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Identification of Optimum Outfall Location for Desalination Plant in the Coastal Waters off Tuticorin, India

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ABSTRACT: Behaviour of the dilution characteristics of the coastal waters off Tuticorin is presented in the background of setting up of a desalination plant. Simulations of dispersion and spreading of the proposed discharges has been carried out. Scenarios of dilutions were assessed based on the results of a 2D model using the advection-dispersion theory. It is observed that under prevailing currents in the region, the dispersion of the discharge will be advected away as a combined plume. Ambient conditions are found achieved in close proximity zones within the discharge location and thus there will not be any changes in the water quality in the adjacent coastal waters. Model validation results showed that the values are well in agreement with the observed values. It is suggested that the offshore waters at a distance of 2 Km away from the coastline could be considered as optimum where the environmental impact on the ecosystem due to the disposal operations is considered to be minimum.

Key words: Salinity, Desalination plant, Site selection, Model simulation, India

INTRODUCTION

Galloping population, rapid industrialization and unrestrained pursuit of multiple associate activities resulted into multifold increase in freshwater demands along the coastal zones of India. Due to the shifts in economic policies, industry driven growth processes will further be accelerated to competition and conflicts to the coastal ecosystems which sustain them. Desalination plants provide practical and realistic solutions for water scarcity in coastal zones where the groundwater resources are poor.(Rachel Einar *et al.*, 2002). Recently, there has been a surge in the number of proposals for desalination plants around the nation which are being conceived to address local problems of fresh water shortages where conventional sources are insufficient or overexploited. Additional freshwater demands for industrial needs necessitated the proposal for setting up of a desalination plant at Tuticorin along the east coast of India (NIO, 2010). The project envisages the setting up of a plant with peak capacity of 25 mld.

The common environmental impact attributed to the brine discharge into the sea is related to its effect on coastal marine ecology due to the pumping of salt concentration back into the coastal waters (Latteman and Hopner, 2008; Thomas and Domenec, 2008). Potential impacts, if any to the marine environment can be minimized by appropriately planning and selecting the suitable outfall location (Robert, 1995). Hence, the discharges to the coastal waters have to be adapted to be site specific and optimum. In effect, the discharge plumes should get dissolved by the action of the prevailing currents in the coastal marine environment (Quetin and M De Rouville, 1996). Physical dilution processes of mixing the concentrated solution release and transport is a prerequisite for brine discharge (Bleninger and Jirka, 2008). Brine dilution is a combination of two physical processes such as primary dilution (jet) in the near field and the natural dilution happening in the far field due to diffusion and mixing produced by the prevailing currents in the sea. Thus, the spreading of an effluent cloud released in an aquatic environment is governed by advection caused by large scale water movements and diffusion caused by comparatively small scale random and irregular movements without causing any net transport of water. Hence the important physical property governing the rate of dilution of an effluent cloud in coastal water is circulation resulting from the prevailing coastal currents (Fischer H.B *et al.*, 1979). For characterizing and modelling brine discharges into the sea, numerical approaches are followed (Hopper and Windelberg, 1996; Morton *et al.*, 1996; Talavera and Ruiz, 2001;

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Purnama *et al.*, 2003; Malcangio and Petrillo, 2010; Palomar, 2011; Palomar and Losada, 2011;Palomar *et al.*, 2012; Palomar *et al.*, 2012a). Numerical modelling assist to provide satisfying clues to the complex situations of dilutions encountered.

Studies were carried out during 2010 (NIO, 2010) to locate optimal site off Tuticorin, India for the proposed desalination outfall in order to minimize the impact of salt concentration release on the marine environment.

MATERIALS & METHODS

The project location is shown in Fig. 1. Tuticorin is one of the industrial cities located on the southern part of Tamilnadu. It is historically known as the Pearl City due to enriched wealth of live pearls in the adjacent sea of Gulf of Mannar. A major port is located in Tuticorin with several major industries around the region. The location of proposed project lies on the southern side of the Tuticorin port. Tides experienced in the region are of mixed semidiurnal type with two high and tow low waters occurring every tidal day (Anonymous, 2011). The predicted tides for Tuticorin shows that the average spring tidal range is about 0.7 m and the average neap tidal range is about 0.16 m. The month-wise wind characteristics derived from Indian Daily Weather Reports shows that predominant wind direction during June to October was from 270°. From November to March, the wind direction during morning hours was from 320° and during evening hours, it was from 70°.

Currents near the coast are found driven primarily by tides and winds, the latter being a major component. Recording current meter data available from the current meter mooring deployed at about 2 km offshore were used in the study (Fig. 1).

The desalination plant proposed is with a peak capacity of 25 mld for with an intake capacity of 93 mld and discharge of 68 mld. Discharge will consists of brine with high salinity of 13 psu in excess of ambient and the temperature rise would be 5 ° C above the ambient values of seawater. Salient details of the plant are presented in Table 1.

Near-field dilution was assessed based on the Buoyant Jet Model for which the governing equations are as follows:

$$\frac{du}{ds} = \frac{2g\lambda^2}{u}\frac{\Delta\rho}{\rho_o}\sin\theta - \frac{2u\alpha}{b}$$

$$\frac{db}{ds} = \frac{2\alpha b g\lambda^2}{u^2} - \frac{\Delta\rho}{\rho_o}\sin\theta$$

$$\frac{d\theta}{ds} = \frac{2g\lambda^2}{u^2} - \frac{\Delta\rho}{\rho_o}\cos\theta$$

$$d\ \frac{\Delta\rho}{ds} = \frac{1+\lambda^2}{\lambda^2}\frac{d\rho}{dy}sin\theta - \frac{2\alpha\Delta\rho}{\rho}$$

$$\frac{dx}{ds} = cos\theta\,;\ \frac{dy}{ds} = sin\theta$$

where

g	=	acceleration due to gravity
ρρ	=	density of effluent
$\rho\rho_o$	=	density of seawater
∝∝	=	constant
λλ	=	entrainment coefficient
x	=	horizontal distance from Jet orifice
y	=	vertical jet coordinate
u	=	jet velocity
θθ	=	angle of jet orifice with horizontal plane
ds	=	step increment

also

$c_o\, u_o\, b_o$ = c u b

where

c	=	concentration at given time
b	=	width of jet/plume at given time

$c_o\, u_o\, b_o$ represent concentration/mass density, jet velocity and jet width at time t = 0.

The model also takes the ambient velocity into account while calculating initial dilution. The above equations were solved explicitly by Range-Kutta integration scheme.

Far-field dilution is calculated using inputs namely (a) bathymetry, (b) tide forcing (c) bottom roughness coefficient and initial boundary

(a) Continuity and mass balance

$$\frac{\partial\eta}{\partial t} = \frac{\partial(HU)}{\partial x} + \frac{\partial\,(HV)}{\partial y} = Hm_v$$

ηη = H - h

where

T	=	time coordinate
ηη	=	water surface elevation

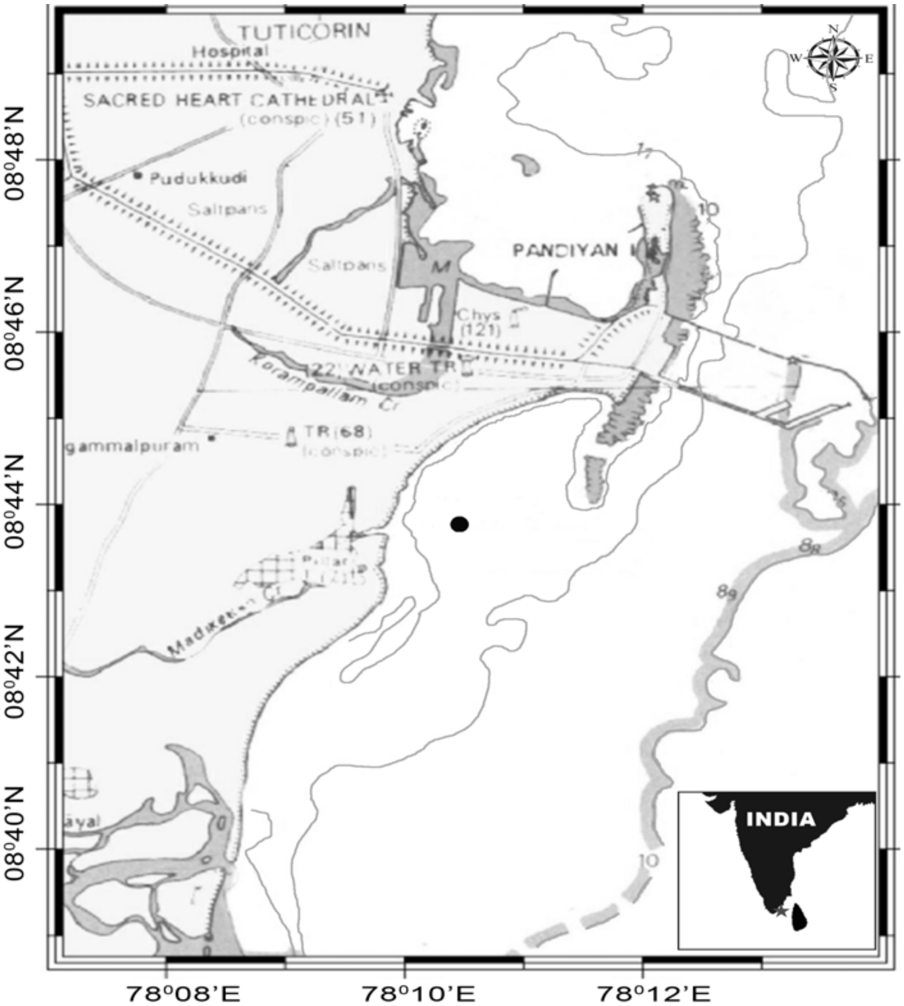

Fig. 1. Location map (•current meter mooring)

Table 1. Design details of the proposed desalination plant

Plant Capacity		416.6 m^3/h	25 mld
Intake capacity	1000 mm ODx2 pipeline	3875 m^3/h	93 mld
Brine Reject Capacity	560 mm ODx2 pipeline	2833.3 m^3/h	68 mld
Return Water			
Feed Salinity, Density	40000 ppm, 1.025		
Brine Reject Salinity, Density	6200 ppm, 1.03		

x, y = set of horizontal, mutually orthogonal cartesian coordinates

H = total instantaneous water depth

U, V = horizontal velocity components in x and y direction respectively

m_v = vertically integrated average rate of mass infection or with drawl of fluid per unit volume divided by the fluid density

h = the depth of water measured positively downwards from the reference datum plane

(b) Continuity and mass balance Momentum balance equations

The vertically integrated momentum balance equations for a shallow water body are given by:

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}=-g\frac{\partial \eta}{\partial x}-\frac{1}{\rho}\frac{\partial P_a}{\partial y}+V+\frac{C_w W^2}{H}cos\theta-\frac{C_d(U^2+V^2)^{1/2}}{H}U+S_u$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}=-g\frac{\partial \eta}{\partial y}-\frac{1}{\rho}\frac{\partial P_a}{\partial y}-\Omega U+\frac{C_w W^2}{H}sin\theta-\frac{C_f(U^2+V^2)^{1/2}}{H}V+S_v$$

$$\frac{\partial(\alpha C)}{\partial t}+\frac{\partial(\alpha V C)}{\partial x_i}=\frac{\partial(\alpha K_c C)}{\partial x_i}+\alpha S_c-\alpha\gamma$$

where

g = acceleration due to gravity

P = fluid mass density

P_a = atmospheric pressure

ΩW = coriolis parameter

C_w = wind stress coefficient

W = wind speed

θ = wind angle measured from the positive direction of x towards the positive direction of y axis.

C_f = the bottom friction coefficient

S_v = average rate of x - momentum generated or dissipated per unit volume derived by the mass density of water.

(c) Continuity and mass balance Momentum balance equations Mass transport equation

The equation for conservation of mass is written as

$$\frac{\partial(\alpha C)}{\partial t}+\frac{\partial(\alpha V C)}{\partial x_i}=\frac{\partial(\alpha K_c C)}{\partial x_i}+\alpha S_c-\alpha\gamma$$

where

C^k =the mass concentration of the K-th species in fluid (concentration of pollutant)

K_c = effective mass diffusivity coefficient

S_c = source of the k-th species

$\gamma\gamma^k$ = net decay of the k-th species

α = Water Depth.

The above equations were solved with ADI scheme considering finite difference approach. The grid resolution was 100 m with total grids of 121 in east direction and 198 in north direction. The time step used was 5 s. The variable bottom friction which is a function of depth was considered. In the study region, currents are driven by both tides and winds. The current pattern changes with seasons, northeast monsoon and southwest monsoon. Model was run for both the seasons for hydrodynamics and mass transport by introducing intake of 93 mld and discharge of 68 mld.

RESULTS & DISCUSSION

It is important to design an effluent disposal scheme in a manner to achieve maximum possible near field dilution. This is particularly important in the present case since effluent is denser (Density: 1130 kg/m^3) than seawater (Density: 1025 kg/m^3) and would tend to sink on emerging from the diffuser ports if sufficient dilution is not attained with the jet forcing. In such a situation the complete water column above the diffuser would not be available for dilution but would be limited to the level up to which the plume rises.

For effluent with density higher than that of the receiving water, release near the surface offers a distinct advantage since the complete water column below the release is available for near-field dilution. However, a surface scheme would require construction of a trestle to lay the pipeline in the absence of suitable existing structure in the area. Hence, the best option is to release the treated effluent through a submarine pipeline terminating into adequately designed diffuser with optimum number of ports discharging at a convenient angle that ensures required near-field dilution. The disposal of discharges generated from the desalination plant is to be achieved through a subsurface outfall installation. The release should be made in such a manner so as to minimise interference with other present and potential uses. This can be achieved by ensuring maximum initial dilution through an appropriate means of disposal and by selecting a location where the dispersive processes of transport and mixing are active. Therefore, if a location is considered in the initial stages, looking at the surrounding hydrography of the region, its suitability can be ascertained from the dispersion pattern and plume behaviour for that particular location. A location that provides requisite results would thus be selected as the final disposal location.

The geographical location 08° 43’ 37" N, 78° 10’ 29" E, where a depth of 4 m is available below Chart Datum, is considered for the discharge of treated effluent with 12 ppt above ambient. As the salinity of seawater at Tuticorin is about 35 ppt, the salinity of the effluent would be 48 ppt. The quantity of the effluent would be 68 mld. A hydrodynamic modelling exercise also has to be carried out to confirm the efficiency of the disposal mechanism and to ensure that optimum discharge standards are achieved.

Model simulations were carried out to ascertain the flow conditions of the region, the extent of the plume movement and its dilution and extent of effect on the surrounding environment. The input parameters for the model are given in Table 2.

Table 2. Input parameters and main run characteristics

Discharge density (kg/m^3)	1032
Seawater density (kg/m^3)	1025
Minimum water depth (m)	4.0-5.0
Current velocity (m/s)	0.05
Discharge rate (m^3/d)	68000
Angle of release (deg)	45
Step increment (m)	0.001

From the computations it is found that salinity would increase marginally from 0.6 to 0.7 ppt at the release site. Hence, to make optimum use of the water column above the diffuser, the effluent should be released in at location 08° 43' 37" N, 78° 10' 29" E with a minimum initial jet velocity of 3 m/s through a 6 port diffuser each port having 0.23 m diameter . The ports should be separated by 6 m making an angle of 45° from the horizontal. The diffuser should be kept at height of 0.5 m above bed level. The ports should align parallel to the coastline. The upward angle of the port is required to allow the fluid to pass through relatively longer trajectory in order to get more initial dilution. As the effluent is heavier than the receiving water it would initially rise to 4 m due to jet velocity and then tend to descend through the column attaining additional dilution. By the time the plume approaches the bed level dilution attained would be 22 times. The salinity would increase by 0.6 ppt at release site, where in the total diffuser length would be 30 m.

When the high density effluent is released in the Tuticorin coastal region, it would be dispersed by advective diffusion which depends on local currents, as well as molecular diffusion that is linked with the concentration gradients. The TIDAL model, a comprehensive computational fluid dynamics software tool for analysis of a wide range of problems in fluid flow, heat transfer and mass transport in shallow water bodies was used to compute far-field dilution. In the present context the effluent is considered as conservative and the mass of effluent released itself was considered as pollutant. Hence, the decay term could be considered as negligible.

Results of the variation of current speed and direction are shown in Fig. 2. The current speed prevailed was found to be moderate.

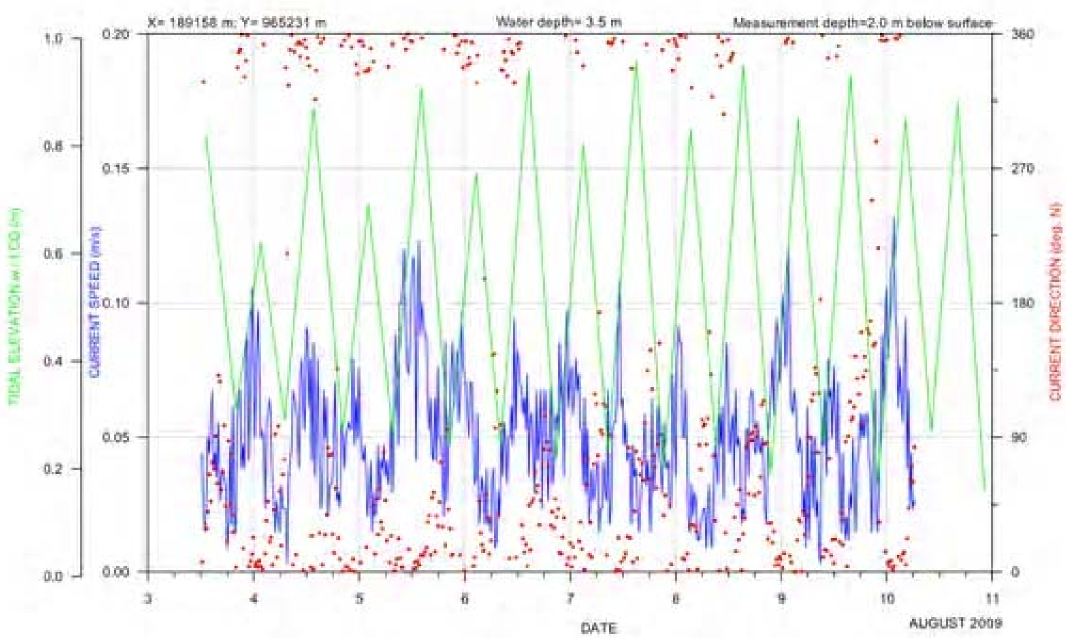

Fig. 2. Variation of current speed and direction

The model was run for 10 days by giving tide at south and northern boundaries. This period represents the northeastern monsoon. Wind speed of 5m/s and direction of 225 degrees were considered for wind forcing. The model was run for one day initially to eliminate the cold start instabilities. After giving inputs of salinity difference, the model was run for 10 days. The model was also made run for southwest monsoon season, giving the wind speed of 7m/s and direction of 45 degrees. Results are shown in Figs 3 to 6. The distribution of current vectors delineated that the current speed increased from coast to offshore. The vectors ran parallel to the coast and the current speed showed moderately high values.

The modelled salinity increase is presented in Figs 7 and 8. During the northeast monsoon season the plume would move towards south and the increase in salinity at the release site would be 0.07 ppt. The temporal variations in salinity increase during the northeast monsoon was found to be 0.01- 0.07 ppt (Fig. 9). During the southwest monsoon period the currents were found to be directed towards north. As a result, the plume would move in that direction where in the increase in salinity would found remained unchanged (Fig. 10).

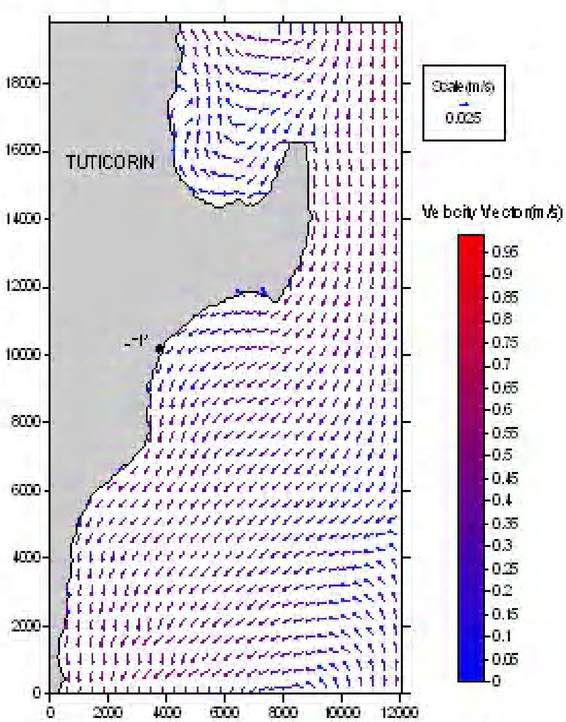

Fig. 3. Modelled current during north east monsoon

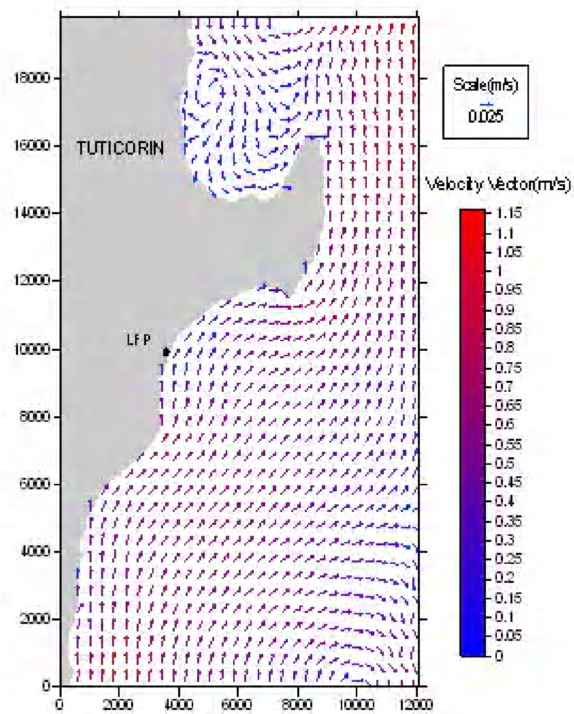

Fig. 4. Modelled current during south west monsoon

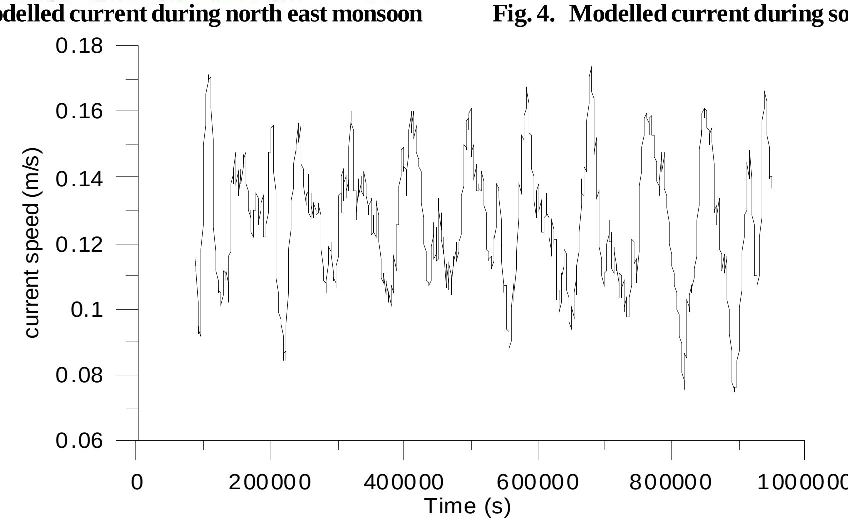

Fig. 5. Temporal variations of currents during north east monsoon

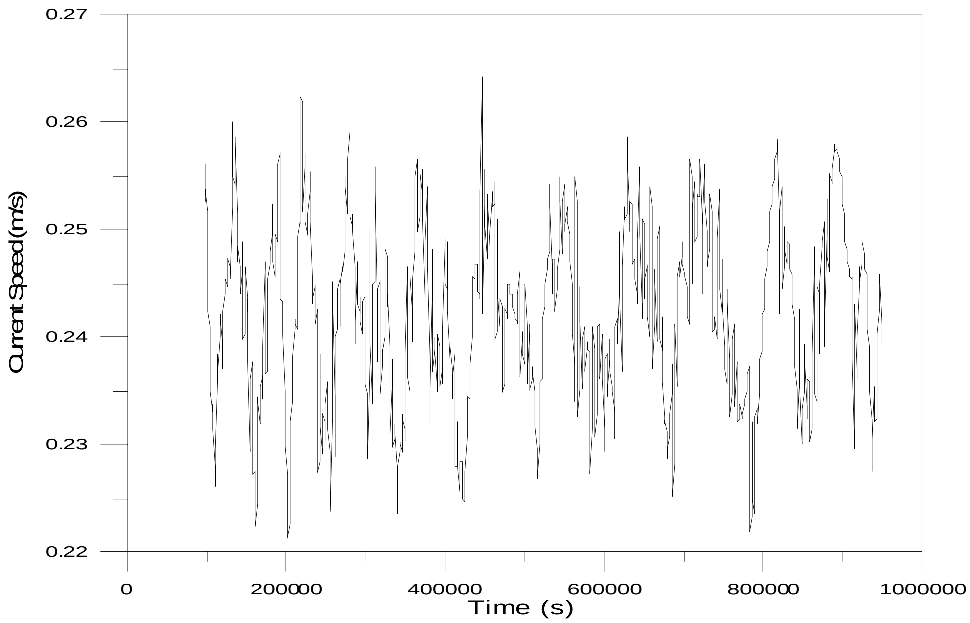

Fig. 6. Temporal variations of currents during south west monsoon

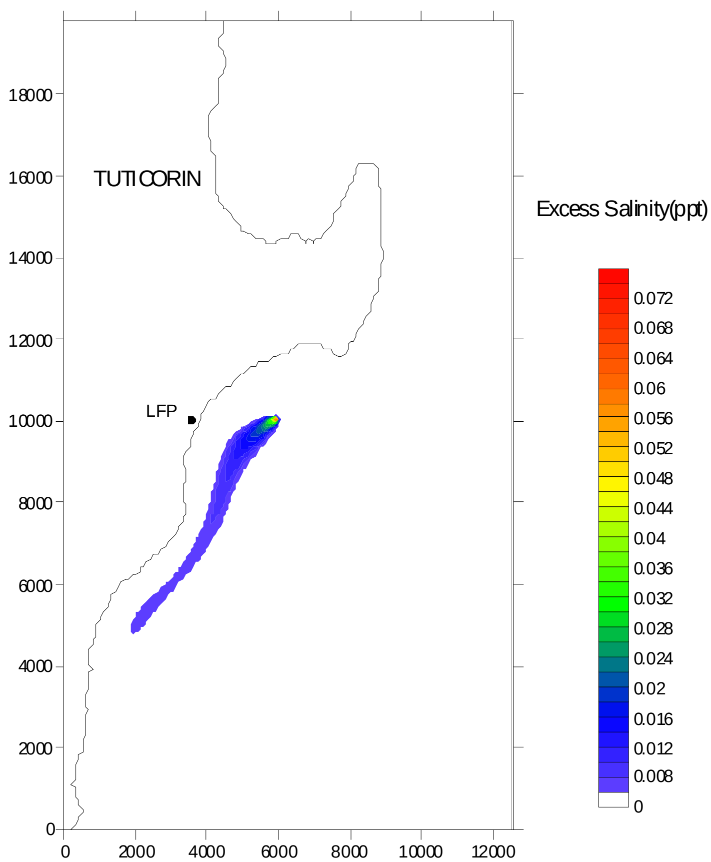

Fig. 7. Modelled salinity during north east monsoon

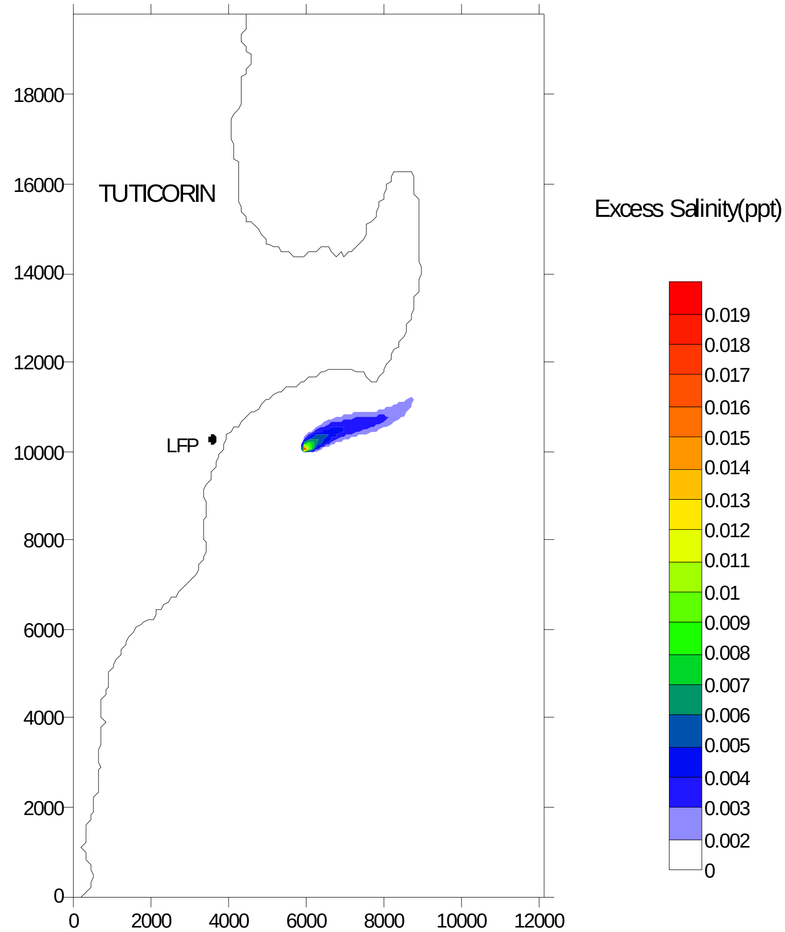

Fig. 8. Salinity distribution during south west monsoon

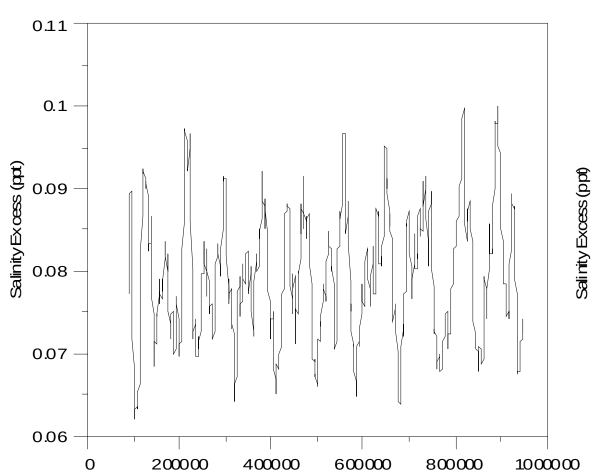

Fig. 9. Temporal variations of salinity during north east monsoon

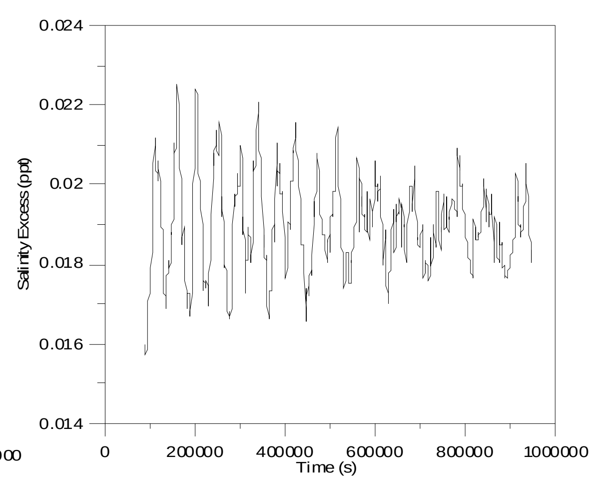

Fig. 10. Temporal variation of salinity during south west monsoon

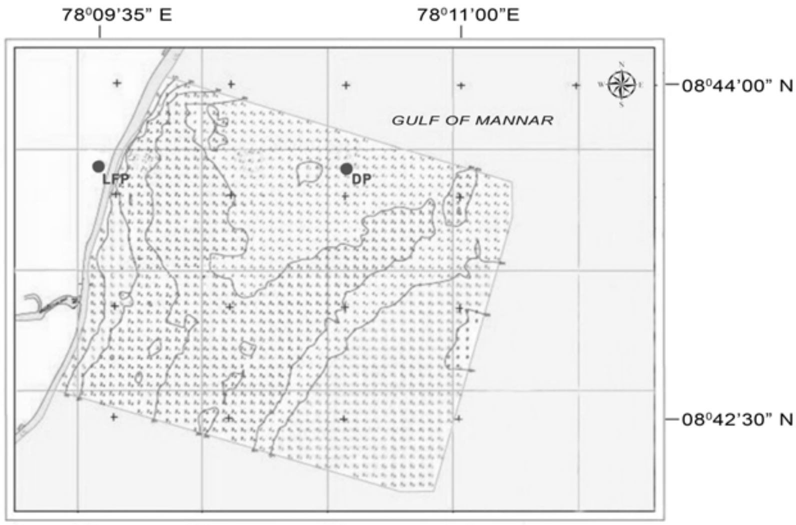

Fig. 11. Location of the discharge point

CONCLUSION

A quantity of 68 mld of high salinity brine is proposed to be disposed off at an offshore location in the sea. Selecting an environmentally acceptable location for the same is a matter of serious concern as the disposal should not present any unacceptable adverse effect on the coastal environment. Flow pattern showed the presence of moderately high currents with a strong alongshore component beyond the 4 m depth contour zones. It was observed that under the prevailing currents in the region, the dispersion of the discharge will be advected away as a combined plume. Using the advection dispersion theory, simulation of the plume dispersion and spreading was carried out for different seasons. Ambient conditions were found achieved in close proximity zones. Based on this, it is recommended that effluent quantity of 68 mld can be released at location where the pipeline extends 2.0 Km to the sea (Fig. 11). Maintaining a minimum initial jet velocity of 3 m/s through a 6 port diffuser each of 0.23 m diameter will enhance the initial dilution. The ports should be separated by 6 m making an angle of 45° from the horizontal. The diffuser should be kept at a height of 0.5 m above bed level with the ports aligned parallel to the coastline. The upward angle of the port is required to allow the fluid to pass through relatively longer trajectory to achieve more initial dilution. As the plume would run parallel to the coast, there will not be any chances of recirculation.

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