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A mathematical model for the prediction of water level along Kharsua River using MIKE11

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Abstract - A hydrodynamic 1D model is used to predict flow conditions in support of a navigation study. The hydrodynamic model uses the cross-section data of Kharsua, Kani and Hansua rivers pertaining to development of National Waterway No. 5 (NW 5) along Brahmani river and Mahanadi river delta in Orissa. The gauge discharge data for Brahmani river at Jenapur gauge site of CWC is available for the period of 33 years. This data is used to provide appropriate boundary conditions at upstream of the model. The downstream boundary conditions will be tidal water levels at Dhamra Port. The topography of Brahmani river delta network in the form of cross-sections is developed using Danish Hydraulic Institute's (DHI) MIKE 11 software to predict the water levels along the river reach under consideration. These predicted flow conditions will be useful for design/planning of waterway for inland navigation and for design of protection works along the reach. The scope of this paper is restricted to calibration and validation of the model.
Keywords - River modeling; MIKE11; 1D hydrodynamic model; boundary conditions; calibration; water levels; navigation

I. INTRODUCTION

Iron ore and coal, being exported (primarily to Japan) from the Odisha Mining Corporation Ltd. (OMC) operated Daitari Mines; via the more or less captive Expressway (NH 5A) from Duburi to Paradeep port is able to cope with cargo and considered economical in today's situation. Presently, a National Highway (NH 42), which runs parallel to the river for almost 100 km and at a short distance away from the river is used for transportation of small consignment. With good prospects of expansion of mining and other industrial activities in the basin, river navigation proposed through (NW 5) could offer a good and cheaper mode of transport. [1]

National Waterway 5 (NW 5) is one of six National Waterways in India and it covers the state of Odisha and a part of West Bengal. It runs a total length of 623 km of which 91 km is within West Bengal and the remaining 532 km is in Odisha. It was declared a National Waterway in November 2008. The NW 5 consists of the stretches from Talcher - Dhamra on the Brahmani River a distance of 265 km including the Kharsua and Dhamra river systems, the Geonkhali - Charbatia stretch of the East Coast Canal of 217 km, the Charbatia - Dhamra stretch of Matai River of 40 km and the Mangalgadi - Paradip stretch of the Mahanadi River Delta running for 101 km. The waterway also includes a 91 km stretch in Bengal between Geonkhali and Nasirabad, West Bengal.

The most important general requirement for navigating through waterway is the availability of sufficient water depth in the waterway. A minimum water depth of about 2.7 meters is generally required for navigating safely and economically; although a depth of about 3.7 meters is generally aspired in the final development of a navigable waterway. Availability of lesser depth in the rivers may completely eliminate the possibility of towing the ships through such rivers or may cause increased unit cost of transport. The width of the waterway should be sufficiently more than the width of the tow itself. The radii of the bends should not be sharp and should be high enough to allow the maximum length of the ship to pass through them. The alignment of the waterway should be as straight as possible. The flow velocities should not be high, as they may cause substantial reduction in the true speed for tows moving upstream and thereby increasing the time of transit and the cost of transport per kilometer. [2]

The present work deals with the development and calibration of the Kharsua river network model using MIKE11 software by checking the predicted water levels with the observed water levels at the gauge discharge site at Jenapur (chainage = 140 km). The paper is organized as follows: Study area and data are discussed in the next section followed by model description and methodology. The results are discussed in the succeeding section giving conclusions at the end.

II. STUDY AREA AND DATA

Brahmani river is one of the east flowing rivers of India and is the second largest river of Orissa next to Mahanadi river. Brahmani river basin is an inter-state river basin. It lies between latitudes 20° 28' N to 23° 35' N and longitudes 83° 52' E to 87° 30' E latitudes. It spreads across the states of Chhattisgarh, Jharkhand and Orissa. The deltaic region starts at Jenapur in Orissa at about 130 km from Bay of Bengal. Here the river branches into numerous spill channels and finally discharges into the Bay of Bengal. The total length of the river is 446 km in Orissa.

At Jenapur, Brahmani river bifurcates into Brahmani (Kimiria) and Kharsua its major deltaic branch on its left. Whereas Brahmani maintains its geometry (channel width, depth & slope) on the main arm, Kharsua has developed as a deeper and narrower channel. Although the two rivers join almost 100 km in the downstream, Kharsua is 15 km shorter in length and therefore is steeper and faster flowing channel. The river receives flood spills from the adjacent Baitarani, before finally discharging into the Bay of Bengal near Dhamra Port. Kani river, a tributary of Kharsua river starts from Rishipur and meets Kharsua river again almost 45 km downstream at Padanipal. Hansua river, a tributary of Kharsua river starts from Mangalgadi and meets Bay of Bengal. Figure 1 shows the Kharsua river reach considered for modeling.

Figure 1. Kharsua river reach considered in the model

Kharsua river has 5 m to 6 m depth and a width of 200 m to 500 m from Jenapur up to its confluence with Brahmani 95 km downstream during monsoon. Thereafter, minimum depth available ranges 7-8 m in the remaining stretch of the river for about 45 km and up to proposed Dhamra port. Maintaining a minimum width of 70 m and depth of 3 m in Kharsua may need a minimum discharge as high as 150 m^3/sec, during March to June, which may become a limiting factor in the future. [1]

The bathymetry survey was carried out by Inland Waterways Authority of India (IWAI) and data was supplied to Water and Power Consultancy Services (WAPCOS) in drawing (.dwg) format. The raw data describes the topography of the river bed and banks. Also, the gauge discharge data from 1980-2012 (33 years) at Jenapur is also provided by WAPCOS.

III. MODEL DESCRIPTION

MIKE 11, developed by Danish Hydraulic Institute in 1987, is a professional engineering software package for the simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. It is a dynamic, user-friendly one-dimensional modeling tool for the detailed design, management and operation of both simple and complex river and channel systems. Due to its exceptional flexibility and speed MIKE 11 provides a complete and effective design environment for engineering, water resources, water quality management and planning applications. [3]

In the present study, gradually varied unsteady flow is solved using MIKE11 which is based on 6 point implicit finite difference scheme developed by Abbott and Ionescu. [4] It is used to solve any form of Saint Venant's equation. The water level and discharge are calculated at each time step by solving continuity and momentum equations with the mass equation centered on h-points and momentum equation centered on Q-points. The water level (h-points) is calculated at each cross section and flow is calculated at the centre between neighbouring h-points and at structures. [5]

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Continuity equation}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial(\alpha \frac{Q^2}{A})}{\partial x} + gA\frac{\partial h}{\partial x} + gA(S_o - S_f) = 0 \ldots\ldots \text{Momentum equation}$$

where A = cross-sectional area normal to the flow, Q = discharge, g = acceleration due to gravity, h = elevation of water surface above a specified datum, S_o = bed slope, S_f = energy slope, t = temporal coordinate and x = longitudinal coordinate.

IV. METHODOLOGY

Processing of the data was done in the drawing file and the data required for the input in MIKE11 was prepared in MS-Excel for every cross-section at the interval of 500 m. First of all, a simulation file was created. It contains the simulation and computation control parameters. It is used to start the simulation and provides a link between network file, cross-section file, boundary file and hydrodynamic file which are the input files. The model was run in unsteady simulation mode which is based on hydrodynamic flow conditions. The time step is kept at 5 minutes, simulation period is kept for the period of 1 month and storing frequency is kept at 1 time step. The initial condition was kept at steady state i.e. the initial conditions will be calculated automatically assuming a steady state condition with discharges and water levels at the boundaries corresponding to the start time of the simulation.

Secondly, a network file is created to draw the network of the three rivers as it supplies the user with an overview of the model setup components defined in the network file itself but also by presenting data which is stored in the other MIKE 11 editors. Thirdly, a cross-section file is created to input the raw data of cross-sections along the reach of Kharsua river (149 km), Kani river (45 km) and Hansua River (13 km); extending over a total length of 207 km which was prepared in MS-Excel. Along with the cross-section, uniform roughness coefficient Manning's "n" value of 0.03 was used. Cross-section file manages, stores and displays all model cross section information. Fourthly, a boundary file is created in which the boundary conditions were added at the upstream and downstream. Boundary conditions at upstream were discharges for low flow and high flow and boundary conditions at downstream were maximum tidal water level (1.94 m w.r.t. MSL). Finally, a hydrodynamic file is created in which wave approximation is kept as high order fully dynamic keeping the other parameters unchanged.

A broad crested weir is incorporated on Kharsua river at Jokadia (chainage = 134 km) which has a length of 235 m and sill level of 14.78 m MSL.

Figure 2 shows the schematic network of entire study area.

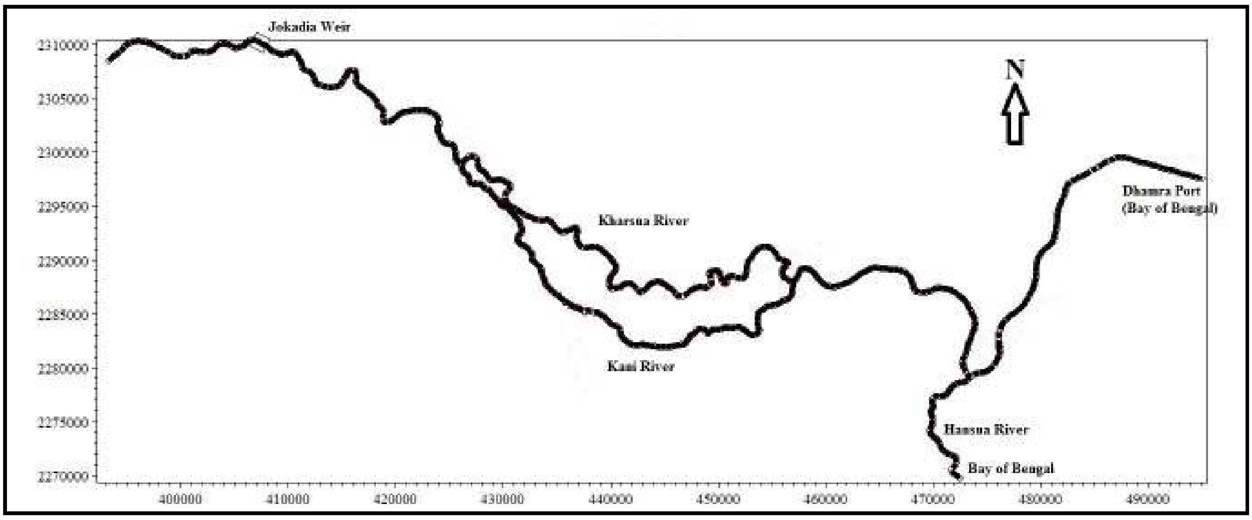

Figure 2. Schematic network of entire study area

V. RESULTS AND DISCUSSION

The discharge 200 m3/s is chosen randomly as a low discharge and discharges 952 m^3/s (Year 2010), 5056 m^3/s (Year 1986) and 13571 m^3/s (Year 2001) are chosen from the gauge discharge data at Jenapur. The above discharges are the annual high floods during that year except 200 m^3/s. Table 1 shows the comparison of the water levels for above discharges to calibrate the model.

The model is calibrated for low discharges (200 m^3/s & 952 m^3/s) keeping Manning's "n" value as 0.03 and predicted water levels match with the observed water levels. The calibrated MIKE11 model is used to simulate for high discharges and the predicted water levels are checked with the observed water levels. It is seen that for low discharges (200 m^3/s & 952 m^3/s), the water flows entirely through Kharsua river and no water flows through Brahmani river. But for high discharges, various trial and error procedures are carried out till predicted water levels match with observed water levels. It is seen that part of the water flows through Kharsua river and remaining through Brahmani river. The main reason being that Kharsua river being deeper and narrower and Brahmani river being shallower and wider at the point of bifurcation. The above trials indicate that for the total discharge of 5056 m^3/s, 70% i.e. 3580 m^3/s flows through Kharsua river and remaining through Brahmani river and for the total discharge of 13571 m^3/s, 44% i.e. 6000 m^3/s flows through Kharsua river and remaining through Brahmani river.

Table 1. Water levels at Jenapur for various discharges

Sr. No.	Discharge (m^3/s)	Predicted Water Level (m)	Observed Water Level (m)
1	200	18.60	18.40
2	952	19.31	19.23
3	3580 (70% of 5056)	22.24	22.20
4	6000 (44% of 13571)	24.37	24.40

VI. CONCLUSION

An attempt has been made to check the performance of the calibrated model for the high discharges along the reach of Kharsua, Kani and Hansua rivers. The calibration and validation results of MIKE11 show that model performs quite satisfactorily in simulating the river reach.

The differences between the predicted and observed water levels may be attributed to the fact that the cross-sections of the Brahmani river from Jenapur till its confluence with Kharsua river downtream were not available. Incorporation of these cross-sections is expected to improve the results and had it been available, discharge bifurcation through Kharsua river and Brahmani river would be automatically available without any trial and error procedure and the predicted water levels with the observed water levels would have been more accurate.

VII. ACKNOWLEDGEMENTS

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