LITERATURE REVIEW

2 LITERATURE REVIEW

Many estuarine areas are heavily urbanized and therefore require an adequate and sustained yield of water which is fit for various purposes. The increased use of groundwater in coastal areas upsets the existing dynamic balance between fresh water and sea water leading to intrusion of sea water in to the aquifer longitudinally and vertically.

Based on this the literature review is presented describing the different approaches. The work done by different persons in the field related to the estuarine area. Similar kinds of the work done and model's used for similar studies are also reviewed.

2.1 Estuaries and Related Problems

An estuary is the tidal mouth of a river. This unique environment mixes the fresh water of the river with the salt water of the sea.

2.1.1 Engineering Problems in Estuaries

One of the important factors contributing to the problems of estuaries has been the rapid growth of population and industrial activity in the surrounding area. In recent years engineering problems in tidal waters have received increased attention from the practitioner, the experimentalist, and the analyst in view of the important functions assigned to estuaries in the human environment. This is true not only for the United States but also for Europe, where most important contributions have been made, particularly in the Netherlands and in England. So it necessitates developing physical understanding of those processes of tidal flows in estuaries which are of primary importance in dealing with diffusion and sedimentation problems. The basic estuary problems of salinity intrusion, pollution by discharged wastes, shoaling and sediment transport are associated with diffusion processes in a stratified flow. Problems of estuarine pollution are significantly different from river or lake pollution. They are concerned with the temporal and spatial distribution of contaminants introduced into the estuary and with their effect on water quality (Ippen, 1966).

Problems of estuarine pollution are significantly different from river or lake pollution. These problems, originating essentially from human activity, are much greater in magnitude and far more widespread than ever before.

2.2 Estuary Dynamics

Estuarine processes are not simple. Estuaries are regions in which many factors like tidal flow from sea to land ward and fresh water flow from upland to sea interact. The estuaries are governed by the tidal action at the confluence with sea and upland river flow. The tidal characteristics are time and space variant. In the estuary salt is the dispersant and hydrodynamics is the transporting agent. The difference in density between fresh water and salt water modifies the hydrodynamics by bringing in the longitudinal circulation or stratified flow conditions (Dalwadi, 1998).

The mechanism of water flow in tidal estuaries is complex and incompletely understood yet. Two quite different operations take place at the opposite ends of an estuary. The lower end is a two way street where a heavier salt layer of water moves upstream near the bottom and a lighter layer of freshwater flows downstream at top. The mechanism for these two layer circulations is the input of fresh water from the catchment area of the river and the tidal movement from the bay. At the upper end of the estuary the entire flow is in one direction subject only to the stop and goes influence of the tide (Calcutta Metropolitan Development Authority, 1972).

The three most important factors operating to produce currents in estuaries are oceanic tides, stream flow and wind. Additionally, the morphology of the basin of the estuary and the channel of the stream modify and determine the stream and tidal dynamics. It should be borne in mind that these forces are not regular and constant. Stream flow varies seasonally with rainfall, while tide height and movement are correlated with lunar effects and wind (Reid, 1961).

The tidal currents in estuaries caused by rise and fall of the tide at the estuary entrance, in general, run "flood" during rising tide and "ebb" during falling tide. The magnitudes and durations of tidal currents in estuaries are functions of the tidal range at the entrance characteristics (semidiurnal and diurnal) of the Ocean tide at the entrance, and physical characteristics of estuary channels. The relationship between tide and current varies appreciably from estuary to estuary and from one location to another within a given estuary (Ippen, 1966).

2.2.1 Salinity Transport in Estuaries

Salinity transport in an estuary depends on the freshet discharge and tidal action. Increased tidal action increases mixing while enhanced freshet discharges will induce stratification during monsoon, the high freshet discharge may cause stratified condition in backwaters of estuary, but in dry season the well mixed conditions prevail to a great extent (Dalwadi, 1998).

The intrusion of salt water into the lower portions of tidal estuaries is of the greatest interest to engineers. The dynamic characteristics of tidal flow as well as with the diffusion processes which result from the discharge of fresh water under the tidal action into the saline reaches of the estuary are important. The diffusion process in estuaries is thus seen to depend on a combination of following three mechanisms (Ippen, 1966).

a. Turbulent diffusion as encountered in random-mixing.
b. The dispersion process inherent in the transient shear flows generated by the tides.
c. The internal circulation generated as a result of density differences.

Estuaries are either once or twice daily washed by the sea water. In fresh water the concentration of salts, or salinity, is nearly zero. The salinity of water in the ocean averages about 35 parts per thousand (ppt). The mixture of sea water and fresh water in estuaries is called brackish water and its salinity can range from 0.5 to 35 ppt. The salinity of estuarine water varies from estuary to estuary, and can change from one day to the next depending on the tides, weather, or other factors.

2.2.2 Estuary Mixing Types

The river discharge is mixed with the sea water by the action of tidal motion, by wind stress on the surface and by the river discharge forcing its way towards the sea (Dyer, 1979). Mixing of fresh water and sea water takes place through turbulent mixing and molecular diffusion.

Estuaries can be grouped in accordance with their mixing conditions which govern their vertical circulation patterns. Thus, three types of estuaries are identified with regard to their mixing conditions and consequent salinity variations.

1. Highly stratified type
2. Partially mixed type
3. Well-mixed type

2.2.2.1 Highly Stratified Type

Where the inflow of fresh water is large with respect to the tidal discharge, the fresh and salt water tend to remain separate with the fresh water (being less dense) flowing out to sea over the top of the salt water layer and the salt water layer intruding underneath the fresh water in a rough wedge shape. The extent to which the salt water wedge penetrates into the estuary is thus a function of the channel depth, the fresh water discharge, and the density differential between the salt and fresh water. In the highly stratified estuary, the ratio of fresh water discharge to tidal prism (the ratio of fresh water volume to the flood tide volume) is of the order of unity or more (figure: 2.1).

2.2.2.2 Partially Mixed Type

In the partially mixed estuary tidal currents are sufficient to produce appreciable vertical mixing of the salt and fresh water. Since the current normally flows both flood and ebb in the partly mixed type, the salt water advances and retreats with each rise or fall of the tide. The interface between the fresh water in the surface strata and the saltier water underneath is not so well defined as in the highly stratified type; however, the presence of the "interface" is indicated by a more or less pronounced transition in the vertical salinity profile or the vertical velocity profile. In the partly mixed estuary, the ratio of fresh water discharge to tidal prism is normally in the range of about0.2 to 0.5 (figure: 2.2).

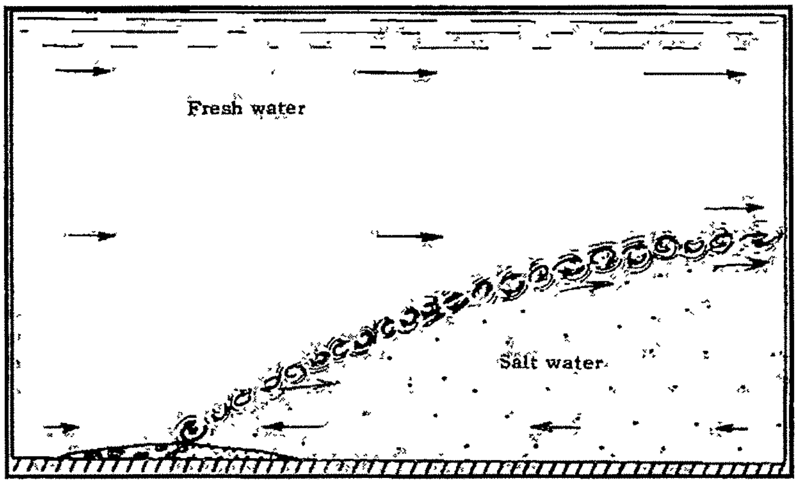

Figure 2.1 Conditions Typical of Highly Stratified Estuary

(Source: Ippen, (1966).

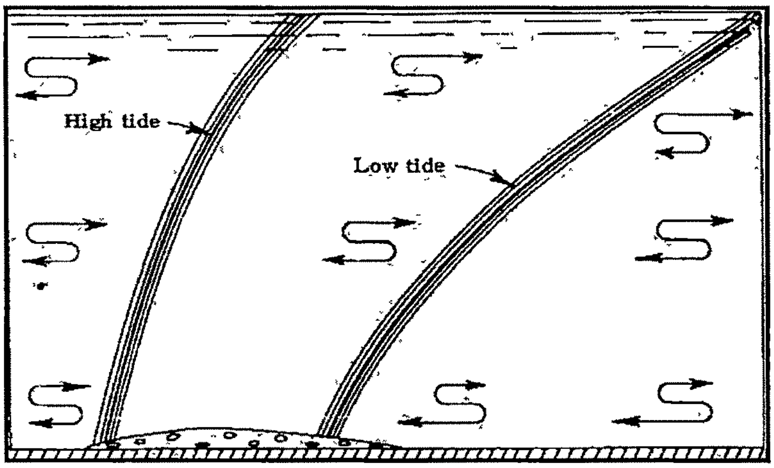

Figure 2.2 Conditions Typical of Partially Mixed Estuary

(Source: Ippen, (1966).

2.2.2.3 Well-Mixed Type

When the tidal range is very large there is sufficient energy available in the turbulence to break down completely the vertical salinity stratification.

In the well-mixed estuary, the tidal forces predominate over the fresh water inflow to such extent that the fresh and salt water are fairly well mixed throughout the vertical. Salinities decrease more or less progressively from sea water at the entrance to fresh water in the upper reaches and bottom salinities normally exceed those at the surface by

15 to 25 percent. In the well-mixed estuary, the ratio of fresh water discharge to tidal prism is normally of the order of 0.1 or less (Ippen, 1966). Refer figure: 2.3.

In this type of estuary there can be lateral variations in salinity and in velocity or, if the lateral mixing is also intense, the estuary can become sectionally homogeneous (also called a one-dimensional estuary) (Dyer, 1979).

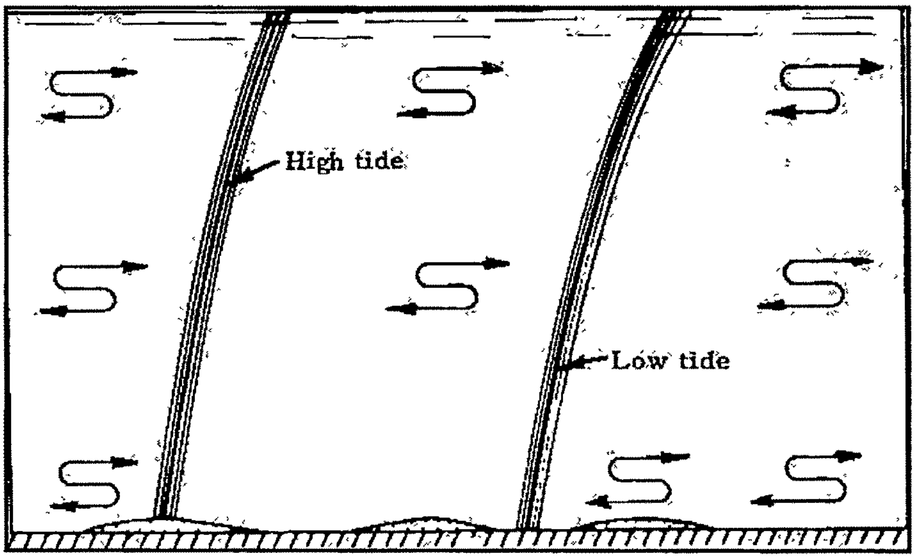

Figure 2.3 Conditions Typical of Well - Mixed Estuary

(Source: Ippen, (1966).

Change in Mixing Type

An estuary may be changed from highly stratified to partly mixed or well mixed by reduction of the fresh water discharge; conversely, one may be changed from well mixed or partly mixed to partly mixed or highly stratified by increasing the fresh water discharge.

Minor changes in mixing types are being constantly effected by the deepening and other improvement of estuary channels for navigation (Ippen, 1966).

2.2.3 Estuarine Area's Problems of World

Estuaries represent one of the most sensitive and ecologically important habitats on earth. Due to their suitability to human settlement estuaries typically have a heavy human presence and of the 32 largest cities in the world, 22 are located on estuaries.

Estuaries have long been important as harbor sites and centers of commerce. Some of the oldest continuous civilizations have flourished in such estuarine environments as the lower region of the Tigris and Euphrates rivers, the Po Rivers delta region of Italy, the Nile delta, the Ganges delta, and the lower Huang He Valley. Developing civilizations soon discovered that the logical site for commercial seaports was the seaward most point of the major river systems. Such cities as London (Thames River), New York City (Hudson River), Montreal (St. Lawrence River), Hamburg (Elbe River) and Bordeaux (Gironde estuary) have developed on estuaries and have become important centers of commerce.

Since estuaries commonly provide excellent harbors, most of the large ports in the United States (New York, Philadelphia, Baltimore, Moblile, Galveston, Seattle, and San Francisco) are located in estuaries. However, the development of high-density population centers causes deleterious effects that can destroy the very properties of the estuary that made development of the region possible. Human impact on estuaries includes reclamation of tidal land by pollution from sewage, solid waste and industrial effluent. Not surprisingly human activities have led to a decline in the health of estuaries making them one of the most threatened ecosystems on Earth.

Among the countries engaged in estuarine water quality studies, USA ranks foremost as many of the estuaries in the country (near New York, Delaware, Potomac, Boston and others) had become/or are becoming virtually destroyed due to the indiscriminate and uncontrolled waste disposal. Similar studies have been done in U.K. also because they have a number of cities on the estuaries such as the Thames, Tee, Mersey (Calcutta Metropolitan Development Authority, 1972).

The occurrence of saline water intrusion is extensive and represents a special category of ground water pollution. The problem exists in localities of most parts of the United States. Sea water intrusion along coasts has received the most attention. In the United States the coastal States most severely affected include New York, Florida, Texas, California, and Hawaii. Internationally, the problem has received attention in populated coastal areas in England, Germany, the Netherlands, Israel and Japan, among others (Todd, 1995).

2.2.4 Estuarine Area's Problems of India

Along the coast line of India, numerous bays and gulfs are formed where big or small rivers meet, thereby forming estuarine zone. Along coastal line numerous brackish water lakes are in existences, which are joined with the sea during floods. A typical Indian estuary is highly productive, as its waters receive abundant qualities of nutrients from the connected fresh water systems and surrounding land areas. Most of the Indian estuaries are monsoon dominated. The abundant fresh water influx in them is more or less limited to the monsoon season extending from July to October. In the summer months of March to June very little fresh waters are added and the severity of pollution hazards comes into prominence at this phase.

The major estuarine systems of the country are: Hooghly-Metlah Estuarine system, Mahanadi Estuarine system, Krishna Estuary, Pulicat Lake, Cauvery Estuary, Vembanad Lake and Narmada-Tapti Estuary. All these water areas, along with a large number of small estuaries scattered throughout both the East and West coasts.

In Mahanadi Estuary, the tidal effect is felt only up to about 35 kms upstream of the mouth. In the Gautami which is the main component of the Godavari Estuarine system, the tidal inflow extends up to about 50km from the mouth. A general trend of increase in salinity has been observed in the rivers in recent years (Calcutta Metropolitan Development Authority, 1972).

2.3 Surface Water Models for Estuarine Area

Lung and O'Conner (1984) developed a simplified analytical model from the equations of momentum, continuity to compute two-dimensional estuarine transport. They applied this analysis to investigate transport and water quality problems in the Sacramento-San Joaquin estuary, the James River estuary, the Patuxent River estuary, and the Hudson River estuary (New York) throughout the country with satisfactory results. Roelfzema et al. (1987) developed a mathematical model system consisting of flow models morphological models and water quality models at Delft Hydraulics for the Rhine-Meuse estuary, the Netherlands.

Chandramohan and Joseph(1999) applied the two-dimensional finite element model FESWMS-2DH developed by USGS, USA for analyzing the dynamics of the Cochin estuary, influenced by seasonally varying sea water intrusion and fresh water discharge. They calibrated and validated the model using velocity measurement at eleven observed location. Senders and Piasecki (2000) optimized the fresh water diversion schedules from estuaries to mitigate the hazards of rising salinity levels further downstream. Liu et al. (2001) applied a real-time, two-dimensional, laterally averaged hydrodynamic mathematical model to analyze residual current and salinity distributions in the Tanshui River estuary in Taiwan.

Chau and Jiang (2001) developed a 3D numerical model and applied to the Pearl River estuary, which is the largest river system in South China, with Hong Kong and Macau at its entrance. Knowles (2002) studied the natural and management influences on fresh water inflows and salinity in the San Francisco estuary at monthly to interannual scales. Chatterjee (2003) used a 3D mathematical model for simulation of the circulation of an alluvial estuary. . He compared water surface elevations and currents from the model with those observed in the Hooghly estuary, Eastern India.

Liu et al. (2004) applied a vertical (laterally integrated) two-dimensional hydrodynamic and salt water intrusion numerical model to study the salt water intrusion in the Tanshui River estuarine system, Taiwan. Pinho and Vieira (2005) implemented the two dimensional hydrodynamic and mass transport model based on the finite element method to study salinity intrusion into the estuary of the river Lima in the north-western region of the Iberian Peninsula, Portugal. Brice et al. (2005) developed a numerical modal based on the finite volume MUSCL-Hancock method and used to simulate the saline intrusion within the Rio Maipo estuary, a well-mixed tidal river in central Chile.

Gross et al. (2005) performed three-dimensional simulations of circulation in the San Francisco Estuary with the three-dimensional hydrodynamic model, TRIM3D, using a generic length scale turbulence closure model. Cuthbertson et al (2006) studied the influence of submerged Tidal Barriers on estuarine mixing and exchange processes. Model studies have been undertaken by them to study the spatial and temporal development supplied by a fresh water inflow and bounded by an impermeable barrier that was overtopped periodically by a tidally generated saline water inflow. They demonstrated that the essential exchange mechanisms controlling the flow over a partially submerged tidal barrier can be simulated satisfactorily by an idealized laboratory model.

They also experimentally illustrate that the dimensions of the brackish pool reach equilibrium after a specific number of tidal cycles, with the normalized thickness of the pool being dependent on the strength of the fresh water inflow.

The above investigators have developed two dimensional and three dimensional mathematical or numerical hydrodynamic flow and mass transport models based on Finite Element Method, Finite Volume Method etc. They studied salinity intrusion into the estuary, circulation of fresh/saline water in the estuary, salinity distribution in estuary the fresh water diversion schedule in estuary, natural and management influences on fresh water inflows and salinity in estuary. Cutbertson et al. (2006) studied the influence of submerged Tidal barriers on estuarine mixing and exchange processes by an idealized laboratory model.

The studies are related to surface flow and salinity intrusion in surface water in estuarine regions of different rivers. They have not considered the infiltration from the estuary, recharge from the rain or water body into the aquifer. This mainly focuses on surface water so groundwater studies related to ground water fluctuations are required to be carried out for the study area.

2.4 Water Quality Studies in Estuarine Area

Patel et al. (1985) studied salinity distribution, pollution dispersion and tidal flushing in Mahi estuary. The tidal limit was observed to be at a distance of about 50 km upstream of the mouth during the summer months of May-June when the river discharge is the lowest. The salinity determination was carried out at the Kavi, J-point and Mahammadpura during pre monsoon (May-June). Linear equations, to determine distribution of salinity the least square method, were used for lower reach of estuary up to J-point. They found Mahi estuary is well mixed estuary. They also worked out dilution factors at Gangha, Kavi, J-point and Mahammadpura. The dispersion coefficients found for Mahi estuary at J-point and Kavi are 4.39 x 106 m^2/ hr and 2.45 x 106 m^2/ hr respectively.

Patel et al. (1986) also studied the effects of waste water discharges on Mahi estuary. The problems of pollution in estuaries are concerned with the temporal and spatial distribution of contaminants introduced into the estuary and with their effect on water quality. They conducted site survey for Mahi estuary, where partially treated effluent is discharged through 56 km long effluent channel from various industries. The effluent channel was commissioned in February-1983. They studied the physical characteristics of Mahi estuary such as tides, surface current speed and Bathymetry to decide the disposal point and to find dispersion coefficient. They found that estuarine channel up to Kavi gets exposed during the low tide. The ebb currents and flood currents in the left bank channel of the Mahi estuary are remarkably strong that is of the order of 0.5 m/s in neap and 1 m/s in spring. Since, the estuary drains nearly completely during low tide up to Kavi, the stretch of channel between J-point and Kavi will be merely, an effluent drain during low tide. It is, therefore, essential that the wastewater be released at certain stage of the high tide for effective dilution and dispersion. Keeping this in mind, the waste water effluent is collected in a lagoon near the shore for fifteen days and released for channel during high tide only. They concluded that to avoid the direct and the cross contamination, the release of the waste water should be carried out in the ebb cycle depending on the tidal phase. To obtain definite ambient dilution close to the slack periods of the tidal currents, the effluent discharge should be carried out through a multipore diffuser.

Nirmala et al. (1990) studied pollution in the coastal zone of Kerala, boarded by Western Ghats on the South West coast. Multi faceted activities like rapid industrialization, expanding population and agricultural activities have adversely affected the status of the environmental zone. Health hazard problems arising out of the contamination of the drinking water sources and recreational sites are noteworthy. This result in a situation where coastal environment is continuously changing and ecology is threatened. They found erratic rainfall and salinity intrusion problems in rivers and lakes are experienced in Kerala coast. They highlighted the major problems related to the coastal zone of Kerala, which would help the further developmental and management activities of the coast.

Patel et al. (1990) assessed river water quality of Mahi, Ambika, Kaveri, Par and Damanganga rivers in Gujarat. The study was started in the year 1979 and completed in 1985. Rivers get polluted by rapid urbanization and industrialization. They ultimately classified the river course as unpolluted, polluted and saline, based on five years test results of water samples collected regularly from the rivers. The waters of Mahi river classified in three zones as (i) Unpolluted zone from village Harod to 14 km d/s of Vasad bridge. (ii) Polluted water zone from D/S of Vasad Bridge to village Jaspur. (iii) Polluted-Saline water zone from Jaspur to Kavi.

They also assessed the contamination of underground water resources and the quality of ground water in wells situated along river course identified as polluted zones of some rivers. Samples were collected during 1981/1982 from wells along polluted and polluted-saline zone of Mahi river. Samples from wells at villages Vasad, Angadh, Jaspur and Dabka along the polluted zone are classified as good to moderate as per U. S. Salinity Diagram, while water samples collected from wells at villages Chamara, Bamangam, Gambhira, Badalpur and Dewan along the polluted-saline zone on right bank and those from Mujpur, Tithor, Kareli, Karkhadi and Kavi on the left bank are classified as bad on the basis of test results.

Yagnik et al. (2003) studied environmental impact assessment along the river Mahi due to industrialization and tidal effect in peripheral areas of Anand and Vadodara District, Gujarat. They assessed the present groundwater quality with the lateral and vertical extent in variation in groundwater quality with respect to space and time. They found groundwater quality largely affected due to man made changes. As compared to 1984, there is substantial increase in the affected area of surface water as well as groundwater pollution due to industrial and tidal water impact. They also concluded that as compared to right bank, left bank is more polluted.

Kumar et al. (2006) studied the sea water intrusion and its effects on water quality in Vasishta-Godavari estuary. The data, the saline water excursion and its variation under different river discharge conditions have been studied. They found practically no saline water intrusion into the estuary for river discharge > 4400 m^3/sec and as the river discharge decreases the saline water intrudes up to 30 km upstream. Under nil discharge condition the saline water extends beyond 30 km upstream. Diurnal variation in saline water excursion indicates increase in salinity during tide and decrease in salinity during falling tide. Under high river discharge conditions the saline water enter into the estuary only in the bottom layers and during ebb period the entire estuary is occupied with fresh water from surface to bottom. During moderate and nil discharge conditions the salinity variations over a tidal cycle are small.

Patel (2006) studied the problems in the tail reaches of the rivers, where the strategy for protection and improvement of groundwater quality in the coastal area near a river are not discussed. The tail ends of rivers are subjected to tides, which create the problem of salt water intrusion and deterioration of groundwater quality. The strategy included the construction of a specially designed weir across the river near the tail end. He also presented a case study of Surat city (India) In the case study the problem of groundwater pollution due to tide water entering into the river Tapi and measures for the improvement of groundwater quality in the study area. It included effect of construction of a weir cum causeway across river Tapi and effect of artificial recharge of the groundwater (either in the existing tube wells and open wells) or by constructing new groundwater recharge wells using rainwater in the affected area. To solve the problem of groundwater deterioration in the area on both sides of downstream of river Tapi, he recommended a specially designed weir near tail end of the river and a network of groundwater recharge wells in the affected area.

Shah and Patel (2010) developed linear regression equations to predict the concentration of water quality constituents having significant correlation coefficient with electrical conductivity of Anand district, Gujarat. Groundwater samples from Anand district were collected by grab sampling method during pre monsoon (May 2008) and post monsoon seasons (October 2008). Physicochemical analysis was conducted following standard methods (IS: 10500:1983). The linear regression analysis between electrical conductivity and strongly correlated TDS and Cl in water showed that these constituents can be estimated from electrical conductivity values in Anand district.

Varadaraj (2010) studied the status of salt water intrusion in parts of Tamil Nadu coast bounded by the Bay of Bengal on the east. The hydro geological conditions and aquifer geometry of various porous and fractured rock media in Tamil Nadu has indicated the presence of multi layered/multi-quality aquifer system. The over exploitation of few fresh water bearing aquifer in Minjur area, Tiruvanmiyar coast, Marakanam-Cuddalore coast, Ramanathapuram Island and Tiruchendur-Udangudi belt resulted in sea water ingress due to human interference while the 'insitu' salinity is existing for few thousand years. He concluded that the interface between fresh water and saline water with marked transition zone is prevalent at different depths in different position with reference to present day coast. Some of the sea water - fresh water interface movement towards land due to over exploitation of groundwater was identified. The sea water ingress due to depleting pressure head and reversal of gradient towards land is observed / predicted in many parts of Tamil Nadu coast. It was also predicted that climatic changes and resulting rise in sea level will also influence the water quality of aquifer system in coming years. He recommended the large scale flood water diversion to the surface water bodies and recharge to ground by injection through tube wells parallel to coast to minimize the problem.

Dhar et al. (2010) investigated the salt water intrusion phenomenon in the Piyali River aquifer located in the South of West Bengal, India. They mentioned that the sluice gate is connected to the Matla River which in turn connected to the Bay of Bengal. So at different distances from sluice gate the samples were collected and by analyzed variation of TDS, EC, and PH etc. They also discussed the variation of chloride content of soil samples. They concluded that maximum values of salinity occurred near the sluice gate of Piyali River. Values reduced a distance of ten km away from the sluice gate. For the coastal community of Piyali River salt water intrusion is a significant concern. The values of PH decrease as the distance from the sluice gate increases.

The above investigators have studied salinity distribution, pollution dispersion, tidal flushing and the effects of waste water discharge on Mahi estuary. They assessed river water quality, contamination of under-ground water resources and quality of groundwater in wells situated along river course of Mahi, Ambica, Kaveri, Par and Damanganga rivers in Gujarat. They also studied environmental impact assessment along the River Mahi due to industrialization and tidal effect in peripherial areas of Anand and Vadodara District, Gujarat, pollution in the coastal zone of Kerala, bordered by Western Ghats on the South West cost, the seawater intrusion and its effects on water quality in Vasista-Godavari estuary and the problems in the tail reaches of the rivers. They developed linear regression equations between electrical conductivity, TDS and cl of Anand district, Gujarat.

These investigators have not considered the effect of distances from sea and from centre line of river on groundwater quality. So this type of investigations by Graphical analysis of field data, development of linear and multiple regression equations are required to be carried out for the study area.

2.5 Coastal Groundwater Models

Sugio et al. (1987) analyzed the problem of sea water intrusion in an unconfined coastal aquifer caused by groundwater withdrawal in the dry season numerically using the assumptions of an abrupt interface, the Darcy equation and the Dupuit approximations. The model employed finite difference numerical Techniques. This model provides a practical design and management tool for predicting the likelihood of sea water intrusion through a semi pervious subsurface barrier in an unconfined coastal aquifer. The movements of both the water table and the fresh water-saltwater interface are numerically simulated in the unsteady state. The computed results are validated with observations obtained from a vertical two-dimensional sand box model. The computer model applied for a proposed subsurface barrier location in a lime stone coastal aquifer on Okinawa-Jima Island in the Western Pacific Ocean. They found that the semi pervious subsurface barrier is able to delay sea water intrusions under critical conditions of continual pumping of the aquifer without recharge. The subsurface barrier is technically feasible and is a viable solution to the problem of sea water intrusion in coastal aquifers.

Rechards and Jones (1997) described research and development in paper "A conceptual model approach for modeling groundwater with GMS". It has been implemented in department of Defence Groundwater Modeling System (GMS). This new approach of handling human interaction with GMS is based on the engineer or scientist visualizing the hydrogeologic conceptual model on the computer screen and then having the computer developed numerical model. A single conceptual model is used to generate a variety of groundwater models, both finite-element and finite- difference. They found that focusing on high level representations of the site rather than on a discretized representation of the site. Simplifies data entry greatly and overall modelling process is enhanced.

Rastogi and Sulekha (2000) developed a coupled groundwater flow and solute transport model to ascertain spread of pollutants in the irrigated area of the Mahi Right Bank Canal (MRBC) command area, Kheda Dist.; Gujarat. The FEM based groundwater flow model is coupled with the transport model by passing the values of groundwater flow velocity to the transport model. Initial concentration and head distribution contour maps were used to linearly interpolate data at the finite element grid nodes. They found that predicted solute concentration in the form of EC values for a period of one year agrees reasonably with the data obtained from the field office.

Cheng and Chen (2001) developed a three–dimensional, density dependent model to study salt water intrusion in multilayered coastal aquifers of Jahe river basin, Shandong Province, China. A coupled Eulerian- Lagrangian method is applied to solve the transport equation, in which the advection part is calculated by a hybrid method of characteristics. They found the reasons for salt water intrusion as excessive groundwater exploitation and improper arrangement of pumping wells in the lower reaches of the Jahe River Basin as well as the tidal affected river. Some of the important reviews are described here.

Kumar (2001) simulated sea water intrusion in Nauru Island which is a Coral Island in the central Pacific Ocean, very near to equator under steady state conditions through Saturated-Unsaturated Transport (SUTRA) model. The application of this model is very useful in those cases where a two-dimensional vertical cross-section adequately represents the groundwater system. The simulation results highlight the importance of tidal forcing for islands and coastal groundwater studies.

Kumar (2002) presented the salient features of available numerical models to enable selection of appropriate code for the specific sea water intrusion problem. He found that the selection of an appropriate modeling code for a particular study is a matter of ensuring that the code has the capability to adequately represent the essential features and flow processes of the groundwater system being studied. It is also important to ensure that the selected code has been verified and benchmarked against standard test problems. Most of the commercially available codes have been verified. No model can replace a comprehensive field program which provides the required data. If reasonably good data is available, numerical model can be employed to provide an important means for guiding management decisions.

Ravi (2003) enumerated the simple and applicable models for various ecosystems. SUTRA a two- dimensional model for Saturated-Unsaturated Transport has been used for analyzing the two-dimensional flow of salt water intrusion under steady-state condition for unconfined aquifer using vertical section concept. He found that the hydraulic gradient and the interface movement are inversely proportional and this interface movement is non-linear. The systems are found to be very sensitive to hydraulic gradient

Senthilkumar and Elango (2004) used a three dimensional mathematical model to simulate groundwater flow in the lower Palar River basin, Southern India. A two layered finite- difference flow model was used. There are three major pumping stations on the riverbed apart from a number of wells distributed over the area. The model simulated for a transient state condition. The transient models run to forecast groundwater flow under various scenarios of over pumping and less recharge. They shown that the aquifer system is stable at the present rate of pumping, excepting for a few locations along the coast where sea water would intrude up to 50-100 m inland. The model predicted that an increase of pumping would lower the groundwater head.

Shoemaker (2004) presented important observations and parameters for a salt water intrusion model. A sensitivity analysis with a density-dependent groundwater flow simulator was conducted to produce insight and understanding of salt water intrusion calibration problems. Five simple experimental simulations presented. He found that dispersivity is a very important parameter for reproducing a steady-state distribution of hydraulic head, salinity and flow in the transition zone between fresh water and salt water in a coastal aquifer system. When estimating dispersivity, observation locations and data types are likely to be most effective. Results are expected to be directly applicable to many complex situations.

Mane et al. (2005) developed Geographic Information System (GIS) interface for groundwater model-MODFLOW. An attempt has made to develop an interface for generating all data files where spatial and temporal variability in rainfall, irrigation, soil, crop and weather are needed. GIS was interfaced with a groundwater model to prepare the input files and process the output of the model. For generating input files, an Arc Info interface program Con2grid for groundwater flow model PMWIN (processing-MODFLOW for Windows) was developed in Arc Macro language as an extension for facilitating modeling. The efficient pre processing capabilities of Con2grid were demonstrated for predicting water table in the command of Dadupur distributary under Ganga canal System of Utter Pradesh in India.

Langevin and Guo (2006) presented the approach for coupling MODFLOW and MT3DMS into a single computer program (SEAWAT) for the simulation of variable-density groundwater flow. The approach consists of formulating the groundwater flow equation in terms of equivalent fresh water head and fluid density, which is calculated from solute concentrations using a linear equation of state.

Elango and Senthilkumar (2006) simulated groundwater head in the part of lower Palar River basin, Tamilnadu, India, for studying the effect of construction of sub-surface barrier across the Palar River on the groundwater flow regime in the aquifer system. The Finite-Difference computer code MODFLOW (McDonald and Harbaugh, 1998) was used to simulate the groundwater flow in the study. Groundwater Modelling System (GMS) was used to give input data and process the model output. The model predicted the effect of the sub-surface barrier on the groundwater system. They found that there would be an increase in groundwater level by about 0.1 to 0.3 m extending up to a radius of about 1.5-2 km along the upstream side of the sub-surface barrier while on the downstream side the groundwater head would lower by 0.1 to 0.2 m.

Ranjan et al. (2006) simulated salt water intrusion in the lower part of Walawe River basin located in the southern coastal aquifer in Sri Lanka through a numerical model based on the sharp interface approach. They found that in arid areas, the fresh groundwater loss increases as the percentage of forest cover increases. With respect to groundwater recharge, agricultural lands are the best land use pattern in arid and semi-arid areas. The combined effects of deforestation and aridity index on fresh groundwater loss indicated that deforestation causes an increase in the recharge and existing fresh groundwater resource in areas having less precipitation and high temperature (arid climates).

Elango (2009) used Groundwater modeling technique to assess the feasibility of pumping seawater from a beach well for Chennai desalination plant. The study was carried out in Nemmili village located 25 km south of Chennai along the coast of Bay of Bengal. The finite-difference computer code MODFLOW was used to simulate the groundwater flow in the study area .Solute transport modeling was carried out using the MT3D code. The pre and post processor, developed by the United States Department of Defence Groundwater Modelling System version 6.0 (GMS), was used to give input data and process the model output, various scenarios with different pumping strategies were modeled. From the results it was concluded that Groundwater occurs as a ridge with flow towards the sea in the east and the Buckingham canal in the west, hence, it is not advisable to go for a beach well to meet the larger requirements, as this will affect the groundwater resources in the vicinity. Further, pumping at higher rate will eventually make the fresh groundwater of this region saline.

Some of the above investigators have analyzed the problem of sea water intrusion in an unconfined coastal aquifer by finite difference numerical techniques using the abrupt interface approach. They described a conceptual model approach for modeling groundwater with GMS and presented the salient features of available numerical models to enable selection of appropriate code and enumerated the simple and applicable models for various ecosystems. They also presented important observations and parameters for a saltwater intrusion model and approach for coupling MODFLOW and MT3DMS into a single computer program (SEAWAT) for the simulation of variable density groundwater flow. They developed a coupled groundwater flow and solute transport model to ascertain spread of pollutants in the irrigated area of the MRBC command area Kheda district, Gujarat. It is a three-dimensional density dependent model to study salt water intrusion in coastal aquifers and GIS interface for groundwater model- MODFLOW to prepare the input files and process the output of the model. They simulated seawater intrusion under steady state conditions through SUTRA model. They used a three dimensional mathematical model based on finite difference to forecast groundwater flow under various scenarios of over pumping and less recharge. They used MODFLOW (McDonald and Harbaugh 1998) as well as GMS to give input data and process the model output to simulate groundwater head for studying the effect of construction of subsurface barrier across the Palar River, Tamilnadu, India on the groundwater flow regime in the aquifer system. They also used MODFLOW to simulate the groundwater flow in the study area, MT3D code for solute transport modeling and GMS version 6.0, to assess the feasibility of pumping sea water from a beach well for Chennai desalination plant.

They have not considered the effects of impoundment of water due to construction of tidal regulator cum recharge structures located on the estuary in influencing the underlying groundwater regime. So this type of groundwater modelling is required to be carried out for the study area. The software GMS is used for this study.

The literature reviewed in this chapter indicates that the problems of Mahi estuarine area can be investigated by applying modelling and other analysis suggested by various researchers.

In order to consider infiltration from the estuary, recharge from the rain or water body into the aquifer, groundwater studies are required to be carried out in the study area. Similarly to include the effect of distances from sea and from centre line of river on groundwater quality, graphical analysis of field data, development of linear and multiple regression equations are required to be carried out for the study area. Also to consider the effects of impoundment of water due to construction of tidal regulator cum recharge structures located on the estuary in influencing the underlying groundwater regime, the groundwater modelling is required to be carried out for the study area. The software GMS is used for this study.