CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Groundwater is the primary source of water for domestic, agricultural and industrial uses in many countries and its contamination has been recognized as one of the most serious problems in Iran. The industrial waste water, sewage sludge and solid waste materials are currently being discharged into the environment indiscriminately. These materials enter subsurface aquifers, resulting in the pollution of irrigation and drinking water. Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors, may cause periodic changes in groundwater quality. Generally, shallow groundwater is affected more by contamination compared with deep groundwater .The coastal groundwater system is fragile and its evaluation will help in the proper planning and sustainable management. A coastal aquifer, characterized by having at least one side of its perimeter in direct contact with sea, besides being exposed to possible urban, industrial or agricultural pollution coming from the mainland, is highly subject both to saltwater intrusion and deterioration of its quality. This problem is very common in many parts of the world. It is often associated with over pumping in coastal regions, resulting in overdraft conditions and creating an inland gradient of saltwater.

The coastal aquifers of Kerala experience severe degradation of water quality due to various anthropogenic activities. Kerala, the southernmost state of India has unique hydrogeological characteristics with wide variation in the rainfall pattern (average 3107 mm). Both qualitatively and quantitatively, the coastal zones of Kerala in recent years witnessed serious groundwater problems. Several studies invariably showed that water quality in the shallow aquifers situated in the coastal zone of Kerala is deteriorating alarmingly amidst plenty of water all around. Owing to the high demand of groundwater to cater a large population in the coastal zones of Thiruvananthapuram, mitigation of the deterioration in the quality of groundwater in shallow coastal aquifers was initiated through groundwater recharge. High population pressure, intense human activities, inappropriate resource use and absence of proper management practices leads into the deterioration.

During rainy seasons, the sea becomes rough and encroaches towards land and during summer seasons the saline water finds its way through tidal channels and it admixes with shallow coastal aquifers. So the qualities of water in the shallow and deeper zones become brackish. Added up problems such as urbanisation, industrialization, unscientific landuse, lack of awareness of the people and saline intrusion all makes the quality of groundwater in Thiruvananthapuram coastal zone worsen. All these contribute to less recharge into the coastal aquifers thereby accentuating groundwater quality and the problem of saltwater intrusion. The present study aims to conduct a study on the coastal regions of Thiruvananthapuram and zone the area based on vulnerability of aquifers due to intrusion of saltwater. This research work consists of Hydrochemical studies, geophysical investigation, modelling of groundwater flow and contaminant transport and the optimum management of coastal aquifers.

In any groundwater studies, hydrochemical studies are very essential. The water quality assessment of the nearby coastal aquifer was carried out by several authors. The interpretation of groundwater quality was done by multivariate statistical analysis.

Ginzburg and Levanon (1976) used vertical electrical soundings using Schlumberger configuration for determining the saltwater interface in Israel. Measurements were repeated six years later and good agreement between the two sets of measurements was found. The results also showed that the saltwater front extend from the shoreline to a point inland.

Mesbah, (1998) has conducted Electric resistivity method used for mapping zones of contaminated soils and groundwater salinity. A dense electrical resistivity survey was carried out at a site near El - Arabia harbour (Suez Governorate) in order to assess the impact of saltwater on geological and hydrogeological environments.

Rajesh Reghunath et al., (2002) have done multivariate statistical techniques in hydrogeochemical studies on Nethravathi river basin. Hydrogeochemical data for 56 groundwater samples were subjected to Q- and R- mode factor and cluster analysis. R-mode analysis reveals the inter-relations among the variables and the Q-mode analysis reveals the inter-relations among the samples studied. The Q-mode factor and cluster analyses indicate that exchange between the river water and the groundwater plays a dominant role in the hydrochemical evolution of Nethravathi river basin groundwater.

Saha et al., (2002) conducted geophysical surveys comprising electrical resistivity and seismic refraction methods for investigating the nature and status of sub-surface saline water contamination in coastal belt of Digha, West Bengal. The sub-surface geologic formations and thickness of saline zones were identified.

Chen-Wuing Liu et al., (2003) has done factor analysis for the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Correlation among 13 parameters was examined. The study reveals that the areas of high saltwater salinization and arsenic pollution correspond well to the groundwater over pumping area. Over - pumping of the local groundwater causes land subsidence and gradual salinization by saltwater.

Mohan et al., (2003) presented combined simulation-optimization approach for saltwater intrusion control. In this study an attempt has been made to solve a problem associated with the intrusion of saltwater in the Thiruvanmiyur-Kovalam aquifer along the Chennai coast by developing a combined simulation optimization methodology. As a result of continuing pumping for domestic purpose, saltwater from sea has intruded into the aquifer, which has made the groundwater in some part of aquifer getting polluted and thus becomes useless for domestic purpose. In order to prevent further spreading of the saltwater into the aquifer, a simulated annealing optimization method is combined with a numerical simulation model, to obtain an optimal pumping strategy. The Visual MODFLOW is used for flow simulation. The optimization coding and interfacing program has been written in Matlab. The results proved that the combined approach offer a better and viable solution for groundwater management problems.

Hwang et al., (2004) studied the vulnerability to saltwater intrusion in Youngkwang-gun, Korea. For mapping the spatial distribution of saltwater geophysical data and hydro geochemical results were used. The relation between resistivity of groundwater and equivalent NaCl concentration was found and the location of saltwater/ fresh water boundary was evaluated.

Rao et al., (2004) developed a management model for planning groundwater development in deltas with paleo channels. Groundwater flow in the aquifers was simulated using a three-dimensional density-dependent flow and transport model SEAWAT. A simulation optimization model was used to determine the optimal locations

and pumpages for a group of production wells for groundwater development, while limiting the salinity below desired levels. The optimization problem was solved using the Simulated Annealing algorithm and the SEAWAT simulation model. A trained Artificial Neural Network (ANN) was used as the virtual SEAWAT model to perform the simulations, in order to reduce the computational burden for application of the model. The applicability of the model was demonstrated on a hypothetical, but near-real, delta system.

Laluraj et al., (2005) conducted chemical analysis to determine the groundwater chemistry of shallow aquifers in coastal zones of Cochin. The study revealed that the wells in that area need more controlled withdrawal of water with more recharging in order to maintain fresh water -saline water equilibrium

Tripathy and Sahu (2005) has done a detailed hydrochemical analysis was carried out on groundwater samples collected from the barrier-spit system of the Chilika lagoon on the east coast of India. The water quality in both pre- and post-monsoon periods and the interactions with the sea water throughout the year were characterized.

Saha and Choudhury (2005) have conducted geophysical studies for delineating saline/ brackish water zones present in the subsurface around the Kolkata metropolis. Mixing of fresh and brackish groundwater has created environmental problems in certain areas. Vertical Electrical Soundings (VES) employing Schlumberger configuration have been deployed in the eastern and south eastern Kolkata metropolis for delineating the subsurface saline water zones. Interpretation of VES data has indicated disposition of saline / brackish and fresh water zones at different depth level which would be useful in the groundwater management with minimum risk of saline contamination. Resistivity surveys have also delineated clay formations, which act as barriers for saline water percolation or transmission.

Mohan et al., (2005) studied management of South Chennai coastal aquifer system using a multi objective approach. Due to constant pumping and improper management, the South Chennai aquifer is facing a severe threat of being contaminated by saltwater. To study the extent of intrusion SEAWAT model is used. Model prediction after calibration has been carried out with management strategies such as modernizing existing tanks, construction of semi pervious barrier and optimization of pumping quantities. In this work the problem has been formulated as a multi objective optimization for maximization of pumping and minimization of total cost of desalination with constraints on water levels and

pumping. From multi objective analysis a trade off curve was developed between the total quantity of water extracted and the desalinated water. The curve gives a range of solutions which represent the optimal trade off for the problem considered in the study.

Khalid Qahman et al., (2005) conducted a numerical assessment of saltwater intrusion in Gaza, Palestine by applying a 3D variable density groundwater flow model. The results show that saltwater intrusion would worsen in the aquifer if the current rate of groundwater pumping continues. To eliminate pumping from intruded area to moderate replenishment by encouraging the implementation of suitable solutions like artificial recharge may limit significantly saltwater intrusion and reduce the current rate of decline of the water levels.

Khalid Qahman et al., (2005) conducted a study on optimal and sustainable extraction of groundwater in coastal aquifer, which is facing a serious threat of saltwater intrusion. The models are tested on a hypothetical confined aquifer with four pumping wells located at various depths. These solutions establish the feasibility of simulating the various management scenarios under complex 3D transport processes in coastal aquifers for the optimal and sustainable use of groundwater.

Katsifarakis and Petala (2005) combined genetic algorithms and boundary elements to optimize coastal aquifers' management. A common problem in coastal aquifers' management is maximization of groundwater extraction rate without saltwater intrusion. Therefore a computational procedure has been developed, combining an optimization and a flow simulation tool to optimize layout of a number of wells and distribution of total flow rate to them. The optimization code is based on genetic algorithms. The respective evaluation function includes numerical simulation of an ''equivalent'' depth-integrated groundwater flow, by means of a boundary element code. Observance of the main constraint, i.e., zero water inflow through the coast, is checked using the sign of flow rate values at the coastal boundary elements. Validity of this approach is checked with the help of an analytical solution.

El Moujabber et al., (2006) evaluate the state of groundwater salinization by saltwater intrusion on the Lebanese Coast. A complete physico-chemical analysis was done and saltwater intrusion in the area was studied through the inter relations between chemical and physical constituents of groundwater and found that some regions were subjected to saltwater intrusion.

Sherif et al., (2006) conducted geoelectrical and hydro geochemical studies for delineating saltwater intrusion in the outlet of Wadi Ham, UAE. 2D dc-resistivity profiling is carried out, and resistivity models were created which was used to detect water zones of different salinities. The relations obtained between earth resistivity and TDS, together with inverted 2D resistivity depth sections were used to identify the average TDS at any point along the 2D resistivity profiles.

Qahman et al., (2006) presented evaluation and numerical modelling of saltwater intrusion in the Gaza aquifer, Palestine. A two-stage finite difference simulation algorithm was used in steady state and transient models. SEAWAT computer code was used for simulating the spatial and temporal evolution of hydraulic heads and solute concentrations of groundwater. Two pumpage schemes were designed in this to use the calibrated model for prediction of future changes in water levels and solute concentrations in the groundwater for a planning period of 17 years. The results show that saltwater intrusion would worsen in the aquifer if the current rates of groundwater pumpage continue.

Ezzy et al., (2006) modelled groundwater flow within a coastal alluvial plain setting using a high-resolution hydrofacies approach in Bells Creek plain, Australia. In this study Ground penetrating radar (GPR) has used in conjunction with direct geological data, to develop a model of aquifer. Finite difference groundwater modelling conducted in this study not only enabled determination of the dominant groundwater flow paths for the plain, but has also quantified the effects of within-facies and between-facies sedimentary heterogeneity on those flow paths.

Gallardo et al., (2007) modelled the dynamics of the freshwater-saltwater interface in response to construction activities at a coastal site. A numerical model was developed to evaluate the response of groundwater flow and the fresh-saltwater interface at the coastal plain of Tokaimura, Japan. In this study, saltwater penetrated up to 250 m inland during predevelopment conditions, reaching more than 400 m at the dewatering phase. Results show that after construction the accelerator forms a barrier that leads to a sharp rise in piezometric levels and creates a new and long-term disequilibrium in the saltwater wedge.

Narayan et al., (2007) conducted modelling of saltwater intrusion in the Burdekin Delta Irrigation using a variable density flow and solute transport model, SUTRA, to define the current and potential extent of saltwater intrusion in the Delta under various pumping and recharge conditions. Modelling results show that saltwater intrusion is far

more sensitive to pumping rates and recharge than to aquifer properties such as hydraulic conductivity. Analysis also shows that the effect of tidal fluctuations on groundwater levels is limited to areas very close to the coast. Tidal influences on saltwater intrusion therefore can be neglected when compared with the effects due to groundwater pumping.

Beatrice et al., (2007) developed a numerical model to control saltwater intrusion in the unconfined coastal aquifer of Ravenna, Italy .This study is aimed at understanding how past and present human activities have affected the saltwater intrusion process in the Phreatic aquifer and how the predicted future sea level rise will affect the salinisation process. The simulations show that over the last century artificial subsidence and heavy drainage started the salinisation process in the study area and a relative sea level rise will accelerate the increase in salt load in the coming decades, affecting the entire aquifer. Climatic conditions in the area result in limited precipitations throughout the year and preclude efficient aquifer recharge, especially in spring and summer when saltwater seepage is extensive and the lack of a continuous coastal dune system favours salt wedge intrusion.

Uddameri et al., (2007) used Simulation-optimization approach to assess groundwater availability in Refugio County. A simulation model characterizing groundwater flow in the shallower unconfined and the deeper semi-confined formations of the Gulf coast aquifer was calibrated and evaluated in this study. The model results were used in conjunction with a mathematical programming scheme to estimate maximum available groundwater in the county. The model results from the study indicate the volume of water can be extracted in a typical year and the management model was noted to be very sensitive to the imposed saltwater intrusion constraint.

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

Pathak et al., (2008) conducted the interpretation of Groundwater Quality Using Multivariate Statistical Technique and cluster analysis in Moradabad City, Western Uttar Pradesh State, India. The concentration of TDS, EC, TH, Ca, Mg, Na, HCO3 and Cl at most of the sampling stations exceeds the safety limits for drinking water. Computational analysis of the data set of hydrochemical constituents in the groundwater suggests that the aquifer (TDS) is mainly controlled by Cl, TH, Na, salinity and EC. There is a strong positive relationship between TDS-EC; TDS-Cl; TDS-TH and TDS-Na. The data were analyzed for factor analysis and first four components are chosen, which contribute 77.38% of the total variance. Dendrogram of the 58 cases and 12 variables are plotted and grouped into four main clusters.

Indrani Gupta et al., (2008) have studied variations in water quality of Mumbai coast through multivariate statistical analysis such as cluster analysis ,principal component analysis and discriminate analysis were applied to evaluate the temporal/spatial variations in marine water quality of Mumbai and to identify pollution sources.

Snodsmith et al., (2008) presented a modelling study of saltwater intrusion in Alabama Gulf Coast, USA to investigate the extent of saltwater intrusion. The SEAWAT code is used to solve the density-dependent groundwater flow and solute transport governing equations. In this study a predictive 40-year simulation run indicates that further saltwater intrusion into the coastal aquifers can occur in the study area.

Benhachmi, et al., (2008) conducted study on Improving Saltwater Barrier Operation with Simulation Optimization in Southern California. A calibrated simulation model is linked with two optimization models to investigate alternatives for enhancing saltwater intrusion barrier operations for the Alamitos Barrier Project in Los Angeles. Two types of management problems are analyzed, the optimal scheduling problem (OSP) and the optimal well location problem. The OSP objective is to minimize the total injected water subject to constraints on the state variables: Hydraulic head and Chloride concentration at target locations. Two OSP formulations are considered, a pure hydraulic gradient formulation, and a combined hydraulic and transport formulation. When considering all 43 injection wells over a five-year planning horizon, the simulation-optimization model could not significantly improve upon the assigned initial injection rates. However, if a subset of the injection wells is exclusively considered, more favourable injection policies are obtained where less water is injected, compared with

either the mean or annual mean derived from the historical record. Next, a genetic algorithm GA is linked with the calibrated simulation model to determine the locations of new injection wells that maximize one of two alternative fitness functions, which quantify barrier improvement.

Karmegam et al., (2010) have done Geochemical Characterization of Groundwater's of Shallow Coastal Aquifer in and around Kalpakkam, South India. 29 shallow coastal groundwater samples were collected and analysed for major and minor cations. The samples analysed were classified with SAR, RSC, TH, CI, IBE, EC and facies to determine their utility. The geochemical facies of the groundwater was attempted and found that Ca-HCO_3 as the dominant type. The factors responsible for their geochemical characterization were also attempted by using standard plot and it w as found that the ion exchange plays a significant role along with few signatures of recharge and sea water intrusion.

Nur Islami (2011) has conducted geoelectrical resistivity method for salt/brackish water mapping for detecting and mapping occurrence of salt/brackish water in the subsurface, North Kelantan - Malaysia. The North Kelantan plain is covered with Quaternary sediments overlying granite bedrock. The drainage system is dendrite with the main river flowing into the South China Sea. The geoelectrical resistivity surveys were made at four different sites. The zone of brackish water was found at a depth of 20-30 m in the resistivity inverse model and an interface between salt/brackish water fresh water was also generated.

Jonathan Tuma et al., (2011) have conducted a study on Dynamics of land use change in the Florida Panhandle Using GIS Optimization Models: A Framework to Determine the Impact of Climate Change on the Florida Panhandle. The western "panhandle" region of Florida experienced greater development in the years 2000-2010 than the previous 40 years and greater than nearly all other parts of the United States. The coastal land in the peninsula of Florida is already developed whereas much of the Panhandle is empty. Climate change is changing land use and land cover in the Panhandle in a number of ways with the most common shift being from managed forest and agricultural land to urban use. The consequences of this change have been increased pressure on the resources, rising temperatures is associated with increasing sea levels and resulting saltwater intrusion on to fresh water and exacerbated land use conflict. To address

the challenges of future land use, a GIS optimization model was developed to determine the spatial and temporal status quo relationships between the drivers and resulting patterns of land uses due to climate change. Resulting models of land use preference and projected population allocation points to the direction of the limiting factor of climate change such as saltwater intrusion and increasing water demand.

2.2 GAP AREAS

The following gap areas were identified from the literature survey.

1. Though many studies on hydrochemistry of coastal aquifers have been reported (Laluraj et al., 2005; Tripathy and Sahu, 2005; Olobaniyi and Owoyemi, 2005; Moujabber et al., 2006; Senthilkumar, 2008; Indrani Gupta, et al., 2008; Karmegam et al., 2010) in the literature, very few studies on hydrochemistry of coastal aquifers have attempted in estimating the lateral extent of saltwater intrusion (Asa Rani and Suresh Babu, 2008). In the present study a graphical method is adopted to estimate the lateral extent of saltwater intrusion in both seasons namely pre monsoon and post monsoon.

2. Many geophysical studies (Nur Islami, 2011; Hwang et al., 2004; Gnanasundar and Elango, 1999) have been conducted in the coastal aquifers but the results of the studies have been used only for the development of isoresistivity contours for ground water potential zones. But the present study has used the iso resistivity contours to develop a series of curves for finding the limiting depth and location of open wells, so that they are in the safe zone free from saltwater intrusion.

3. Majority of the earlier studies have used sharp interface approach to model the saltwater intrusion (McElwee, 1985; Calvache and Pulido-Bosch, 1997; Kacimov et.al., 2006). This approach is easier to model and computationally less demanding. But it can misrepresent the realistic situation. Hence the preferred model for saltwater intrusion should be the density dependent miscible solute transport model (Khalid Qahman et al., 2005). Based on this finding the present study has used density dependent solute transport model.

4. Optimization has been widely used in groundwater planning and management. Generally there are three approaches to incorporate the physically based groundwater models into their constraints: the embedding, the response matrix and simulation optimization approach. The embedding technique incorporates the finite difference or finite element based simulation equations into the constraint set of the optimization model. The response matrix approach requires the evaluation of the response of the groundwater system subject to a set of perturbations, and is based on the principle of super position. It is valid only for linear or slightly nonlinear systems. In the simulation optimization approach, the simulation model is repeatedly called to compare the state variables (groundwater head and concentration) and their gradients subject to the perturbation of the control (decision) variables. This approach is powerful when there are a large number of state variables and a small number of control variables and it may be the only option if complex physics needs to be modelled. The present study has used the above mentioned third approach.

5. The Genetic Algorithm to solve the optimisation model is powerful because of its effectiveness in finding the global optimal solution especially for non linear non convex problems. But this capability has not been explored to a great extent in the earlier studies. Hence in the present study the optimization part is solved using Genetic Algorithm and its effectiveness is brought out.

6. Most of the earlier studies have not dealt with a real life situation but rather used Henry problem (a hypothetical confined aquifer with four pumping wells) to simulate various management scenarios like increase in pumping, effect of sea level rise and reduction in recharge in coastal aquifers for the optimal and sustainable use of groundwater. In cases where the real life situation is dealt, aquifer data can contain a large degree of uncertainty. In some cases reported in literature, where they have simulated real life situation, they have adopted simpler technique like response matrix approach (Mohan et al., 2005). The present study simulates a real life situation through simulation optimization approach taking into account all the complexities involved while dealing with a real life situation.

7. The earlier studies in the literature reveals that management of a coastal aquifer system is taken up only as a curative measure on such aquifers (Mohan et al., 2005), where the contamination of that aquifer has already happened. But in the present study, a preventive approach is adopted where in areas which are prone to contamination are identified in the initial phase of the study and then such vulnerable areas identified are modelled and the behaviour of the model under different hypothetical scenarios are predicted to arrive at an optimum and feasible pattern of pumping strategy through simulation optimization approach.

2.3 OBJECTIVES OF THE PRESENT STUDY

The objectives are formulated to fill up the above mentioned gap areas identified through the literature review.

i. To assess the existing quality of coastal groundwater in the study area.

ii. To identify the zones in the study area which are prone to saltwater intrusion using indicators and empirical modelling as the first step of preventive approach.

iii. To estimate the lateral and temporal extent of saltwater intrusion in the study area using graphical approach by conducting hydrochemical study.

iv. To develop "limiting depth" curves for open wells in study area using isoresistivity contour obtained by conducting geophysical survey of the area

v. To develop a density dependent groundwater flow and contaminant transport model for simulating the dynamics of saltwater intrusion.

vi. To apply simulation optimization approach to model a real life situation and thus arrive at an optimum pumping rate for the study area.

vii. To study the movement of freshwater - saltwater interface under different scenarios like increase in pumping, reduction in recharge and effect of sea level rise.

viii. To estimate the injection rate and location of injection well in the study area to sustain the present pumping pattern without affecting further advancement of saltwater intrusion.

2.4 METHODOLOGY

The study comprises of four parts such as hydrogeochemistry, geophysical survey, modelling of groundwater and contaminant transport and management of coastal aquifers by optimisation model. Fig.2.1 shows the flow chart of methodology adopted in the present study.

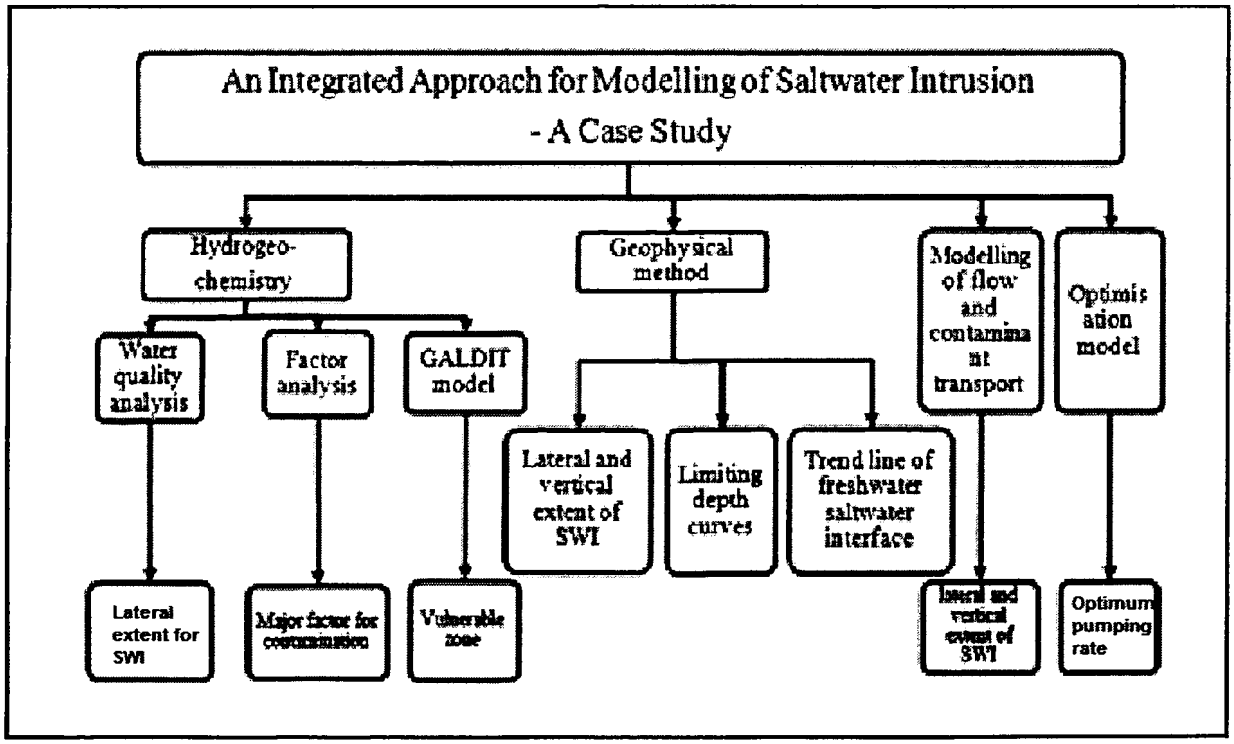

Fig.2.1 Flow Chart of Methodology