GROUNDWATER FLOW MODELLING USING VISUAL MODFLOW AND STUDIES ON THE EFFECT OF SALINE WATER INTRUSION IN PONNANI-TAVANUR AREA

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PROJECT REPORT

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DECLARATION

We hereby declare that this project entitled **"GROUNDWATER FLOW MODELLING USING VISUAL MODFLOW AND STUDIES ON THE EFFECT OF SALINE WATER INTRUSION IN TAVANUR- PONNANI AREA"** is abonafide record of project work done by us during the course of project and the report has not previously formed the basis for the award to us for any degree, diploma, associateship, fellowship or other similar title of any other university society.

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CERTIFICATE

Certified that this project report entitled "**GROUNDWATER FLOW MODELLING USING VISUAL MODFLOW AND STUDIES ON THE EFFECT OF SALINE WATER INTRUSION IN TAVANUR- PONNANI AREA** " is a bonafide record of project work jointly done by Anjali E. J.(*Admn, No. 2014-02-006*), Lekshmi .N. Kurup (*Admn. No. 2014-02-027*) and Megha .A.S. (*Admn. No. 2014-02-030*) under my guidance and supervision and that is has not previously formed the basis for the award of my degree, diploma, fellowship, associateship, or other similar title of any other University or Society to them.

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SYMBOLS AND ABBREVIATIONS

%	-	Percent
‘	-	Minute
“	-	Second
º	-	Degree
3D	-	Three-dimensional
BMP	-	Bit map
D	-	Days
EC	-	Electrical Conductivity
et al.	-	and others
etc.	-	et cetra
Fig.	-	Figure
GIS	-	Geographic Information System
GPS	-	Global Positioning System
Ha	-	Hectare
K	-	Hydraulic Conductivity
Km	-	Kilometer
m	-	Meter

mS	-	MilliSiemen
mm	-	Millimeter
MODFLOW	-	MODular finite-difference ground water FLOWmodel
MSL	-	Mean Sea Level
MT3DMS	-	Modular 3-Multi-Species Transport Model
NE	-	North East
NTU	-	Nephelometric Turbidity Unit
Ow	-	Observation Well
PC	-	Personal Computer
ppt	-	parts per trillion
RMS	-	Root Mean Square
S	-	Second
Ss	-	Specific Storage
Sy	-	Specific Yield
SWAT	-	Soil And Water Assessment
T	-	Time
USGS	-	United States Geological Survey
y	-	Year

Dedicated to

Tavanur-Ponnani

Natives

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 GENERAL OVERVIEW

Water covers 71% of the Earth's surface. It is vital for all known forms of life. A greater quantity of water is found in the earth's interior. Groundwater is the main source of water for industrial, agricultural & domestic usages. The world's total water resource is estimated as 1.37×10^{8} million ha-m. Of these global water resources only 2.8% is available as fresh water at any time on the planet earth. Out of 2.8% about 2.2% is available as surface water and 0.6% as groundwater. Out of the 0.6% of stored ground water only 0.3% can be economically extracted with the present drilling technology, the remaining being unavailable as it is situated below a depth of 800m. Groundwater is replenished by surface water from precipitation, streams and rivers when the recharge reaches the water table. The main source of groundwater is the precipitated water. The aquifers are geological units that permit the movement of water, with this movement being from areas of high pressure to areas of low pressure at a rate that is depended on the condition of aquifer material. The movement of groundwater in the subsurface water is responsible for a variety of environmental and geological process including heat transfer and solute transfer. The groundwater is extracted from aquifer through pumping wells and with increase in withdrawal of groundwater the quality of groundwater has been continuously deteriorating.

The increasing demand for water to meet drinking, domestic, agricultural and industrial need is placing greater emphasis on the development of groundwater resources in coastal areas of Kerala. This is because of high population and unpotability of water along the large number of backwater near absence of perennial fresh water bodies in the coastal stretch of state, resulted almost complete dependence on ground water for making drinking and domestic needs of the vast majority of population living in the coastal area. Availability of ground water has therefore an important crucial factor for development and sustained living in the state in general and coastal area in particular.

Kerala state lies as a narrow strip of land along the southwest corner of India bordered by the Western Ghats on the eastern side and the Lakshadweep Sea on the western side. The state lie between the North latitude 8˚18' and 12˚48' and East longitude 74˚52' and 77˚22'.Though the state is blessed with plenty of rainfall and water resources, the availability of water resources, especially the groundwater is not uniform throughout. It varies from place to place. The state has varied hydrogeological and geomorphological characteristics and hence the ground water potential, too differ from place to place.

Malappuram has a unique place in the geological history in view, the district lies between North latitudes 10˚40' and 11˚32' and East longitude 75º50' and 76 ˚36'.Geomorphologically the district can be divided into three viz. coastal plain, mid land and highland. Hydrogeologically, the aquifer system in the district can be broadly divided into Crystalline aquifers (fractured basement rock aquifers), Laterite aquifers, Lateralized sedimentary (Tertiary) aquifers and Alluvial aquifers. Crystalline and Laterite aquifers constitute major part (85%) of the district. The main problem encountered in the coastal belt is the deterioration of the quality of ground water due to the influence of the adjacent sea. This problem is severe during dry periods (April-May) of the year when the rainfall is zero. The ground water available in this period becomes unsuitable for domestic and irrigation purposes. This problem is less severe during monsoon season (June -November).

So groundwater management has become critical issue for current and future generations. Groundwater models play an important role in the development and management of groundwater resources and in predicting effects of management measures. With rapid increase in computational ability and wide availability of computers and model software, groundwater modeling has become a standard tool for effective groundwater management. Good management requires information on the response of the system to various stresses. A predication of the response of the system can be obtained by constructing and solving mathematical models of the investigated domain.

1.2 FLOW MODELS

A groundwater model may be a scale model or an electric model of a groundwater situation or aquifer. Groundwater models are used to represent the natural groundwater flow in the environment. Some groundwater models include (chemical) quality aspects of the groundwater. Such groundwater models try to predict the fate and movement of the chemical in natural, urban or hypothetical scenario. Groundwater models may be used to predict the effects of hydrological changes (like groundwater abstraction or irrigation developments) on the behavior of the aquifer and are often named groundwater simulation models. Also nowadays the groundwater models are used in various water management plans for urban areas.As the computations in mathematical groundwater models are based on groundwater flow equations which are differential equations that can often be solved only by approximate methods using a numerical analysis, these models are also called mathematical, numerical, or computational groundwater models. The mathematical or the numerical models are usually based on the real physics the groundwater flow follows. These mathematical equations are solved using numerical codes such as MODFLOW, ParFlow, Hydrogeosphere, OpenGeoSys etc.Various types of numerical solutions are finite difference method and the finite element method

During the 1970's,the application of computer models of groundwater flow grew dramatically within the U.S. Geological Survey (USGS) because they provided improved capability for solving water resources problems. The only computers capable of running such codes were very expensive and available only to large organization. Initially, the codes were two dimensional, then three dimensional codes were developed as computers became more powerful. At that time, USGS hydrologists were accustomed to modifying and adapting existing model codes to their specific needs and preferences. Users would add or modify hydrologic simulation capabilities. Most USGS users had their own modified version of a published code. Because the programs used nonstandard version of Fortran, they were not portable. As models became widely used in USGS studies, it was important to create one program that combines the best capabilities of all the variation of model programs used in the USGS. Michael McDonald who worked in the office of groundwater, offered to develop entirely new program. The new code would include all the capabilities commonly used by USGS Modular Three-Dimensional Finite-Difference Groundwater Flow Model. Informally, we called the code the Modular Model. The model became known as MODFLOW several years later.

1.3 MODFLOW

MODFLOW is the USGS Modular Three- dimensional Finite- Difference Groundwater Flow model. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation and its rigorous USGS peer review, MODFLOW has become the worldwide standard groundwater flow model. MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering (McDonald and Harbaugh, 1988).Groundwater flow within the aquifer is simulated in MODFLOW using block-centered finite difference approach. Layer can be simulated as confined, or a combination of both. Flows from external stress such as flow to wells, areal recharge, evapotranspiration, flow to drains and flow through riverbeds can also be simulated. A large amount of information and a complete description of the flow system are required to make the most efficient use of MODFLOW.MODFLOW is the U.S. Geological Survey modular finite-difference flow model, which is a set of computer programs that solves the groundwater flow equations (Harbaugh, 2005).To use MODFLOW, the region to be simulated must be divided into cells with a rectilinear grid resulting in layers, rows and columns. Files must be prepared that contain hydraulic parameters (hydraulic conductivity, transmissivity, specific yield, specific storage etc.),boundary conditions(location of impermeable boundaries and constant heads) and stress(pumping wells ,recharge from precipitation, rivers, drains, evapotranspiration, etc).

The applications of MODFLOW, a modular three-dimensional finite-difference groundwater model of the U.S. Geological Survey, to the description and predication of the behavior of groundwater system have increased significantly over the last few years. The “original” version of MODFLOW-88 (McDonald and Harbaugh,1988) or MODFLOW-96 (Harbaugh and McDonald,1996a,1996b) can simulate the effects of wells, rivers, drains, head-dependent boundaries and recharge . Since the publication of MODFLOW various codes have been developed by numerous investigators. These codes are called packages, models or sometimes simply programs. Packages are integrated with MODFLOW, each packages deals with a specific feature of the hydrologic system to be simulated, such as wells, recharge or rivers. Models or programs can be stand-alone codes or can be integrated with MODFLOW. A Stand alone model or program communicates with MODFLOW through data files. Visual MODFLOW is an integrated modeling environment for MODFLOW,MODPATH and MT3DMS.It provides professional 3D groundwater flow and contaminant transport modeling using MODFLOW,MODPATH,MT3DMS and RT3D.It allows to graphical design the model grid, properties and boundary conditions, visualize the model input parameters in two or three dimensions, run the groundwater flow, path line and contaminant transport simulations, automatically calibrate the model using Win PEST or manual methods, display and interpret the modeling results in three dimensional space.

Visual MODFLOW can be applied for a).Evaluate groundwater remediation systems, b).Delineate well capture zones, c).Simulate natural attenuation of 182 contaminated groundwater, d). Estimate the reductive dechlorination of Trichloroethylene and Polychloroethylene in groundwater, e).Design and optimize pumping well locations for dewatering projects, f). Determine contaminant fate and exposure pathways for risk assessment. The Visual MODFLOW interface has been specially designed to increase modeling productivity and decrease the complexities typically associated with building three-dimensional groundwater flow and contaminate transport models. The interface is divided into three separates modules viz.., Input Module, Run Module and Output Module.

1.4 STEPS IN GROUNDWATER FLOW MODELLING

Every groundwater flow modeling consists of the following stages;

1. Concept development - It is the most important part of modelling and basis for all further activities.

2. Selection of computer code for simulation. - Code is selected such that it can most effectively simulate the concept and purpose of modeling

3. Definition of model geometry. - It include lateral and vertical extent of area to be modeled defined by boundaries, grid layout, position and number of layers.

4. Definition of cell types. (Active, inactive, constant head cell)

5. Input of hydro-geologic parameters for each cell - Hydraulic conductivity (horizontal and vertical), storage properties and porosity are assigned to each zone.

6. Definition of boundary conditions (boundaries with known head)

7. Definition of initial head. (Distribution of hydraulic head)

8. Definition of stresses acting upon system (areal recharge, well pump age)

9. Model run - It includes choosing a mathematical model for solving the system of algebraic equation, iteration criteria and acceptable error criteria for terminating the iteration process.

10. Calibration and sensitivity analysis - This is probably the lengthiest and most demanding part of any modelling process.

11. Verification of model validity. - The calibrated model is checked against another set of field data that was not used in model design

12. Prediction - In most cases it is the purpose of model design

13. Presentation of result - This includes both the prediction result and relevant data documenting stages of model design.

1.5 STUDY BACKGROUND AND OBJECTIVES OF THE STUDY

The Tavanur-Ponnani region is selected as the study area which is a coastal belt, for observing the reduction in groundwater levels. So the proper management of the available water is the main solution for the current and future periods. Groundwater models play an important role in the development and management of groundwater resources and in predicting effects of management measures.

So the main objective of the study area is:

1. To study the ground water table fluctuation along the coastal area of Tavanur – Ponnani region of Malappuram district.
2. To assess the quality of water.
3. To study the impact of socio-economic changes on salt-water intrusion along the coastal belt.
4. The steady state flow of groundwater through an aquifer is analysed by groundwater modeling (VISUAL MODFLOW).

1.6 OVERVIEW OF THE STUDY

The project work is organized into three major parts: review of literature, materials and methods and results and discussions. Chapter 1 is the introductory part which deals with the importance of topic and the associated research questions. Chapter 2 deals with the review of literature on past knowledge about groundwater modelling and its importance in the study of hydrologic systems and also make a detailed literature on the saltwater intrusion in various regions and its effects on living status of the community. Chapter 3 focuses on the detailed description of the model development of Tavanur-Ponnani region by using available data for the modeling work. It also discuss about the modeling tools and procedures. The chapter 4 deals with the calibration, validation, prediction and various model outputs along with quality analysis of the collected samples in the study area and also include detailed survey with the local people about the quality of the water. Summary and conclusion of the present work is presented in chapter 5 on the ideas and issues for further work in the focus area.

REVIEW OF LITERATURE

CHAPTER2

REVIEW OF LITERATURE

The chapter reviews the concepts and literatures available on ground water flow, details of MODFLOW and finally the case studies of salt water intrusion in coastal belt.

2.1 GROUNDWATER MODELLING

Tiwari et al. (2014) developed a modeling for Groundwater Resources in alluvial region of upper Narmada basin using Visual MODFLOW to suggest a groundwater development and utilization plan for future. The specific objectives were to simulate groundwater system in a selected area of alluvial plain of Narmada basin, to calibrate and validate the model using past data and to predict the groundwater scenario of the selected area in the year 2025. Model calibration for steady-state shows a good agreement between observed and simulated initial water level contour. Results of the calibrated flow model (steady and transient state) indicates that the hydraulic conductivity of upper Narmada basin ranges between 0.000257 and 0.000567 m/s. While predicting for the year 2025 increased abstraction rate by 12% of the current withdrawal rate were considered. It was observed during the prediction run that maximum head range of 456 to 463m and minimum head range 306 to 308 which 0.2% to 0.3% less than the present head value.

Nassim et al. (2013) used MODFLOW Program for Evaluation of Groundwater Resources in Alluvial Aquifer in Evan sub basin (Iran). The model was calibrated and verified using historical and observed water level data for periods 2005 to 2006 and 2006 to 2007, respectively. The model was run to generate groundwater scenario for a 10 year period from 2005 to considering the existing rate of groundwater draft and recharge. The water budget predictions indicate a decrease from 8.34 to 4.43 MCM in groundwater storage system. The predicted water table contour maps for the years 2015 have been generated. The study indicates that over exploitation of groundwater will leads to extreme reduction of water resources in period 2014-2015.

Shri Kant et al. (2013) studied the groundwater in sonar sub-basin, Madhya Pradesh using Visual MODFLOW. The study of groundwater levels in unconfined aquifer in different regions of the Madhya Pradesh, experienced significant groundwater decline during the last decade due to excessive groundwater withdrawal. The results obtained from the model were found to be in agreement with the observed records. Water level data from 15 piezometer evaluated and analysis of predicted results indicate that the probability of the next few years the water level drops in the aquifer, in the case of a large harvest process, will be very severe.

Koohestanietal. (2013) Hernandez et.al (2012) worked on modeling groundwater levels on the Calera aquifer region in Central Mexico using MODFLOW. Result evaluation yielded average coefficients of determination of 0.81 and 0.67 and root mean square error value lower than 25.1 and 25.9 m. for the calibration and validation process respectively, these results are indicative of a good agreement between predicted and observed groundwater levels. However, further improvements in the conceptual model may be needed to improve prediction in other path of the CAR for evaluating alternatives groundwater management strategies.

GurunadhaRao et al. (2009) studied groundwater flow modeling in the upper Angara river watershed, Yaounde, Cameroon. The computation has converged after 170 iterations with a convergence criterion of 0.01 m. The computed groundwater level contours have been following the trend of observed ones. The computed groundwater balance indicated that base flows come from the groundwater regime. The results indicated that the topography controls groundwater flow in the watershed and that base flow to river is an important factor moderating groundwater movement.

Kushwaha et al.(2009) used MODFLOW based Groundwater Resource Evaluation and Prediction in Mendha Sub-Basin, NE Rajasthan. The model was run to generate groundwater scenario for 15 year period from 2006 to 2020 considering the existing rate of groundwater draft & recharge. The water budget predictions indicate a decrease from 349.50 to 222.90 MCM in the groundwater storage system, whereas groundwater abstraction shows an increase from 258.69 to 358.74 MCM per annum. The predicted water table contour maps for the year 2007, 2015 and 2020 were also generated.

Mondal and Singh (2009) has mass transport modeling of an industrial belt using visual MODFLOW and MODPATH: A case study. This modeling study has indicated that even if the pollutant sources were reduced to 50% of the present level, TDS concentration level in the groundwater, even after 20 years, would not be reduced below 50% of it. The study suggested immediate measures for arresting the deteriorating in groundwater quality as argumentation for restoration of aquifer in some parts of the study area.

Studies on groundwater flow modelling of Yamuna–Krishniinterstream, a part of central Ganga Plain Uttar Pradesh showed that the model is most sensitive to hydraulic conductivity and recharge parameters. Three scenarios were considered to predict aquifer responses under varied conditions of groundwater abstraction (Ahmed and Umar (2009).

Abu-El-Shar and Hatamleh (2007) usedMODFLOW and MT3D Groundwater Flow and Transport Models as a Management Tool for the Azraq Groundwater System Jardon. Five scenarios of pumping with different abstraction rates for years 2005 through 2020 have been explored using the three dimensional finite difference flow model (MODFLOW (PM5)). Solute transport model (MT3D) was used to predict the transport of total dissolved solids given in terms of Electric Conductivity (EC). Different parameters including EC, recharge, model boundary and advection parameters were adjusted to run the model. Simulation results indicated that the effect of the different scenarios on the values of EC is less profound than the effects on the drawdown values. Attempt has been made to solve the problem of groundwater flow in porous media using a finite difference code called 'MODFLOW'. While this code performs satisfactorily in solving simple two or three dimensional problems, it takes a large computational effort when used to solve flow through layered soil strata with varying hydraulic conductivities. The modular structure of the code renders itself for the development of a parallelized code.

Barth et al. (2006) carried out the application and investigation of a loosely coupled modeling approach, combining two well-known models the Precipitation Runoff Modeling System (PRMS) and the Modular Finite-Difference Groundwater Flow Model (MODFLOW) in order to simulate complex hydrological processes in the EsperstedterRied basin, an ungauged, Mesoscale, groundwater-dominated catchment in central Germany. The results of this case study demonstrate the potential of coupling a surface water model and a groundwater model to obtain more complex and accurate analyses and simulations of hydrologic systems.

Sekhar (2005) has adopted an integrated groundwater modeling approach for better assessment of water balance components. The study showed that impact of pumping resulted in regional groundwater flows influencing the hydrogeological regime in the recharge zone of the sub basin. MODFLOW is calibrated assuming specified transmissivities for each of the zones obtained from several pump tests in the region. The calibrated model was used to simulate the behavior of the groundwater system using variable draft systems. The simulated responses for the water levels were in good agreement with the observed data.

Abdulla and Assad (2005) have studied modeling of groundwater flow for Mujib aquifer, Jordan. The results of the calibrated model showed that the horizontal hydraulic conductivity of the B2/A7 aquifer ranges between 0.001 and 40 m/d. Calibrated specific yield ranges from 0.0001 to 0.15. The water balance for the steady state condition indicated that the total annual direct recharge is 20.4 × 106 m3, the total annual inflow is 13.0 × 106 m3, springs discharge is 15.3 × 106 m3, and total annual outflow is 18.7 × 106 m3. Different scenarios were considered to predict aquifer system response under different conditions. The results of the sensitivity analysis show that the model is highly sensitive to horizontal hydraulic conductivity and anisotropy and with lower level to the recharge rates. Also the model is sensitive to specific yield.

A mathematical model was developed by Anandha Kumar and Sinha (2003) using MODFLOW Package of USGS to generate alternative management scenario to evolve optimal conjunctive use strategy. The model was calibrated using field hydrographs and using the observed and computed water table contours. It was then used to develop different water use scenarios and their effect on the groundwater regime. The studies shows that the water logging condition prevailing in part of the Hirakund command area can be controlled by development of groundwater in conjunction with surface water without any deterioration to the groundwater regime.

Thangarajan et al. (2000) simulated a multi-leaky aquifer system in shashe river valley (Okavango delta), Botswana to study the aquifer response and there by evolve the optimum pumping schemes. In order to quantify the upward flow from the saline unit, a multi-layer model was constructed and calibrated for both steady state and transient state condition. The calibration has shown that vertical conductivity (K) of the confining layers has a considerable influence on the hydrodynamics of multi-aquifer system. The upper reaches of the middle semi confinedaquifer are likely to become concentration of total dissolved solids. The study suggested that the situation may be improved by reconfiguration of well fields.

N B Narasimha Prasad conducted a study on assessment on groundwater resources in Nileshwerbasin(2003). The study has carried out in the Nileshwer river basin, Kasargod District of Kerala. The pattern of water level fluctuation in different physiographic regions, depth to water table and saturated thickness in different seasons, hydrogeological properties of the rocks with in the basin, groundwater assessment, groundwater quality etc have been studied. All this have been integrated to determine groundwater condition, in the river basin in terms of groundwater potential. The annual groundwater availability has been estimated as 9.4 million cubic meter and the gross annual groundwater draft has been estimated as 3.5 million cubic meter for Nileshwer basin. The stage of groundwater development has been computed as 37%. There is no significant rise or fall of water level during both pre-monsoon and post-monsoon in the basin. It has been categorized that the Nileshwer basin is SAFE for future groundwater development.

Mike Nimmer et al. (2010) conducted a modeling on water table modeling and contaminant transport beneath storm-water infiltration basins. The main objectives of the study were to link an unsaturated and saturated flow model for the purpose of evaluating modeling and contaminant transport beneath an infiltration basin, and to evaluate the potential for contaminant transport with a numerical fate and transport model. Mound formation may reduce the thickness of the soil to retard the pollutant movement, reduce the infiltration rate of the basin if the mound intersects the basin bottom, and facilitate the contaminant movement away from the basin. Two storm events were modeled using the three-dimensional saturated numerical model MODFLOW. Recharge used in MODFLOW was taken from the seepage flux of the unsaturated one-dimensional model HYDRUS. A good fit was achieved between model and measured timing and the magnitude of the water table rise from both storms. The three-dimensional saturated fate and transport MT3D was used to simulate a tracer study.

Lachaal et al.(2012) conducted an implementation of a 3-D groundwater flow model in a semi arid region using MODFLOW and GIS tools. In this work an integrated methodology was developed to investigate hydrological processing in Zeramdina-Beni Hassan Miocena aquifer and to validate ground water property deducted from the geological, geophysical, hydrodynamic and hydrochemical studied done in the region using the coupling of groundwater flow model MODFLOW 2000 code with geographical information system tools. A 3-D groundwater flow model was developed from this aquifer using a large amount of geological and hydrological data. The results of the groundwater dynamic simulation of the study aquifer shows that calculated water level are close to the observed values. The model leads the groundwater characterization. The used methodology allowed us to complete and finalize the groundwater hydrogeological comprehension. The model simulation shows a good degree of understand to the aquifer hydrological and also ZBH aquifer exhibits the highest sensibility to changes of water infiltration and hydraulic conductivity.

Hariharan et al.(2017) conduct a study on review of visual MODFLOW applications in groundwater modelling .Visual MODLOW is a Graphical User Interface for the USGS MODFLOW. It is a commercial software that is popular among the hydrogeologists for its user-friendly features. The software is mainly used for Groundwater flow and contaminant transport models under different conditions. This article is intended to review the versatility of its applications in groundwater modelling for the last 22 years. Agriculture, airfields, constructed wetlands, climate change, drought studies, Environmental Impact Assessment (EIA), landfills, mining operations, river and flood plain monitoring, salt water intrusion, soil profile surveys, watershed analyses, etc., are the areas where the software has been reportedly used till the current date. The review will provide a clarity on the scope of the software in groundwater modelling and research. It is evident from the review that the software has found applications in a variety of groundwater flow simulation settings. This shows an optimistic research potential with the software for the future. It is notable that the Middle East and the Asian countries (especially, China) have used the software comparatively more than other nations in modelling. The study of literature shows that the same research methodologies can be adopted for similar scenarios in other countries as well. Integrating other modelling software such GIS, SWAP, SWAT, etc., with Visual MODFLOW have been attempted in some studies. Such attempts add novelty to the research.

Berehanu et al. (2014) conduct a study on Challenges of Groundwater Flow Model Calibration Using MODFLOW in Ethiopia: With Particular Emphasis to the Upper Awash River Basin. In this work, most important problems related to model calibration have been assessed using MODFLOW. Particular emphasis is given to the Upper Awash river basin where many boreholes have been drilled for municipal and industrial uses compared with other regions in Ethiopia.

Static Water Level (SWL) records from water supply wells drilled for about 32 years in the Upper Awash basin is considered to illustrate the commonly used groundwater flow model calibration procedures and associated problems. The assumptions made in the modeling procedures to use SWL data collected over many years from water supply boreholes to calibrate steady state models is too much of an assumption. Alternatives on steady and pseudo transient model calibration approaches in data scarce areas based on logical assumptions and reasonable representation of groundwater systems has been suggested. Hence, numerical groundwater flow models may play the expected key role for the sustainable groundwater resource management of the country, which is solving practical ground-water related problems. A groundwater table mapped using groundwater level records collected over significant time periods, cannot realistically produce a water table or potentiometric surface. Unless it is well justified or tested, to just assume the head remains constant for many years is too much of an assumption. Hence, it leads to oversimplification of the groundwater model, which in turn results in ground water flow models, which are more of hypothetical than depicting the reality. The assumptions of steady state condition can be reasonable, at least if the observation head values were collected within short period of time, within which it is logical to assume that there is no significant change in all the model stresses and therefore, the model assumes equilibrium state.

Malik et al.(2012) conducted study on Ground water modeling with processing MODFLOW for windows, for the water balance study and suitable recharge site: case of Gurgaon district, Haryana, India .Total Gurgaon district area of 1254.62 km2 was modeled using 102 column and 66 rows making total grid cell number of 6732, in which 3861 cells were coming within the boundary of Gurgaon district. Each grid cell had 570.03 m length by 570.03 m width making 324934.20 m2 areas. Ground water observation well data for about 75 wells evenly spread all over the geographic area of Gurgaon district was utilized for the analysis. Then input of model parameters viz. storage coefficient (0.011) and effective porosity (0.16) were given and transmissivity was specified as the model calculated value. Then results were obtained for aquifer parameters viz. storage coefficient, and transmissivity using pump tests and average value of Theis Method, Cooper-Jacob Method, Chow’s Method solutions and recovery test. Using calculated pumping and recharge quantities inputs for MODFLOW model were generated. Calibrated and validated model was used to find out 1974 to 2008 period as well as for future predictions at 2025 and 2050. MODFLOW model was calibrated to match the observed drawdowns with model calculated drawdowns using different values of aquifer parameters. Existing water was analyzed to understand different component of water pumping, recharge and change in water levels. Various scenarios viz. normal rainfall and no-pumping, roof top water harvesting with recharge and water conservation structure recharge were formulated for sustainable planning and management. 3D graphical analysis was carried out to understand spatial drawdown patterns, flow patterns as well as to identify potential recharge sites. Using this calibrated model and water balance inputs of 35 years averaged over five year period, recharge, pumping, balanced water as well as horizontal exchange at various time developmental stages and potential were estimated.

Varalakshmi et al. done a groundwater flowmodelling of a head rock aquifer as a case study. The study area were primarily underlain by granite, basalt and a little bit of laterite. A 3-D groundwater flow model for the Osmansagar and Himayathsagar catchment- a semiarid hard rock area in India with two conceptual layers was developed under transient conditions using visual MODFLOW for the period 2005 to 2009. The groundwater estimation was achieved with the help of geographical information system (GIS) and the water table fluctuation method that is well fitted into the flow model with an average value of 21% of the average annual rainfall. They arrived at certain conclusions that the Himayatsagar and Osamansagar catchments are sensitively balanced with finite groundwater resources, and are at risk of being overexploited in the coming decades. . The results indicate that there is no chance to further increase the groundwater draft in the Shankarpally, Moinabad, and Shamshabadmandals, and there is a scope for further groundwater withdrawals in the mandals of Vikarabad, Pargi, and Pudur. The results of the forecast scenarios suggest that the groundwater levels will fall by more than 45 m by the end of 2020 if the present rate of pumping continues. The results also suggest that a reduction of 40% groundwater use will increase the groundwater levels in the future. G Balachandran Pillai conducted a study on Effects of groundwater table fluctuations on saltwater intrusion along the coastal belt of Malappuram Disrict.The ground water table fluctuation and its effect on salinity intrusion, ground water availability and its utilization pattern and quality of ground water for drinking and other purposeswere studied in the coastal belt of Chamravattam, Ponnani region of Malappuram District. His experiment was conducted in six regions viz. Biyyam, Puzhambram, Chamaravattom, Kadavanad, Ponnani and Puthuponnani in coastal areas were also studied. Firstly observation wells of about 41 are established in these 6 regions. Among them water samples are taken from 15 observation wells .The depth of water level in the observation wells were measured from the ground level with the help of measuring tape, once in 20 days during monsoon and once in ten days during summer season. The quantity of water samples collected from 15 wells are tested for total dissolved solids (TDS), pH, suspended solids, E-coli, Mg, Ca, iron etc. Then the groundwater was estimated by multiplying the MGWL fluctuates with specific yield and utilization by field survey .At the end of experiment it reveals as the water level goes down, the amount of TDS in water was found to be increased vice-versa. ThepH content was found to be within the permissible limit of 6.5-8.5 at Chamravattam and Ponnani and other two regions are more alkaline. The suspended solids, SO4, alkalinity and iron content in the well water were observed within the permissible limits in all the 6 regions. At the end of water quality analysis it shows that the well water in 4 regions (Puzhambram, Kadavanad, Ponnani&Puthuponnani) was not suitable for drinking purpose.

Faunt et al. (2004) constructed a 3D model which is a digital HFM (hydrogeological framework model). It defines the physical geometry and materials of hydrogeological units and the hydro geological structures. Identified hydrogeological units were represented in the form of HFM. These units are about twenty five. The HFM was discretized into numerical flow model input arrays using Hydrogeological Unit Flow package of MODFLOW-2000.

Kumar and Elango (2006) developed a MODFLOW model to simulate the groundwater flow. It was used to assess the effect of a subsurface barrier in the Palar river basin, Tamil Nadu on groundwater. To meet the ever increasing demand for groundwater by the nearby nuclear power station, a subsurface barrier or dam was proposed across Palarriver to improve the groundwater potential. It predicted the groundwater levels would increase by 0.1-0.3m at a distance of about 1.5-2km from upstream side and a decline of 0.1-0.2m on the downstream.

Sivakumar et al. (2006) developed for South Chennai coastal aquifer, a numerical model to understand the behavior of systems with varying hydrological stresses. This study simulated the effect of increase in pumping and changes in rainfall pattern. It was carried out to develop a numerical model for the area in order to understand the behavior of the system with changes in hydrological stresses. They used the finite difference computer code MODFLOW (Modular 3-D Finite Difference Flow) with Groundwater Modelling System (GMS) as pre and post processor.

Palma et al. (2007) presented a regional-scale groundwater flow model for the Leon-Chinandega aquifer in Nicaragua. Groundwater flow in the aquifer was simulated using transient and steady state numerical models. In the study visual MODFLOW a numerical groundwater flow model was used to study the groundwater flow system and the effects of groundwater developments. Model results indicated that pumping induces a decrease in base flow, depleting river discharge. This becomes critical during dry periods, when irrigation is highest. Transient modelling indices that the response time of the aquifer is about one hydrologic year, which allows the development of management strategies within short time horizons.

Zume and Tarhule (2007) used a visual MODFLOW, numerical groundwater flow model to evaluate the impacts of groundwater exploitation on stream flow depletion in the Alluvial and Terrace aquifer of the Beaver-North Canadian River (BNCR) in Oklahoma, USA. Using MODFLOW's stream flow routing package, pumping-induced changes in base flow and stream leakage were analysed to estimate stream flow depletion in the BNCR system. Simulation results indicates that groundwater pumping has reduced base flow to streams by approximately 29% and has also increased stream leakage into the aquifer by 18% for a net stream flow loss of 47%.

Arshad et al. (2008) carried out a study to measure and assesses the recharge contribution of a distributary of canal in Pakistan for crop irrigation using groundwater flow model. This study was carried out because of increasing groundwater demand by various crops specially wheat and rice, which consume the maximum quantity of water. With the increase in consumption of these crops and to cater the necessity of water by these crops heavy pumping is being carried out. Therefore assessment of recharge through distributary was carried out using a groundwater flow-MODFLOW model, Model calibration involved changing input parameters within reasonable limits until acceptable matches were obtained between the observed and simulated water levels for all observed hydrographs concluded, recharge contribution was 16.5% of the inflow rate of the distributary. Using predicted results of the model a relationship between recharge (R) and discharge (Q) was also developed.

Dr. Saied Mostaghimi et al. (2000) carried out study to determine the impact of land use activities on the subsurface flow regime in the Upper Roanoke River Watershed in Virginia to determine the impacts of land use change on the subsurface flow system, and to provide a tool for future management decisions. MODFLOW, the USGS, three-dimensional, finite-difference, groundwater flow model was used to develop a regional conceptualization of the flow system. The 575m2 study area was divided into cells with dimensions of 0.25 miles by 0.5 miles and containing four layers. The upper model layer was used to simulate the saturated unconsolidated deposits that lie on top of the fractured bed rock and serve primarily as a recharge reservoir. The second layer simulated shallow flow driven by recharge and the withdrawal of water by pumping wells. The bottom two layers were used to simulate deep regional flow within the system and account for possible vertical flow that may be occurring through deep fractures. The groundwater flow model was calibrated using USODE, a USGS code for universal inverse modeling. Parameter estimation was conducted using USODE for a total of 18 parameters, including hydraulic conductivities river bottom conductance values, and recharge rates. Results indicate that flow in the system is predominantly horizontal. There is no deep vertical flow from possible deep fractures. There may be shallow vertical flow occurring that is driven by recharge, however due to the resolution of the model, this flow is not simulated. In general, the simulation of horizontal flow follows the overall trend of the hydraulic gradient from west to east, which also follows the overall flow, possible impacts from land use change, and a discussion of the results with respect to gaining a more complete understanding of the subsurface flow system.

Shao et al. (2009) constructed a regional groundwater model for the North China Plain in order to assess groundwater development potential. The model covered an area of 139,000km2 with a uniform grid of 4kmby 4km. The thickness of the aquifer system ranges from 550m to 650m and was simulated with 3 model layers. The model was calibrated with data from 2002 to 2003, with monthly stress periods.

Post, (2011) presented a new package, periodic boundary condition (PBC) package into MODFLOW to overcome the difficulties encountered with tidal boundaries in modeling coastal groundwater system. It highlights the boundary condition for head and concentration during simulations and allows for development of seepage face. This new package was developed forMODFLOW and SEAWAT Boundary conditions are assigned to the nodes at the sediment water interface depending on a user-defined tidal signal.

2.2 SALT WATER INTRUSION

K S Anil kumar et al. conducted a Study of saline water intrusion into the shallow coastal aquifers of Periyar river basin, Kerala using hydrochemical and electrical resistivity method. Electrical resistivity sounding techniques and hydrochemical studies are widely used to determine the interaction between groundwater and saline water/seawater in coastal aquifers. Vertical electrical soundings were carried out at 15 locations in the midland and coastal plain reaches of Periyar River basin in central Kerala, India (9˚ 55'-10˚ 20'N latitude and 76˚ 05'-76˚ 25' E) longitude using CRM 500 model aqua meter. In-situ water quality parameters of water samples from 63 shallow well were also measured using hand-held multi-parameter instrument. The cation and anion content of selected water samples were also determined. Electrical resistivity profiles were interpreted qualitatively and quantitatively to obtain nature and thickness of different resistivity layers. The depth to fresh-saline water interface was delineated from resistivity model. The study indicates majority of the curves obtained are Q type with 3 layers. The depth to saline-fresh water interface varied from <1 to 5 m at different locations. The high salinity clay horizons are identified at various depths. Hydrochemical data was analysed using hill-piper diagram and statistical plots to understand groundwater-seawater mixing/interaction in the coastal aquifers. The dominant groundwater type is NaCl followed by MgClat few places. Higher pH, EC and TDS is noted in the western part towards seaward side. Turbidity levels are found increasing towards southwest parts. The Na+, Cl^- and (SO4)2^- content is found higher in the northwestern parts.

S Gopinath et al. conducted study on modeling saline water intrusion in Nagapattinam coastal aquifers, Tamil Nadu, India. Groundwater levels were measured at 61 locations in Nagapattinam and Karaikal coastal region, identified flow direction pointing toward the coast with no major change in groundwater table. Groundwater samples were collected and analyzed for major ionic parameters, represented higher concentration of conductivity, total dissolved solids, sodium and chloride along the coastal parts of the study area. A computer package for the simulation of dimensional variable density groundwater flow, SEAWAT, has been used to model the seawater intrusion in the coastal aquifers of the study area. The model was stimulated to predict the amount of seawater incursion in the study area for a period of 50 years. Water chemistry data signifies higher EC and TDS during both the seasons along the coastal regions suggesting saline water traces. Sodium and Chloride were found to be dominating along the coastal regions. Higher nitrate and sulphate suggests evidences of fertilizer influences. The ionic ratio plots suggest influence of saline water intrusion along the coasts and significance of rock water interaction.

Chan-hee-park conducted a study on saltwater intrusion in coastal aquifer in Georgia institute of technology in September 2004.He conducted the experiment to optimize the pumping rate as well as the well location in the coastal aquifer for freshwater extraction and controlling the salt water intrusion. And also variable density flow in a saturated porous medium is developed in this study through a 3-dimensional finite element model(Techflow),and tested through various benchmark test problems such as the Elder problem and HYDROCOIN for comparison between the developed model and 3D temporal experimental measurement. The conclusions obtained from the numerical experiment in Elder problem are globally continuous velocity estimation can help to reduce the grid density while obtaining convergent solutions to salt water intrusion problems, it is difficult to solve the Elder problem because of the physical instability, Elder problem is sensitive to local grid regularity. Due to 3D nature of application, the location of well screen does make a difference in lateral saltwater encroachment between upper zone and lower zone. Thusthe analysis is focused on the water flow between unsaturated zone and saturated zone. Thus the results obtained from the application can be used for the interpretation of scaled-up applications.

A Ghosh Bobba conducted a study on Numerical Modelling of Salt Water Intrusion due to human activities & sea level change in the GODAVARI Delta, India on August 2002. This study demonstrates the sensitivity of salt-water intrusion Unsaturated (Transportmodel), a finite element model, to predict the water table elevations and freshwater depth due to anthropogenic effect (eg.irrigation) ,and climate change (rainfall land sea-level changes) in the Godavari Delta, India. Physical parameters, initial heads, and boundary conditions of the delta were defined on the basis of available field data, steady-state groundwater model was constructed to calibrate the observed head values corresponding to the initial development phase of the aquifer. Initial and determined from the areal calibration were used to evaluate steady-state, Hydraulic heads. Consequently, the initial position of the hydraulic head distribution was calibrated under steady-state conditions. The changes of initial hydraulic distribution, under discharge and recharge conditions, were calculated, and the present-day position of the interface was predicted. The present-day distribution of hydraulic head was estimated via a 20-year simulation. The results indicate that a considerable advance in seawater intrusion can be expected in the coastal aquifer if current rates of groundwater exploitation continue and an important part of the freshwater from the river is channeled from the reservoir for irrigation, industrial and domestic purposes.

MATERIALS AND METHODS

CHAPTER-3

MATERIALS AND METHODS

This chapter presents the details of the study area, the region of Tavanur and Ponnani and data collected for ground water system. Establishment of observation wells, measurement of groundwater table fluctuations and collection of samples are detailed in this section. Quality analysis of collected samples along with the effect of salinity intrusion on socio-economic status of the living community is also included. Data acquisition and methods used for data processing and methodologies for extracting model input are described in details. A brief description of the Visual MODFLOW model, operation and its limitation along the description of input file used for evaluating the model performance are also included in this chapter. Procedure used for all input data and calibration of the model under steady state condition are described in this chapter. Various criteria used for evaluating the model performance for stimulating the groundwater flow are also presented.

3.1 STUDY AREA

The present study has been carried out in Tavanur and Ponnani region in Malappuram , Northern part of Kerala, India. The Malappuram district lies between north latitudes 10º 40´ and 11º 32´ and east longitude 75º50´ and 76º36´. The district has geographical area of 3550 km^2. Malappuram district is mainly drained by the Kadalundi River, Chaliyarriver and Bharathappuzha which is locally known as Ponnani River.

Ponnani is a municipality in Ponnani Thaluk, Malappuram District, in the state of Kerala. It is situated at the estuary of Bharathappuzha (River Ponnani), on its southern bank, and is bounded by the Arabian sea on the west and series of brackish lagoons in the south. It extends to an area of 25 km^2. It is more or less flat with a gentle slope towards west and north direction. Main issue facing in this area is due to the salt water intrusion into the coastal aquifers. Therefore proper groundwater management is necessary and groundwater flow modeling is essential for proper management.

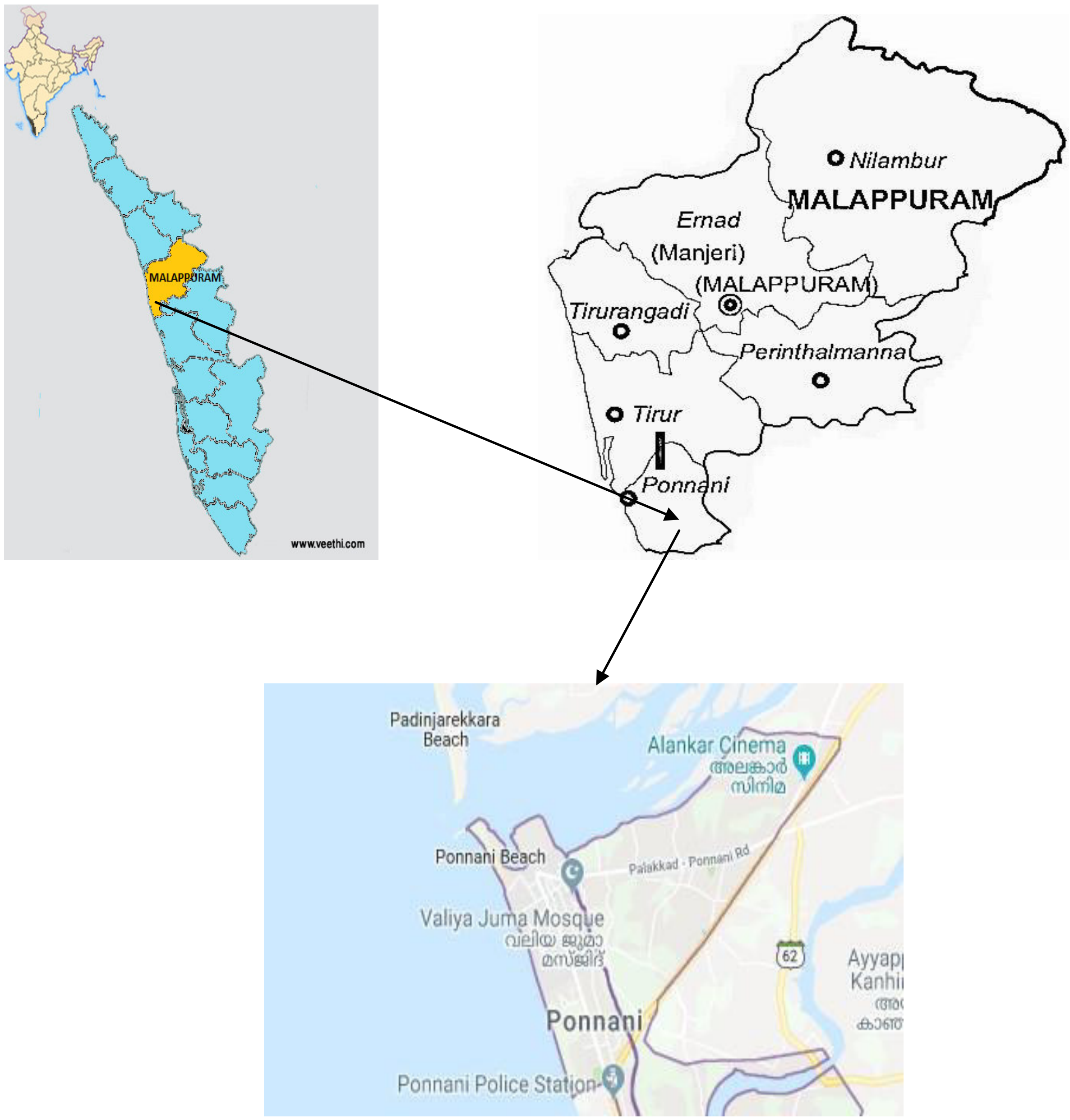

Fig 3.1 Location map of study area

3.1.1 Geographical location

Ponnani lies in north latitude 10.767º and east longitude75.925º. Total geographical area of ponnani is 25km^2. The population density of the city is 3646 persons per km^2.It is situated at the estuary of Bharathappuzha, on its southern bank, and is bounded by the Arabian sea on the west and series of brackish lagoons in the south. It is more or less flat with a gentle slope towards west and north direction.

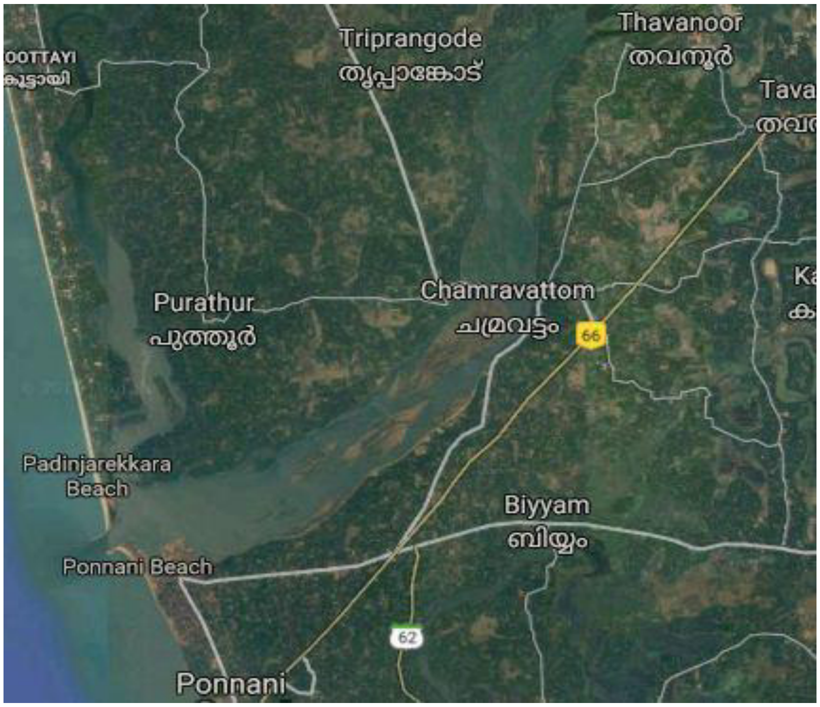

Fig 3.2 BMP Map of study area

3.1.2 Meteorological data

3.1.2.1 Rainfall and Climate

Yearly average rainfall of Tavanur - Ponnani is 2200mm. This city experience wet type climate. The maximum rainfall distribution is from south-west monsoon season followed by North-East monsoon season. The other seasons are comparatively contributing less rainfall. The South West monsoon is usually very heavy and nearly 73.5% of the rainfall is received during this season. NE monsoon contributes nearly 16.4% and March to May summer rain contributes nearly 9.9% and the balance 0.2% is accounted for during January and February months.

3.1.2.2 Temperature

The climate is generally hot and humid. March and April months are the hottest and January and February months are the coldest. The maximum temperatures ranges from 28.9 to 36.2°C and the minimum temperatures range from 17.0 to 23.4°C. The temperature starts rising from January and reaches the peak in the month of March and April and then decreases during the monsoon month and again rising from September onwards.

3.1.2.3 Humidity

The humidity is more during South-west monsoon i.e during june to September. The relative humidity ranges from 84 to 94% during morning hours.

3.1.2.4 Wind

The wind is predominant from east as well as west during morning and evening hours. The wind speed is more during December to February months. It ranges from 2.9 to 7.2 km per hour.

3.1.3 Drainage characteristics

Malappuram district is mainly drained by the Kadalundi River, Chaliyar River and Bharathapuzha. Among them Bharathapuzha river is flowing through Ponnani town. The Bharathapuzha or the Ponnani River is the second longest river of Kerala, originating from the Anamalai Hills (1964 m above msl) in the Western Ghats. It drains into the Lakshadweep Sea near Ponnani town in Malappuram district. Bharathapuzha is non-perennial and all others get dried up in summer and hence Ponnani is highly drought prone.

3.1.4 Topography

Topography of malappuram district consist of three natural divisions: lowland, midland and highland. The topography of study area of Tavanur - Ponnani is undulating, starting from nearly hilly region and end towards low land area. While the lowest elevation shows at Northern boundary of the studied area (about5-10m) and highest elevation towards South-west region (35-40m).

3.1.5 Study boundaries

The study area is bounded by Bharathappuzha river in the north , Arabian sea in the South-West and Ponnani-Kuttippuram bypass road in the North-West side. Along the east and west boundaries the ground is slopping uniformly towards the Arabian sea.

3.1.6 Hydrogeology

The subsurface strata in the study area consist mainly of metamorphic origin. The subsurface strata of the study area includes lateritic rock, lateritic soil and sandy soil. The thicknesses of the various layers vary spatially in different regions in the study area. The layer1, i.e., lateritic rock is present in the high elevation part (at the North-East portion of study area). The second layer, i.e., lateritic soil is below the first layer. Next layer is sandy soil, which is deep towards the South-East portion.

Layer No.	Soil type	Hydraulic conductivity(m/s)
Layer 1	Lateritic Rock	3.8×10^{-5}
Layer 2	Lateritic Soil	3.47×10^{-3}
Layer 3	Sandy Soil	5.0×10^{-4}

Table 3.1 Hydrogeology of the study area

3.1.7 Groundwater

The regional aquifer underlying the area is mainly of lateritic origin. The dominant sources of recharge to the study area are precipitation river leakage and from sea.

3.1.8 Recharge

Spatially distributed recharge over the entire first layer of the study area (in mm/y) was taken as one in tenth of the average precipitation for the purpose of the study.

3.2 DATA COLLECTION AND ANALYSIS

3.2.1 Establishment of observation well network

18 observation wells were selected and the observation wells were spread over different region viz. Chamaravattom, Purathur, Nariparambu, Maravancheri, Ponnani ,Tavanur and Chamravattom – Ponnani coastal stretch. For water quality analysis a representative sample of 18 observation wells ,which spread over the study area were selected.

3.2.2 Measurement of ground water table fluctuation

The variation of water level in wells depends mainly on nearness to sea shore and river, daily withdrawal of water from wells, type of geological formation and the relative height from mean sea level. The depth to water level in the observation wells were measured from the ground level, with the help of a measuring tape, once in 30days for all the regions selected for the study. The ground water table fluctuation behavior along the study area was assessed by analyzing the average depth to ground water level in the observation wells during the consecutive months.

3.2.3 Quality analysis of ground water

A detailed study on quality of well water from the observation wells was done to get an idea about the ground water quality of the coastal area. Salinity intrusion along the coastal area was assessed by measuring the level of salinity contained in the water samples collected from the 18 observation wells, selected for this purpose. These sample were tested for electrical conductivity, salinity and turbidity using water analyser and electrical conductivity meter.

Fig 3.3 Water sample collected

Fig 3.4 Salinity analysis using water analyser

Fig 3.5 Stock solution preparation

Fig 3.6 Electrical conductivity meter

3.2.3.1 Measurement of salinity

Salinity is the measure of amount of dissolved salt present in the water. For measuring salinity in water analyser first we need to calibrate the instrument. A standard solution of NaCl (30 ppt) was prepared by dissolving 3 gram of NaCl in 100 ml of distilled water. Calibration of the instrument was done using this solution. After the calibration of instrument salinity was tested by dipping electrodes in the collected sample water with the salinity mode on. The instrument directly displays the salinity in ppt.

3.2.3.2 Measurement of Turbidity

Turbidity is the measure of amount of suspended matter present in the water, which may cause cloudiness or haziness in the water sample and also low transparency of water. Before measuring turbidity in water analyser, for calibration we have to prepare a stock solution of 4000 NTU.

The stock standard of 4000 NTU is prepared as per following procedure:

1. Take 5 grams of reagent grade 'Hydrazine Sulphate' dissolve in 400 ml of distiiled water. This is solution 'A'.
2. Next, dissolve 50 grams of pure 'Hexamethylene Tetra amine' in 400ml of distilled water. This is solution 'B'.
3. Mix solution 'A' and 'B' and make it upto 1 litre by adding distilled water and allow this mixture to settle for 48 hours at normal room temperature.

2.5ml of this stock solution was mixed with 100ml of distilled water to make it upto 100 NTU. By using this standard solution water analyser was calibrated for turbidity. For measuring turbidity, the sample was taken in a small bottle and aligns as per the marking on the block keeping light shaded cover always on the bottle during measurement. The instrument directly displays the turbidity in NTU.

3.2.3.3 Measurement of electrical conductivity

Electrical conductivity is the ability to pass electrical current through the water sample due to the presence of dissolved salts. Calibration was done by using 0.1 N KCl solution which was prepared by mixing 0.756 gram of KCl in 100ml of distilled water. And measurement was done by dipping the electrodes in the water samples. Instrument display electrical conductivity in mS. And EC can also be measured by using electrical conductivity meter. The temperature was adjusted to 25˚C and same procedure is repeated.

3.2.4 Effect of salinity intrusion on socio-economic status of the coastal belt

The extent of quality of groundwater in the study area has got a great influence on the living status of the community. Similarly, the problem of salt-water intrusion has increased due to the intervention of humans. Detailed socio-economic survey was conducted with the help of structured schedule and personal interviews with the local people in the study area and the following details were collected.

Survey questionnaire;

1. Number of members in the family.

2. Area of land possessed, major crops cultivated, irrigated or not.

3.Livestock and poultry possessed by family.

4. Agricultural implements possessed

5. Main source of drinking water.

6. How would you assess the water quality?

7. Are you satisfied by the aesthetic appearance of water?

8. What do you feel about the taste of water?

9. Is water saline, especially in summer?

10. Is water adequate for you?

11. Is water good for irrigation of crops?

12. Do you feel any health hazards for the drinking water?

13. Economic status (APL/BPL/Red card).

3.3 GROUNDWATER MODEL

A model that simulates groundwater flow is the simplified representation of the subsurface aquifer system, which may be used to predict aquifer response to various input/output stresses. The three-dimensional movement of groundwater of constant density through porous medium may be described by partial-differential equation (McDonald and Harbaugh,1988). MODFLOW uses the following equations for groundwater flow simulation:

3.3.1 Flow Equation

Groundwater modelling begins with a conceptual understanding of the physical problem. The next step is translating the physical system to mathematical terms. Most models solve the general form of the three- dimensional groundwater flow equation which is a combination of water balance equation and Darcy's law, given by

$$\frac{\partial \left(Kx \frac{\partial h}{\partial x}\right)}{\partial x} + \frac{\partial \left(Ky \frac{\partial h}{\partial y}\right)}{\partial y} + \frac{\partial \left(Kz \frac{\partial h}{\partial z}\right)}{\partial z} \pm W = Ss \ \frac{\partial h}{\partial t}$$

Where,

Kx, *Ky*, and *Kz* are the values of hydraulic conductivity along the x, y and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity h is the potentiometric aquifer head,

W = Volumetric flux per unit volume representing sources and/or sinks of water, with *W* <0.0 for flow out of the groundwater system, and *W* >0.0 for flow in the groundwater system,

S_s =Specific storage of the porous material, and

t = Time.

This equation, when combined with boundary and initial conditions, describes transient three-dimensional groundwater flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions. McDonald and Harbaugh (1988) used a finite difference version of this equation in MODFLOW, where the groundwater flow system is divided into a grid of cells. For each cell there is a single point called node at which the head is calculated. The equation is solved in MGO using the modular three dimensional finite difference ground water flow model, MODFLOW.

3.4 DATA COLLECTED FOR THE STUDY

The following data are needed for the study area;

1. Base map of the study area
2. Spatial location of the observation wells obtained using Garmin GPS model etrex 30
3. Hydrogeologic and geologic characteristics and parameters of the study area including the hydraulic conductivity and bottom elevations of layers were collected from previous work.
4. Water table data collected from 18 observation wells in the area.

3.5 DETAILED METHODOLOGY

The model was developed using VISUAL MODFLOW 2.8. Microsoft Excel was also used for input data preparation. The final model design follows several model runs to best match field data with model results. The conceptual model information is translated into mathematical model and model choices are made to suit the data entered and output required. Visual MODFLOW requires model data to be entered in consistent units. Selected units are meters and day, except for recharge where mm/y is used.

Model needs include:

- Layers
- Recharge

- Surface elevation
- Elevation limits
- Bottom elevation
- River conductance
- Grid

3.5.1 Creating the model

Map of the study area coming under Tavanur - Ponnani region, obtained from Google Satellite view is taken as base map which is converted in to bmp format and is imported into the model. The base map is georeferenced with co-ordinates (0,0) and (9561.3,9623.9). Thus the study area is confined to a base map .The model is based on a rectangular block-centred grid network. The model domain and units of measurement is given in Fig 3.3. The model configuration is presented in Table 3.2.The grid formation of the study area given in Figure 3.4.

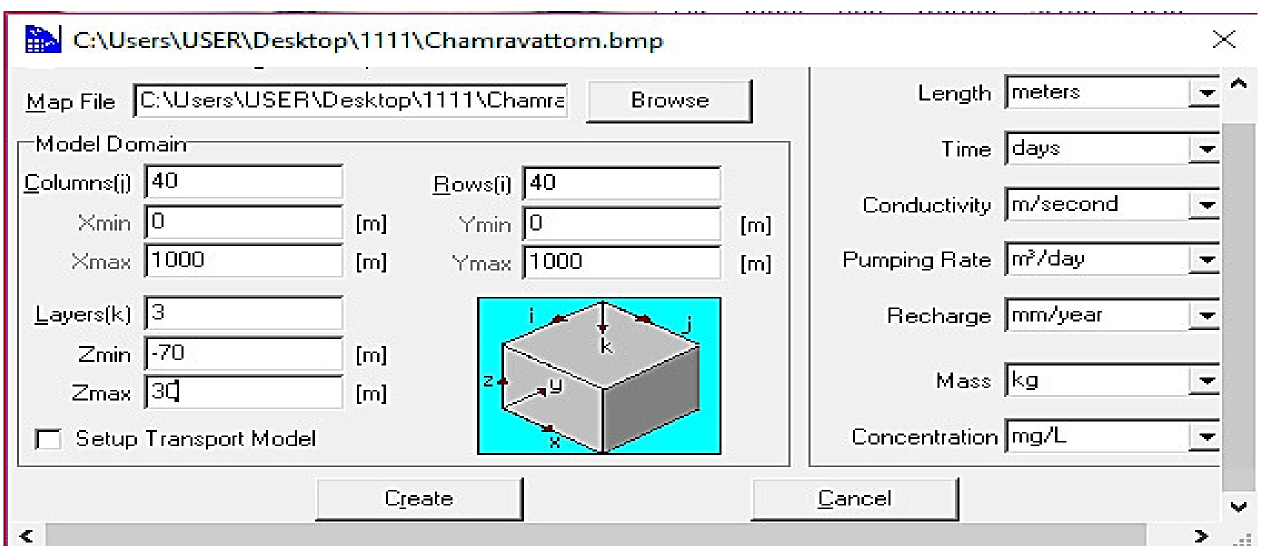

Fig 3.7 Model domain and units of measurement

Characteristics	Value
Maximum model elevation	30
Minimum model elevation	-70
Layers	3
Rows	40
Columns	40

Table 3.2 Model Configuration

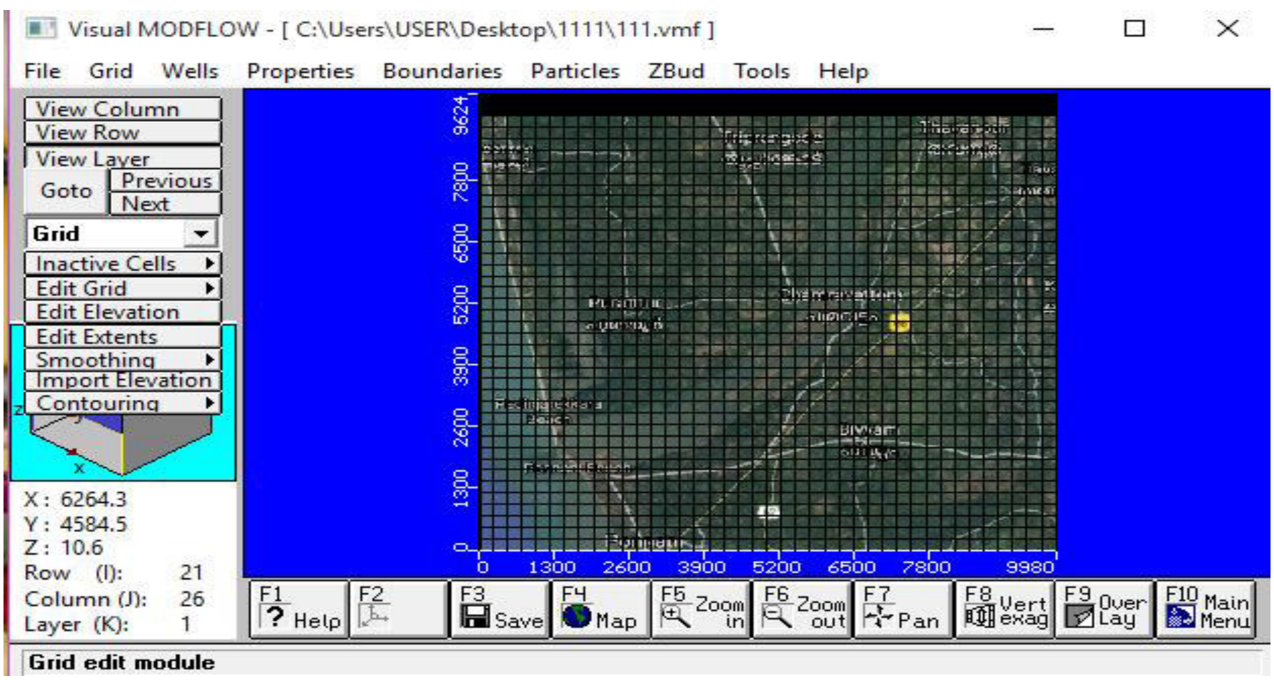

Fig 3.8 Grid formation of study area

3.5.2 Vertical Exaggeration

To properly the display the three layers you will need to add vertical exaggeration to the cross-section.

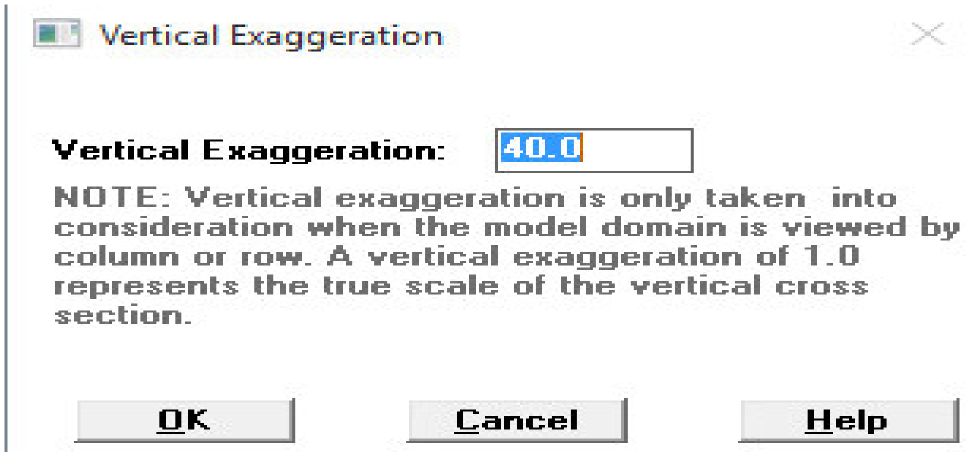

Fig 3.9 Vertical exaggeration

3.5.3 Importing elevation

Elevation data of 3 layers were exported from Microsoft Excel and imported to Visual MODFLOW. The model surface elevation values prepared as a Microsoft Excel file and it is given in Appendix 1.

3.5.4 Adding wells

Field observations of elevation and head observations at successive intervals from observation wells are input to the Visual MODFLOW to get model output values. Coordinates for the position of observation wells are also imported. The observation well data are given as a table in Appendix 2. The details of adding wells in MODFLOW is given in Figures 3.6 and 3.7.

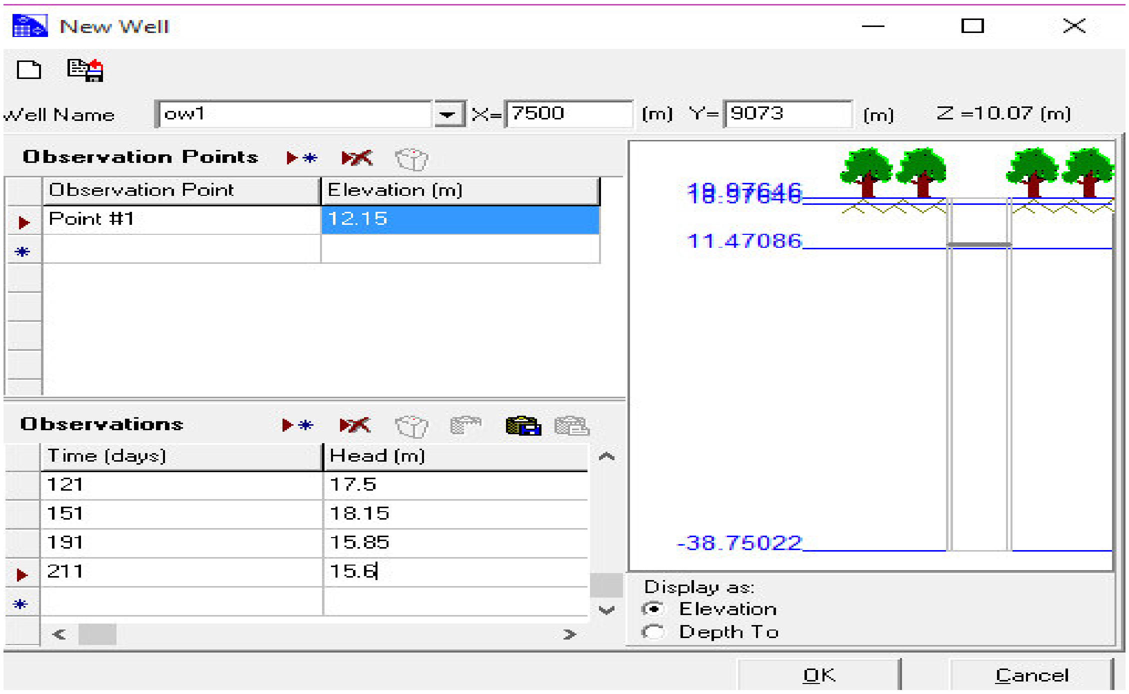

Fig 3.10 Observation wells add mode

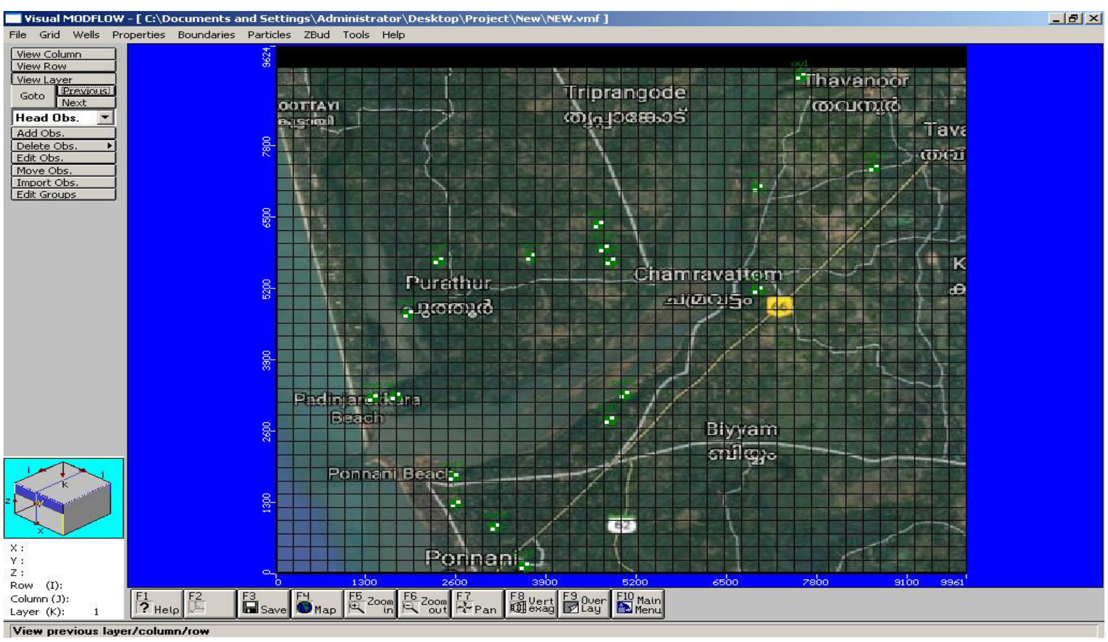

Fig 3.11 Adding wells

3.5.5 Adding properties

The hydrogeologic layers of the model are bounded by lateritic rock in the top and at bottom bounded by sandy soil and lateritic soil in between these two. The steady state model requires the hydraulic conductivity of each model layer. The hydraulic conductivity zone vary widely in the area and the hydraulic conductivity of various layers given in Table 3.1.The resulting window in MODFLOW is shown in Fig 3.8

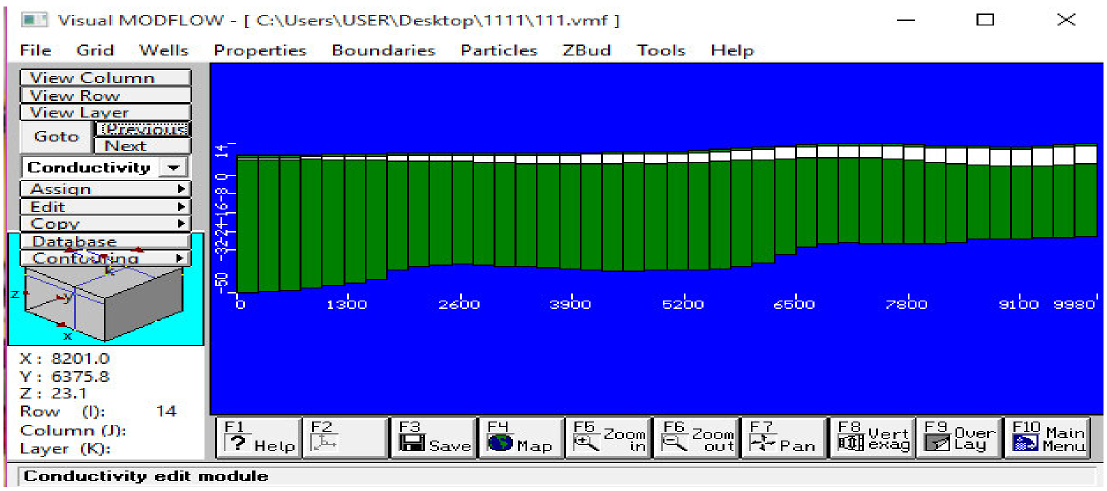

Fig 3.12 Adding hydraulic conductivity-column view

3.5.6 Storage

Visual MODFLOW requires four parameters such as Specific storage (*Ss*) in m^{-1}, Specific yield (*Sy*), Effective porosity (Eff. Por.) and Total porosity (Tot. Por) as input in the storage menu. The model determines primary storage coefficient (sf1) by multiplying specific storage (*Ss*) with the layer thickness. The storage term of unconfined aquifer is known as the specific yield. Storage properties used in this study were collected from different literature and is presented in Table 3.3.

Model Characteristics	Values
Specific storage, $S_s(m^{-1})$	0.00035
Specific yield, S_y	0.20
Effective Porosity	0.35
Total Porosity	0.40

Table 3.3 Model characteristics

3.5.7 Adding boundaries

The boundary conditions of any model must represent the system's relationship with the surrounding areas. Model results depend on the quality of these data. For the study area three types of boundaries supported by MODFLOW were chosen: River, constant head and recharge.

3.5.7.1 River

The river boundary condition is used to simulate the influence of a surface water body on the ground water flow. The effect of flow between the rivers and aquifer was simulated by dividing the rivers into reaches containing single cells. The MODFLOW river package input file requires the following information for each grid cell containing a river boundary.

River Stage: The free water surface elevation of the surface water body. This elevation may change with time.

Riverbed Bottom: The elevation of the bottom of the seepage layer (bedding material) of the surface water body.

Conductance: A numerical parameter representing the resistance to flow between the surface water body and the ground water caused by the seepage layer (riverbed).

Bharathapuzha river is flowing through the study area and is having different river stage elevations. River stage elevation (m), river bottom elevation, start time(day), stop time(day) and conductance of river are entered as shown in Fig 3.8. The river boundary in the study area is as given in Fig 3.9.

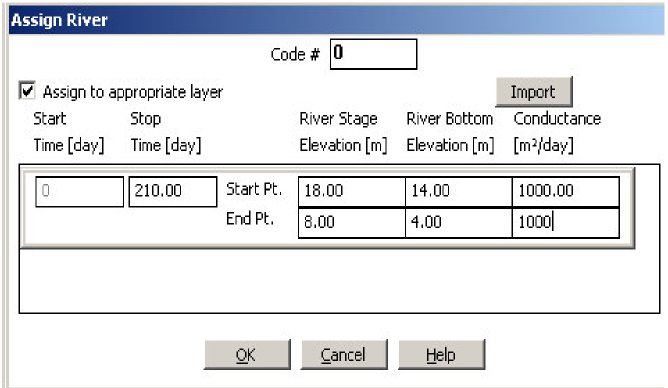

Fig 3.13 Assigning river boundaries

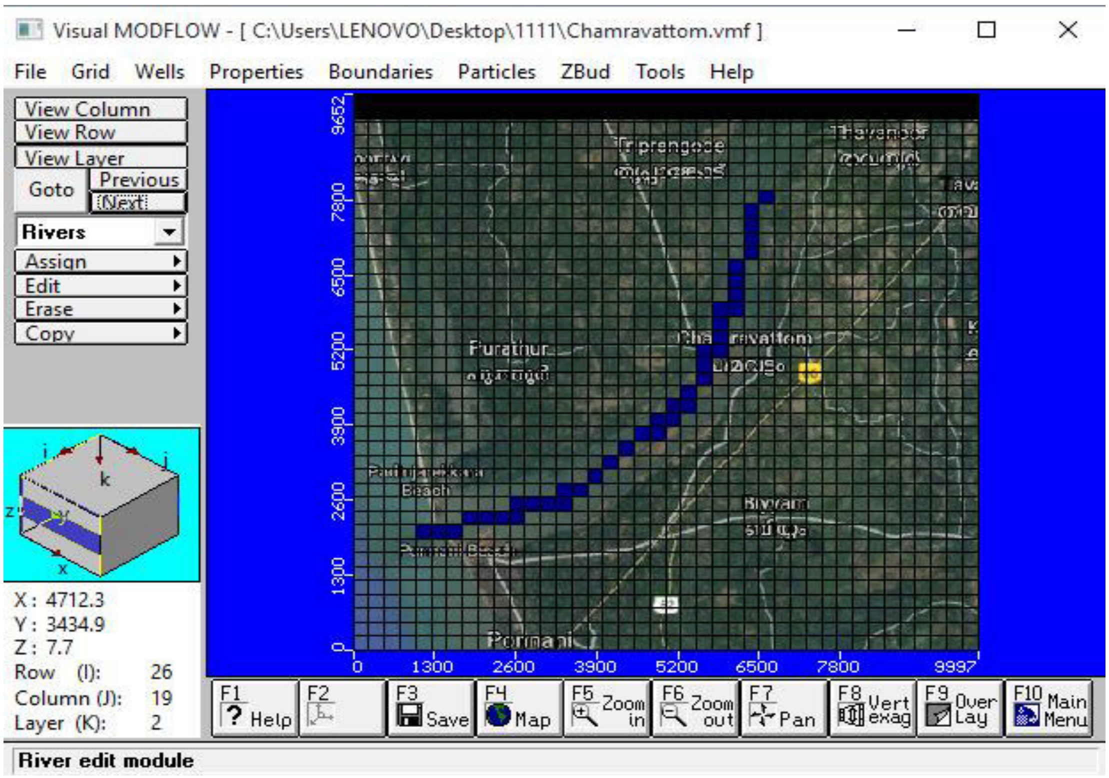

Fig 3.14 River in study area

3.5.7.2 Constant head

The West boundary is considered as constant head boundary. While entering the data, the start point and the end point are given as 7 and 7 respectively. The details of entering the constant head boundary data given in Figures 3.10 and 3.11.

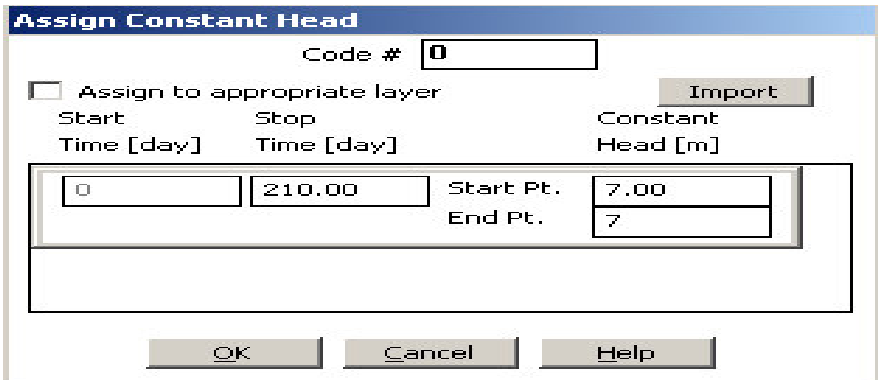

Fig 3.15 Assigning constant head

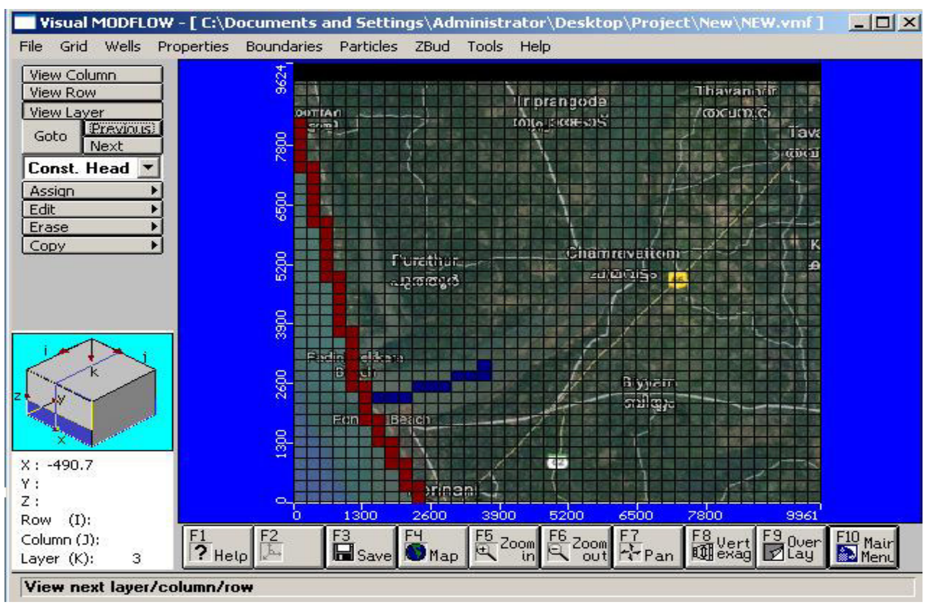

Fig 3.16 Constant head boundary

3.5.7.3 Recharge

Most commonly, aerial recharge occurs as a result of precipitation that percolates into the groundwater system. The recharge package is designed to simulate aerial distributed recharge to the groundwater system. The recharge data entered in Fig 3.12 and is given in Appendix 3.

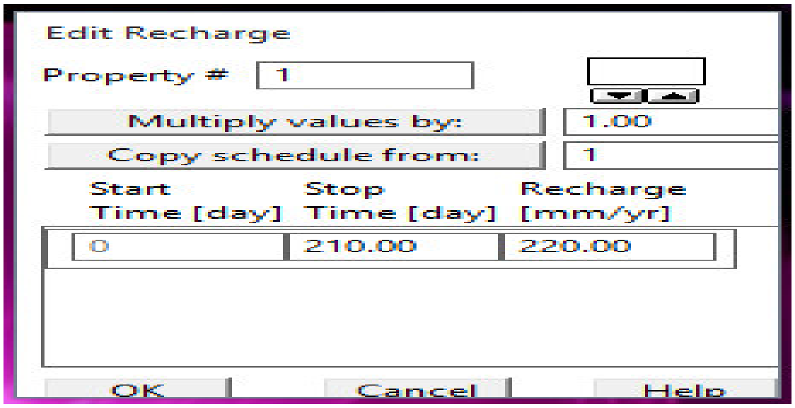

Fig 3.17 Assigning recharge

3.5.8 MODFLOW Run

After completing the input parameters, run model is selected. By selecting [Run] in the main menu, select run type dialogue box appears. The model was run for steady state condition as given below.

Fig 3.18 Run type

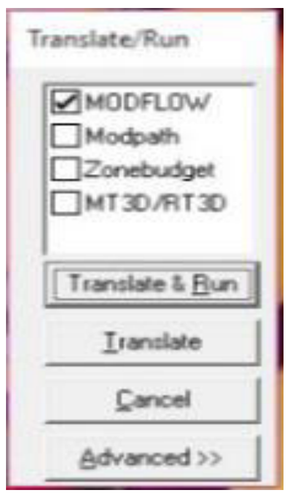

Fig 3.19 Translate and run

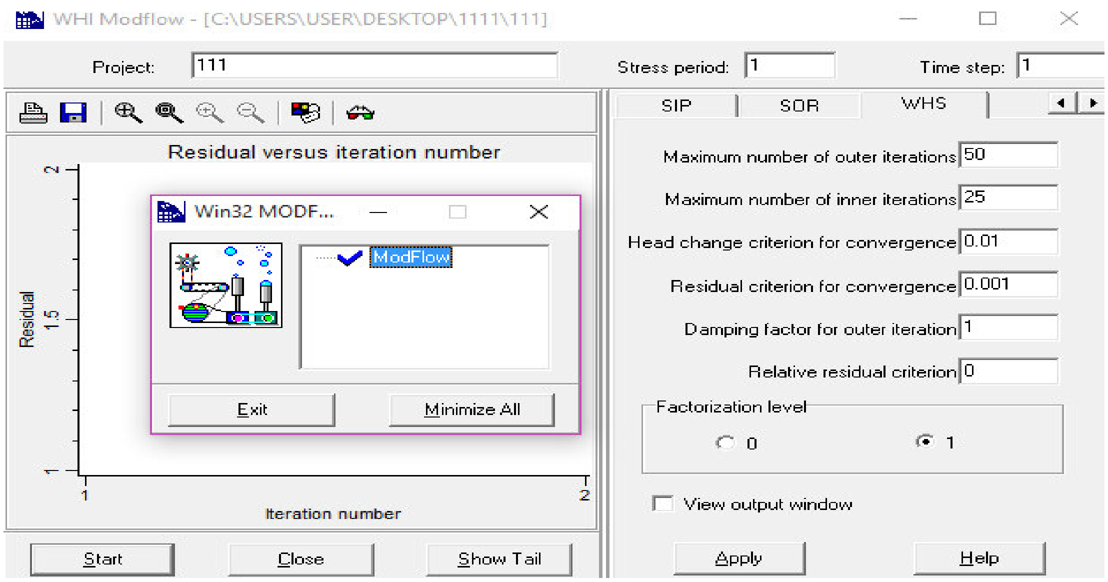

Fig 3.20 After running

3.5.9 Model Calibration

The model was calibrated using observed water level data collected, so that model was capable to produce field measured hydraulic heads and flow. Calibration is a process where in certain parameters of the model such as recharge and hydraulic conductivity are altered in a systematic fashion and the model is repeatedly run until the computed solution matches field-observed values within an acceptable level of accuracy. For the calibration, Root Mean Square (RMS) has been chosen as the calibration criteria and calibration process was continued till no further reduction in RMS values was possible.

3.5.10 Model Validation

After successful completion of calibration of the steady state, the model was used for validating the results obtained. This is accomplished by testing the system with data, which are not used calibration. For this study purpose 18 wells were selected in the study area and water samples and water level data were collected for a period of Eight months.

3.5.11 Model Prediction

From the available validated model, we had predicted the water table values of the next few months by adding more days in the output and time steps of [**Run**].

RESULTS AND DISCUSSIONS

CHAPTER 4

RESULTS AND DISCUSSION

This chapter deals with the results and interpretation related to the modelling of groundwater resources in Tavanur–Ponnani region using Visual MODFLOW. This chapter also includes calibration results and validation results under steady state condition. The Visual MODFLOW output includes contours of head equipotentials, head difference, water table and elevation and also provides velocity vectors with direction of flow. Result of quality analysis of collected water sample and socio-economic survey are also discussed in this chapter. Result obtained in different scenario is also considered for discussion.

4.1 MODEL CALIBRATION

Groundwater model to be used in any type of predictive role, it must be demonstrated that the model can successfully simulate observed aquifer behavior. A steady state calibration of the model was used in reduction of unknown terms of governing equations of groundwater system and uses the results in making the unsteady model. The results of the calibration model in steady state for estimating aquifer hydraulic conductivity and recharge were used in the transient state model. The model performance was evaluated using various criterions including graphical and linear regression method, calibration residual, residual mean, absolute residual mean, standard error of estimate, root mean square, normalized root mean square, correlation coefficient, confidence interval.

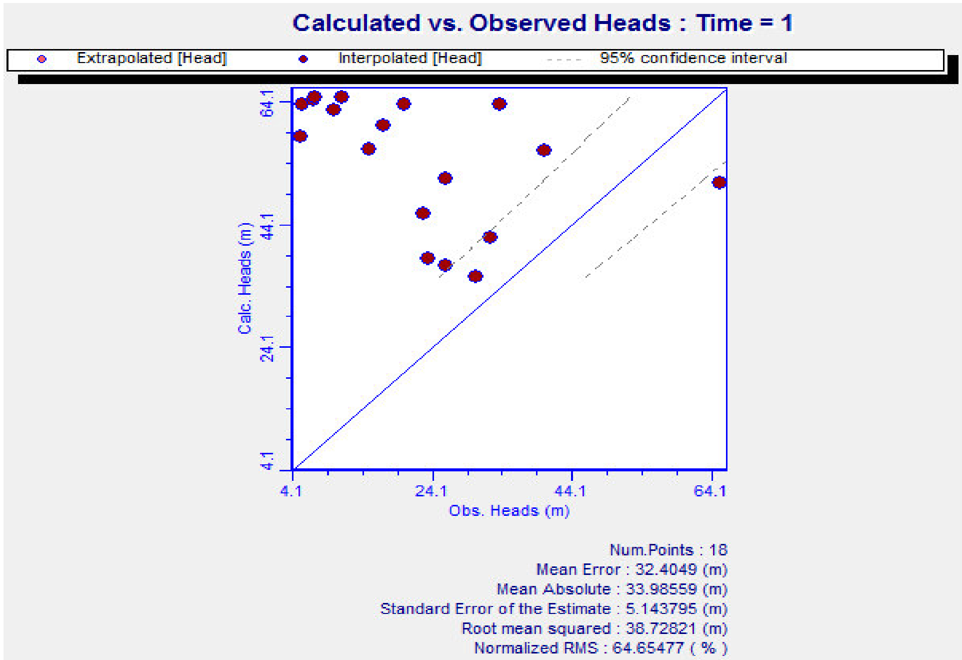

Fig 4.1 Before Calibration

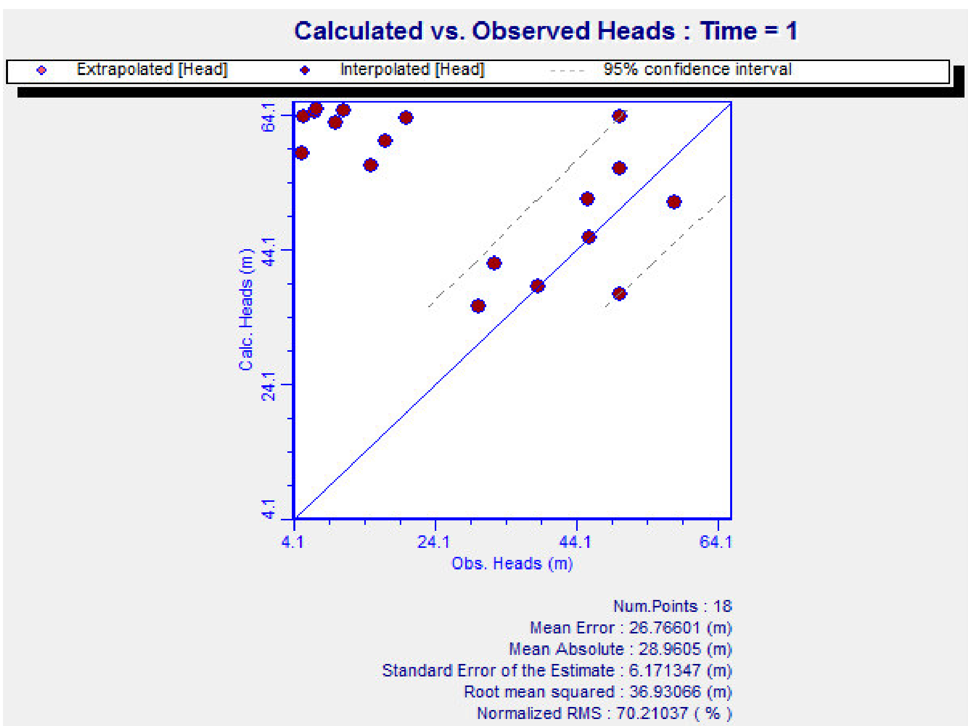

Fig 4.2 After calibration

4.2 MODEL VALIDATION

Validation was carried out to establish greater confidence in the model by using the set of calibrated parameter values and stresses to reproduce a second set of field data . After calibration process, water level data of eight months were used for model validation. Then, the validated model was considered as a useful tool for predicting aquifer response in this study area for various future strategies.

The known observed values of water level for three wells were compared and found matched with the data and the result is presented below in Table 4.1.

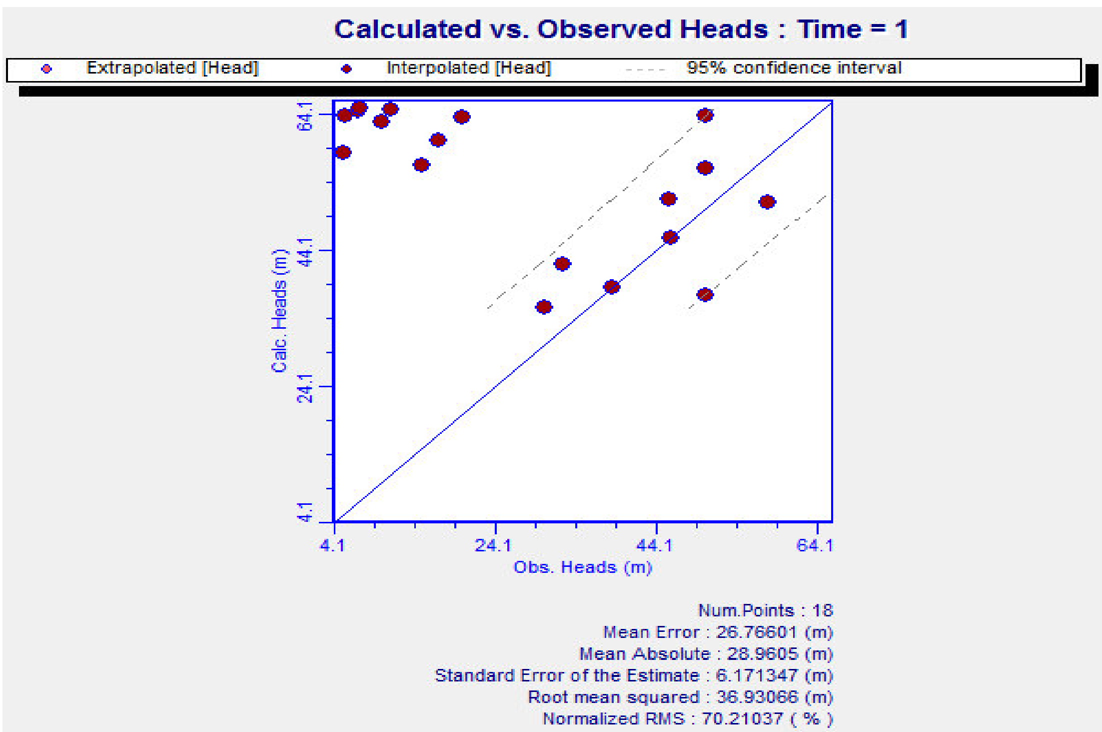

Fig 4.3 Model Validation

Well No	Observed water level, m (Day- 330)	Calcualted water level , m (Day-330)
OW9	61.1	63.73
OW13	51.9	50.97
OW18	40.55	42.09

Table 4.1 Model Calibration

4.3 MODEL PREDICTION

The appropriate prediction of water table is possible only if a validated model is available. From the available validated model, we had predicted the water table values of the next few months by adding more days in the output and time steps of [**Run**].

4.4 OUTPUTS FROM THE MODEL

4.4.1 Zone Budget

Zone budget calculates sub regional water budget using results from steady state or transient MODFLOW simulations. Zone Budget calculates budgets by tabulating the budget data that MODFLOW produces using the cell-by-cell flow option. The user simply specifies the sub-regions for which budgets will be calculated. These sub-regions are entered as 'zones' analogous to the way that properties, such as hydraulic conductivity, are entered. The zone budget in the zone is calculated by the model as shown in Figure4.4.

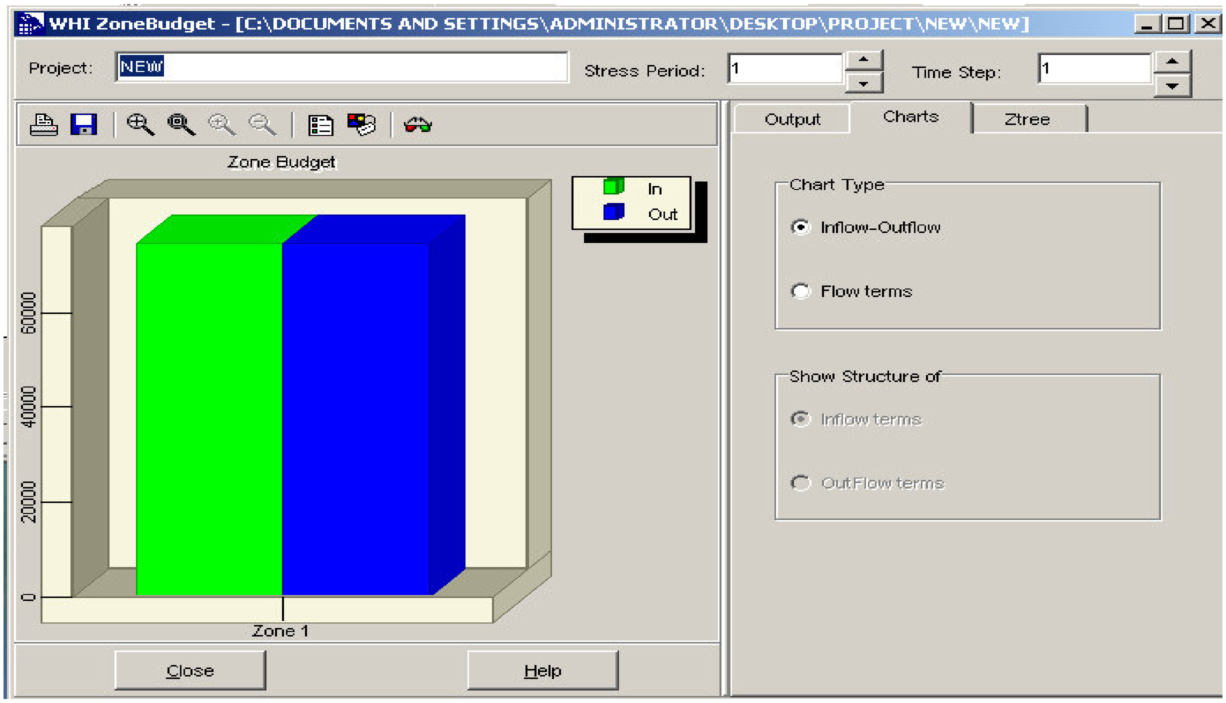

Fig 4.4 Zone Budget

4.4.2 Water Balance

One of the methods of expressing model results is through a water balance. Groundwater leaves the system through river leakage and constant head. Since constant head boundary is assigned along the border of the sea, constant head input value is zero and output value is maximum. Main input of groundwater into the model is river recharge (57453.79m^3) and river leakage (16951.01m^3). And finally water flows into the river (2633.181m^3) and reaches into the sea(71571.62m^3).

Volumetric water balance of the model, input & output volumetric water balance of model in percentage of components are presented in Figures 4.5, 4.6 & 4.7 respectively and input and output in terms of volume in Table 4.2.

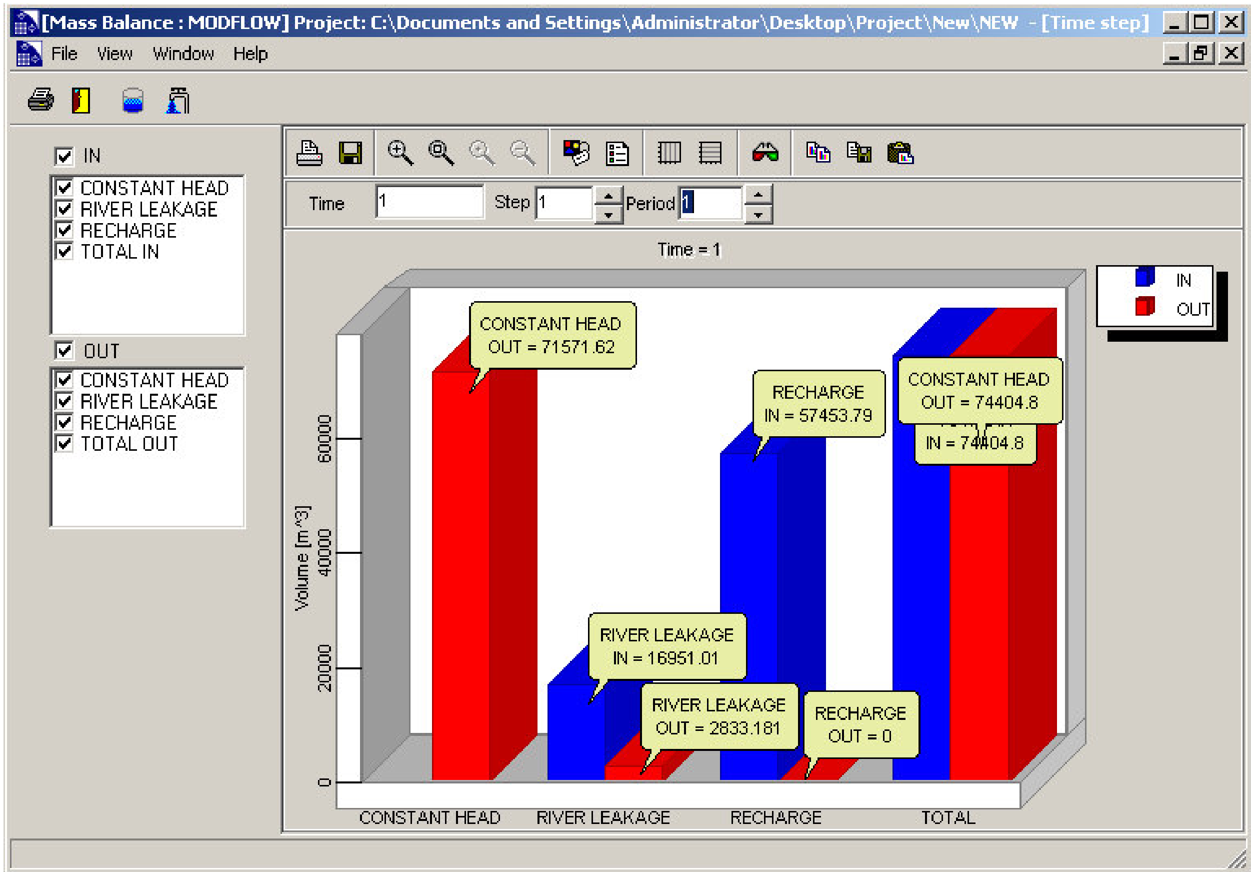

Fig 4.5 Volumetric Water Balance of the Model

ITEM	IN(m^3/d)	OUT(m^3/d)
Constant Head	0	71571.62
River Leakage	16951.01	2833.181
Recharge	57453.79	0
Total	74404.8	74404.8

Table 4.2. Input and Output in terms of Volume

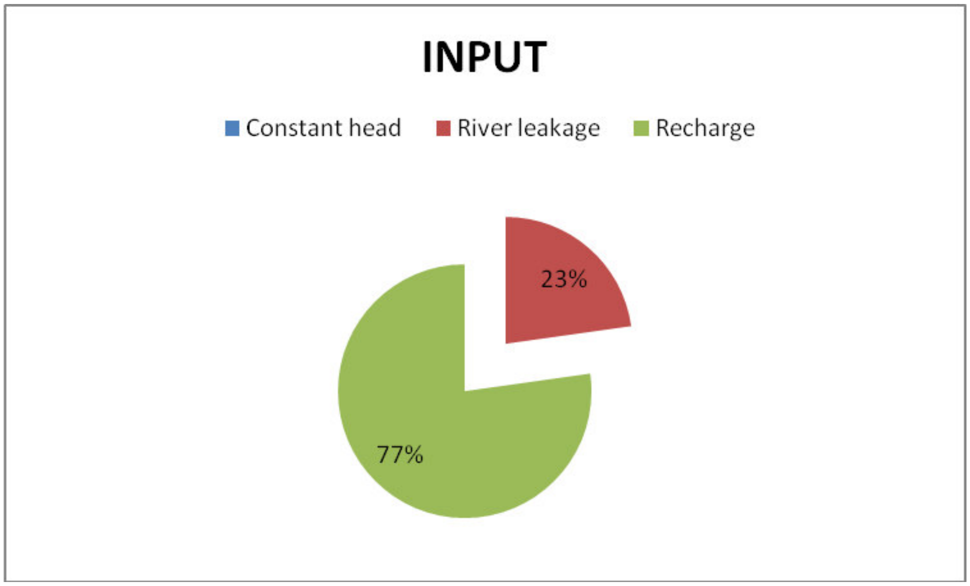

Fig 4.6 Input volumetric water balance of the model in percentage of components

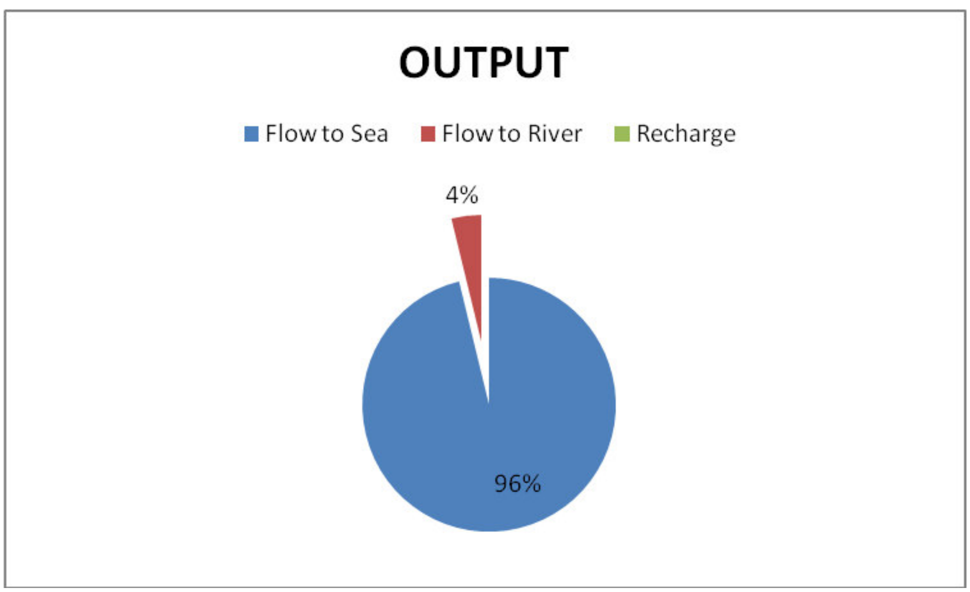

Fig 4.7 Output volumetric water balance of model in percentage of components

4.4.3 Water table contour

The blue lines with labels shows water table contour, that is, lines joining equipotential heads in the study area. South - West boundary of the study area is bounded by Arabian Sea , having constant head and it varying when moving to the North - East region of the study area.

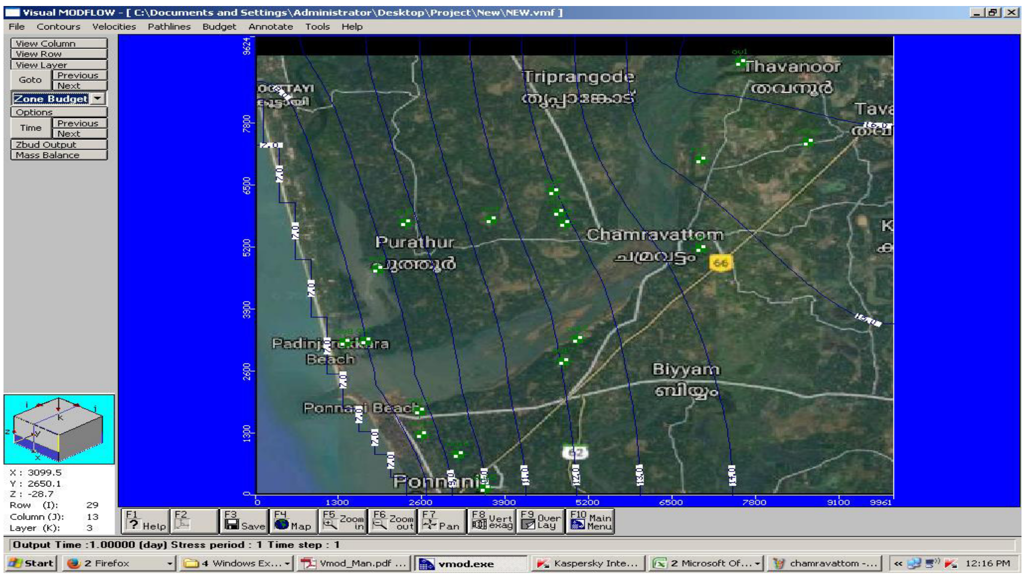

Fig 4.8 Water Table Contour

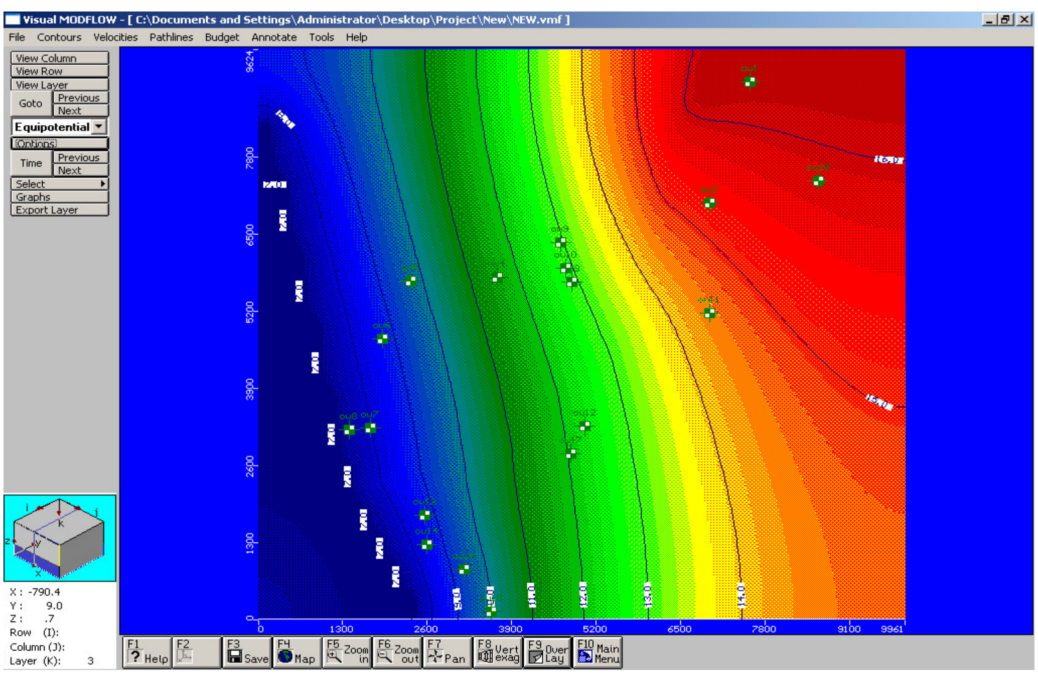

Fig 4.9 Colour shaded Water Table Contour

From the water table contour map of the study area, it can be seen that there is a gradual lowering of water table and the piezometric level as the ground slopes down to the sea.

4.4.4. Velocity Vectors

The Fig 4.7 shows the direction and rate of movement of ground water. It can be seen from the figure that the flow actually takes place from North-East part of study area and reaches to the Sea through river and the land.

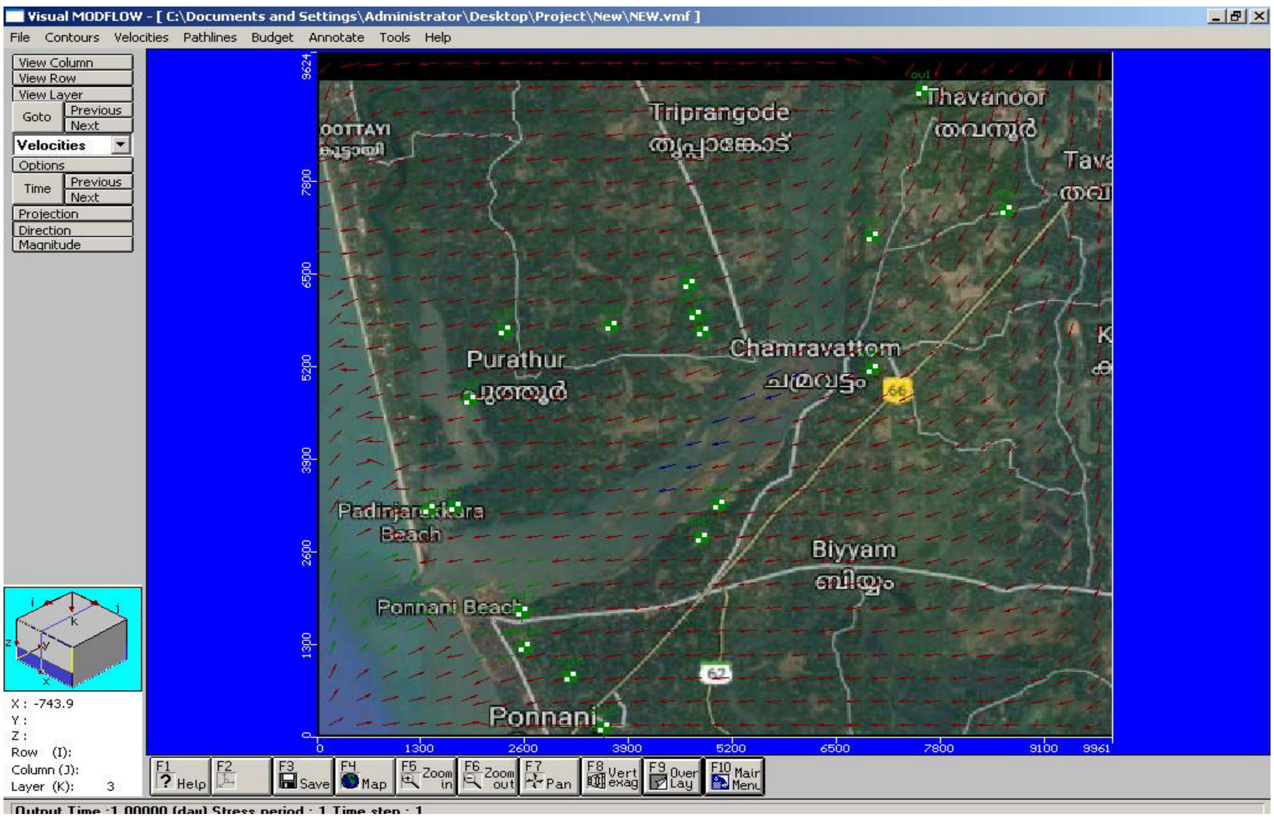

Fig 4.10 Velocity Vector

4.5. QUALITY ANALYSIS OF COLLECTED SAMPLES

The representative samples collected from the 18 wells in study area from May 2017 to January 2018, are subjected to various quality analysis such as Salinity, Electrical Conductivity and Turbidity etc. by using Water Analyser and Electrical Conductivity Meter. The results are shown below

4.5.1 Salinity

The results of the salinity analysis using water analyser is presented in Table 4.3 and the variation of Salinity in some of the wells with time is plotted in Fig 4.11.

Table 4.3 Salinity (ppt) in 18 observation wells

Wells	1st day	31st day	61st day	91st day	121st day	151st day	181st day
1	0.27	0.48	0.40	0.212	0.159	0.3	0.341
2	0.48	0.47	0.41	0.261	0.256	0.31	0.351
3	0.29	0.30	0.28	0.188	0.217	0.27	0.188
4	0.25	0.48	0.41	0.178	0.232	0.39	0.31
5	0.31	0.22	0.28	0.017	0.111	0.18	0.13
6	0.44	0.39	0.25	0.371	0.513	0.36	0.447
7	0.46	0.77	0.32	0.202	0.144	0.21	0.154
8	0.32	0.87	0.39	0.056	0.16	0.2	0.1
9	0.13	0.29	0.15	0.13	0.15	0.18	0.106
10	0.2	0.22	0.23	0.14	0.13	0.19	0.163
11	0.17	0.17	0.21	0.149	0.149	0.26	0.217
12	0.11	0.32	0.29	0.227	0.207	0.28	0.17
13	0.22	0.23	0.29	0.202	0.202	0.30	0.232
14	0.22	0.37	0.40	0.222	0.15	0.30	0.341
15	0.23	0.32	0.25	0.193	0.168	0.24	0.197
16	0.1	0.06	0.27	0.178	0.163	0.283	0.178
17	0.21	0.47	0.20	0.232	0.222	0.25	0.437
18	0.30	0.32	0.24	0.149	0.14	0.20	0.193

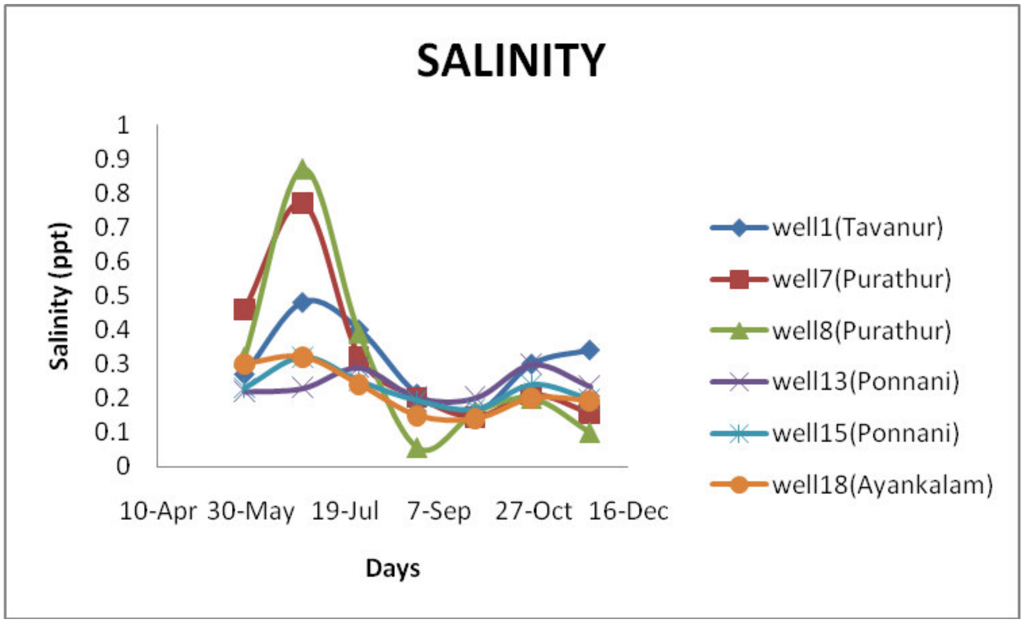

Fig 4.11 Graph showing the effect of salinity in various wells

It can be seen from the graph that for wells nearer to the sea the salt content is maximum till the end of June in and then decreases as the rain water inflow to the sea increases, indicating salt water intrusion in the coastal areas during summer months. One well in Tavanur area shows comparatively higher salinity content for all readings, may be due to local contamination due to excessive fertilizer content or other reasons. For other wells not nearer to the sea, there is not much variation of salinity content.

4.5.2 Electrical Conductivity

The electrical conductivity of the samples were determined using the electrical conductivity meter and is presented in Table 4.4. A graph showing the variation of EC with time for some of the wells is plotted in Fig 4.12. The trend in the variation of EC is also similar to salinity, i. e., with higher variation of EC (maximum and minimum) in wells nearer to sea and less variation in other wells

Well	1st day	31st day	61st day	91st day	121st day	151st day	181st day
1	0.7	0.956	0.52	0.35	0.33	0.31	0.4
2	0.963	0.5	0.57	0.39	0.33	0.32	0.45
3	0.59	0.619	0.4	0.39	0.31	0.3	0.39
4	0.544	0.882	0.6	0.37	0.3	0.35	0.31
5	0.633	0.467	0.42	0.2	0.23	0.348	0.32
6	0.947	0.824	0.73	0.5	0.19	0.4	0.60
7	0.956	0.804	0.6	0.42	0.3	0.45	0.7
8	0.676	1.08	0.65	0.6	0.12	0.49	0.75
9	0.264	0.246	0.23	0.61	0.26	0.339	0.22
10	0.412	0.454	0.33	0.29	0.27	0.37	0.34
11	0.359	0.347	0.32	0.31	0.25	0.39	0.45
12	0.240	0.678	0.46	0.47	0.29	0.37	0.36
13	0.476	0.48	0.42	0.42	0.42	0.37	0.45
14	0.663	0.785	0.69	0.46	0.32	0.35	0.7
15	0.494	0.672	0.36	0.4	0.35	0.32	0.41
16	0.204	0.135	0.4	0.37	0.34	0.443	0.37
17	0.8	0.903	0.59	0.48	0.39	0.478	0.59
18	0.625	0.666	0.35	0.31	0.29	0.392	0.4

Table 4.4 Electrical Conductivity (mS) in 18 Observation wells

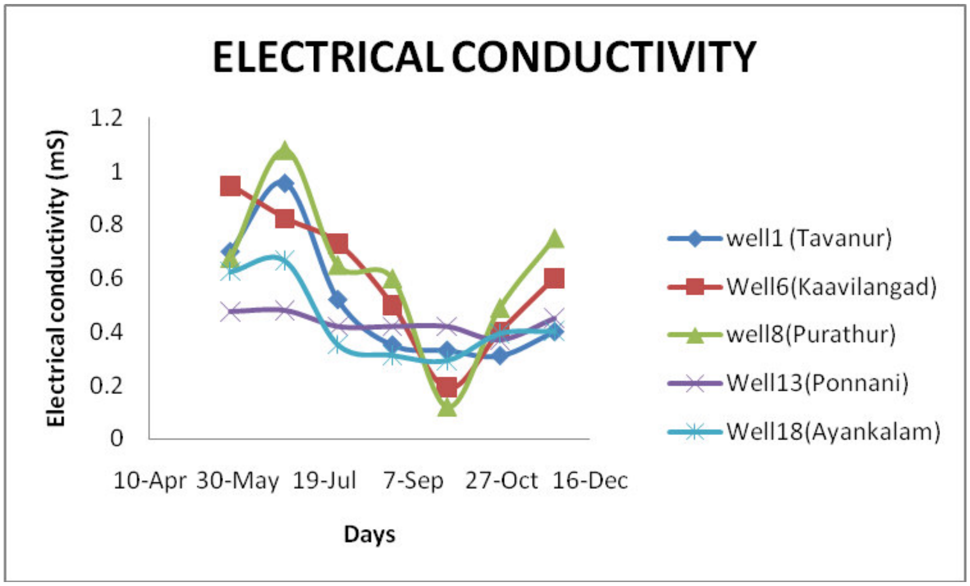

Fig. 4.12 Graph showing the effect of Electrical Conductivity in various wells

4.5.3 Turbidity

The results of turbidity analysis is given in Table 4.5 and Fig 4.13.

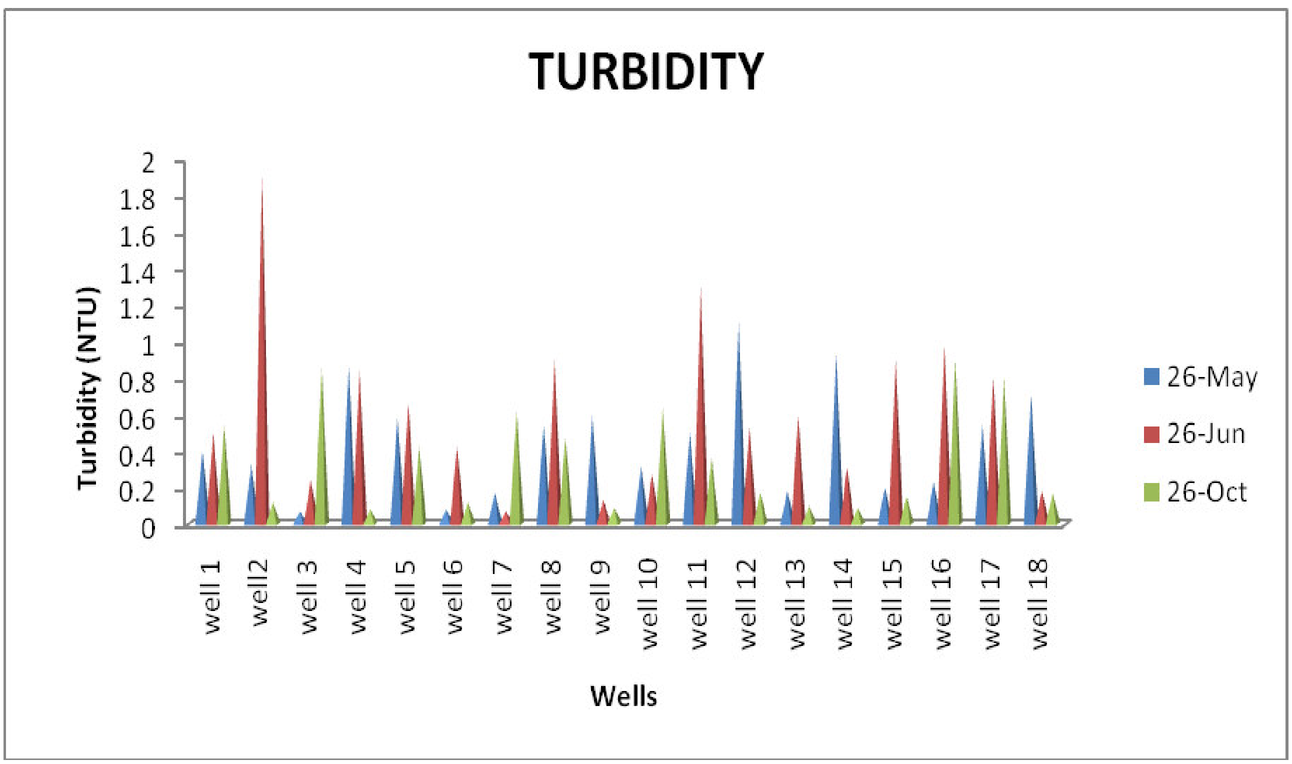

Fig 4.13 Graph showing the effect of turbidity in various wells

Wells	26 May	26 June	26 October
well 1	0.4	0.5	0.54
well2	0.33	1.9	0.12
well 3	0.07	0.24	0.85
well 4	0.86	0.84	0.08
well 5	0.58	0.66	0.42
well 6	0.08	0.42	0.12
well 7	0.17	0.07	0.61
well 8	0.54	0.9	0.47
well 9	0.59	0.13	0.09
well 10	0.32	0.27	0.64
well 11	0.5	1.3	0.36
well 12	1.1	0.53	0.17
well 13	0.18	0.59	0.1
well 14	0.93	0.31	0.09
well 15	0.2	0.9	0.15
well 16	0.23	0.98	0.9
well 17	0.55	0.8	0.8
well 18	0.71	0.18	0.17

Table 4.5 Turbidity in 18 Observation wells

4.5.4 Water table level variation

Water table in the wells for the study period is presented in Table 4.6 and also as graph in Fig 4.14. The variations of water level in the observation wells follows the rainfall pattern of the area.

wells	May 26	June26	July 26	Aug 26	Sep 26	Oct 26	Nov 26	Dec 26
well 1	4.85	2.9	5.9	8.5	2.5	1.85	4.15	4.4
well2	5.7	0.45	0.6	0.7	0.7	1.1	1.9	2.65
well3	4.6	1.9	4.1	9	2.74	2.3	3.9	4.2
well4	3.7	0.47	2.1	3.8	0.8	1.3	2.45	3
well5	4.95	2.85	5.2	7.55	2.1	2.95	3.3	3.65
well6	2.4	0.32	2.9	4.35	0.7	0.85	2.15	1.5
well7	1.2	0.25	3.7	4.7	0.9	0.9	0.9	0.95
well8	0.97	0.27	4.1	4.57	0.87	0.62	0.82	0.62
well9	2.83	0.55	3.6	4.1	1.3	1.3	1.2	1.55
well10	3.2	0.45	3.9	4.5	0.9	1.5	1.9	2.35
well11	2.65	0.4	4	4.15	0.9	1.3	1.6	1.79
well12	3.45	0.15	2.9	3.25	0.6	1.2	2.15	2.55
well13	2.1	0.15	1.8	2.7	0.4	0.73	1.25	1.65
well14	2.9	1.2	5.4	7.7	0.6	2.27	2.5	2.9
well15	2.65	0.8	3.2	4.7	0.9	1.25	1.2	2.05
well16	3.05	0.3	2.5	3.9	0.8	1.1	1.65	1.85
well17	3.9	0.59	3.3	4.5	0.95	0.9	1.55	2.3
well18	4.3	0.65	2.6	4.5	0.5	1.18	2.2	2.15

Table 4.6 Water Table Variations in Observation Wells

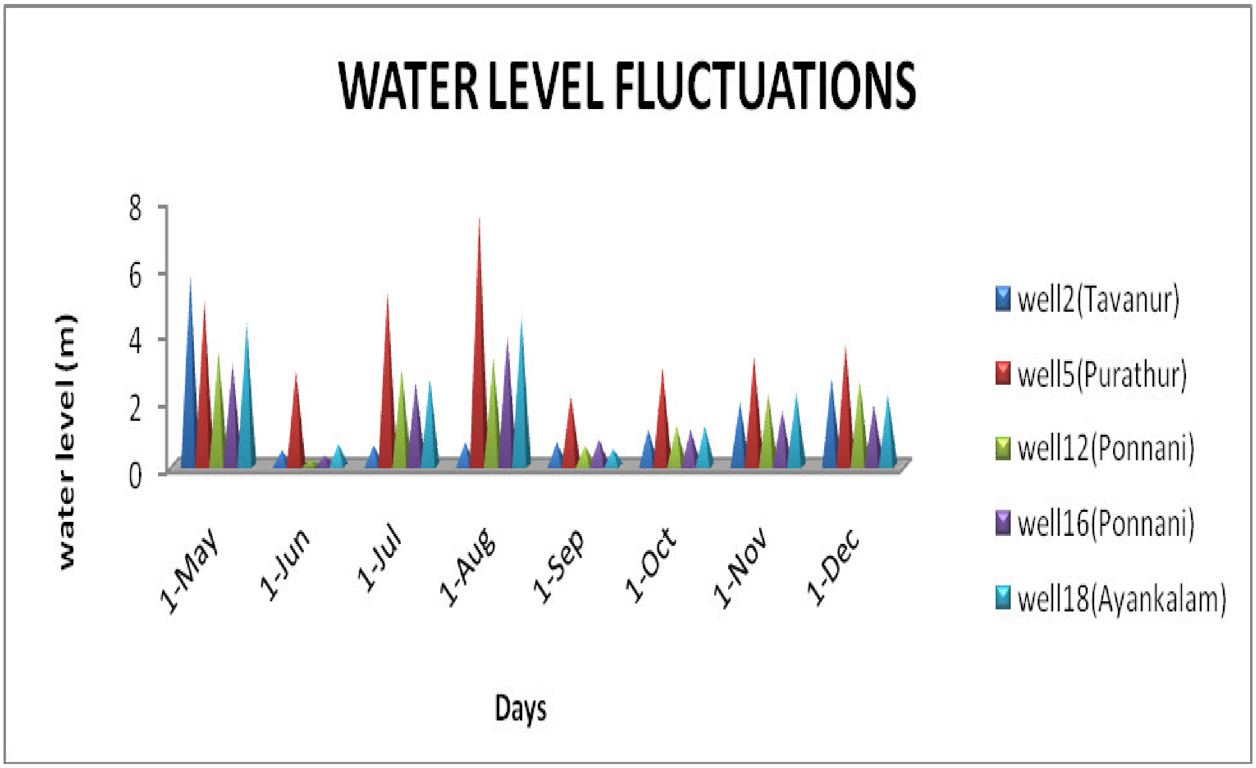

Fig.4.14 Graph showing the Water Table Variations during the Study Period

4.6.SOCIO-ECONOMIC SURVEY

The results of the socio-economic survey conducted in the study area, is presented in table below with the percentage of persons who opted for that answer.

QUESTIONS	ANSWERS
Main Source of drinking Water?	• Open Well (83%) • Tube well (17%)
Is there any cultivation?	• Cultivated (35%) • Not cultivated (65%)
Agricultural Implements possessed?	• No (0%)
How would you assess the water quality?	• Good (50%) • Fare (33%) • Not at all Good(17%)
Are you satisfied with the aesthetic appearance of water?	• Good (66%) • Fare (20%) • Not at all Good (14%)
What you feel about the taste of water?	• Good (22%) • Fare (61%) • Not at all Good(17%)
Is water saline, especially in summer?	• No (88%) • May be • Yes (12%)
Is water adequate for your family?	• No (33.3%) • Yes (66.6%)
Is water good for irrigation purposes?	• No (45%) • Yes (55%)
Do you feel any health hazards for drinking the water in the well?	• No (100%) • Yes (0%)
Economic Status(APL/BPL)	• APL (87%) • BPL (17%)

Table 4.7 Results of socio-economic survey

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

Utilisation of groundwater is increasing day by day, leading to decrease in groundwater availability and increase in the extent of saline water intrusion. The ponnani coastal area is also subjected to these problems and so this area is selected for the study. In this study, Visual MODFLOW software version 2.8.1 was used for the flow modelling of the study area. The conceptual model for the study area was developed. 18 observation wells are selected from the study area. After the conceptual model developement, the study area was discretized and analysed. Hydrogeological parameters such as hydraulic conductivity, specific storage, specific yield, porosity and initial heads and boundary conditions of the model domain including constant head, rivers, drains, recharge were used as input of Visual MODFLOW. After giving the input parameters, the model was run for steady state. The model was developed and calibrated. Then the developed model is validated tan be used to predict the flow head for future.

Chamravattom-Ponnani region is a coastal region, so in order to understand the salt water intrusion in these area we collected water samples from 18 observation wells. And these water samples are tested for salinity using water analyser. Electrical conductivity and turbidity are also measured. And to study the effect of salinity on public a socio-economic survey was also conducted in the study area.

5.2 CONCLUSION

A steady state groundwater model has been developed by using Visual MODFLOW. The model water balance was calculated. The input parameters were taken from previous studies. In this approach, the distributed wells, vertical and horizontal hydraulic conductivity of the three layers, constant head, river, and recharge boundary conditions were the inputs to the groundwater system. The groundwater level and the flow budget were calculated as outputs of the model. The general flow direction was towards the river and to the sea. Uncertainty of parameter estimates and boundary conditions may be the most significant limitation. Slight alterations in parameters such as hydraulic conductivity and recharge can lead to dramatic differences in model output.

Similarly, boundary conditions strongly control the flow regime, and so a poor representation can result in an inaccurate model.

Salinity and electrical conductivity test reveals that there is an influence of sea water in the study area. This affect is more during non rainy reasons. That is, we found significant influence of sea water intrusion in Coastal region of Ponnani.

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CHAPTER 6

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GROUNDWATER FLOW MODELLING USING VISUAL MODFLOW AND STUDIES ON THE EFFECT OF SALINE WATER INTRUSION IN TAVANUR - PONNANI AREA

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ABSTRACT

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ABSTRACT

Groundwater is an important source of water which is drastically declining due to the increased exploitation by human beings. Groundwater models are increasingly used in modelling of groundwater flow problems to develop useful information about groundwater resources.

Visual MODFLOW is an efficient groundwater flow modelling software. In this study the MODFLOW model is applied to assess the groundwater flow and availability in Tavanur-Ponnani area of Malappuram district, Kerala. 18 0bservation wells were established in the study area. A conceptual model was constructed based on the topographical, climatic and hydrogeological data of the area along with the field observation data including the water table level in the observation wells. The recharge in the area was taken as 10% of the average rainfall of the area during the period of study. A steady state model was developed on the basis of the average groundwater heads for a 3 year period.

The study also includes the calibration of the model, the validation of the model and the prediction of the groundwater conditions of the study area in the succeeding year. The model predicted the flow of groundwater and its velocity in magnitude and direction. The western part of the study area is taken as the constant head boundary and the river boundary is taken along the river bharathapuzha with proper values of river stage and bottom elevations. The model created during our study provides a clear idea of the groundwater characteristics of the Tavanur-Ponnani area and it will help in the future studies and development of the groundwater management in the area. The groundwater modelling using the visual MODFLOW software is well understood by this study. Samples of water were collected from the observation wells established in the study area. Quality analysis of the water sample was done to assess the quality of groundwater and the extent of salt water intrusion

the area. A socio-economic survey was done to get an idea about the effects of saline water intrusion on the living status of people in the area. This study helped us to get an overall idea about the quality of water and its effect on people in our study area.

APPENDIX I

ELEVATION DATA OF DIFFERENT WELLS

X Coordinates	Y Coordinates	Ground Layer	Lateritic Rock	Lateritic Soil	Sandy Soil
7168.2	9073	20	19.5	11.5	-23.5
6552.1	7025	14	14	8	-27
6049	5854.4	13	13	7	-43
4824	5690.3	10	10	6	-41
3684.7	5773.3	9	9	4	-41
2352.1	5705.1	10	10	6	-33
1617.5	4729.9	8	8	8	-57
1728.7	3233	8	8	8	-62
1400.6	3203.5	8	8	8	-64
4659.1	6357.7	10	10	5	-40
4734.7	5931.8	11	11	6	-44
5917.7	5170.5	11	11	5	-30
4734.7	3258.8	12	12	6	-23
2558.1	1765.6	18	18	14	-41
1398.7	1256.9	11	11	7	-43
2095.1	34.7	10	10	5	-36
3176.1	838.4	9	9	4	-51
4805.7	2790.6	9	9	3	-42

APPENDIX II

WELL DATA

Time (days)	Ow 1	Ow 2	Ow 3	Ow 4	Ow 5	Ow 6	Ow 7	Ow 8	Ow 9	Ow 10	Ow 11	Ow 12	Ow 13	Ow 14	Ow 15	Ow 16	Ow 17
1	17.2	10	7	5.3	7	5.6	6.8	7.0	7.5	13	7.35	6.5	12	11.5	10	11	10
31	16.1	13.5	9.8	8.5	7.1	7.6	7.7	7	9.4	13.5	8.5	7	12.5	11.2	9.1	10	10.1
61	16.5	12.8	8.9	7.9	7.7	7.2	4.8	6.8	8.7	12.7	8	7.1	12.2	11.2	9	10	10.5
91	17.5	13.3	8	5.2	7.4	6.5	5.8	6.9	7.5	9.5	8.2	7.5	11	11.5	9.5	9.2	10.2
121	18.1	13.3	7.2	8.2	7.9	6.2	5.4	6.7	7.2	13.1	8.7	7.2	11.9	11.4	9.4	9.5	10.4
151	15.8	12.9	7.7	7.7	7.0	7.1	5.4	6.5	7.1	12.5	8.5	6.8	11.8	11.2	9.4	9.7	10.2
181	15.6	12.1	6.1	6.5	6.7	5.8	5.1	6.2	7	12.1	9.2	6.4	11.5	11.2	9.3	9.6	10.2
211	15.2	11.3	5.5	6	6.3	5.7	5.1	6.2	7.1	11.6	8.3	6	11.5	11.4	9.5	9.6	10.7