CHAPTER 3

METHODOLOGY

3.1 GENERAL

Estuaries have long provided foci for settlement and industry all over the world. Water is the most vital element among the natural resources, and is crucial for the survival of all living organisms. The fate of industrial discharge and its impact on the coastal environment should be closely monitored. The study of water movement, predominantly caused by tides and wind is termed “hydrodynamics”. Consideration of hydrodynamic issues is very important when major development is proposed in estuarine or coastal environment.

In order to simultaneously solve the equations of motion, a number of solution techniques have been developed. The two most powerful solution techniques in the area of open-channel flow are finite differences and finite elements analysis. These solution methods are easily implemented through the use of computers, and provide a fairly accurate approximation to the exact solution of the complete equations of motion.

Numerical models are extensively used to simulate the processes of estuarine hydrodynamics in the recent years with the advanced development of computational systems. MIKE 21 is professional numerical modelling software for 2D free surface flows.
3.2 STUDY AREA

Coastal environment plays a vital role in nation’s economy by virtue of the resources, productive habitats and rich biodiversity. India has a coastline of about 7,500 km. Tamil Nadu has a coastal stretch of about 1076 km and constitutes about 15% of the Indian coast. The study area Uppanar Estuary is situated at Latitude 11° 43’ North and Longitude 79° 49’ East at the confluence of Gadilam and Uppanar rivers with Bay of Bengal at Cuddalore (Figure 3.1).

![Figure 3.1 Uppanar Estuary](image_url)

Uppanar estuarine system is an open type with semi-diurnal tides mostly dominated by the backwaters of sea. Mean tidal elevation of the estuary is about 0.9 m. Average depth of the estuary is about 3.5 m near the mouth and 2.5 m towards upstream. Uppanar river runs parallel to the coast south of
Cuddalore town. Estuary water quality is very much affected by the SIPCOT industrial discharges for the past two decades, as well as agricultural runoff, port activities and sewage discharge from Cuddalore old town.

Cuddalore Port is located in Gadilam river 0.5 km inside the river mouth. About 1132 m of wharf length with depth varying from 1.5 to 2m is available for berthing lighters. The railway sidings at all these wharves are connected to the Cuddalore port junction is on the main lines of the Southern Railway. Shipping and landing facilities are available on the western side of Uppanar river near New Port Office (ENVIS, 2006).

The climate in the study area is tropical. It is neither extreme hot nor extreme cold. Monthly mean temperature ranges from 17.7 to 40.5°C. The annual average rainfall 1300 mm occurs mostly from northeast monsoon between October and December. Predominant wind direction during summer is SSE, NE and NNE during premonsoon. The relative humidity ranges from 50 to 97%. The wind speed varies between 0.1 and 13.5 km/hr. The soils are acidic to neutral in nature with high permeability and low water holding capacity. The total population of the fishing villages in Cuddalore District is 40582, of which approximately 14000 people are actively engaged in fishing.

3.3 RESEARCH METHODOLOGY

The present study couples the real time field data with the numerical model. Estuarine modelling simulates the potential changes in water levels, currents and pollutant dispersion which in turn help to assess the existing conditions in Uppanar estuary and the impact of the SIPCOT.

The work plan includes the collection of past data from earlier studies and base line data collection of rainfall, wind, wave, tide, temperature, water
quality, agriculture and socioeconomic conditions, from government departments and other agencies. Figure 3.2 shows the simplified methodology of the present work.

3.4 FIELD DATA COLLECTION

3.4.1 Water Quality

To understand the spatial and temporal variability of the estuarine system, five sampling stations were identified in the Uppanar estuary and coastal waters of Cuddalore. Water samples were collected during spring and neap tides from April 2004 to March 2005 in both high and low tides. A detailed water sample collection and analysis methods are presented in chapter 4.

3.4.2 Bathymetry Survey

Water circulation in an estuary is controlled by its geometry. The accuracy of the results of any numerical model is directly proportional to the accuracy of the bathymetric data. Therefore, the bathymetric information is the most important one for the setup of the model. In this study, the bathymetry was developed using the measured field data and National Hydrographic Chart data. Bathymetry or depth of the Uppanar estuarine system was measured during a field survey in April, 2004. The bathymetry survey was conducted using a fiber boat equipped with a GPS and Echo-Sounder to traverse the study area. The bathymetric data was logged to a hand-held notebook at every 10 m intervals using an Echo sounder. Simultaneously, positions were logged using a GPS (Make: Garmin GPS 12, U.S.A) receiver. After correcting the obtained depth data with MSL a ‘xyz’ file for water containing latitude/longitude (x, y) and water depth (z) were prepared. Another xyz file for land area was also prepared. These xyz files were then fed as input to MIKE 21 software to calculate depth contours for model domain.
Figure 3.2 Schematic Flow Chart of Methodology
3.5 MODEL SELECTION

Models are by their very nature, abstractions of reality used to simulate, rather than mimic, natural systems (Groot et al. 1999). The targets are to identify the simplest model that addresses all of the important phenomena affecting the hydrodynamics and water quality problems, and to select from those the most useful analytical formula or computer model.

The physical process that need to be modeled such as applicability, the quantity and quality of data available to run the model, simulation time and number of simulation, cost of use, the quality of result required etc were considered for the selection of model. Based on these criteria a two dimensional model was found to be most appropriate. As field data collection and earlier studies of Uppanar estuary indicated the absence of stratification in the estuary. Hence density driven flows need not be considered.

A 2D model should be sufficient to predict changes to tidal elevation or flows; it would predict changes in flow distribution across an estuary or provide sufficient information for sediment transport. Hence a three dimensional model is not needed. A number of well-established process-based modelling packages are now available. From the well known and widely used models MIKE 21, DELFT 3D, HSCTM-2D, and AQUASEA, it was decided to use MIKE 21 for the present study.

3.6 MIKE 21

3.6.1 Introduction to MIKE 21

MIKE Zero is the common name of DHI's (Danish Hydraulic Institute) fully Windows integrated graphical user interface for setting up simulations, pre- and post-processing analysis, presentation and visualization for MIKE21. The two-dimensional MIKE 21 model was selected for the simulation. MIKE 21 is a professional engineering software package containing a
comprehensive modelling system for 2D free-surface flows, developed by the DHI. MIKE 21 is used widely to simulate hydraulics and hydraulics-related phenomena in estuaries, coastal waters, and seas where stratification can be neglected. Briefly, MIKE21 consists of a suite of computational packages that are designed for the purpose of simulating various environmental processes in coastal waterways. Each package consists of a series of modules. The general processes treated by the model include: coastal hydraulics and oceanography, environmental hydraulics, waves, and sediment processes.

### 3.6.2 Advantages of MIKE 21

MIKE-21 is a two dimensional model which treats the entire water column as a single layer. Thus the variables computed by the model are representative of depth averaged conditions. MIKE 21 consists of a hydrodynamic module to which other modules can be added to address different phenomenon including advection-dispersion, waves, and sediment transport. The advantages of MIKE 21 are as follows:

i) MIKE 21 provides the design engineer with a unique and flexible modelling environment using techniques which have set the standards in 2D modelling.

ii) It is provided with a modern user-friendly interface facilitating the application of the system. A wide range of support software for use in data preparation, analysis of simulation results and graphical presentation is included.

iii) MIKE 21 is compiled as a true 32-bit application implying that it can only be executed under operating systems Windows 98, NT 2000, XP, Vista and Windows 7.

iv) An advanced GUI combined with a series of highly efficient computational engines
v) GUI facilities for easy applications
vi) GIS integration
vii) Free tools, e.g. for processing of model data in MATLAB
viii) Modules for virtually any kind of 2D water modelling needs
ix) Open, flexible and easy ecology and water quality modelling
x) Sophisticated tools for data handling, analysis and visualization
xi) Multiple computational grid options ensuring optimal model application

MIKE 21 is the result of more than 20 years of continuous development and is tuned through the experience gained from thousands of applications worldwide. DHI continues to use MIKE 21 in its own studies, thus giving a valuable symbiosis between development and application. MIKE 21 flow model contains the following modules.

i) PP - Pre- and Post-processing
ii) HD – Hydrodynamics
iii) AD - Advection-Dispersion
iv) ST - Sand Transport
v) MT - Mud Transport
vi) PT - Particle Tracking
vii) SA - Spill Analysis
viii) ECO Lab - Ecological Modelling
ix) NSW - Near Shore Spectral Wind-Waves
x) PMS - Parabolic Mild Slope Waves
xi) EMS - Elliptic Mild Slope Waves
xii) BW - Boussinesq Waves
MIKE 21 Hydrodynamic and Advection dispersion module were used for the present study.

3.7 MIKE 21 HD

The hydrodynamic model in the MIKE 21 flow model (HD) is a general numerical modelling system for the simulation of water levels and flows in estuaries, bays, and coastal area (Warner and Bach 1992). It simulates the changes in water levels and velocities in response to tides, wind, and freshwater inflows. It solves the time-dependent, vertically integrated equations of continuity and conservation of momentum in two horizontal dimensions. The equations can be solved by a finite difference method. Water levels and flows are resolved on a rectangular grid covering the area of interest. It simulates unsteady two dimensional flows in vertically homogeneous fluids and has been applied in a large number of studies. The following equations, the conservation of mass and momentum integrated over the vertical, describe the flow and water level variations:

\[
\frac{\partial \xi}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t}
\]  

\[
\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left( pq \right) + gh \frac{\partial \xi}{\partial x} + \frac{gq \sqrt{p^2 + q^2}}{c^2 h^2} - \frac{1}{\rho_w} \left[ \frac{\partial}{\partial x} \left( \sigma_{xy} \right) + \frac{\partial}{\partial y} \left( \sigma_{xy} \right) \right] = \Omega_q
\]

\[-fVV_x + \frac{h}{\rho_w} \frac{\partial}{\partial x} (p_a) = 0 \]  

\[
\frac{\partial q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{q^2}{h} \right) + \frac{\partial}{\partial y} \left( pq \right) + gh \frac{\partial \xi}{\partial y} + \frac{gp \sqrt{p^2 + q^2}}{c^2 h^2} - \frac{1}{\rho_w} \left[ \frac{\partial}{\partial y} \left( \sigma_{xy} \right) + \frac{\partial}{\partial x} \left( \sigma_{xy} \right) \right] = \Omega_p
\]

\[-fVV_y + \frac{h}{\rho_w} \frac{\partial}{\partial y} (p_a) = 0 \]
Where

\[ h(x, y, t) \] - Water depth \( (= \zeta - d, m) \)

\[ d(x, y, t) \] - Time varying water depth (m)

\[ \zeta(x, y, t) \] - Surface elevation (m)

\[ p, q(x, y, t) \] - flux densities in x- and y- directions \( (m^3/s/m) \)

\( (uh,vh),(u,v) \) = depth averaged velocities in x and y directions

\[ C(x, y) \] - Chezy resistance \( (m^{1/2}/s) \)

\[ g \] - Acceleration due to gravity \( (m/s^2) \)

\[ f(V) \] - Wind friction factor

\[ V, V_x, V_y(x, y, t) \] - Wind speed and components in x- and y- directions \( (m/s) \)

\[ \Omega(x, y) \] - Coriolis parameter, latitude dependent \( (s^{-1}) \)

\[ p_e(x, y, t) \] - Atmospheric pressure \( (kg/m/s^2) \)

\[ \rho_w \] - Density of water \( (kg/m^3) \)

\[ x, y \] - Space coordinates (m)

\[ t \] - Time (s)

\[ \tau_{xx}, \tau_{xy}, \tau_{yy} \] - Components of effective shear stress

### 3.7.1 Input for MIKE 21 of Flow Model HD

The main inputs for MIKE 21 of flow model HD includes

i) Bathymetry

ii) Bed resistance

iii) Wind velocities

iv) Hydrographic boundary conditions (e.g., tides and inflows).

In addition to the above inputs, Wind shear stress at the surface, Bottom shear stress by Chezy’s equation using Manning’s n, Barometric
pressure gradients, Coriolis forces, Turbulent viscosity, Sources and Sinks, Floodling and drying are also included for superior results. Calibration parameters include Manning’s n and eddy viscosity coefficients. Pre- and post-processing software include graphical interfaces that ease the input of data and analysis of the simulation result. The detailed description of MIKE 21 HD model setup, simulation, results and discussion are presented in Chapter 5.

3.8 MIKE 21 AD MODEL

The Advection – Dispersion module solves the so-called advection – dispersion equation for dissolved or suspended substances in two dimensions. This is in fact the mass-conservation equation. Discharge quantities and compound concentrations at source and sink points are included together with a decay rate. The equations and numerical formulation used in the Advection – Dispersion module of MIKE 21 flow model are shown below.

\[
\frac{\partial}{\partial t} (hc) + \frac{\partial}{\partial x} (uhc) + \frac{\partial}{\partial y} (vhc) = \frac{\partial}{\partial x} \left( h.D_x \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left( h.D_y \frac{\partial c}{\partial y} \right) - F \cdot h \cdot c + S
\]

... (3.4)

Where
- \( c \) - Compound concentration
- \( u, v \) - Horizontal velocity components in x, y directions (m/s)
- \( h \) - Water depth (m)
- \( D_x, D_y \) - Dispersion coefficients in the x, y directions (m\(^2\)/s)
- \( F \) - Linear decay coefficient (sec\(^{-1}\))
- \( S \) - \( Q_s, (c_s - c) \)
- \( Q_s \) - Source / sink discharge (m\(^3\)/s/ m\(^2\))
- \( C_s \) - Concentration of compound in the source/sink discharge
3.8.1 Input for MIKE 21 of Flow Model AD

MIKE 21 HD model is the fundamental model for MIKE 21 AD. In addition to the MIKE 21 HD model inputs, the following are the essential basic inputs for MIKE 21 AD model.

i) Components
ii) Initial concentration of the components
iii) Source and sinks
iv) Boundary concentration
v) Deposition concentration
vi) Dispersion co-efficient

3.9 MODEL CALIBRATION AND VALIDATION

A mathematical model is by definition an attempt to approximate and reproduce real phenomena (Cheng et al., 1991). The approximations and parameterisations used for the synthesis of the model lead to discrepancies and deviations of model results from nature. Therefore, before being applied to a specific location, the models should be calibrated. Model calibration appears in various forms, dependent on data availability, characteristics of water body and most of all the perceptions and opinions of modellers (HSU, 1999)

In this study, it is applied a two-dimensional vertically integrated hydrodynamic model MIKE 21 developed from DHI was used. The MIKE21 hydrodynamics model was validated against field data obtained during the sampling period. In general, calibration and validation is accomplished by qualitative comparison of short time-series of water level or velocity produced by the numerical model with field data for the same location and for the same period of time (Cheng et al., 1993). After the sensitivity tests were carried out
with varying eddy viscosity and bed resistance values, the model was validated through comparisons of measured and calculated water levels and velocity time series for different eddy viscosity and bed resistance values. The model calibration and validation processes were described in Chapter 5.