Numerical Model Study of Industrial and Municipal Sewage Dispersion At Alandi

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Abstract- *Alandi town is situated on the banks of Indrayani River in Khed Taluka in District Pune. Town is approximately 25 km from Pune city. This sewage is discharged into Indrayani River without any proper treatment. This results in degradation of water quality and contamination of river water, which is harmful for environment and human beings. The present study deals with Numerical Model Study of Industrial and Municipal Sewage Dispersion at Alandi. Numerical modeling was carried out by using MIKE 21 software. It is two dimensional water modeling software developed by DHI, Denmark. It consists of different Flexible Mesh (FM) modules, out of which this study used the following sub modules - Hydrodynamic Module (HD) and Ecology Module (ECO Lab). Hydrodynamic module was coupled with ECOLAB module for environmental water quality modeling studies. Numerical model was setup and simulated using the Cross Section and Discharge data of Indrayani River in Hydrodynamic module. ECOLAB module was used for simulation of water quality analysis using physical, chemical and biological parameters. Then through the comparison of model simulated data and observed data, the model parameters were calibrated and the simulation results were verified. The numerical modeling results show that the natural dispersion occurring in Indrayani River is very low. The numerical model study developed as a result of a present study will be very helpful to determine the effect of changes in magnitudes of the polluting parameters along the selected reach of the river. The excessive pollution of Indrayani river water has affected the water quality at downstream side of the river.*

Keywords- Numerical Modeling, MIKE 21, Water Quality, Dispersion

I. INTRODUCTION

Rivers are major part of our ecosystem, out of total water quantity on planet Earth, 2.5% of water is fresh water out of which 10.6 million km^3 is in liquid form and it is present in rivers, lakes, groundwater, etc. Rivers play significant role since the water is used for irrigation, drinking, and sanitation by humans and animals, recreation, and commercial water transport of goods and materials. In addition, rivers are also used for disposal of industrial and domestic wastewater which decreases water quality of rivers and river pollution has become a serious worldwide problem. Hence, water quality modeling has become a very important river management tool for water quality and ecological studies.

This research study was conducted for a small town named Alandi, which is located about 25 km away from Pune City. The town is located on both the banks of Indrayani River. The town has several industrial and municipal outfalls, which discharge directly in the Indrayani River.

The Numerical model software used in this Dissertation is MIKE 21, which is a software developed by Danish Hydraulics Institute (DHI), Denmark. MIKE 21 was used to assess degree of water pollution in river and impact of water pollution on river under industrial and wastewater loading. It was used to study the process of transport and dispersion of pollutants in rivers. It can be used to find the values of water quality parameters after dispersion at any specified distance along the river reach.

OBJECTIVES OF THE STUDY

1. Laboratory measurements for water quality analysis at industrial and municipal outfall.
2. Formulation and development of Hydrodynamic Module (MIKE 21-HD).
3. Formulation and development of ECOLAB Module using water quality parameters BOD, DO, Ammonia, Nitrate, Phosphate, Coliform, Arsenic, Lead, Cadmium and Mercury at industrial and municipal outfall.
4. Model Validation using Field Data.
5. Model simulation and assessment of municipal and industrial effluent dispersion using MIKE 21.

II. STUDY AREA

The Indrayani River originates in Kurvande village near Lonavla town situated in the Sahyadri Ghat area. It flows east from there to meet the Bhima river, through the religious villages of Dehu and Alandi, situated north of Pune. At the confluence is town of Tulapur in Havali Taluka. The Alandi town is situated on both the banks of the Indrayani River in Khed taluka in District Pune, approximately 25 km from Pune. Municipal outfall is located at N18^0 40'30.10"Latitude and E 073^0 53'48.01" Longitude. Industrial outfall is located at N18^0 41'05.50" Latitude and E 073^0 49'09.07" Longitude at 14 km upstream of Alandi.

Figure 1: Location Map of Study Area

III. METHODOLOGY

1. DATA COLLECTED

Hydrological conditions have important effects on water quality. In rivers, such factors as the discharge, the velocity of flow, turbulence and depth will influence water quality. Thus, to carry out dispersion studies using MIKE 21 above mentioned data was required.

Table 1: Details of Data Collected

Sr.no	Data	Source
1	Spatial Data	Google Earth and Topographic Map
2	Cross-Sectional Data	Field Survey and Irrigation Department, Pune
3	Obtained River Discharge Data	Jala-Sampada Department, Govt. of Maharashtra, Nashik
5	Waste Water Quality Parameters	Laboratory Testing at COEP and Microtech Laboratory

2. LABORATORY MEASUREMENTS

2.1. Location for Sample Collection

Table 2: Details of Waste water Outfalls

Location	Description	Latitude	Longitude
Moi	Industrial Waste Water	N 18^0 41'05.50"	E 73^0 49'09.07"
Alandi	Municipal Waste Water	N 18^0 40'30.10"	E 73^0 53'48.01"

2.2 Testing of the Water Quality Parameters

Water quality parameters were tested for the month of March 2016. In a non-monsoon period, the river discharge is low and quantity of municipal waste is high, thus dispersion is minimum this is the sever condition for pollution dispersion in rivers.

1) Laboratory Results for Moi Outfall

Table 3: Water Quality at Moi Outfall

Location	Parameters	Lab Results	Permissible Limits
Moi	BOD	139 mg/l	Max 30 mg/l
	DO	0.1 mg/l	Min 4 mg/l
	Ammonia	41 mg/l	Max 5 mg/l
	Nitrate	21 mg/l	Max 50 mg/l
	Phosphate	32.8 mg/l	Max 10 mg/l
	Faecal Coli	6 MPN/100 ml	-
	Total Coli	20 MPN/100 ml	-

2) Laboratory Results for Alandi Outfall

Table 4: Water Quality at Alandi Outfall

Location	Parameters	Lab Results	Permissible Limits
Alandi	BOD	258 mg/l	Max 30 mg/l
	DO	0.1 mg/l	Min 4 mg/l
	Ammonia	41 mg/l	Max 5 mg/l
	Nitrate	18 mg/l	Max 50 mg/l
	Phosphate	26.6 mg/l	Max 10 mg/l
	Faecal Coli	17 MPN/100 ml	-
	Total Coli	48 MPN/100 ml	-

3. SOFTWARE DETAILS

3.1 HYDRODYNAMIC MODEL MIKE21-HD

The hydrodynamic model in the MIKE 21 Flow Model is a numerical modeling system for the simulation of water levels and flows in rivers, estuaries, bays and coastal areas. It simulates unsteady two-dimensional flows in one layer (vertically homogeneous) fluids and is based on the following non-linear vertically integrated 2-D equations of conservation of mass and momentum.

x- direction

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z}=fv-g\frac{\partial \zeta}{\partial x}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{g}{\rho_0}\int_z^{\zeta}\frac{\partial \rho}{\partial x}dz+F_u+\frac{\partial}{\partial z}\left(\upsilon_t\frac{\partial u}{\partial z}\right)+u_s$$

y- direction

$$\underbrace{\frac{\partial v}{\partial t}}_{1}+\underbrace{\frac{\partial v^2}{\partial y}+\frac{\partial uv}{\partial x}+\frac{\partial wv}{\partial z}}_{2}=\underbrace{fu}_{3}-\underbrace{g\frac{\partial \zeta}{\partial y}}_{4}-\underbrace{\frac{1}{\rho_0}\frac{\partial p_a}{\partial y}}_{5}-\underbrace{\frac{g}{\rho_0}\int_z^{\zeta}\frac{\partial \rho}{\partial y}dz}_{6}+\underbrace{F_v}_{7}+\underbrace{\frac{\partial}{\partial z}\left(\upsilon_t\frac{\partial v}{\partial z}\right)}_{8}+\underbrace{v_s S}_{9}$$

1. Fluid acceleration
2. Horizontal gradients in the velocity
3. Coriolis acceleration
4. Acceleration from sea-surface elevation
5. Pressure gradient term
6. Acceleration from buoyancy effects
7. Imbalance of horizontal Reynolds stresses
8. Vertical stresses from the Boussinesq approximati
9. Acceleration from discharges

3.2 WATER QUALITY MODEL MIKE21-ECOLAB

ECO Lab is a numerical lab for Ecological Modelling. It is an open and generic tool for costumizing Aquatic Ecosystem models to describe water quality, eutrophication, heavy metals and ecology. The module is used for modelling water quality as part of an Environmental Impact Assessment (EIA) of different human activities. Another use is in online forecasts of water quality. The strength of this tool is the easy modification and implementation of mathematical descriptions of ecosystems into the hydrodynamic engines of DHI. The 2D depth-averaged transport equation for a non-conservative pollutant is given as:

$$\frac{\partial C}{\partial t}=Dx\frac{\partial^2 C}{\partial x^2}+Dy\frac{\partial^2 C}{\partial y^2}-U\frac{\partial C}{\partial x}-V\frac{\partial C}{\partial y}-\lambda C$$

where D_x , D_y are the dispersion coefficients in x and y direction; U, V are the depth mean velocities in the x and y directions, respectively (m/sec); λ is the decay coefficient (s^{-1}). This equation is numerically solved by an explicit finite difference scheme using MIKE21.

3.3 LIMITATIONS OF THE MODEL

MIKE 21 is a 2D model; its major limitation is that it gives vertically averaged depths and currents each grid point under the assumption of well mixed condition. Whatever, the computation has been carried out the results may be averaged based on the depth. The computational timing depends on the grid type, if coarse grid is used less computational timing is required and finer grid more computational timing is required. However, the accuracy of the model remains the same. In ECO Lab model the maximum permitted value for water quality parameters are limited, e.g. maximum limit for BOD value is 200 mg/l, maximum limit for nitrate value is 50 mg/l, etc. Large region can be simulated by this model, and it can give guidelines for refinement by 3D mathematical/physical model.

3.4 NUMERICAL MODEL STUDY USING MIKE 21

Numerical modeling was done using MIKE 21 software; the step by step procedure which was carried out for study was as follows:

1. Pre-Processing

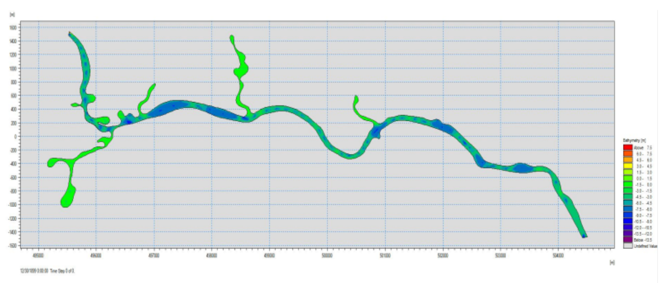
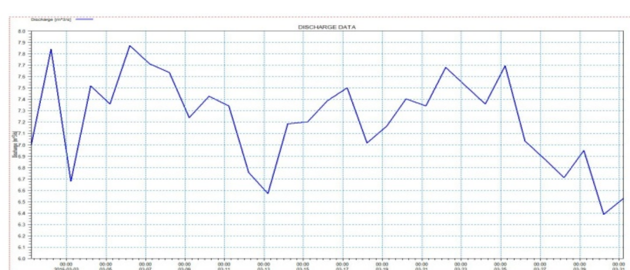


Figure 1: Bathymetry

Bathymetry was prepared using triangular mesh. The total numbers of elements used in the mesh were 568 with 525 nodes. The Courant–Friedrichs–Lewy (CFL) number was chosen as 0.8 for stability.



Graph 1: Discharge for Month of March 2016

Graph 1 shows the time history of discharge data for the river water during March. The average discharge in the river was in the order of 7.5 m^3/s during March month.

2. Model Formulation

- Duration :1/12/2015 – 31/12/2015 (1 Month)
- No. of Time Steps : 86400
- Time Step Duration : 30 sec
- Mesh Type : Triangular Mesh
- Mesh Size : 30m – 170m
- Project Area : 14km x 0.17 km
- Effluent Discharge : 5 MLD
- Frequency of result Stored : 30 min
- Chezy's Constant : 32 $m^{1/3}/s$

3. Model Simulation

- **Development of Hydrodynamic Model- HD**
  Inputs given for development of HD model are Bathymetry, Boundary Conditions, Discharge data, Eddy viscosity, Bed resistance, Location of Source. To specify eddy viscosity Smagorinsky formulation was selected and smagorinsky coefficient of constant 0.28 was specified. In the present study chezy constant of 32 $m^{1/3}/s$ was used.

- **Development of Water Quality Model- ECO Lab**
  Inputs given for development of ECO Lab model was ECO Lab template WQ level 6 and coli + P: BOD-DO, nutrients and Coliform bacteria which included water quality parameters like BOD, DO, Ammonia, Nitrate, Phosphate, Faecal Coliform, Total Coliform.

3.5 MODEL VALIDATION

In the present study six locations were selected from the specified river domain and the actual observed values at those locations and the simulated values at those points were compared. Figure 7.2 shows the location of validation points on map and Table 7.1shows the detail description of all the six locations.

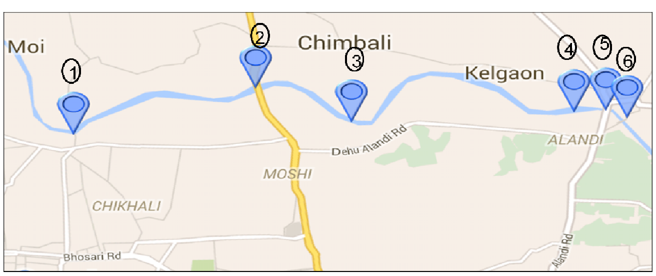


Figure 10: Location of points for Validation

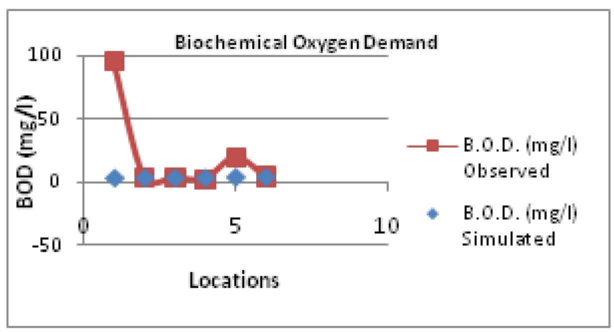
Table 5: Details of Validation Points

Sr. No	Location	Description	Latitude	Longitude
1	Moi	Industrial Waste Outfall	N18⁰ 41.096'	E 073⁰ 49.145'
2	Bridge 1	-	N18⁰ 41.344'	E 073⁰ 50.766'
3	Bridge 2	-	N18⁰ 40.845'	E 073⁰ 51.505'
4	Bridge 3	-	N18⁰ 40.644'	E 073⁰ 53.395'
5	Alandi	Municipal Sewage Outfall	N18⁰ 40.506'	E 073⁰ 53.826'
6	Alandi d/s	-	N18⁰ 40.448'	E 073⁰ 49.880'

1. Biochemical Oxygen Demand (BOD)

Table 5: Biochemical Oxygen Demand Validation

Location		1	2	3	4	5	6
B.O.D. (mg/l)	Simulated	3.26	3.28	3.271	3.3	3.93	3.93
	Observed	95	4	4	3	20	5

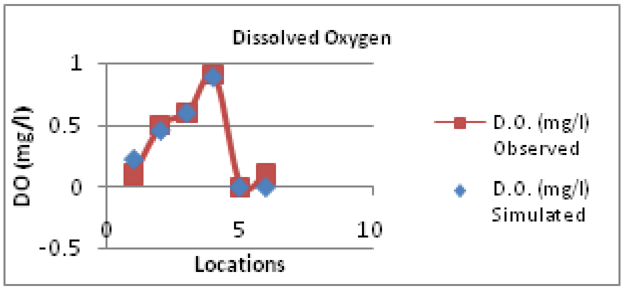


Graph 12: Comparison of Simulated and Observed BOD Values

2. Dissolved Oxygen (DO)

Table 6: Dissolved Oxygen Validation

Location		1	2	3	4	5	6
D.O. (mg/l)	Simulated	0.224	0.455	0.598	0.88	0	0
	Observed	0.1	0.5	0.6	0.9	0	0.1

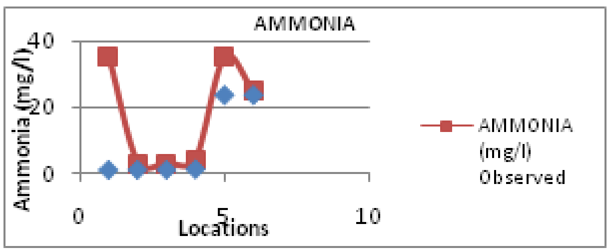


Graph 13: Comparison of Simulated and Observed DO Values

3. Ammonia

Table 7: Ammonia Validation

Location		1	2	3	4	5	6
Ammonia (mg/l)	Simulated	1.2	1.26	1.26	1.43	23.9	23.9
	Observed	35	3	3	4	35	25

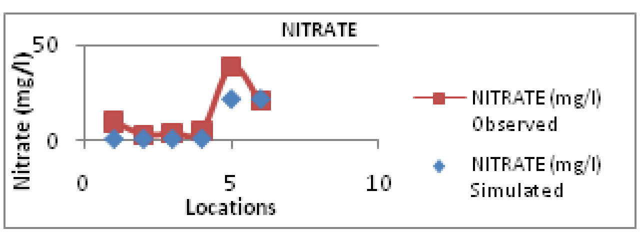


Graph 14: Comparison of Simulated and Observed Ammonia Values

4. Nitrate

Table 8: Nitrate Validation

Location		1	2	3	4	5	6
Nitrate (mg/l)	Simulated	0.31	0.323	0.32	0.48	21.3	21.3
	Observed	9.1	2.5	3.19	4.2	38	20

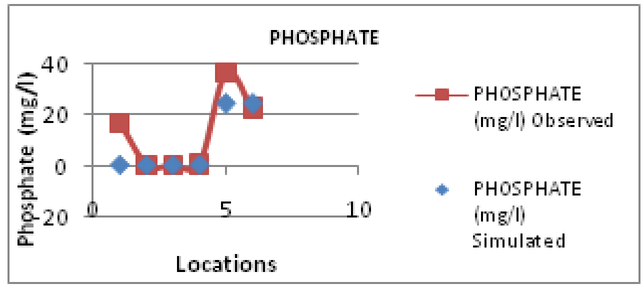


Graph 14: Comparison of Simulated and Observed Nitrate Values

5. Phosphate

Table 9: Phosphate Validation

Location		1	2	3	4	5	6
Nitrate (mg/l)	Simulated	0.31	0.323	0.32	0.48	21.3	21.3
	Observed	9.1	2.5	3.19	4.2	38	20



Graph 15: Comparison of Simulated and Observed Phosphate Values

3.6 DISPERSION RESULTS

1. Biochemical Oxygen Demand (BOD)

River water quality parameter BOD was simulated using MIKE21 ECOLAB Module in the proposed study area for the month of March. Fig.10.12 shows the biochemical oxygen demand dispersion plume during March from existing outfalls at Alandi and Moi. The plume spreads along longitudinal direction with minimum concentration of 0 to 24 mg/l. The length of the plume extends toward downward direction as well as upward direction up to a distance of about 1 km with the concentration of 50 to 96 mg/l and 96 to 112 mg/l during March. The width of the plume was found to be about 17 m.

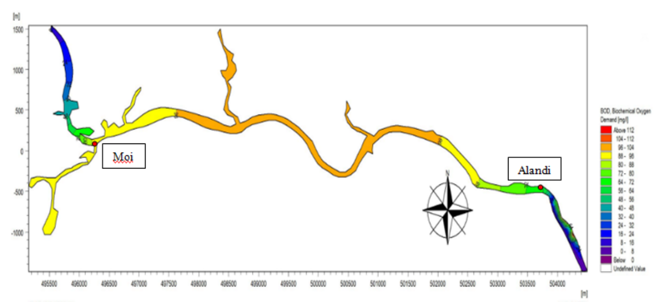


Figure 3: Dispersion of BOD at Alandi/Moi

2. Dissolved Oxygen (DO)

River water quality parameter DO was simulated using MIKE21 ECOLAB Module in the proposed area. Fig. 10.13 shows the dissolved oxygen dispersion plume during March from the existing outfall at Alandi and Moi. The plume spreads along longitudinal direction and cross sectional direction with concentration up to 0.02 to 0.05 mg/l. The length of the plume extends toward downward direction up to a distance of about more than 1 km with the concentration of 0.02 mg/l during the March. The width of the plume was found to be about 0.17 m up to the bank of the river. With the continuous discharge of the domestic and industrial effluents from the existing two outfalls, the DO concentration reduced in the ambient water.

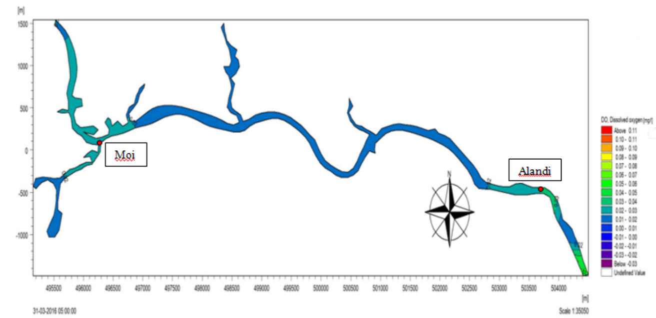


Figure 4: Dispersion of DO at Alandi/Moi

3. Ammonia

River water quality parameter Ammonia was simulated using MIKE21 ECOLAB Module in the proposed area. Fig.10.14 shows the Ammonia dispersion plume during March from the existing outfall points at Alandi and Moi. The plume spreads along river length with concentration of 0 to 50 mg/l. The length of the plume extends toward north direction up to a distance of about more than 1.25 km with the concentration of 23 to 36 mg/l. The width of the plume was found to be about 0.17 km up to the river bank. With the continuous discharge of the effluent from the existing outfalls, the ammonia concentration increased up to 50 mg/l at downstream of Alandi.

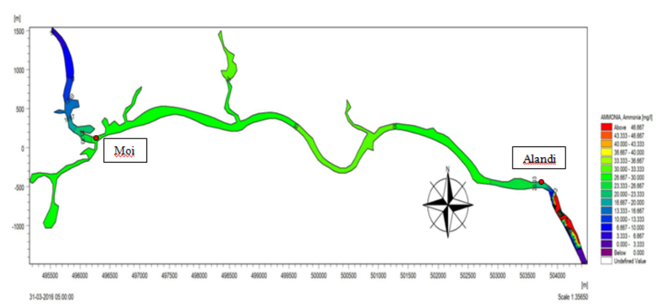


Figure 5: Dispersion of Ammonia at Alandi/Moi

4. Nitrate

River water quality parameter Nitrate was simulated using MIKE21 ECOLAB Module in the proposed area. Fig. 10.15 shows the nitrate dispersion plume during March from the existing outfall points. The plume spreads along river length with concentration of 1 to 21 mg/l in the ambient. The length of the plume extends towards downward direction upto a distance of about more than 1.25 Km with the concentration of 81 to 85 mg/l. The width of the plume is found to be about 0.17 Km up to the river bank. With the continuous discharge of the effluent from the existing outfall, the nitrate concentration increased in the ambient water up to 85 mg/l.

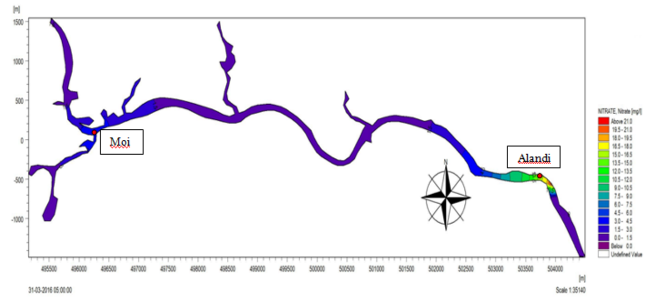


Figure 6: Dispersion of Nitrate at Alandi/Moi

5. Phosphate

River water quality parameter phosphate was simulated using MIKE21 ECOLAB Module in the proposed area. Fig.10.16 shows the phosphate dispersion plume during March from the existing outfall points. The plume spreads along downward direction with concentration of 0 to 15 mg/l. The length of the plume extends toward north direction from Moi outfall up to a distance of about more than 1 km with the concentration of 12 to 8 mg/l. The width of the plume was found to be about 0.17 km up to the river bank. With the continuous discharge of the effluent from the existing Alandi outfall, the phosphate concentration reached up to 15 mg/l.

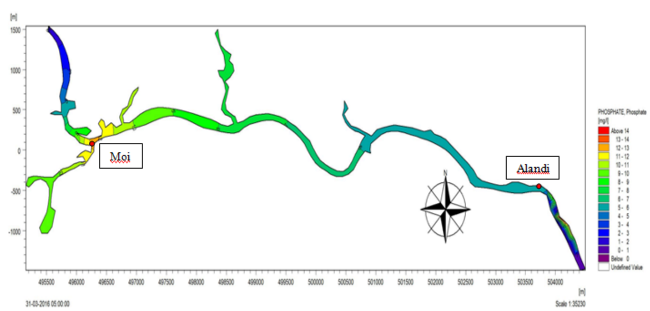


Figure 7: Dispersion of Phosphate at Alandi/Moi

6. Faecal Coliform

River water quality parameter Faecal Coliform was simulated using MIKE21 ECOLAB Module in the proposed area. Fig. 10.17 shows the faecal coliform dispersion plume during March from the existing outfall points. The plume spreads along river length in longitudinal and transverse direction with concentration of 2 to 72 count. The length of the population extends from Moi outfall towards downward direction up to a distance of about more than 1.50 Km with the population of 0 to 10 count. The width of the population is found to be about 0.17 Km up to the river bank. With the continuous discharge of the domestic effluent from the existing outfall, the population increased at Alandi outfall up to 70 count.

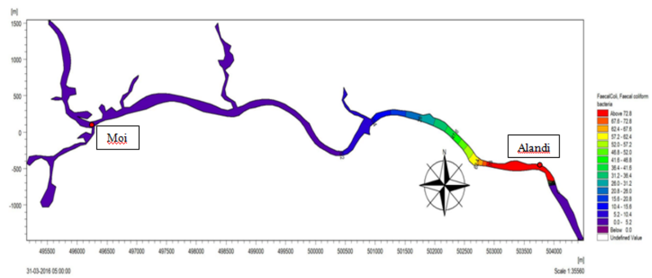


Figure 8: Dispersion of Faecal Coliform at Alandi/Moi

7. Total Coliform

River water quality parameter Total Coliform was simulated using MIKE21 ECOLAB Module in the proposed area. Fig. 10.18 shows the total coliform dispersion plume during March from the existing outfall points. The plume spreads along river length in longitudinal and transverse direction with concentration of 2 to 10 count. The length of the population extends from Moi outfall towards downward direction up to a distance of about more than 1.50 Km with the population of 0 to 3 count. The width of the population is found to be about 0.17 Km up to the river bank. With the continuous discharge of the domestic effluent from the existing outfall, the population increased at Alandi outfall up to 10 count.

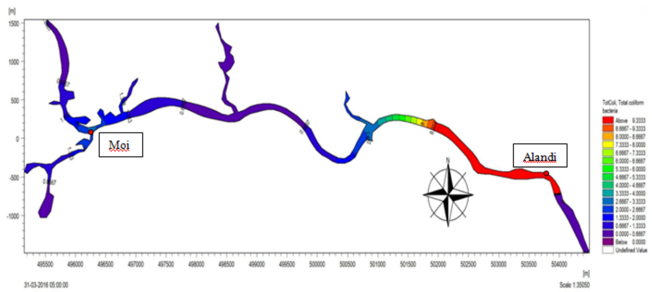


Figure 9: Dispersion of Total Coliform at Alandi/Moi

IV. CONCLUSIONS

1. The model used for the present study was MIKE 21 developed by Danish Hydraulics Institute (DHI), Denmark; which is found to be a successful tool in studying the dispersion effect on Indrayani River at Alandi.
2. The numerical model study developed as a result of a present study will be very helpful to determine the effect of changes in magnitudes of the polluting parameters along the selected reach of the river.
3. Model validation gave the successful results for BOD, DO, Ammonia, Nitrate and Phosphate, thus this model can be used to determine the concentration of above five parameters at any location on the selected river reach.
4. The study showed the following results –
   a) The plume spreads along the longitudinal and transverse direction; the length of the plume extends towards downward direction as well as upward direction depending on the direction of currents.
   b) With the continuous discharge of effluent from industrial and municipal outfall the BOD concentration increased at Alandi was above 112 mg/l and DO concentration was reduced till 0.1 mg/l in the month of March.
   c) The concentration of Ammonia obtained through model was above 50 mg/l in the months of March at the downstream of Alandi outfall.
   d) The concentration of Nitrate obtained through model was above 21 mg/l in the months of March. at the downstream of Alandi outfall.
   e) The concentration of phosphate obtained through model was above 14 mg/l in the months of March at the downstream of Alandi outfall.
   f) Faecal Coliform and Total Coliform were also increased till 72 and 10 in March.
4. The numerical modeling results show that the natural dispersion occurring in Indrayani River is very low.
5. The current practice of releasing untreated municipal waste has severely degraded the water quality of the river. The excessive pollution of Indrayani river water has affected the water quality at downstream side of the river.

APPENDIX

Appendix 1

Table 10: Method used for testing parameters

TESTS	METHOD USED
Dissolved Oxygen (DO)	Winkler's Method with Azide Modification
Biochemical Oxygen Demand (BOD)	Winkler's Method with Azide Modification
Ammonia	Kjeldahl Method
Nitrate	Spectrophotometer
Phosphate	Spectrophotometer
Faecal Coliform MPN/ 100mL	E.coli Procedure
Total Coliform MPN/ 100mL	Multiple-tube fermentation technique

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