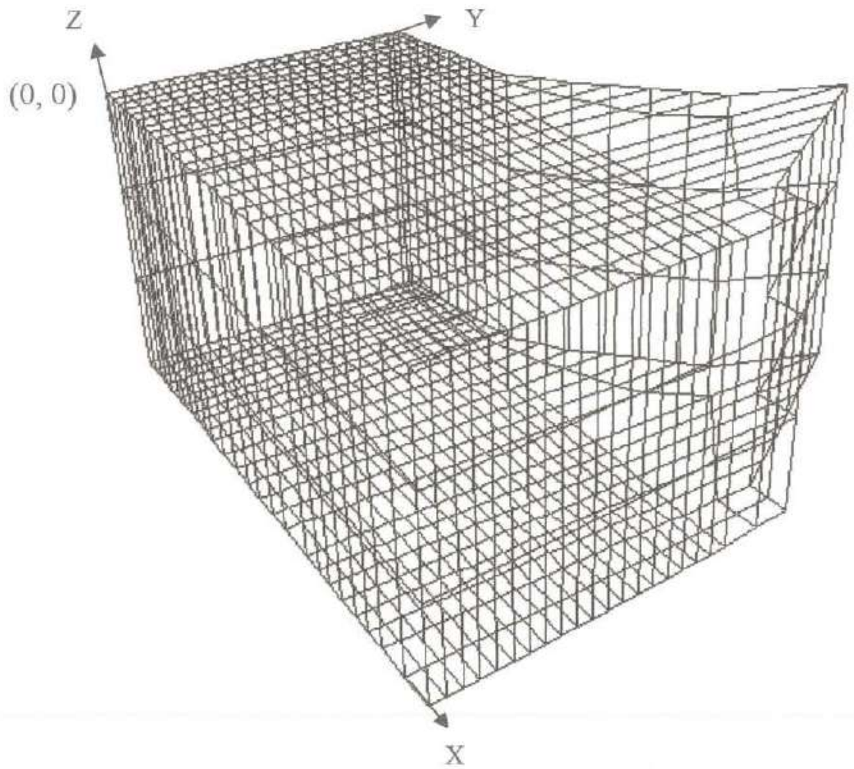
- For the simulation of saltwater intrusion in the study area, the section of the aquifer along the line A-A' - 4575m long and 25 m deep, was discretized to 63 rectangular elements and 88 nodes.
- Another section of the aquifer along the line B-B' - 4550m long and 25 m deep, was discretized to 75 rectangular elements and 104 nodes.

Therefore, the total number of elements and nodes considered in the 3D simulation are 1575 and 2288 respectively. The vertical spacing was kept constant at 5m from top of the aquifer to 25 m depth below mean sea level (MSL).

The recharge due to rainfall has been specified at the top of the aquifer for all the study areas. Along the western Gurpur study area, a hydrostatic pressure defined by Equation (3.18) has been imposed. The boundary conditions for the transport simulation are dependent on the flow boundary conditions. The total dissolved solids (TDS) of recharge due to rainfall is zero ($C^* = 0$ kg TDS/kg fluid).Any flow out of the mesh, at the specified pressure boundaries, occurs at the ambient concentration of the aquifer fluid. Solute may neither disperse nor advect across the no-flow boundary.



(a)



(b)

Fig. 3.12 3D finite-element mesh for the Gurpur study area: (a) Top view; and (b) oblique view

3.9 VULNERABILITY ASSESSMENT

The GALDIT method is a weightage driven approach to assess the vulnerability of coastal aquifers using hydro-geological parameters. It is a tool for aquifer pollution vulnerability evaluation and ranking for the estimation of vulnerability index. GALDIT index is developed in the framework of the EU-India INCO-DEV COASTIN project aiming the assessment of aquifer vulnerability to saltwater intrusion in coastal aquifers. GALDIT method was developed by Chachadi and Ferreira (2001).

3.10 VULNERABILITY EVALUATION AND RANKING

The most important factors that control the saltwater intrusion are found to be:
(Ferreira et al, 2005)

- **G**roundwater occurrence (aquifer type; unconfined, confined and leaky confined).
- **A**quifer hydraulic conductivity.
- Height of groundwater **L**evel above sea level.
- **D**istance from the shore (distance inland perpendicular from shoreline).
- **I**mpact of existing status of saltwater intrusion in the area.
- **T**hickness of the aquifer which is being mapped.

The acronym GALDIT is formed from the highlighted letters of the parameters for ease of reference. These factors, in combination, are used to assess the general saltwater intrusion potential of each hydro-geologic setting. The GALDIT factors represent measurable parameters for which data are generally available from a variety of sources without detailed reconnaissance.

The system contains three significant components- weights, ranges and importance ratings. Each GALDIT factor has been evaluated with respect to the other to determine the relative importance of each factor. The basic assumption made in the analysis is that the bottom of the aquifer lies below the mean sea level.

The various parameters influencing the saltwater intrusion are adopted in the evolution of the present method. This task was achieved through extensive discussions and consultations with the experts, academicians etc. The indicator weights depict the relative importance of the indicator to the process of saltwater intrusion. After identifying the indicators, a group of people consisting of geologists, hydrogeologists, environmentalists, students, in-house experts were asked to weigh these indicators in the order of importance to the process of saltwater intrusion. The feedback from all such interactions were analyzed statistically and the final consensus list of indicator weights was prepared. The most significant indicators have weights of 4 and the least a weight of 1 indicating the parameter of less significance in the process of saltwater intrusion. As the indicator weights are derived after elaborate discussions and deliberations among the experts, academicians, researchers, etc., they must be considered for general application and may not be changed under normal circumstances. Each of the indicators is subdivided into variables according to the specified attributes to determine the relative significance of the variable in question on the process of saltwater intrusion. The importance ratings range between 2.5 and 10. Higher importance rating indicates high vulnerability to saltwater intrusion.

3.11 INDICATOR DESCRIPTIONS

3.11.1 Groundwater occurrence (Aquifer type)

In nature, groundwater generally occurs in the geological layers and these layers may be confined, unconfined, leaky confined or limited by one or more boundaries. The extent of saltwater intrusion is dependent on this basic nature of groundwater occurrence. For example, a confined aquifer under natural conditions would be more affected by saltwater intrusion compared to unconfined aquifer as the confined aquifer is under more than atmospheric pressure. Similarly, a unconfined aquifer may be more prone to saltwater intrusion compared to leaky confined aquifer as the leaky confined aquifer maintains minimum hydraulic pressure by way of leakages from adjoining aquifers. Therefore, in assigning the relative weights to GALDIT parameter **G** one should carefully study the disposition and type of the aquifers in the study area. The confined aquifer is more vulnerable due to larger cone of depression and instantaneous release of water to wells during pumping and hence scores the high rating. In case of multiple aquifer system in an area, the highest rating may be adopted. For example, if an area has all the three aquifers, the rating of 10, for confined aquifer may be chosen. The following table-3.3 gives the ratings for different hydro-geological conditions.

Table 3.3 - Ratings for groundwater occurrence/aquifer type

Indicator	Weight	Indicator Variables	Importance Rating
Groundwater occurrence/ Aquifer type	1	Confined aquifer	10
		Unconfined aquifer	7.5
		Leaky confined aquifer	5
		Bounded aquifer(recharge and/or impervious boundary aligned parallel to the coast	2.5

3.11.2 Aquifer hydraulic conductivity

The aquifer hydraulic conductivity is used to measure the rate of flow in the aquifer. The hydraulic conductivity is the result of the interconnected pores (effective porosity) in the sediments and fractures in the consolidated rocks. The magnitude of saltwater front movement is influenced by the hydraulic conductivity of the aquifer. Higher the conductivity, higher is the inland movement of the saltwater front. The higher conductivity also results in wider cone of depression during pumping. In this case, the user should take into account the hydraulic barriers like clay layers and impervious dykes parallel to the coast, which may act as walls to saltwater intrusion.

There exists a relation between the length of saltwater intrusion (L) and the flow of fresh groundwater to the sea (Q) (Fig.3.13). The freshwater discharge to the sea is the difference between the natural recharge (W) to the aquifer and the total withdrawal. According to Bear and Verrujit (1987), the equations governing the length (L) of saltwater interface for confined and unconfined aquifer are given as below:

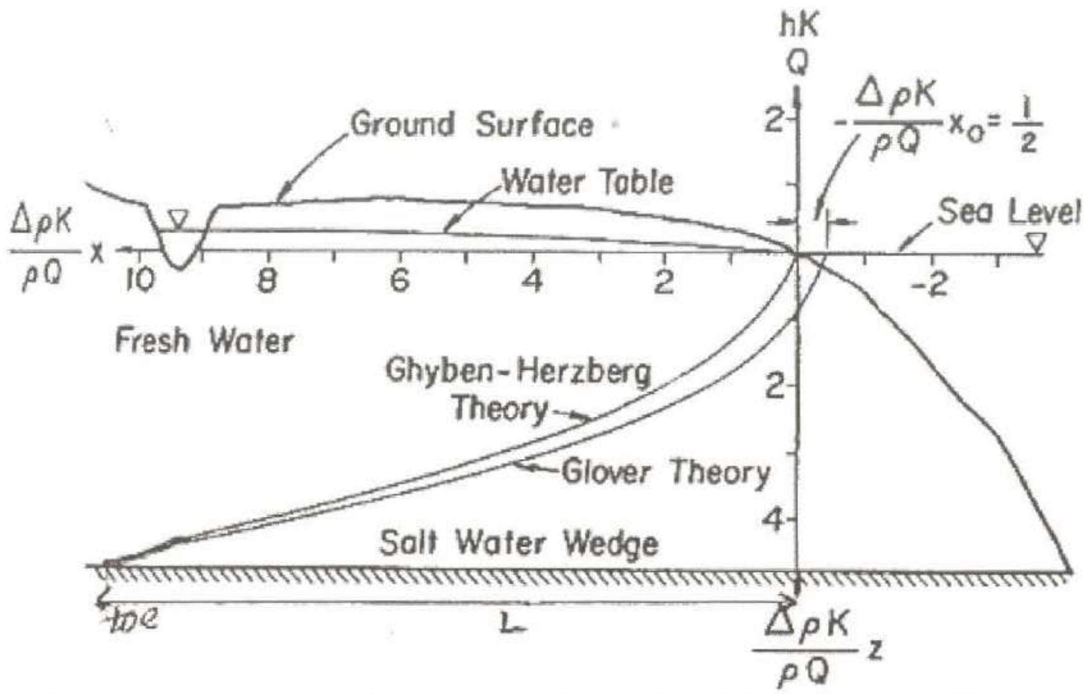


Fig. 3.13 Saltwater intrusion in the coastal aquifer (Chachadi et al., 2005)

Confined Aquifer

$L = KB^2/2Q(\delta)$ for $L > B$ (3.29)

where, K is the aquifer hydraulic conductivity, B is the saturated aquifer thickness, and δ is equal to $\{\rho_f / [\rho_s - \rho_f\} \approx 40$, where ρ is the density of water, subscripts 'f' and 's' refer to freshwater and saltwater respectively.

Unconfined Aquifer

$Q = [KB^2 / 2L] \times [(1+\delta) / \delta^2] - WL/2$, where W is the natural recharge.

The saltwater intrusion is aggressive during the dry season when there is no rainfall recharge. Therefore, for W=0, the above relation reduces to

$L = 0.0257 \times [KB^2/2Q]$ (3.30)

By substituting identical values of K, B, and Q in equations (3.29) and (3.30) the length (L) of the computed saltwater toe would be nearly identical. The ratings for the GALDIT parameter A, which are modified after Aller et al (1987) are as given in table 3.4

Table 3.4 - Ratings for the aquifer hydraulic conductivity

Indicator	Weight	Indicator Variables		Importance Rating
		CLASS	*RANGE*	
Aquifer hydraulic conductivity	3	High	> 40	10
		Medium	10 – 40	7.5
		Low	5 – 10	5
		Very Low	< 5	2.5

3.11.3 Height of groundwater level above sea level

The level of groundwater with respect to mean sea elevation is a very important factor in the evaluation of the saltwater intrusion in an area primarily because it determines the hydraulic pressure available to push back the saltwater front. As per the Ghyben-Herzberg relation, for every meter of fresh water stored above mean sea elevation, 40 meters of freshwater is stored below it down to the interface. In other words, if the groundwater levels are held constant, the change in sea level can cause the same effect. When the sea level rises, the amount of fresh water outflow Q to sea reduces as relayed in equations (3.22) and (3.23) and hence the length L the saltwater interface increases.

In assigning the ratings to the GALDIT parameter L, one should look into the long-term variation of the groundwater levels in the area. Generally, the values pertaining to minimum groundwater levels above sea may be considered, as this would provide the highest possible vulnerability risk. The ratings adopted for L are given in table 3.5

Table 3.5 - Ratings for the height of groundwater level above the mean sea level

Indicator	Weight	Indicator Variables		Importance Rating
		CLASS	*RANGE*	
Height of groundwater level above MSL (m)	4	High	< 1	10
		Medium	1 – 1.5	7.5
		Low	1.5 – 2	5
		Very Low	> 2	2.5

The height of groundwater level above mean sea level is calculated depending on the elevation of the well points using a hand held GPS and water level in the wells. The water level in each of the observation well is monitored on monthly basis during November 2006 to May 2007 to obtain the parameter "L".

3.11.4 Distance from the shore

The impact of saltwater intrusion generally decreases as one moves inland at right angles to the shore or the creek. The following table (3.6) provides the general guidelines for rating of the GALDIT parameter **D** assuming the aquifer is under undisturbed conditions;

Table 3.6 - Ratings for the distance from shore / high tide

Indicator	Weight	Indicator Variables		Importance Rating
		CLASS	*RANGE*	
Distance from shore/ river (m)	4	Very small	< 500	10
		Small	500 – 750	7.5
		Medium	750 – 1000	5
		Far	> 1000	2.5

The study area considered in the present work comprises of the Gurupur and Pavanje rivers. The two rivers are being seasonal and tidal in nature, salt water intrusion into adjoining aquifers during the non- monsoon period is greatly felt up to several kilometers inland along the river courses. Hence the parameter "D" is considered as the distance of the location from the shore or river, whichever is minimum. The google earth imagery (www.googleearth.com) is made use of to arrive at the distances from the wells to the shore or the rivers.

3.11.5 Impact of existing status of saltwater intrusion

If the area under mapping is invariably under stress and this stress has already modified the natural hydraulic balance between saltwater and fresh groundwater, this should be considered while mapping the aquifer vulnerability to saltwater intrusion. Chachadi and Ferreira (2001) have recommended the ratio of Cl^{-} / $[HCO_3^{-1} + CO_3^{-2}]$ as another criterion to evaluate the extent of saltwater intrusion into the coastal aquifers. The Chloride ion is dominant in the saltwater and it is present in small quantities in fresh groundwater. The bicarbonate, which is available in large quantities in groundwater, occurs only in very small quantities in saltwater. This ratio is used while assigning the rating for the GALDIT parameter "I". The following ratings are given for "I" to take care of chloride-bicarbonate ratio (table3.7).

Table 3.7 - Ratings for status of saltwater intrusion

Indicator	Weight	Indicator Variables		Importance Rating based on Cl^-/ [HCO_3^{-1} + CO_3^{-2}], ratio of groundwater
		CLASS	*RANGE OF Cl^-/ [HCO_3^{-1} + CO_3^{-2}] ratio in ppm in groundwater*	
Impact status of existing saltwater intrusion	1	High	> 2	10
		Medium	1.5 - 2	7.5
		Low	1 – 1.5	5
		Very low	< 1	2.5

The impact of existing ground water intrusion is calculated for 9 data sets (November 2006 to May 2007, with fortnightly data for the month of April and May) using the formula, Cl^-/ (CO_3^{-1} + HCO_3^{-2}). However, in the water samples collected, CO_3^{-1} is absent; therefore HCO_3^{-2} is the total alkalinity. Chemical analysis is undertaken for the water samples collected from each of the observation wells for the presence of Cl^- and HCO_3^{-2} ions.

The chloride associated with sodium exerts salty taste when its concentration is more than 250 mg/l. Hence chlorides are generally limited to 250mg/l in supplies intended for public use. Excess chlorides can also corrode concrete by extracting calcium in the form of calcide. The chloride determination in natural waters is required for drinking water supplies.

The vulnerability classes are also (Agarwadkar, 2005) depending on the chloride content in the drinking water and can be given as in table 3.8.

Table 3.8Vulnerability classes based on the chloride content

Chloride content	Vulnerability class
0 – 250	Non-vulnerable
250 – 500	Less vulnerable
500 – 1000	Moderately vulnerable
1000 onwards	Highly vulnerable

The alkalinity of water is its acid neutralizing capacity. The alkalinity of surface water is primarily a function of carbonate, bicarbonate and hydroxide content. The principle and procedure of the chemical analysis is discussed in detail in APPENDIX-I

3.11.6 Thickness of the aquifer

The aquifer thickness or saturated thickness of an unconfined aquifer plays an important role in determining the extent and magnitude of saltwater intrusion in the coastal areas. It is well established as per equations (3.29) and (3.30) that larger the aquifer thickness, greater the extent of saltwater intrusion and vice versa. Keeping this as a guideline, the following ratings are given (table 3.9) for various ranges of aquifer thicknesses.

Table 3.9 - Ratings for the saturated aquifer thickness

Indicator	**Weight**	**Indicator Variables**		**Importance Rating based on saturated aquifer thickness**
		CLASS	***RANGE***	
Aquifer thickness (saturated) in metres	2	Large	> 10	10
		Medium	7.5 – 10	7.5
		Small	5 – 7.5	5
		Very small	< 5	2.5

The VES carried out at 23 locations of the study area gives the estimated thickness (in meters) of soil and laterite-clay capping over the hard rock. The saturated thickness needed for the analysis is obtained by deducting the water level of the wells with respect to the locations where VES is carried out.

3.12 COMPUTATION OF THE GALDIT INDEX

Each of the six indicators has a pre-determined fixed weight that reflects its relative importance to saltwater intrusion. The GALDIT index is then obtained by computing the individual indicator scores and summing them as per the following expression:

$$\textbf{GALDIT-Index} = \sum_{i=1}^{6} \{(W_i) R_i\} / \sum_{i=1}^{6} W_i \qquad (3.31)$$

where W_i is the weight of the i^{th} indicator and R_i is the importance rating of the i^{th} indicator.

Thus, the user can use hydro-geologic and geological information from the area of interest and choose variables to reflect specific conditions within that area, choose corresponding importance ratings and compute the indicator score. This system allows the user to determine a numerical value for any hydro-geological setting by using this additive model. The maximum value of GALDIT-index is obtained by substituting the maximum importance ratings of the indicators as shown below:

$$\text{Max} = \{(1)^*R_1 + (3)^*R_2 + (4)^*R_3 + (4)^*R_4 + (1)^*R_5 + (2)^*R_6\} / \sum_{i=1}^{6} Wi$$

$$= \{(1)^*10 + (3)^*10 + (4)^*10 + (4)^*10 + (1)^*10 + (2)^*10\}/15$$

$$= 10 \qquad (3.32)$$

Similarly, the minimum GALDIT-index is obtained by substituting the minimum importance ratings of the indicators as shown below:

$$\text{Min} = \{(1)^*R_1 + (3)^*R_2 + (4)^*R_3 + (4)^*R_4 + (1)^*R_5 + (2)^*R_6\} / \sum_{i=1}^{6} Wi$$

$$= \{(1)^*2.5 + (3)^*\ 2.5 + (4)^*\ 2.5 + (4)^*\ 2.5 + (1)^*\ 2.5 + (2)^*\ 2.5/15$$

$$= 2.5 \qquad (3.33)$$

Therefore, the GALDIT-index varies between 2.5 and 10. The vulnerability of the area to saltwater intrusion is assessed based on the magnitude of the GALDIT Index. In a general way, lower the index less vulnerable to saltwater intrusion.

3.13 DECISION CRITERIA

Once the GALDIT-index has been computed, it is possible to classify the coastal area into various categories of saltwater intrusion vulnerability. The range of GALDIT - index scores (*i.e.* 2.5 to 10) is divided into 3 groups as shown in table 3.10. All the six indicators categorized into these groups. The summary of GALDIT parameter weights, rates and ranges are given in table 3.11

Table3.10 - GALDIT vulnerability classes

Sl. No.	GALDIT–Index Range	Vulnerability Class
1	≥ 7.5	Highly vulnerable
2	5 – 7.5	Moderately vulnerable
3	< 5	Low vulnerability

Table 3.11 - Summary of GALDIT parameter weights, rates and ranges

Sr. No.	Indicator	Weight	Indicator Variable		Importance ratings
			Class	Ratings	
1	Groundwater occurrence/ Aquifer type	1	Confined Aquifer		10
			Unconfined Aquifer		7.5
			Leaky confined Aquifer		5
			Bounded Aquifer (recharge and/or impervious boundary aligned parallel to the coast)		2.5
2	Aquifer Hydraulic Conductivity (m/day) 3	3	High	>40	10
			Medium	10-40	7.5
			Low	5-10	5
			Very low	<5	2.5
3	Height of Groundwater Level above MSL (m)	4	High	<1.0	10
			Medium	1.0-1.5	7.5
			Low	1.5-2.0	5
			Very low	>2.0	2.5
4	Distance from shore /river, m		Very small	<500	10
			Small	500-750	7.5
			Medium	750-1000	5
			Far	>1000	2.5
5	Impact status of existing saltwater intrusion Cl- / $[HCO3^{-1} + CO3^{2-}]$	1	High	>2	10
			Medium	1.5-2.0	7.5
			Low	1-1.5	5
			Very low	<1	2.5
6	Aquifer thickness (saturated) in m.	2	Large	>10	10
			Medium	7.5-10	7.5
			Small	5-7.5	5
			Very small	<5	2.5

CHAPTER 4

RESULTS AND DISCUSSION

4.1 PARAMETER ESTIMATION

4.1.1 Estimation of aquifer parameters from pumping tests

The pumping tests were conducted in the study area to estimate the hydraulic properties of the aquifer. In total, about 15 pumping tests are conducted in the area and the details of the wells are given in tables 1.1 and 4.1. The analysis of the pumping tests conducted for the open wells in the study area are given here. The wells are generally of large diameter (>3m) and of shallow depth (<10m). The maximum pumping duration was about 2½ hours due to water shortage, electricity problems etc. The details of the wells in the study area are given in table 4.1. The time-drawdown and recovery data of a few of them are listed in tables 4.2 to 4.8. From the field observations it is evident that the aquifer is shallow and unconfined in nature.

Table 4.1 Details of the pumping wells

Well No	Well location	Village	Date of pumping	Diameter of the well (m)	Total depth of the well (m)	Depth to water level before test (m)	Discharge (m^3/day)
P1	13° 00′26.27″ N 74° 47′59.60″ E	Munchoor	09-02-2007	5.12	5.25	0.83	906.34
P2	12° 58′44.19″ N 74°48′08.49″E	Hosabettu	20-02-2007	3.1	4.72	1.51	1163.29
P3	12° 59′04.79″ N 74°48′19.55″E	Surathkal	16-03-2007	5.62	8.9	5.36	679.58
P4	12° 57′23″ N 74° 50′56.11″E	Kenjaru	23-03-2007	10.60	5.45	2.80	1642.12

Well No.13 (Near NITK Boy's hostel) Date 1-9-2005

Well Diameter = 7.5m. Initial water level=7.115m (msl), Discharge = 432m^3/day

Table 4.2 Time-drawdown recovery data for the well no.13

Time (min)	Drawdown (m)	
	During Pumping	After Pumping was stopped
2	0.03	0.22
5	0.06	0.20
10	0.09	0.17
15	0.12	0.15
20	0.15	0.13
30	0.18	0.13
40	0.21	0.13
50	0.23	0.13
60	0.23	0.13
75	0.21	0.13
90	0.23	0.12
105	0.23	0.12
120	0.23	0.12

Well No.11 (Near NITK campus) Date 27-12-2006

Well Diameter = 3.15m, Initial water level = 0.374 (msl), Discharge = 387.072m^3/day.

Table 4.3 Time-drawdown recovery data for the well no.11

Time (min)	Drawdown (m)	
	During Pumping	After Pumping was stopped
1	0.06	1.12
2	0.1	1.05
3	0.1	1
4	0.17	1
5	0.14	0.97
6	0.31	0.94
7	0.34	0.93
8	0.39	0.89
9	0.43	0.88
10	0.45	0.87
12	0.49	0.81
15	0.55	0.76
18	0.63	0.71
20	0.72	0.65

25	0.76	0.61
30	1.01	0.53
35	1.12	0.46
40		0.41
50		0.31
60		0.21
70		0.2
80		0.15
90		0.12
100		0.1
120		0.1
130		0.1

Well No.40 (Near NITK Professor's Quarters) Date: 24-3-2006

Well Diameter= 5.71m, Initial water level= 1.507m (msl), Discharge = 528.29m^3/day

Table 4.4 Time-drawdown recovery data for the well no.40

Time (min)	Drawdown (m)	
	During Pumping	After Pumping was stopped
1	0.03	4.04
2	0.06	4.04
3	0.07	4.04
4	0.08	4.01
5	0.09	4
6	0.1	4
7	0.12	4
8	0.14	4
9	0.15	3.99
10	0.16	3.99
12	0.2	3.99
15	0.26	3.98
18	0.29	3.98
20	0.34	3.98
25	0.42	3.98
30	0.48	3.98
35	0.56	3.98
40	0.66	3.97
50	0.8	3.95
60	0.94	3.95
70	1.1	3.95
80	1.27	3.94
90	1.37	3.91

100	1.56	3.89
120	1.68	-
140	1.82	3.88
160	1.97	3.86 (time = 130)
180	2.27	3.07 (time = 900)
200	2.47	2.89 (time = 1110)
220	2.72	
240	2.93	
260	3.16	
280	3.37	
300	3.58	
330	3.78	
340	4.05	

Table 4.5 Time-drawdown and recovery data for the well no.P1

Time (mins)	During pumping		After pumping	
	Depth to water level (m)	Drawdown (m)	Depth to water level (m)	Recovery (m)
1	0.84	0.01	1.24	0.00
2	0.85	0.02	1.22	0.02
3	0.88	0.05	1.19	0.05
4	0.90	0.07	1.17	0.07
5	0.91	0.08	1.15	0.09
6	0.93	0.10	1.13	0.11
7	0.94	0.11	1.11	0.13
8	0.95	0.12	1.09	0.15
9	0.98	0.15	1.06	0.18
10	0.99	0.16	1.03	0.21
12	1.03	0.20	1.02	0.22
15	1.05	0.22	1.00	0.24
18	1.06	0.23	0.98	0.26
20	1.07	0.24	0.97	0.27
25	1.10	0.27	0.95	0.29
30	1.12	0.29	0.93	0.31
35	1.13	0.30	0.92	0.32
40	1.15	0.32	0.91	0.33
50	1.19	0.36	0.88	0.36
60	1.20	0.37	0.85	0.39
70	1.21	0.38	0.84	0.40
80	1.23	1.40	0.84	0.40
110	1.25	0.42	0.84	0.40
120	1.26	0.43	0.84	0.40

Table 4.6 Time-drawdown and recovery data for the well no.P2

Time (min)	During pumping		After pumping	
	Depth to water level (m)	Drawdown (m)	Depth to water level (m)	Recovery (m)
1	1.54	0.03	2.23	0.00
2	1.57	0.06	2.20	0.03
3	1.59	0.08	2.18	0.05
4	1.62	0.11	2.17	0.06
5	1.65	0.14	2.15	0.08
6	1.66	0.15	2.13	0.10
7	1.69	0.18	2.12	0.11
8	1.71	0.20	2.11	0.12
9	1.73	0.22	2.10	0.13
10	1.75	0.24	2.09	0.14
12	1.79	0.28	2.06	0.17
15	1.85	0.34	2.03	0.21
18	1.88	0.37	2.00	0.24
20	1.91	0.40	1.97	0.27
25	1.96	0.45	1.92	0.31
30	2.02	0.51	1.89	0.35
35	2.06	0.55	1.86	0.37
40	2.10	0.59	1.82	0.41
50	2.16	0.65	1.77	0.47
60	2.19	0.68	1.73	0.50
70	2.22	0.71	1.70	0.53
80	2.24	0.73	1.68	0.55
90	2.25	0.74	1.66	0.57
120			1.51	0.72

Table 4.7 Time-drawdown and recovery data for the well no.P3

Time (min)	During pumping		After pumping	
	Depth to water Level (m)	Drawdown (m)	Depth to water level (m)	Recovery (m)
1	5.51	0.00	6.21	0.00
2	5.52	0.01	6.18	0.03
3	5.54	0.04	6.16	0.05
4	5.56	0.05	6.13	0.08
5	5.58	0.08	6.11	0.10
6	5.60	0.10	6.09	0.12
7	5.62	0.12	6.08	0.13
8	5.64	0.14	6.06	0.15
9	5.66	0.16	6.03	0.18
10	5.68	0.18	6.00	0.21
12	5.70	0.20	5.97	0.24
15	5.75	0.25	5.95	0.26
18	5.78	0.28	5.93	0.28
20	5.81	0.31	5.90	0.31
25	5.86	0.36	5.85	0.36
30	5.91	0.41	5.81	0.40
35	5.94	0.44	5.78	0.43
40	5.96	0.46	5.76	0.45
50	6.00	0.50	5.74	0.48
60	6.05	0.55	5.71	0.50
70	6.09	0.59	5.68	0.53
80	6.13	0.63	5.65	0.57
90	6.18	0.68	5.61	0.60
100	6.21	0.71	5.58	0.64
120	6.24	0.74	5.52	0.69

Table 4.8 Time-drawdown and recovery data for the well no.P4

Time (min)	During pumping		After pumping	
	Depth to water level (m)	Drawdown (m)	Depth to water level (m)	Recovery (m)
1	2.81	0.01	3.29	0.00
2	2.83	0.03	3.28	0.01
3	2.83	0.03	3.28	0.01
4	2.84	0.04	3.28	0.01
5	2.85	0.05	3.27	0.02
6	2.85	0.05	3.27	0.02
7	2.85	0.05	3.27	0.02
8	2.86	0.06	3.27	0.02
9	2.86	0.06	3.27	0.02
10	2.87	0.07	3.26	0.03
12	2.87	0.07	3.26	0.03
15	2.88	0.08	3.25	0.04
18	2.90	0.10	3.25	0.04
20	2.91	0.11	3.24	0.05
25	2.95	0.15	3.24	0.05
30	2.99	0.19	3.23	0.06
35	3.00	0.20	3.23	0.06
40	3.02	0.22	3.23	0.06
50	3.08	0.28	3.22	0.07
60	3.13	0.33	3.22	0.07
70	3.20	0.40	3.21	0.08
80	3.25	0.45	3.19	0.11
90	3.30	0.50	3.17	0.12

The observations to be made during a pumping test mainly include measurement of water levels and discharge rate with time. The measurements must be taken at specified intervals during the course of the test and as accurately as possible. Since water level drops faster during the first one to two hours of the test, readings should be taken at shorter intervals and the time between readings being gradually increased as pumping continues (Rajagopalan et al., 1983). After the pump is shut down, the water levels in the pumped well start rising. In the first hour it rises rapidly, but as time goes on the rate of rise decreases. This water level rise is to be measured which is known as recovery test.

The pumping test analysis was carried out using Aquifer Win32 software based on Neuman (1974) method which is outlined in the previous chapter. Another option available for the analysis is the Laplace transform solution by Moench (1997) which is applicable for flow to a partially penetrating well of finite diameter in a slightly compressible water table aquifer. The solution, which allows for evaluation of both pumped well and observation piezometer data, accounts for effects of well bore storage and skin and allows for the noninstantaneous release of water from the unsaturated zone the solution approaches line source solution derived by Neuman (1974) as the diameter of the pumped well approaches zero. However, it has been found out that the Neuman (1972, 1974) model, when properly applied, can be used to estimate the most important water table aquifer parameters (horizontal hydraulic conductivity , vertical hydraulic conductivity , and specific yield) with reasonable accuracy Moench (1997) .The transmissivity and specific yield are estimated from the Figs. 4.1-4.15.

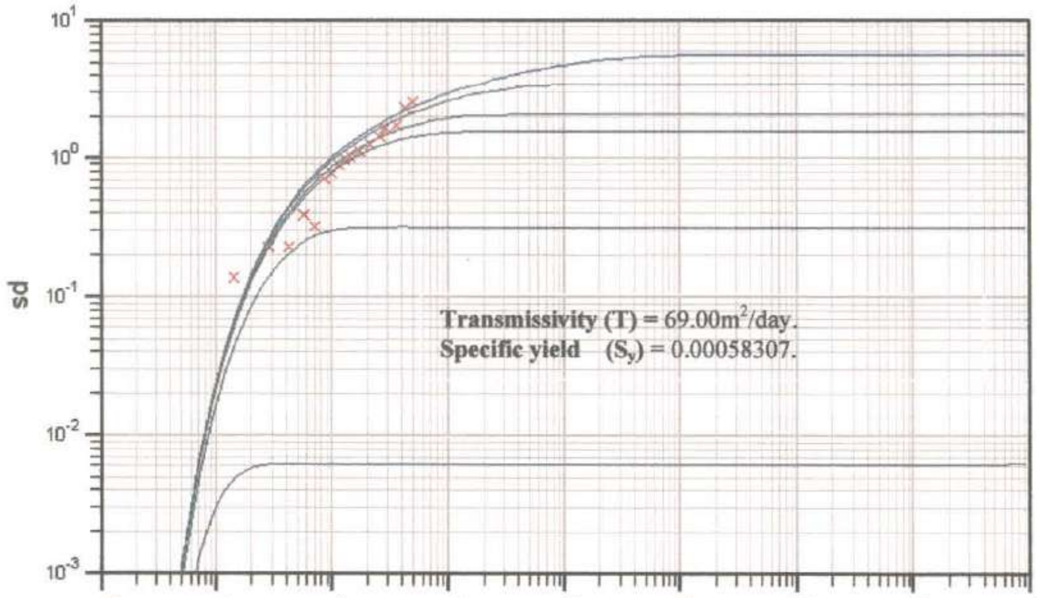


Fig.4.1. Time-drawdown graph for well no.11

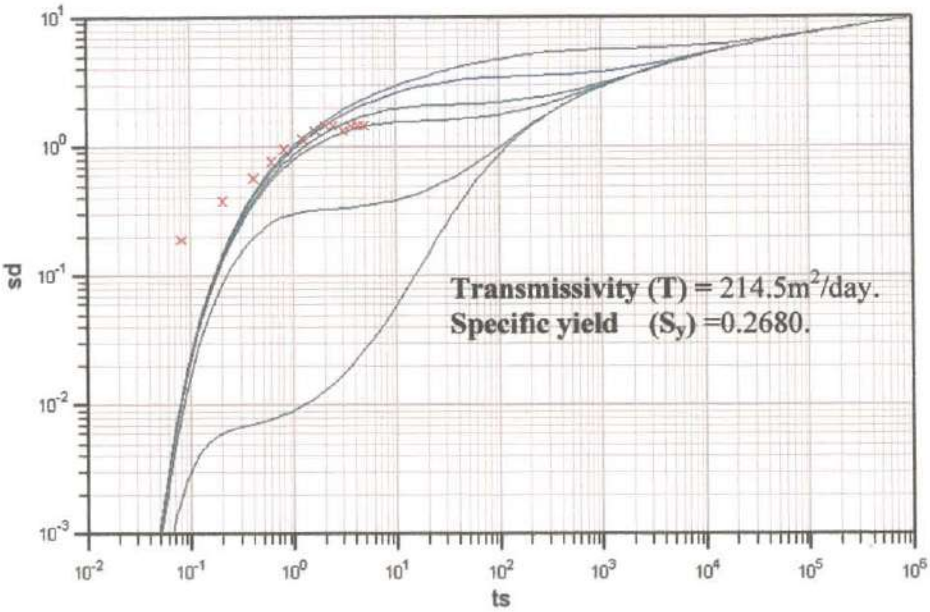


Fig.4.2 Time-drawdown graph for well no.13

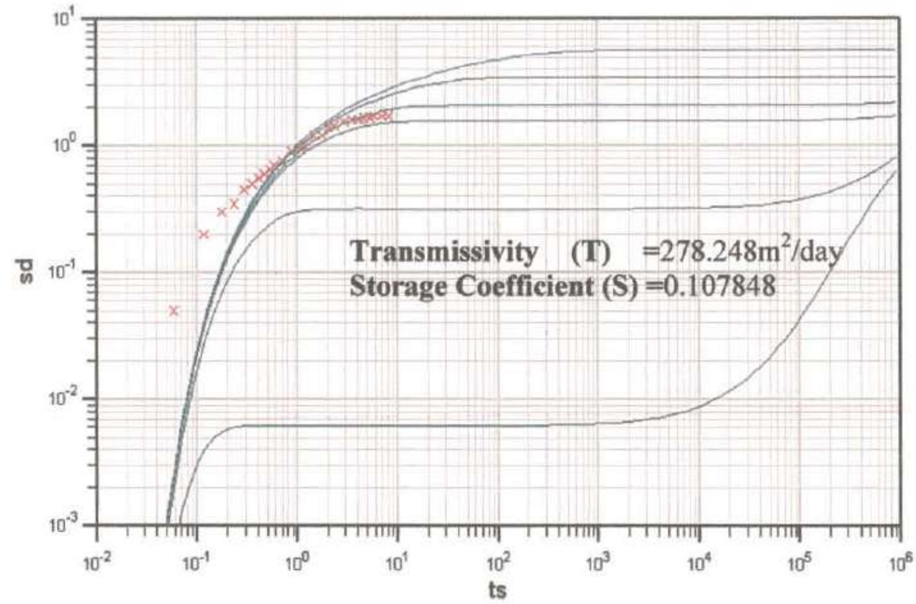


Fig.4.3 Time-drawdown graph for well no.14

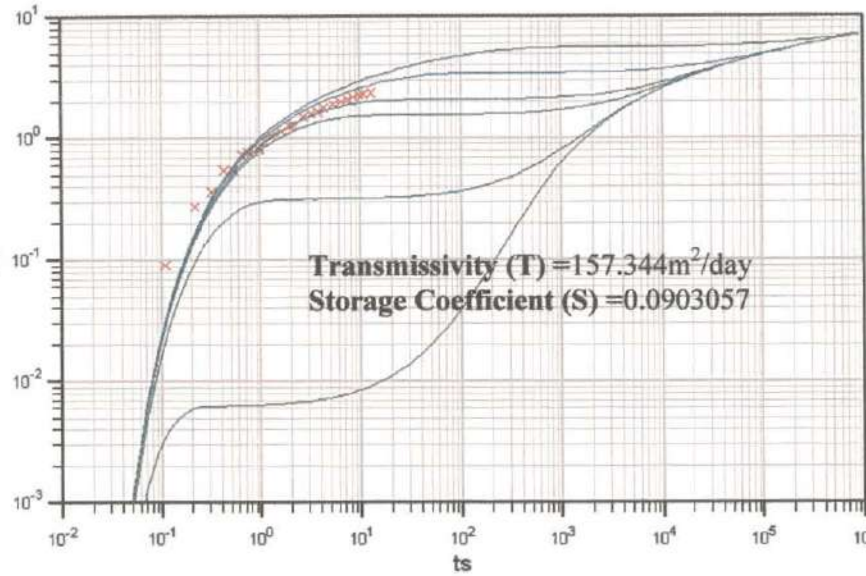


Fig.4.4 Time-drawdown graph for well no.17

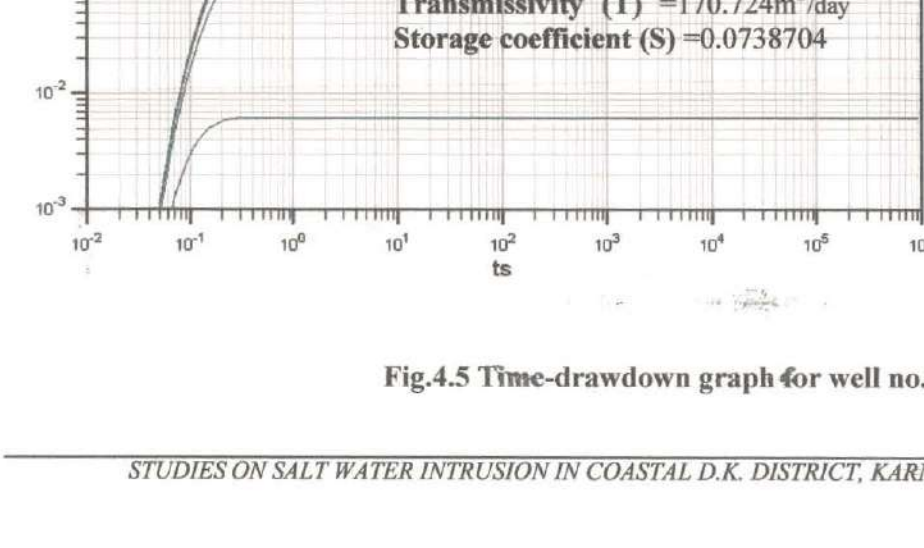


Fig.4.5 Time-drawdown graph for well no.24

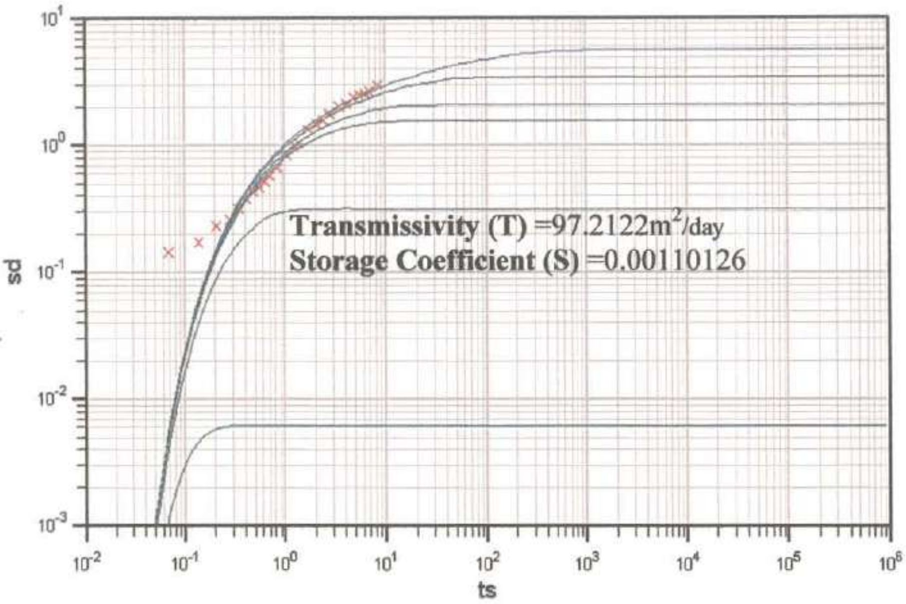


Fig.4.6 Time-drawdown graph for well no.26

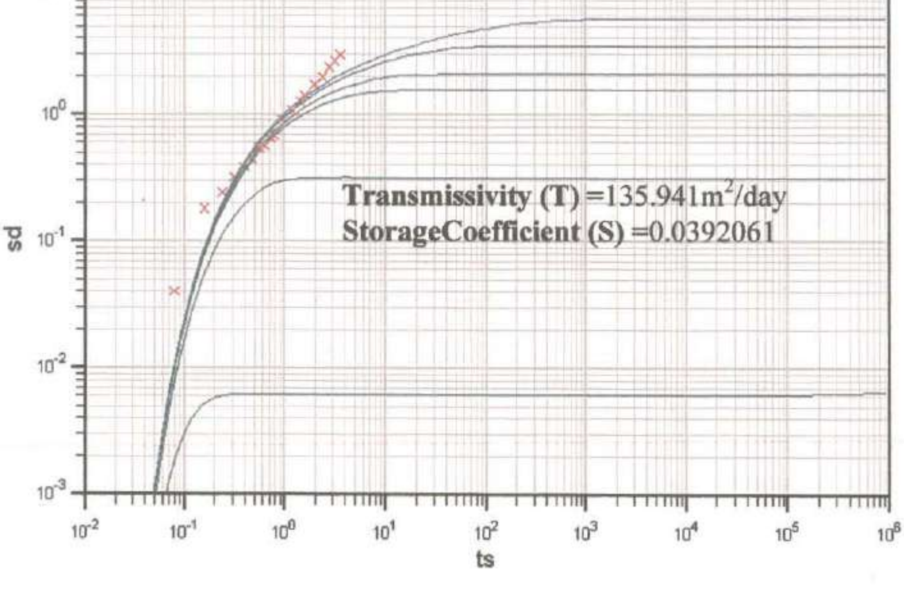


Fig.4.7 Time-drawdown graph for well no.32

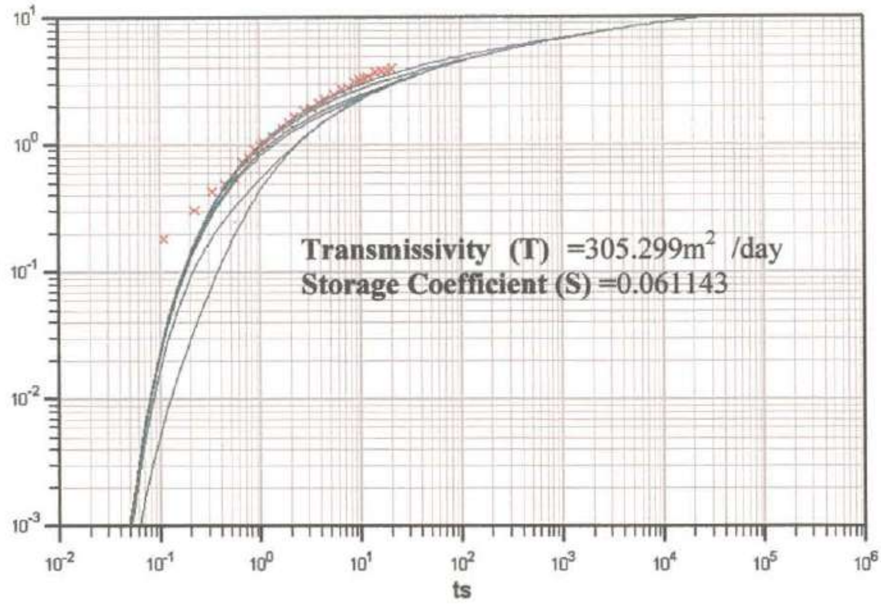


Fig.4.8 Time-drawdown graph for well no.37

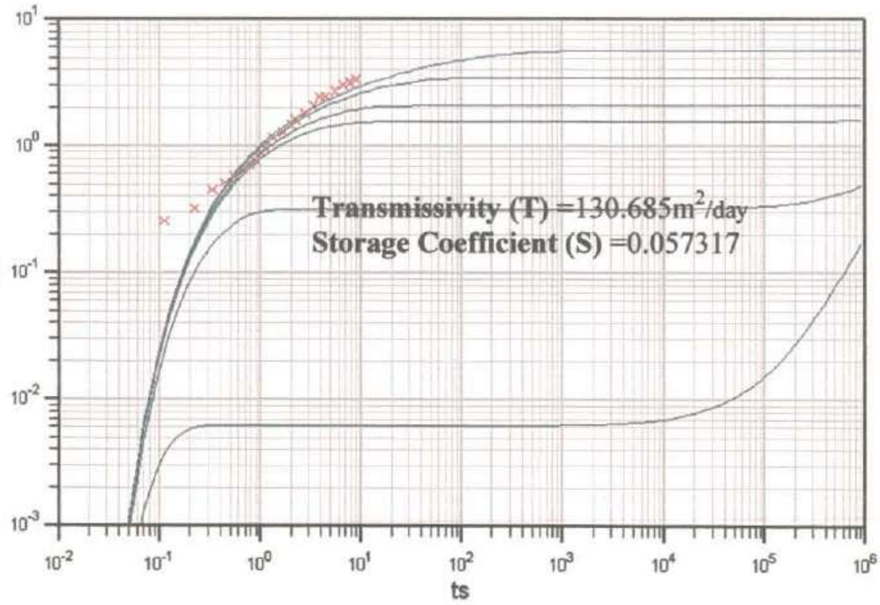


Fig.4.9 Time-drawdown graph for well no.38

Fig.4.10 Well No.39

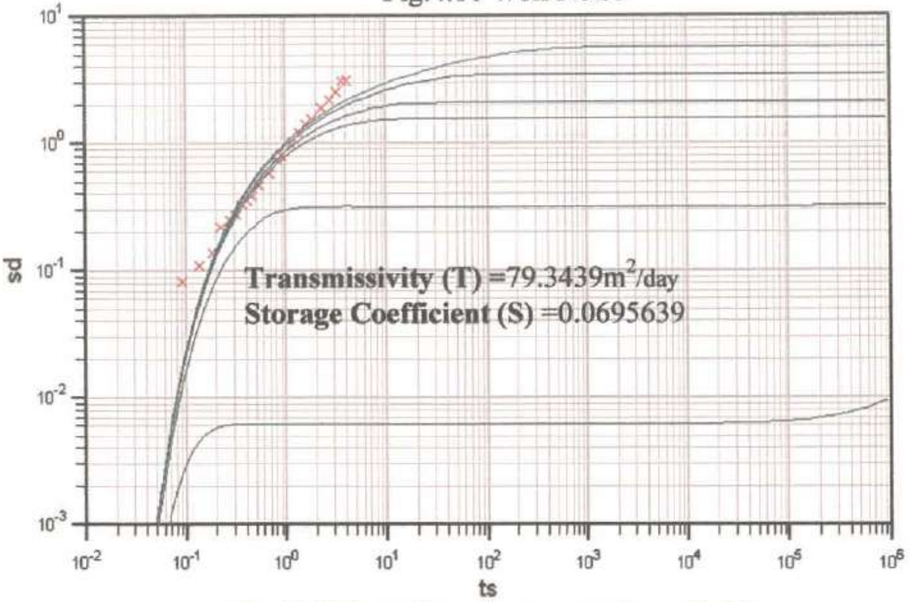


Fig.4.10Time-drawdown graph well-39

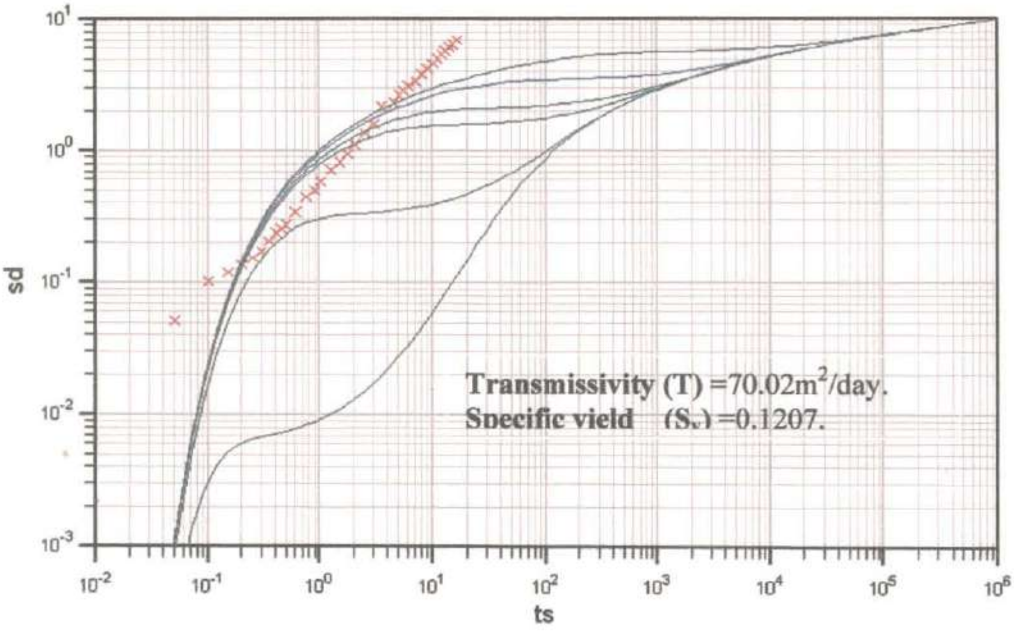


Fig.4.11 Time-drawdown graph for well no.40

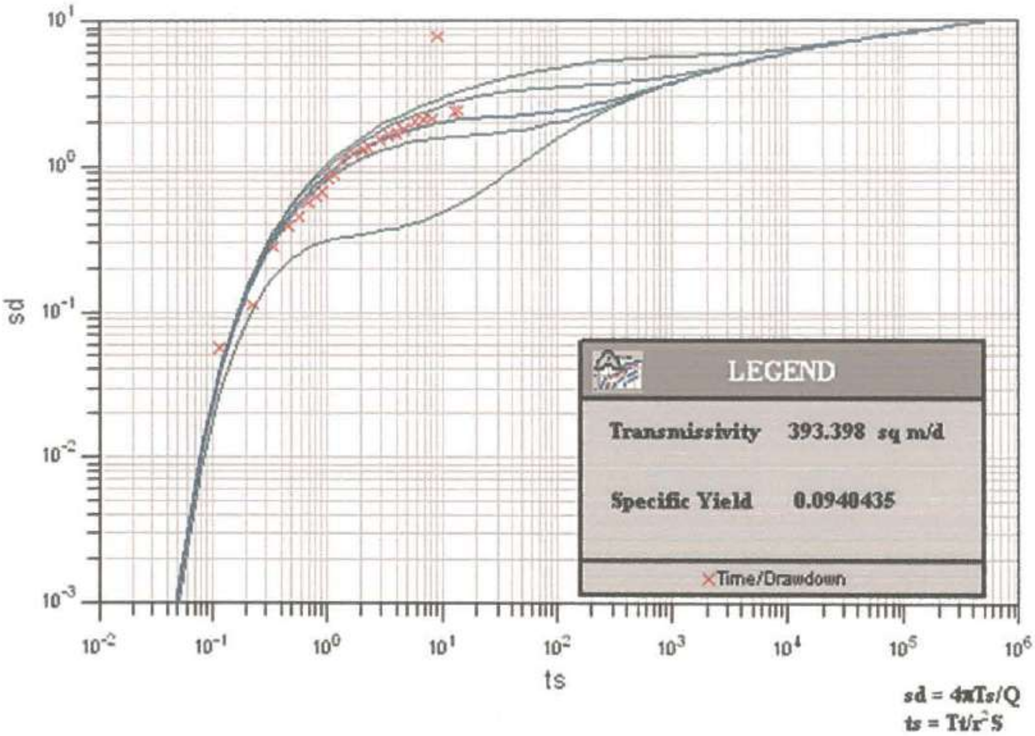


Fig.4.12. Time-drawdown graph for well no.P1

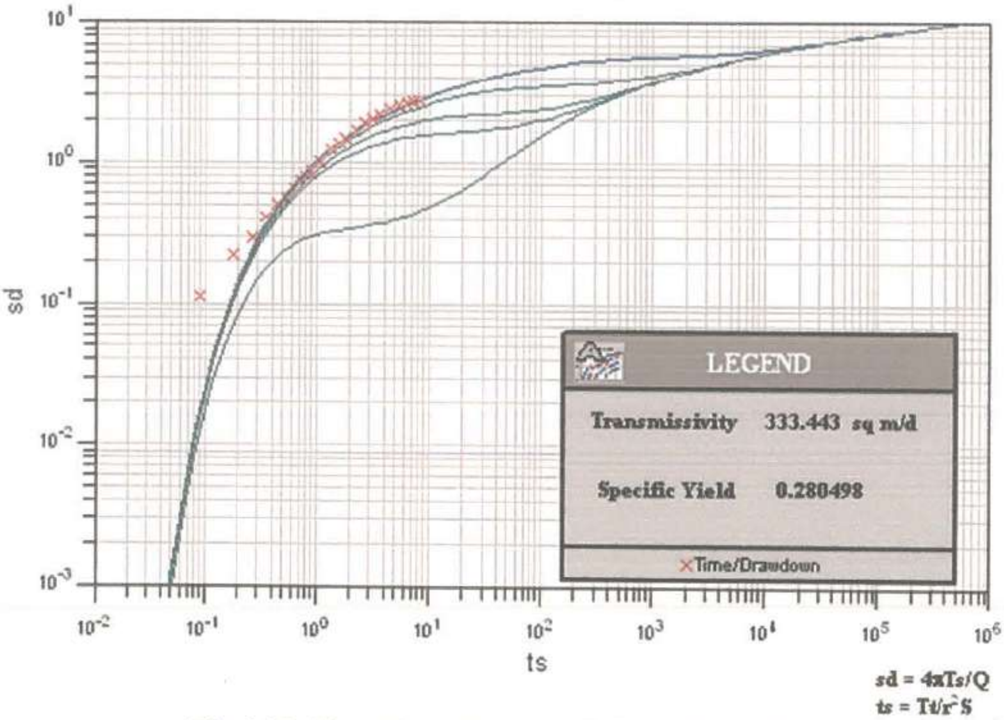


Fig 4.13. Time-drawdown graph for well no. P2

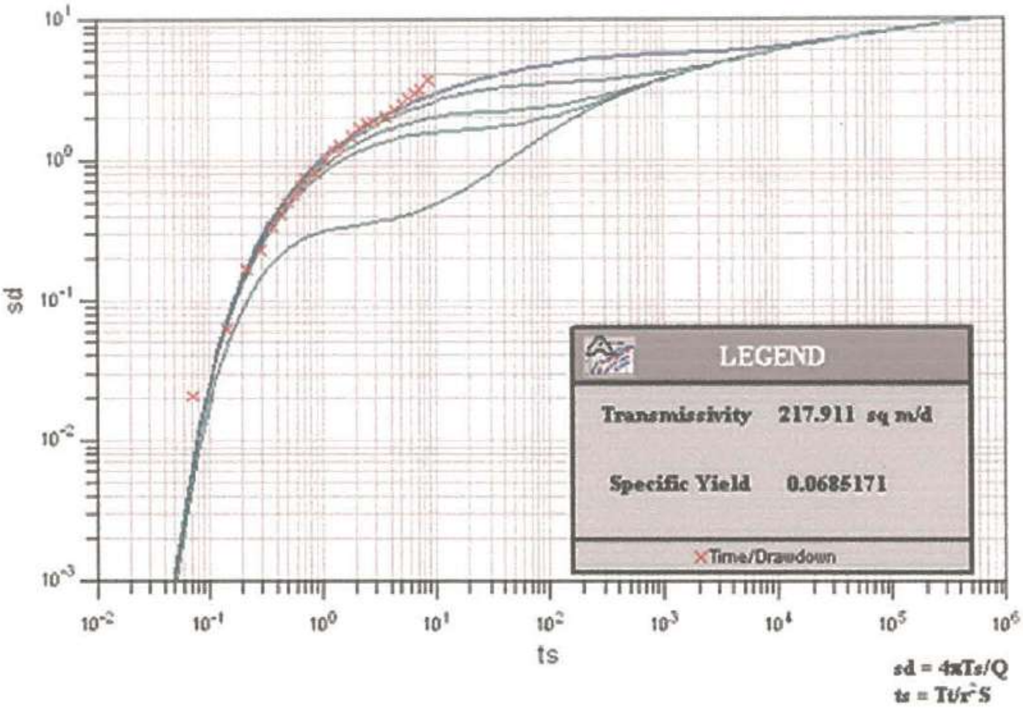


Fig.4.14. Time-drawdown graph for well no. P3

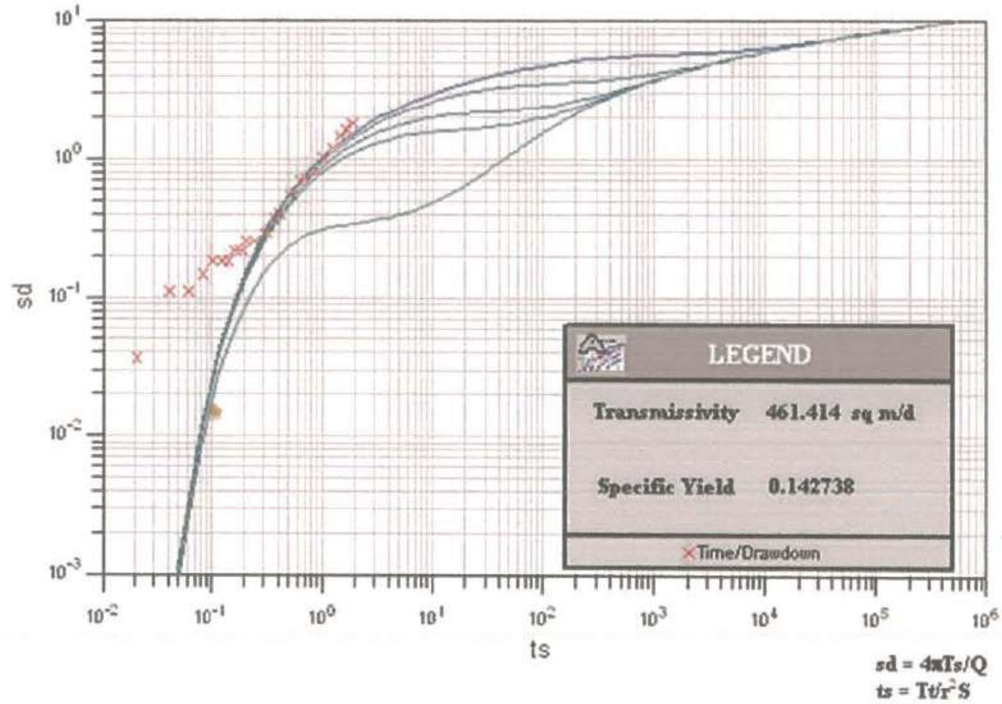


Fig.4.15 Time-drawdown graph for well no. P4

The results of the pumping tests for the wells are as given in table 4.9

Table 4.9. Aquifer parameters determined from the pumping tests

Sl. No.	Well No.	Transmissivity (T) m2/day	Storage Coefficient
1	11	69.0	0.00058
2	13	214.5	0.26800
3	14	278.2	0.10784
4	17	157.3	0.09030
5	24	170.7	0.07387
6	26	97.2	0.00110
7	32	135.9	0.03920
8	37	305.3	0.06114
9	38	130.7	0.05731
10	39	79.3	0.06956
11	40	70.0	0.12070
12	P1	393.4	0.09400
13	P2	333.4	0.28050
14	P3	217.9	0.06850
15	P4	461.4	0.14270

From the result it was found out that Transmissivity values range from $69m^2$/day to $461.4m^2$/day in the study area which indicates that the aquifer is medium to good in groundwater potential.. Transmissivity values increase towards the northern part of the basin with a patch of high transmissivity in south-eastern part of the basin. The lowest transmissivity was found near the coast and highest values are found in the south eastern values region (near NMPT). It maybe concluded that there is a general increase in transmissivity values towards the northern boundary of the study area. For unconfined aquifers, the storage coefficient is same as the specific yield (because of gravity flow). Under confined conditions the mechanism of water release is due to the compressibility of aquifer and the expansion of water. The specific yield values range from 0.00058 to 0.2805. The specific yield values indicate that the aquifer is having average to good yield. Lowest specific yield values are found near the coast and highest values are found near the eastern boundary of the study area. This is also confirmed from the studies conducted by Raghuntha et al., (2001).

The permeability or hydraulic conductivity of a soil refers to the readiness with which a soil conducts or transmits water. Some of the factors like grain size, properties of the pore fluid, void ratio of the soil, structure of soil, etc. readily influence permeability. In general, permeability increases with porosity and with size of the pores.

The hydraulic conductivity "K" can be determined by dividing transmissivity by the total thickness of the aquifer or the total saturated thickness of the aquifer pierced by the well (Sharma and Seetharam, 1981). The details are given in the table 4.10

$$K = T / B \tag{4.1}$$

where, K= Hydraulic conductivity in m/day

T = Transmissivity in m^2/day

B = Total thickness of the aquifer tapped in meter.

Table 4.10 Hydraulic conductivity estimated from the pumping tests

Well No.	Transmissivity (m^2/day)	Saturated aquifer thickness (B) in m	Hydraulic conductivity (m/day)	Specific yield
P1	393.398	4.46	88.206	0.0940
P2	333.443	3.21	103.88	0.2805
P3	217.911	2.47	88.22	0.0685
P4	461.414	2.65	174.12	0.1427

4.2 The Vertical Electrical Sounding

The vertical electrical sounding tests were conducted at the earlier specified locations by Dr.B.M.Ravindra, Senior Geologist, Dept. of Mines and Geology, Bangalore. The results are tabulated in table 4.11 a and b. The distance AB/2 (in meters) refers to half of the outer electrode spacing. The overburden refers to the estimated thickness (in meters) of soil and laterite-clay capping over the hard rock. Underneath the overburden, the hard rock is represented by gneiss in the area. The presence of salinity is indicated with low values of the resistivity. The estimated depth to saline layer is indicated in the results. The fractures refer to estimated depths at which major ground water bearing aquifer formations are expected to strike while drilling bore wells. Litholog is constructed based on the field observations coupled by VES studies. The [soil + sand, silt + laterite + clays] section constitutes the total overburden in the area.

AB/2 (m)	W1	W2	W3	W4	W7	W9	W10	W11	W12	W13	W14	W17	W19	W24
10	438.52	173.28	114	82.8	839.1	1610.4	957.6	200.64	136.1	29.6	159.6	58.52	203.6	47.12
20	495.9	991.8	220.9	167.1	**70.5**	354.7	661.2	365.4	334.1	62.6	**1.7**	113.1	71.3	**3.48**
30	1057.4	622	556.6	289.2	295.45	634.4	1418.2	304.78	590.9	108.8	115.1	174.16	130.6	**31.1**
40	1770.9	759.8	1080.1	577.7	621.7	1257.8	2373.8	753.6	1180.6	207.2	979.6	307.7	**25.12**	357.96
50	1832.6	1862	1538.6	862.4	891.8	1950.2	2832.2	2352	872.2	313.6	480.2	2303	**9.8**	480.2
60	303.8	784	2254	1656.2	921.2	1852.2	1293.6	1568	1450.4	303.8	744.8	480.2	1421	294
70	1200.4	1372	**29.4**	940.8	862.4	1744.4	774.2	882	2616.6	294	1107.4	2979.2	235.2	793.8
80	743.33	2410.8	2651.8	1446.4	1808.1	4299.2	1185.3	602.7	2752.3	nm	nm	823.6	200.9	1526.8
90	76.2	4064	nm	nm	nm	5791.2	1981.2	584.2	nm	nm	nm	nm	nm	nm
Overburden	18m	24m	24m	28m	24m	18m	20m	24m	24m	22m	24m	22m	24m	24m
Salinity			56m		18m						16m		35m	16m
Fractures	50,72m	24,50m	16,24,56m	32,56m	32,58m	24m	56m	65,70m	40m	56m	40m	30,60m	35,60m	48m
Litholog	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
	-	-	-	-	Sand,silt	-	-	-	-	-	-	-	-	Sand,silt
	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite
	clays	clays	clays	clays	clays	clays	clays	clays	clays	clays	clays	clays	clays	clays
	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss

Table 4.11(a): Apparent resistivity data for the study area

AB/2	W 26	W 31	W 32	W 33	W 35	W 36	W 38	W 40
10	319.2	440.8	288.8	106.4	294.12	410.4	77.52	243.2
20	**28.8**	107.88	**53.94**	**36.54**	208.8	73.08	106.14	156.6
30	**45.31**	**18.66**	127.51	321.29	245.69	223.92	80.86	450.95
40	251.2	383.08	**87.92**	238.64	200.96	797.56	288.88	1130.4
50	313.6	**58.8**	421.4	**29.4**	107.8	1519	2577.4	2058
60	nm	**68.6**	186.2	480.2	**78.4**	176.4	1166.2	1617
70	nm	705.6	940.8	362.6	284.2	323.4	813.4	725.2
80	nm	1607.2	803.6	863.87	683.06	1506.75	1808.1	1386.21
Overburden	24m	24m	30m	20m	24m	24m	26m	24m
Salinity	16m	24 m	16m	16m				
Fractures	32,40m	40,50m	32,48,64m	40m	50m	48,56m	56m	56m
Litholog	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
	-	-	-	-	Sand,silt	-	-	-
	laterite	laterite	laterite	laterite	laterite	laterite	laterite	laterite
	clays	clays	clays	clays	clays	clays	clays	clays
	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss	gneiss
	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil

Table 4.11(b): Apparent resistivity data for the study area

4.2.1 Determination of the hydraulic conductivity from the VES data

The transmissivity is evaluated from the VES data as follows:

Transmissivity,T=834.4+0.8795T' (Nath et. al. , 2000) (4.2)

where T'= transverse resistance, Ω-m^2

The hydraulic conductivity values calculated from VES data are tabulated in table.4.12. The hydraulic conductivity in the study area shows a very wide distribution ranging from 43.42m/day to 623.45m/day.

Table 4.12 Aquifer parameters evaluated from the VES data.

Location (Well No.)	Thickness of the aquifer ,B from VES data (m)	Resistivity, ρ_0 (Ω-m) of the aquifer	Transverse resistance, T'(Ω-m^2)	Predicted transmissivity, T(m^2/day)	Hydraulic conductivity, K=T/B (m/day)
1	20	495.9	9918	9561.28	478.06
2	20	991.8	19836	18284.16	914.21
3	20	220.9	4418	4724.03	236.20
4	30	289.2	8676	8468.94	282.30
7	20	70.5	1410	2078.50	103.92
9	20	354.7	7094	7077.57	353.88
10	20	661.2	13224	12468.91	623.45
11	20	365.4	7308	7265.79	363.29
12	20	334.1	6682	6715.22	335.76
13	20	62.6	1252	1939.53	96.98
14	20	1.7	34	868.30	43.42
17	20	113.1	2262	2827.83	141.39
19	20	71.3	1426	2092.57	104.63
24	20	3.48	69.6	899.61	44.98
26	20	28.8	576	1344.99	67.25
31	20	107.88	2157.6	2736.01	136.80
32	30	127.51	3825.3	4202.75	140.09
33	20	321.29	6425.8	6489.89	324.49
35	20	245.69	4913.8	5160.09	258.00
36	20	223.92	4478.4	4777.15	238.86
38	30	80.86	2425.8	2971.89	99.06
40	20	156.6	3132	3592.99	179.65

The SURFER 8 package is used to draw the vulnerability contour map and all the six GALDIT parameters. The SURFER 8 is a contouring and 3D surface mapping program that runs in Microsoft Windows. It quickly and easily converts the data into contour, surface, wire frame, vector, image, shaded relief, and post maps. Fig.4.16 shows the hydraulic conductivity distribution in the study area as per VES data.

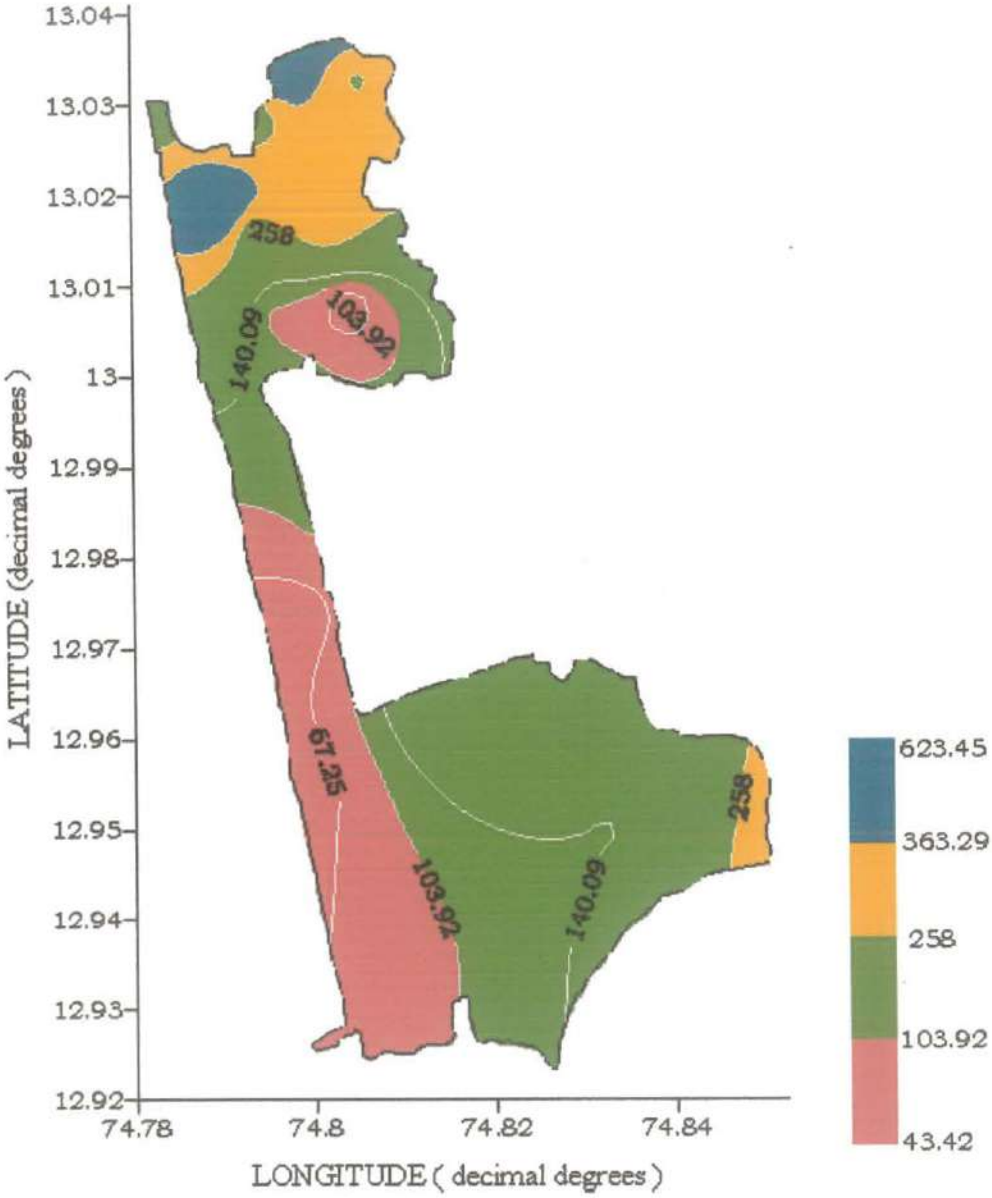


Fig.4.16 (a) Hydraulic conductivity distribution in the study area as per VES **(b) Distribution index (m/day)**

The figure shows values lesser than 100 m/day along the coast and a higher range around the Gurupur river (Baikampady, Kenjar, Jokatte) between 100 m/day to 250 m/day. The values greater than 250m/day were estimated around Surathkal, Chelaru, Haleyangadi and Mukka. The very high values of 914.21m/day and 623.45m/day near well nos. 2 and 10 are estimated which may be due to the presence of saline water and hence may not be taken into consideration. While studying the physical properties of normal and saline soils of Utter Pradesh, Pandey and Pathak (1975) found that, the hydraulic conductivity is logarithmically related to the degree of saturation of the soil with sodium.

4.2.2 Assessment of saltwater intrusion based on VES data

In table.4.11 (a) and (b) the resistivity values depicted in bold indicates very low resistivity (< 70 Ω-m) and saltwater intrusion is suspected in such locations. Also, the estimated depth of saline incursion is given in the table for the respective location. From these results it indicates that the areal extent of saltwater intrusion at present is not significant. Fig.4.17 shows the saltwater intrusion affected spots in the study area. According to the figure well nos.3 (Haleyangadi), 7 (Mukka), 14 and 19 (Surathkal), 24 (Hasaobettu), 26 (Chitrapur), 31 (Biakampady), 32 and 33 (Kenjar) seems to be affected by saltwater intrusion.

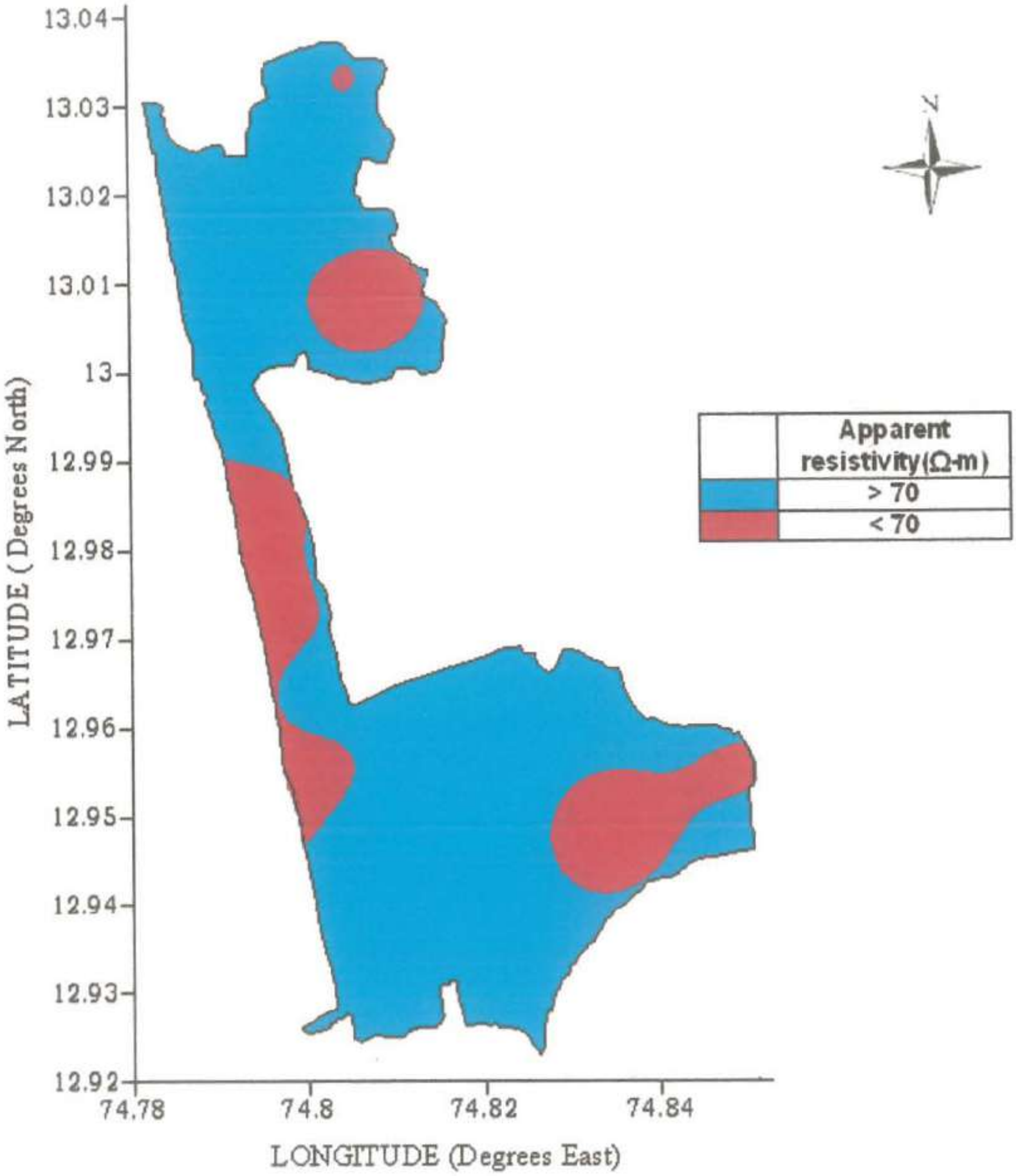


Fig.4.17 Saltwater intrusion affected areas from VES data

4.2.3 Determination of the hydraulic conductivity from soil investigations (Barr, 2000):

4.2.3.1 Determination of specific gravity

The results of the specific gravity analysis of eight soil samples near the monitoring wells are presented in the table 4.13. The specific gravity range observed was 2.12 to 2.79.

Table4.13 Specific gravity analysis results

Soil sample/Well No. →		1/2	2/4	3/12	4/40	5/26	6/31	7/36	8/38
Sl. No.	Details								
1	W_1(grams)	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4
2	W_2(grams)	53.6	51	49.5	42.9	52.5	41.6	38.6	42.7
3	W_3(grams)	92.9	92.7	91.1	87.3	93.1	87.2	86	87.8
4	W_4(grams)	80.1	80.1	80.1	80.1	80.1	80.1	80.1	80.1
5	Gs	2.12	2.4	2.21	2.14	2.29	2.39	2.79	2.38

4.2.3.2 Determination of bulk density by core cutter method

The results of the bulk density of eight soil samples near the monitoring wells are presented in the table 4.14. The bulk density range observed was 1.265gms/cc to.1.842gms/cc.The bulk density of most soils ranges from 1.0gms/cc for clays to 1.8 gms/cc for sands (Richards, 1968)

Diameter of the core (d) =10.1 cm

Height of the core (h) = 12.1 cm

Volume of the core (V) = $\pi d^2h/4$ = 969.43 cc

Table 4.14 Bulk and dry densities of soil mass in the study area

Soil sample/Well No. →		1/2	2/4	3/12	4/40	5/26	6/31	7/36	8/38
Sl. No.	Details								
1	W_1(grams)	1715	1715	1715	1715	1715	1715	1715	1715
2	W_2(grams)	3500.3	3391.1	3265.8	2941.7	3357.9	3462.5	3485.8	3458
3	ρ (gms/cc)	1.842	1.729	1.600	1.265	1.695	1.803	1.827	1.798
Water content of soil									
4	A (grams)	24.6	26.8	22.4	25	28.5	28.4	26.3	27.1
5	B (grams)	75.9	73.3	73.5	48.4	77.4	71	68.7	69.6
6	C (grams)	70	72	72.1	47.7	76.9	68.2	63.2	64.5
7	ω (%)	13	2.88	2.82	3.08	1.03	7.04	14.91	13.64
8	ρ_d (gms/cc)	1.630	1.681	1.556	1.228	1.677	1.684	1.590	1.582

4.2.3.3 Determination of the porosity

This is an important factor because it is also involved in the hydraulic radius. The position of the interface is not affected by the change in the porosity. It leads to the change in the time period to achieve the steady state of the interface. Reduction in porosity accelerates the movement of the interface and it drives the system to steady state over a shorter time period. Theoretically, it can be explained as the freshwater head leads to steady state more rapidly since less water must drain from the pores and the interface changes more rapidly. The porosity of the laterite formation in the area ranges from 0.25-0.3 (Bhosale and Kumar, 2001).

Table 4.15 Porosity of soil mass in the study area

Soil → sample/WellNo.	½	2/4	3/12	4/40	5/26	6/31	7/36	8/38
Specific gravity,Gs	2.12	2.4	2.21	2.14	2.29	2.39	2.79	2.38
Dry bulk density (gm/cc)	1.63	1.681	1.556	1.228	1.677	1.684	1.59	1.582
Void ratio	0.301	0.428	0.420	0.743	0.366	0.419	0.755	0.504
Porosity (%)	23.113	29.958	29.593	42.617	26.769	29.540	43.011	33.529

The results about the porosity of the soil samples are presented in table 4.15.The samples indicate medium porosity in the range 23.113% to 43.011%. The sieve analysis details of the soil samples are given in table 4.16. From the above details, the aquifer hydraulic conductivity values are evaluated as given in table 4.17. The hydraulic conductivity values range between 37.14m/day to 717.99 m/day from the soil investigations as it is evident from table 4.17.

Table 4.16 Sieve analysis results

		Soil+sieve wt (gms)								Weight of the soil (gms)								Volume of particles (mm^3)
Soil sample/WellNo →		½	2/4	3/12	4/40	5/26	6/31	7/36	8/38	1/2	2/4	3/12	4/40	5/26	6/31	7/36	8/38	
Sieve size (mm)	Empty sieve wt. (gms)																	
4.750	395.1	564.6	594.3	558.7	570.08	423.64	740.12	591.5	442.02	169.5	199.2	163.6	174.98	28.54	345.02	196.4	169.5	56.1377
2.360	403.1	613.03	594.53	569.13	588.64	427.04	591.85	662.3	478.66	209.93	191.43	166.03	185.54	23.94	188.75	259.2	209.93	6.88509
1.180	333.3	573.76	558.69	526.4	526.64	460.76	509.68	640.9	450.69	240.46	225.39	193.1	193.34	127.46	176.38	307.6	240.46	0.86064
0.600	372.3	567.99	564.26	578.67	558.88	434.61	547.45	513.3	722.34	195.69	191.96	206.37	186.58	62.31	175.15	141	195.69	0.11314
0.300	209.9	295.36	303.42	330.32	308.77	545.72	277.9	263.6	466.99	85.46	93.52	120.42	98.87	355.82	68	53.7	85.46	0.01414
0.150	458.3	520.28	520.12	559.55	536.66	811.29	490.63	485.4	574.42	61.98	61.82	101.25	78.36	352.99	32.33	27.1	61.98	0.00177
0.075	319.7	345.8	347.4	354.28	367.55	361.87	330.5	333.3	342.14	26.1	27.7	34.58	47.85	42.17	10.8	13.6	26.1	0.00022
PAN	451.7	462.56	460.68	466.35	486.16	478.49	455.28	452.1	466.16	10.86	8.98	14.65	34.46	26.79	3.58	1.4	10.86	5.24E-10
										999.98	1000	1000	999.98	1000.02	1000.01	1000	999.98	

Table 4.17 Determination of the hydraulic conductivity

Weight of one particle retained on each sieve (gms)								
Soil sample/WellNo. → Sieve size (mm)	1\2	2\4	3\12	4\40	5\26	6\31	7\36	8\38
4.750	0.11917	0.13473	0.12400	0.12029	0.12839	0.13429	0.15650	0.13333
2.360	0.01462	0.01652	0.01521	0.01475	0.01575	0.01647	0.01919	0.01635
1.180	0.00183	0.00207	0.00190	0.00184	0.00197	0.00206	0.00240	0.00204
0.600	0.00024	0.00027	0.00025	0.00024	0.00026	0.00027	0.00032	0.00027
0.300	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00004	0.00003
0.150	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.075	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Pan	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
No. of Particles on each sieve								
4.750	1.42E+03	1.48E+03	1.32E+03	1.45E+03	2.22E+02	2.57E+03	1.25E+03	3.52E+02
2.360	1.44E+04	1.16E+04	1.09E+04	1.26E+04	1.52E+03	1.15E+04	1.35E+04	4.62E+03
1.180	1.32E+05	1.09E+05	1.02E+05	1.05E+05	6.48E+04	8.57E+04	1.28E+05	5.74E+04
0.600	8.15E+05	7.07E+05	8.26E+05	7.70E+05	2.41E+05	6.47E+05	4.47E+05	1.30E+06
0.300	2.85E+06	2.76E+06	3.85E+06	3.26E+06	1.04E+07	2.01E+06	1.36E+06	7.65E+06
0.150	1.65E+07	1.46E+07	2.59E+07	2.07E+07	8.73E+07	7.64E+06	5.50E+06	2.77E+07
0.075	5.56E+07	5.22E+07	7.08E+07	1.01E+08	8.34E+07	2.04E+07	2.21E+07	4.28E+07
Pan	9.77E+09	7.14E+09	1.27E+10	3.07E+10	2.24E+10	2.86E+09	9.59E+08	1.16E+10
Surface area of particles(mm^2)								
4.750	4.03E+05	4.19E+05	3.74E+05	4.13E+05	6.30E+04	7.29E+05	3.56E+05	9.98E+04
2.360	1.01E+06	8.11E+05	7.64E+05	8.81E+05	1.06E+05	8.02E+05	9.45E+05	3.24E+05
1.180	2.30E+06	1.91E+06	1.78E+06	1.84E+06	1.13E+06	1.50E+06	2.24E+06	1.01E+06
0.600	3.69E+06	3.20E+06	3.74E+06	3.48E+06	1.09E+06	2.93E+06	2.02E+06	5.90E+06
0.300	3.22E+06	3.12E+06	4.36E+06	3.69E+06	1.17E+07	2.27E+06	1.54E+06	8.66E+06
0.150	4.67E+06	4.12E+06	7.33E+06	5.85E+06	2.47E+07	2.16E+06	1.56E+06	7.82E+06

0.075	3.93E+06	3.69E+06	5.01E+06	7.15E+06	5.90E+06	1.44E+06	1.56E+06	3.02E+06
Pan	1.23E+05	8.98E+04	1.59E+05	3.86E+05	2.81E+05	3.59E+04	1.21E+04	1.46E+05
Total	1.93E+07	1.74E+07	2.35E+07	2.37E+07	4.50E+07	1.19E+07	1.02E+07	2.70E+07
Hydraulic Conductivity (m/day)	201.00	249.67	136.06	134.16	37.14	533.53	717.99	103.41

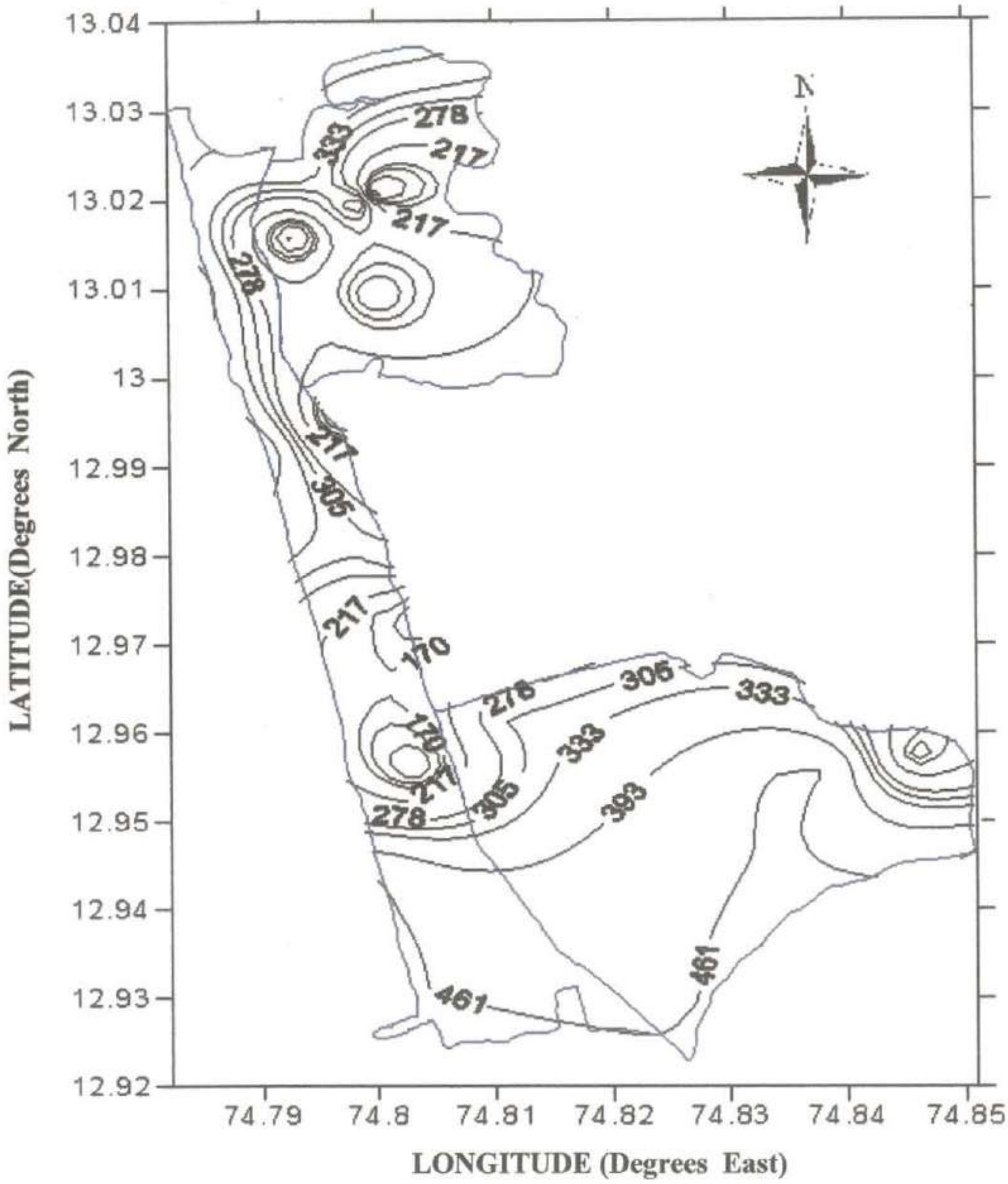


Fig. 4.18 Transmissivity contours for the study area

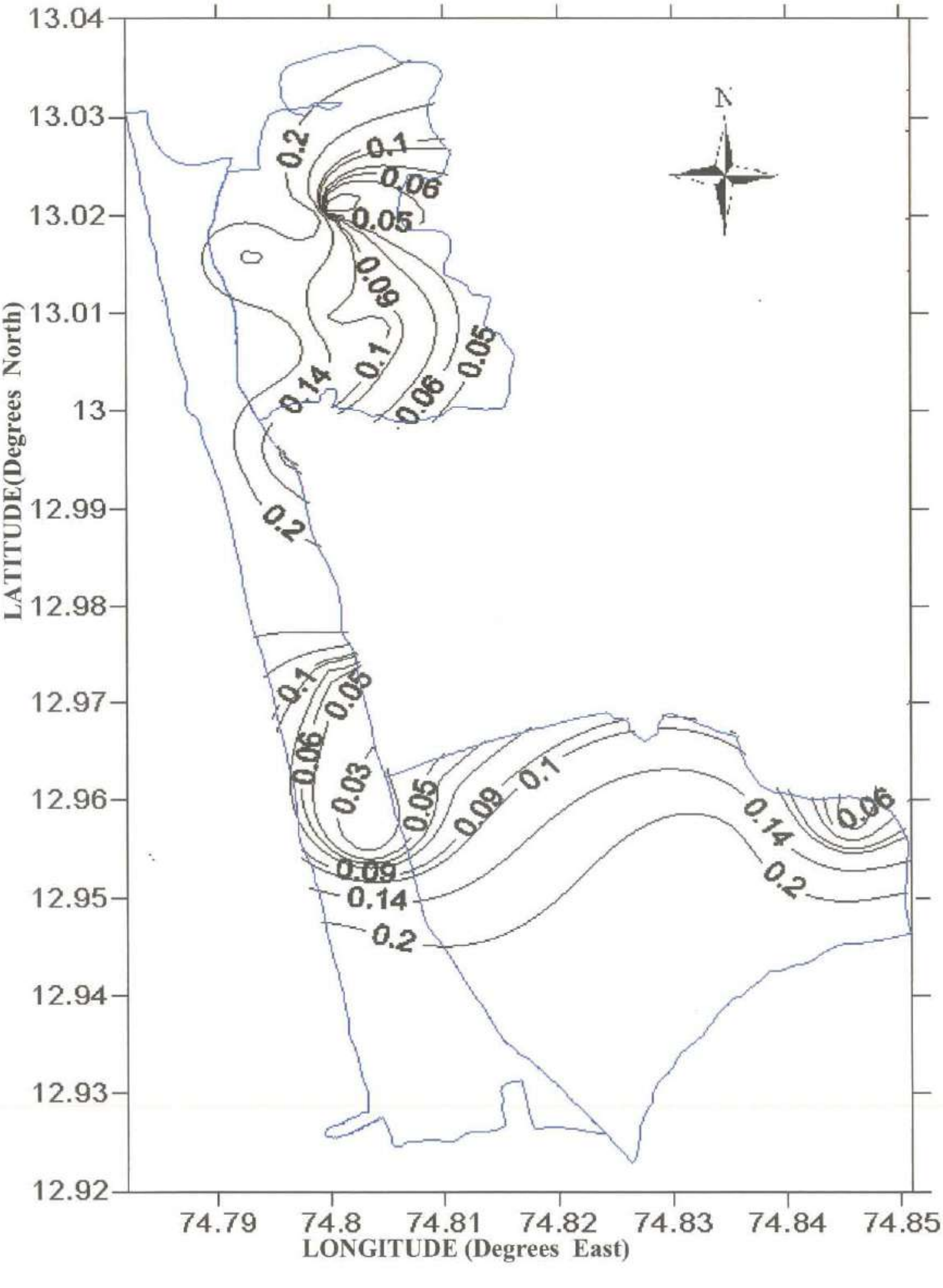


Fig. 4.19 Specific yield contours for the study area

In the study conducted by Raghuntha et al., (2001) thematic maps were generated depicting the aquifer parameters which have been calculated using drawdown and recovery data in the Nethravati river basin. The study revealed that the specific yield and total time for full recovery increases towards the eastern part of the basin (towards the western ghats) whereas the specific capacity and optimum yield decreases. Two patches have been identified (in north-western and south-eastern quarter of the basin) which is characterized by high values of specific capacity and transmissivity and relatively high values of optimum yield and specific yield with fairly low total time for full recovery. Having estimated the transmissivity of the aquifer, the hydraulic conductivity is evaluated as shown below. Considering saturated thickness (b) of the aquifer to be 25m.

4.3 Water table fluctuation

Regular monitoring of water table and water quality was carried out in the study area. From the field observations, the water table contours are prepared on monthly basis and are presented in figs. 4.20-4.28. The results indicate that, the aquifer at present has medium build up (0-5m) of water table above the mean sea level (msl). The water table elevation was found to reach its maximum during the month of September. The details on the water table fluctuations are mentioned in the following sections.

4.4 ESTIMATION OF GALDIT PARAMETERS

4.4.1 Groundwater occurrence, G

From the pump test data it is evident that the aquifer is unconfined in nature with rich groundwater potential and hence a rating of 7.5 is adopted as per the specifications. Also, from the field observations it is evident that the aquifer is shallow and unconfined in nature.

4.4.2 Aquifer hydraulic conductivity, A

Finally, from all the studies conducted to evaluate the hydraulic conductivity in the study area, we can conclude that the hydraulic conductivity varies from 40m/day – 914m/day and hence a common GALDIT rating of 10 can be assigned for the entire study area. Also, earlier investigations in the area (Ranganna et. al., 1985) have indicated the values ranging from 78m/day to 820 m/day from the pumping test carried out in the Gurupur and Pavanje riverbasins.

4.4.3 Height of water above the sea level, L

The groundwater levels were measured every month at the monitoring wells identified. The parameter required for the present study, "L" is obtained by reducing the water level with respect to the mean sea level and is presented in table 4.18. The water level varies from 0.75m to 9.40m in the post-monsoon season (November to January) and varies from 1.33m to 11m in the pre-monsoon season (February to May)

Table 4.18 Height of water above Mean Sea level (m)

Well No.	Height of groundwater above the mean sea level (m)										
	NOV (06)	NOV (06)	DEC (06)	JAN (07)	JAN (07)	FEB (07)	MAR (07)	APRL (07)	APRL (07)	MAY (07)	MAY (07)
1	1.74	1.54	1.14	0.64	0.43	0.07	-0.09	-0.51	-0.35	-0.15	-0.31
2	1.69	1.27	0.91	0.78	0.72	0.39	0.31	-0.12	-0.17	0.00	-0.13
3	4.87	4.54	4.47	4.41	4.39	3.89	3.80	3.31	3.54	3.88	3.36
4	4.79	4.79	4.70	4.70	4.60	4.43	4.23	3.27	3.14	3.13	2.96
5	5.59	5.58	5.68	5.42	5.36	5.34	5.31	4.84	4.87	4.91	4.68
6	-0.80	0.63	-0.48	-0.13	-0.20	-0.62	-2.40	-0.98	-0.36	-0.13	-0.51
8	2.59	2.42	2.14	1.43	1.29	0.82	0.89	0.61	0.59	0.67	0.58
9	2.36	2.12	2.10	1.63	1.51	1.20	0.74	0.46	0.80	0.94	0.73
10	3.68	3.19	3.26	2.57	2.33	1.40	0.91	0.87	0.58	0.72	0.98
11	1.52	1.04	0.36	-0.05	-0.09	-1.00	-1.34	-1.85	-0.73	0.03	-0.88
12	1.24	1.19	0.94	0.75	0.54	-0.07	-0.65	-1.01	-0.15	0.54	0.42
13	5.82	5.70	3.96	1.20	1.62	0.94	2.23	1.72	1.17	3.09	2.73
14	1.47	1.35	1.33	0.96	1.11	0.76	0.43	0.10	0.48	-0.93	0.52
16	3.59	3.50	3.34	2.91	2.74	2.40	2.32	2.84	2.62	3.09	2.60
17	3.81	3.74	3.49	2.90	2.72	2.46	2.25	1.87	2.41	3.00	2.72
18	3.06	2.90	2.59	2.18	2.06	1.82	1.66	1.34	2.08	2.63	1.98
19	3.49	3.19	2.90	2.56	2.37	2.01	1.79	1.44	1.63	1.79	1.74
20	2.78	2.93	2.78	2.63	2.53	2.29	2.05	1.63	1.96	2.30	2.38
21	1.86	1.79	1.75	1.59	1.53	1.35	1.17	1.07	1.33	1.58	1.42
22	2.27	1.78	1.83	1.69	1.56	1.37	1.30	1.31	1.49	1.70	1.61
23	2.44	2.57	2.29	1.84	1.60	1.31	1.08	0.75	0.06	1.14	0.87
24	1.13	1.09	0.94	0.47	0.33	0.35	0.24	0.13	0.32	0.43	0.43
25	1.16	1.24	1.06	0.41	0.60	0.27	0.35	0.25	-0.25	0.68	0.64
26	0.73	0.64	0.58	0.38	0.25	0.20	0.11	-0.06	0.06	0.24	0.41
27	3.11	3.14	2.94	2.41	2.37	1.68	1.68	1.23	1.66	1.67	1.57
28	3.45	3.33	2.82	2.61	2.35	2.02	1.79	0.93	1.17	1.45	1.04
29	3.60	3.62	3.09	2.49	2.09	1.68	1.41	0.88	0.95	1.54	1.35
30	0.53	0.25	0.05	-0.29	-0.47	-2.75	-1.16	-1.20	-0.86	-0.40	-0.45
31	1.08	0.88	0.63	-0.26	-0.50	-1.12	-1.70	-2.70	-2.97	-2.28	-2.94
32	-0.69	-0.78	-1.08	-1.40	-2.28	-2.54	-2.70	-3.31	-2.98	-2.70	-2.98
33	-0.79	-0.62	-1.02	-1.72	-1.82	-2.22	-2.32	-2.48	-2.39	-2.32	-2.51

34	-0.09	-0.36	-0.85	-1.31	-1.51	-1.79	-2.07	-2.85	-3.09	-3.16	-3.29
35	-0.55	-0.55	-0.77	-1.12	-1.37	-1.63	-2.09	-3.32	-3.52	-2.65	-3.75
36	1.14	1.09	0.91	0.94	0.78	-0.10	-0.43	-0.63	-0.28	0.39	0.26
37	2.44	1.80	1.70	1.64	1.15	0.75	0.50	1.01	1.12	1.64	1.45
38	2.95	3.25	2.79	2.55	2.53	2.25	1.98	1.74	1.88	2.45	2.29
39	4.53	4.38	3.93	3.51	3.18	3.00	2.69	2.44	2.64	2.86	2.76
40	4.81	4.34	3.70	1.51	-0.76	0.04	1.64	-2.36	1.94	1.60	1.10
41	7.73	7.37	6.59	6.92	6.28	6.56	6.34	6.11	6.59	7.03	6.84

In the study area, the coastal wells are sunk in the porous soil. They are shallow and get filled to the brim during the rainy season. The water level gradually declines after the rains. In the above table, we can see some negative values which need to be exploited very carefully considering the possibility of saltwater intrusion. The monthly water table distribution is presented in figs 4.20 to 4.28.

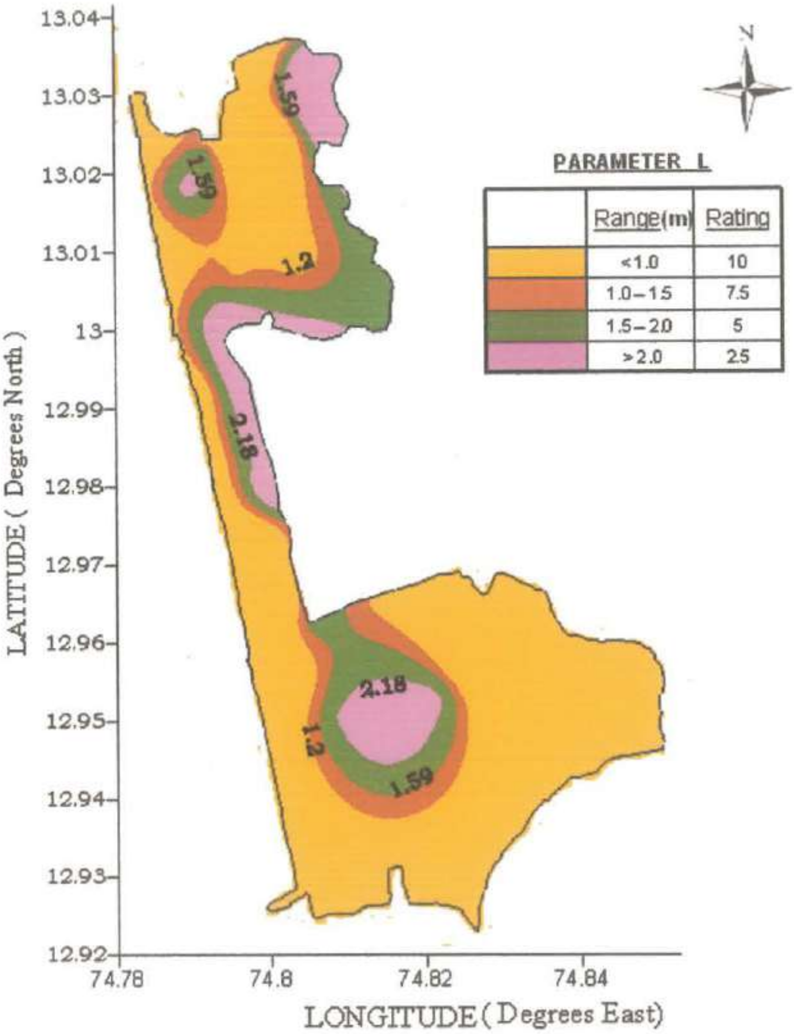


Fig.4.20 The water table elevation on 7th November 2006

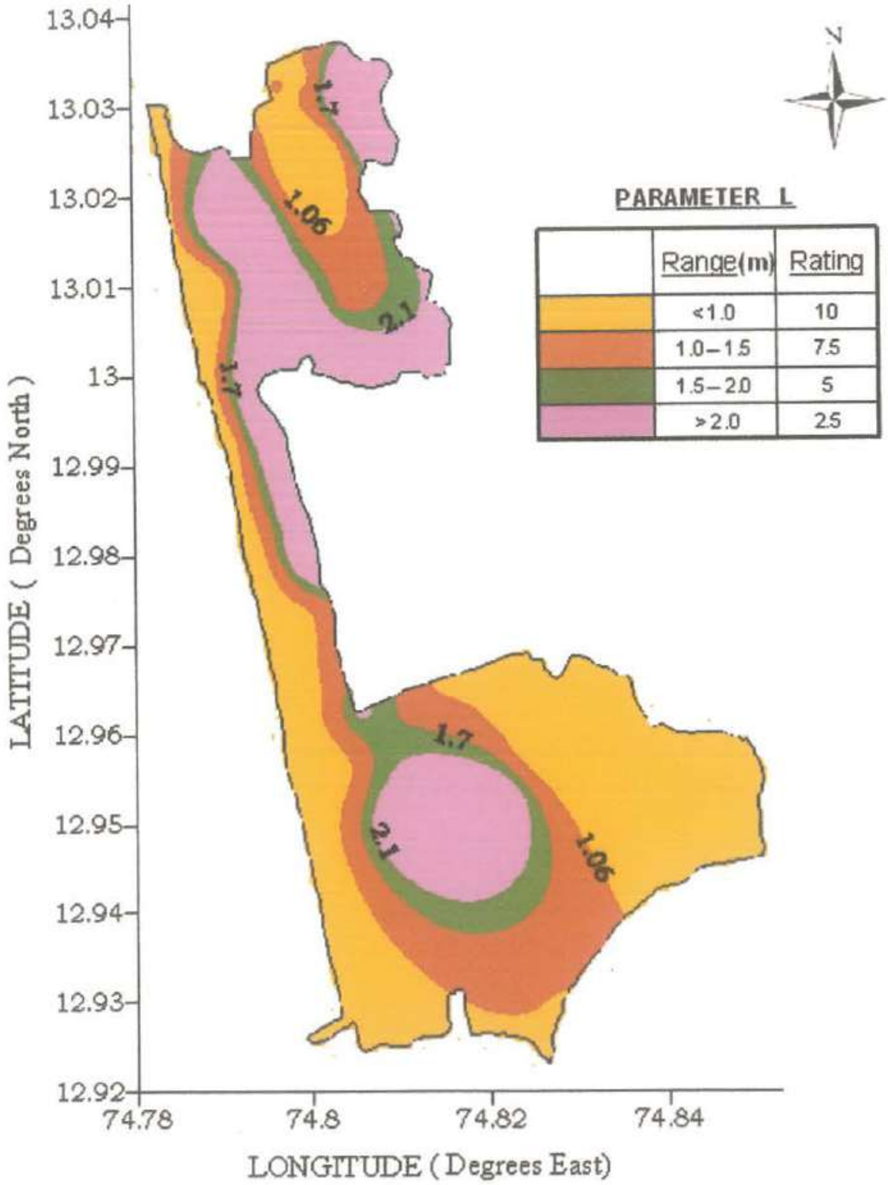


Fig.4.21 The water table elevation on 12th December 2006

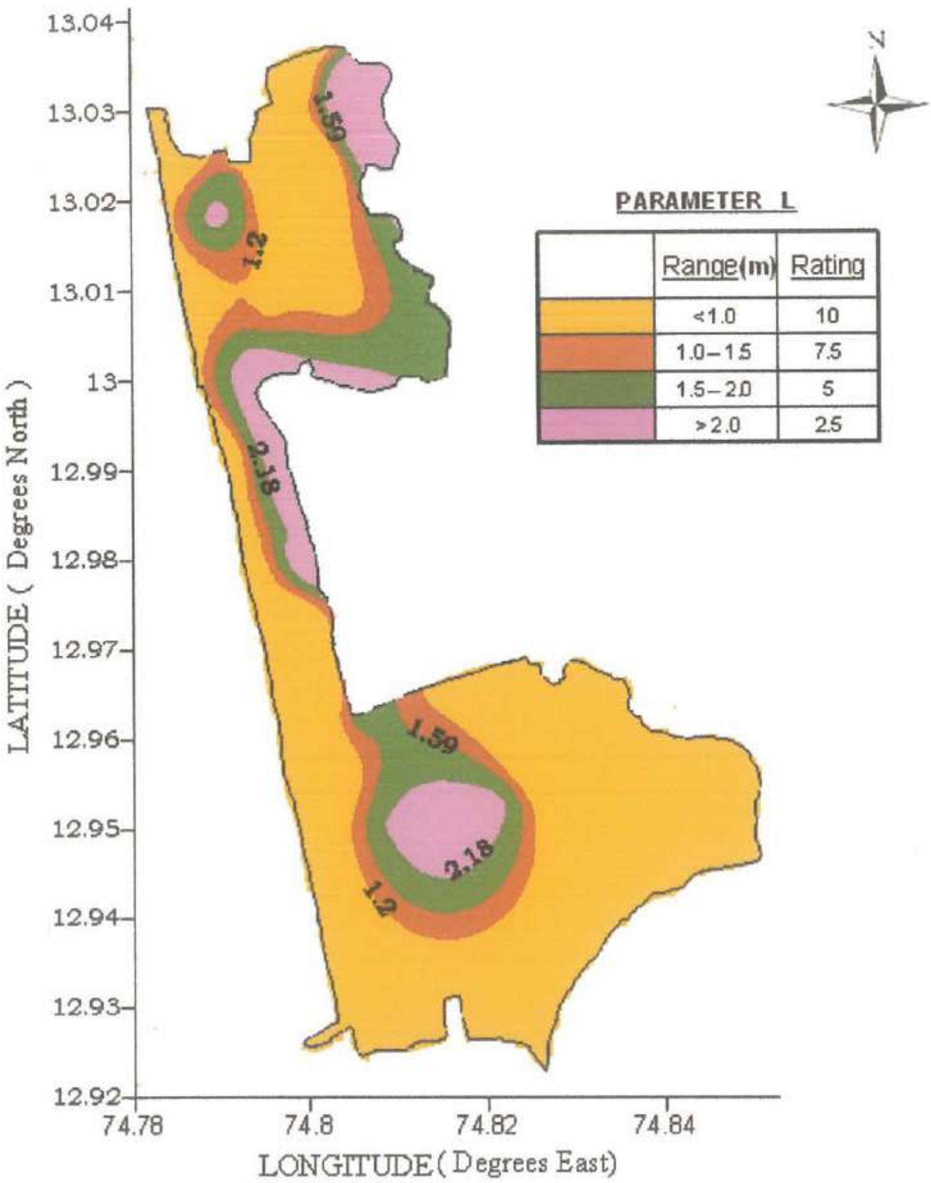


Fig.4.22 The water table elevation on 9th January 2007

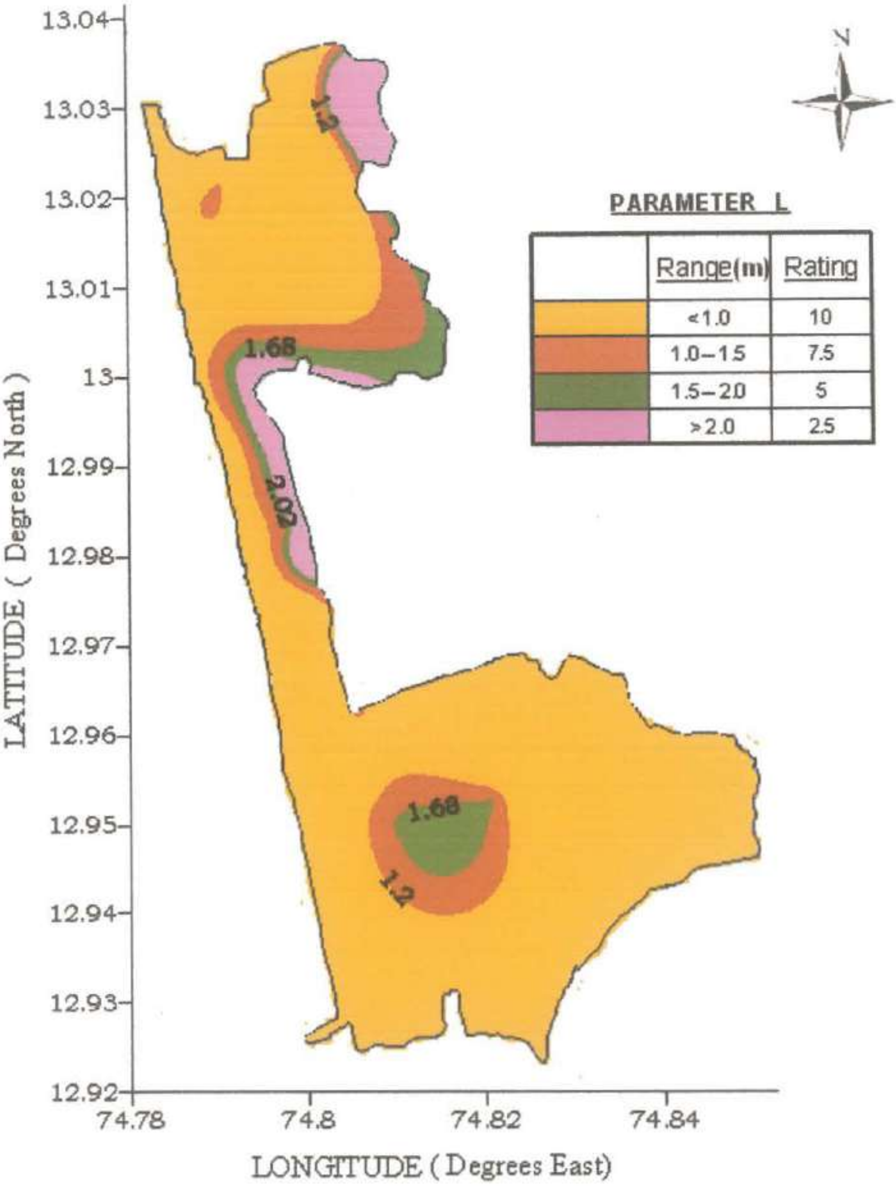


Fig.4.23 The water table elevation on 20th February 2007

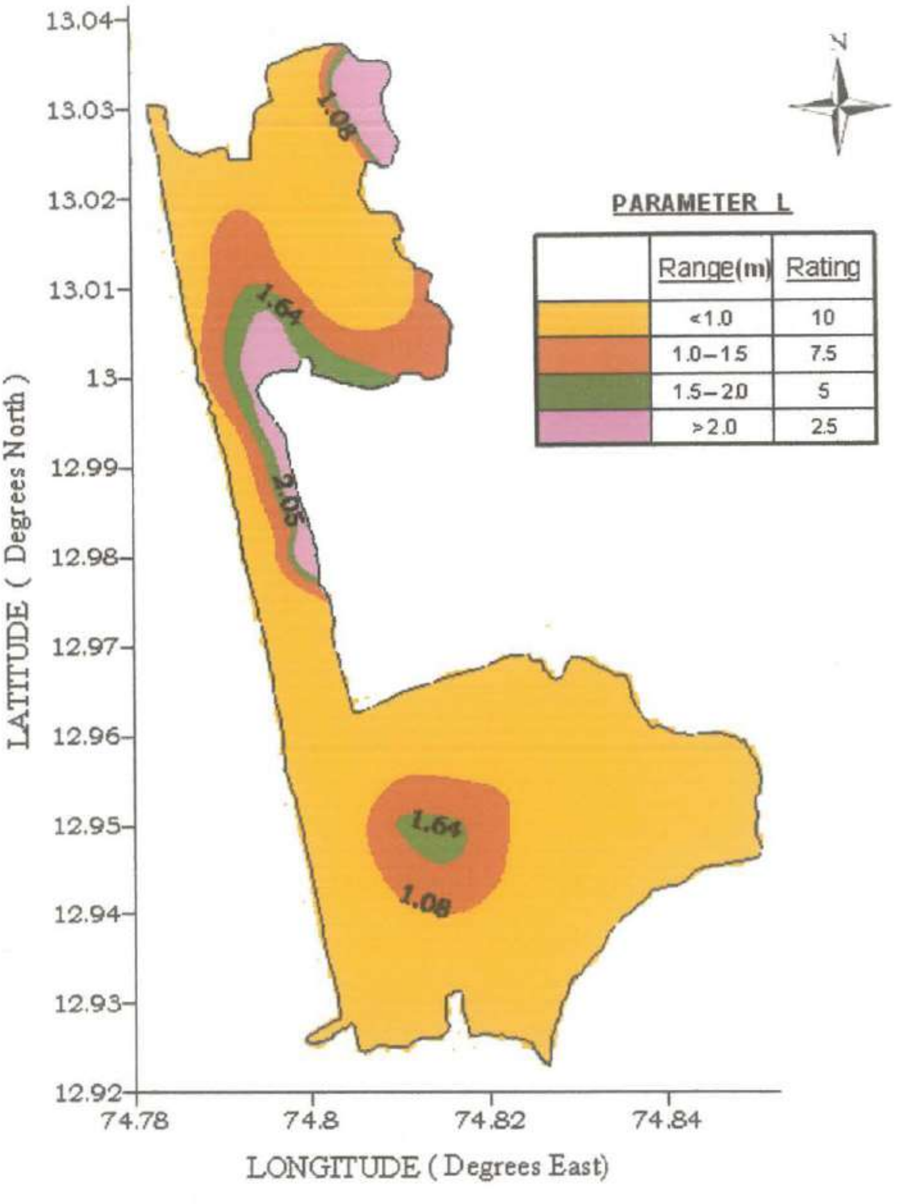


Fig.4.24 The water table elevation on 5th March2007

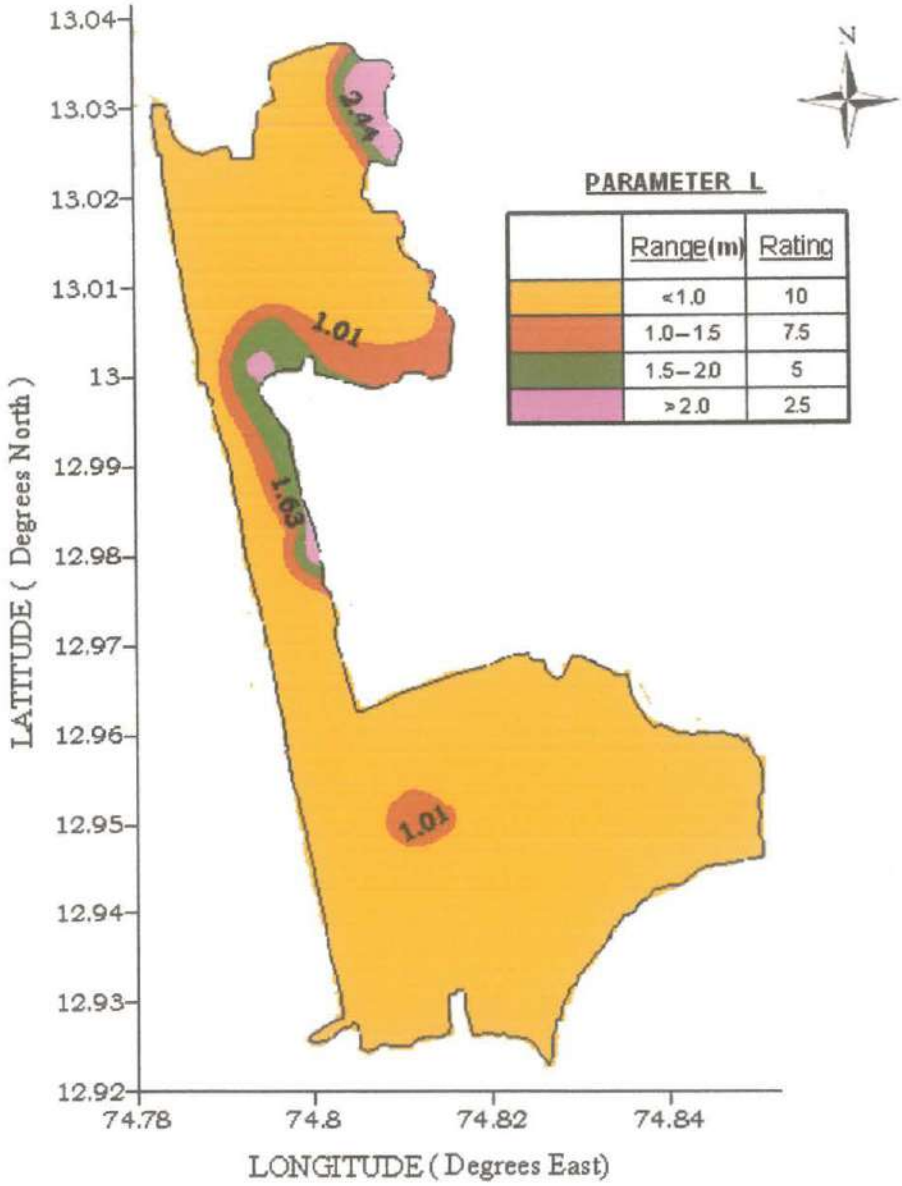


Fig.4.25 The water table elevation on 5th April 2007

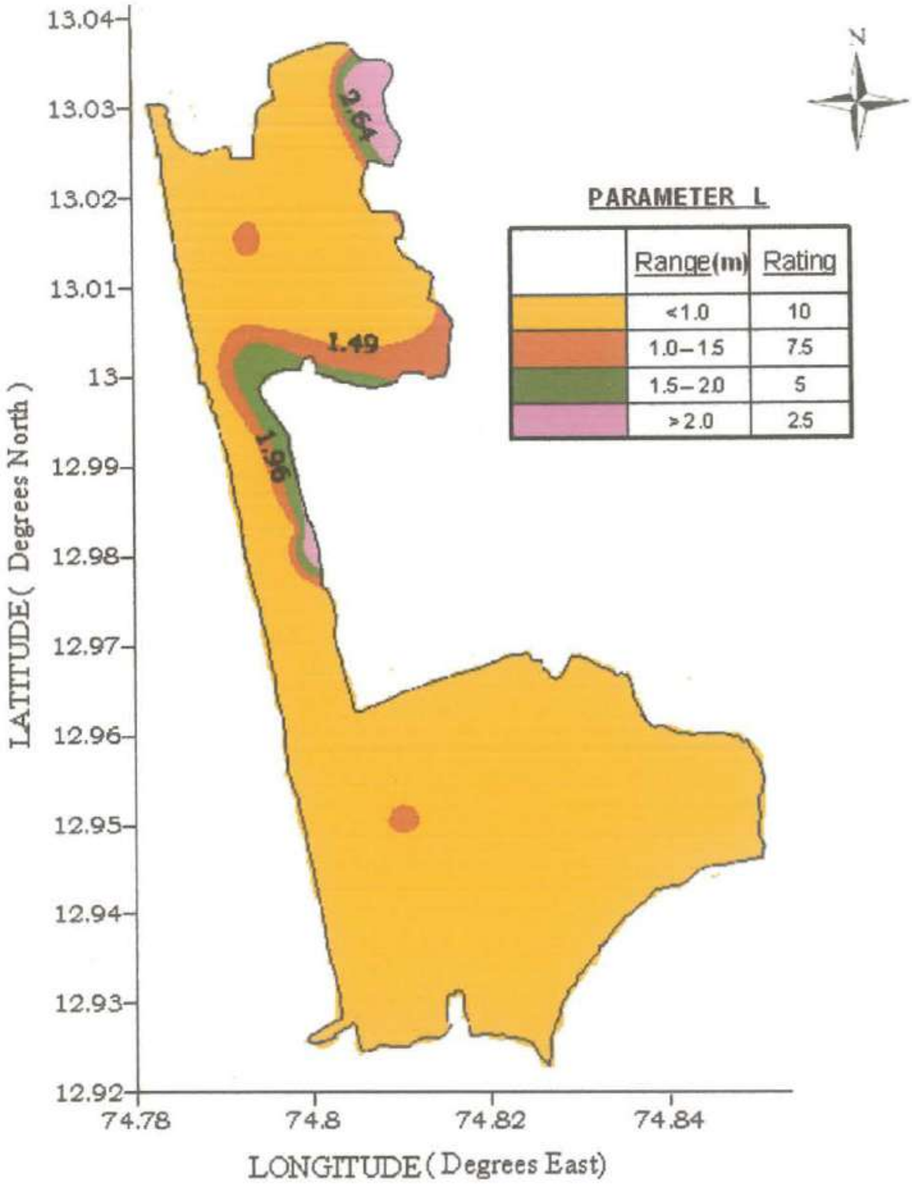


Fig.4.26 The water table elevation on 24th April 2007

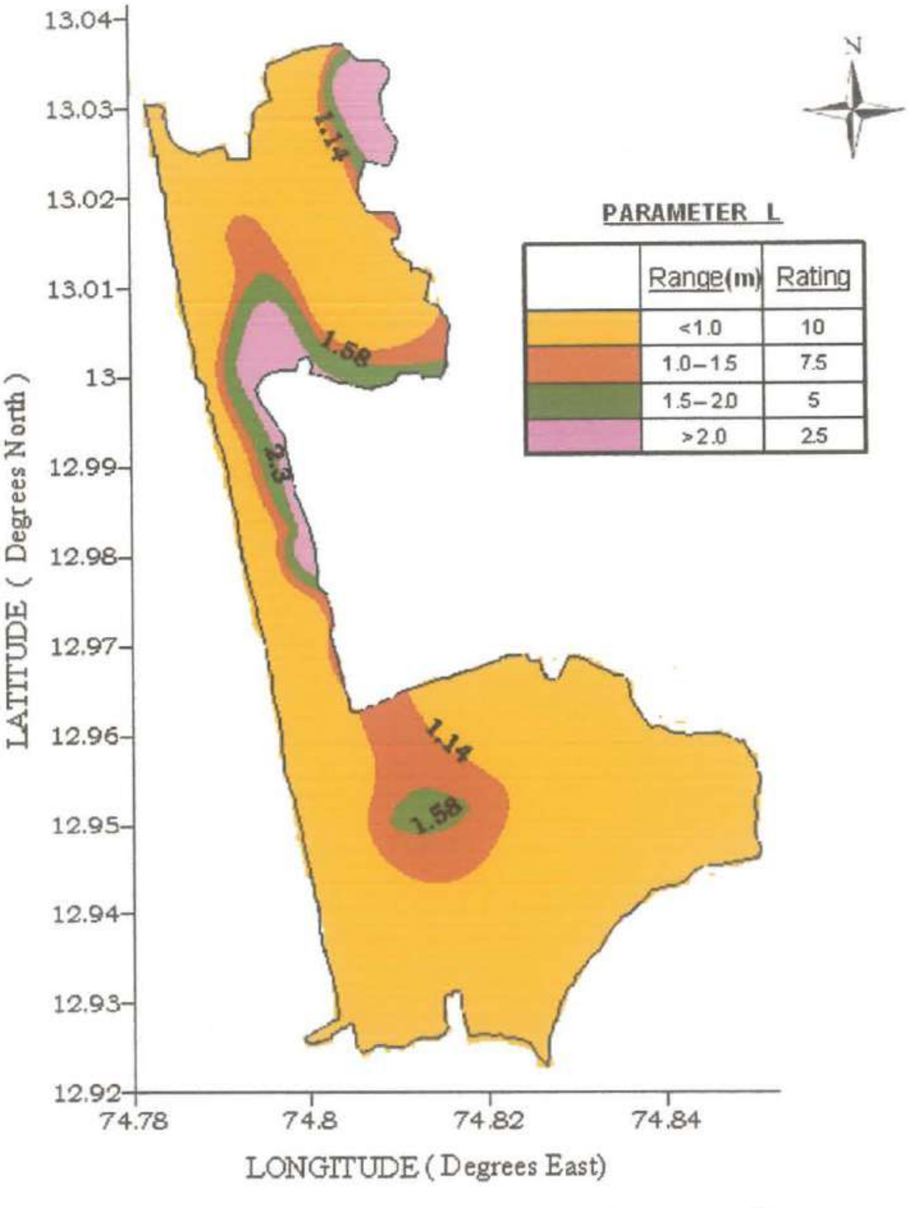


Fig.4.27 The water table elevation on 9th May 2007

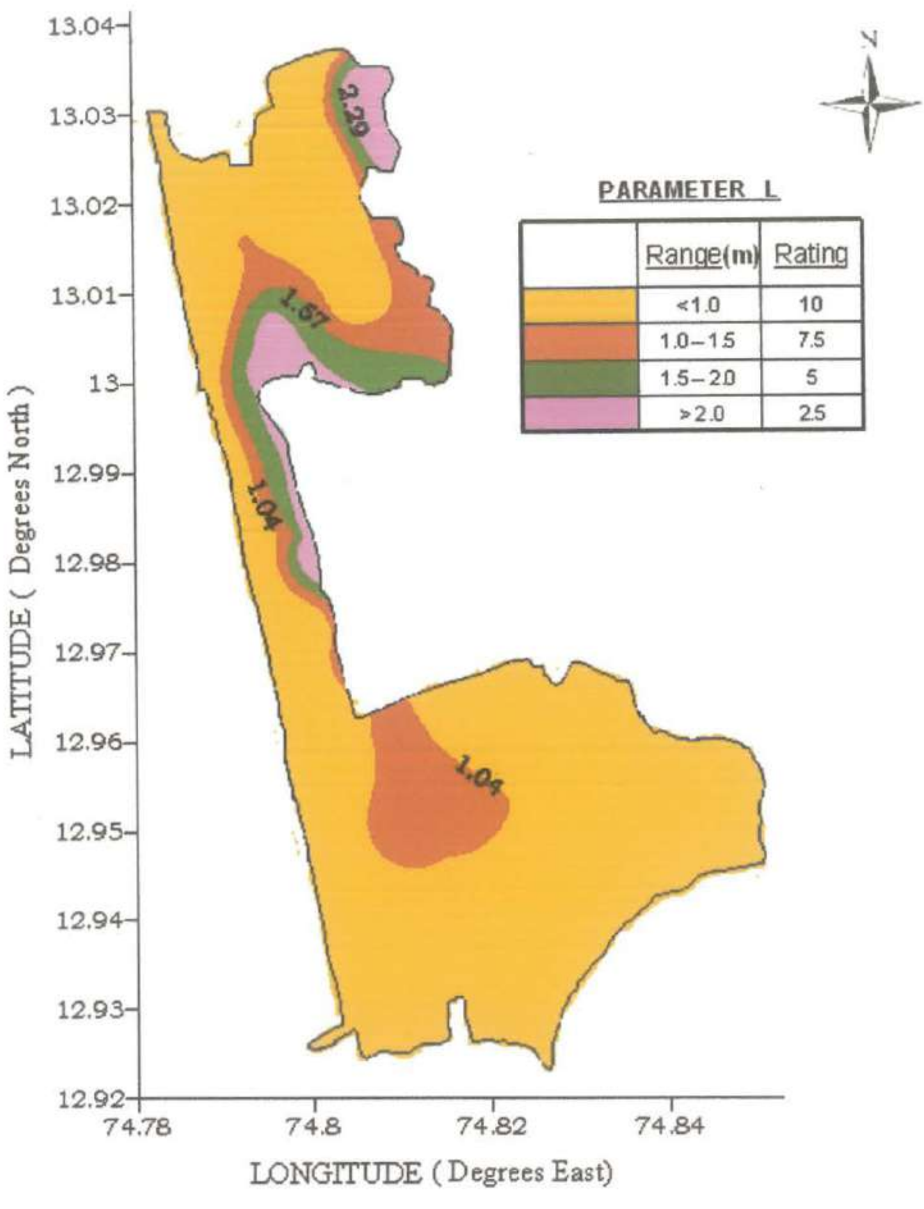


Fig.4.28 The water table elevation on 24th May 2007

From Figs 4.20 to 4.28 we can observe that the parameter "L" is lowest along the coast and near around the Pavanje and Gurupur rivers. And also the yellow patch of colour spreads over larger area as the summer approaches and is maximum in April and May.

4.4.4 Distance from the shore/river, D

The perpendicular distance of each monitoring well either from the sea or the river is noted and are presented in table 4.19.

Table 4.19 Distance of the monitoring well from the shore or the river

Well No.	RL of bottom of the well (m)	Latitude /Longitude	Distance from the shore (m)	Distance from the river (m)	River name
1	-2.282	13° 1' 57" N 74° 47' 49.3" E	1351.44	**160.32**	Pavanje
2	-0.344	13° 1' 59.9" N 74° 48' 1.2" E	1724.53	**414.45**	Pavanje
3	0.742	13° 1' 58.2" N 74° 48' 18.7" E	2230.36	**512.23**	Pavanje
4	-0.504	13° 1' 53.9" N 74° 48' 27.1" E	2463.66	**306.75**	Pavanje
5	2.452	13° 1' 44.3" N 74° 48' 35.6" E	2660.44	**237.09**	Pavanje
6	-1.984	13° 1' 28.8" N 74° 48' 5.2"E	1679.23	**1080.89**	Pavanje
7	-1.618	13° 1' 43.4" N 74° 47' 36"E	886.51	**351.77**	Pavanje
8	-0.363	13° 1' 36.1" N 74° 47' 24.2"E	500.78	**303.94**	Pavanje
9	-1.5	13° 1' 23.8"N 74° 47' 33.4"E	**708.90**	724.42	Pavanje
10	-0.739	13° 1' 6.2"N 74° 47' 23.1"E	**315.87**	1220.10	Pavanje
11	-2.936	13° 1' 14.3"N 74° 47' 58.8" E	1418.98	**1387.31**	Pavanje
12	-3.259	13° 00' 58.9" N 74° 48' 5.9"E	**1536.76**	1825.35	Pavanje
13	0.165	13° 00' 24.2"N 74° 47' 44.8"E	**723.70**	2599.19	Pavanje
14	-2.103	13° 00' 30.9"N 74° 48' 16.2"E	**1689.55**	2191.30	Pavanje
15	-2.761	13° 00' 28.7"N 74° 48' 7.3"	**1413.00**	2372.52	Pavanje

16	1.341	13° 00' 5.2" N 74° 47' 37.4"E	**366.20**	3152.20	Pavanje
17	-0.034	12° 59' 55.4"N 74° 47' 55"E	**739.40**	3505.27	Pavanje
18	0.81	12° 59' 38.6" N 74° 48' 49.4"E	**537.10**	4241.64	Pavanje
19	0.406	12° 58' 59"N 74° 47' 56" E	**459.25**	5032.68	Pavanje
20	-0.818	12° 58' 39.4"N 74° 48' 11.3"E	**739.60**	5426.29	Pavanje
21	-0.616	12° 58' 28.8" N 74° 48' 10.7" E	**658.80**	5808.97	Pavanje
22	-0.486	12° 58' 7.9" N 74° 48' 16.8"E	**718.38**	4428.56	Gurupur
23	0.505	12° 57' 44.8"N 74° 48' 20.3"E	**693.47**	3820.59	Gurupur
24	-1.587	12° 58' 25.2"N 74° 47' 58.7"E	**285.17**	5094.63	Gurupur
25	-0.648	12° 57' 54.2" N 74° 48' 4.8"E	**284.29**	4340.51	Gurupur
26	-1.869	12° 57' 22"N 74° 48' 11.4"E	**312.50**	3632.04	Gurupur
27	1.527	12° 57' 2.3" N 74° 48' 34"E	**879.06**	2728.77	Gurupur
28	0.886	12° 56' 49.4" N 74° 48' 54.3" E	**1411.42**	1989.75	Gurupur
29	-0.314	12° 57' 10.6"N 74° 49' 16.4"E	2183.87	**1813.19**	Gurupur
30	-3.103	12° 57' 28.9"N 74° 49' 33.2"E	2775.59	**1801.71**	Gurupur
31	-3.475	12° 57' 00" N 74° 49' 57.1" E	3330.10	**640.92**	Gurupur
32	-4.281	12° 57' 25.8"N 74° 50' 44"E	4857.76	**825.60**	Gurupur
33	-3.524	12° 57' 23" N 74° 50' 56.1"E	5204.42	**661.98**	Gurupur

34	-4.641	12° 57' 36.5" N 74° 50' 48.2"E	5035.57	**1125.97**	Gurupur
35	-3.202	12° 57' 47.1"N 74° 50' 18.2"E	4201.79	**1643.57**	Gurupur
36	-2.695	12° 57' 57.3"N 74° 48' 51.6"E	**1688.20**	3310.33	Gurupur
37	-2.109	12° 57' 42.6" N 74° 48' 34.1"E	**1089.47**	3473.74	Gurupur
38	-2.37	12° 58' 34.1"N 74° 48' 15.6"E	**833.16**	5520.34	Pavanje
39	0.827	12° 59' 45.3"N 74° 47 ° ' 47.2"E	**475.38**	3770.90	Pavanje
40	-2.823	13 ° 00' 57.82" E 74 ° 47' 34.87" N	**607.81**	1520.83	Pavanje
41	2.928	12 ° 58' 56.59" E 74 ° 48' 05.39" N	**696.25**	1500.07	Pavanje

In the above table, the distances depicted in bold indicate the nearest distance to the well either from the river or from the shore which has been adopted for the present study. Since the Gurpur and Pavanje rivers are tidal in nature, the adjoining aquifers get contaminated by salt water from these rivers for considerable distance upstream during the non-monsoon period. The rivers from the highlands undergo a drop in the velocity when they reach the low lands. They flow in a meandering course too, on an almost flat terrain. During the high tides in the sea, salt water ingresses into the rivers and the river water turns saline and becomes unfit for any use. It is found (Ranganna, et al, 1996) that saline water ingress up to a distance of more than 22 km along the Gurupur river in the intense summer month (May). Along the Pavanje river, the ingression of sea water is prevented by means of a saltwater exclusion dam at a distance of about 9 kms from the river mouth. So, the salinity levels are rather low. From the work of Gajendragad et al., (1988), the saline ingression was reported to extend beyond 12.5 km in the Pavanje river. Hence these rivers are also treated as saline source for the computation of the parameter "D". Out of the monitoring network of wells, the nearest location to the saline source is well no.1 (D= 160m) and the farthest location is well no.29 (D=1813.19m).

4.4.5 Impact of existing status of saltwater intrusion, I

Because of the conservative nature of Cl^-, it can be used as an indicator of salinity, which influences groundwater quality in an area. Where no other source of saline contamination exists, higher concentration of Cl^- in groundwater can be considered as definite proof of salt-water contamination. Several studies have used the chloride concentration of groundwater to define the extent of saltwater intrusion, who specify the threshold chloride concentration in the range of 40 to 300 mg/l as indicative of saltwater invasion. (Edet. and Okereke, 2001). The present results (Table 4.20) infer that the aquifer water is contaminated with saltwater, as Cl^-, the most abundant ion in saltwater, is in higher proportions. The HCO_3^- ion which is the most dominant ion in fresh groundwater occurs generally in small amounts in saltwater. Chloride concentration greater than 250 mg/l is considered unfit for drinking purpose.

Table 4.20 The ratio of Cl/HCO3 for the samples taken from monitoring wells

Well No.	Cl/HCO_3							
	DEC (06)	JAN (07)	FEB (07)	MAR (07)	APRL (07)	APRL (07)	MAY (07)	MAY (07)
1	4.308	3.717	3.397	3.525	2.938	2.674	3.408	3.231
2	1.481	1.474	2.193	1.859	1.316	1.161	1.175	1.511
3	1.123	1.156	0.992	0.940	0.751	0.940	0.979	0.995
4	1.156	1.100	0.931	0.858	0.876	1.047	1.152	1.009
5	0.588	0.564	0.564	0.737	0.419	0.385	0.415	0.373
6	8.460	6.833	8.076	14.355	6.635	6.043	4.700	5.640
8	0.987	1.058	0.932	1.354	0.665	1.160	1.168	1.253
9	2.403	1.987	2.081	2.023	1.870	1.763	2.115	2.115
10	0.397	0.470	0.415	0.524	0.427	0.518	0.463	0.464
11	5.961	6.639	4.089	9.988	8.930	9.400	11.562	9.762
12	2.065	1.939	2.603	2.726	3.217	2.986	2.977	2.996
13	1.790	1.821	1.923	1.821	1.163	1.410	1.898	1.561
14	2.977	2.679	2.397	2.891	2.436	2.436	2.712	2.386
16	0.959	0.963	0.804	0.959	0.674	0.846	0.954	0.974
17	0.604	1.296	1.287	1.259	1.293	1.276	0.951	1.312
18	0.513	0.595	0.684	0.695	0.470	0.513	0.584	0.529
19	3.701	0.458	0.412	0.222	0.321	0.362	0.489	0.401
20	0.613	0.743	0.740	0.75	0.872	0.728	0.823	0.889
21	0.697	0.834	1.090	0.623	0.857	0.886	0.917	0.627
22	0.308	0.338	0.308	0.318	0.276	0.346	0.353	0.377
23	0.653	0.745	0.714	0.715	0.763	0.836	0.468	0.823
24	0.237	0.235	0.192	0.203	0.201	0.231	0.222	0.508
25	2.969	2.836	3.620	3.493	2.593	4.070	4.291	3.917
26	0.677	0.691	0.679	0.718	0.679	0.734	0.859	0.804
27	2.332	1.837	1.554	2.136	2.095	2.076	3.102	1.992

28	1.721	1.674	1.987	2.281	2.074	2.115	3.878	2.256
29	4.935	5.718	5.217	5.852	4.772	6.922	8.284	8.46
30	0.809	0.977	0.722	0.452	0.499	0.713	1.472	1.32
31	1.448	1.888	2.247	2.557	3.102	3.644	3.704	3.856
32	1.723	2.136	2.328	2.35	2.238	3.924	4.005	4.583
33	0.453	0.517	0.887	1.775	1.309	1.819	2.247	1.457
34	1.763	1.799	1.216	1.334	1.095	1.064	1.039	0.582
35	1.263	1.704	1.833	1.873	0.366	0.305	1.808	1.338
36	0.831	1.598	1.293	1.108	1.012	1.154	1.226	1.074
37	2.820	3.205	4.442	3.408	2.019	1.720	1.316	1.251
38	0.521	0.625	0.526	1.138	0.672	0.694	0.786	0.547
39	1.168	1.933	1.895	1.866	1.620	2.256	2.115	2.041
40	0.572	0.726	0.546	0.533	0.492	0.683	0.578	0.578
41	2.891	4.331	3.525	3.384	2.256	2.440	2.495	2.585

From the above table we can observe that well nos. 1, 6 ,11 and 29 show very high values of Cl/HCO^3 ranging from 2.938 to 14.355.The first three wells are located closer to the Pavanje river than to the shore and well no 29 is nearer to the Gurupur river (from table 4.19). The well nos. 12 ,14 , 41 and 25 also show ratios greater than 2 throughout. The well nos. 25 and 41 are 284.29m and 696.25m away from the shore. The well nos. 31 ad 32 are within 1000m closer to the Gurupur river and hence show values greater than 3 in the month of April and May Overall, the values of Cl/HCO_3 range from 0.235 to 8.460 during the post-monsoon period and from 0.192 to 14.355 during the pre-monsoon period. Figs. 4.29 to 4.34 show the variation of Cl/HCO_3 in the study area during Dec.-May, 2007.

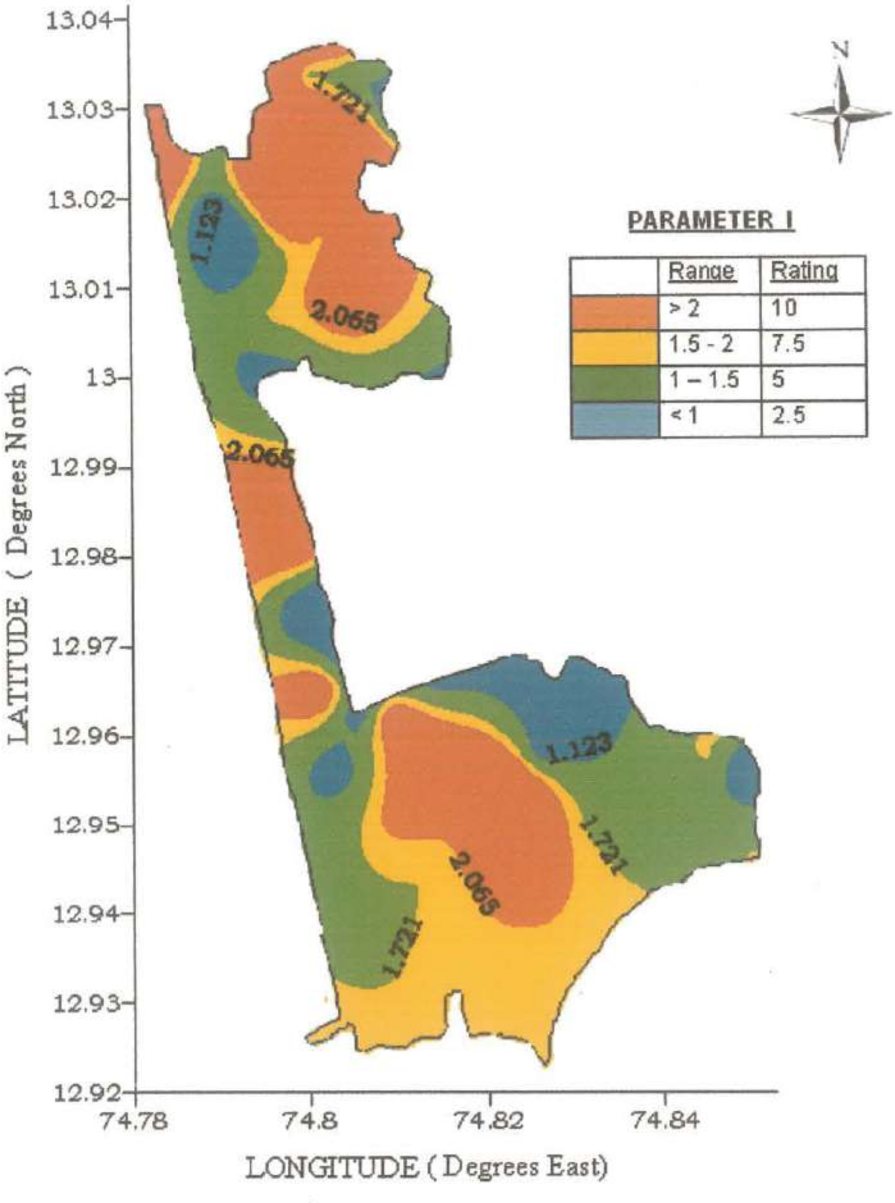


Fig.4.29 The distribution of chloride-bicarbonate ratio in the study area on 12th December 2006

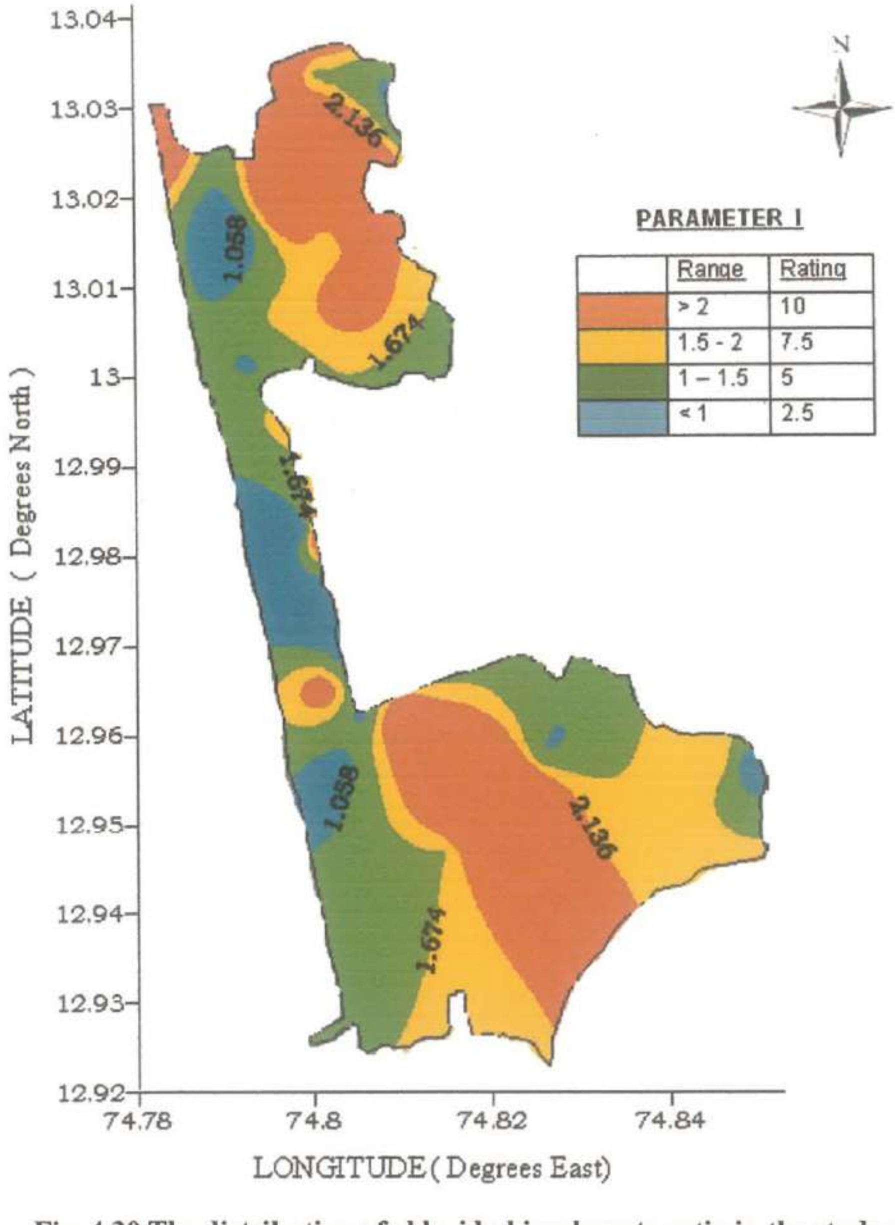


Fig. 4.30 The distribution of chloride-bicarbonate ratio in the study area on 9th January 2007

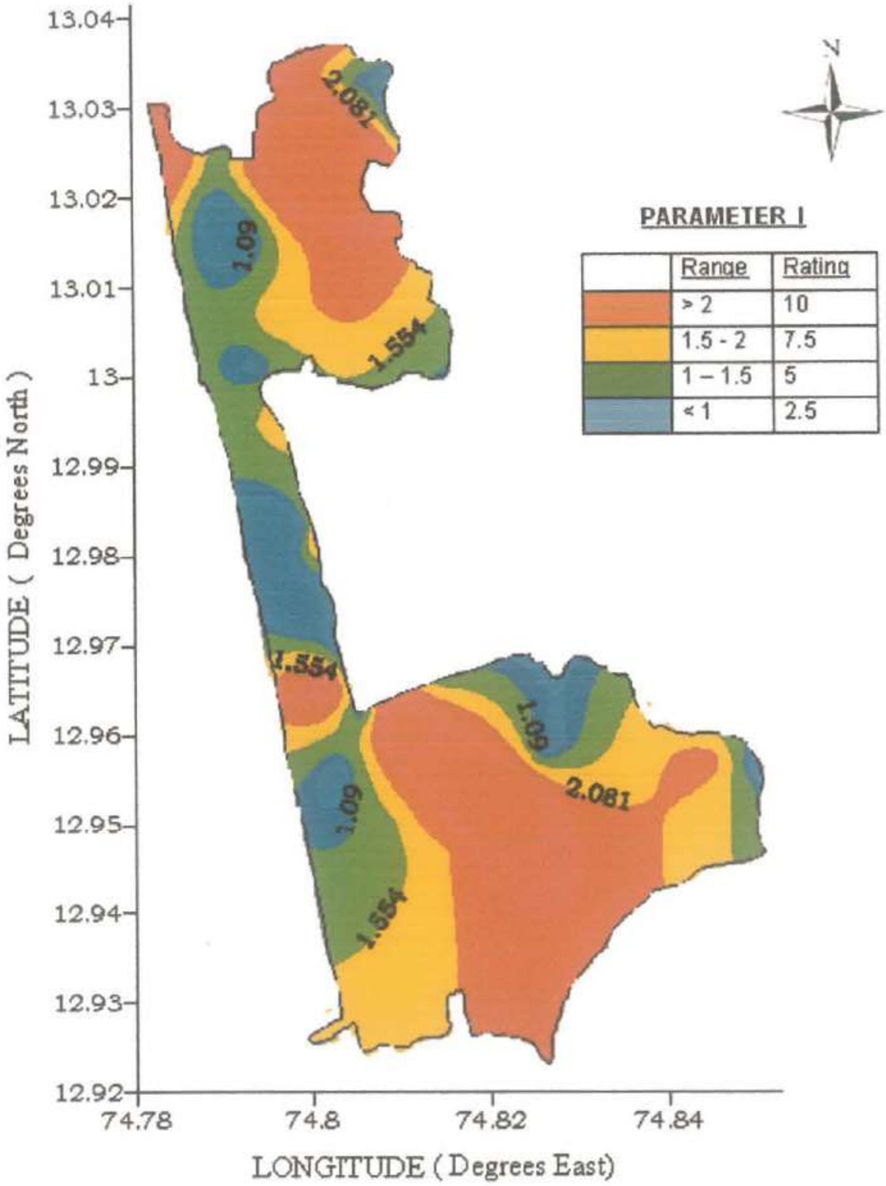


Fig. 4.31 The distribution of chloride-bicarbonate ratio in the study area on 20th February 2007

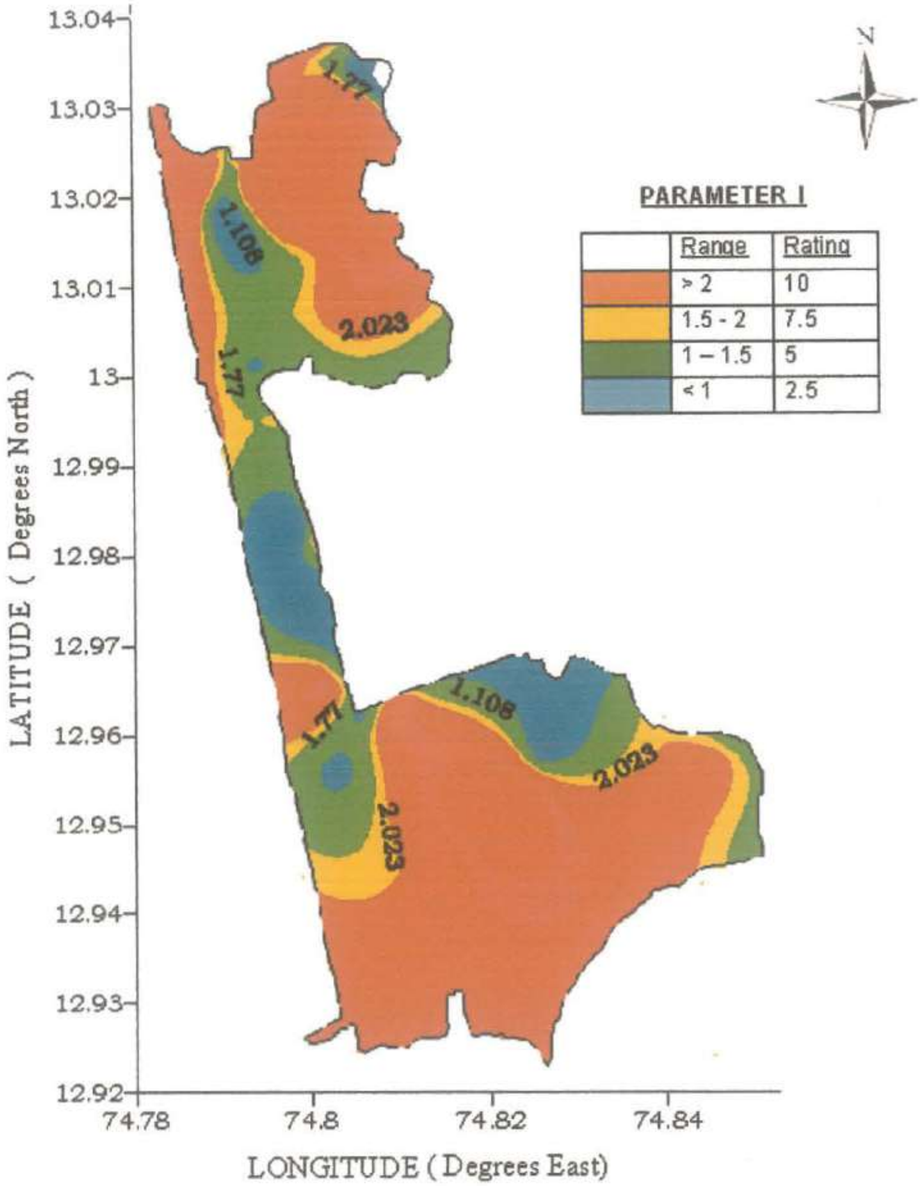


Fig. 4.32 The distribution of chloride-bicarbonate ratio in the study area on 5th March 2007

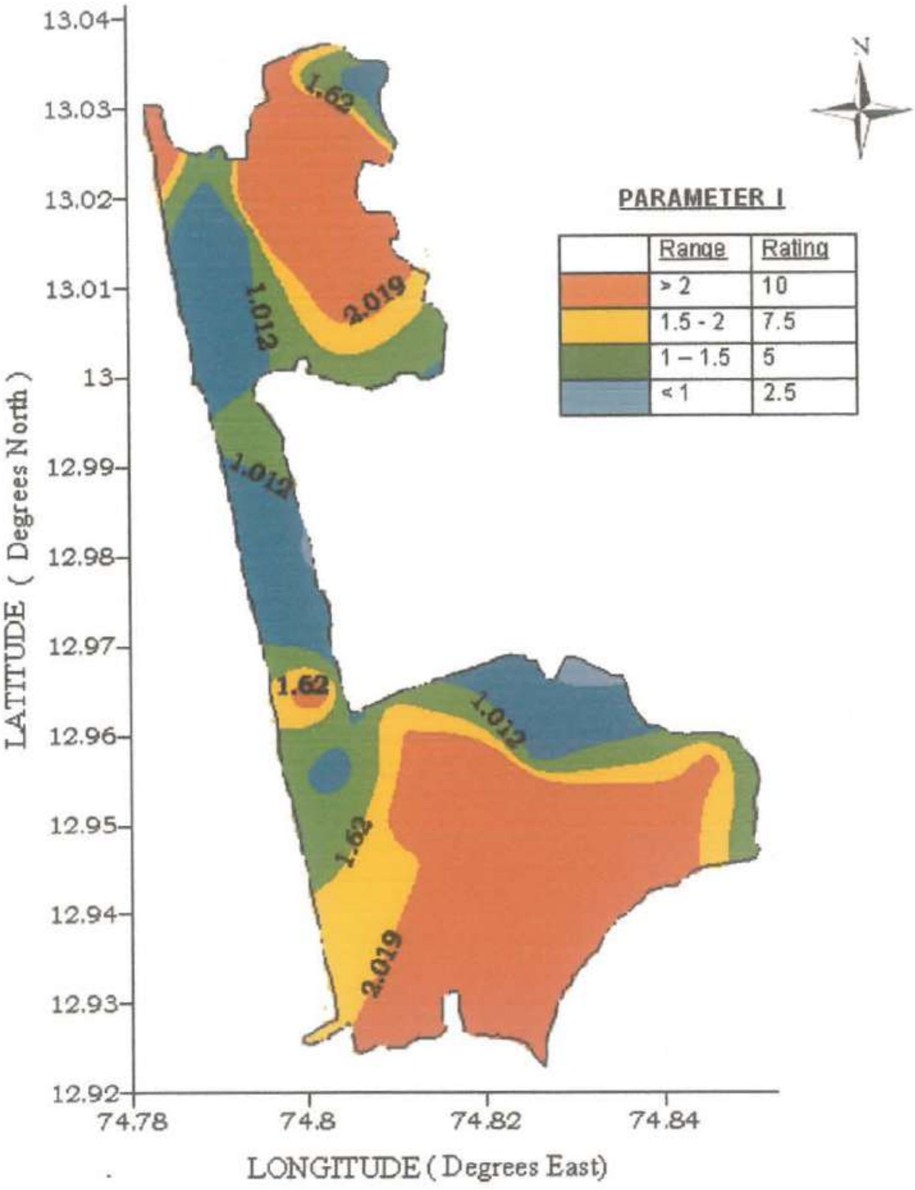


Fig. 4.33 The distribution of chloride-bicarbonate ratio in the study area on 5th April 2007

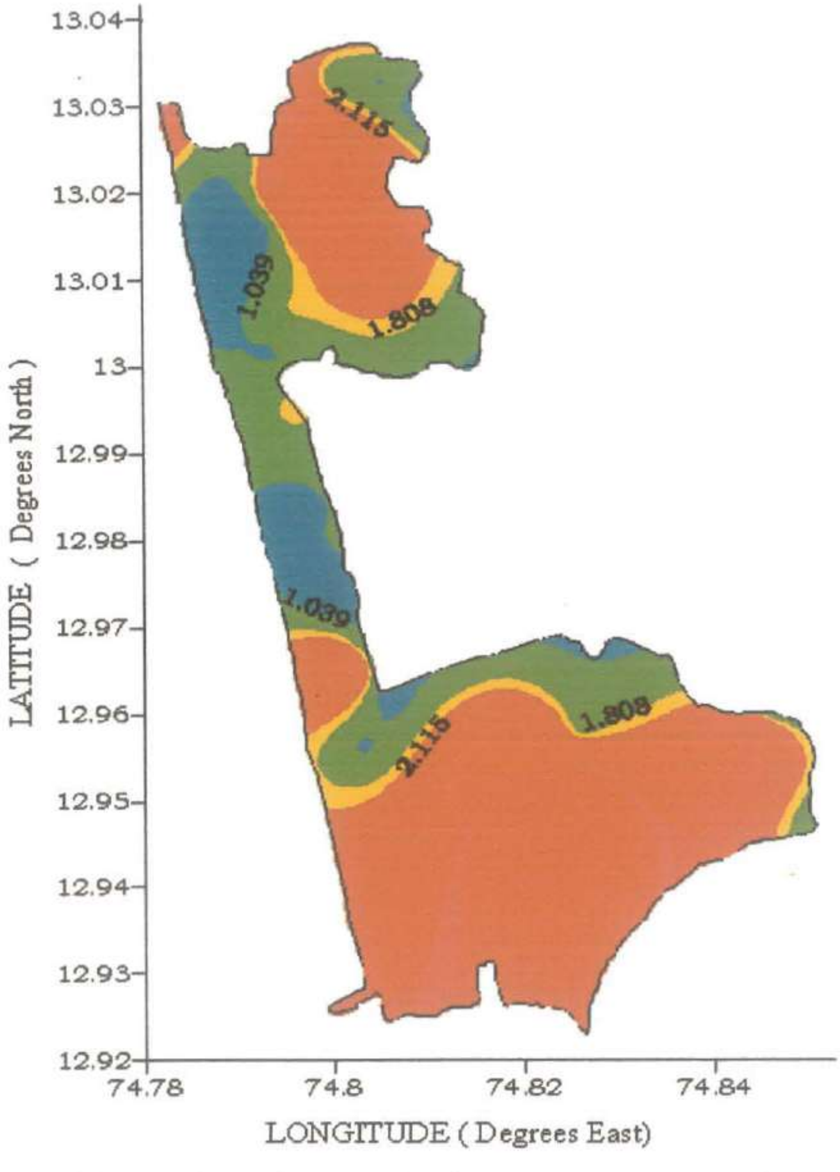


Fig. 4.34 The distribution of chloride-bicarbonate ratio in the study area on 9th May 2007

The figures 4.29 to 4.34 show that the orange colour (higher salinity) in the southern part of the study area, i.e. around the Gurupur river spreads over a larger area as summer approaches. This is due to the fact that the well nos 29, 30, 31,32,33,34 and 35 are closer to the Gurupur river (table 4.19). Also, Baikampady, Kenjar and Jokatte are the low lying areas.

4.4.6 Thickness of the aquifer, T

The thickness of the aquifer is obtained from the electrical resistivity survey conducted in the study area at 22 locations. In table 4.11 (a) and (b) results of electrical resistivity survey are tabulated, where the overburden is estimated. The resistivity survey indicated that the area consists of shallow unconfined aquifer with the thickness ranging from 18m to 30m.From the table 4.11 (a) and (b) we can observe that all the values are greater than 10m, and hence the GALDIT rating of 10 is adopted throughout the study area.

4.5 COMPUTATION OF GALDIT INDEX

The GALDIT index calculated for the study area from the month of November to May is tabulated in table 4.21. The detailed calculation of GALDIT index for each month is given in the APPENDIX-II

Table. 4.21 GALDIT- Index for the study area from Nov'06 to May'07

Well No.	Nov'06	Dec'06	Jan'07	Feb'07	March'07	April'07	May'07
1	8.50	9.17	9.83	9.83	9.83	9.83	9.83
2	8.83	9.50	9.50	9.83	9.67	9.50	9.50
3	6.83	6.83	6.83	6.67	6.67	6.67	6.67
4	7.50	7.50	7.50	7.33	7.33	7.33	7.50
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	7.83	7.83	7.83	7.83	7.83	7.83	7.83
8	7.33	7.33	8.83	9.33	9.50	9.33	9.50
9	7.17	7.17	7.67	8.50	9.17	9.00	9.17
10	7.33	7.33	7.33	8.67	9.33	9.33	9.33
11	7.17	7.83	7.83	7.83	7.83	7.83	7.83
12	7.17	7.83	7.67	7.83	7.83	7.83	7.83
13	7.00	7.00	8.33	9.00	7.00	7.50	7.00
14	7.17	7.17	7.83	7.83	7.83	7.83	7.83
16	7.33	7.33	7.33	7.33	7.33	7.33	7.33
17	6.67	6.67	6.83	6.83	6.83	7.50	6.67
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	6.67	6.67	6.67	6.67	6.67	7.33	6.67
21	7.33	7.33	7.33	8.17	8.00	8.00	7.33

22	7.33	7.33	7.33	8.00	8.00	8.00	7.33
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	8.67	9.33	9.33	9.33	9.33	9.33	9.33
25	9.17	9.17	9.83	9.83	9.83	9.83	9.83
26	9.33	9.33	9.33	9.33	9.33	9.33	9.33
27	6.50	6.50	6.33	7.00	7.17	7.83	7.17
28	5.67	5.67	5.67	5.67	6.50	7.83	7.17
29	5.83	5.83	5.83	6.50	7.17	7.83	6.50
30	7.33	7.33	7.33	7.33	7.33	7.33	7.50
31	8.83	8.83	9.00	9.17	9.17	9.17	9.17
32	8.33	8.33	8.50	8.50	8.50	8.50	8.50
33	8.67	8.67	8.67	8.67	9.00	8.83	9.17
34	7.67	7.67	7.67	7.50	7.50	7.50	7.50
35	7.50	7.50	7.67	7.67	7.67	7.33	7.67
36	6.67	7.33	7.67	7.50	7.50	7.50	7.50
37	6.50	6.50	6.50	7.83	7.83	7.17	6.17
38	6.00	6.00	6.00	6.00	6.83	6.67	6.00
39	7.50	7.50	7.67	7.67	7.67	7.67	7.83
40	6.67	6.67	7.33	8.67	7.33	8.67	7.33
41	7.17	7.17	7.17	7.17	7.17	7.17	7.17

The RL of the bottom of well nos. 3,5,13,16,18,19,23,27,28,39 and 41 are positive, which indicate that the well bottom is above the mean sea level. Hence the GALDIT index for these wells is to be assigned zero which may be considered as low vulnerable region for saltwater intrusion. But, except well nos. 5, 18, 19 and 23 the other wells have the ratio of Cl/HCO_3 greater than unity and hence may be considered as medium vulnerable region for saltwater intrusion. Figs. 4.35 to 4.41 show the saltwater-intrusion vulnerability map as depicted by GALDIT scores for the normal sea level during November'06 to May'07.

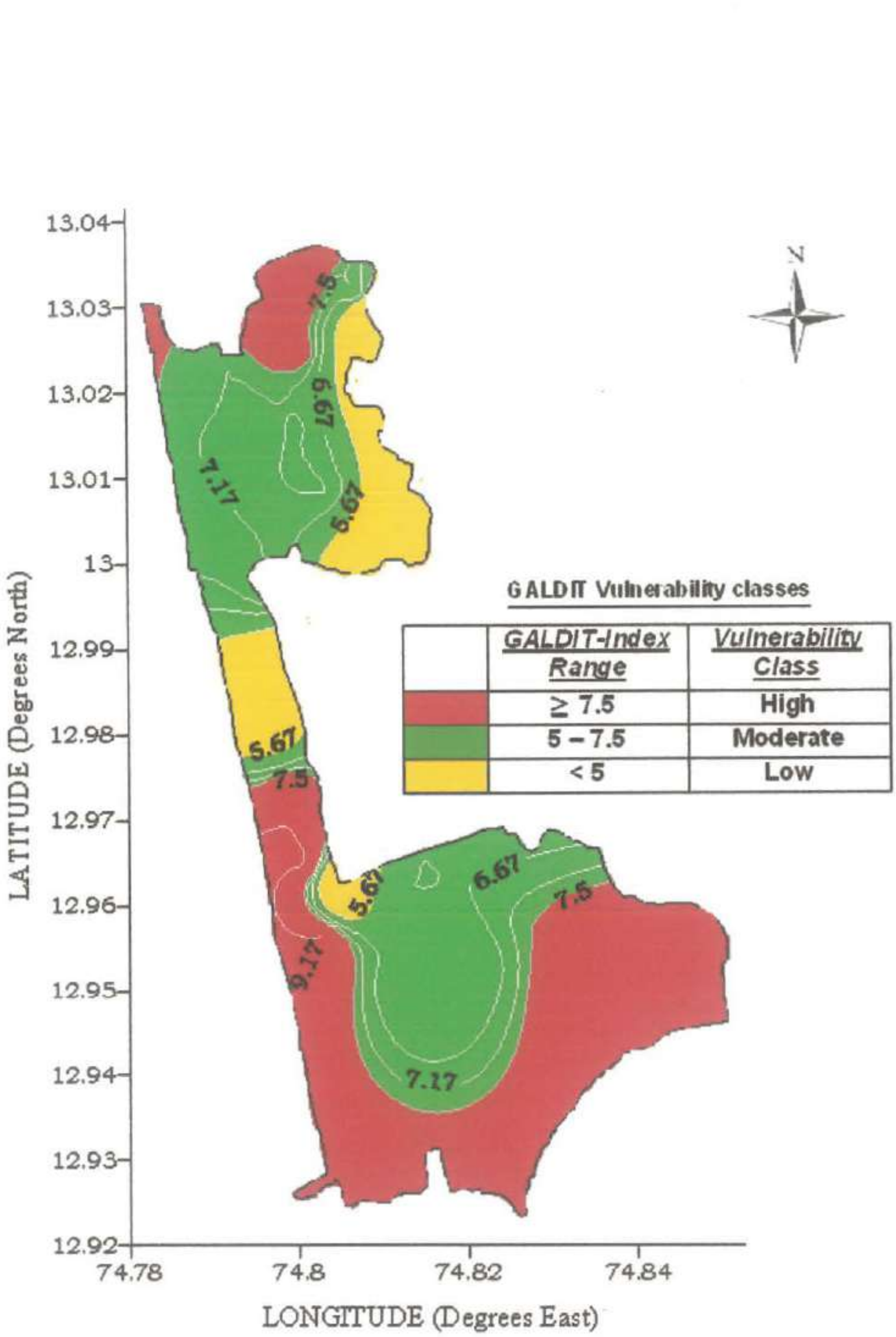
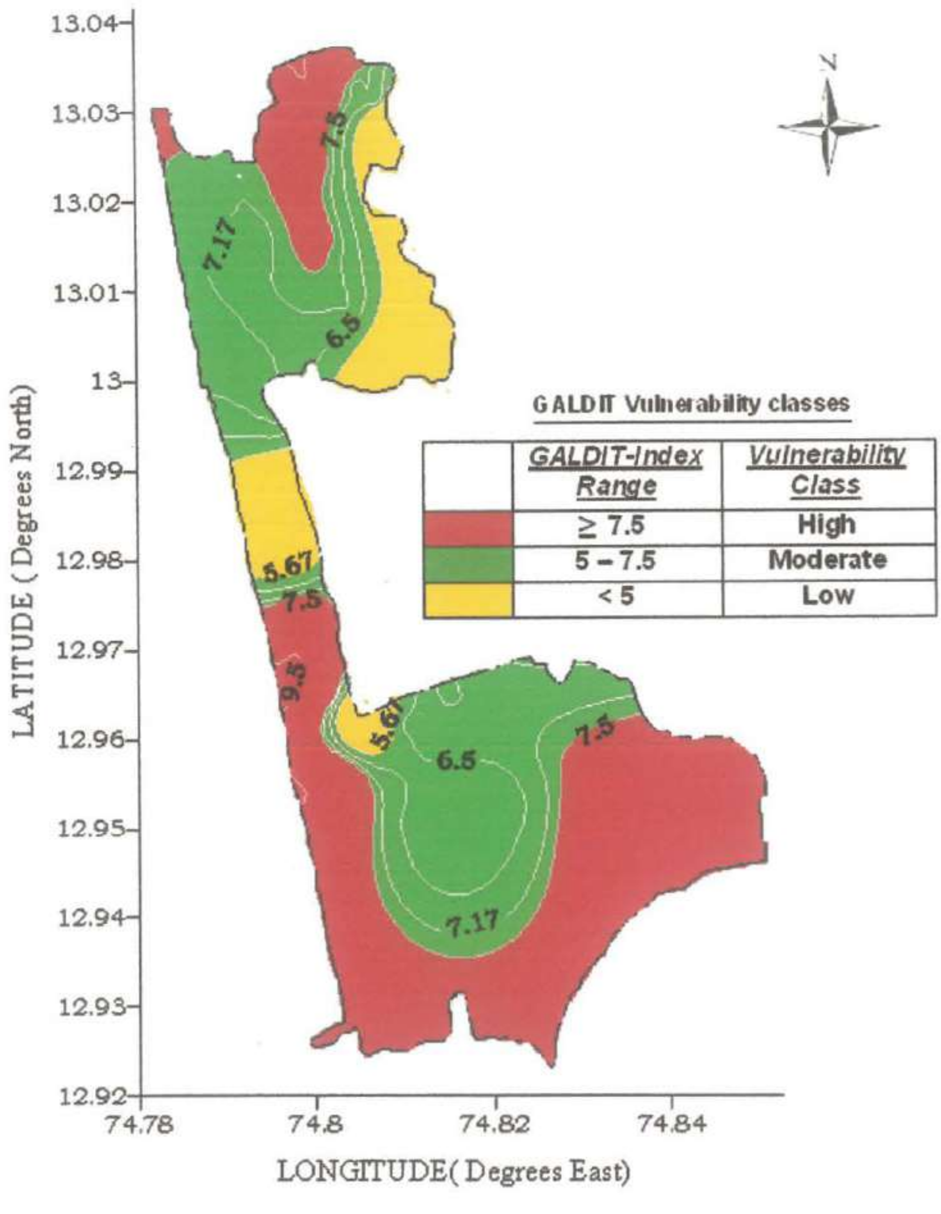


Fig.4.35. Saltwater-intrusion vulnerability map as depicted by the GALDIT scores for normal sea level (November, 2006)



	GALDIT-Index Range	Vulnerability Class
	≥ 7.5	High
	5 – 7.5	Moderate
	< 5	Low

Fig.4.36. Saltwater-intrusion vulnerability map as depicted by the GALDIT scores for normal sea level (December, 2006)

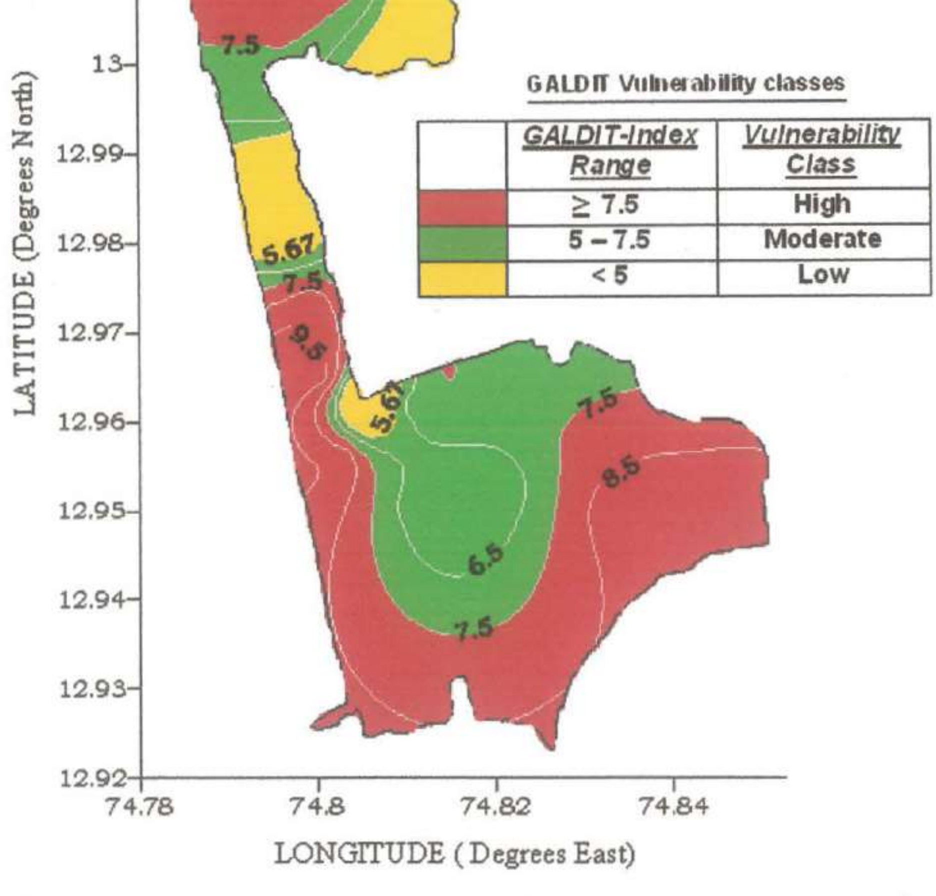


Fig.4.37. Saltwater-intrusion vulnerability map as depicted by the GALDIT scores for normal sea level (January, 2007)

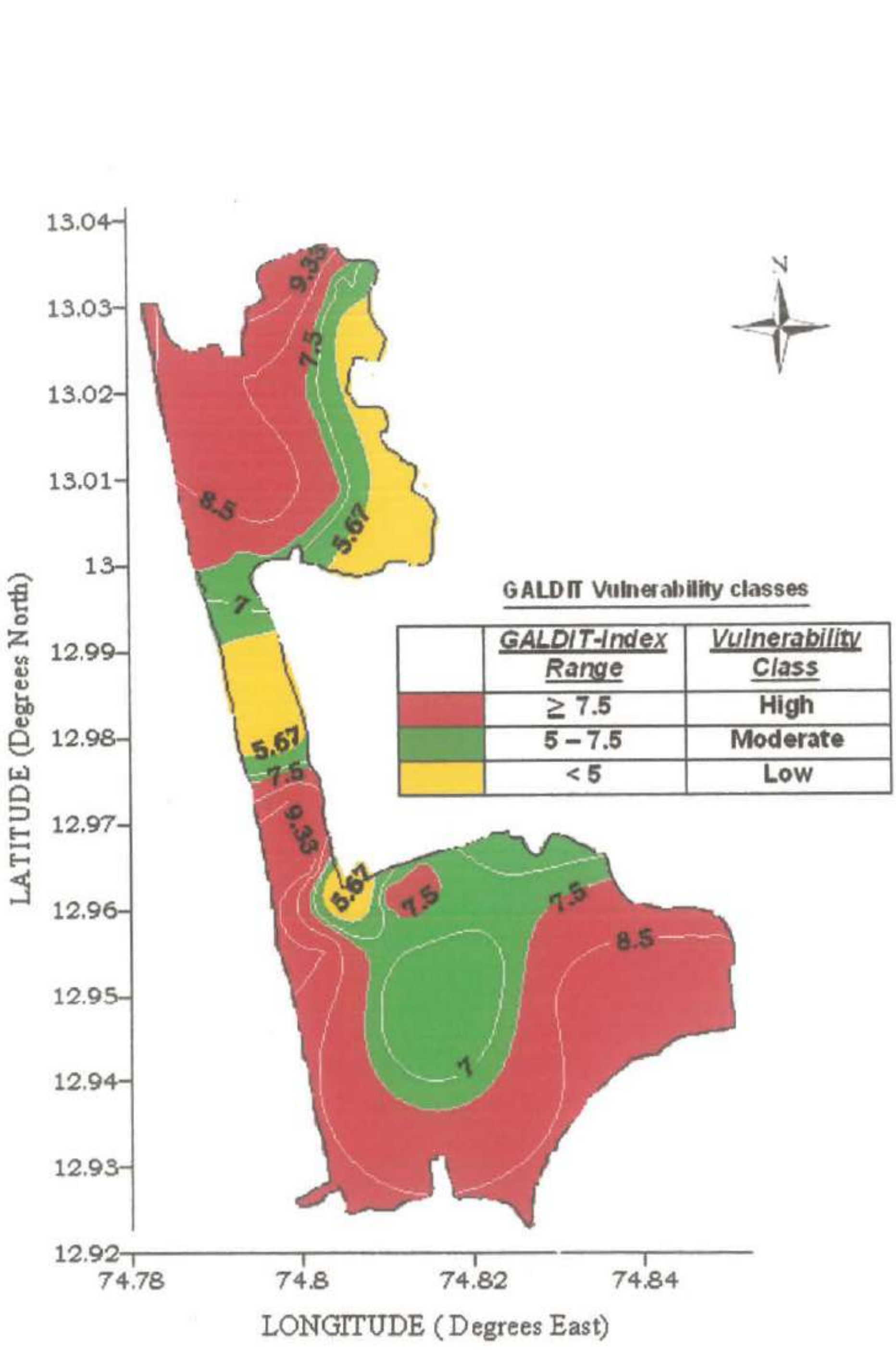


Fig.4.38: Saltwater-intrusion vulnerability map as depicted by the GALDIT scores for normal sea level (February, 2007)

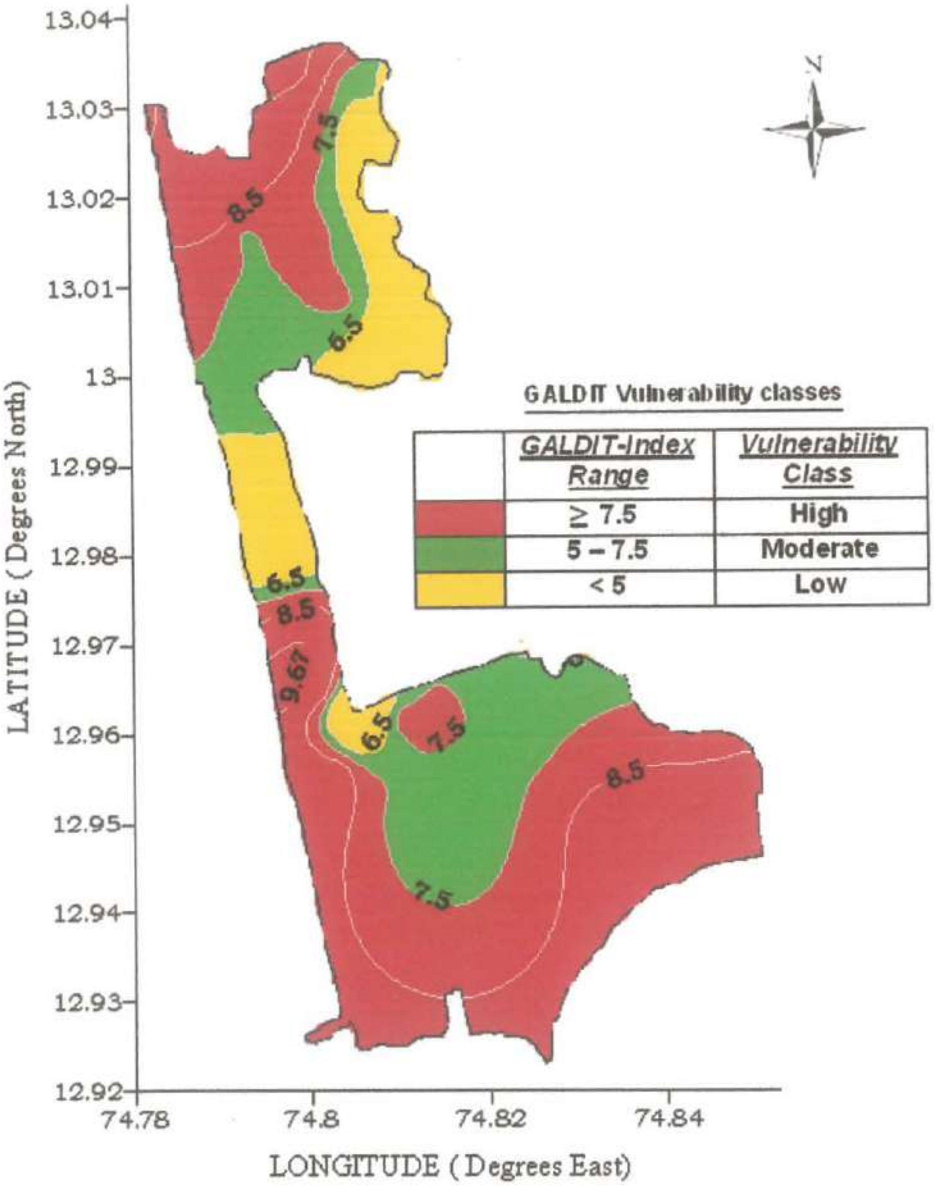


Fig.4.39. Saltwater-intrusion vulnerability map as depicted by the GALDIT scores for normal sea level (March ,2007)

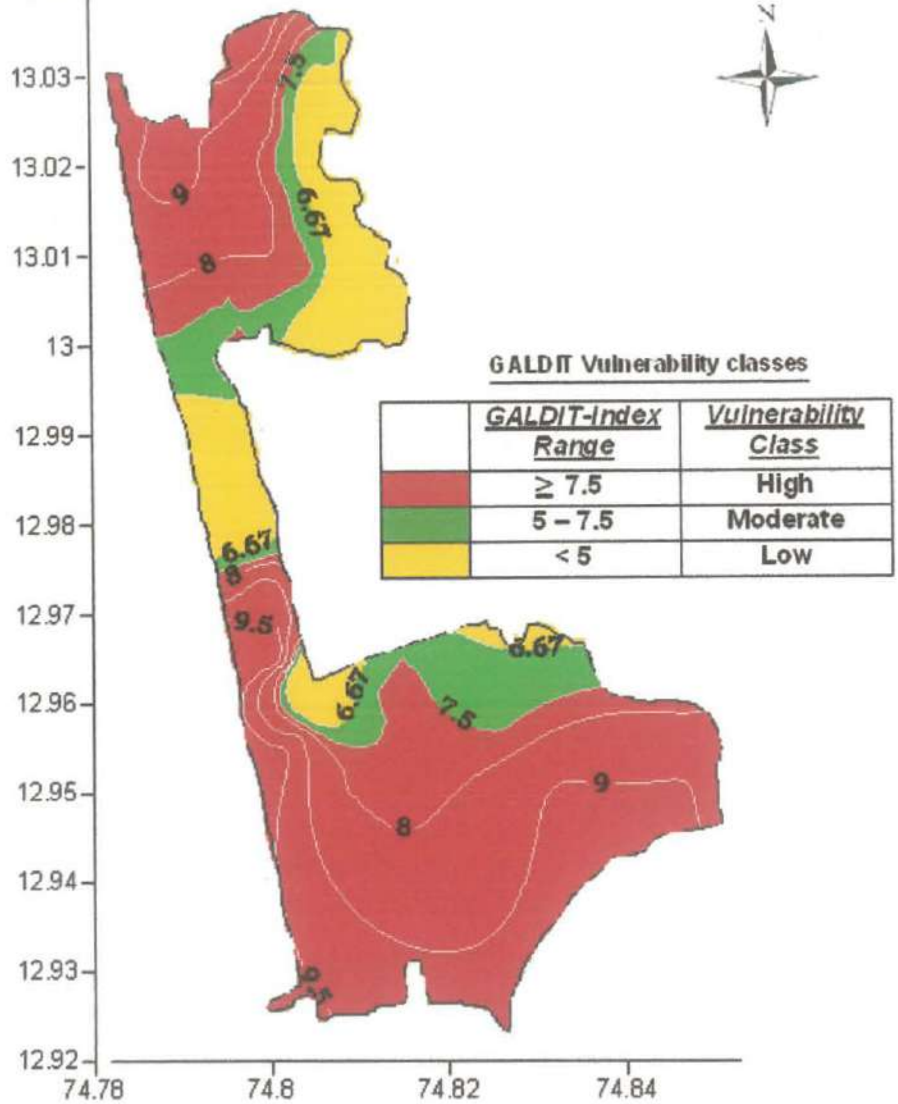


Fig.4.40. Saltwater-intrusion vulnerability map as depicted by the GALDIT scores for normal sea level (April, 2007)

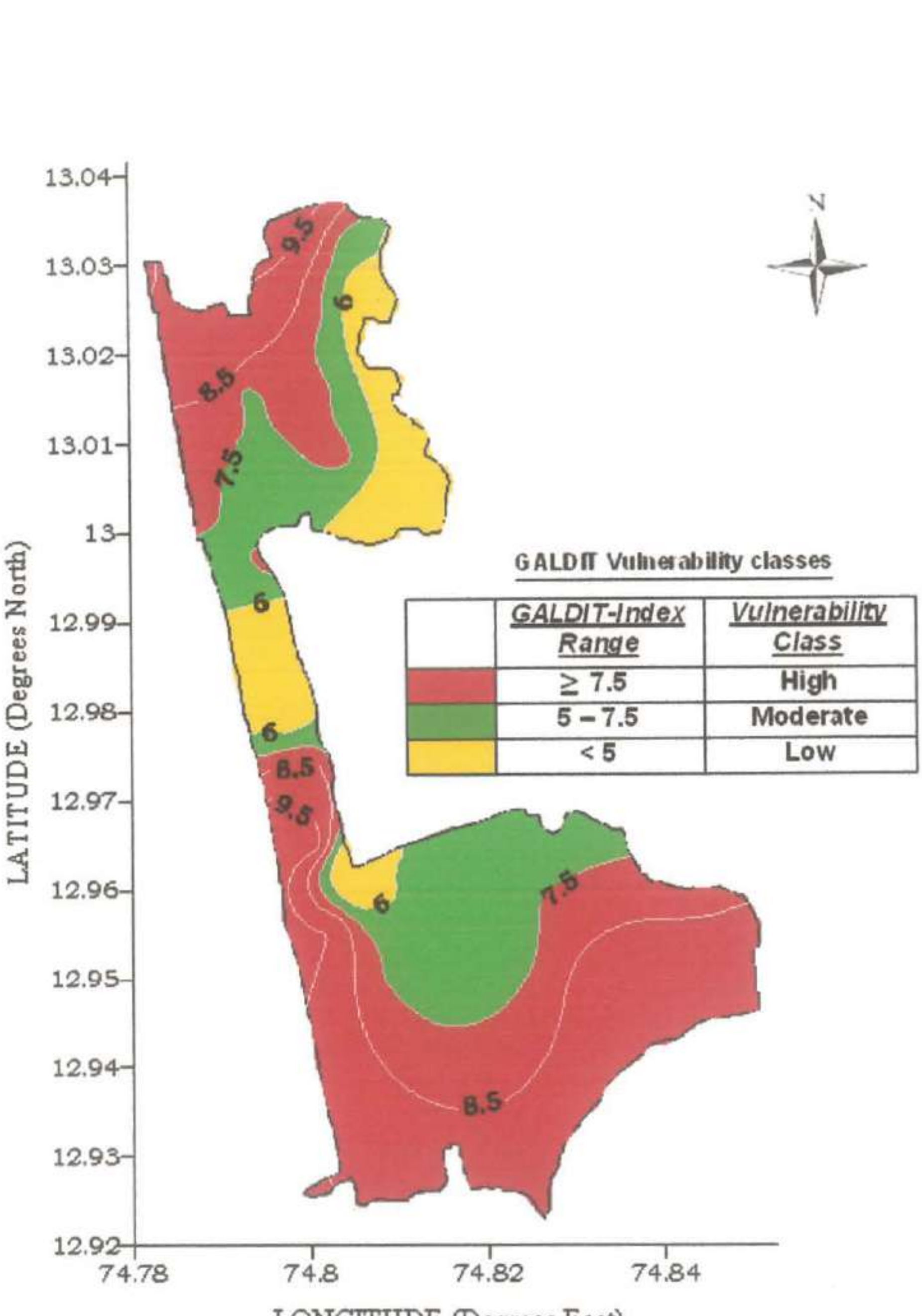


Fig.4.41. Saltwater-intrusion vulnerability map as depicted by the GALDIT scores for normal sea level (May, 2007)

We can see from figs. 4.35 to 4.41 that the study area falls under three categories of vulnerability ie low, moderately or highly vulnerable to saltwater intrusion. As evident from the figs., the study area is worst affected in the month of April. The area on the northern side viz Chelaru, Mukka, Pavanje and Haleyangadi are less effected during the post-monsoon season (Nov to Jan). However, during the pre-monsoon season (Feb to May) they come under the zone of highly vulnerable category. The areas down south viz Baikampady, Kenjar, Jokatte and Kulai are seen to be greatly affected by the saltwater intrusion in the month of April and May.

4.51 Vulnerability assessment for the sea level rise

Change in groundwater levels with respect to the mean sea elevation along the coast largely influences the extent of saltwater intrusion in the fresh water aquifers. The GALDIT rating for a rise in the sea level of 0.25m is evaluated for the intense summer months of April and May. Figs 4.42 and 4.43 represent the vulnerability map of the study area for 0.25m rise. With the 0.25m rise in sea level no much change is observed in the GALDIT index vulnerability map for the study area, except that wells nos.23 and 37 (in the Kulai area) turn highly vulnerable to saltwater intrusion in the month of April, unlike during the normal sea level condition.

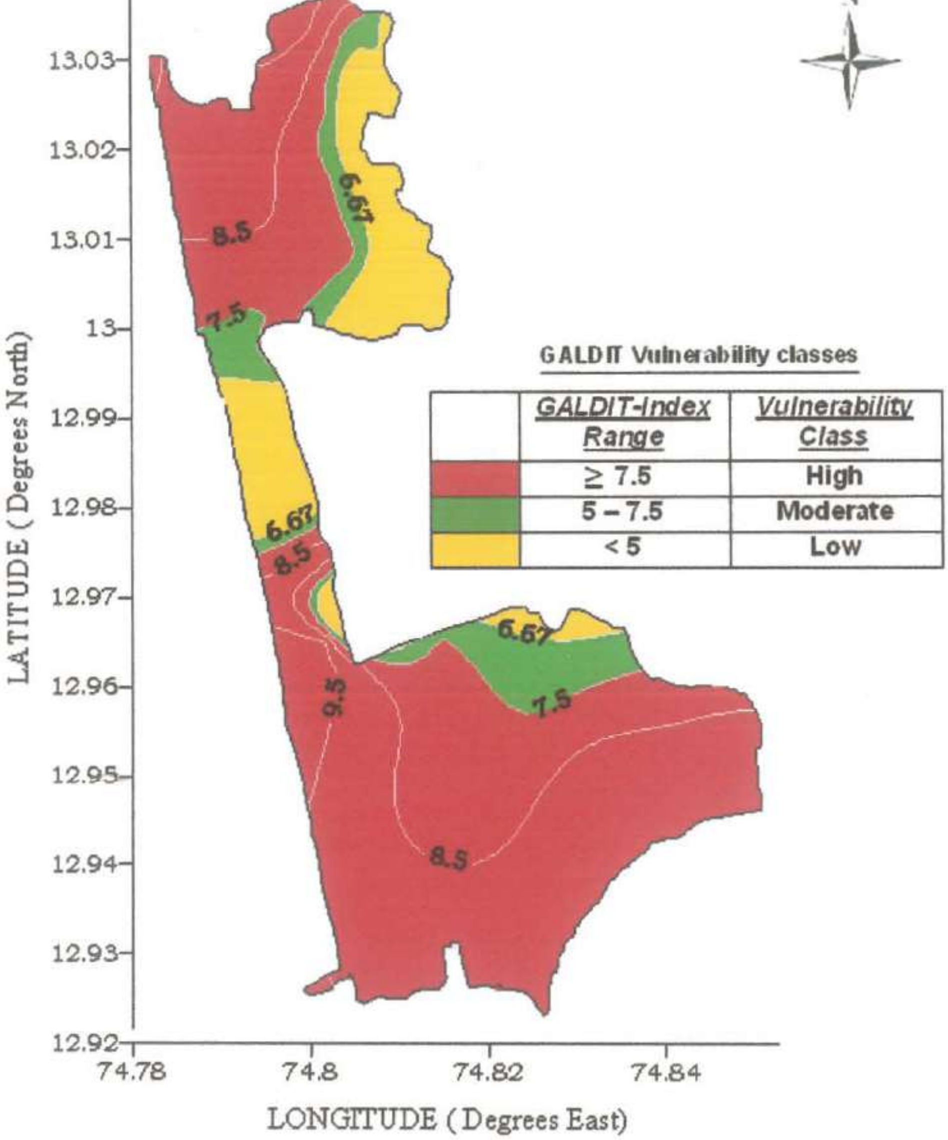


Fig.4.42. Saltwater-intrusion vulnerability map as depicted by GALDIT scores for 0.25m rise of sea level (April, 2007)

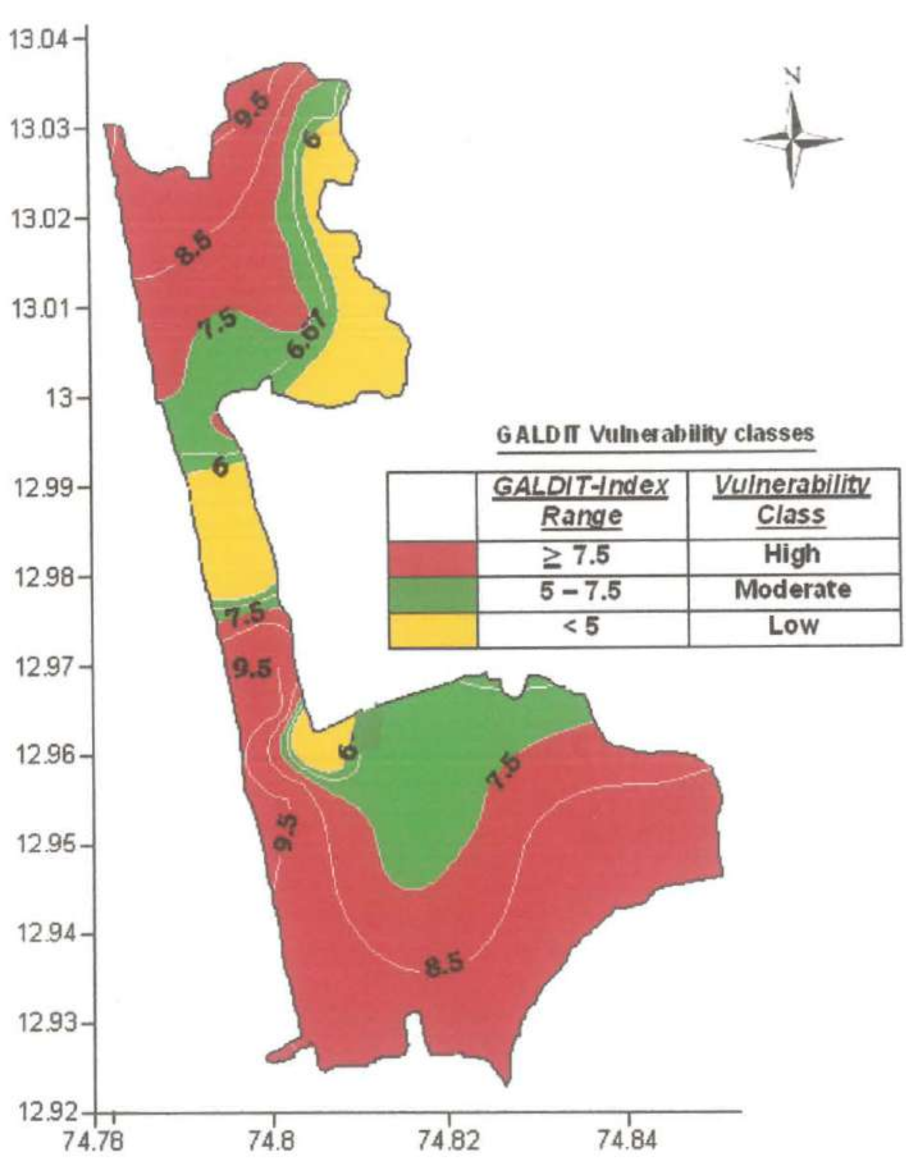


Fig.4.43. Saltwater-intrusion vulnerability map as depicted by GALDIT scores for 0.25m rise of sea level (May, 2007)

4.6 Water Quality Results

The major thrust in the study is to assess the extent of saltwater intrusion the basin. Hence salinity of ground water collected from the wells is analyzed. The results indicate salinity ranging from 0mg/l to 2900mg/l in the wells. The well nos. 4, 7, 12, 19, 11, 24, 25, 26, 27, 30, 31, 32, 33, and 35 are having salinity greater than 300mg/l and are severely affected by saltwater intrusion due to proximity to the sea. Some of the wells show the salinity with the advancement of summer. In addition to salinity, drinking water standards are also looked into and are being analyzed. The wells 4, 7, 11, 12, 25, 31, 32, 33 and 35 are with TDS greater than 500mg/l (normal range) and are affected by the TDS .The pH values of the samples are normally within the range. Turbidity values of all the wells are little bit higher than the normal values. i.e. more than 5NTU. Table. 4.22 shows the drinking water standards as per WHO (Garg, 1998) requirement. Drinking water must be colourless, odourless and tasteless. It should be free from turbidity and excessive or toxic chemical compounds. Harmful micro-organisms and radioactivity must be absent. The quality of water for municipal supplies is therefore, should be controlled throughout. Coliform test was conducted for the following well samples (Table.4.23). Well nos1, 2, 3, 6, 11, 12, 13, 14, 19, 20, 23, 32, 33, 35, 36, 37 and 38 are having the highest count, which require precautionary measures for drinking purposes. Preferably chlorination and boiling the water before drinking will ensure safety against the coliforms. As the summer advances (January-April), the water level decline was clearly observed in almost all the wells The other drinking water parameter values of the samples are given in table 4.24 which indicate that a few wells contain excessive iron, chloride and nitrate contents.

Table.4.22. Drinking water standards as per WHO (Garg, 1998)

Parameters	Normal Range
pH	6.5-8.5
TDS	500mg/l
Salinity	0mg/l
Turbidity	5NTU
Coliform [MPN]	Nil
Conducivity	750(microSiemens/cm)

Table.4.23 Results of the MPN(coliform) test in 2006.

Well No	Most Probable Number as MPN Index/100ml	Well No	Most Probable Number as MPN Index/100ml
1	80	21	39
2	110	22	21
3	300	23	130
4	22	24	Nil
5	34	25	17
6	220	26	4
7	33	27	90
8	14	28	13
9	13	29	80
10	34	30	7
11	500	31	26
12	140	32	542
13	1600	33	141
14	900	34	79
15	No Sample	35	278
16	70	36	109
17	50	37	141
18	26	38	109
19	500	39	7
20	1600		

If MPN is Nil, the water quality is good for drinking purpose

Table 4.24. Test Report on Water Samples

Sl.No	Total Hardness as $CaCO_3$ mg/L	Iron, as Fe mg/l	Chloride as Cl^- mg/L	Sulfate as SO^-_4 mg/L	Nitrate as NO^-_3 mg/L
1	60	0.11	49.0	11.86	7.81
2	7	0.10	9.0	0.79	3.49
3	18	0.09	16.5	2.80	9.69
4	35	0.17	49.0	15.67	4.63
5	25	0.10	6.5	1.44	5.68
6	49	0.03	53.0	1.15	11.90
7	120	0.07	350.0	15.02	11.26
8	50	0.08	19.0	7.33	8.40
9	28	0.06	30.5	2.16	6.07
10	37	0.08	8.0	4.38	5.50
11	21	0.12	23.0	8.70	5.52
12	13	0.03	18.0	2.87	7.20
13	11	0.16	15.0	1.29	3.95
14	15	0.05	19.0	1.87	4.64
15	No Sample				
16	130	0.07	56.0	12.72	9.17
17	50	0.11	29.0	15.74	4.22
18	125	0.11	25.0	11.07	1.31
19	140	0.10	24.0	20.27	3.99
20	110	0.03	26.5	14.45	3.99
21	90	0.15	40.0	5.82	3.42
22	58	Nil	21.5	17.83	Nil
23	97	Nil	25.5	17.68	Nil
24	217	0.16	35.5	12.72	2.35
25	120	Nil	215.0	22.21	36.66
26	89	0.25	42.5	11.57	4.67
27	124	0.22	44.0	16.24	82.58
28	23	Nil	20.5	5.82	6.95
29	13	Nil	20.0	1.22	2.00
30	45	0.06	27.0	10.06	2.77
31	54	Nil	36.5	12.94	Nil
32	29	Nil	32.5	7.04	Nil
33	20	0.57	9.0	4.03	Nil
34	33	0.01	38.0	1.15	Nil
35	17	0.08	10.0	11.72	Nil
36	20	0.66	19.0	4.67	0.95
37	32	Nil	22.5	10.28	8.43
38	70	Nil	18.0	5.75	1.81
39	38	Nil	27.0	3.09	3.21

Hardness-300mg/l, Iron-0.3mg/l, Chloride-250mg/l, Sulfate-200mg/l, Nitrate-45mg/l

4.6.1 Salinity Contours

The spatial and temporal salinity distribution during the study period is given in figs. 4.44 – 4.58.

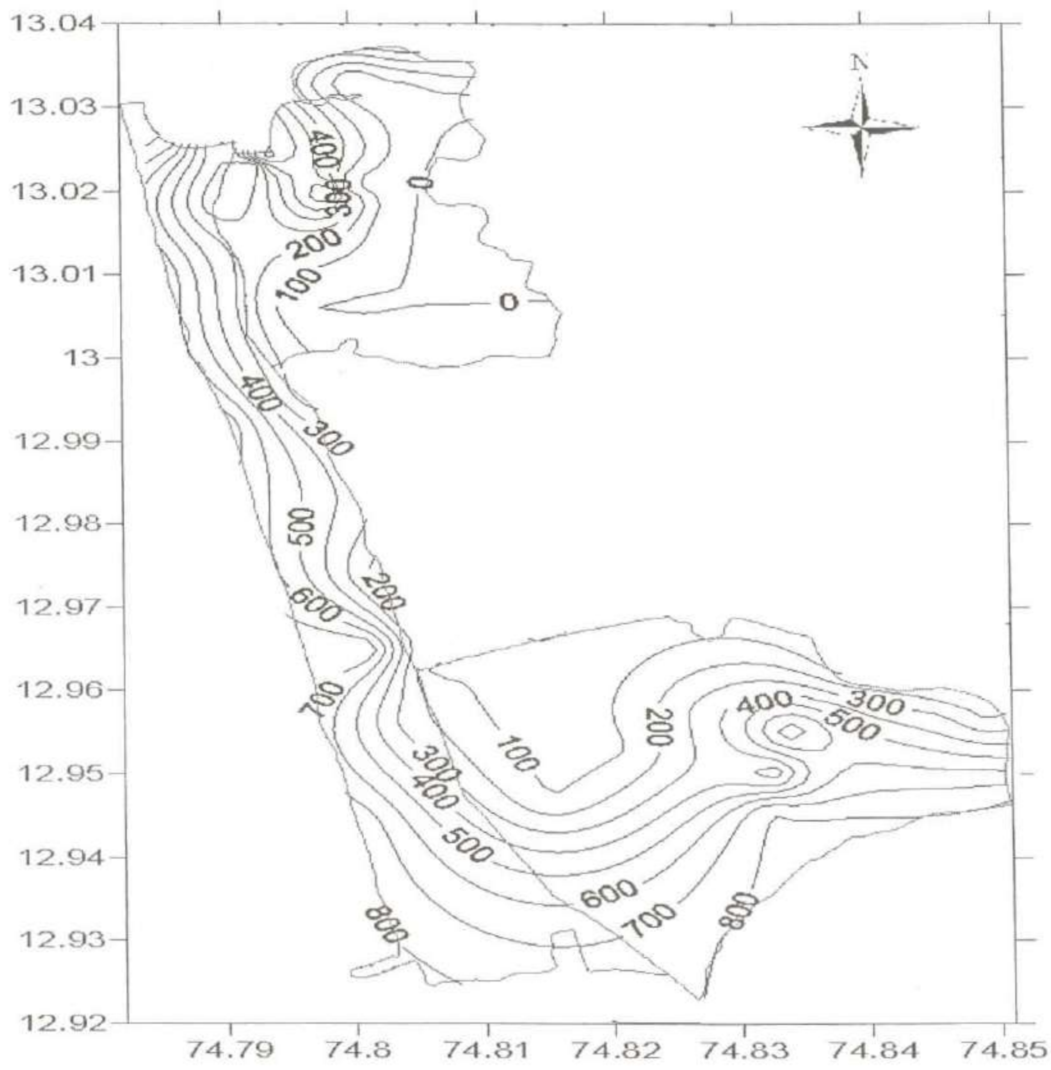


Fig.4.44. Salinity contour (Feb -2005)

The salinity starts increasing in the area since the withdrawal of the monsoon season. The max. salinity of greater than 2000mg/lit was observed along the coastline and adjoining the tidal rivers during April-May.

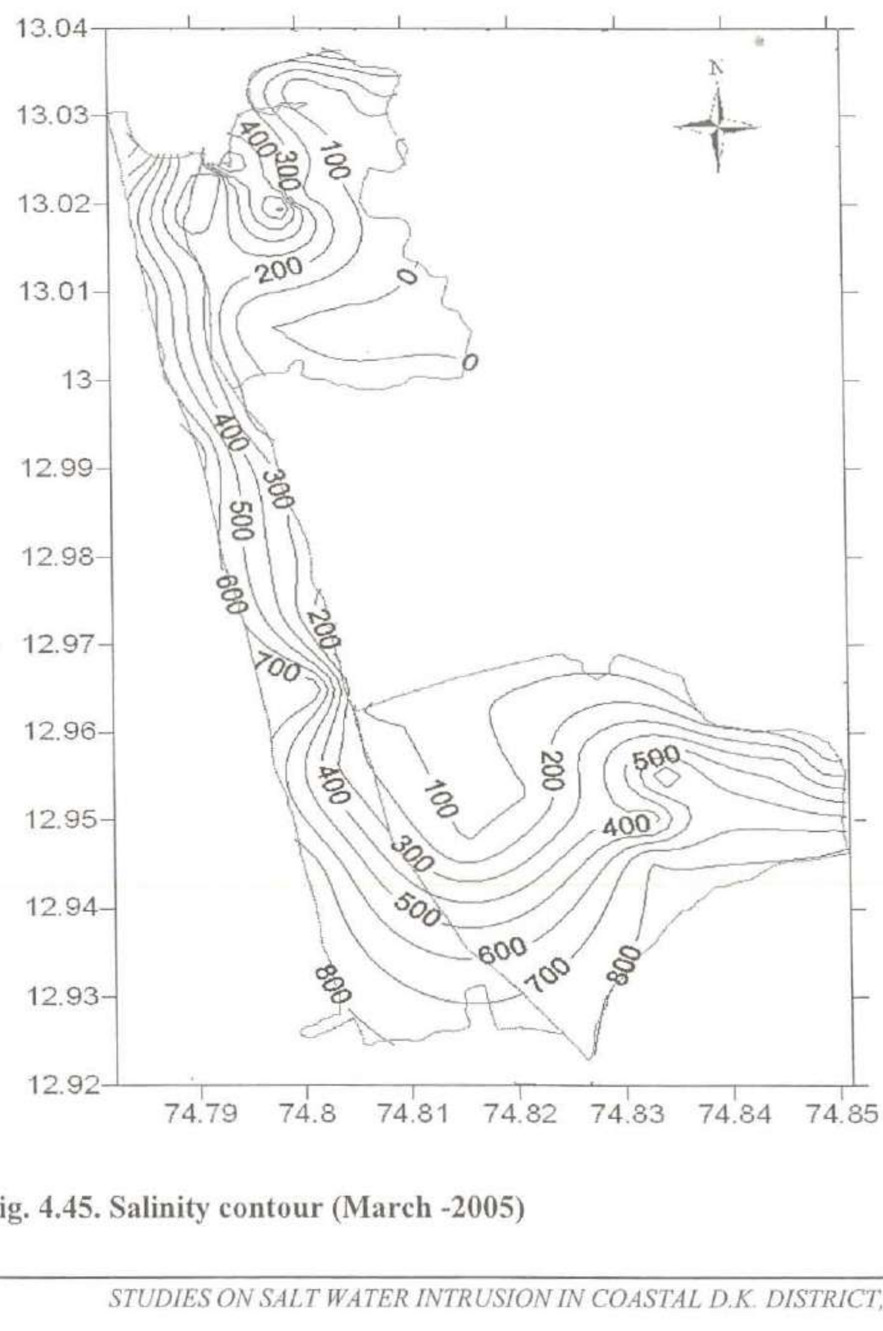


Fig. 4.45. Salinity contour (March -2005)

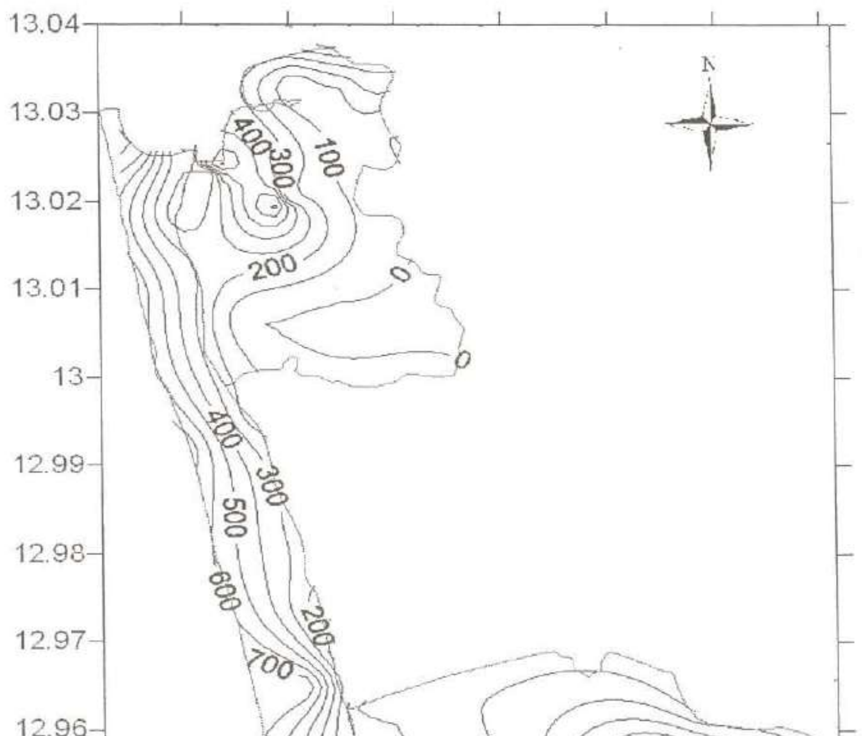


Fig. 4.46. Salinity contour (April- 2005)

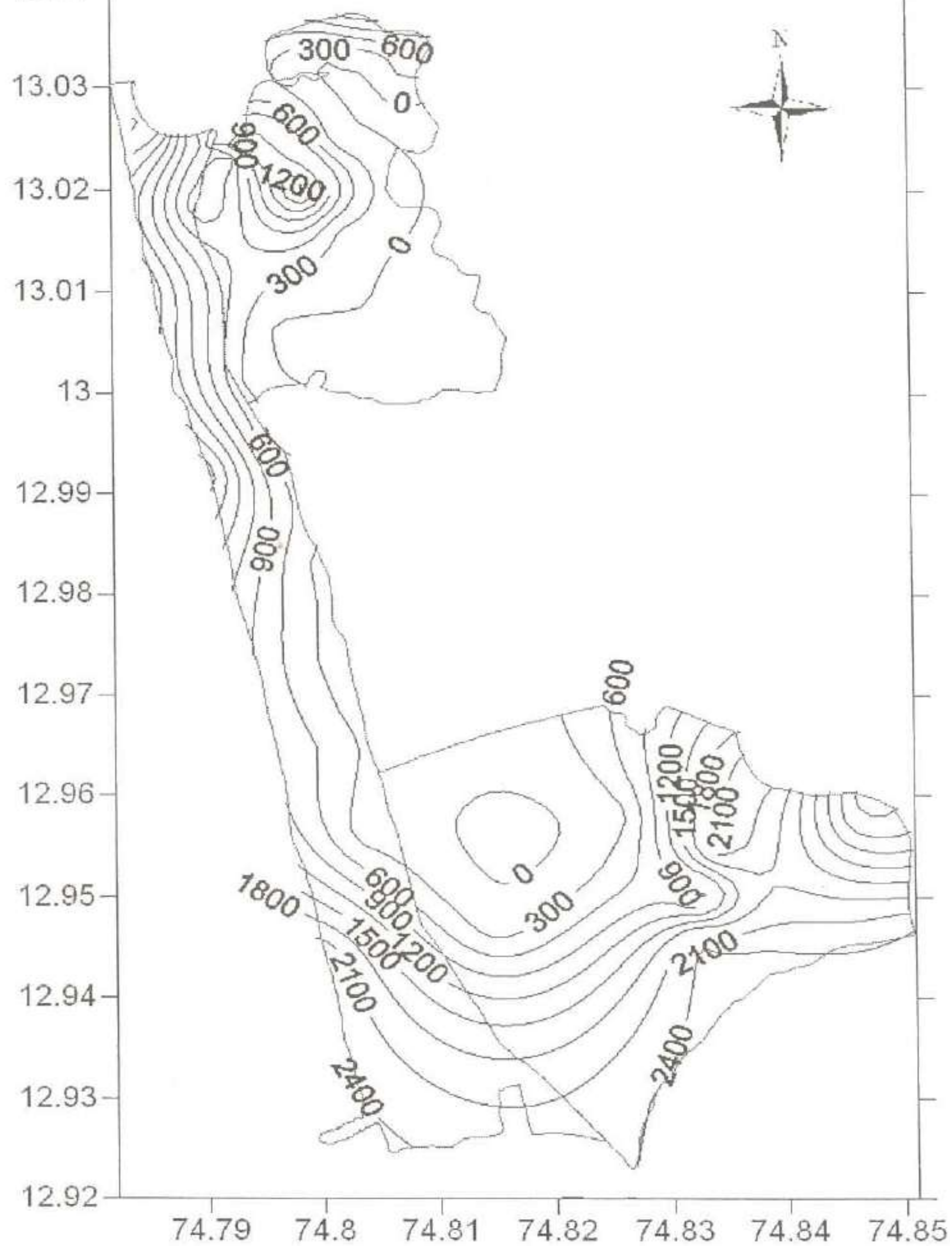


Fig. 4.47. Salinity contour (May 2005)

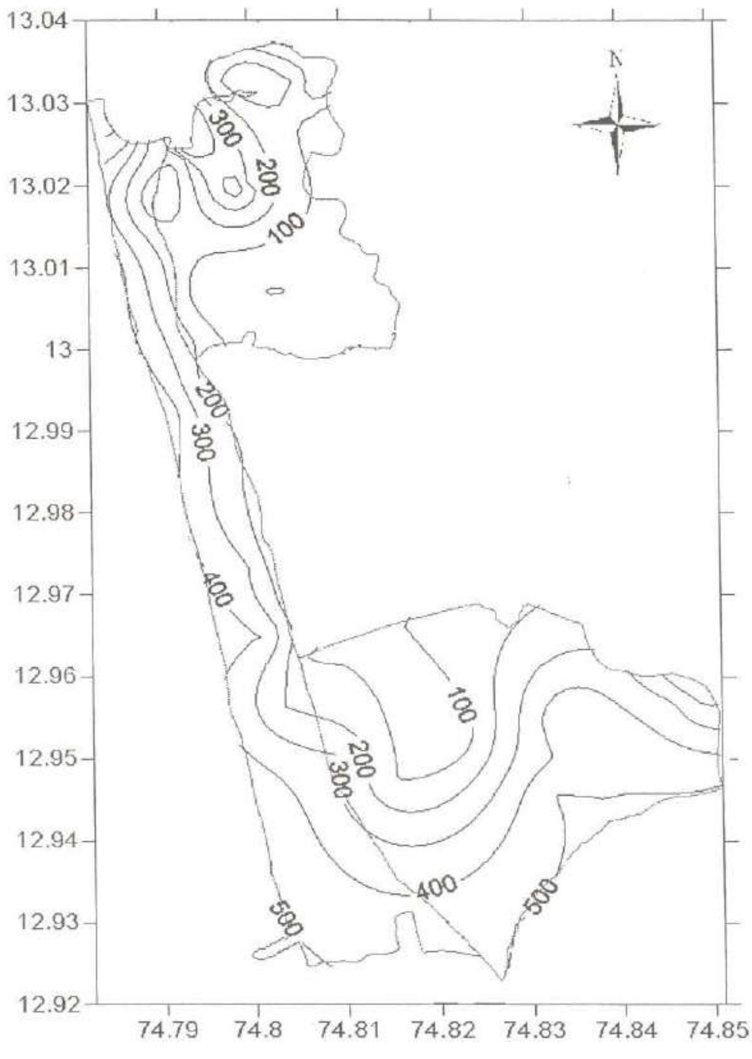


Fig. 4.48. Salinity contour (June 15- 2005)

The salinity values decrease once the monsoon rains set in the region as evident in fig. 4.48.

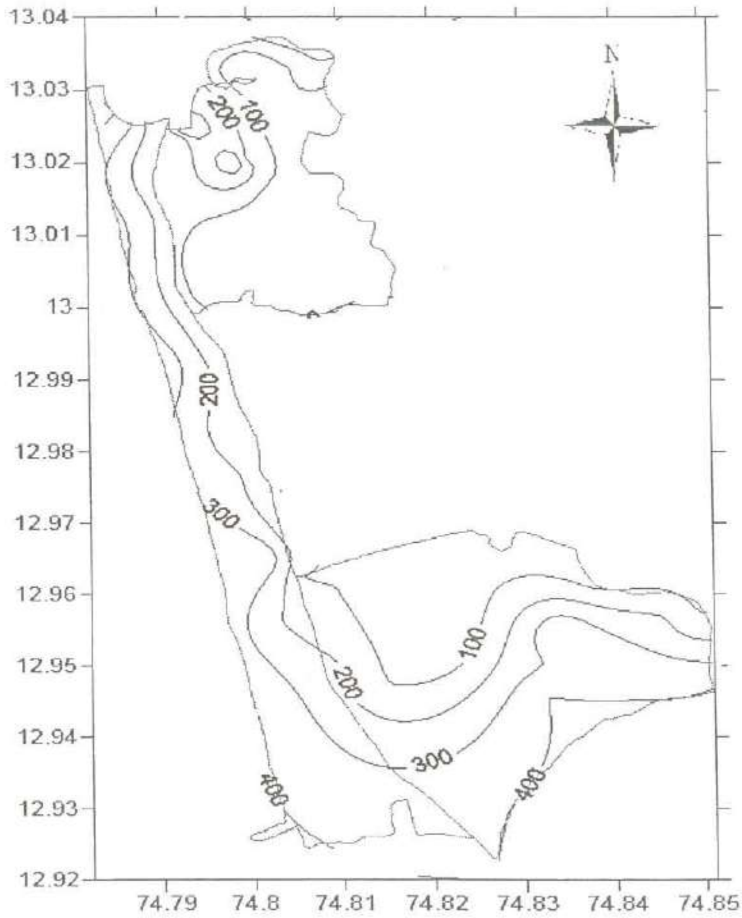


Fig. 4.49. Salinity contour (July- 2005)

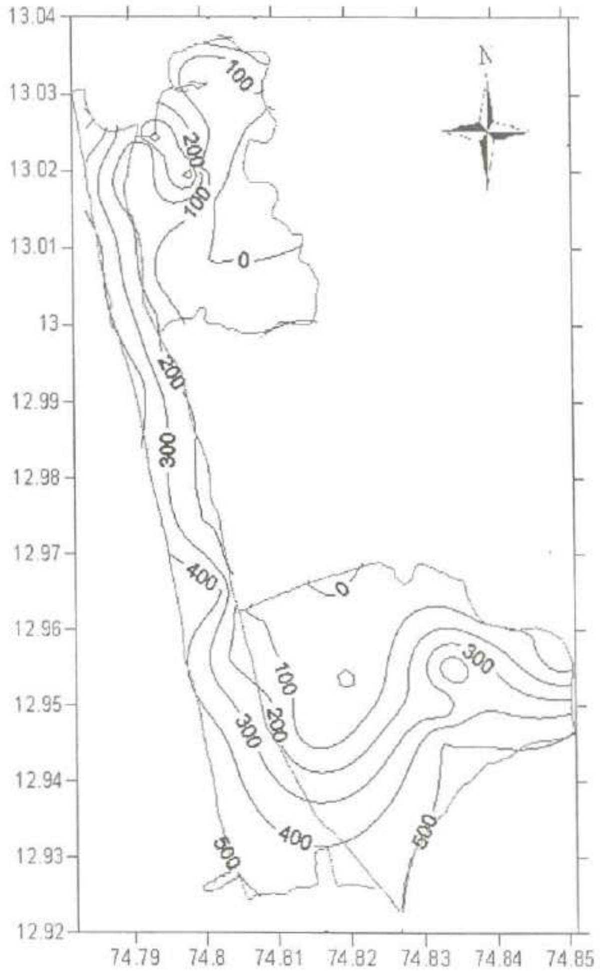


Fig. 4.50. Salinity contour (Aug- 2005)

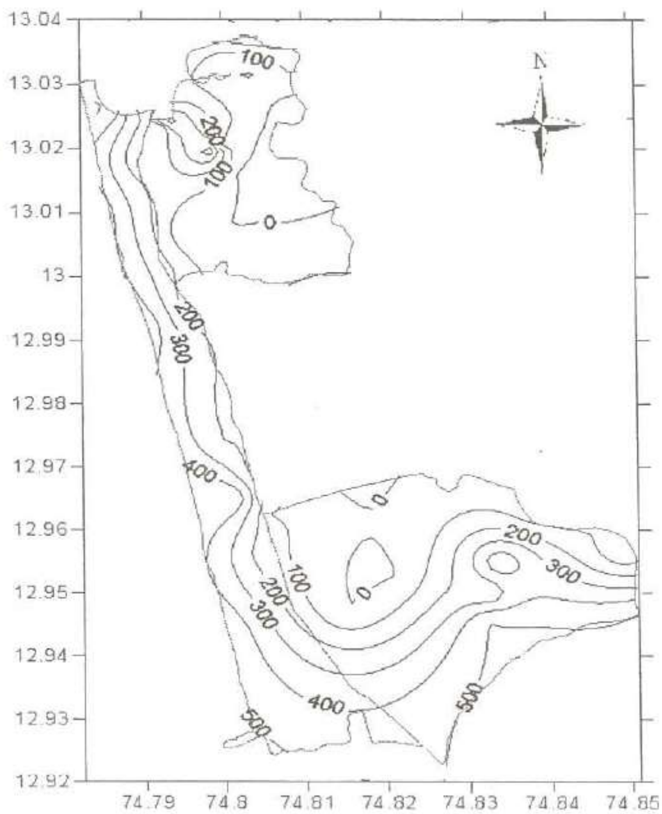


Fig. 4.51. Salinity contour (Sept- 2005)

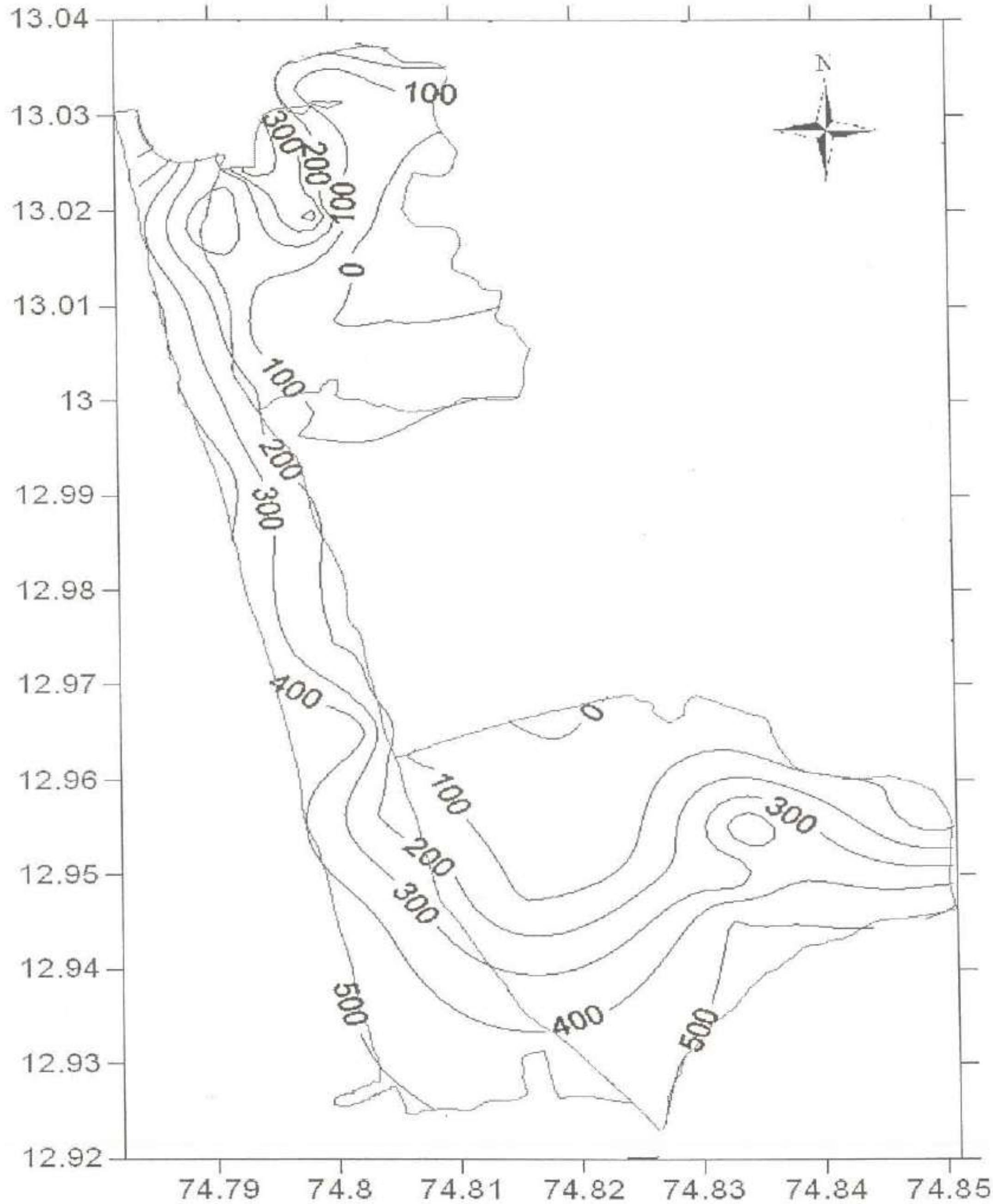


Fig. 4.52. Salinity contour (Oct- 2005)

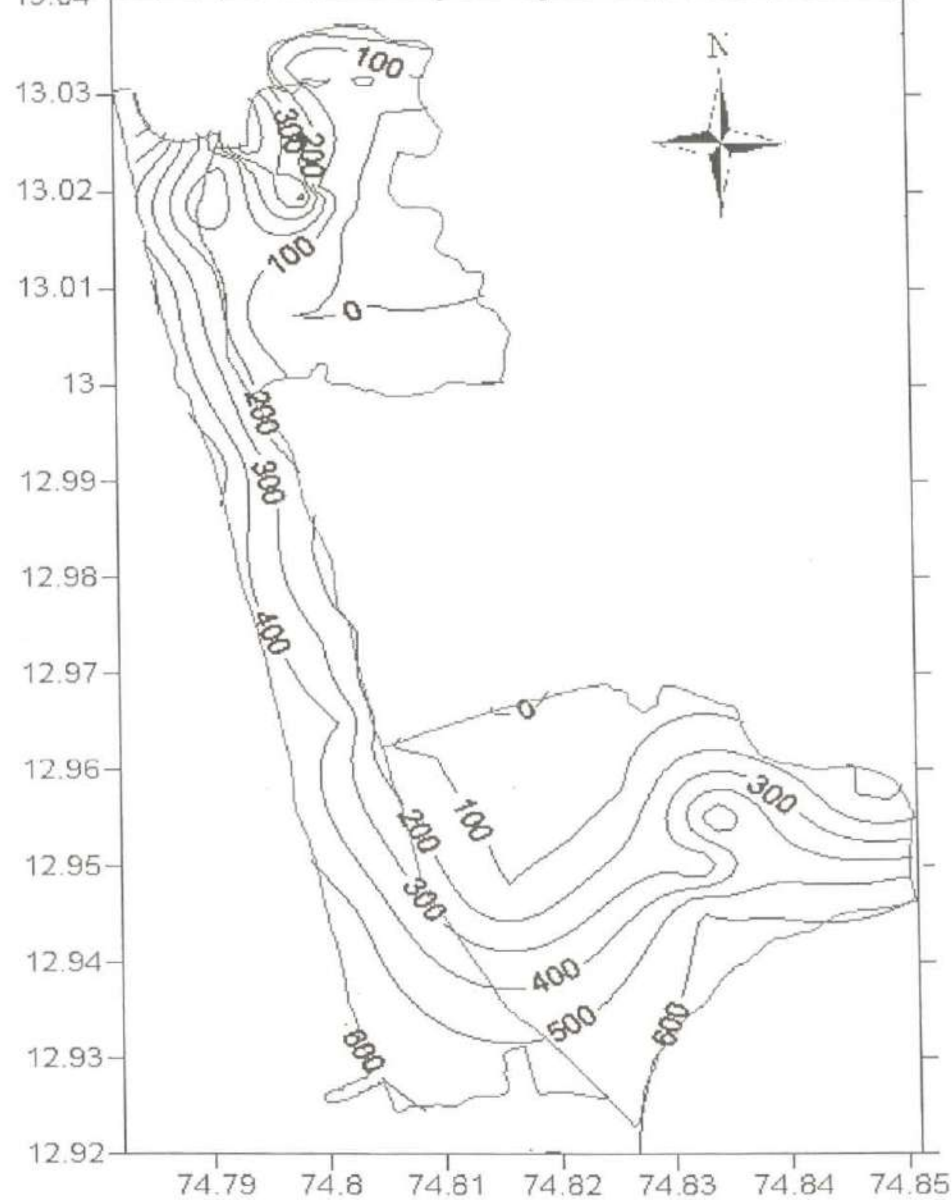


Fig.4.53. Salinity contour (Nov- 2005)

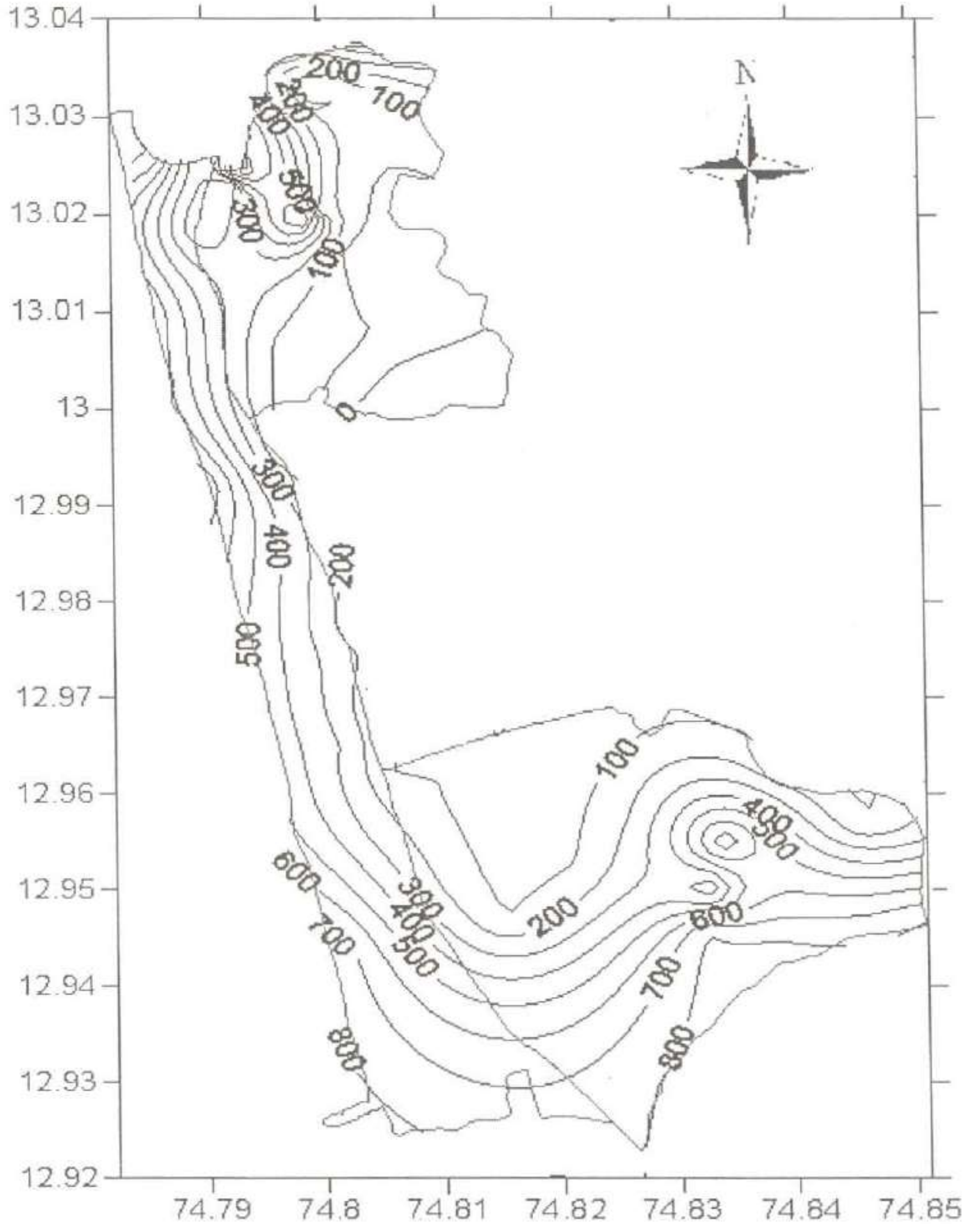


Fig. 4.54 Salinity contour (Dec- 2005)

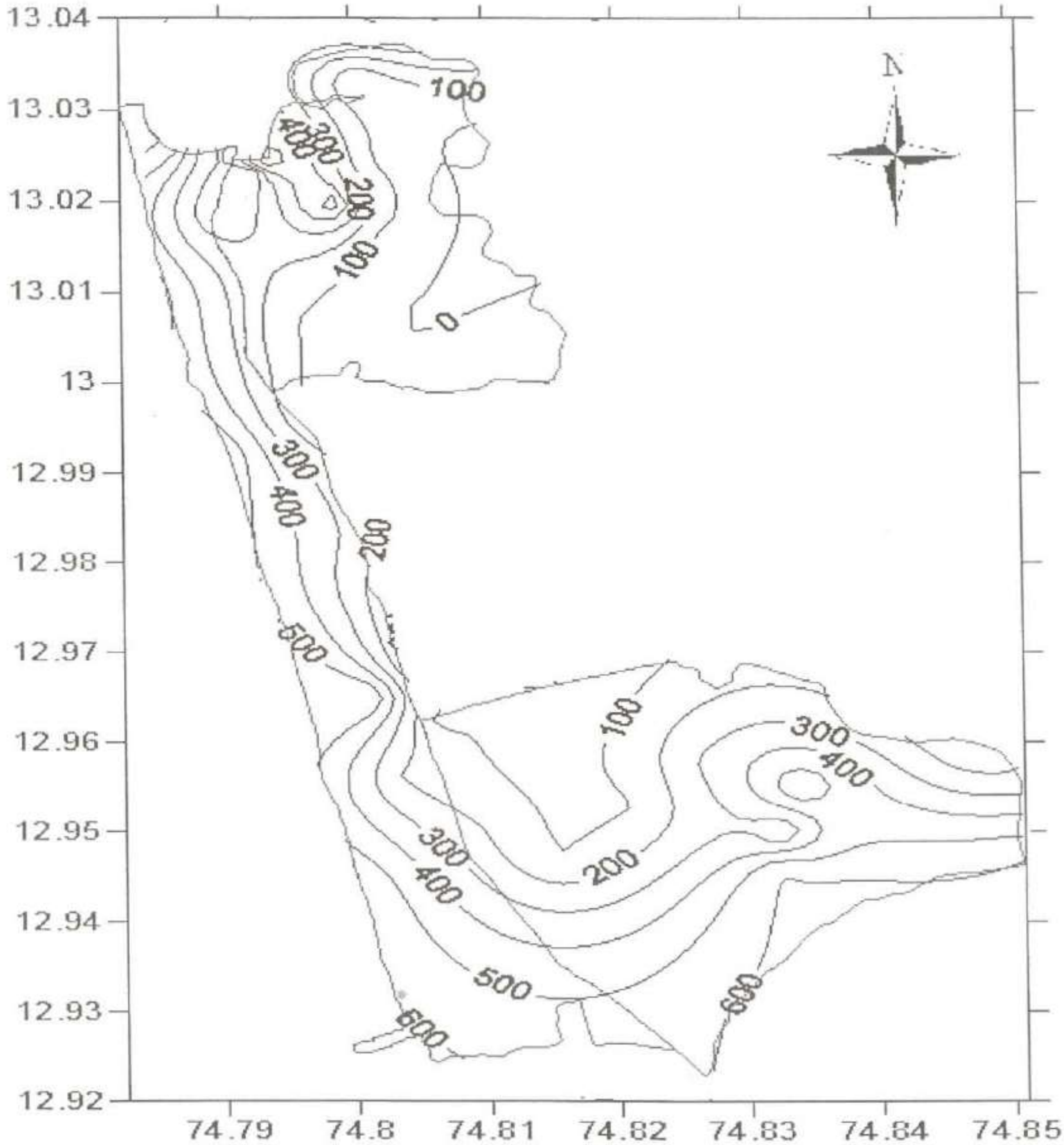


Fig. 4.55. Salinity contour (Jan -2006)

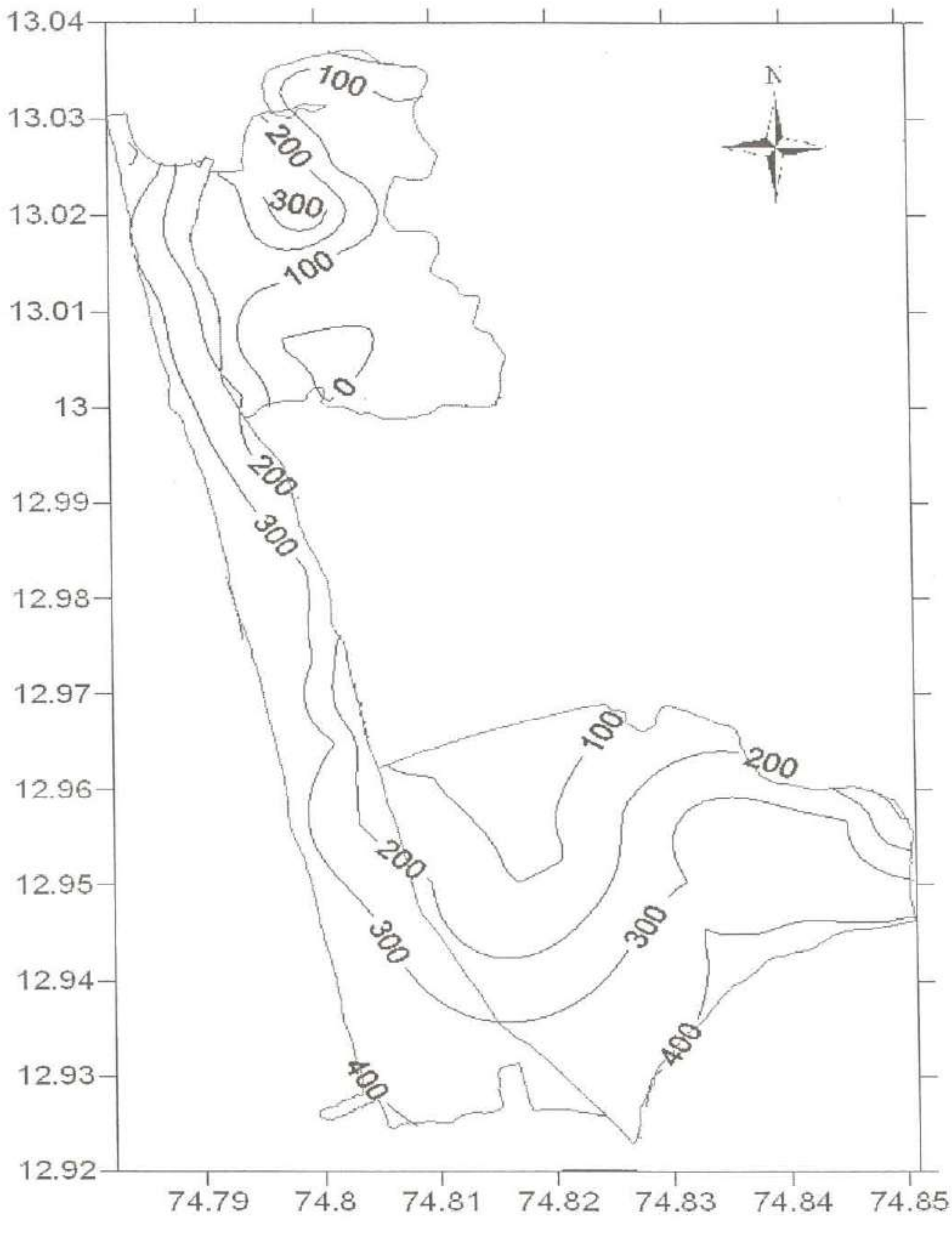


Fig. 4.56. Salinity contour (Feb -2006)

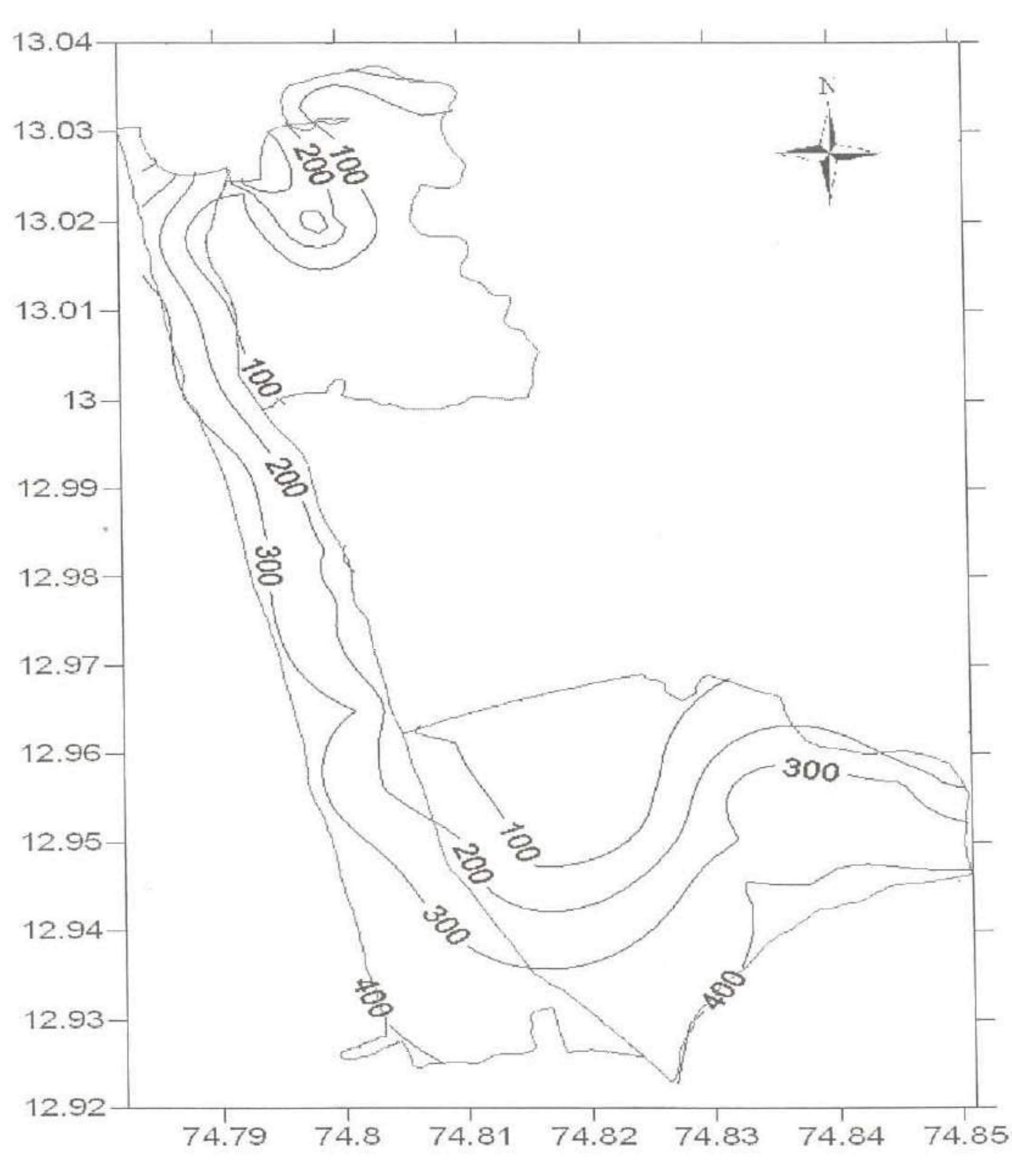


Fig. 4.57. Salinity contour (May -2006)

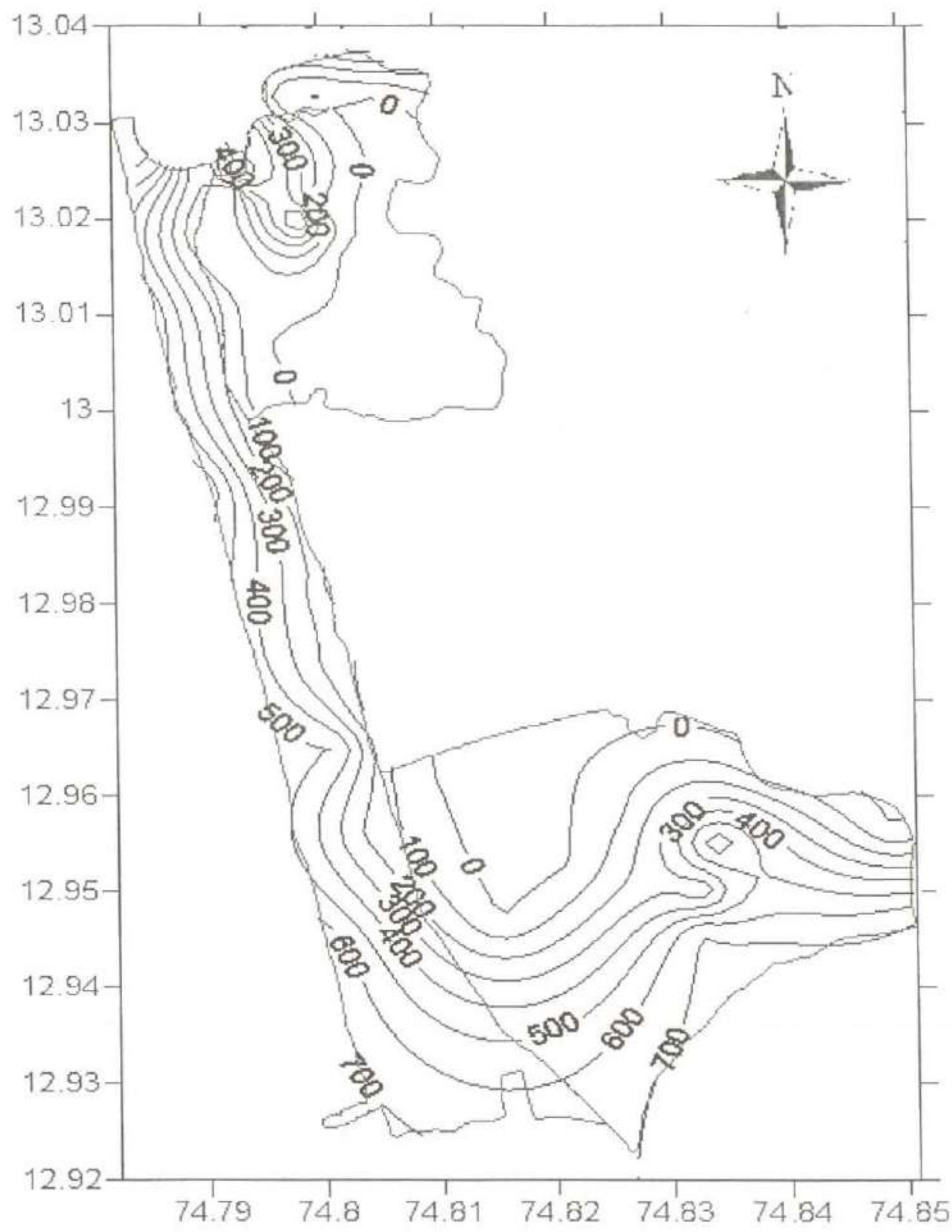


Fig. 4.58. Salinity contour (Mar-2007)

4.6.2 TDS Contours

The TDS count indirectly indicates the presence of saltwater. A similar trend observed in the case of salinity was observed for TDS also as evident from figs.4.59 – 4.66.

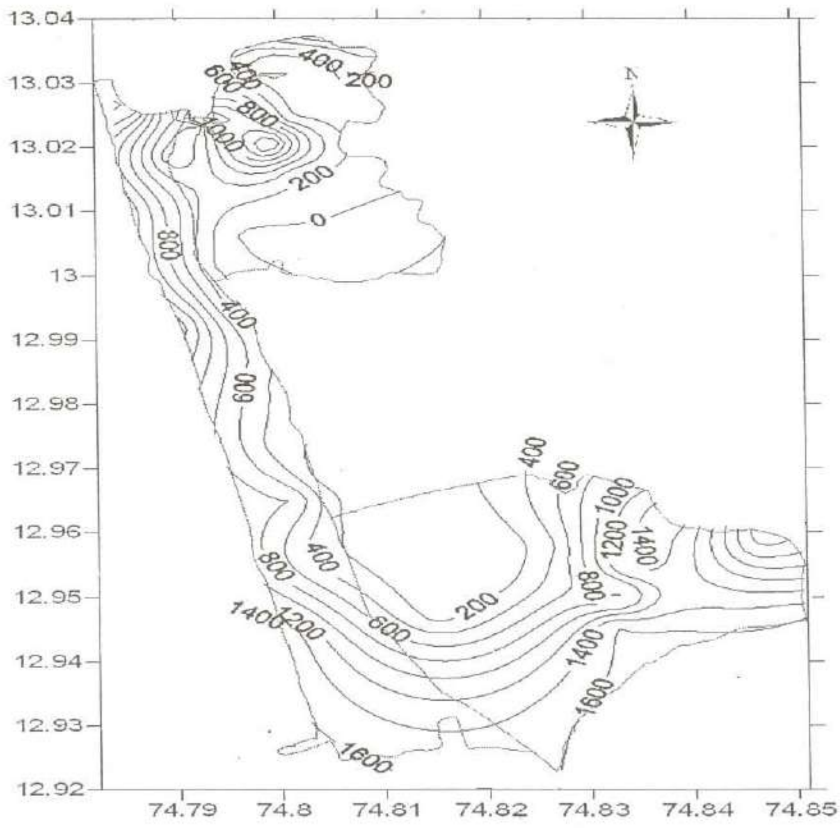


Fig. 4.59 TDS Contour (Apr.-05)

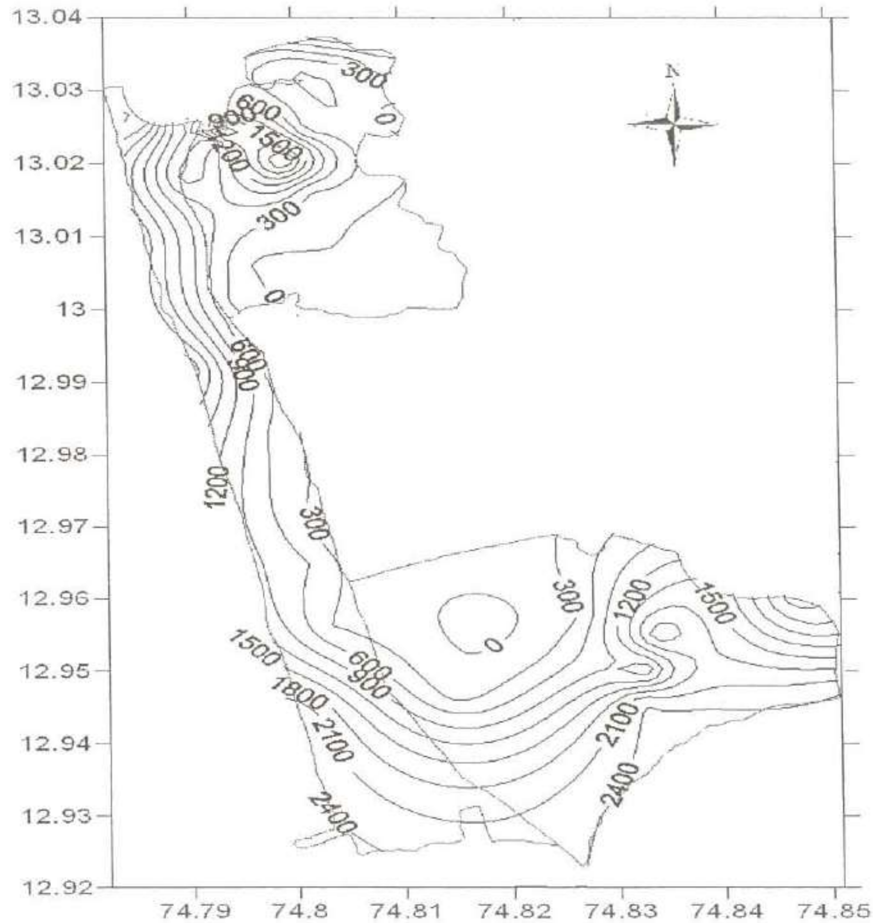


Fig. 4.60. TDS Contour (May-05)

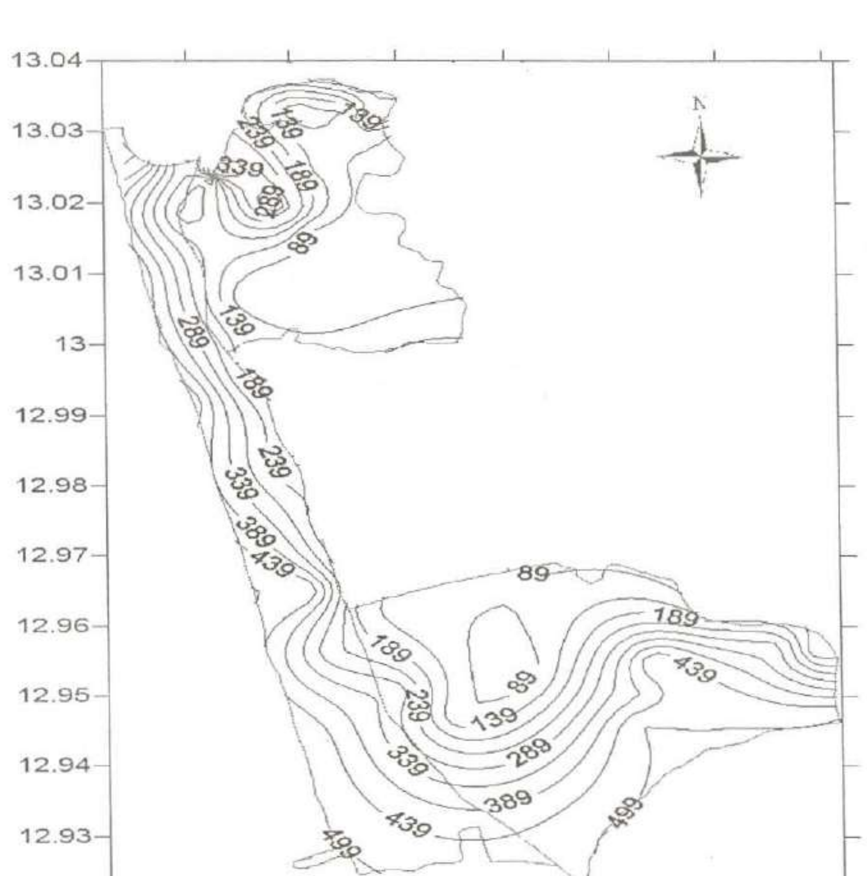


Fig. 4.61 TDS Contour (July-05)

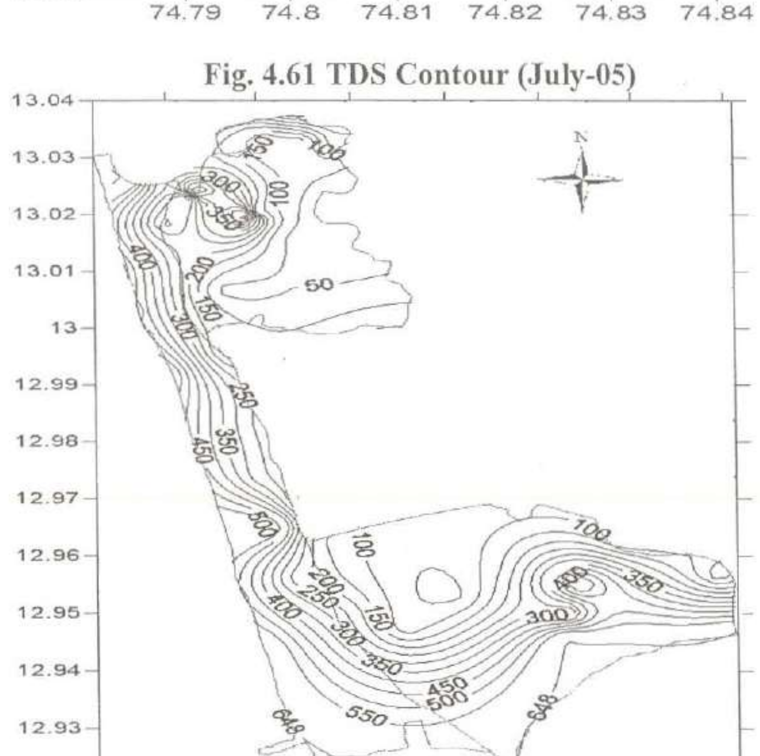


Fig. 4.62. TDS Contour (Aug-05)

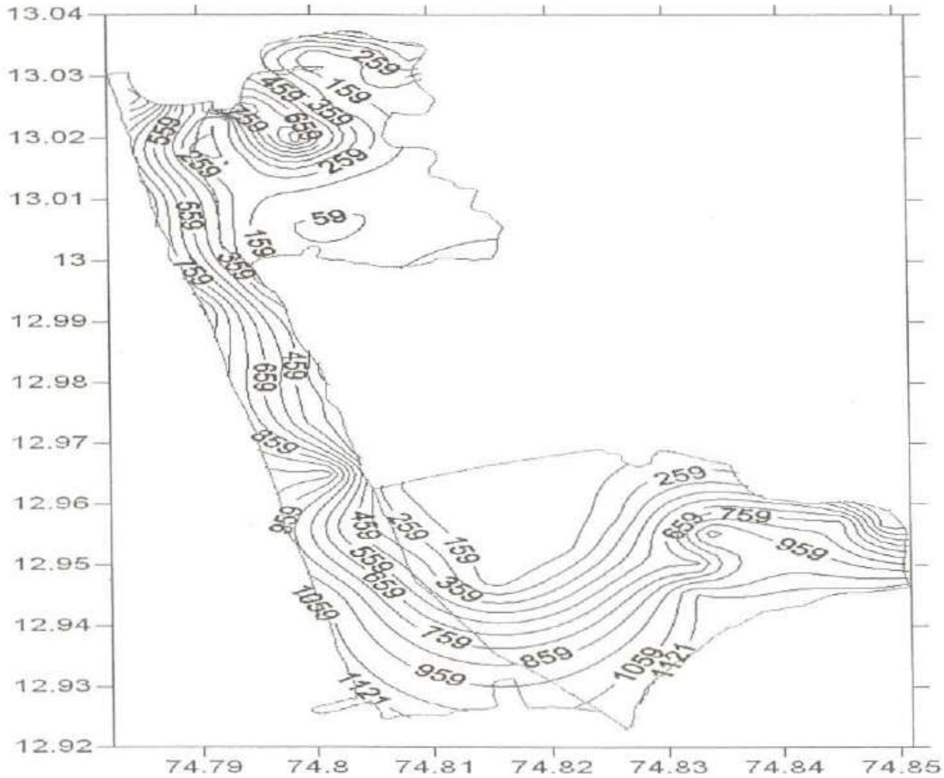


Fig. 4.63 TDS Contour (Apr-06)

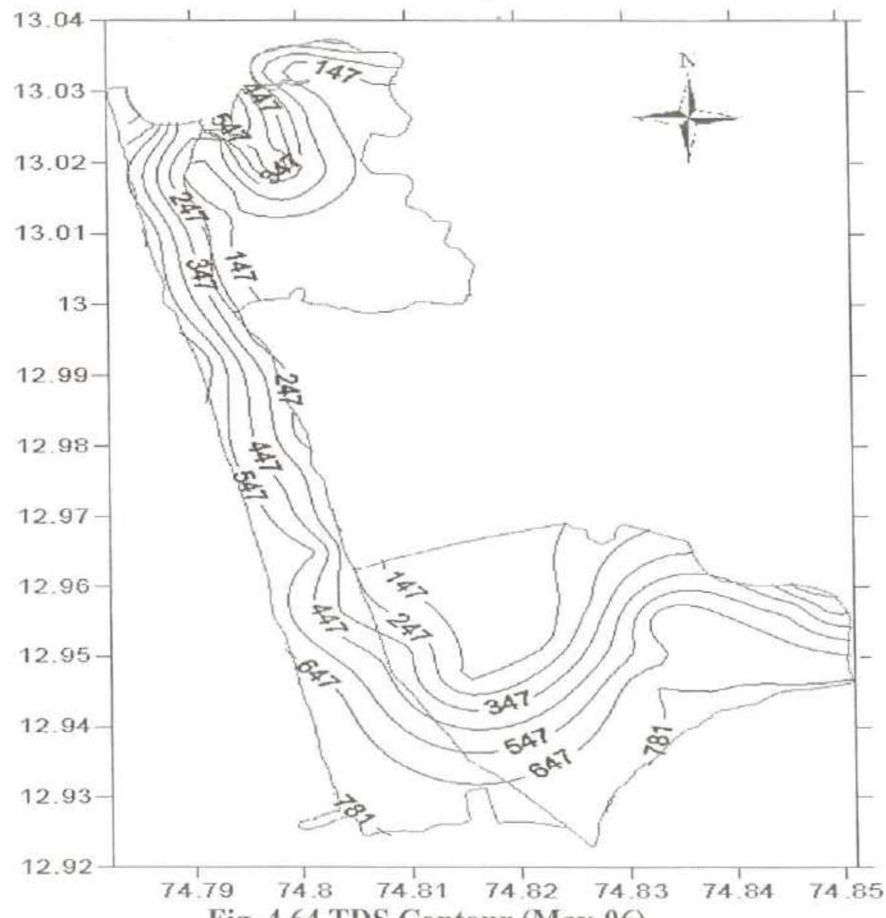


Fig. 4.64 TDS Contour (May-06)

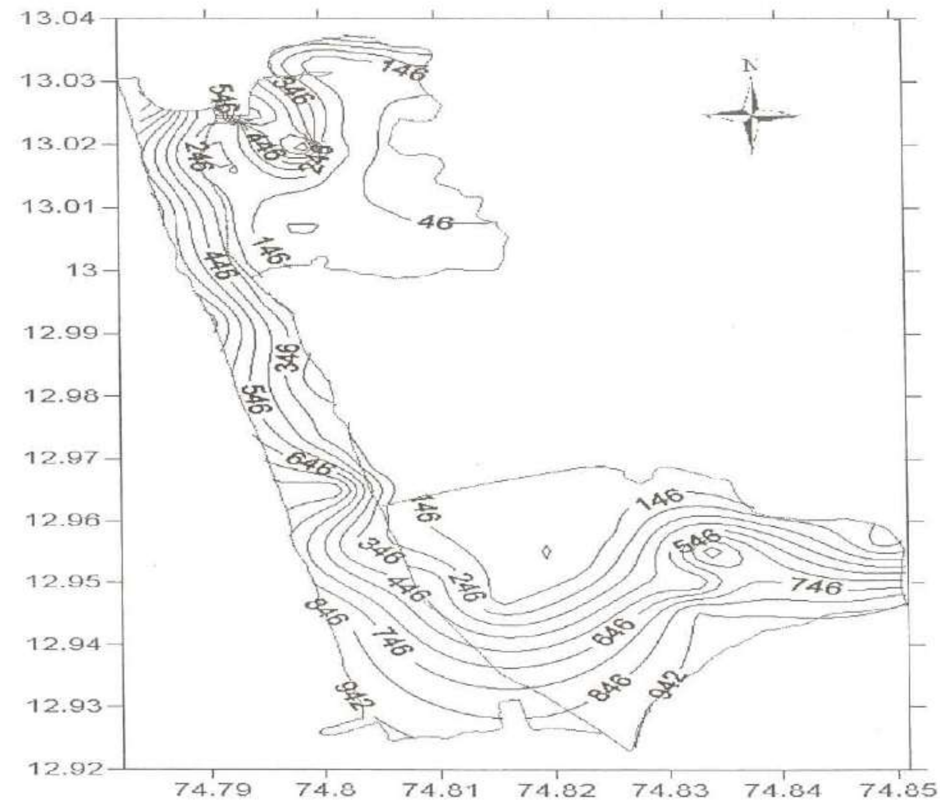


Fig. 4.65 TDS Contour (June-06)

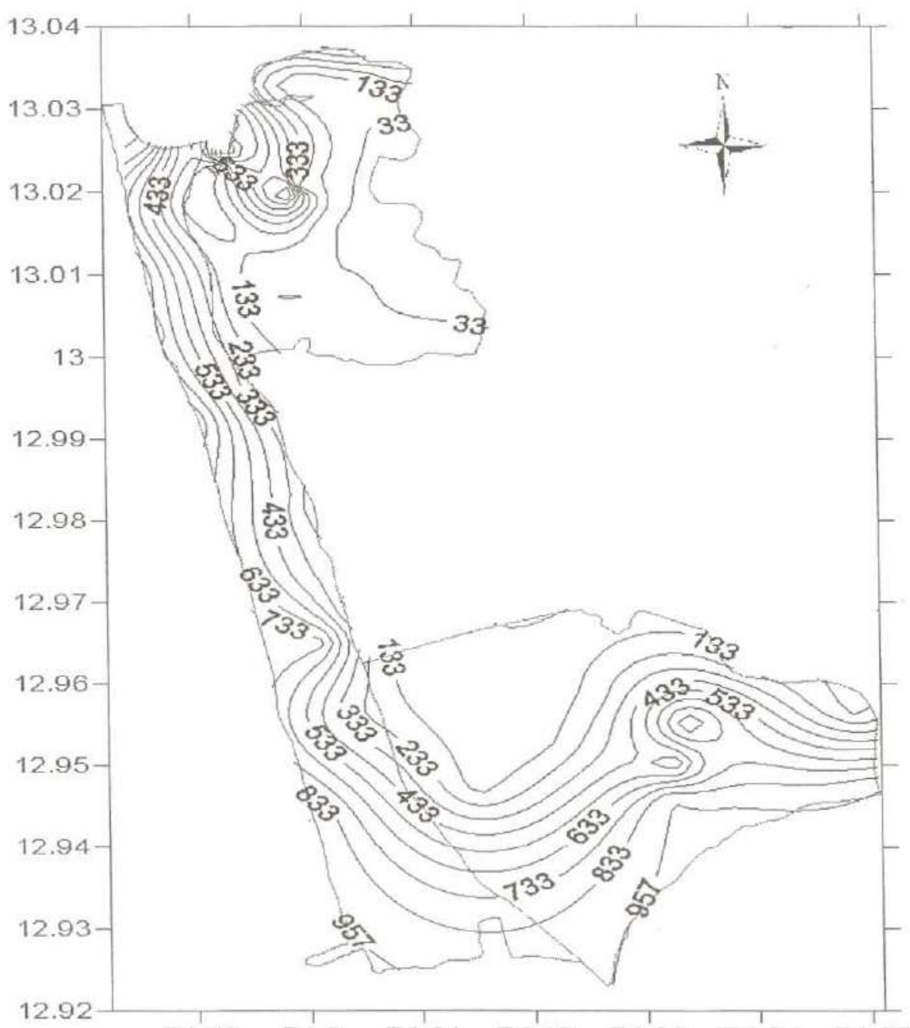


Fig. 4.66. TDS Contour (Mar-07)

4.6.3 Turbidity Contours

Turbidity is an index of groundwater contamination which usually occurs during the monsoon rains as evident from figs. 4.67 and 4.68.

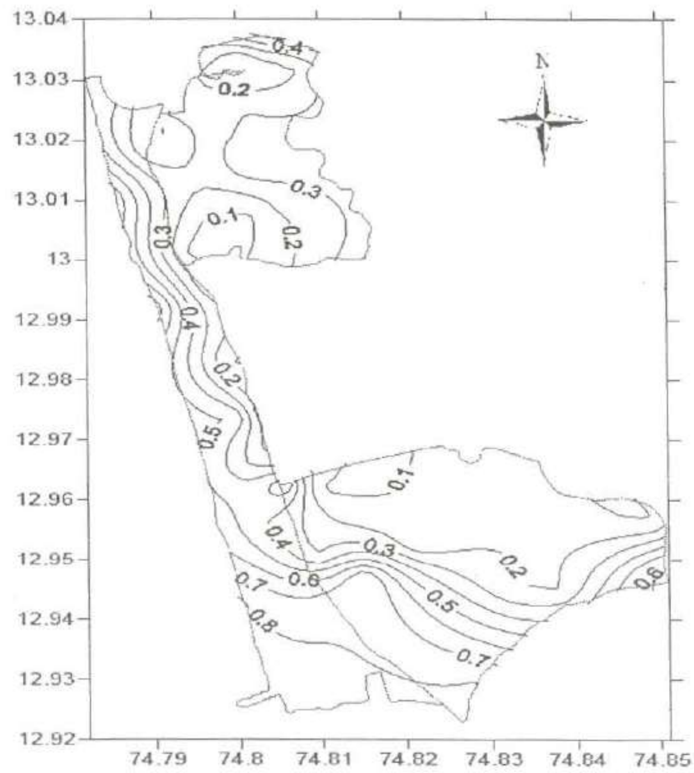


Fig. 4.67 Turbidity contour (Apr-2005)

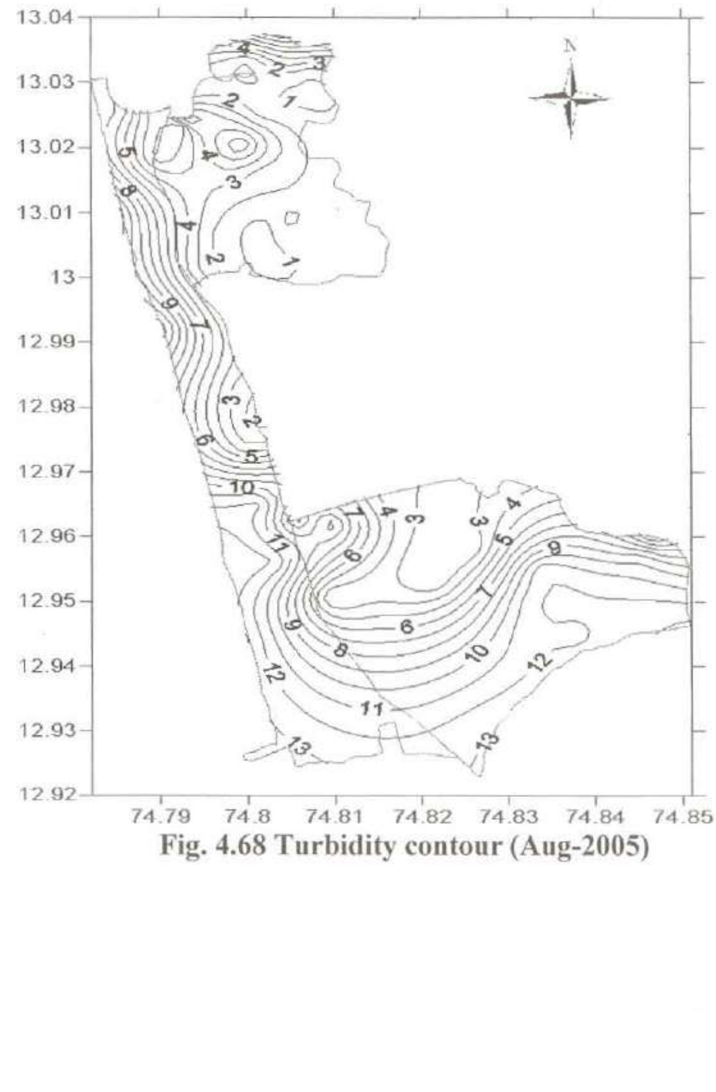


Fig. 4.68 Turbidity contour (Aug-2005)

4.6.4 Conductivity Contours

The conductivity of water is also an indirect indication of the saline intrusion. The advancing conductivity with the summer season is observed in the region and also evident from figs. 4.69 & 4.70.

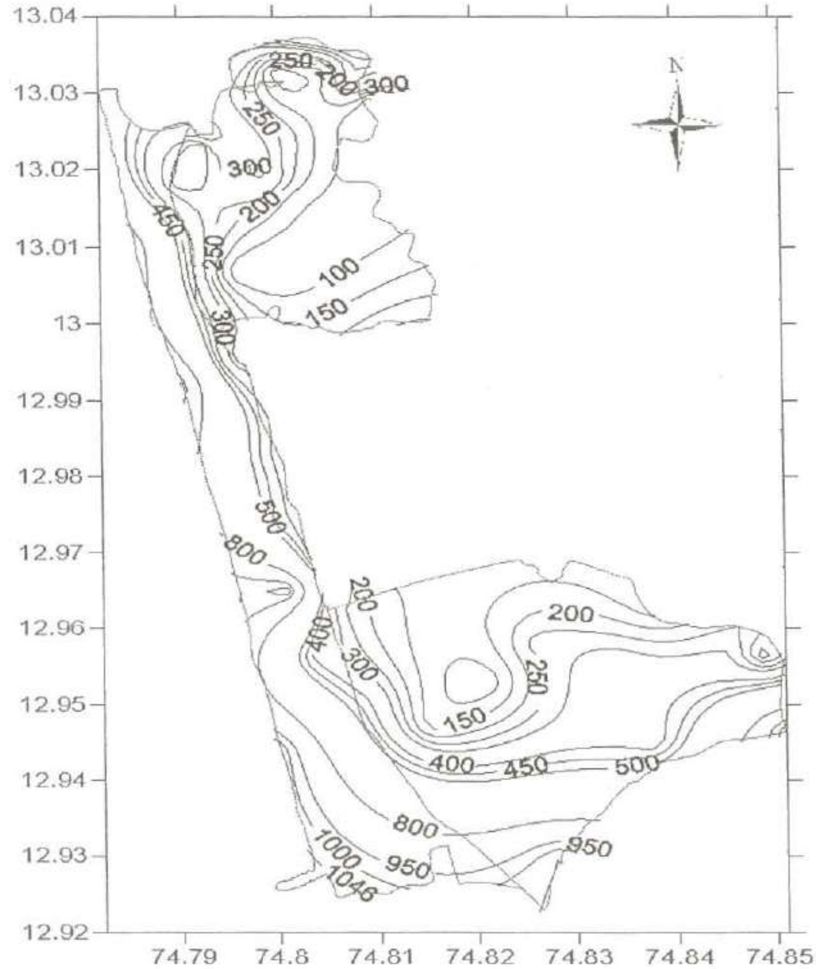


Fig.4.69 Conductivity contours (Aug-2005)

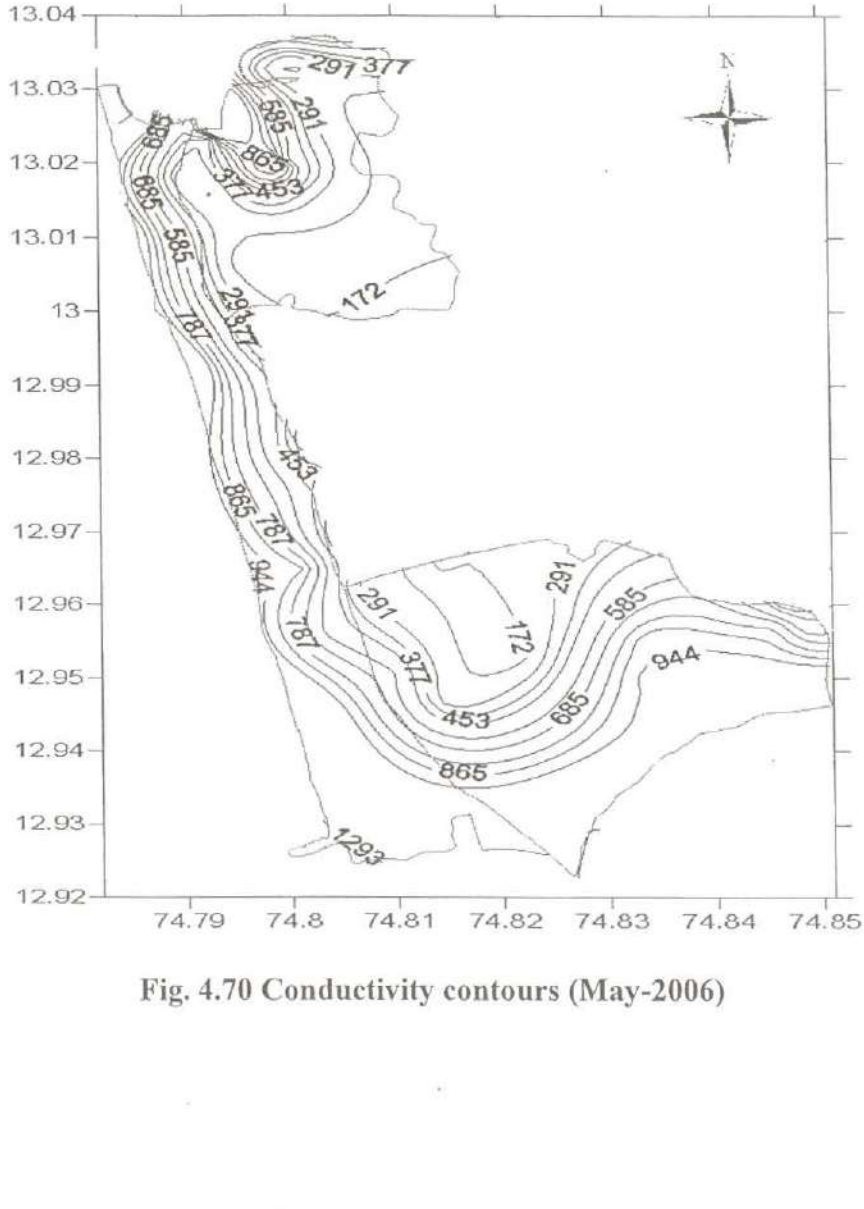


Fig. 4.70 Conductivity contours (May-2006)

4.7 SALTWATER INTRUSION MODEL (SUTRA) RESULTS

4.7.1 Transient Analysis

Single step steady state results of SUTRA are usually not appropriate for non-linear problems with variable density, saturation, viscosity (Voss and Provost, 2003). SUTRA simulation may be employed for 2D areal, cross sectional and 3D modeling of saturated groundwater systems.

4.7.2 Estimation of Lateral flow

The study area is predominantly covered by the sea on the boundaries. However, land boundary also exists and the lateral flow entering or leaving the aquifer from the surrounding land is crucial for the assessment of seaward freshwater gradient. For the estimation of lateral flow, the coastline study area has been divided into six parts according to the variation in the transmissivity values as shown in table 4.25(a-c). Saturation thickness is taken as 25m for all the sub basins. The contour map of the water table in the study area is given in figs. 4.71a&b.

Near Pavanje River (I):

The discharge (lateral flow) calculation is as given below

$K = \frac{T}{b} = \frac{70}{25} = 2.8$ m/day; A = 25 * 425 = 10625m^2. $i = \frac{h}{l} = \frac{0.2}{500} = 0.00044$.

$$Q = \frac{70*0.2*25*425}{25*500} = 29.75\text{m}^3\text{/day}.$$

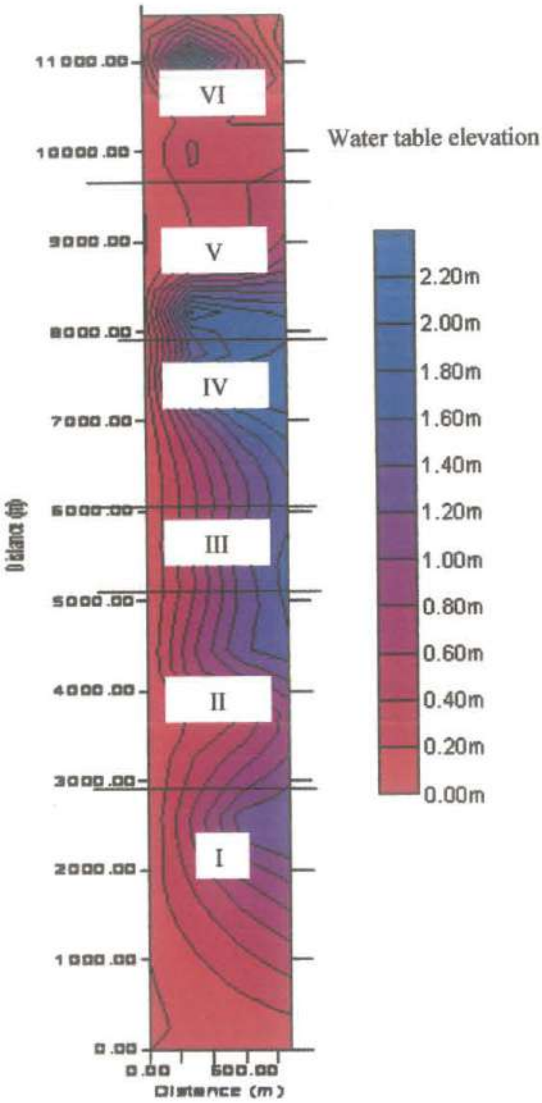


Fig. 4.71a Water level contour map showing the different locations-Coastline study area

Similarly, Pavanje study area has been divided into six parts according to the variation in the Hydraulic Head values as shown in Table 4.26(a-c).Transmissivity value of 240m^2/day has been taken throughout the study area.

Table 4.25a Lateral flow into the coastline study area (monsoon period)

Location	Hydraulic Head (m)	Transmissivity (T) (m^2/day)	Discharge (Q) (m^3/day)
I	0.2	70	29.75
II	0.4	70	65.33
III	2	157	942
IV	1.4	130	546
V	1.2	97.22	349.99
VI	1.2	180	648

Table 4.25b Lateral flow into the coastline study area (post-monsoon period)

Location	Hydraulic Head (m)	Transmissivity (T) (m^2/day)	Discharge (Q) (m^3/day)
I	3.5	70	208.25
II	6.5	70	1061.67
III	7	157	3297
IV	5	130	1950
V	3	97.22	874.98
VI	2.5	180	1350

Table 4.25c Lateral flow into the coastline study area (pre-monsoon period)

Location	Hydraulic Head (m)	Transmissivity (T) (m^2/day)	Discharge (Q) (m^3/day)
I	1.2	70	71.4
II	1.8	70	294
III	3.4	157	1601.4
IV	2	130	780
V	1.2	97.22	349.99
I	1.2	180	648

Near Pavanje River (VI):

The discharge (lateral flow) calculation is as given below

$K = \frac{T}{b} = \frac{240}{25} = 9.6$m/day.

A = 25 * 4000 = 100000m^2.

$i = \frac{h}{l} = \frac{4.5}{2000} = 0.00225.$

$Q = \frac{240 * 4.5 * 25 * 4000}{25 * 2000} = 2160$ m^3/day.

Table 4.26a Lateral flow into the Pavanje study area (monsoon period)

Location	Hydraulic Head (m)	Discharge (Q) (m^3/day)
I	1	480
II	1.5	720
III	2	960
IV	2.5	1200
V	3	1440
VI	4.5	2160

Table 4.26b Lateral flow into the Pavanje study area (post-monsoon period)

Location	Hydraulic Head (m)	Discharge (Q) (m^3/day)
I	0.5	240
II	1.5	720
III	1.5	720
IV	1.5	720
V	1.5	720
VI	5.5	2640

Table 4.26c Lateral flow into the Pavanje study area (pre-monsoon period)

Location	Hydraulic Head (m)	Discharge (Q) (m^3/day)
I	1.5	720
II	2	960
III	2.5	1200
IV	3	1440
V	3.5	1680
VI	5	2400

Discharge (lateral flow) calculation for the Gurpur study area (table 4.27) is as shown below. Transmissivity value of 135.9m^2/day has been taken throughout the study area.

$$K = \frac{T}{b} = \frac{135.9}{25} = 5.436 \text{m/day}.$$

$$A = 25 * 2450 = 61250 m^2.$$

$$i = \frac{h}{l} = \frac{4}{4375} = 0.000914.$$

$$Q = \frac{135.9 * 4 * 25 * 2450}{25 * 4375} = 304.416 m^3/\text{day}.$$

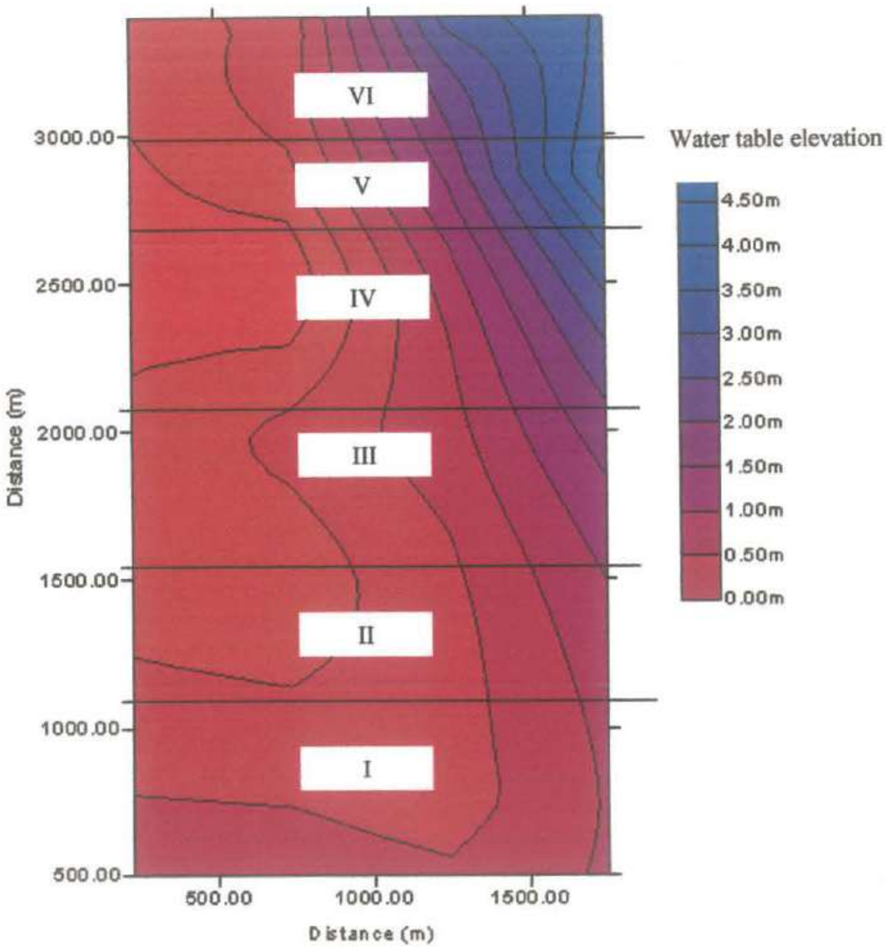


Fig. 4.71b Water level contour map showing the different locations-Pavanje study area

Table 4.27 Lateral flow into the Gurpur study area

Period	Hydraulic Head (m)	Discharge (Q) (m^3/day)
Monsoon	3.5	266.364
Post-monsoon	4	304.416
Pre-monsoon	4	304.416

4.7.3 Comparison between observed and simulated salinity contours

The results of the dispersive 3D model (SUTRA) are presented in terms of pressure and concentration. A typical output sheet from the model is given in the Appendix. From the output data file (Transient condition) the salinity contours were plotted Fig. (4.72 - 4.93) which show zones of fresh water, saline water and transition zones. As per WHO standards, water having less than 500mg/l of TDS (0.00050kg DS/kg fluid) can be considered as fresh water. However, for all practical purposes, up to 750mg/lit is acceptable as potable water with no health hazards.

The salinity measurements for 39 wells were carried out for the present study area (Table 4.28). Salinity measurements were obtained through pen type salinity meter. Well numbers 1, 4, and 11 located in Pavanje river basin found to be saline during post-monsoon and pre-monsoon period. Well numbers 7 and 25 in coastal zone are found to be saline throughout the year. Well numbers 32, 33 and 35 in Gurpur river basin are found to be affected during pre monsoon period. The comparison between the observed and the simulated salinity contours are shown in figs. 4.72-4.92. The observed and simulated salinity contours were found to match to a satisfactory to perfect levels. The input used and output obtained from SUTRA model are given in APPENDIX III

Table 4.28 Observed salinity values in the wells

Wells(salinity(ppm))	Pre monsoon						Monsoon					Post monsoon			
	Feb (05)	Mar	Apr	Apr	May	May	June	June	July	Aug	Sept	Oct	Nov	Dec	Jan (06)
1	200	200	200	200	200	200	200	100	100	100	100	1100	100	100	200
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	100	100	100	100	100	100	100	100	100	0	0	100	0	100	100
4	100	200	300	400	400	500	600	300	200	200	100	100	100	100	100
5	0	0	200	0	0	0	0 .	0	0	0	0	0	0	100	0
6	200	200	0	200	200	200	200	200	100	100	100	100	100	100	100
7	700	500	500	500	500	500	500	500	300	200	100	500	600	800	500
8	100	100	100	100	100	100	100	100	100	200	100	100	100	100	100
9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
10	100	100	100	0	0	100	0	0	100	100	100	0	0	100	100
11	100	200	600	1200	1700	2400	2900	300	200	100	100	100	100	200	300
12	100	300	300	300	300	300	500	200	100	0	0	0	0	0	100
13	0	0	100	0	0	0	0	0	0	0	0	0	0	100	100
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	No	No	No	No
16	200	200	200	200	200	200	200	200	100	200	200	200	200	200	200
17	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0
18	200	100	100	100	0	100	100	200	200	200	200	200	200	200	200
19	400	300	300	300	300	300	300	200	100	200	200	200	200	300	300
20	200	200	200	100	100	100	100	100	200	100	100	100	100	100	100

Table 4.28 continued

Wells(salinity(ppm))	Pre monsoon						Monsoon					Post monsoon			
	Feb (05)	Mar	Apr	Apr	May	May	June	June	July	Aug	Sept	Oct	Nov	Dec	Jan (06)
21	100	100	100	100	100	100	100	100	100	200	200	200	200	200	100
22	100	0	100	0	0	0	0	100	100	100	100	100	100	100	0
23	100	100	200	100	100	100	100	100	100	100	100	100	100	100	100
24	300	300	300	400	300	300	300	300	200	200	200	200	300	300	300
25	800	800	800	600	500	1000	1000	400	400	500	500	500	400	300	600
26	300	300	300	200	200	300	300	200	200	200	200	200	300	300	200
27	200	200	300	300	300	300	300	300	200	200	100	200	200	200	200
28	100	100	100	100	100	100	100	100	100	0	0	100	100	100	100
29	100	100	100	100	100	100	100	0	0	0	0	0	100	100	100
30	300	300	300	200	200	200	200	200	100	100	100	100	100	200	300
31	200	300	400	400	400	400	400	400	300	200	200	200	200	200	200
32	300	400	400	400	500	500	500	300	200	100	100	100	100	100	200
33	200	200	500	500	500	400	300	200	100	0	0	0	100	200	200
34	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
35	0	0	700	1100	2400	1600	1900	300	0	0	0	0	100	100	200
36	0	100	100	100	100	100	100	100	100	0	0	0	0	0	0
37	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
38	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
39	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

4.7.3.1.Coastline study area

From the Fig. 4.72a it is observed that the well situated in the zone 3500m to 4500m was affected by saltwater intrusion. The salinity value obtained for this well was found to be 500mg/l during monsoon period. The reason for this could be the well being situated in an industrial area. The salinity value for the rest of the wells of this area was observed to be within the permissible limits for the same period.

Concentration contours are simulated for the monsoon period in the study area. For different increasing time steps there is inward movement of the concentration contours from the sea boundary into the study area. The simulation is started at the beginning of the monsoon season and ends at the onset of post monsoon season. Fig. 4.72b shows the concentration contour at the end of the monsoon season. For all the nodes at the left side of the Coastline study area, hydrostatic pressure was given with saltwater concentration of 0.035 irrespective of the simulation period. Concentration contours have been generated through SURFER.

It can be observed from Fig.4.72b that up to 200m of the coastal area has already been affected by brackish water. The region beyond 200m is not affected during the monsoon period. Hence it conforms to fig. 4.72a which is the observed salinity contour map.

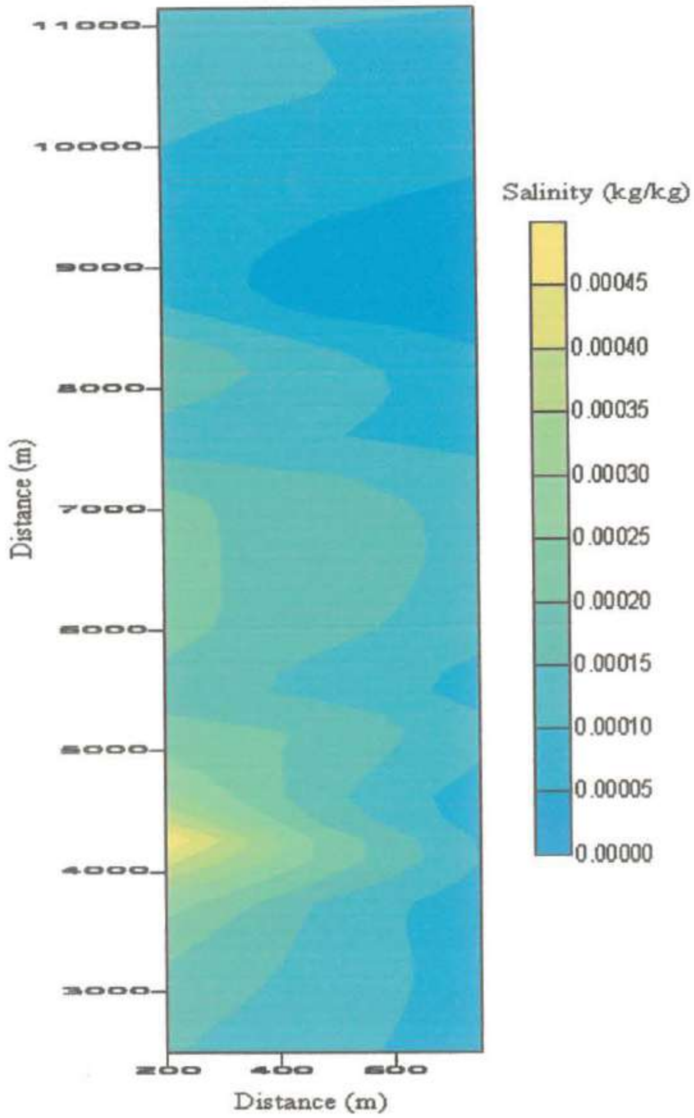


Fig. 4.72a Observed concentration contours for the monsoon period in the Coastline study area

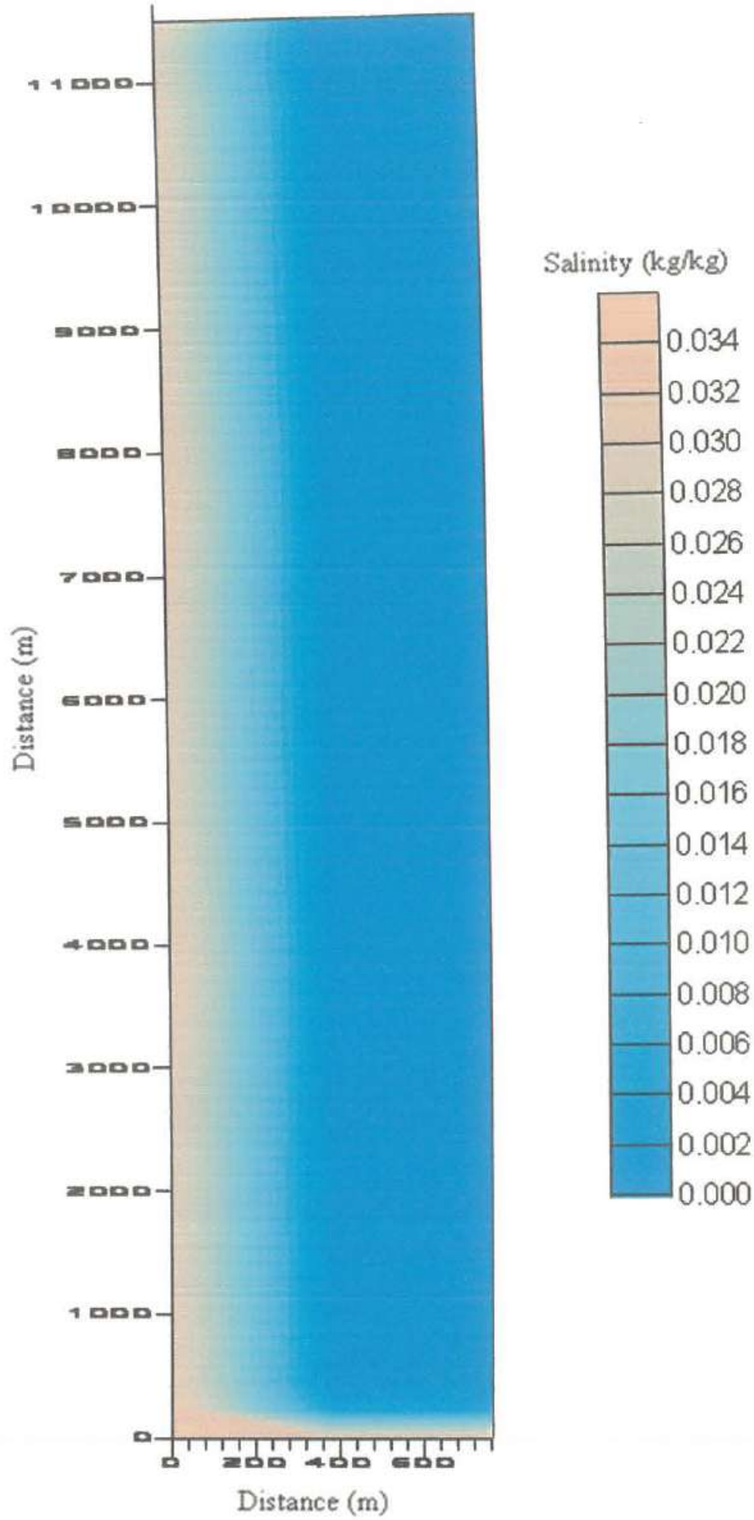


Fig. 4.72b Simulated Concentration contours for the monsoon period in the Coastline study area

In the next simulation, for the post-monsoon period, (Fig. 4.72b) there is further landward movement of the concentration contour from the sea boundary into the study area as compared to the monsoon period (Fig. 4.72b).

From the fig. 4.73a, it can be observed that there is a further increase in the salt concentration which pushes the zone of intrusion further towards the land during the summer period. The region 3000m to 5000m is most vulnerable zone since it houses some of the major industries of the area.

The third set of simulation is carried on by giving the saltwater concentration at the portion where Pavanje river touches the Coastline study area during the pre monsoon season. It can be observed from fig. 4.74(a-b) there is an inward movement of the concentration contour from Pavanje river along the northern boundary into the study area .During the pre monsoon period, freshwater flow in the Pavanje river ceases and saline water intrudes along the river for a few kms upstream.

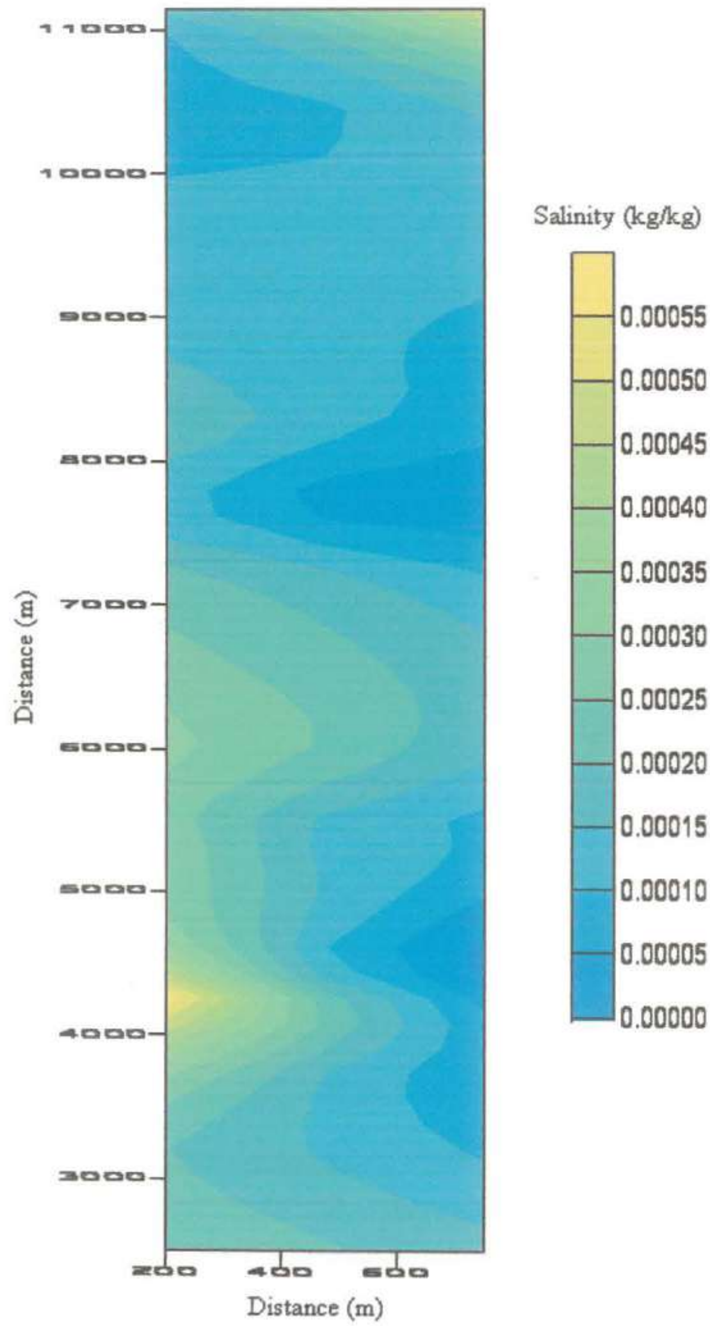


Fig. 4.73a Observed concentration contours for the post-monsoon period in the Coastline study area

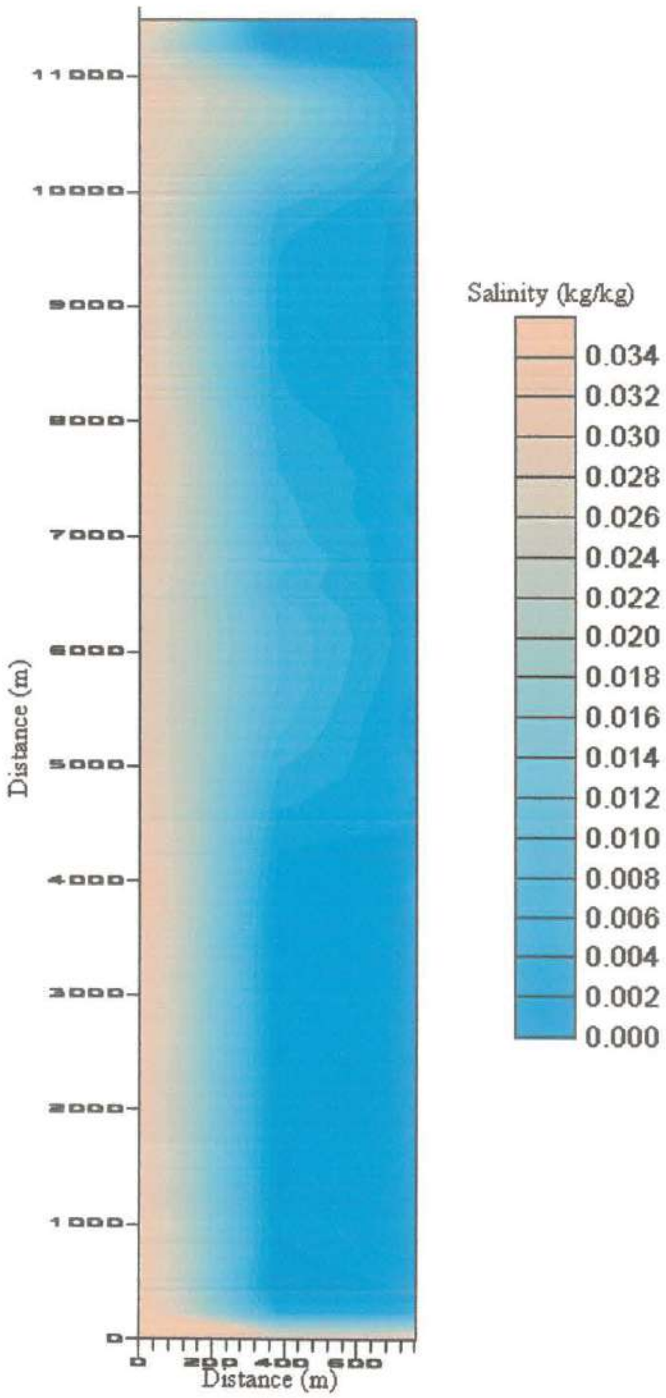


Fig. 4.73b Simulated concentration contours for the post-monsoon period in the Coastline study area

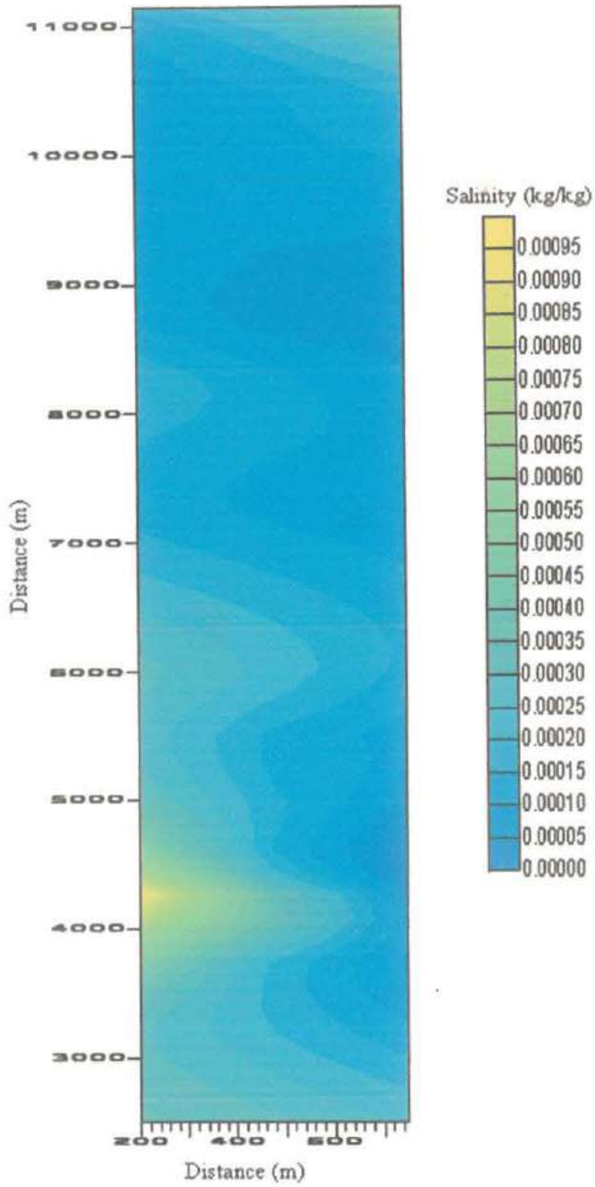


Fig. 4.74a Observed concentration contours for the pre-monsoon period in the Coastline study area

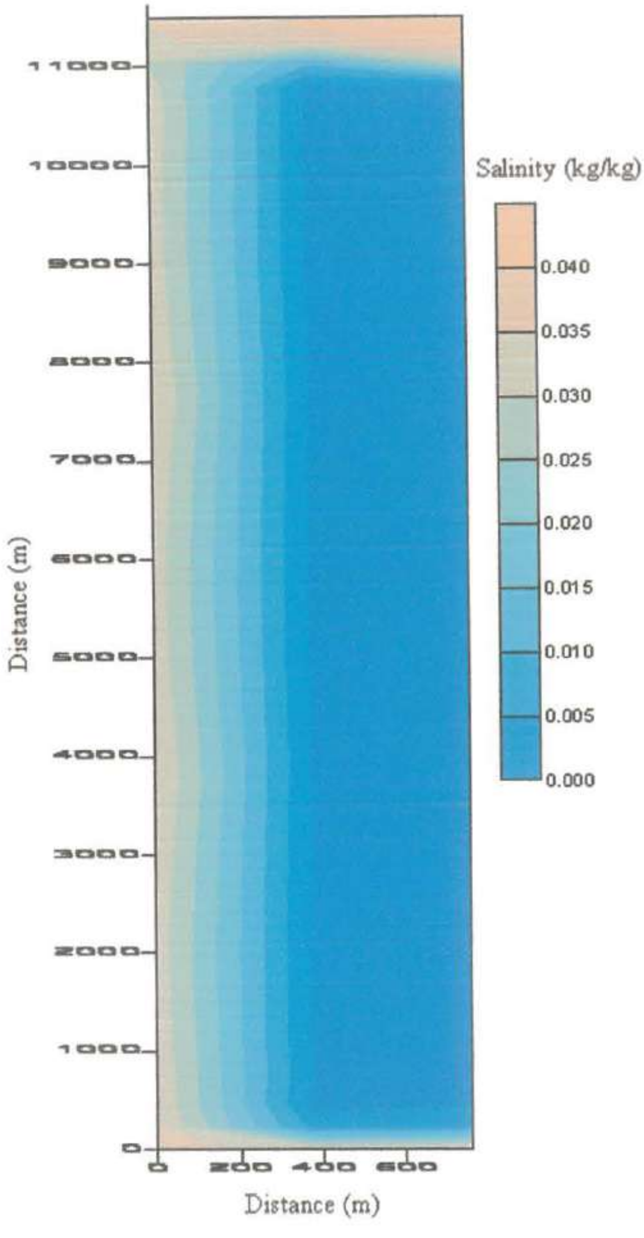


Fig. 4.74b Simulated Concentration contours for the pre-monsoon period in the Coastline study area

4.7.3.2. Pavanje study area

From fig. 4.75a, it can be observed that the region is unaffected by saltwater during the monsoon period.

Concentration contours are simulated for the monsoon period in the study area. For increasing time steps there is an inward movement of the concentration contours from the sea boundary into the study area. The simulation is started at the beginning of the monsoon season and ends at the onset of post monsoon season. Fig. 4.75b shows the concentration contour at the end of the monsoon season. It can be observed from the fig. 4.75b that the simulated salinity contours follow the same pattern as the observed contours.

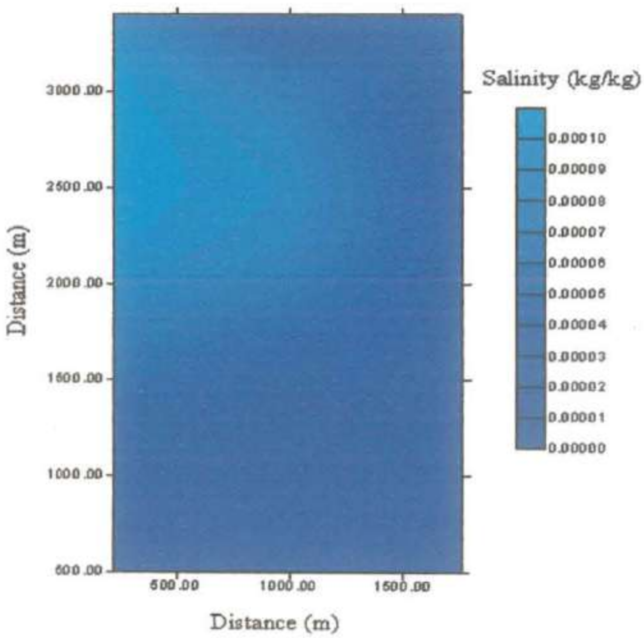


Fig. 4.75a Observed concentration contours for the monsoon period in the Pavanje study area

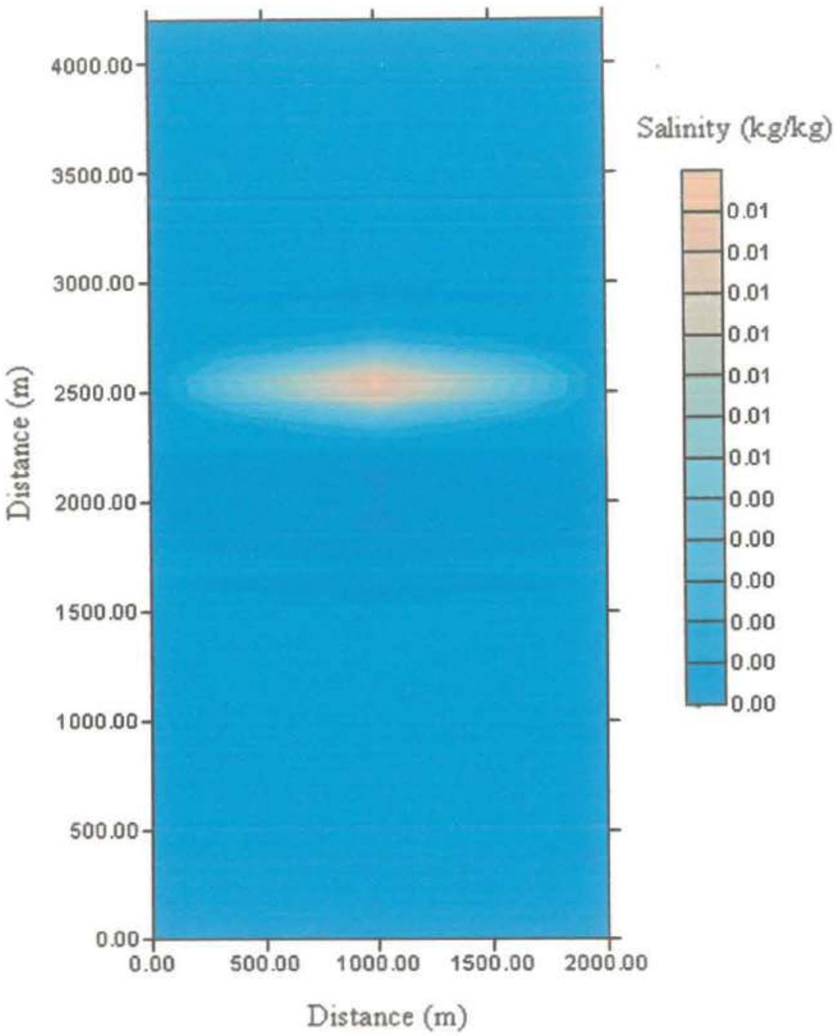


Fig. 4.75b Simulated concentration contours for the monsoon period in the Pavanje study area

From the fig. 4.76a it can be observed that the concentration advances inland as compared to the monsoon period. The zone for about 1500m to 2500m is most vulnerable to saltwater intrusion due to its proximity to the tributary and low water table depths as shown earlier.

In the next simulation, for the post monsoon period, the initial conditions are taken from the previous simulation. It can be observed from the fig. 4.75b that there is an increase in the inward movement of the concentration from the Pavanje river boundary into the study area as compared to the monsoon period fig. 4.76b.

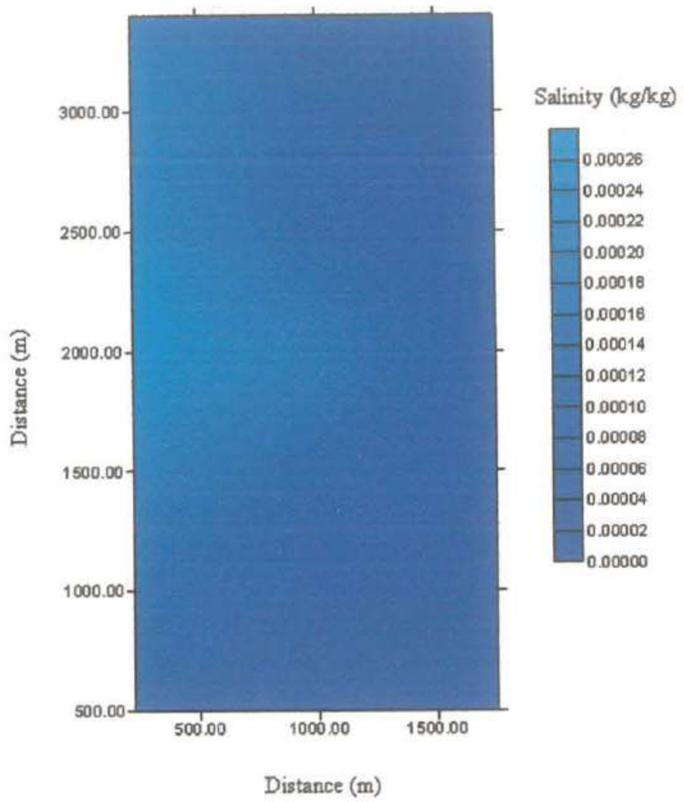


Fig. 4. 76a Observed concentration contours for the post-monsoon period in the Pavanje study area

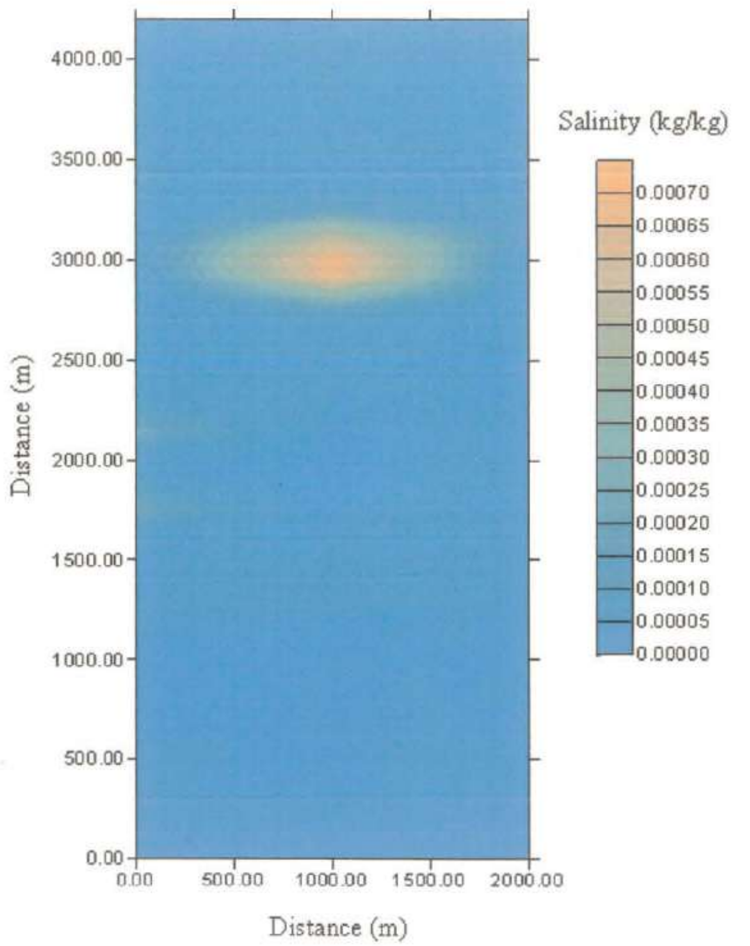


Fig. 4.76b Concentration contours for the post-monsoon period in the Pavanje study area

From the fig. 4.77a it can be observed that there is further increase in the salt concentration during the summer which pushes the zone of intrusion further towards the land. The region 1500m to 2500m is most vulnerable zone the water table depth is the lowest and its proximity to the tributary.

The third set of simulation is carried on by giving the saltwater concentration at the portion where Pavanje river touches the study area during the pre-monsoon season. It can be observed from the fig. 4.77b there is an inward movement of concentration contour from the Pavanje river along the western boundary into the study area .During the pre-monsoon period the Pavanje river carries saltwater which is susceptible to saltwater intrusion into the adjoining aquifer. The model predicts higher range of saltwater concentration than the observed salinity values (Table 4.28).

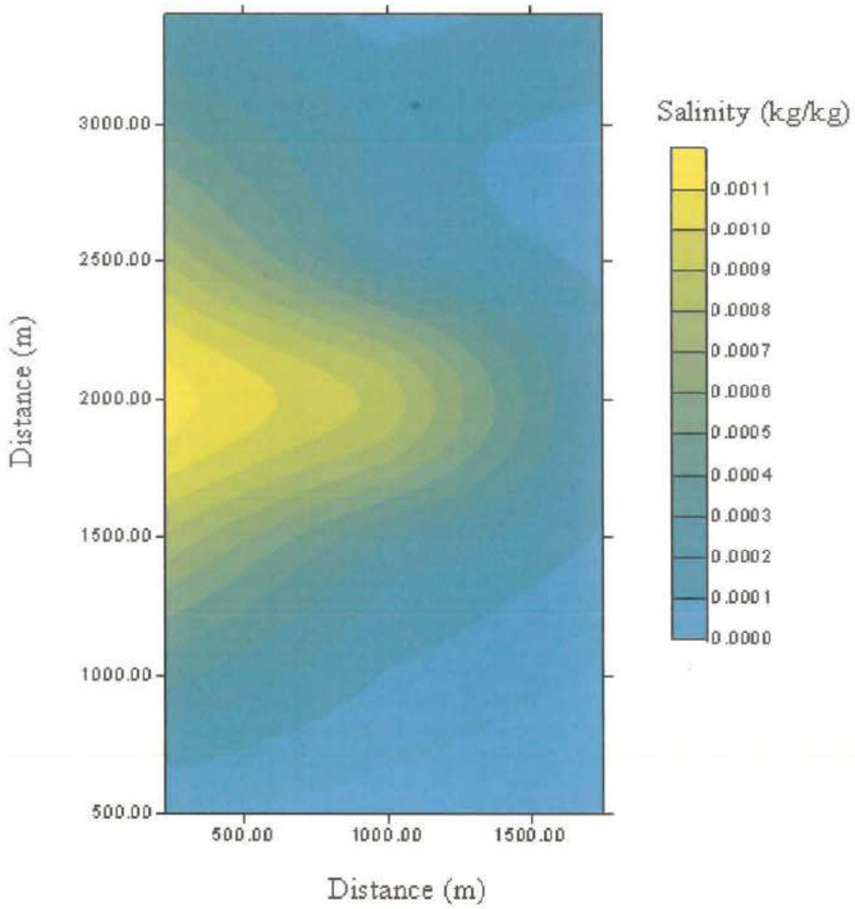


Fig. 4.77a Observed concentration contours for the pre-monsoon period in the Pavanje study area

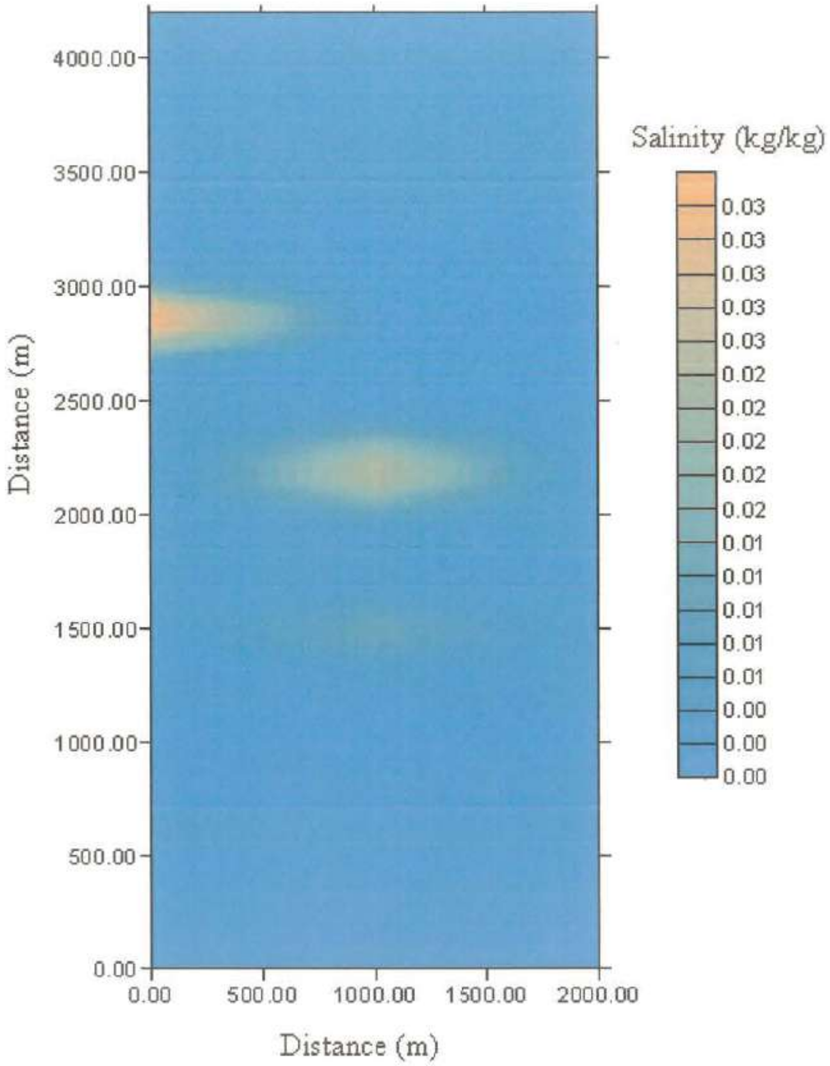


Fig. 4.77b Simulated Concentration contours for the pre-monsoon period in the Pavanje study area

4.7.3.3 Gurpur study area

From the fig. 4.78a it can be observed that the region is unaffected during the monsoon period.

Concentration contours are simulated for the monsoon period in the study area. For increasing time steps there is an inward movement of the concentration contours from the sea boundary into the study area. The simulation is started at the beginning of the monsoon season and ends at the onset of post-monsoon season. Fig. 4.78b shows the concentration contour at the end of the monsoon season. It can be observed from the Fig. 4.77b that the simulated salinity contours follow the same pattern as the observed contours. The water quality in the Gurpur study area is found to be unaffected by saltwater during the monsoon period.

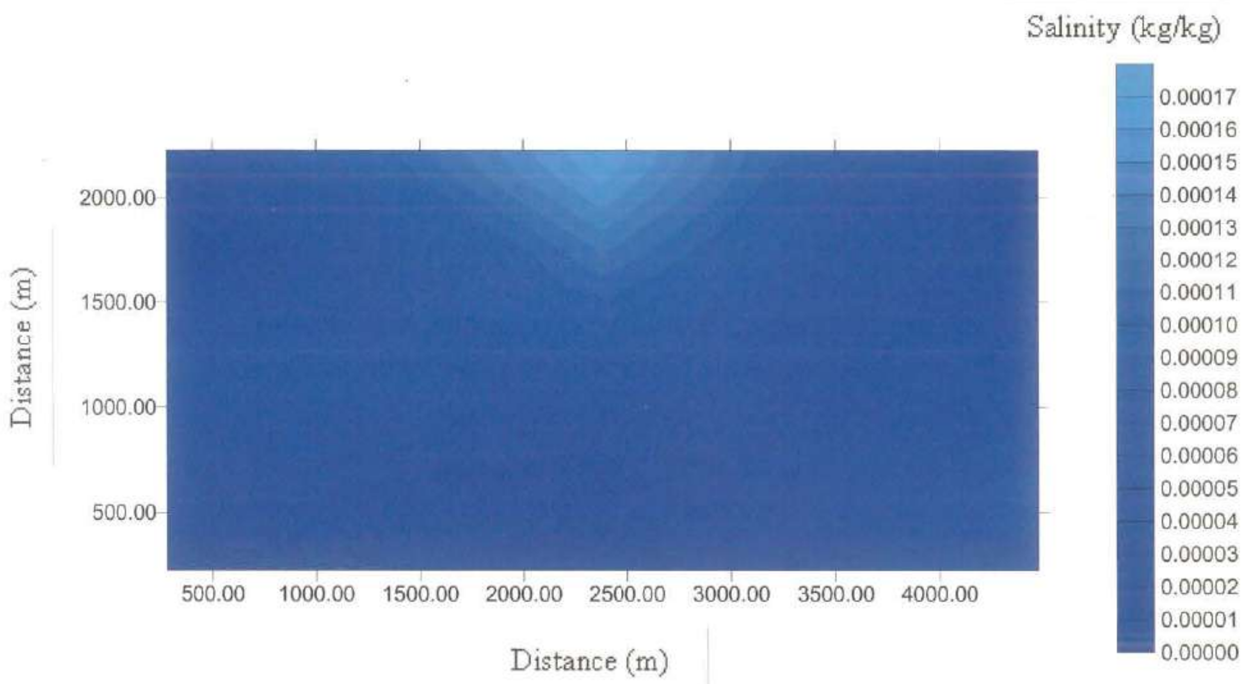


Fig. 4.78a Observed concentration contours for the monsoon period in the Gurpur study area

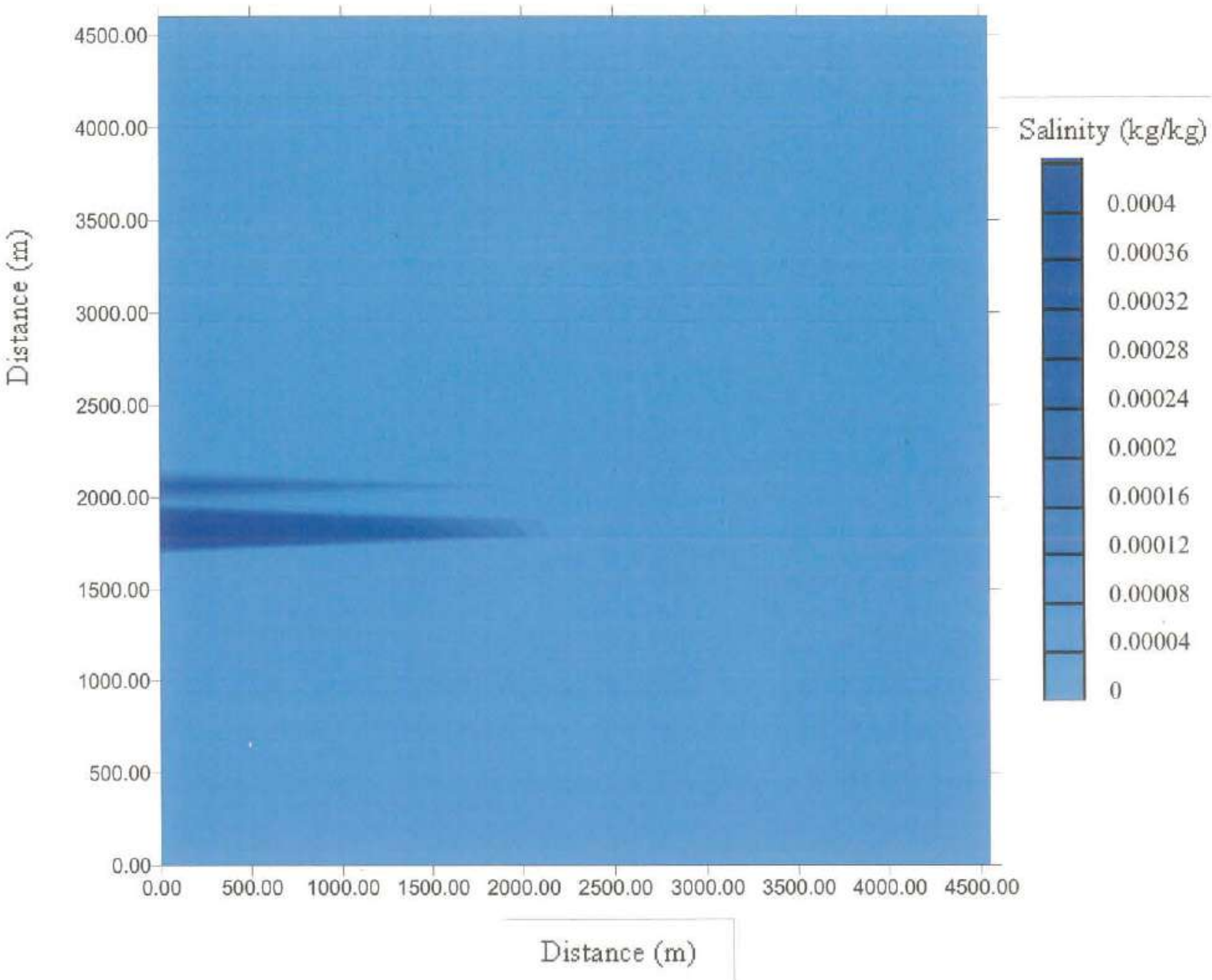


Fig. 4.78b Simulated Concentration contours for the monsoon period in the Gurpur study area

From the fig. 4.79a it can be observed that the concentration contour increases as the summer advances. The zone upto 2000m to 1500m from the Gurpur river is most vulnerable to saltwater intrusion due to its proximity to the tributary and low water table depth .

In the next simulation, for the post-monsoon period, it is observed from the fig. 4.79b that the region near to the tributary is the most affected

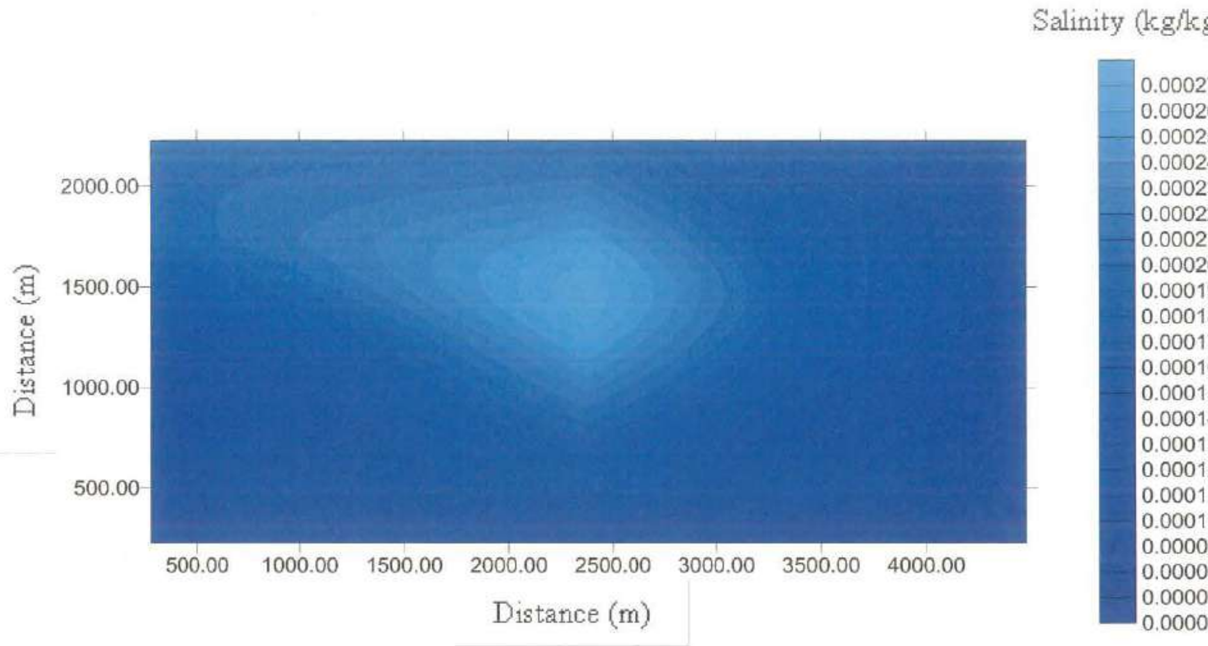


Fig. 4.79a Observed concentration contours for the post-monsoon period in the Gurpur study area

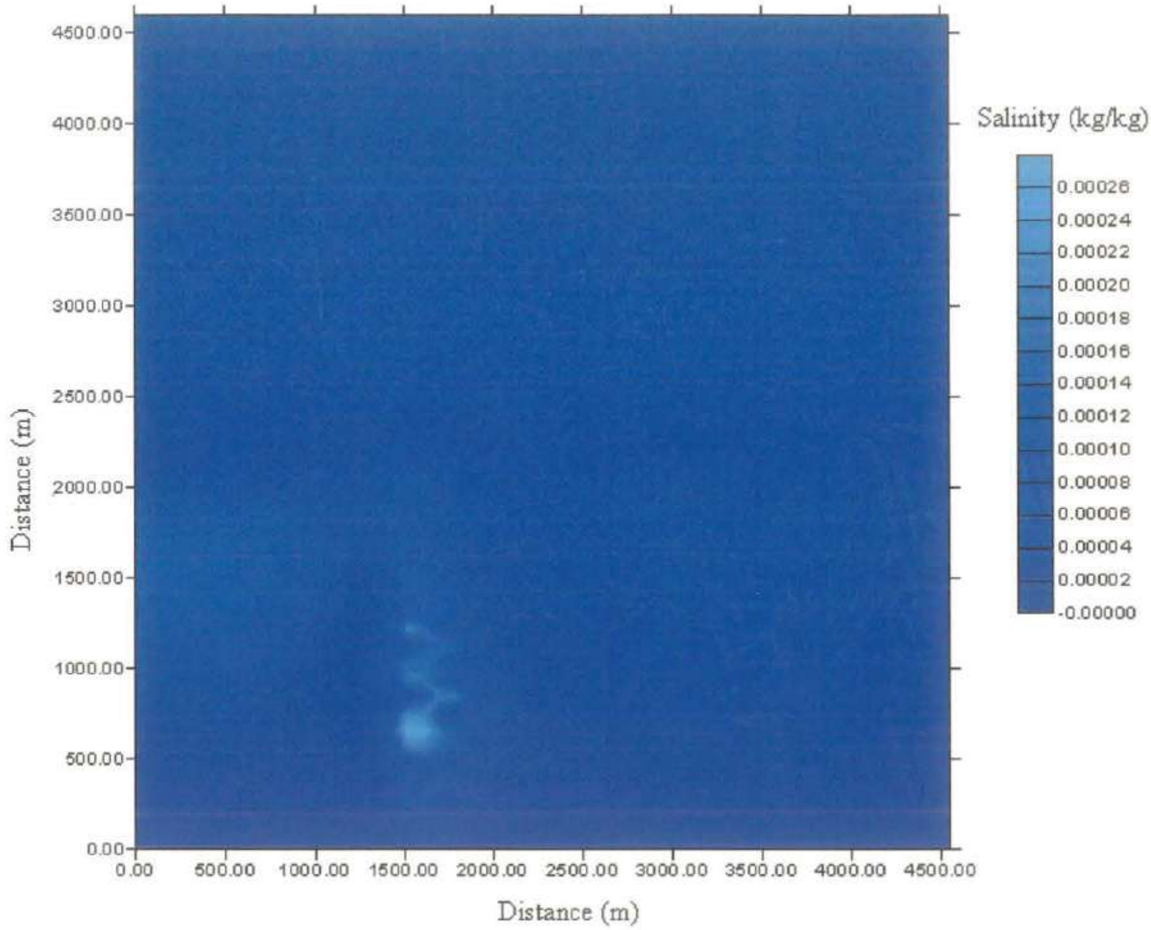


Fig. 4.79b Concentration contours for the post-monsoon period in the Gurpur study area

During the summer (Fig. 4.80a), it can be observed that there is a further increase in the salt concentration which pushes the zone of intrusion further towards the land. The region up to 1500m to 1000m is the most vulnerable zone as the water table depth is the lowest and its proximity to the tributary.

The third set of simulation is carried on by giving the saltwater concentration at the portion where Gurpur river touches the study area during the pre-monsoon season. It can be observed from the fig. 4.80b there is an inward movement of concentration contour from the Gurpur river along the southern boundary into the study area. During the pre-monsoon period the Gurpur river runs dry which makes it all the more susceptible to the saltwater intrusion.

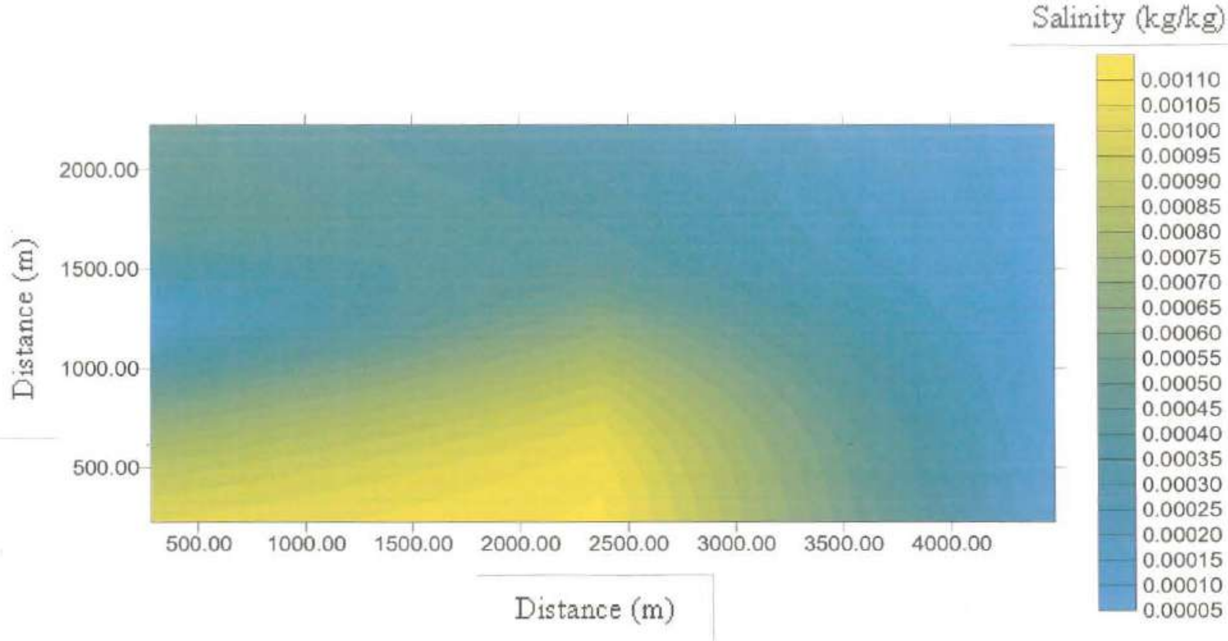


Fig. 4.80a Observed concentration contours for the pre-monsoon period in the Gurpur study area

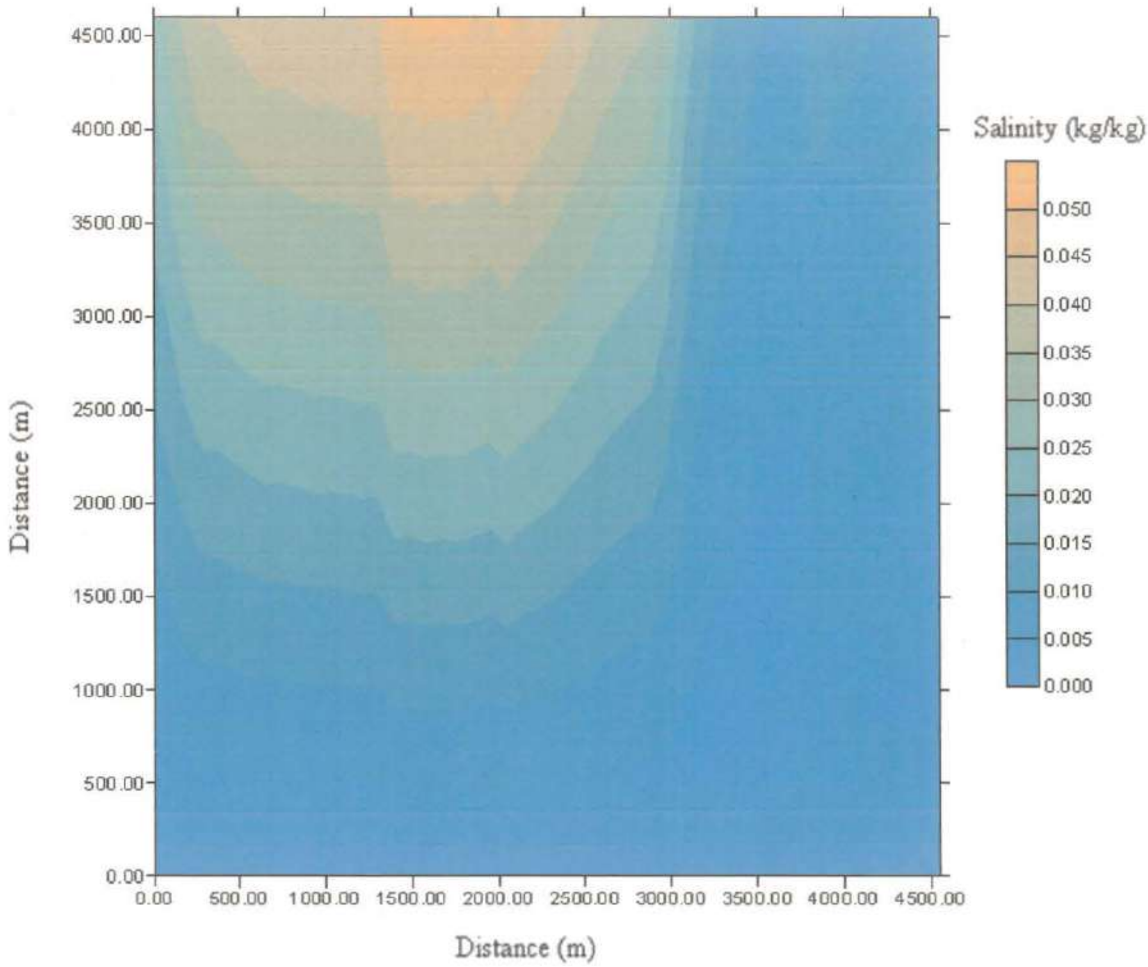


Fig. 4.80b Simulated Concentration contours for the pre-monsoon period in the Gurpur study area

4.7.4. Time variation of salinity of water

To estimate the progress of saltwater intrusion with time, a well in the campus was selected. The water level and quality are monitored regularly. The well was not affected by salinity. However minor variations in the salinity are as shown in fig.4.81.

In fig.4.81 the predicted as well as the observed salinity values decreases with increase in the water table elevation. Salinity increases in the months of March, April, November, December and January. A small difference between the salinity values was observed during Jan. 06 between the simulated and observed values. This difference between the observed and predicted salinity may be due to the possible error in the simulated salinity.

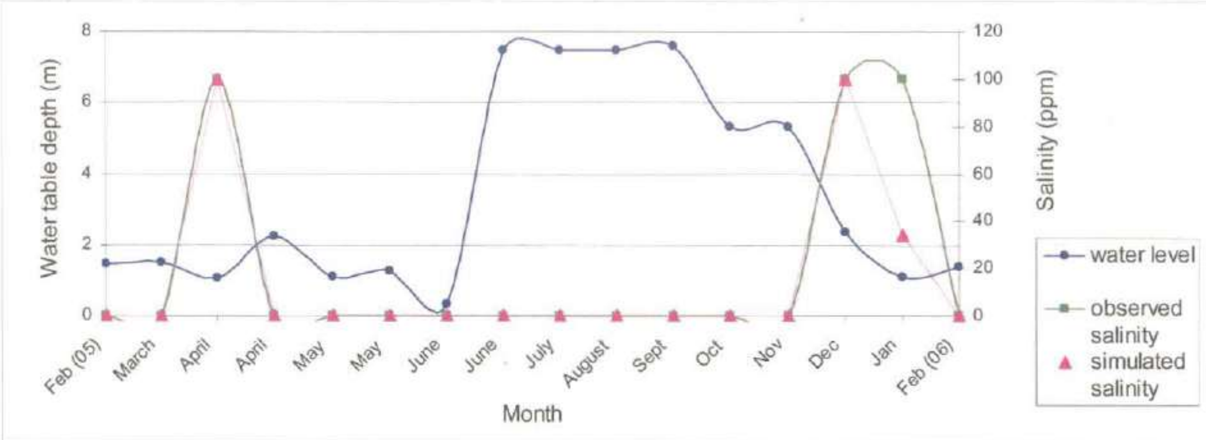


Fig. 4.81 Time variation of salinity of water in well no.13

4.8 COASTAL AQUIFER MANAGEMENT – FUTURE SCENARIO

Saltwater intrusion can be caused by over-pumping in sensitive portions of coastal aquifers. It often results in the degradation of water quality within the aquifer and may ultimately require costly remedial measures. Development of a well-planned pumping strategy can arrest further degradation of the aquifer water quality, remediate an already contaminated aquifer, and contain the contamination within a certain region of the aquifer.

In order to develop any simulation that necessarily seeks to optimally exploit a coastal aquifer, it is necessary to investigate the coastal aquifer responses to the plausible stress scenarios. One of the stress scenarios that have been simulated in this model is the effect of over pumping.

The coastline study area has been divided into two zones of interest; region around NITK campus and the industrial region (NMPT), as the rate of pumping in these zones are higher in comparison to the rest of the study area.

Steady state analysis incorporating the effect of over pumping has been done for the two zones for pumping rates of 2000m^3/day, 100m^3/day, 500m^3/day and 300m^3/day as shown in Figs. 4.82(a-c) considering the developmental activities in the region.

In the NITK campus, 4 wells with pumping duration which varies from 1-2 hrs in May to 8-10 hrs in December-January are operated. Hence the pumping rate works out to be highest in monsoon around 500m^3/day and the least in summer 250-300m^3/day. For the pumping rate of 300m^3/day the present pattern of saltwater intrusion is continuing. Pumping rates of 500m^3/day was found to increase the saltwater intrusion much beyond the limits north of NITK campus (Figs.4.82a-c).

From the Fig. 4.82c it is observed that when a draft of 2000m^3/day was considered near NMPT , the fresh water contour shifts from 200m to 400m. But considering the present pumping rate which is about 1000m^3/day (Fig. 4.82d) the present scenario of saltwater intrusion was maintained.

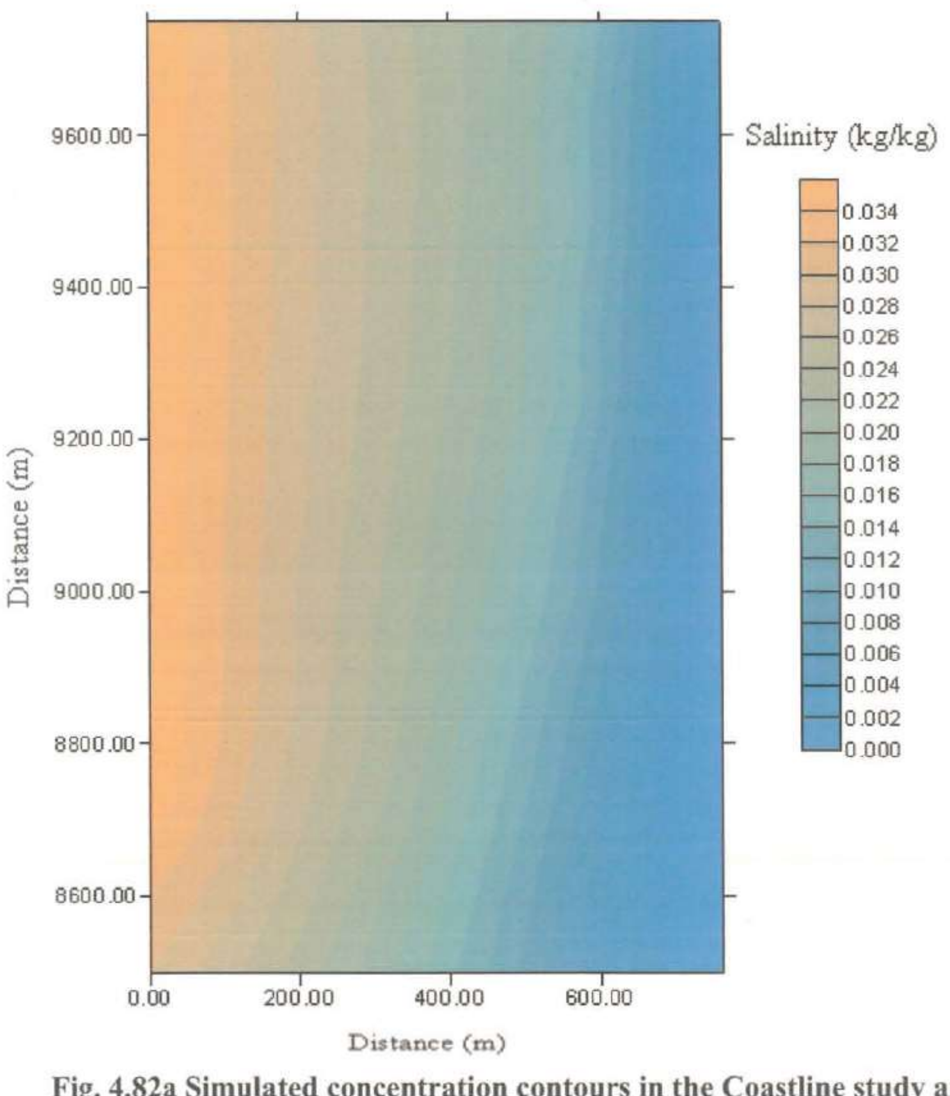


Fig. 4.82a Simulated concentration contours in the Coastline study area (NITK, 500m^3/day)

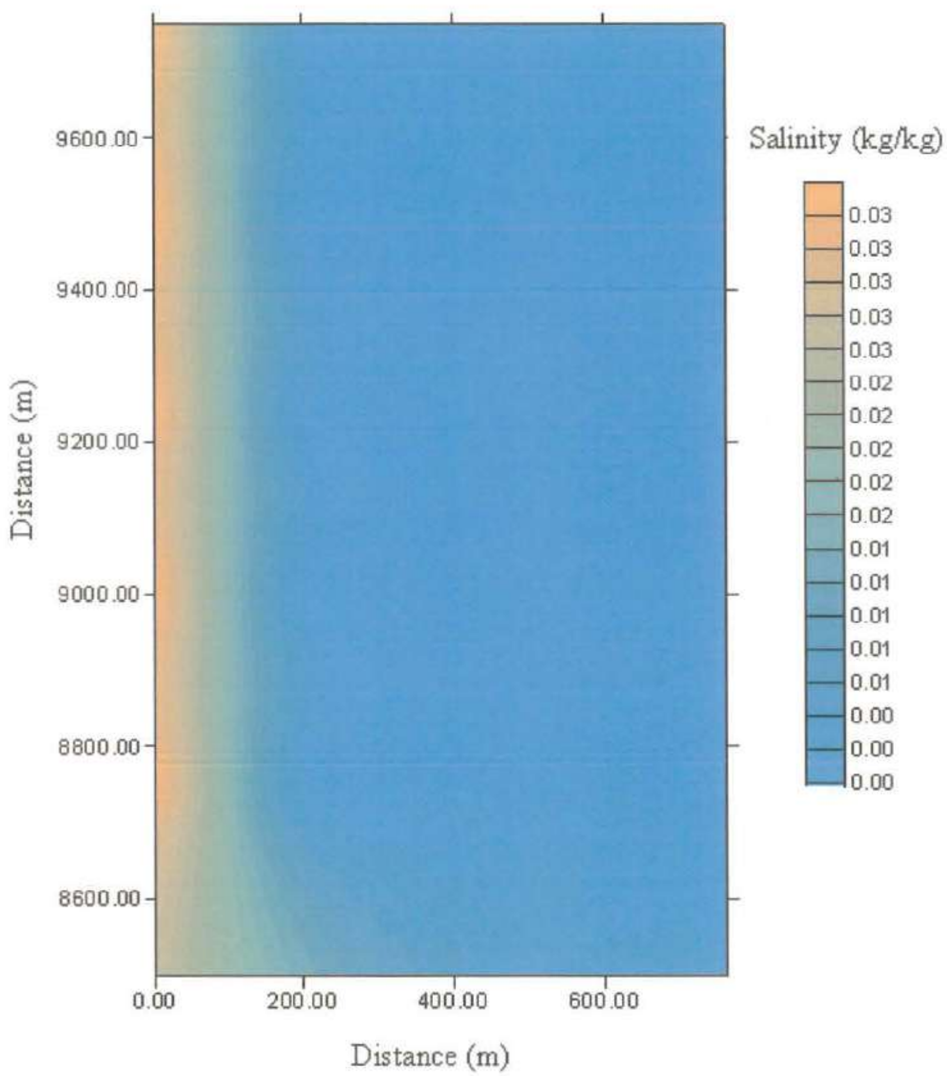


Fig. 4.82b Simulated concentration contours in the Coastline study area (NITK, 300m^3/day)

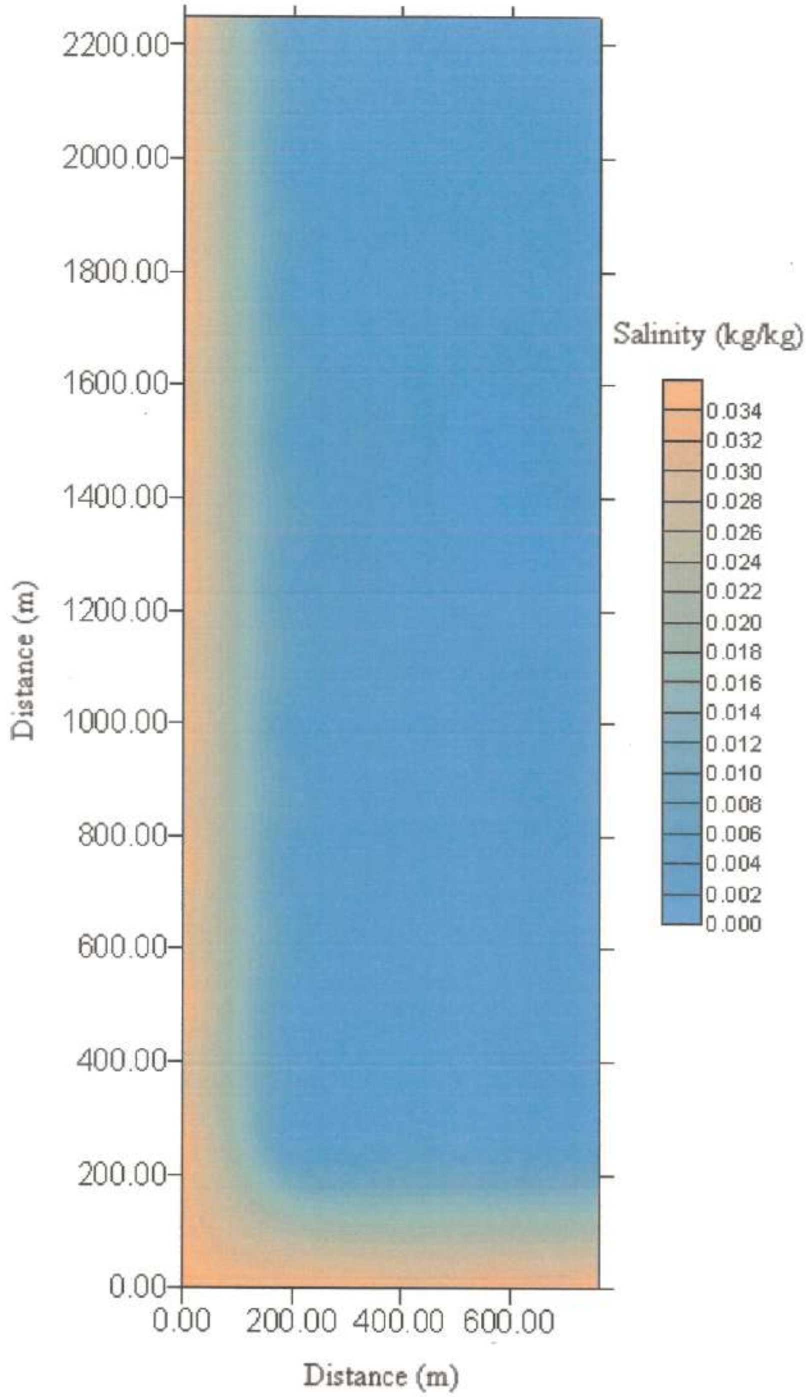


Fig. 4.82c Simulated concentration contours in the Coastline study area (NMPT, 1000m^3/day)

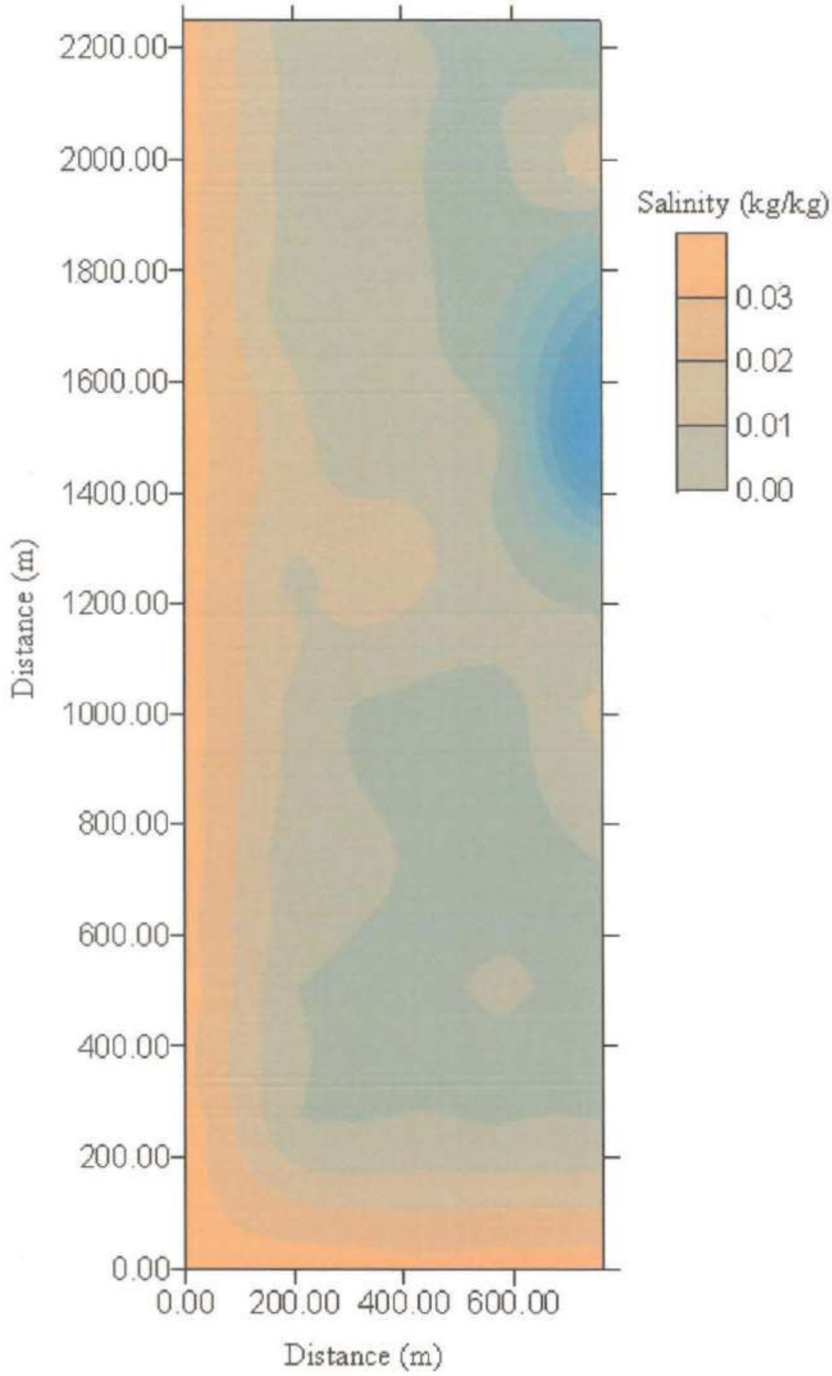


Fig. 4.82d Simulated concentration contours in the Coastline study area (NMPT, 2000m^3/day)

Pavanje study area where agriculture is predominant, the pumping ranges from $2m^3$/day to $4m^3$/day which is much less than the pumping in the coastline study area. Therefore, effect of over pumping is not significant during the monsoon and post-monsoon periods.

Simulation was carried out for pumping rates of $300m^3$/day. Saltwater intrusion was found to increase than the present projected rate for a pumping rate of $300m^3$/day hence it can be considered as the safe pumping limit.

In the Gurpur study area, the present situation when projected for another 100 years was found to cause saltwater intrusion below 2000m from Gurpur river (Fig.4.83a). The projected pumping rate for NMPT is $2000m^3$/day. The model was simulated considering a pumping rate of $2000m^3$/day. A distance of around 2000m from Gurpur river was found to be affected by saltwater intrusion (Fig.4.83b). This may pose serious problems like degradation of water quality.

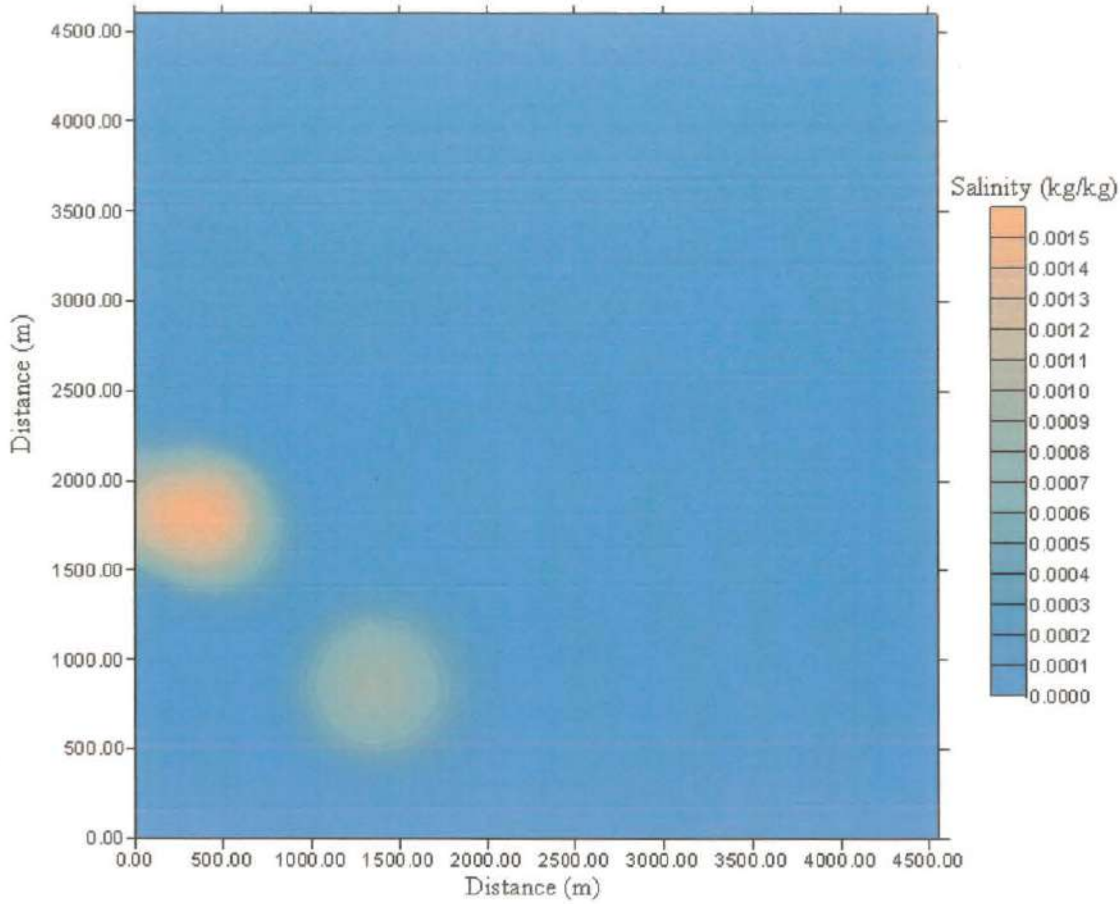


Fig. 4.83a Simulated concentration contours in the Gurpur study area ($1000m^3$/day)

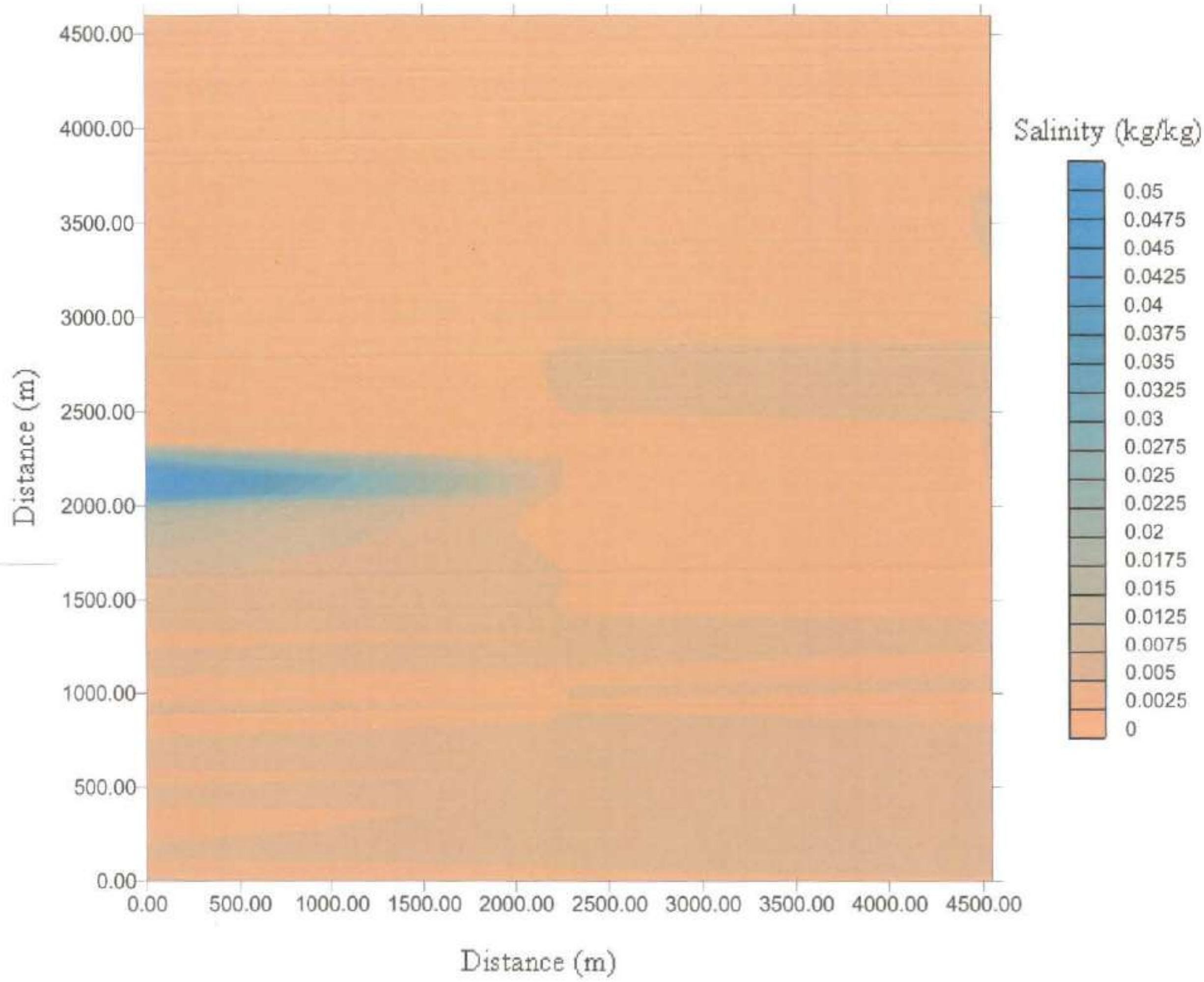


Fig. 4.83b Concentration contours for the pre-monsoon period in the Gurpur study area for withdrawal of 2000m^3/day

In view of the above results, it is apparent that the present scenario is not causing any problem of saltwater intrusion in the area except certain locations including NMPT during summer. However, proper precautions need to be taken when the groundwater abstraction is increased due to developmental activities in the region as evidenced by the projected scenario on saltwater intrusion.

CHAPTER 5
CONCLUSIONS

5.1 AQUIFER CHARACTERIZATION

In the present study, an attempt was made to characterize the aquifer from the field tests and categorize the region into different vulnerable regions to saltwater intrusion based on the hydro-geological parameters. The results from the study would be useful input for further developments/investigations in the region from the view point of saltwater intrusion. The salient features of the investigation are highlighted below.

- From the VES geo-electrical studies conducted, it is evident that the study area consists of shallow unconfined aquifer with the thickness ranging from 18m to 30m. Also, from the studies we find that the areas Haleyangadi, Mukka, Surathkal, Hosabettu, Chitrapur, Biakampady and Kenjar are affected by saltwater intrusion.

- The aquifer is having moderate to good groundwater potential with the transmissivity ranging from $34.9 m^2/day$ to $461.4\ m^2/day$ and specific yield from 0.0685 to 0.2805. Transmissivity values were found to increase towards the northern boundary of the study area and it was low near the coast. Lowest specific yield values were found near the coast and highest values were found near the eastern boundary of the study area.

- Based on the soil test at few selected locations, the porosity was found to be ranging from 23-43 %.

- The hydraulic conductivity of the aquifer was evaluated through pumping tests, soil analysis and the electrical resistivity data which indicate a range of 40m/day to 914m/day.

- The well nos. 24, 25 and 26 which are very close to the coast with a distance of less than 315m, were found to be saline throughout the year. The well nos. 5, 18, 19 and 23 are considered to be low vulnerable to saltwater intrusion due to their elevation above the mean sea level. The wells 1, 2, 4 and 8 are closer to the Pavanje river with a distance less than 500m and hence show a considerable increase in GALDIT index in the summer period (Feb to May).

- The well nos. 23 and 37 are predicted to turn highly vulnerable to saltwater intrusion in the month of April due to the 0.25m rise in sea level.

- The saltwater vulnerability maps derived for the area using the GALDIT method indicate that the aquifer is medium to highly vulnerable to saltwater intrusion at majority of the locations. This calls for judicious planning of groundwater development in the region.

- The maps derived from this can be used for the management of the coastal groundwater resources.

5.2 NUMERICAL SIMULATION

Saltwater intrusion was simulated in the study area under transient and steady state conditions through Saturated-Unsaturated TRAnsport (SUTRA) model. The simulated values are compared with the observed values of the water quality parameters. The salient features of the results from the investigation are as follows.

- Well numbers 1, 4, and 11 located in Pavanje river basin were found that the salinity exceeded the standard limit during post monsoon and summer period. Well numbers 7 and 25 in coastal zone were found to be saline throughout the year. Well numbers 32, 33 and 35 in Gurpur river basin were found to be affected during summer period. Hence proper remedial measures need to be taken in these areas to contain saltwater intrusion.

- In the coastline study area, saltwater was found to intrude up to 200m of the coastal area. During the summer period, the NMPT region (between y = 3000m and y =5000m) is the most vulnerable zone and the saline water intrudes along the tributary of Pavanje river for a few kms. upstream as the freshwater flow ceases.

- In the Pavanje study area, saltwater intrusion was observed in the isolated region of 850 to 1000m due to the region's proximity to a tributary which is at a lower elevation.

- In the Gurpur study area, the water quality is not affected in the monsoon period and the post-monsoon period. But during the summer period, nearly 2000m either side is affected by saltwater intrusion from the Gurpur river and its tributary.

- Comparison of the 2D and 3D models for saltwater intrusion were found to be agreeable in the Coastline and Pavanje study area. For the Gurpur study area these models were found to give slightly varying results since the cross section adopted for both were different.

- In the NITK campus the water quality is unaffected even though differs in the taste compared to potable river water. The pumping should be within $300m^3$/day in the summer and up to $500m^3$/day during the monsoon to prevent the saltwater intruding from the tributary of the Pavanje river.

- For Pavanje study area optimal pumping rate should be preferably below $300m^3$/day for all the seasons to avoid the problem of saltwater intrusion.

- The Gurpur study area has serious problems in summer due to over pumping by NMPT. The pumping rate should be below $1000m^3$/day for the summer period to avoid the contamination of freshwater.

5.3 SCOPE FOR THE FUTURE WORK

The present work can be further focused on a smaller region with extensive data on dispersivity, intrinsic permeability etc. This would be useful in accurately assessing the progress of saltwater intrusion. Also, the aquifer stress scenarios could be better simulated over a smaller region with accurate data.

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APPENDIX-I

Principle and procedure for determining the chloride and alkalinity of water (APHA, 1998)

CHLORIDE IN WATER

Principle

Chloride ion is determined by Mohr's method, titration with standard silver nitrate solution in which silver chloride is precipitated at first. The end of titration is indicated by formation of red silver chromate from excess AgnO3 and potassium chromate used as an indicator in neutral to slightly alkaline solution.

$$AgNO_3 + Cl^- \longrightarrow \underset{\text{White}}{AgCl} + NO_3^-$$

$$2AgNO_3 + K_2CrO_4 \xrightarrow[\text{Red}]{} Ag_2CrO_4 + 2KNO_3$$

Reagents

1. 0.0141N Standard sodium chloride solution
2. Potassium chromate as indicator
3. Silver nitrate solution (0.0141N)
4. Distilled water

Procedure

A STANDARDIZATION OF SILVE NITRATE SOLUTION

10 ml of 0.0141N Standard sodium chloride solution is taken. Add two drops of potassium chromate solution as indicator and titrate against the silver nitrate solution, till the end point is reached, i.e. till the colour changes from yellow to brick red. The procedure is repeated till concordant readings are obtained.

B. BLANK TEST

Take 10 ml of distilled water and two drops of potassium chromate solution. The solution is titrated against the silver nitrate solution till colour changes from yellow to brick red. This is repeated for concordant colour values.

C CHLORIDE DETERMINATION

100 ml of water sample is taken in a conical flask. 2 drops of potassium chromate is added as indicator and titration is continued till a brick red colour is obtained. This is repeated for concordant readings. The chloride concentration is calculated as below.

ALKALINITY OF WATER

Principle

Hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes react with addition of standard acid. Hence, alkalinity depends on the end point pH used. The quantity measured by titration to pH 8.3 is the "Phenolphthalein alkalinity", a traditionally used term, and that of to pH 4.3 is the "Total alkalinity" or methyl orange alkalinity. Phenolphthalein or metacresol purple may be used for alkalinity titration to pH 8.3. For total alkalinity, methyl orange, bromcresol green indicator (pH 4.5) or mixed bromcresol green-methyl red indicator solution.

Calculation of alkalinity relationship

The result obtained from the phenolphthalein and total alkalinity determinations offer a means for stoichiometric classification of the three principle forms of alkalinity present in many waters. The classification ascribes the entire alkalinity to bicarbonate, carbonate and hydroxide and assumes the absence of other (weak) inorganic or organic acids, such as silicic, phosphoric and boric acids. According to this scheme:

1. Carbonate (CO_3^{2-}) alkalinity is present when phenolphthalein alkalinity is not zero but is less than total alkalinity.
2. Hydroxide (HO^-) alkalinity is present if phenolphthalein alkalinity is more than half the total alkalinity.
3. Bicarbonate (HCO_3) alkalinity is present if phenolphthalein alkalinity is less than half the total alkalinity. These relationships may be calculated by the following scheme, where P is phenolphthalein alkalinity and T is total alkalinity. The mathematical conversion of the results is shown in the table below:

Result of titration	Hydroxide alkalinity as CaCO3	Carbonate alkalinity as CaCO3	Bicarbonate alkalinity as CaCO3
P=0	0	0	T
P<½ T	0	2P	T-2P
P=½ T	0	2P	0
P>½ T	2P-T	2(T-P)	0
P=T	T	0	0

Reagents

a. *Carbon dioxide – free distilled water*: Prepare all standard solutions with distilled water which has a pH of not lower than 6.0

b. *Standard Sulphuric acid or hydrochloric acid*, 0.1N: Prepare standard solution of 0.1N sulphuric acid solution by diluting 2.8 ml of concentrated H2SO4 to 1 L or 0.1 N hydrochloric acid by diluting 8.3 ml of concentrated HCl t o1L.

c. *Standard sulphuric acid or hydrochloric acid*, 0.02N: Dilute 200 ml 0.1000N standard acid to 1000 ml with distilled water.

d. *Sodium carbonate solution, 0.0200N:* Dissolve 1.060g anhydrous Na_2CO_3 (primary standard grade), oven dried at 140°C, and diluting to the mark of 1L with distilled water.

e. *Phenolphthalein indicator solution:* Dissolve 5g phenolphthalein disodium salt in distilled water and dilute t o1000 ml or dissolve 5g phenolphthalein in 500 ml 95% ethyl or isopropyl alcohol and add 500 ml distilled water . If necessary, add 0.02N NaOH dropwise until a faint pink colour appears.

f. *Metacresol purple indicator solution, pH 8*.2 Indicator: Dissolve 100 mg metacresol purple in 100 ml distilled water.

g. *Methyl orange indicator solution:* Dissolve 500 mg methyl orange powder in 1L distilled water.

h. *Bromcresol green indicator solution, pH 4*.5 indicator: Dissolve 100 mg bromocresol green, sodium salt, in 100 ml distilled water.

i. *Mixed Bromcresol green-methyl red indicator solution:* Dissolve 20 mg methyl red and 100 mg bromcresol green in 100 ml 95% ethyl or isopropyl alcohol. An aqueous solution may also be prepared from the sodium salts of the indicators of same quality.

Procedure

a. *Standardization:* Take 10ml of 0.0200N sodium carbonate solution in a conical flask. Add 2 drops of methyl orange indicator. Titrate over a white surface with standard sulphuric acid. Colour change is from yellow to wine ed. Calculate the strength of sulphuric acid using the equation $N_1V_1=N_2V_2$.

b. *Sample analysis:* Take 100 ml of water sample in a conical flask. Add 2 drops phenolphthalein indicator to get a pink colour and titrate with standard sulphuric acid. Colour change is from pink to colourless. Note down the P end point. (If the sample contains only bicarbonate, then no pink colour will be developed after adding phenolphthalein indicator. Then, P value will be zero. To determine total alkalinity, add 2 drops of methyl orange at pH 4.6 and wine red at pH 4.0. Note down the T end point. If mixed bromcresol green-methyl red indicator is used, the colour change will be from greenish blue to light blue with lavender grey at pH 5.0; light pink grey with bluish cast at pH 4.8; and light pink at 4.6.

APPENDIX-II

Galdit Analysis for November 2006

		Groundwater occurance			Aquifer Hydraulic conductivity (m/day)				Height of Groundwater above the sea level(m)				Distance from the shore/river(m)				Impact or existing status/ Quality of Water				Aquifer Thickness(m)				GALDIT-Index		
Sr.No.	Observation Well ID	G=1			A=3				L = 4				D = 4				I =1				T =2						
		Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	1.54	Low	5.00	20.00	160.32	Very Small	10.00	40.00	4.308	High	10.00	10.00	13.97	Large	10.00	20.00	127.50	8.50	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	1.27	Medium	7.50	30.00	414.45	Very Small	10.00	40.00	1.481	Low	5.00	5.00	18.81	Large	10.00	20.00	132.50	8.83	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	4.54	Very Low	2.50	10.00	512.23	Small	7.50	30.00	1.123	Low	5.00	5.00	21.30	Large	10.00	20.00	102.50	6.83	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	4.79	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	1.156	Low	5.00	5.00	26.09	Large	10.00	20.00	112.50	7.50	High
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	5.58	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.588	Very Low	2.50	2.50	16.78	Large	10.00	20.00	110.00	0.00	Low
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	0.63	High	10.00	40.00	1080.89	Far	2.50	10.00	8.460	High	10.00	10.00	21.61	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	2.42	Very Low	2.50	10.00	303.94	Very Small	10.00	40.00	0.987	Very Low	2.50	2.50	22.08	Large	10.00	20.00	110.00	7.33	Moderate
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	2.12	Very Low	2.50	10.00	708.90	Small	7.50	30.00	2.403	High	10.00	10.00	16.72	Large	10.00	20.00	107.50	7.17	Moderate
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	3.19	Very Low	2.50	10.00	315.87	Very Small	10.00	40.00	0.397	Very Low	2.50	2.50	18.08	Large	10.00	20.00	110.00	7.33	Moderate
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	1.04	Medium	7.50	30.00	1387.31	Far	2.50	10.00	5.961	High	10.00	10.00	21.98	Large	10.00	20.00	107.50	7.17	Moderate
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	1.19	Medium	7.50	30.00	1536.76	Far	2.50	10.00	2.065	High	10.00	10.00	21.65	Large	10.00	20.00	107.50	7.17	Moderate
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	5.70	Very Low	2.50	10.00	723.70	Small	7.50	30.00	1.790	Medium	7.50	7.50	18.88	Large	10.00	20.00	105.00	7.00	Moderate
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	1.35	Medium	7.50	30.00	1689.55	Far	2.50	10.00	2.977	High	10.00	10.00	22.45	Large	10.00	20.00	107.50	7.17	Moderate
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	3.50	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.959	Very Low	2.50	2.50	19.91	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	3.74	Very Low	2.50	10.00	739.40	Small	7.50	30.00	0.604	Very Low	2.50	2.50	20.07	Large	10.00	20.00	100.00	6.67	Moderate
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	2.90	Very Low	2.50	10.00	537.10	Small	7.50	30.00	0.513	Very Low	2.50	2.50	21.94	Large	10.00	20.00	100.00	0.00	Low
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	3.19	Very Low	2.50	10.00	459.25	Very Small	10.00	40.00	3.701	High	10.00	10.00	22.38	Large	10.00	20.00	117.50	0.00	Low
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	2.93	Very Low	2.50	10.00	739.6	Small	7.50	30.00	0.613	Very Low	2.50	2.50	23.50	Large	10.00	20.00	100.00	6.67	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.79	Low	5.00	20.00	658.8	Small	7.50	30.00	0.697	Very Low	2.50	2.50	24.26	Large	10.00	20.00	110.00	7.33	Moderate
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.78	Low	5.00	20.00	718.38	Small	7.50	30.00	0.308	Very Low	2.50	2.50	23.27	Large	10.00	20.00	110.00	7.33	Moderate
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	2.57	Very Low	2.50	10.00	693.47	Small	7.50	30.00	0.653	Very Low	2.50	2.50	22.86	Large	10.00	20.00	100.00	0.00	Low
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	1.09	Medium	7.50	30.00	285.17	Very Small	10.00	40.00	0.237	Very Low	2.50	2.50	22.28	Large	10.00	20.00	130.00	8.67	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	1.24	Medium	7.50	30.00	284.29	Very Small	10.00	40.00	2.969	High	10.00	10.00	20.74	Large	10.00	20.00	137.50	9.17	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	0.64	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.677	Very Low	2.50	2.50	21.91	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	3.14	Very Low	2.50	10.00	879.06	Medium	5.00	20.00	2.332	High	10.00	10.00	20.06	Large	10.00	20.00	97.50	6.50	Moderate
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	3.33	Very Low	2.50	10.00	1411.42	Far	2.50	10.00	1.721	Medium	7.50	7.50	21.14	Large	10.00	20.00	85.00	5.67	Moderate
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	3.62	Very Low	2.50	10.00	1813.19	Far	2.50	10.00	4.935	High	10.00	10.00	20.53	Large	10.00	20.00	87.50	5.83	Moderate
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	0.25	High	10.00	40.00	1801.71	Far	2.50	10.00	0.809	Very Low	2.50	2.50	22.00	Large	10.00	20.00	110.00	7.33	Moderate
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	0.88	High	10.00	40.00	640.92	Small	7.50	30.00	1.448	Low	5.00	5.00	21.25	Large	10.00	20.00	132.50	8.83	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-0.78	High	10.00	40.00	825.6	Medium	5.00	20.00	1.723	Medium	7.50	7.50	28.50	Large	10.00	20.00	125.00	8.33	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.62	High	10.00	40.00	661.98	Small	7.50	30.00	0.453	Very Low	2.50	2.50	18.70	Large	10.00	20.00	130.00	8.67	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-0.36	High	10.00	40.00	1125.97	Far	2.50	10.00	1.763	Medium	7.50	7.50	21.73	Large	10.00	20.00	115.00	7.67	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-0.55	High	10.00	40.00	1643.57	Far	2.50	10.00	1.263	Low	5.00	5.00	20.00	Large	10.00	20.00	112.50	7.50	High
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	1.09	Medium	7.50	30.00	1688.2	Far	2.50	10.00	0.831	Very Low	2.50	2.50	23.18	Large	10.00	20.00	100.00	6.67	Moderate
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	1.80	Low	5.00	20.00	1089.47	Far	2.50	10.00	2.820	High	10.00	10.00	19.46	Large	10.00	20.00	97.50	6.50	Moderate
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	3.25	Very Low	2.50	10.00	833.16	Medium	5.00	20.00	0.521	Very Low	2.50	2.50	24.52	Large	10.00	20.00	90.00	6.00	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	4.38	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	1.168	Low	5.00	5.00	21.20	Large	10.00	20.00	112.50	7.50	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	4.34	Very Low	2.50	10.00	607.81	Small	7.50	30.00	0.572	Very Low	2.50	2.50	19.70	Large	10.00	20.00	100.00	6.67	Moderate
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	7.37	Very Low	2.50	10.00	696.25	Small	7.50	30.00	2.891	High	10.00	10.00	17.37	Large	10.00	20.00	107.50	7.17	Moderate

Galdit Analysis for December 2006

Sr.No.	Observation Well ID	Groundwater Occurance			Aquifer Hydraulic conductivity(m/day)				Height of Groundwater above the sea level(m)				Distance from the shore/river(m)				Impact or existing status/ Quality of Water				Aquifer Thickness(m)				GALDIT-INDEX		
		G = 1			A=3				L = 4				D = 4				I = 1				T =2						
		Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	1.14	Medium	7.50	30.00	160.32	Very Small	10.00	40.00	4.308	High	10.00	10.00	13.57	Large	10.00	20.00	137.50	9.17	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	0.91	High	10.00	40.00	414.45	Very Small	10.00	40.00	1.481	Low	5.00	5.00	18.45	Large	10.00	20.00	142.50	9.50	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	4.47	Very Low	2.50	10.00	512.23	Small	7.50	30.00	1.123	Low	5.00	5.00	21.23	Large	10.00	20.00	102.50	6.83	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	4.70	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	1.156	Low	5.00	5.00	26.00	Large	10.00	20.00	112.50	7.50	High
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	5.68	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.588	Very Low	2.50	2.50	16.88	Large	10.00	20.00	110.00	0.00	Low
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.48	High	10.00	40.00	1080.89	Far	2.50	10.00	8.460	High	10.00	10.00	20.50	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	2.14	Very Low	2.50	10.00	303.94	Very Small	10.00	40.00	0.987	Very Low	2.50	2.50	21.80	Large	10.00	20.00	110.00	7.33	Moderate
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	2.10	Very Low	2.50	10.00	708.90	Small	7.50	30.00	2.403	High	10.00	10.00	16.70	Large	10.00	20.00	107.50	7.17	Moderate
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	3.26	Very Low	2.50	10.00	315.87	Very Small	10.00	40.00	0.397	Very Low	2.50	2.50	18.15	Large	10.00	20.00	110.00	7.33	Moderate
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	0.36	High	10.00	40.00	1387.31	Far	2.50	10.00	5.961	High	10.00	10.00	21.30	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	0.94	High	10.00	40.00	1536.76	Far	2.50	10.00	2.065	High	10.00	10.00	21.40	Large	10.00	20.00	117.50	7.83	High
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	3.96	Very Low	2.50	10.00	723.70	Small	7.50	30.00	1.790	Medium	7.50	7.50	17.14	Large	10.00	20.00	105.00	7.00	Moderate
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	1.33	Medium	7.50	30.00	1689.55	Far	2.50	10.00	2.977	High	10.00	10.00	22.43	Large	10.00	20.00	107.50	7.17	Moderate
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	3.34	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.959	Very Low	2.50	2.50	19.75	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	3.49	Very Low	2.50	10.00	739.40	Small	7.50	30.00	0.604	Very Low	2.50	2.50	19.82	Large	10.00	20.00	100.00	6.67	Moderate
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	2.59	Very Low	2.50	10.00	537.10	Small	7.50	30.00	0.513	Very Low	2.50	2.50	21.63	Large	10.00	20.00	100.00	0.00	Low
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	2.90	Very Low	2.50	10.00	459.25	Very Small	10.00	40.00	3.701	High	10.00	10.00	22.09	Large	10.00	20.00	117.50	0.00	Low
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	2.78	Very Low	2.50	10.00	739.6	Small	7.50	30.00	0.613	Very Low	2.50	2.50	23.35	Large	10.00	20.00	100.00	6.67	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.75	Low	5.00	20.00	658.8	Small	7.50	30.00	0.697	Very Low	2.50	2.50	24.22	Large	10.00	20.00	110.00	7.33	Moderate
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.83	Low	5.00	20.00	718.38	Small	7.50	30.00	0.308	Very Low	2.50	2.50	23.32	Large	10.00	20.00	110.00	7.33	Moderate
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	2.29	Very Low	2.50	10.00	693.47	Small	7.50	30.00	0.653	Very Low	2.50	2.50	22.58	Large	10.00	20.00	100.00	0.00	Low
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	0.94	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.237	Very Low	2.50	2.50	22.13	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	1.06	Medium	7.50	30.00	284.29	Very Small	10.00	40.00	2.969	High	10.00	10.00	20.56	Large	10.00	20.00	137.50	9.17	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	0.58	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.677	Very Low	2.50	2.50	21.85	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	2.94	Very Low	2.50	10.00	879.06	Medium	5.00	20.00	2.332	High	10.00	10.00	19.86	Large	10.00	20.00	97.50	6.50	Moderate
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	2.82	Very Low	2.50	10.00	1411.42	Far	2.50	10.00	1.721	Medium	7.50	7.50	20.63	Large	10.00	20.00	85.00	5.67	Moderate
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	3.09	Very Low	2.50	10.00	1813.19	Far	2.50	10.00	4.935	High	10.00	10.00	20.00	Large	10.00	20.00	87.50	5.83	Moderate
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	0.05	High	10.00	40.00	1801.71	Far	2.50	10.00	0.809	Very Low	2.50	2.50	21.80	Large	10.00	20.00	110.00	7.33	Moderate
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	0.63	High	10.00	40.00	640.92	Small	7.50	30.00	1.448	Low	5.00	5.00	21.00	Large	10.00	20.00	132.50	8.83	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-1.08	High	10.00	40.00	825.6	Medium	5.00	20.00	1.723	Medium	7.50	7.50	28.20	Large	10.00	20.00	125.00	8.33	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-1.02	High	10.00	40.00	661.98	Small	7.50	30.00	0.453	Very Low	2.50	2.50	18.30	Large	10.00	20.00	130.00	8.67	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-0.85	High	10.00	40.00	1125.97	Far	2.50	10.00	1.763	Medium	7.50	7.50	21.24	Large	10.00	20.00	115.00	7.67	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-0.77	High	10.00	40.00	1643.57	Far	2.50	10.00	1.263	Low	5.00	5.00	19.78	Large	10.00	20.00	112.50	7.50	High
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	0.91	High	10.00	40.00	1688.2	Far	2.50	10.00	0.831	Very Low	2.50	2.50	23.00	Large	10.00	20.00	110.00	7.33	Moderate
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	1.70	Low	5.00	20.00	1089.47	Far	2.50	10.00	2.820	High	10.00	10.00	19.36	Large	10.00	20.00	97.50	6.50	Moderate
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	2.79	Very Low	2.50	10.00	833.16	Medium	5.00	20.00	0.521	Very Low	2.50	2.50	24.06	Large	10.00	20.00	90.00	6.00	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	3.93	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	1.168	Low	5.00	5.00	20.75	Large	10.00	20.00	112.50	7.50	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	3.70	Very Low	2.50	10.00	607.81	Small	7.50	30.00	0.572	Very Low	2.50	2.50	19.06	Large	10.00	20.00	100.00	6.67	Moderate
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	6.59	Very Low	2.50	10.00	696.25	Small	7.50	30.00	2.891	High	10.00	10.00	16.59	Large	10.00	20.00	107.50	7.17	Moderate

Galdit Analysis for January 2007

Sr.No.	Observation Well ID	Groundwater Occurance G = 1			Aquifer Hydraulic conductivity(m/day) A=3				Height of Groundwater above the sea level(m) L = 4				Distance from the shore/river(m) D = 4				Impact or existing status/ Quality of I =1				Aquifer Thickness(m) T =2				GALDIT-INDEX		
		Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	0.64	High	10.00	40.00	160.32	Very Small	10.00	40.00	3.717	High	10.00	10.00	13.07	Large	10.00	20.00	147.50	9.83	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	0.78	High	10.00	40.00	414.45	Very Small	10.00	40.00	1.474	Low	5.00	5.00	18.32	Large	10.00	20.00	142.50	9.50	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	4.41	Very Low	2.50	10.00	512.23	Small	7.50	30.00	1.156	Low	5.00	5.00	21.17	Large	10.00	20.00	102.50	6.83	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	4.70	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	1.100	Low	5.00	5.00	26.00	Large	10.00	20.00	112.50	7.50	High
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	5.42	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.564	Very Low	2.50	2.50	16.62	Large	10.00	20.00	110.00	0.00	Low
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.13	High	10.00	40.00	1080.89	Far	2.50	10.00	6.833	High	10.00	10.00	20.85	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	1.43	Medium	7.50	30.00	303.94	Very Small	10.00	40.00	1.058	Low	5.00	5.00	21.09	Large	10.00	20.00	132.50	8.83	High
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	1.63	Low	5.00	20.00	708.90	Small	7.50	30.00	1.987	Medium	7.50	7.50	16.23	Large	10.00	20.00	115.00	7.67	High
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	2.57	Very Low	2.50	10.00	315.87	Very Small	10.00	40.00	0.470	Very Low	2.50	2.50	17.46	Large	10.00	20.00	110.00	7.33	Moderate
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	-0.05	High	10.00	40.00	1387.31	Far	2.50	10.00	6.639	High	10.00	10.00	20.89	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	0.75	High	10.00	40.00	1536.76	Far	2.50	10.00	1.939	Medium	7.50	7.50	21.21	Large	10.00	20.00	115.00	7.67	High
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	1.20	Medium	7.50	30.00	723.70	Small	7.50	30.00	1.821	Medium	7.50	7.50	14.38	Large	10.00	20.00	125.00	8.33	High
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	0.96	High	10.00	40.00	1689.55	Far	2.50	10.00	2.679	High	10.00	10.00	22.06	Large	10.00	20.00	117.50	7.83	High
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	2.91	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.963	Very Low	2.50	2.50	19.32	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	2.90	Very Low	2.50	10.00	739.40	Small	7.50	30.00	1.296	Low	5.00	5.00	19.23	Large	10.00	20.00	102.50	6.83	Moderate
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	2.18	Very Low	2.50	10.00	537.10	Small	7.50	30.00	0.595	Very Low	2.50	2.50	21.22	Large	10.00	20.00	100.00	0.00	Low
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	2.56	Very Low	2.50	10.00	459.25	Very Small	10.00	40.00	0.458	Very Low	2.50	2.50	21.75	Large	10.00	20.00	110.00	0.00	Low
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	2.63	Very Low	2.50	10.00	739.6	Small	7.50	30.00	0.743	Very Low	2.50	2.50	23.20	Large	10.00	20.00	100.00	6.67	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.59	Low	5.00	20.00	658.8	Small	7.50	30.00	0.834	Very Low	2.50	2.50	24.06	Large	10.00	20.00	110.00	7.33	Moderate
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.69	Low	5.00	20.00	718.38	Small	7.50	30.00	0.338	Very Low	2.50	2.50	23.18	Large	10.00	20.00	110.00	7.33	Moderate
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	1.84	Low	5.00	20.00	693.47	Small	7.50	30.00	0.745	Very Low	2.50	2.50	22.13	Large	10.00	20.00	110.00	0.00	Low
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	0.47	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.235	Very Low	2.50	2.50	21.66	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	0.41	High	10.00	40.00	284.29	Very Small	10.00	40.00	2.836	High	10.00	10.00	19.91	Large	10.00	20.00	147.50	9.83	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	0.38	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.691	Very Low	2.50	2.50	21.65	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	2.41	Very Low	2.50	10.00	879.06	Medium	5.00	20.00	1.837	Medium	7.50	7.50	19.33	Large	10.00	20.00	95.00	6.33	Moderate
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	2.61	Very Low	2.50	10.00	1411.42	Far	2.50	10.00	1.674	Medium	7.50	7.50	20.42	Large	10.00	20.00	85.00	5.67	Moderate
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	2.49	Very Low	2.50	10.00	1813.19	Far	2.50	10.00	5.718	High	10.00	10.00	19.40	Large	10.00	20.00	87.50	5.83	Moderate
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	-0.29	High	10.00	40.00	1801.71	Far	2.50	10.00	0.977	Very Low	2.50	2.50	21.46	Large	10.00	20.00	110.00	7.33	Moderate
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	-0.26	High	10.00	40.00	640.92	Small	7.50	30.00	1.888	Medium	7.50	7.50	20.12	Large	10.00	20.00	135.00	9.00	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-1.40	High	10.00	40.00	825.6	Medium	5.00	20.00	2.136	High	10.00	10.00	27.88	Large	10.00	20.00	127.50	8.50	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-1.72	High	10.00	40.00	661.98	Small	7.50	30.00	0.517	Very Low	2.50	2.50	17.60	Large	10.00	20.00	130.00	8.67	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-1.31	High	10.00	40.00	1125.97	Far	2.50	10.00	1.799	Medium	7.50	7.50	20.78	Large	10.00	20.00	115.00	7.67	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-1.12	High	10.00	40.00	1643.57	Far	2.50	10.00	1.704	Medium	7.50	7.50	19.43	Large	10.00	20.00	115.00	7.67	High
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	0.94	High	10.00	40.00	1688.2	Far	2.50	10.00	1.598	Medium	7.50	7.50	23.03	Large	10.00	20.00	115.00	7.67	High
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	1.64	Low	5.00	20.00	1089.47	Far	2.50	10.00	3.205	High	10.00	10.00	19.30	Large	10.00	20.00	97.50	6.50	Moderate
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	2.55	Very Low	2.50	10.00	833.16	Medium	5.00	20.00	0.625	Very Low	2.50	2.50	23.82	Large	10.00	20.00	90.00	6.00	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	3.51	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	1.933	Medium	7.50	7.50	20.33	Large	10.00	20.00	115.00	7.67	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	1.51	Low	5.00	20.00	607.81	Small	7.50	30.00	0.726	Very Low	2.50	2.50	16.87	Large	10.00	20.00	110.00	7.33	Moderate
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	6.92	Very Low	2.50	10.00	696.25	Small	7.50	30.00	4.331	High	10.00	10.00	16.92	Large	10.00	20.00	107.50	7.17	Moderate

APPENDIX II

Galdit Analysis for February 2007

		Groundwater Occurance			Aquifer Hydraulic conductivity(m/day)				Height of Groundwater above the sea level(m)				Distance from the shore/river(m)				Impact or existing status/ Quality of				Aquifer Thickness(m)				GALDIT-INDEX		
		G = 1			A=3				L = 4				D = 4				I =1				T =2						
Sr.No.	Observation Well ID	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	0.07	High	10.00	40.00	160.32	Very Small	10.00	40.00	3.397	High	10.00	10.00	12.50	Large	10.00	20.00	147.50	9.83	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	0.39	High	10.00	40.00	414.45	Very Small	10.00	40.00	2.193	High	10.00	10.00	17.93	Large	10.00	20.00	147.50	9.83	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	3.89	Very Low	2.50	10.00	512.23	Small	7.50	30.00	0.992	Very Low	2.50	2.50	20.65	Large	10.00	20.00	100.00	6.67	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	4.43	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	0.931	Very Low	2.50	2.50	25.73	Large	10.00	20.00	110.00	7.33	Moderate
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	5.34	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.564	Very Low	2.50	2.50	16.54	Large	10.00	20.00	110.00	0.00	Low
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.62	High	10.00	40.00	1080.89	Far	2.50	10.00	8.076	High	10.00	10.00	20.36	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	0.82	High	10.00	40.00	303.94	Very Small	10.00	40.00	0.932	Very Low	2.50	2.50	20.48	Large	10.00	20.00	140.00	9.33	High
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	1.20	Medium	7.50	30.00	708.90	Small	7.50	30.00	2.081	High	10.00	10.00	15.80	Large	10.00	20.00	127.50	8.50	High
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	1.40	Medium	7.50	30.00	315.87	Very Small	10.00	40.00	0.415	Very Low	2.50	2.50	16.29	Large	10.00	20.00	130.00	8.67	High
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	-1.00	High	10.00	40.00	1387.31	Far	2.50	10.00	4.089	High	10.00	10.00	19.94	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	-0.07	High	10.00	40.00	1536.76	Far	2.50	10.00	2.603	High	10.00	10.00	20.39	Large	10.00	20.00	117.50	7.83	High
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	0.94	High	10.00	40.00	723.70	Small	7.50	30.00	1.923	Medium	7.50	7.50	14.13	Large	10.00	20.00	135.00	9.00	High
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	0.76	High	10.00	40.00	1689.55	Far	2.50	10.00	2.397	High	10.00	10.00	21.86	Large	10.00	20.00	117.50	7.83	High
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	2.40	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.804	Very Low	2.50	2.50	18.81	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	2.46	Very Low	2.50	10.00	739.40	Small	7.50	30.00	1.287	Low	5.00	5.00	18.79	Large	10.00	20.00	102.50	6.83	Moderate
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	1.82	Low	5.00	20.00	537.10	Small	7.50	30.00	0.684	Very Low	2.50	2.50	20.86	Large	10.00	20.00	110.00	0.00	Low
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	2.01	Very Low	2.50	10.00	459.25	Very Small	10.00	40.00	0.412	Very Low	2.50	2.50	21.20	Large	10.00	20.00	110.00	0.00	Low
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	2.29	Very Low	2.50	10.00	739.6	Small	7.50	30.00	0.740	Very Low	2.50	2.50	22.86	Large	10.00	20.00	100.00	6.67	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.35	Medium	7.50	30.00	658.8	Small	7.50	30.00	1.090	Low	5.00	5.00	23.82	Large	10.00	20.00	122.50	8.17	High
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.37	Medium	7.50	30.00	718.38	Small	7.50	30.00	0.308	Very Low	2.50	2.50	22.86	Large	10.00	20.00	120.00	8.00	High
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	1.31	Medium	7.50	30.00	693.47	Small	7.50	30.00	0.714	Very Low	2.50	2.50	21.60	Large	10.00	20.00	120.00	0.00	Low
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	0.35	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.192	Very Low	2.50	2.50	21.54	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	0.27	High	10.00	40.00	284.29	Very Small	10.00	40.00	3.620	High	10.00	10.00	19.77	Large	10.00	20.00	147.50	9.83	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	0.20	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.679	Very Low	2.50	2.50	21.47	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	1.68	Low	5.00	20.00	879.06	Medium	5.00	20.00	1.554	Medium	7.50	7.50	18.60	Large	10.00	20.00	105.00	7.00	Moderate
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	2.02	Very Low	2.50	10.00	1411.42	Far	2.50	10.00	1.987	Medium	7.50	7.50	19.83	Large	10.00	20.00	85.00	5.67	Moderate
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	1.68	Low	5.00	20.00	1813.19	Far	2.50	10.00	5.217	High	10.00	10.00	18.59	Large	10.00	20.00	97.50	6.50	Moderate
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	-2.75	High	10.00	40.00	1801.71	Far	2.50	10.00	0.722	Very Low	2.50	2.50	19.00	Large	10.00	20.00	110.00	7.33	Moderate
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	-1.12	High	10.00	40.00	640.92	Small	7.50	30.00	2.247	High	10.00	10.00	19.26	Large	10.00	20.00	137.50	9.17	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-2.54	High	10.00	40.00	825.6	Medium	5.00	20.00	2.328	High	10.00	10.00	26.74	Large	10.00	20.00	127.50	8.50	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-2.22	High	10.00	40.00	661.98	Small	7.50	30.00	0.887	Very Low	2.50	2.50	17.10	Large	10.00	20.00	130.00	8.67	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-1.79	High	10.00	40.00	1125.97	Far	2.50	10.00	1.216	Low	5.00	5.00	20.30	Large	10.00	20.00	112.50	7.50	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-1.63	High	10.00	40.00	1643.57	Far	2.50	10.00	1.833	Medium	7.50	7.50	18.92	Large	10.00	20.00	115.00	7.67	High
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.10	High	10.00	40.00	1688.2	Far	2.50	10.00	1.293	Low	5.00	5.00	22.00	Large	10.00	20.00	112.50	7.50	High
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	0.75	High	10.00	40.00	1089.47	Far	2.50	10.00	4.442	High	10.00	10.00	18.41	Large	10.00	20.00	117.50	7.83	High
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	2.25	Very Low	2.50	10.00	833.16	Medium	5.00	20.00	0.526	Very Low	2.50	2.50	23.52	Large	10.00	20.00	90.00	6.00	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	3.00	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	1.895	Medium	7.50	7.50	19.82	Large	10.00	20.00	115.00	7.67	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	0.04	High	10.00	40.00	607.81	Small	7.50	30.00	0.546	Very Low	2.50	2.50	15.40	Large	10.00	20.00	130.00	8.67	High
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	6.56	Very Low	2.50	10.00	696.25	Small	7.50	30.00	3.525	High	10.00	10.00	16.56	Large	10.00	20.00	107.50	7.17	Moderate

Galdit Analysis for March 2007

Sr.No.	Observation Well ID	Groundwater Occurance			Aquifer Hydraulic conductivity(m/day)				Height of Groundwater above the sea				Distance from the shore/river(m)				Impact or existing status/ Quality of				Aquifer Thickness(m)				GALDIT-INDEX		
		G = 1			A=3				L = 4				D = 4				I =1				T =2						
		Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	-0.09	High	10.00	40.00	160.32	Very Small	10.00	40.00	3.525	High	10.00	10.00	12.34	Large	10.00	20.00	147.50	9.83	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	0.31	High	10.00	40.00	414.45	Very Small	10.00	40.00	1.859	Medium	7.50	7.50	17.85	Large	10.00	20.00	145.00	9.67	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	3.80	Very Low	2.50	10.00	512.23	Small	7.50	30.00	0.940	Very Low	2.50	2.50	20.56	Large	10.00	20.00	100.00	6.67	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	4.23	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	0.858	Very Low	2.50	2.50	25.53	Large	10.00	20.00	110.00	7.33	Moderate
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	5.31	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.737	Very Low	2.50	2.50	16.51	Large	10.00	20.00	110.00	0.00	Low
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-2.40	High	10.00	40.00	1080.89	Far	2.50	10.00	14.355	High	10.00	10.00	18.58	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	0.89	High	10.00	40.00	303.94	Very Small	10.00	40.00	1.354	Low	5.00	5.00	20.55	Large	10.00	20.00	142.50	9.50	High
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	0.74	High	10.00	40.00	708.90	Small	7.50	30.00	2.023	High	10.00	10.00	15.34	Large	10.00	20.00	137.50	9.17	High
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	0.91	High	10.00	40.00	315.87	Very Small	10.00	40.00	0.524	Very Low	2.50	2.50	15.80	Large	10.00	20.00	140.00	9.33	High
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	-1.34	High	10.00	40.00	1387.31	Far	2.50	10.00	9.988	High	10.00	10.00	19.60	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	-0.65	High	10.00	40.00	1536.76	Far	2.50	10.00	2.726	High	10.00	10.00	19.81	Large	10.00	20.00	117.50	7.83	High
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	2.23	Very Low	2.50	10.00	723.70	Small	7.50	30.00	1.821	Medium	7.50	7.50	15.41	Large	10.00	20.00	105.00	7.00	Moderate
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	0.43	High	10.00	40.00	1689.55	Far	2.50	10.00	2.891	High	10.00	10.00	21.53	Large	10.00	20.00	117.50	7.83	High
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	2.32	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.959	Very Low	2.50	2.50	18.73	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	2.25	Very Low	2.50	10.00	739.40	Small	7.50	30.00	1.259	Low	5.00	5.00	18.58	Large	10.00	20.00	102.50	6.83	Moderate
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	1.66	Low	5.00	20.00	537.10	Small	7.50	30.00	0.695	Very Low	2.50	2.50	20.70	Large	10.00	20.00	110.00	0.00	Low
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	1.79	Low	5.00	20.00	459.25	Very Small	10.00	40.00	0.222	Very Low	2.50	2.50	20.98	Large	10.00	20.00	120.00	0.00	Low
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	2.05	Very Low	2.50	10.00	739.6	Small	7.50	30.00	0.750	Very Low	2.50	2.50	22.62	Large	10.00	20.00	100.00	6.67	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.17	Medium	7.50	30.00	658.8	Small	7.50	30.00	0.623	Very Low	2.50	2.50	23.64	Large	10.00	20.00	120.00	8.00	High
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.30	Medium	7.50	30.00	718.38	Small	7.50	30.00	0.318	Very Low	2.50	2.50	22.79	Large	10.00	20.00	120.00	8.00	High
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	1.08	Medium	7.50	30.00	693.47	Small	7.50	30.00	0.715	Very Low	2.50	2.50	21.37	Large	10.00	20.00	120.00	0.00	Low
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	0.24	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.203	Very Low	2.50	2.50	21.43	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	0.35	High	10.00	40.00	284.29	Very Small	10.00	40.00	3.493	High	10.00	10.00	19.85	Large	10.00	20.00	147.50	9.83	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	0.11	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.718	Very Low	2.50	2.50	21.38	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	1.68	Low	5.00	20.00	879.06	Medium	5.00	20.00	2.136	High	10.00	10.00	18.60	Large	10.00	20.00	107.50	7.17	Moderate
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	1.79	Low	5.00	20.00	1411.42	Far	2.50	10.00	2.281	High	10.00	10.00	19.60	Large	10.00	20.00	97.50	6.50	Moderate
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	1.41	Medium	7.50	30.00	1813.19	Far	2.50	10.00	5.852	High	10.00	10.00	18.32	Large	10.00	20.00	107.50	7.17	Moderate
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	-1.16	High	10.00	40.00	1801.71	Far	2.50	10.00	0.452	Very Low	2.50	2.50	20.59	Large	10.00	20.00	110.00	7.33	Moderate
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	-1.70	High	10.00	40.00	640.92	Small	7.50	30.00	2.557	High	10.00	10.00	18.68	Large	10.00	20.00	137.50	9.17	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-2.70	High	10.00	40.00	825.6	Medium	5.00	20.00	2.350	High	10.00	10.00	26.58	Large	10.00	20.00	127.50	8.50	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-2.32	High	10.00	40.00	661.98	Small	7.50	30.00	1.775	Medium	7.50	7.50	17.00	Large	10.00	20.00	135.00	9.00	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-2.07	High	10.00	40.00	1125.97	Far	2.50	10.00	1.334	Low	5.00	5.00	20.02	Large	10.00	20.00	112.50	7.50	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-2.09	High	10.00	40.00	1643.57	Far	2.50	10.00	1.873	Medium	7.50	7.50	18.46	Large	10.00	20.00	115.00	7.67	High
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.43	High	10.00	40.00	1688.2	Far	2.50	10.00	1.108	Low	5.00	5.00	21.67	Large	10.00	20.00	112.50	7.50	High
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	0.50	High	10.00	40.00	1089.47	Far	2.50	10.00	3.408	High	10.00	10.00	18.16	Large	10.00	20.00	117.50	7.83	High
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	1.98	Low	5.00	20.00	833.16	Medium	5.00	20.00	1.138	Low	5.00	5.00	23.25	Large	10.00	20.00	102.50	6.83	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	2.69	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	1.866	Medium	7.50	7.50	19.51	Large	10.00	20.00	115.00	7.67	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	1.64	Low	5.00	20.00	607.81	Small	7.50	30.00	0.533	Very Low	2.50	2.50	17.00	Large	10.00	20.00	110.00	7.33	Moderate
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	6.34	Very Low	2.50	10.00	696.25	Small	7.50	30.00	3.384	High	10.00	10.00	16.34	Large	10.00	20.00	107.50	7.17	Moderate

Galdit Analysis for April 2007

Sr.No.	Observation Well ID	Groundwater Occurance			Aquifer Hydraulic conductivity(m/day)				Height of Groundwater above the sea level(m)				Distance from the shore/river(m)				Impact or existing status/ Quality of Water				Aquifer Thickness(m)				GALDIT-INDEX		
		G = 1			A=3				L = 4				D = 4				I =1				T =2						
		Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	-0.51	High	10.00	40.00	160.32	Very Small	10.00	40.00	2.938	High	10.00	10.00	11.92	Large	10.00	20.00	147.50	9.83	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	-0.12	High	10.00	40.00	414.45	Very Small	10.00	40.00	1.316	Low	5.00	5.00	17.42	Large	10.00	20.00	142.50	9.50	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	3.31	Very Low	2.50	10.00	512.23	Small	7.50	30.00	0.751	Very Low	2.50	2.50	20.07	Large	10.00	20.00	100.00	6.67	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	3.27	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	0.876	Very Low	2.50	2.50	24.57	Large	10.00	20.00	110.00	7.33	Moderate
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	4.84	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.419	Very Low	2.50	2.50	16.04	Large	10.00	20.00	110.00	0.00	Low
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.98	High	10.00	40.00	1080.89	Far	2.50	10.00	6.635	High	10.00	10.00	20.00	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	0.61	High	10.00	40.00	303.94	Very Small	10.00	40.00	0.665	Very Low	2.50	2.50	20.27	Large	10.00	20.00	140.00	9.33	High
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	0.46	High	10.00	40.00	708.90	Small	7.50	30.00	1.870	Medium	7.50	7.50	15.06	Large	10.00	20.00	135.00	9.00	High
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	0.87	High	10.00	40.00	315.87	Very Small	10.00	40.00	0.427	Very Low	2.50	2.50	15.76	Large	10.00	20.00	140.00	9.33	High
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	-1.85	High	10.00	40.00	1387.31	Far	2.50	10.00	8.930	High	10.00	10.00	19.09	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	-1.01	High	10.00	40.00	1536.76	Far	2.50	10.00	3.217	High	10.00	10.00	19.45	Large	10.00	20.00	117.50	7.83	High
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	1.72	Low	5.00	20.00	723.70	Small	7.50	30.00	1.163	Low	5.00	5.00	14.90	Large	10.00	20.00	112.50	7.50	High
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	0.10	High	10.00	40.00	1689.55	Far	2.50	10.00	2.436	High	10.00	10.00	21.20	Large	10.00	20.00	117.50	7.83	High
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	2.84	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.674	Very Low	2.50	2.50	19.25	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	1.87	Low	5.00	20.00	739.40	Small	7.50	30.00	1.293	Low	5.00	5.00	18.20	Large	10.00	20.00	112.50	7.50	High
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	1.34	Medium	7.50	30.00	537.10	Small	7.50	30.00	0.470	Very Low	2.50	2.50	20.38	Large	10.00	20.00	120.00	0.00	Low
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	1.44	Medium	7.50	30.00	459.25	Very Small	10.00	40.00	0.321	Very Low	2.50	2.50	20.63	Large	10.00	20.00	130.00	0.00	Low
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	1.63	Low	5.00	20.00	739.6	Small	7.50	30.00	0.872	Very Low	2.50	2.50	22.20	Large	10.00	20.00	110.00	7.33	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.07	Medium	7.50	30.00	658.8	Small	7.50	30.00	0.857	Very Low	2.50	2.50	23.54	Large	10.00	20.00	120.00	8.00	High
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.31	Medium	7.50	30.00	718.38	Small	7.50	30.00	0.276	Very Low	2.50	2.50	22.80	Large	10.00	20.00	120.00	8.00	High
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	0.75	High	10.00	40.00	693.47	Small	7.50	30.00	0.763	Very Low	2.50	2.50	21.04	Large	10.00	20.00	130.00	0.00	Low
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	0.13	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.201	Very Low	2.50	2.50	21.32	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	0.25	High	10.00	40.00	284.29	Very Small	10.00	40.00	2.593	High	10.00	10.00	19.75	Large	10.00	20.00	147.50	9.83	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.06	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.679	Very Low	2.50	2.50	21.21	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	1.23	Medium	7.50	30.00	879.06	Medium	5.00	20.00	2.095	High	10.00	10.00	18.15	Large	10.00	20.00	117.50	7.83	High
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	0.93	High	10.00	40.00	1411.42	Far	2.50	10.00	2.074	High	10.00	10.00	18.74	Large	10.00	20.00	117.50	7.83	High
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	0.88	High	10.00	40.00	1813.19	Far	2.50	10.00	4.772	High	10.00	10.00	17.79	Large	10.00	20.00	117.50	7.83	High
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	-1.20	High	10.00	40.00	1801.71	Far	2.50	10.00	0.499	Very Low	2.50	2.50	20.55	Large	10.00	20.00	110.00	7.33	Moderate
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	-2.70	High	10.00	40.00	640.92	Small	7.50	30.00	3.102	High	10.00	10.00	17.68	Large	10.00	20.00	137.50	9.17	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-3.31	High	10.00	40.00	825.6	Medium	5.00	20.00	2.238	High	10.00	10.00	25.97	Large	10.00	20.00	127.50	8.50	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-2.48	High	10.00	40.00	661.98	Small	7.50	30.00	1.309	Low	5.00	5.00	16.84	Large	10.00	20.00	132.50	8.83	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-2.85	High	10.00	40.00	1125.97	Far	2.50	10.00	1.095	Low	5.00	5.00	19.24	Large	10.00	20.00	112.50	7.50	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-3.32	High	10.00	40.00	1643.57	Far	2.50	10.00	0.366	Very Low	2.50	2.50	17.23	Large	10.00	20.00	110.00	7.33	Moderate
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.63	High	10.00	40.00	1688.2	Far	2.50	10.00	1.012	Low	5.00	5.00	21.47	Large	10.00	20.00	112.50	7.50	High
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	1.01	Medium	7.50	30.00	1089.47	Far	2.50	10.00	2.019	High	10.00	10.00	18.67	Large	10.00	20.00	107.50	7.17	Moderate
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	1.74	Low	5.00	20.00	833.16	Medium	5.00	20.00	0.672	Very Low	2.50	2.50	23.01	Large	10.00	20.00	100.00	6.67	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	2.44	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	1.620	Medium	7.50	7.50	19.26	Large	10.00	20.00	115.00	7.67	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	-2.36	High	10.00	40.00	607.81	Small	7.50	30.00	0.492	Very Low	2.50	2.50	13.00	Large	10.00	20.00	130.00	8.67	High
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	6.11	Very Low	2.50	10.00	696.25	Small	7.50	30.00	2.256	High	10.00	10.00	16.11	Large	10.00	20.00	107.50	7.17	Moderate

Galdit Analysis for May 2007

		Groundwater Occurance			Aquifer Hydraulic conductivity(m/day)				Height of Groundwater above the sea				Distance from the shore/river(m)				Impact or existing status/ Quality of				Aquifer Thickness(m)				GALDIT-INDEX		
		G = 1			A=3				L = 4				D = 4				I =1				T =2						
Sr.No.	Observation Well ID	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	-0.15	High	10.00	40.00	160.32	Very Small	10.00	40.00	3.408	High	10.00	10.00	12.28	Large	10.00	20.00	147.50	9.83	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	0.00	High	10.00	40.00	414.45	Very Small	10.00	40.00	1.175	Low	5.00	5.00	17.54	Large	10.00	20.00	142.50	9.50	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	3.88	Very Low	2.50	10.00	512.23	Small	7.50	30.00	0.979	Very Low	2.50	2.50	20.64	Large	10.00	20.00	100.00	6.67	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	3.13	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	1.152	Low	5.00	5.00	24.43	Large	10.00	20.00	112.50	7.50	High
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	4.91	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.415	Very Low	2.50	2.50	16.11	Large	10.00	20.00	110.00	0.00	Low
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.13	High	10.00	40.00	1080.89	Far	2.50	10.00	4.700	High	10.00	10.00	20.85	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	0.67	High	10.00	40.00	303.94	Very Small	10.00	40.00	1.168	Low	5.00	5.00	20.33	Large	10.00	20.00	142.50	9.50	High
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	0.94	High	10.00	40.00	708.90	Small	7.50	30.00	2.115	High	10.00	10.00	15.54	Large	10.00	20.00	137.50	9.17	High
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	0.72	High	10.00	40.00	315.87	Very Small	10.00	40.00	0.463	Very Low	2.50	2.50	15.61	Large	10.00	20.00	140.00	9.33	High
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	0.03	High	10.00	40.00	1387.31	Far	2.50	10.00	11.562	High	10.00	10.00	20.97	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	0.54	High	10.00	40.00	1536.76	Far	2.50	10.00	2.977	High	10.00	10.00	21.00	Large	10.00	20.00	117.50	7.83	High
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	3.09	Very Low	2.50	10.00	723.70	Small	7.50	30.00	1.898	Medium	7.50	7.50	16.27	Large	10.00	20.00	105.00	7.00	Moderate
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.93	High	10.00	40.00	1689.55	Far	2.50	10.00	2.712	High	10.00	10.00	20.17	Large	10.00	20.00	117.50	7.83	High
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	3.09	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.954	Very Low	2.50	2.50	19.50	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	3.00	Very Low	2.50	10.00	739.40	Small	7.50	30.00	0.951	Very Low	2.50	2.50	19.33	Large	10.00	20.00	100.00	6.67	Moderate
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	2.63	Very Low	2.50	10.00	537.10	Small	7.50	30.00	0.584	Very Low	2.50	2.50	21.67	Large	10.00	20.00	100.00	0.00	Low
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	1.79	Low	5.00	20.00	459.25	Very Small	10.00	40.00	0.489	Very Low	2.50	2.50	20.98	Large	10.00	20.00	120.00	0.00	Low
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	2.30	Very Low	2.50	10.00	739.6	Small	7.50	30.00	0.823	Very Low	2.50	2.50	22.87	Large	10.00	20.00	100.00	6.67	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.58	Low	5.00	20.00	658.8	Small	7.50	30.00	0.917	Very Low	2.50	2.50	24.05	Large	10.00	20.00	110.00	7.33	Moderate
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.70	Low	5.00	20.00	718.38	Small	7.50	30.00	0.353	Very Low	2.50	2.50	23.19	Large	10.00	20.00	110.00	7.33	Moderate
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	1.14	Medium	7.50	30.00	693.47	Small	7.50	30.00	0.468	Very Low	2.50	2.50	21.43	Large	10.00	20.00	120.00	0.00	Low
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	0.43	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.222	Very Low	2.50	2.50	21.62	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	0.68	High	10.00	40.00	284.29	Very Small	10.00	40.00	4.291	High	10.00	10.00	20.18	Large	10.00	20.00	147.50	9.83	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	0.24	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.859	Very Low	2.50	2.50	21.51	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	1.67	Low	5.00	20.00	879.06	Medium	5.00	20.00	3.102	High	10.00	10.00	18.59	Large	10.00	20.00	107.50	7.17	Moderate
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	1.45	Medium	7.50	30.00	1411.42	Far	2.50	10.00	3.878	High	10.00	10.00	19.26	Large	10.00	20.00	107.50	7.17	Moderate
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	1.54	Low	5.00	20.00	1813.19	Far	2.50	10.00	8.284	High	10.00	10.00	18.45	Large	10.00	20.00	97.50	6.50	Moderate
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	-0.40	High	10.00	40.00	1801.71	Far	2.50	10.00	1.472	Low	5.00	5.00	21.35	Large	10.00	20.00	112.50	7.50	High
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	-2.28	High	10.00	40.00	640.92	Small	7.50	30.00	3.704	High	10.00	10.00	18.10	Large	10.00	20.00	137.50	9.17	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-2.70	High	10.00	40.00	825.6	Medium	5.00	20.00	4.005	High	10.00	10.00	26.58	Large	10.00	20.00	127.50	8.50	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-2.32	High	10.00	40.00	661.98	Small	7.50	30.00	2.247	High	10.00	10.00	17.00	Large	10.00	20.00	137.50	9.17	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-3.16	High	10.00	40.00	1125.97	Far	2.50	10.00	1.039	Low	5.00	5.00	18.93	Large	10.00	20.00	112.50	7.50	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-2.65	High	10.00	40.00	1643.57	Far	2.50	10.00	1.808	Medium	7.50	7.50	17.90	Large	10.00	20.00	115.00	7.67	High
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	0.39	High	10.00	40.00	1688.2	Far	2.50	10.00	1.226	Low	5.00	5.00	22.48	Large	10.00	20.00	112.50	7.50	High
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	1.64	Low	5.00	20.00	1089.47	Far	2.50	10.00	1.316	Low	5.00	5.00	19.30	Large	10.00	20.00	92.50	6.17	Moderate
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	2.45	Very Low	2.50	10.00	833.16	Medium	5.00	20.00	0.786	Very Low	2.50	2.50	23.72	Large	10.00	20.00	90.00	6.00	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	2.86	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	2.115	High	10.00	10.00	19.68	Large	10.00	20.00	117.50	7.83	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	1.60	Low	5.00	20.00	607.81	Small	7.50	30.00	0.578	Very Low	2.50	2.50	16.96	Large	10.00	20.00	110.00	7.33	Moderate
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	7.03	Very Low	2.50	10.00	696.25	Small	7.50	30.00	2.495	High	10.00	10.00	17.03	Large	10.00	20.00	107.50	7.17	Moderate

Galdit Analysis for April 2007 for 0.25m rise in seal level

Sr.No.	Observation Well ID	Groundwater occurance G=1			Aquifer Hydraulic conductivity(m/day) A=3				Height of Groundwater above the sea level(m) L = 4				Distance from the shore/river(m) D = 4				Impact or existing status/ Quality of Water I =1				Aquifer Thickness(m) T =2				GALDIT-INDEX		
		Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	-0.76	High	10.00	40.00	160.32	Very Small	10.00	40.00	2.938	High	10.00	10.00	11.92	Large	10.00	20.00	147.50	9.83	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	-0.37	High	10.00	40.00	414.45	Very Small	10.00	40.00	1.316	Low	5.00	5.00	17.42	Large	10.00	20.00	142.50	9.50	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	3.06	Very Low	2.50	10.00	512.23	Small	7.50	30.00	0.751	Very Low	2.50	2.50	20.07	Large	10.00	20.00	100.00	6.67	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	3.02	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	0.876	Very Low	2.50	2.50	24.57	Large	10.00	20.00	110.00	7.33	Moderate
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	4.59	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.419	Very Low	2.50	2.50	16.04	Large	10.00	20.00	110.00	7.33	Moderate
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-1.23	High	10.00	40.00	1080.89	Far	2.50	10.00	6.635	High	10.00	10.00	20.00	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	50	High	10.00	30.00	0.36	High	10.00	40.00	303.94	Very Small	10.00	40.00	0.665	Very Low	2.50	2.50	20.27	Large	10.00	20.00	140.00	9.33	High
9	Well No. 9	Unconf.	7.50	7.50	353.88	High	10.00	30.00	0.21	High	10.00	40.00	708.90	Small	7.50	30.00	1.870	Medium	7.50	7.50	15.06	Large	10.00	20.00	135.00	9.00	High
10	Well No. 10	Unconf.	7.50	7.50	623.45	High	10.00	30.00	0.62	High	10.00	40.00	315.87	Very Small	10.00	40.00	0.427	Very Low	2.50	2.50	15.76	Large	10.00	20.00	140.00	9.33	High
11	Well No. 11	Unconf.	7.50	7.50	363.29	High	10.00	30.00	-2.10	High	10.00	40.00	1387.31	Far	2.50	10.00	8.930	High	10.00	10.00	19.09	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	335.76	High	10.00	30.00	-1.26	High	10.00	40.00	1536.76	Far	2.50	10.00	3.217	High	10.00	10.00	19.45	Large	10.00	20.00	117.50	7.83	High
13	Well No. 13	Unconf.	7.50	7.50	96.98	High	10.00	30.00	1.47	Medium	7.50	30.00	723.70	Small	7.50	30.00	1.163	Low	5.00	5.00	14.90	Large	10.00	20.00	122.50	8.17	High
14	Well No. 14	Unconf.	7.50	7.50	43.42	High	10.00	30.00	-0.15	High	10.00	40.00	1689.55	Far	2.50	10.00	2.436	High	10.00	10.00	21.20	Large	10.00	20.00	117.50	7.83	High
16	Well No. 16	Unconf.	7.50	7.50	50	High	10.00	30.00	2.59	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.674	Very Low	2.50	2.50	19.25	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	141.39	High	10.00	30.00	1.62	Low	5.00	20.00	739.40	Small	7.50	30.00	1.293	Low	5.00	5.00	18.20	Large	10.00	20.00	112.50	7.50	High
18	Well No. 18	Unconf.	7.50	7.50	50	High	10.00	30.00	1.09	Medium	7.50	30.00	537.10	Small	7.50	30.00	0.470	Very Low	2.50	2.50	20.38	Large	10.00	20.00	120.00	8.00	High
19	Well No. 19	Unconf.	7.50	7.50	104.63	High	10.00	30.00	1.19	Medium	7.50	30.00	459.25	Very Small	10.00	40.00	0.321	Very Low	2.50	2.50	20.63	Large	10.00	20.00	130.00	8.67	High
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	1.38	Medium	7.50	30.00	739.6	Small	7.50	30.00	0.872	Very Low	2.50	2.50	22.20	Large	10.00	20.00	120.00	8.00	High
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	0.82	High	10.00	40.00	658.8	Small	7.50	30.00	0.857	Very Low	2.50	2.50	23.54	Large	10.00	20.00	130.00	8.67	High
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.06	Medium	7.50	30.00	718.38	Small	7.50	30.00	0.276	Very Low	2.50	2.50	22.80	Large	10.00	20.00	120.00	8.00	High
23	Well No. 23	Unconf.	7.50	7.50	50	High	10.00	30.00	0.50	High	10.00	40.00	693.47	Small	7.50	30.00	0.763	Very Low	2.50	2.50	21.04	Large	10.00	20.00	130.00	8.67	High
24	Well No. 24	Unconf.	7.50	7.50	44.98	High	10.00	30.00	-0.12	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.201	Very Low	2.50	2.50	21.32	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	50	High	10.00	30.00	0.00	High	10.00	40.00	284.29	Very Small	10.00	40.00	2.593	High	10.00	10.00	19.75	Large	10.00	20.00	147.50	9.83	High
26	Well No. 26	Unconf.	7.50	7.50	67.25	High	10.00	30.00	-0.31	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.679	Very Low	2.50	2.50	21.21	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	0.98	High	10.00	40.00	879.06	Medium	5.00	20.00	2.095	High	10.00	10.00	18.15	Large	10.00	20.00	127.50	8.50	High
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	0.68	High	10.00	40.00	1411.42	Far	2.50	10.00	2.074	High	10.00	10.00	18.74	Large	10.00	20.00	117.50	7.83	High
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	0.63	High	10.00	40.00	1813.19	Far	2.50	10.00	4.772	High	10.00	10.00	17.79	Large	10.00	20.00	117.50	7.83	High
30	Well No. 30	Unconf.	7.50	7.50	50	High	10.00	30.00	-1.45	High	10.00	40.00	1801.71	Far	2.50	10.00	0.499	Very Low	2.50	2.50	20.55	Large	10.00	20.00	110.00	7.33	Moderate
31	Well No. 31	Unconf.	7.50	7.50	136.8	High	10.00	30.00	-2.95	High	10.00	40.00	640.92	Small	7.50	30.00	3.102	High	10.00	10.00	17.68	Large	10.00	20.00	137.50	9.17	High
32	Well No. 32	Unconf.	7.50	7.50	140.09	High	10.00	30.00	-3.56	High	10.00	40.00	825.6	Medium	5.00	20.00	2.238	High	10.00	10.00	25.97	Large	10.00	20.00	127.50	8.50	High
33	Well No. 33	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-2.73	High	10.00	40.00	661.98	Small	7.50	30.00	1.309	Low	5.00	5.00	16.84	Large	10.00	20.00	132.50	8.83	High
34	Well No. 34	Unconf.	7.50	7.50	50	High	10.00	30.00	-3.10	High	10.00	40.00	1125.97	Far	2.50	10.00	1.095	Low	5.00	5.00	19.24	Large	10.00	20.00	112.50	7.50	High
35	Well No. 35	Unconf.	7.50	7.50	258	High	10.00	30.00	-3.57	High	10.00	40.00	1643.57	Far	2.50	10.00	0.366	Very Low	2.50	2.50	17.23	Large	10.00	20.00	110.00	7.33	Moderate
36	Well No. 36	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-0.88	High	10.00	40.00	1688.2	Far	2.50	10.00	1.012	Low	5.00	5.00	21.47	Large	10.00	20.00	112.50	7.50	High
37	Well No. 37	Unconf.	7.50	7.50	50	High	10.00	30.00	0.76	High	10.00	40.00	1089.47	Far	2.50	10.00	2.019	High	10.00	10.00	18.67	Large	10.00	20.00	117.50	7.83	High
38	Well No. 38	Unconf.	7.50	7.50	99.06	High	10.00	30.00	1.49	Medium	7.50	30.00	833.16	Medium	5.00	20.00	0.672	Very Low	2.50	2.50	23.01	Large	10.00	20.00	110.00	7.33	Moderate
39	Well No. 39	Unconf.	7.50	7.50	50	High	10.00	30.00	2.19	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	1.620	Medium	7.50	7.50	19.26	Large	10.00	20.00	115.00	7.67	High
40	Well No. 40	Unconf.	7.50	7.50	179.65	High	10.00	30.00	-2.61	High	10.00	40.00	607.81	Small	7.50	30.00	0.492	Very Low	2.50	2.50	13.00	Large	10.00	20.00	130.00	8.67	High
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	5.86	Very Low	2.50	10.00	696.25	Small	7.50	30.00	2.256	High	10.00	10.00	16.11	Large	10.00	20.00	107.50	7.17	Moderate

Galdit Analysis for Mayl 2007 for 0.25m rise in seal level

Sr.No.	Observation Well ID	Groundwater occurance G=1			Aquifer Hydraulic conductivity(m/day) A=3				Height of Groundwater above the sea level(m) L = 4				Distance from the shore/river(m) D = 4				Impact or existing status/ Quality of I =1				Depth of Well (Aquifer Thickness) T =2				GALDIT-INDEX		
		Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Value	Category	Rating	Weighted Rating	Total	Index	Vulnerability Class
1	Well No. 1	Unconf.	7.50	7.50	478.06	High	10.00	30.00	-0.40	High	10.00	40.00	160.32	Very Small	10.00	40.00	3.408	High	10.00	10.00	12.28	Large	10.00	20.00	147.50	9.83	High
2	Well No. 2	Unconf.	7.50	7.50	914.21	High	10.00	30.00	-0.25	High	10.00	40.00	414.45	Very Small	10.00	40.00	1.175	Low	5.00	5.00	17.54	Large	10.00	20.00	142.50	9.50	High
3	Well No. 3	Unconf.	7.50	7.50	236.2	High	10.00	30.00	3.63	Very Low	2.50	10.00	512.23	Small	7.50	30.00	0.979	Very Low	2.50	2.50	20.64	Large	10.00	20.00	100.00	6.67	Moderate
4	Well No. 4	Unconf.	7.50	7.50	282.3	High	10.00	30.00	2.88	Very Low	2.50	10.00	306.75	Very Small	10.00	40.00	1.152	Low	5.00	5.00	24.43	Large	10.00	20.00	112.50	7.50	High
5	Well No. 5	Unconf.	7.50	7.50	50	High	10.00	30.00	4.66	Very Low	2.50	10.00	237.09	Very Small	10.00	40.00	0.415	Very Low	2.50	2.50	16.11	Large	10.00	20.00	110.00	7.33	Moderate
6	Well No. 6	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.38	High	10.00	40.00	1080.89	Far	2.50	10.00	4.700	High	10.00	10.00	20.85	Large	10.00	20.00	117.50	7.83	High
8	Well No. 8	Unconf.	7.50	7.50	353.88	High	10.00	30.00	0.42	High	10.00	40.00	303.94	Very Small	10.00	40.00	1.168	Low	5.00	5.00	20.33	Large	10.00	20.00	142.50	9.50	High
9	Well No. 9	Unconf.	7.50	7.50	623.45	High	10.00	30.00	0.69	High	10.00	40.00	708.90	Small	7.50	30.00	2.115	High	10.00	10.00	15.54	Large	10.00	20.00	137.50	9.17	High
10	Well No. 10	Unconf.	7.50	7.50	363.29	High	10.00	30.00	0.47	High	10.00	40.00	315.87	Very Small	10.00	40.00	0.463	Very Low	2.50	2.50	15.61	Large	10.00	20.00	140.00	9.33	High
11	Well No. 11	Unconf.	7.50	7.50	335.76	High	10.00	30.00	-0.22	High	10.00	40.00	1387.31	Far	2.50	10.00	11.562	High	10.00	10.00	20.97	Large	10.00	20.00	117.50	7.83	High
12	Well No. 12	Unconf.	7.50	7.50	96.98	High	10.00	30.00	0.29	High	10.00	40.00	1536.76	Far	2.50	10.00	2.977	High	10.00	10.00	21.00	Large	10.00	20.00	117.50	7.83	High
13	Well No. 13	Unconf.	7.50	7.50	43.42	High	10.00	30.00	2.84	Very Low	2.50	10.00	723.70	Small	7.50	30.00	1.898	Medium	7.50	7.50	16.27	Large	10.00	20.00	105.00	7.00	Moderate
14	Well No. 14	Unconf.	7.50	7.50	50	High	10.00	30.00	-1.18	High	10.00	40.00	1689.55	Far	2.50	10.00	2.712	High	10.00	10.00	20.17	Large	10.00	20.00	117.50	7.83	High
16	Well No. 16	Unconf.	7.50	7.50	141.39	High	10.00	30.00	2.84	Very Low	2.50	10.00	366.20	Very Small	10.00	40.00	0.954	Very Low	2.50	2.50	19.50	Large	10.00	20.00	110.00	7.33	Moderate
17	Well No. 17	Unconf.	7.50	7.50	50	High	10.00	30.00	2.75	Very Low	2.50	10.00	739.40	Small	7.50	30.00	0.951	Very Low	2.50	2.50	19.33	Large	10.00	20.00	100.00	6.67	Moderate
18	Well No. 18	Unconf.	7.50	7.50	104.63	High	10.00	30.00	2.38	Very Low	2.50	10.00	537.10	Small	7.50	30.00	0.584	Very Low	2.50	2.50	21.67	Large	10.00	20.00	100.00	6.67	Moderate
19	Well No. 19	Unconf.	7.50	7.50	50	High	10.00	30.00	1.54	Low	5.00	20.00	459.25	Very Small	10.00	40.00	0.489	Very Low	2.50	2.50	20.98	Large	10.00	20.00	120.00	8.00	High
20	Well No. 20	Unconf.	7.50	7.50	50	High	10.00	30.00	2.05	Very Low	2.50	10.00	739.6	Small	7.50	30.00	0.823	Very Low	2.50	2.50	22.87	Large	10.00	20.00	100.00	6.67	Moderate
21	Well No. 21	Unconf.	7.50	7.50	50	High	10.00	30.00	1.33	Medium	7.50	30.00	658.8	Small	7.50	30.00	0.917	Very Low	2.50	2.50	24.05	Large	10.00	20.00	120.00	8.00	High
22	Well No. 22	Unconf.	7.50	7.50	50	High	10.00	30.00	1.45	Medium	7.50	30.00	718.38	Small	7.50	30.00	0.353	Very Low	2.50	2.50	23.19	Large	10.00	20.00	120.00	8.00	High
23	Well No. 23	Unconf.	7.50	7.50	44.98	High	10.00	30.00	0.89	High	10.00	40.00	693.47	Small	7.50	30.00	0.468	Very Low	2.50	2.50	21.43	Large	10.00	20.00	130.00	8.67	High
24	Well No. 24	Unconf.	7.50	7.50	50	High	10.00	30.00	0.18	High	10.00	40.00	285.17	Very Small	10.00	40.00	0.222	Very Low	2.50	2.50	21.62	Large	10.00	20.00	140.00	9.33	High
25	Well No. 25	Unconf.	7.50	7.50	67.25	High	10.00	30.00	0.43	High	10.00	40.00	284.29	Very Small	10.00	40.00	4.291	High	10.00	10.00	20.18	Large	10.00	20.00	147.50	9.83	High
26	Well No. 26	Unconf.	7.50	7.50	50	High	10.00	30.00	-0.01	High	10.00	40.00	312.5	Very Small	10.00	40.00	0.859	Very Low	2.50	2.50	21.51	Large	10.00	20.00	140.00	9.33	High
27	Well No. 27	Unconf.	7.50	7.50	50	High	10.00	30.00	1.42	Medium	7.50	30.00	879.06	Medium	5.00	20.00	3.102	High	10.00	10.00	18.59	Large	10.00	20.00	117.50	7.83	High
28	Well No. 28	Unconf.	7.50	7.50	50	High	10.00	30.00	1.20	Medium	7.50	30.00	1411.42	Far	2.50	10.00	3.878	High	10.00	10.00	19.26	Large	10.00	20.00	107.50	7.17	Moderate
29	Well No. 29	Unconf.	7.50	7.50	50	High	10.00	30.00	1.29	Medium	7.50	30.00	1813.19	Far	2.50	10.00	8.284	High	10.00	10.00	18.45	Large	10.00	20.00	107.50	7.17	Moderate
30	Well No. 30	Unconf.	7.50	7.50	136.8	High	10.00	30.00	-0.65	High	10.00	40.00	1801.71	Far	2.50	10.00	1.472	Low	5.00	5.00	21.35	Large	10.00	20.00	112.50	7.50	High
31	Well No. 31	Unconf.	7.50	7.50	140.09	High	10.00	30.00	-2.53	High	10.00	40.00	640.92	Small	7.50	30.00	3.704	High	10.00	10.00	18.10	Large	10.00	20.00	137.50	9.17	High
32	Well No. 32	Unconf.	7.50	7.50	324.49	High	10.00	30.00	-2.95	High	10.00	40.00	825.6	Medium	5.00	20.00	4.005	High	10.00	10.00	26.58	Large	10.00	20.00	127.50	8.50	High
33	Well No. 33	Unconf.	7.50	7.50	50	High	10.00	30.00	-2.57	High	10.00	40.00	661.98	Small	7.50	30.00	2.247	High	10.00	10.00	17.00	Large	10.00	20.00	137.50	9.17	High
34	Well No. 34	Unconf.	7.50	7.50	258	High	10.00	30.00	-3.41	High	10.00	40.00	1125.97	Far	2.50	10.00	1.039	Low	5.00	5.00	18.93	Large	10.00	20.00	112.50	7.50	High
35	Well No. 35	Unconf.	7.50	7.50	238.86	High	10.00	30.00	-2.90	High	10.00	40.00	1643.57	Far	2.50	10.00	1.808	Medium	7.50	7.50	17.90	Large	10.00	20.00	115.00	7.67	High
36	Well No. 36	Unconf.	7.50	7.50	50	High	10.00	30.00	0.14	High	10.00	40.00	1688.2	Far	2.50	10.00	1.226	Low	5.00	5.00	22.48	Large	10.00	20.00	112.50	7.50	High
37	Well No. 37	Unconf.	7.50	7.50	99.06	High	10.00	30.00	1.39	Medium	7.50	30.00	1089.47	Far	2.50	10.00	1.316	Low	5.00	5.00	19.30	Large	10.00	20.00	102.50	6.83	Moderate
38	Well No. 38	Unconf.	7.50	7.50	50	High	10.00	30.00	2.20	Very Low	2.50	10.00	833.16	Medium	5.00	20.00	0.786	Very Low	2.50	2.50	23.72	Large	10.00	20.00	90.00	6.00	Moderate
39	Well No. 39	Unconf.	7.50	7.50	179.65	High	10.00	30.00	2.61	Very Low	2.50	10.00	475.38	Very Small	10.00	40.00	2.115	High	10.00	10.00	19.68	Large	10.00	20.00	117.50	7.83	High
40	Well No. 40	Unconf.	7.50	7.50	50	High	10.00	30.00	1.35	Medium	7.50	30.00	607.81	Small	7.50	30.00	0.578	Very Low	2.50	2.50	16.96	Large	10.00	20.00	120.00	8.00	High
41	Well No. 41	Unconf.	7.50	7.50	50	High	10.00	30.00	6.78	Very Low	2.50	10.00	696.25	Small	7.50	30.00	2.495	High	10.00	10.00	17.03	Large	10.00	20.00	107.50	7.17	Moderate

APPENDIX III

SUTRA MAIN INPUT FILE

```
DATASET 1: Output Heading
[TITLE 1]
[TITLE 2]
3D simulation of groundwater flow
SUTRA simulation is adapted
```

For the definition and model values of the parameters refer to Voss and Provost (2003)

```
DATASET 2: Simulation Type and Mesh Structure
[SIMULA]
'SUTRA SOLUTE TRANSPORT'
[MSHSTR]          [NN1]    [NN2]    [NN3]
[NBLK1] [LDIV1]
[NBLK2] [LDIV2]
[NBLK3] [LDIV3]
'3D BLOCK WISE MESH'    5        6        46
    4   1   1    1   1
    1   5
    6   9   9    9   9     7      2

DATASET 3: Simulation Control Numbers
[NN]     [NE]   [NPBC]    [NUBC]  [NSOP]   [NSOU]  [NOBS]
   1380     900     306     0    519    0   19

DATASET 4: Simulation Mode Options
[CUNSAT]         [CSSFLO]  [CSSTRA]          [CREAD] [ISTORE]
   'SATURATED'' 'TRANSIENT FLOW' 'TRANSIENT TRANSPORT''' 'COLD'1

DATASET 5: Numerical Control Parameters
[UP]     [GNUP]     [GNUU]
    .0         0.1     1.

DATASET 6: Temporal Control and Solution Cycling Data
[ITMAX]     [DELT]          [TMAX]  [ITCYC]  [DTMULT]          [DTMAX]  [NPCYC]   [NUCYC]
   3 2629800. 10519200. 1    1.2629800. 1 1

DATASET 7: Iteration and Matrix Solver Controls
[ITRMAX]         [RPMAX]   [RUMAX]
   1
[CSOLVP]         [ITRMXP]  [TOLP]
    'CG' 300 1.e+01
[CSOLVU]   [ITRMXU]       [TOLU]
    'GMRES' 300  1.e+01

DATASET 8: Output Controls and Options
[NPRINT]  [CNODAL]  [CELMNT]  [CINCID]     [CVEL]   [CBUDG]   [CSCRN]  [CPAUSE]
   1'Y' 'Y' 'Y' 'Y' 'Y' 'Y' 'Y'
[NCOLPR]      [NCOL]
   1 'N' 'X' 'Y' 'Z' 'P' 'U' 'S' '-'
[LCOLPR]      [LCOL]
   1  'N' 'X' 'Y' 'Z' 'VX' 'VY' 'VZ' '-'
[NOBCYC]          [INOB]
     1
   304
   392
   454
```

512
544
632
634
635
664
753
873
903
934
993
1054
1202
1264
1323
1355
0

DATASET 9: Fluid Properties
[COMPFL] [CW] [SIGMAW] [RHOWO] [URHOWO] [DRWDU] [VISCO]
0. 0. 1.8871e-05 1000. 0. 700. 0.001

DATASET 10: Solid Matrix Properties
[COMPMA] [CS] [SIGMAS] [RHOS]
0. 0. 0. 2600.

DATASET 11: Adsorption Parameters
[ADSMOD] [CH11] [CH12]
'NONE'

DATASET 12: Production of Energy or Solute Mass
[PRODF0] [PROS0] [PRODF1] [PRODS1]
0. 0. 0. 0

DATASET 13: Orientation of Coordiantes to Gravity
[GRAVX] [GRAVY] [GRAVZ]
0. 0. -9.81

DATASET 14: Sample Porosity values for 27 nodes

	[SCALX]	[SCALY]	[SCALZ]	[PORFAC]
'NODE'	2.5000000D+0.2	2.5000000+D	1.0000000D+00	1.0000000D+00

[II]	[NREG (II)]	[X (II)]	[Y (II)]	[Z (II)]	[POR (II]
1	0	0.0000000D+00	0.0000000D+00	0.0000000D+00	3.0000000D-01
2	0	8.0000000D-01	0.0000000D+00	0.0000000D+00	3.0000000D-01
3	0	1.3000000D+00	0.0000000D+00	0.0000000D+00	3.0000000D-01
4	0	2.2500000D+00	0.0000000D+00	0.0000000D+00	3.0000000D-01
5	0	3.0500000D+00	0.0000000D+00	0.0000000D+00	3.0000000D-01
6	0	0.0000000D+00	0.0000000D+00	-5.0000000D+00	3.0000000D-01
7	0	8.0000000D-01	0.0000000D+00	-5.0000000D+00	3.0000000D-01
8	0	1.3000000D+00	0.0000000D+00	-5.0000000D+00	3.0000000D-01
9	0	2.2500000D+00	0.0000000D+00	-5.0000000D+00	3.0000000D-01
10	0	3.0500000D+00	0.0000000D+00	-5.0000000D+00	3.0000000D-01
11	0	0.0000000D+00	0.0000000D+00	-1.0000000D+01	3.0000000D-01
12	0	8.0000000D-01	0.0000000D+00	-1.0000000D+01	3.0000000D-01
13	0	1.3000000D+00	0.0000000D+00	-1.0000000D+01	3.0000000D-01
14	0	2.2500000D+00	0.0000000D+00	-1.0000000D+01	3.0000000D-01
15	0	3.0500000D+00	0.0000000D+00	-1.0000000D+01	3.0000000D-01
16	0	0.0000000D+00	0.0000000D+00	-1.5000000D+01	3.0000000D-01
17	0	8.0000000D-01	0.0000000D+00	-1.5000000D+01	3.0000000D-01
18	0	1.3000000D+00	0.0000000D+00	-1.5000000D+01	3.0000000D-01
19	0	2.2500000D+00	0.0000000D+00	-1.5000000D+01	3.0000000D-01
20	0	3.0500000D+00	0.0000000D+00	-1.5000000D+01	3.0000000D-01
21	0	0.0000000D+00	0.0000000D+00	-2.0000000D+01	3.0000000D-01

22	0	8.0000000D-01	0.0000000D+00	-2.0000000D+01	3.0000000D-01
23	0	1.3000000D+00	0.0000000D+00	-2.0000000D+01	3.0000000D-01
24	0	2.2500000D+00	0.0000000D+00	-2.0000000D+01	3.0000000D-01
25	0	3.0500000D+00	0.0000000D+00	-2.0000000D+01	3.0000000D-01
26	0	0.0000000D+00	0.0000000D+00	-2.5000000D+01	3.0000000D-01
27	0	8.0000000D-01	0.0000000D+00	-2.5000000D+01	3.0000000D-01

DATASET 15: Sample Dispersivity values for 27 nodes
[PMAXFA] [PMIDFA] [PMINFA] [ANGIFA] [ANG2FA] [ANG3FA] [ALMAXF] [ALMIDF]
[ALMINF] [ATMAXF] [ATMIDF] [ATMINF]
'ELEMENT' 1.0000000D+00 1.0000000D+00 1.0000000D+00 1.0000000D+00 1.0000000D+00 1.0000000D+00
1.0000000D+00 1.0000000D+00 1.0000000D+00 1.0000000D+00 1.0000000D+00 1.0000000D+00
[L] [NREG(L)] [PMAX(L)] [PMID(L)] [PMIN(L)] [ANGLE1(L)] [ANGLE2(L)] [ANGLE3(L)] [ALMAX(L)]
[ALMID(l)] [ALMIN(L)] [ATMXA(L)] [ATMID(L)] [ATMIN(L)]
1 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
2 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
3 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
4 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
5 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
6 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
7 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
8 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
9 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
10 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
11 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
12 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
13 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
14 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
15 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
16 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
17 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
18 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
19 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
20 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
21 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
22 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0 000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
23 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
24 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01

25 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
26 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01
27 0 4.7241000D-11 4.7241000D-11 4.7241000D-11 0.0000000D+00 0.0000000D+00 0.0000000D+00
3.0000000D+01 3.0000000D+01 3.0000000D+01 3.0000000D-01 3.0000000D-01 3.0000000D-01

DATASET 16: (NOT USED)

DATASET 17: Sample data for fluid source and sinks

[IQCP]	[QINC]	[UINC]
304	-0.609	0
392	-0.609	0
454	-0.609	0
512	-0.609	0
544	-0.609	0
632	-0.609	0
634	-0.609	0
635	-0.609	0
664	-0.609	0
753	-0.609	0
873	-0.609	0
903	-0.609	0
934	-0.609	0
992	-0.609	0
1054	-0.609	0
1202	-0.609	0
1264	-0.609	0
1323	-0.609	0
1355	-0.609	0
351	0.028055556	0
40	0.028055556	0
45	0.028055556	0
50	0.028055556	0
55	0.028055556	0
60	0.028055556	0
65	0.028055556	0
70	0.028055556	0
75	0.028055556	0
80	0.028055556	0
85	0.028055556	0
90	0.028055556	0
95	0.028055556	0
100	0.028055556	0
105	0.028055556	0
110	0.028055556	0
115	0.028055556	0
120	0.028055556	0
125	0.028055556	0
130	0.028055556	0
135	0.028055556	0
140	0.028055556	0
145	0.028055556	0
150	0.028055556	0
155	0.028055556	0
160	0.028055556	0
165	0.028055556	0
170	0.028055556	0
175	0.028055556	0
180	0.028055556	0
185	0.028055556	0

190	0.028055556	0
195	0.028055556	0
200	0.028055556	0
205	0.028055556	0
210	0.028055556	0
215	0.028055556	0
220	0.028055556	0
845	0.117013889	0
850	0.117013889	0
855	0.117013889	0
860	0.117013889	0
865	0.117013889	0
870	0.117013889	0
875	0.117013889	0
880	0.117013889	0
885	0.117013889	0
890	0.117013889	0
895	0.117013889	0
900	0.117013889	0
905	0.117013889	0
910	0.117013889	0
915	0.117013889	0
920	0.117013889	0
925	0.117013889	0
930	0.117013889	0
935	0.117013889	0
940	0.117013889	0
945	0.117013889	0
950	0.117013889	0
955	0.117013889	0
960	0.117013889	0
965	0.117013889	0
970	0.117013889	0
975	0.117013889	0
980	0.117013889	0
985	0.117013889	0
990	0.117013889	0
995	0.117013889	0
1000	0.117013889	0
1005	0.117013889	0
1010	0.117013889	0
1015	0.117013889	0
1020	0.117013889	0
1025	0.117013889	0
1030	0.117013889	0
1035	0.117013889	0
1040	0.117013889	0
1045	0.117013889	0
1050	0.117013889	0
1055	0.117013889	0
1060	0.117013889	0
1065	0.117013889	0
1070	0.117013889	0
1075	0.117013889	0
1080	0.117013889	0
1085	0.117013889	0
1090	0.117013889	0
1095	0.117013889	0
1100	0.117013889	0
1105	0.117013889	0
1110	0.117013889	0
1115	0.096446759	0

1120	0.096446759	0
1125	0.096446759	0
1130	0.096446759	0
1135	0.096446759	0
1140	0.096446759	0
1145	0.096446759	0
1150	0.096446759	0
1325	0.625	0
1330	0.625	0
1335	0.625	0
1340	0.625	0
1345	0.625	0
1350	0.625	0
1355	0.625	0
1360	0.625	0
1365	0.625	0
1370	0.625	0
1375	0.625	0
1380	0.625	0
1	0.863	0
2	0.863	0
3	0.863	0
4	0.863	0
5	0.863	0
31	0.863	0
32	0.863	0
33	0.863	0
34	0.863	0
35	0.863	0
61	0.863	0
62	0.863	0
63	0.863	0
64	0.863	0
65	0.863	0
91	0.863	0
91	0.863	0
93	0.863	0
94	0.863	0
95	0.863	0
121	0.863	0
122	0.863	0
123	0.863	0
124	0.863	0
125	0.863	0
151	0.863	0
152	0.863	0
153	0.863	0
154	0.863	0
155	0.863	0
181	0.863	0
182	0.863	0
183	0.863	0
184	0.863	0
185	0.863	0
211	0.863	0
212	0.863	0
213	0.863	0
214	0.863	0
215	0.863	0
241	0.863	0
242	0.863	0
243	0.863	0

244	0.863	0
245	0.863	0
271	0.863	0
272	0.863	0
273	0.863	0
274	0.863	0
275	0.863	0

DATASET 18: Data for energy or solute mass sources and sinks
[IQCU] [QUINC]
*** *** ‹‹‹ Remove "#" & supply values only if NSOU>0
0000000000000000000000000000 ‹‹‹ Remove "#" only if NSOU>0

DATASET 19: Sample specified pressure for 55 nodes

[IPBC]	[PBC]	[UBC]
1	0.0000000000000D+00	3.5700000000000D-02
6	0.0000000000000D+00	3.5700000000000D-02
11	0.0000000000000D+00	3.5700000000000D-02
16	0.0000000000000D+00	3.5700000000000D-02
21	0.0000000000000D+00	3.5700000000000D-02
26	0.0000000000000D+00	3.5700000000000D-02
31	0.0000000000000D+00	3.5700000000000D-02
36	0.0000000000000D+00	3.5700000000000D-02
41	0.0000000000000D+00	3.5700000000000D-02
46	0.0000000000000D+00	3.5700000000000D-02
51	0.0000000000000D+00	3.5700000000000D-02
56	0.0000000000000D+00	3.5700000000000D-02
61	0.0000000000000D+00	3.5700000000000D-02
66	0.0000000000000D+00	3.5700000000000D-02
71	0.0000000000000D+00	3.5700000000000D-02
76	0.0000000000000D+00	3.5700000000000D-02
81	0.0000000000000D+00	3.5700000000000D-02
86	0.0000000000000D+00	3.5700000000000D-02
91	0.0000000000000D+00	3.5700000000000D-02
96	0.0000000000000D+00	3.5700000000000D-02
101	0.0000000000000D+00	3.5700000000000D-02
106	0.0000000000000D+00	3.5700000000000D-02
111	0.0000000000000D+00	3.5700000000000D-02
116	0.0000000000000D+00	3.5700000000000D-02
121	0.0000000000000D+00	3.5700000000000D-02
126	0.0000000000000D+00	3.5700000000000D-02
131	0.0000000000000D+00	3.5700000000000D-02
136	0.0000000000000D+00	3.5700000000000D-02
141	0.0000000000000D+00	3.5700000000000D-02
146	0.0000000000000D+00	3.5700000000000D-02
151	0.0000000000000D+00	3.5700000000000D-02
156	0.0000000000000D+00	3.5700000000000D-02
161	0.0000000000000D+00	3.5700000000000D-02
166	0.0000000000000D+00	3.5700000000000D-02
171	0.0000000000000D+00	3.5700000000000D-02
176	0.0000000000000D+00	3.5700000000000D-02
181	0.0000000000000D+00	3.5700000000000D-02
186	0.0000000000000D+00	3.5700000000000D-02
191	0.0000000000000D+00	3.5700000000000D-02
196	0.0000000000000D+00	3.5700000000000D-02
201	0.0000000000000D+00	3.5700000000000D-02
206	0.0000000000000D+00	3.5700000000000D-02
211	0.0000000000000D+00	3.5700000000000D-02
216	0.0000000000000D+00	3.5700000000000D-02
221	0.0000000000000D+00	3.5700000000000D-02
226	0.0000000000000D+00	3.5700000000000D-02
231	0.0000000000000D+00	3.5700000000000D-02

236	0.0000000000000D+00	3.5700000000000D-02
241	0.0000000000000D+00	3.5700000000000D-02
246	0.0000000000000D+00	3.5700000000000D-02
251	0.0000000000000D+00	3.5700000000000D-02
256	0.0000000000000D+00	3.5700000000000D-02
261	0.0000000000000D+00	3.5700000000000D-02
266	0.0000000000000D+00	3.5700000000000D-02
271	0.0000000000000D+00	3.5700000000000D-02

DATASET 20: Data for specified concentration or temperature nodes
[IUBC] [UBC] *** *** ‹‹‹ Remove "#" & supply values only if NUBC›0
000000000000000000000000000000 ‹‹‹ Remove "#" & only if NUBC›0

DATASET 21: (NOT USED)

DATASET 22: Sample element incidence for 42 nodes
[LL] [IIN(1)] [IIN(2)] [IIN(3)] [IIN(4)] [IIN(5)] [IIN(6)] [IIN(7)] [IIN(8)]
'INCIDENCE'

1	6	7	37	36	1	2	32	31
2	7	8	38	37	2	3	33	32
3	8	9	39	38	3	4	34	33
4	9	10	40	39	4	5	35	34
5	11	12	42	41	6	7	37	36
6	12	13	43	42	7	8	38	37
7	13	14	44	43	8	9	39	38
8	14	15	45	44	9	10	40	39
9	16	17	47	46	11	12	42	41
10	17	18	48	49	12	13	43	42
11	18	19	49	48	13	14	44	43
12	19	20	50	49	14	15	45	44
13	21	22	52	51	16	17	47	46
14	22	23	53	52	17	18	48	47
15	23	24	54	53	18	19	49	48
16	24	25	55	54	19	20	50	49
17	26	27	57	56	21	22	52	51
18	27	28	58	57	22	23	53	52
19	28	29	59	58	23	24	54	53
20	29	30	60	59	24	25	55	54
21	36	37	67	66	31	32	62	61
22	37	38	68	67	32	33	63	62
23	38	39	69	68	33	34	64	63
24	39	40	70	69	34	35	65	64
25	41	42	72	71	36	37	67	66
26	42	43	73	72	37	38	68	67
27	43	44	74	73	38	39	69	68
28	44	45	75	74	39	40	70	69
29	46	47	77	76	41	42	72	71
30	47	48	78	77	42	43	73	72
31	48	49	79	78	43	44	74	73
32	49	50	80	79	44	45	75	74
33	51	52	82	81	46	47	77	76
34	52	53	83	82	47	48	78	77
35	53	54	84	83	48	49	79	78
36	54	55	85	84	49	50	80	79
37	56	57	87	86	51	52	82	81
38	57	58	88	87	52	53	83	82
39	58	59	89	88	53	54	84	83
40	59	60	90	89	54	55	85	84
41	66	67	97	96	61	62	92	91
42	67	68	98	97	62	63	93	92

SUTRA MAIN OUTPUT FILE

3D simulation of groundwater flow
SUTRA simulation is adapted

3-D, REGULAR MESH (5)*(6)*(46)=1380 Nodes

SAMPLE NODEWISE RESULTS 4 Time steps printed

Time steps in this file	Time (sec)	[Printed? / Latest time step computed] Press		Conc		Sat	
0	0.000000E+00	Y	0	Y	0	Y	0
1	2.629800E+06	Y	1	Y	1	Y	1
2	5.259600E+06	Y	2	Y	2	Y	2
3	7.889400E+06	Y	3	Y	3	Y	3

TIME STEP 0 Duration: 0.0000E+00 sec Time 0.0000E+00 sec

NODE	X	Y	Z	Pressure	Concentration	Saturation
1	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
2	2.0000000E+02	0.0000000E+00	0.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
3	3.2500000E+02	0.0000000E+00	0.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
4	5.6250000E+02	0.0000000E+00	0.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
5	7.6250000E+02	0.0000000E+00	0.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
6	0.0000000E+00	0.0000000E+00	-5.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
7	2.0000000E+02	0.0000000E+00	-5.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
8	3.2500000E+02	0.0000000E+00	-5.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
9	5.6250000E+02	0.0000000E+00	-5.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
10	7.6250000E+02	0.0000000E+00	-5.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
11	0.0000000E+00	0.0000000E+00	-1.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
12	2.0000000E+02	0.0000000E+00	-1.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
13	3.2500000E+02	0.0000000E+00	-1.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
14	5.6250000E+02	0.0000000E+00	-1.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
15	7.6250000E+02	0.0000000E+00	-1.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
16	0.0000000E+00	0.0000000E+00	-1.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
17	2.0000000E+02	0.0000000E+00	-1.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
18	3.2500000E+02	0.0000000E+00	-1.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
19	5.6250000E+02	0.0000000E+00	-1.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
20	7.6250000E+02	0.0000000E+00	-1.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
21	0.0000000E+00	0.0000000E+00	-2.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
22	2.0000000E+02	0.0000000E+00	-2.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
23	3.6250000E+02	0.0000000E+00	-2.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
24	5.6250000E+02	0.0000000E+00	-2.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
25	7.6250000E+02	0.0000000E+00	-2.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
26	0.0000000E+00	0.0000000E+00	-2.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
27	2.0000000E+02	0.0000000E+00	-2.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
28	3.2500000E+02	0.0000000E+00	-2.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
29	5.6250000E+02	0.0000000E+00	-2.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
30	7.6250000E+02	0.0000000E+00	-2.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
31	0.0000000E+00	2.5000000E+02	0.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
32	2.0000000E+02	2.5000000E+02	0.0000000E+00	0.0000000E+00	0.0000000E+00	1.0000000E+00
33	3.2500000E+02	2.5000000E+02	0.0000000E+00	0.0000000E+00	0.0000000E+00	1.0000000E+00
34	5.6250000E+02	2.5000000E+02	0.0000000E+00	1.9620000E+03	0.0000000E+00	1.0000000E+00
35	7.6250000E+02	2.5000000E+02	0.0000000E+00	1.9620000E+03	0.0000000E+00	1.0000000E+00
36	0.0000000E+00	2.5000000E+02	-5.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
37	2.0000000E+02	2.5000000E+02	-5.0000000E+00	0.0000000E+00	0.0000000E+00	1.0000000E+00
38	3.2500000E+02	2.5000000E+02	-5.0000000E+00	0.0000000E+00	0.0000000E+00	1.0000000E+00

39	5.6250000E+02	2.5000000E+02	-5.0000000E+00	1.9620000E+03	0.0000000E+00	1.0000000E+00
40	7.6250000E+02	2.5000000E+02	-5.0000000E+00	1.9620000E+03	0.0000000E+00	1.0000000E+00
41	0.0000000E+00	2.5000000E+02	-1.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
42	2.0000000E+02	2.5000000E+02	-1.0000000E+01	0.0000000E+00	0.0000000E+00	1.0000000E+00
43	3.2500000E+02	2.5000000E+02	-1.0000000E+01	0.0000000E+00	0.0000000E+00	1.0000000E+00
44	5.6250000E+02	2.5000000E+02	-1.0000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
45	7.6250000E+02	2.5000000E+02	-1.0000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
46	0.0000000E+00	2.5000000E+02	-1.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
47	2.0000000E+02	2.5000000E+02	-1.5000000E+01	0.0000000E+00	0.0000000E+00	1.0000000E+00
48	3.2500000E+02	2.5000000E+02	-1.5000000E+01	0.0000000E+00	0.0000000E+00	1.0000000E+00
49	5.6250000E+02	2.5000000E+02	-1.5000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
50	7.6250000E+02	2.5000000E+02	-1.5000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
51	0.0000000E+00	2.5000000E+02	-2.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
52	0.0000000E+00	2.5000000E+02	- 2.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
53	3.2500000E+02	2.5000000E+02	-2.0000000E+01	0.0000000E+00	0.0000000E+00	1.0000000E+00
54	5.6250000E+02	2.5000000E+02	-2.0000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
55	7.6250000E+02	2.5000000E+02	-2.0000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
56	0.0000000E+00	2.5000000E+02	-2.5000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
57	2.0000000E+02	2.5000000E+02	-2.5000000E+01	0.0000000E+00	0.0000000E+00	1.0000000E+00
58	3.2500000E+02	2.5000000E+02	-2.5000000E+01	0.0000000E+00	0.0000000E+00	1.0000000E+00
59	5.6250000E+02	2.5000000E+02	-2.5000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
60	7.6250000E+02	2.5000000E+02	-2.5000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
61	0.0000000E+00	5.0000000E+02	0.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
62	2.0000000E+00	5.0000000E+02	0.0000000E+01	0.0000000E+00	3.5700000E-02	1.0000000E+00
63	3.2500000E+02	5.0000000E+02	0.0000000E+01	1.9620000E+03	0.0000000E+00	1.0000000E+00
64	5.6250000E+02	5.0000000E+02	0.0000000E+01	3.9240000E+03	0.0000000E+00	1.0000000E+00
65	7.6250000E+02	5.0000000E+02	0.0000000E+01	3.9240000E+03	0.0000000E+00	1.0000000E+00
66	0.0000000E+00	5.0000000E+02	-5.0000000E+00	0.0000000E+00	3.5700000E-02	1.0000000E+00
67	2.0000000E+02	5.0000000E+02	-5.0000000E+00	0.0000000E+00	0.0000000E-02	1.0000000E+00
68	3.2500000E+02	5.0000000E+02	-5.0000000E+00	1.9620000E+03	0.0000000E+00	1.0000000E+00
69	5.6250000E+02	5.0000000E+02	-5.0000000E+00	3.9240000E+03	0.0000000E+00	1.0000000E+00
70	7.6250000E+02	5.0000000E+02	-5.0000000E+00			