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Flood Inundation Simulation for the Delta Region of Mahanadi River Basin Using MIKE FLOOD

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ABSTRACT: In this study, a coupled 1D-2D hydrodynamic model, MIKE FLOOD is used to simulate the flood inundation extent and flooding depth in the delta region of Mahanadi River basin in India. Initially, the 1D model MIKE 11 is calibrated using river water level data of two gauging sites for the monsoon period (June to September) of the year 2001. Subsequently, the calibrated set up is validated using water level data for the same period for the year 2002. The performance of the calibration and validation results of MIKE 11 are evaluated for all the years using the error functions, modeling efficiency (E) and index of agreement (d). The simulated water levels are found to be in close agreement with the observed water levels. A bathymetry (equivalent to a Digital Elevation Model (DEM)) of the study area with a spatial resolution of 250 m is prepared and provided as an input to the 2D model, MIKE 21. MIKE 11 and MIKE 21 models are then linked to form the MIKE FLOOD model set up for simulating the two dimensional flood inundations in the study area. MIKE FLOOD model is calibrated for the year 2001 by comparing the maximum flood inundation extent simulated by the model with the corresponding actual inundated area obtained from remote sensing data of IRS-1D WiFS. The calibration is carried out by changing the Manning's roughness coefficient (n) of the flood plain, which is assessed from the land use map of the study area developed using IRS-1D LISS III data. The results of calibration show a close agreement between the simulated maximum flood inundation extent and the inundation extent obtained from remote sensing data. The calibrated MIKE FLOOD model set up is then validated for the year 2003 by comparing the model simulated inundation extent with inundation extent obtained from the flood reports prepared by the State Water Resources Department (SWRD) and United Nations Development Program (UNDP). The aerial extent of the maximum flood inundation is found to be 514.7 km^2 for the year 2003, which is in close agreement with the observed maximum inundation extent of 550.0 km^2 as reported by the SWRD and UNDP.

Keywords: Flood Inundation, Hydrodynamic Model, Bathymetry, MIKE FLOOD, MIKE 11, MIKE 21, Remote Sensing Data.

INTRODUCTION

The delta region of Mahanadi river basin in eastern India is a highly populated and major paddy growing region in the state of Orissa. Floods are a frequent phenomena occurring in this part of the state during monsoon period (June–September), which causes severe damages to crops as well as lives. For the management of floods, two types of measures, i.e., structural and non-structural may be adopted. The structural measures such as embankments, levees, spurs, etc., can only be effective to a certain extent. On the other hand, non-structural measures, such as flood risk zoning and flood forecasting allow flooding, but ensure that damages are minimized (NNRMS, 2000). Therefore, they may be quite effective in reducing the impact of flood to a considerable extent. For the development of flood hazard and risk zone maps, it is essential to simulate the flood inundation in the floodplains caused by floods of different magnitudes. In the past few years, various researchers have used the hydraulic modeling approach to simulate flood inundation in the floodplains (Werner, 2004; Bates *et al.*, 2005). The hydraulic modeling approach of flood inundation simulation essentially involves the solution of one dimensional and two dimensional Saint Venant equations using various numerical methods. Various numerical models have been developed for flood plain delineation/flood inundation and flow simulation which may be used as tools to delineate the flood plain zones bordering the rivers and calculate the associated risk considering hypothetical floods of various return periods. These numerical models essentially involve solving the governing equations for flow in rivers and flood plains using certain computational algorithms. Based on the approximations used, the numerical models are categorized into (a) one-dimensional (1D)

[1]Conference speaker

models, (b) two-dimensional (2D) models, and (c) one-dimensional river flow models coupled with two-dimensional flood plain flow (1D-2D) models.

The numerical models with 1D approximation are mostly based on the finite difference method (Cunge *et al.*, 1980; Chaudhury, 1993) and the finite element method (Cooley and Moin, 1976; Nwaogazie and Tyagi, 1984; Adeff and Wang, 1985; Szymkiewicz, 1991; Sen and Garg, 1998). The finite difference method is more popular due to comparatively less computational effort. Various software, like HEC-RAS (HEC River Analysis System) from the U.S. Army Corps of Engineer's Hydrologic Engineering Center (Tate, 1999; HEC, 2002), U.S. National Weather Service's (NWS) DWOPER and FLDWAV (Fread *et al.*, 1998), MIKE11 developed at the Danish Hydraulic Institute, Denmark (DHI, 1997; Gourbesville, 1998; Snead, 2000; Hammersmark, 2002), ISIS (Penning-Rowsell and Tunstall, 1996), SOBEK-1D developed at the Delft Hydraulics, Delft (Werner, 2001) etc. have been used extensively for dynamic 1D flow simulation in rivers.

The 1D models, though simple to use while providing information on bulk flow characteristics, fail to provide detailed information regarding the flow field. Hence, attempts have been made to model the 2D nature of flood plain flow. The first attempt in the direction of a 2D model approach was a "Quasi 2D" approach (Zanobetti *et al.*, 1970; Cunge *et al.*, 1980; Laura and Wang, 1984; Han *et al.*, 1998, Sudhakar *et al.*, 1999; Sen, 2002) which is not a truly dynamic simulation of 2D flow. Based on a similar approach, Bechteler *et al.* (1994) developed a code called FLOODSIM, while Bates and De Roo (2000) developed a code called LISFLOOD-FP which was improved by Horritt and Bates (2001).

Subsequently, various numerical schemes have been used to solve the 2D flow equations. The three main approaches that have been used are the methods of: Finite Difference (Garcia and Kahawita, 1986; Fennema and Chaudhury, 1989&1990; Casulli, 1990), Finite Element (Katopodes, 1984; Akanbi and Katopodes, 1988; Bates *et al.*, 1992; Hervougt and Janin, 1994; Tucciarelli and Termini, 1999), and Finite Volume (Nujic, 1995; Zhao *et al.*, 1994 and 1996; Lal, 1998; Anastasiou and Chan, 1997; Sleigh *et al.*, 1997; Valiani *et al.*, 1999; Beffa and Connell, 2001). Various software based on these algorithms are available, but some of the most widely used ones are FLO 2D (O'Brien, 2005; O'Brien, 2006), RMA2 (King *et al.*, 2001), MIKE-21 (DHI, 2000a&b; McCowan and Collins, 1999), DELFT-FLS (Beffa and Connell, 2001; Hesselink *et al.*, 2003), DELFT-3D (Stelling and Duinmeijer, 2003) and TELEMAC-2D (Bates *et al.*, 1999; Hervouet, 2000; Bates and De Roo, 2000; Horritt and Bates, 2001). FLO 2D, MIKE-21, DELFT-FLS and DELFT-3D are based on the finite difference methodology while RMA2 and TELEMAC-2D are based on the finite element methodology.

The 1D models fail to provide information on the flow field while the 2D models require substantial computer time; hence, attempts have been made to couple 1D river flow models with 2D flood plain flow models. The coupled 1D-2D models offer great advantage for real-time simulations of flooding events. In this approach, the flow in the main river channel is simulated using the 1D equations. For the water spilling over the banks of the overflowing river onto the flood plains, the 2D equations are solved using one of the schemes described above. The link between the two kinds of flow is usually done by a mass conservation equation. Verwey (2001) and Dhondia and Stelling (2002) describe the 1D-2D model SOBEK (Rural/Urban) developed by the laboratory at Delft Hydraulics. Also, MIKE-21 has been dynamically linked to the MIKE-11 model, into a single package called MIKE FLOOD developed at the Danish Hydraulic Institute (Kjelds and Rungo, 2002; Rungo and Olesen, 2003).

In this study, MIKEFLOOD is used to simulate the flood inundation for the delta region of Mahanadi River basin in India. The delta region of Mahanadi river basin is highly prone to floods due to the presence of a number of rivers, which flow full during the monsoon season. For the flood inundation simulation, first the MIKE 11 model is calibrated and validated for the rivers of delta region of Mahanadi River basin and subsequently, the flood inundation is simulated using MIKE FLOOD by coupling the MIKE 11 and MIKE 21 models. The model simulated flood inundation is validated using remote sensing data.

DESCRIPTION OF MIKE FLOOD

The governing flow equations of MIKE 11 are one dimensional and are of shallow water types which are the modifications of Saint Venant equations. Equations (1) and (2) represent the Saint Venant equations of conservation of mass and momentum, respectively,

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \qquad \ldots (1)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial\left[\gamma\frac{Q^2}{A}\right]}{\partial x}+gA\frac{\partial h}{\partial x}+\frac{gQ|Q|}{C^2AR}=0 \qquad \ldots (2)$$

where Q = discharge (m^3/s); A = flow area (m^2); q = lateral inflow (m^2/s); h = stage above datum; C = Chezy's resistance coefficient ($m^{1/2}/s$); R = hydraulic radius (m); γ = momentum distribution coefficient; g = acceleration due to gravity (9.81 m/s^2); x = longitudinal distance in the direction of flow (m); and t = elapsed time (s).

The MIKE 21 model solves the full, time dependent, non-linear equations of continuity and conservation of momentum which are two-dimensional in nature (Eqns. 3 to 5),

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \qquad \ldots (3)$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{(p^2+q^2)}}{C^2.h^2} -\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h\tau_{xx}\right)+\frac{\partial}{\partial y}\left(h\tau_{xy}\right)\right]-\Omega_q -fVV_x+\frac{h\partial}{\rho_w \partial x}\left(p_a\right)=0 \qquad \ldots (4)$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{(p^2+q^2)}}{C^2.h^2} -\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}\left(h\tau_{yy}\right)+\frac{\partial}{\partial x}\left(h\tau_{xy}\right)\right]+\Omega_p -fVV_y+\frac{h\partial}{\rho_w \partial y}\left(p_a\right)=0 \qquad \ldots (5)$$

where, ζ = surface elevation (m), p, q = flux density ($m^3/s/m$), x, y = space coordinates (m), d = time varying water depth (m), h = water depth ($\zeta - d$, m), Ω_q = Coriolis parameter (s^{-1}), τ = effective shear stress, ρ_w = density of water, p_a = atmospheric pressure and $f(V)$ = wind friction factor.

Equations 1 and 2 are transformed to a set of implicit finite difference equations, and solved using the double sweep algorithm while equations 3 to 5 are solved using an implicit finite difference scheme of the second order accuracy. MIKE FLOOD integrates the one-dimensional MIKE 11 river network with the two dimensional MIKE 21 floodplain (bathymetry) through various hydrodynamic links (Kjelds and Rungo, 2002). The hydrodynamic links include lateral link, standard link, structural link and zero flow link. A lateral link allows a string of MIKE 21 cells to be laterally linked to a given reach in MIKE 11 i.e., either a section of a branch or an entire branch whereas in the standard linkage, one or more MIKE 21 cells are linked to the end of a MIKE 11 branch.

STUDY AREA

The delta region of Mahanadi River basin in India forms the study area (Figure 1). It is located in the north-eastern part of coastal Orissa in India and lies between the longitudes 85° 45′ E and 86° 52′ E and the latitudes 19° 50′ and 20° 45′ N. The areal extent of the delta is about 9500 km^2 of which more than 80% of the total cropped area is affected by floods during the period from July to September. The flooding in the delta region is due to the river Mahanadi and its tributaries. The tributaries of the river Mahanadi include Devi, Nuna, Kushabhadra, Bhargavi, Chitrotpala, Daya and Biluakhai. The flooding problem is more severe in the rivers Devi, Kushabhadra and in the downstream end of the main course of the Mahanadi River as compared to others. The area receives heavy rainfall during the monsoon period (July-September) as a result of which all the rivers flow full and flooding occurs. The layout of the river network in the delta region of Mahanadi river basin is shown in Figure 1. In this study, the upstream point of river Mahanadi at Naraj (Mahanadi at 0.0 km chainage) is considered as the most upstream point of the entire river system in the study area.

DATA USED

The data used in this study are the time series of discharge or water level or both of different gauging stations, river cross sections at different locations, contour map, topographical map and published data related to floods in the study area from different sources. The time series data include the daily water levels at the gauging sites, Kanas, Nimapara, Machhagaon, Tarapur, Balanga, Alipingal, Cuttack and Balianta as well as daily discharge at Naraj gauging site for the monsoon period (July to September) for the years 2001, 2002 and 2003. These data are collected from the Central Water Commission, Bhubaneswar and the Flood Cell, State Water Resources Department (SWRD), Bhubaneswar. The river cross-sections available at different sections of the river reaches are used. Survey of India (SOI) Toposheets (No. 73l and 73h at the scale 1:2,50,000) are procured from SOI, Kolkata for digitizing the river network and to mark the locations of the above gauging sites. The contour map of the study area is obtained from the Flood Cell, SWRD, Bhubaneswar. Further, the information regarding the areal extent of flooding in the study area during the period of interest are obtained from various published reports from

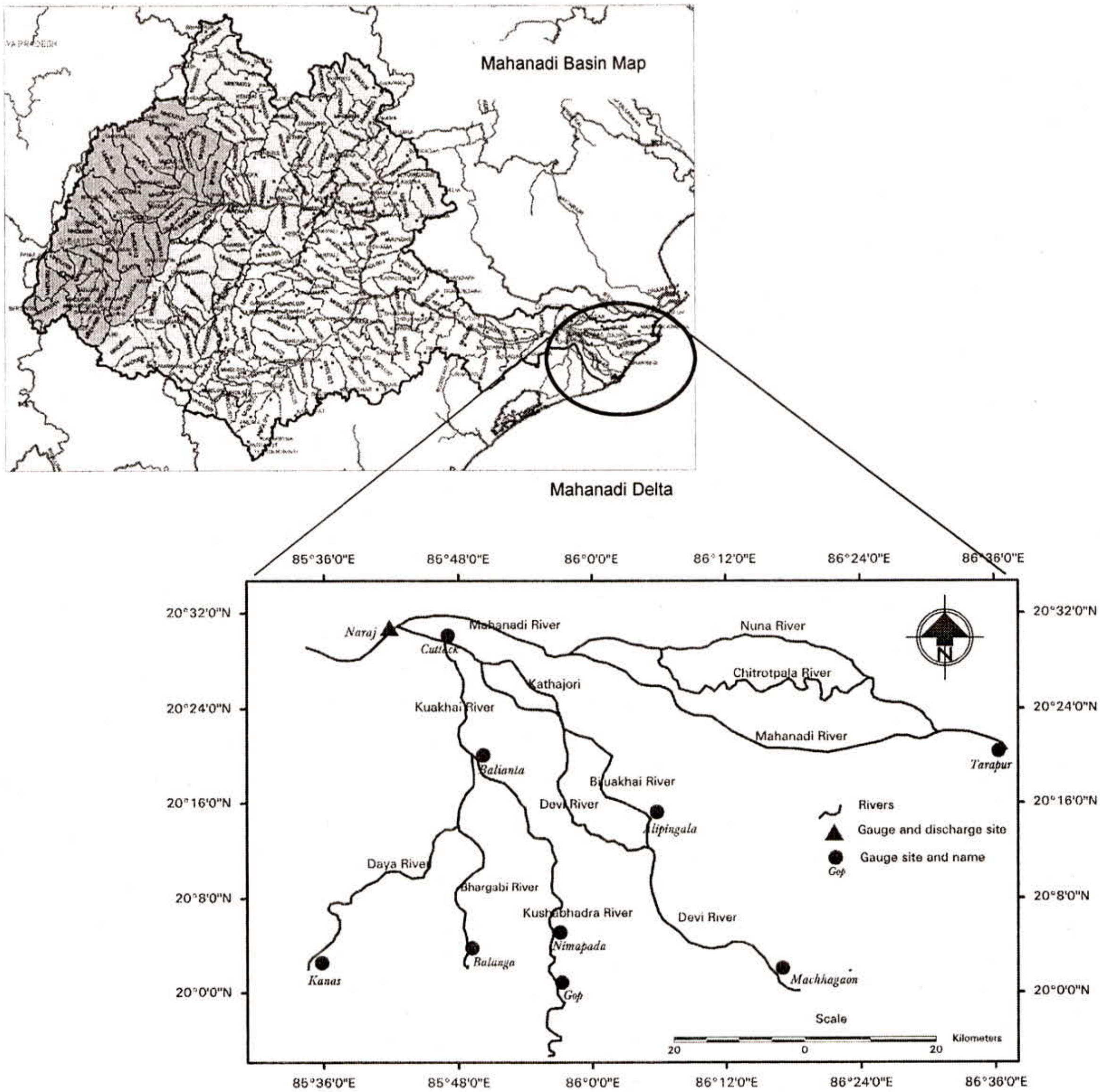


Fig. 1: Index map of delta region of Mahanadi river basin

United Nations Development Programme (UNDP), Flood Cell, SWRD, Bhubaneswar and from the website www.orissawater.com. Remote sensing data of IRS-1D WiFS pertaining to 31st July, 2001 and IRS-1D LISS-III pertaining to 11th October, 1999 are procured from National Remote Sensing Agency (NRSA), Hyderabad for the validation of the simulated flood inundation extent obtained from MIKE FLOOD and to prepare the land use/land cover map of the study area, respectively.

METHODOLOGY

Initially, the Survey of India Toposheets No. 73l and 73h (scale 1:2,50,000) are georeferenced and mosaiced using the Digital Image Processing (DIP) software, ERDAS Imagine 8.5. This forms the base map of the study area which is used in the MIKE 11 network editor to digitize the river system of the delta region of the Mahanadi River basin. Subsequently, the contour map obtained from the Flood Cell, SWRD, Bhubaneswar is scanned and georeferenced using the georefenced base map in ERDAS Imagine. The contours are digitized, cleaned and built for topology using the GIS software, Arc-Info 8.1. The Digital Elevation Model (DEM) of the study area is then prepared in Arc-Info in the form of a grid file. The grid format is converted to ASCII and the ASCII form of the DEM grid is converted to a MIKE-21 compatible DT2 format using a C-program. This DT2 format of DEM is processed using the MIKE zero grid editing tool for preparation of bathymetry which is the only input for MIKE 21 in the present study. Bathymetry is the term used in MIKE 21 which is equivalent to the DEM and represents the surface elevation of the study area. The grid size of the bathymetry in the present study is 250 m × 250 m.

Initially, the MIKE 11 set up is prepared for the river network in the delta region of the Mahanadi River system and simulated for the monsoon period (July to September) of the years 2001 and 2002. The daily water levels for the monsoon period at the gauging sites, Kanas, Nimapara, Machhagaon, Tarapur, Balanga and the time series of discharge at Naraj are used as the boundary conditions for the MIKE 11 model set up. The daily discharges at Naraj are used as the upstream boundary condition while the daily water levels at Kanas, Nimapara, Machhagaon, Tarapur, Balanga are used as the downstream boundary conditions. The observed daily water levels for the monsoon period at two gauging sites viz., Balianta (River: Kushabhadra) and Daleighai (River: Kathajori) for the year 2001 are used for calibration of the MIKE 11 model while the observed daily water levels for the monsoon period at the two gauging sites viz., Balianta and Cuttack (River: Mahanadi) for the year 2002 are used for validation of the MIKE 11 model. In addition, the river cross-sections at various gauging sites in different river reaches are provided as an input to the MIKE 11 setup. The Manning's *n* values corresponding to the different river reaches are taken from Chow *et al.* (1973), which are subsequently modified during the process of model calibration.

Two goodness of fit criterion are used to compare the simulated water levels with the observed values during MIKE 11 model calibration and validation. These are (i) the Nash-Sutcliffe coefficient (E_{ns}) and (ii) the index of agreement (d), which are as follows,

$$E_{ns} = 1 - \frac{\sum (Q_o - Q_s)^2}{\sum (Q_o - Q_{av})^2} \quad \ldots (6)$$

$$d = 1 - \frac{\sum (Q_o - Q_s)^2}{\sum \left(|Q_o - Q_{av}| + |Q_s - Q_{av}| \right)^2} \quad \ldots (7)$$

Where, Q_o = observed discharge (m^3/s), Q_s = simulated discharge (m^3/s), Q_{av} = mean of the observed discharge (m^3/s).

Subsequently, the calibrated MIKE 11 model is coupled with the bathymetry of MIKE 21 model by lateral links for flood inundation simulation using MIKE FLOOD for the monsoon period of the year 2001. The flow between the river and flood plain is in the form of a weir flow. The MIKE FLOOD model set up for the year 2001 is calibrated by comparing the model simulated maximum inundated extent with the actual inundation extent obtained from remote sensing data of IRS-1D WiFS. Figure 2 presents the steps followed to obtain the delineated flooded area from WiFS data for the calibration of MIKE FLOOD set up. The calibration is carried out by adjusting the Manning's n values of the flood plain. IRS-1D LISS III data is processed to develop the land use/land cover

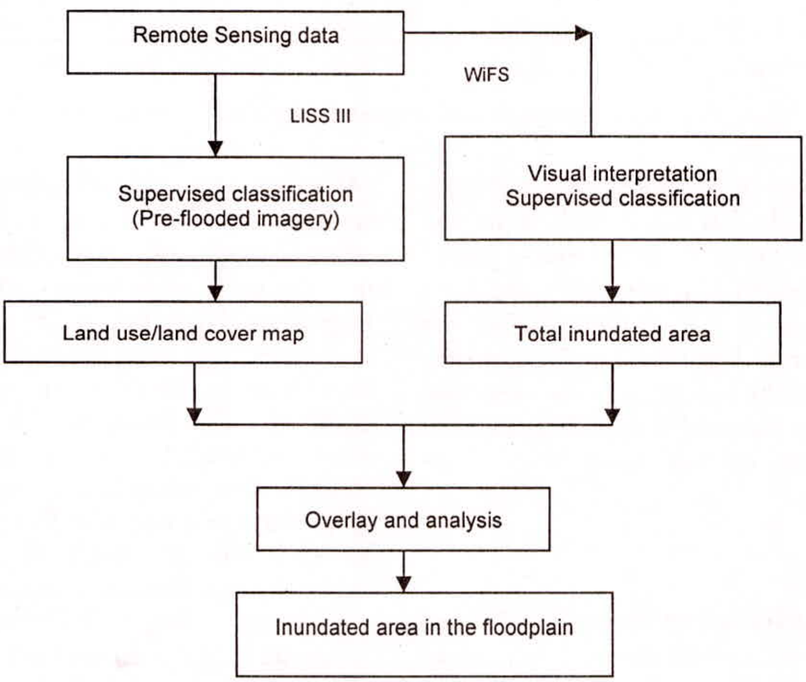


Fig. 2: Schematic outlines to obtain flood inundated area from remote sensing data

map of the study area using ERDAS IMAGINE 8.5. The calibrated model is validated for the year 2003 using the maximum flood inundated extent reported in UNDP flood reports (UNDP, 1995) and flood reports obtained from Flood Cell, SWRD, Bhubaneswar.

Mike 21 Model Setup

The MIKE 21 model simulates the two dimensional flood flows over the flood plain. For the present study, the only inputs to this model are the bathymetry which contains the information regarding the elevations of the flood plain, and the Manning's *n* values for the floodplain. The bathymetry of the study area is shown in Figure 3. For the development of MIKE 21 set up, the simulation period is kept the same as in MIKE 11 i.e., 1st July to 30th September, 2001, but the model computational time steps are kept as 30–120 s in order to keep the Courant number (C_R) value less than 2. Figure 4 presents the landuse map of the study area obtained from the supervised classification of IRS-1D LISS-III image of 11th October, 1999 using ERDAS Imagine software. From Figure 4 it is seen that the major part of the study area is covered by arable land and the remaining portion is covered by marshy land which are mostly affected by floods. Initially, an average value of Manning's n equal to 0.05 is used for the floodplain as per the land features obtained from the landuse map (Chow, 1973).

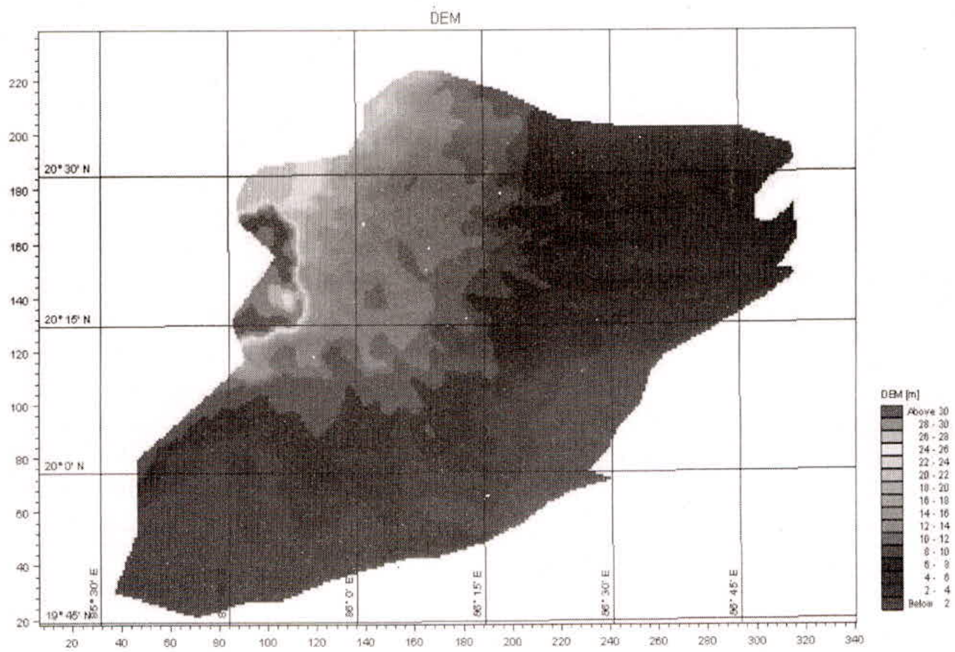


Fig. 3: Bathymetry of Mahanadi Delta

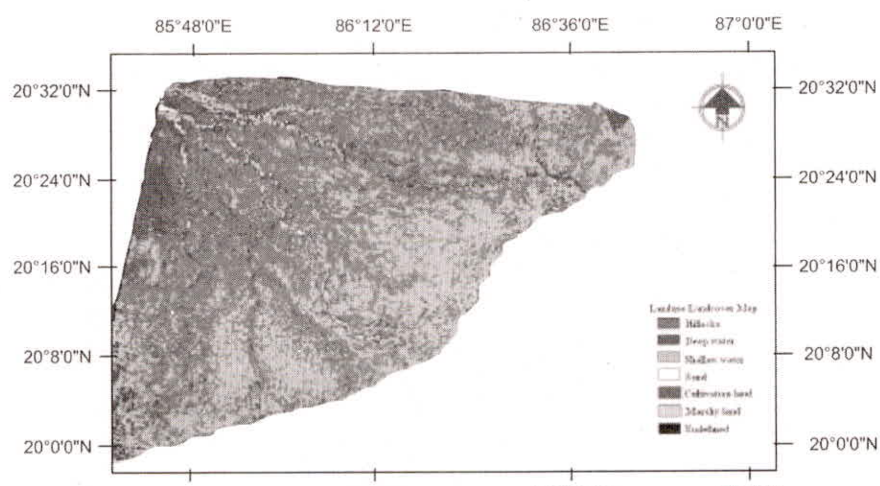


Fig. 4: Landuse map of the study area obtained from IRS-1D LISS-III image of 11th October, 1999

Mike Flood Model Setup

The calibrated MIKE 11 setup and MIKE 21 setup (with bathymetry and Manning's n as the only inputs) are used as input for MIKE FLOOD. The MIKE FLOOD model is run for the period 1st July to 30th September, 2001 and 2003. All rivers in MIKE 11 model are linked to the MIKE 21 cells only by lateral links as shown in Figure 5.

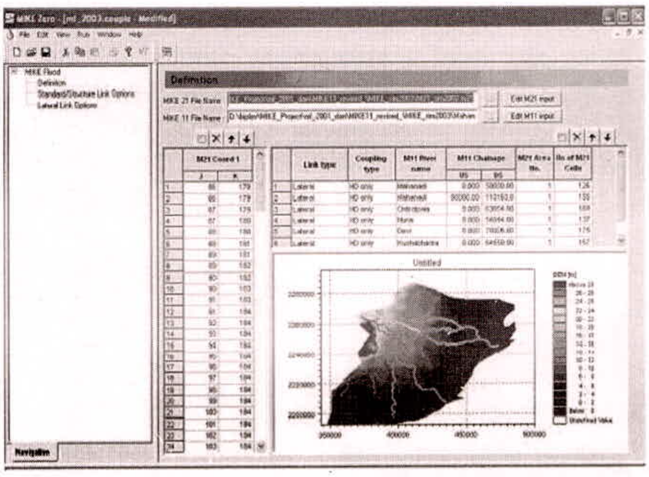


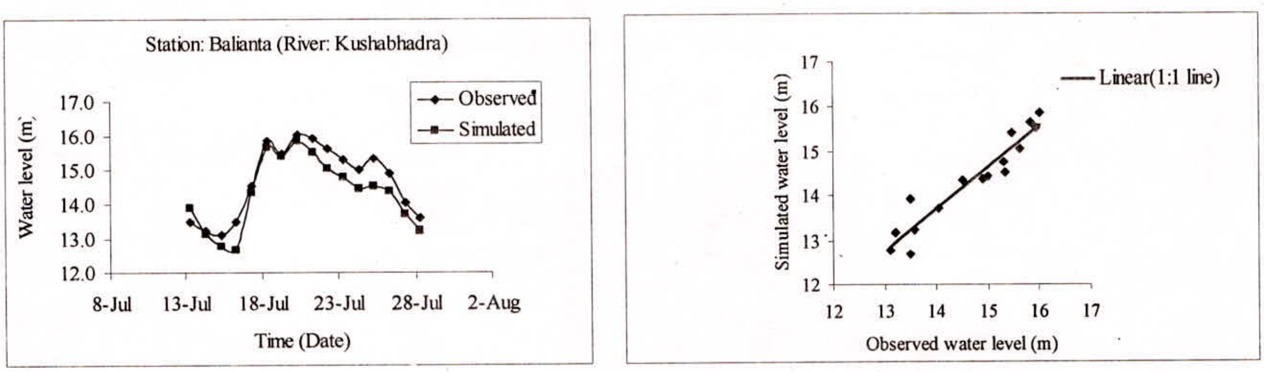
Fig. 5: Linking the river network of MIKE11 with the bathymetry of MIKE 21 in MIKE FLOOD

RESULTS AND DISCUSSION

The MIKE 11 hydrodynamic model is calibrated using data for the monsoon period of the year 2001 and validated using data for the monsoon period of the year 2002. Subsequently, MIKE FLOOD is used to simulate the flood inundation for the monsoon period of the year 2001 using the MIKE 11 and MIKE 21 setup. The simulated flood inundation extent obtained from MIKE FLOOD is calibrated for the year 2001 using remote sensing data and validated for the year 2003 using published flood inundation reports collected from SWRD and UNDP.

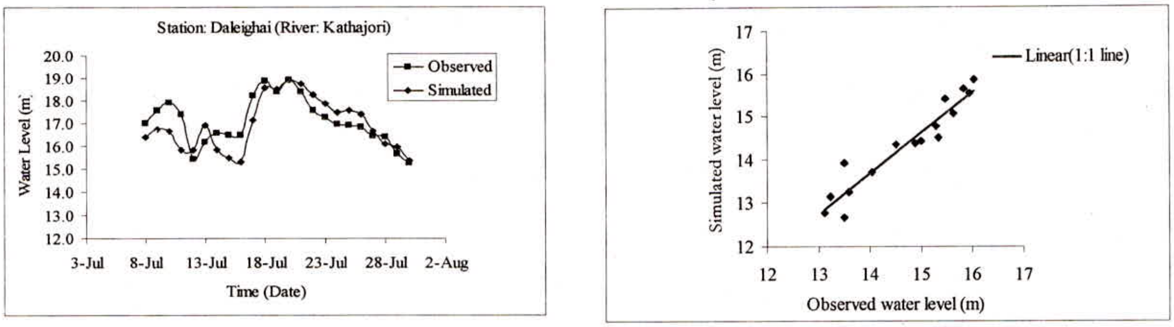
Calibration of Mike 11 Model

MIKE 11 model is calibrated using data for the period 1st July to 30th September, 2001. During the process of calibration, the local and global values of the Manning's roughness coefficient, n are adjusted to bridge the gap between the observed and simulated water levels at the two gauging stations viz., Balianta and Daleighai. The local values of n refer to the Manning's roughness coefficient of all individual rivers in the study area while the global value refers to the one for the entire river system of the study area. Initially, the MIKE 11 setup is run using local as well as the global values of n as 0.04. During calibration, the MIKE 11 setup is run for different combinations of global and local values of n till a close agreement between the simulated and observed water levels at the two gauging sites is obtained. After calibration, the final global value of n is obtained as 0.04 whereas the local values ranged from 0.03–0.04 as shown in Table 1. Figures 6(a)-(b) and Figures 7(a)-(b) show the comparison of the observed and simulated water levels at Balianta and Daleighai gauging stations, respectively for calibration period. It is observed that at both the gauging sites though the model sometimes over predicts and sometimes under predicts the water levels, the simulated peak water levels are in reasonably close agreement with the corresponding observed values.



(a) (b)

Fig. 6(a)&(b): Comparison of observed and simulated water levels at Balianta gauging site for the year 2001 during calibration



(a) (b)

Fig. 7(a)&(b): Comparison of observed and simulated water levels at Daleighai gauging site for the year 2001 during calibration

Table 1: Calibrated Values of Manning's Roughness Coefficient n for MIKE 11 Setup during Calibration

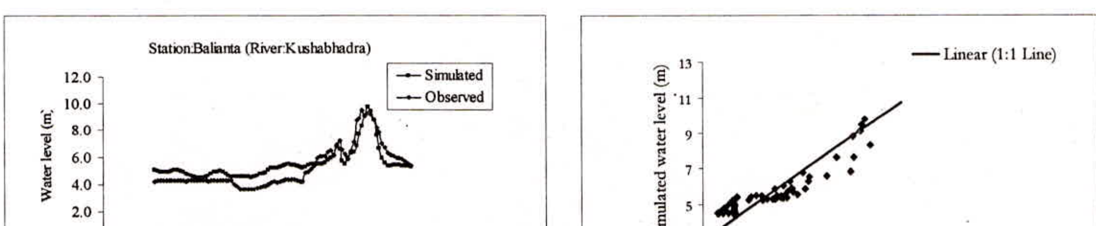
	Manning's n for different rivers in the Delta Region of Mahanadi River basin								
Local/ Global 'n'	*Maha-nadi*	*Chitr-otpala*	*Nuna*	*Kath-ajorhi*	*Serua*	*Devi*	*Bhar-gabi*	*Daya*	*Kusha-bhadra*
Local '*n*'	0.03	0.033	0.033	0.038	0.03	0.032	0.03	0.040	0.04
Global '*n*'	0.04								

The performance of the model during calibration is evaluated using two goodness of fit criteria i.e., Nash–Sutcliffe coefficient, E_{ns} and the index of agreement, d. The values of E_{ns} for the gauging stations, Balianta and Daleighai are found to be 0.79 and 0.98, respectively, while the values of d are found to be 0.95 and 0.95, respectively. These values of E_{ns} and d show that there is a close agreement of the simulated and observed water levels during calibration.

Validation of Mike 11 Model

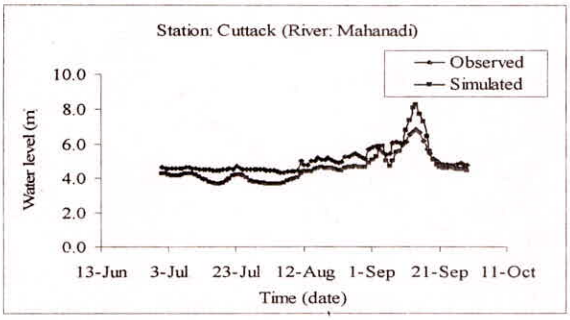
The calibrated setup of MIKE 11 is run using water level and discharge boundaries for the period from 1st July to 30th September, of the year 2002 for model validation. The observed and simulated water levels are compared at two gauging stations viz., Balianta and Cuttack. Figures 8(a)-(b) and Figures 9(a)-(b) show the comparison of the observed and simulated water levels at Balianta and Cuttack gauging stations, respectively during validation for the year 2002. The simulated water levels are found to be in reasonably close agreement with corresponding observed values for both the gauging stations. The peak water level is found to occur on 15th September and its values are found to be near about the same for both observed and simulated cases for Balianta. However, the model slightly under predicted peak for Cuttack. The values of E_{ns} for the gauging stations, Balianta and Cuttack are found to be 0.76 and 0.61, respectively, while the values of d are found to be 0.91 and 0.85, respectively. These values of E_{ns} and d show that there is a reasonably close agreement of the simulated and observed water levels during validation.

Thus, the performance of the MIKE 11 model is found to be reasonably good during validation for both the years 2002 and 2003.

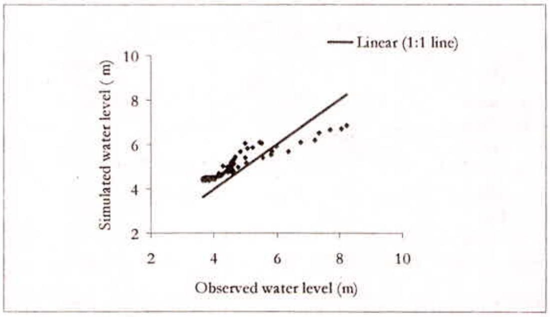


(a) (b)

Fig. 8(a)&(b): Comparison of observed and simulated water levels at Balianta gauging site during validation period 2002



(a)



(b)

Fig. 9(a)&(b): Comparison of observed and simulated water levels at Cuttack gauging site during validation period 2002

Calibration of MIKE FLOOD Results with Remote Sensing Data for the Year 2001

The IRS-1D WiFS image of 31st July, 2001 is processed and analyzed to obtain the actual flood inundated area as shown in Figure 10. It is observed that during the year 2001, flooding in the delta region of Mahanadi River basin is due to the Mahanadi, Devi and Khushabhadra Rivers. The total flood inundated area obtained from WiFS data is found to be 589.6 km^2. Also, the maximum flood inundation extent reported in the published reports of SWRD and UNDP for the year 2001 for the delta region of the Mahanadi River basin is about 685.2 km^2.

Initially, the flood inundation is simulated using MIKE FLOOD for the monsoon period of the year, 2001 using an average value of Manning's n equal to 0.05 for the floodplains as stated earlier. From the flood inundation simulations it is observed that the flood inundation in the floodplain commences from the 2nd week of July, 2001 and continues till the first week of August and the maximum flooding extent is observed to occur on 23rd July, 2001. Subsequently, during the calibration process, the Manning's n values for the floodplains are varied in the range 0.04 to 0.06 so as to obtain a close agreement between (i) the simulated flood inundation extent of 31st July, 2001 and the inundation extent obtained from WiFS image for 31st July, 2001 i.e. 589.6 km^2, and (ii) the maximum simulated flood inundation extent corresponding to 23rd July, 2001 and the maximum inundation extent reported by the SWRD and UNDP i.e. 685.2 km^2. Finally, the calibrated value of Manning's is found to be 0.05 for the floodplains.

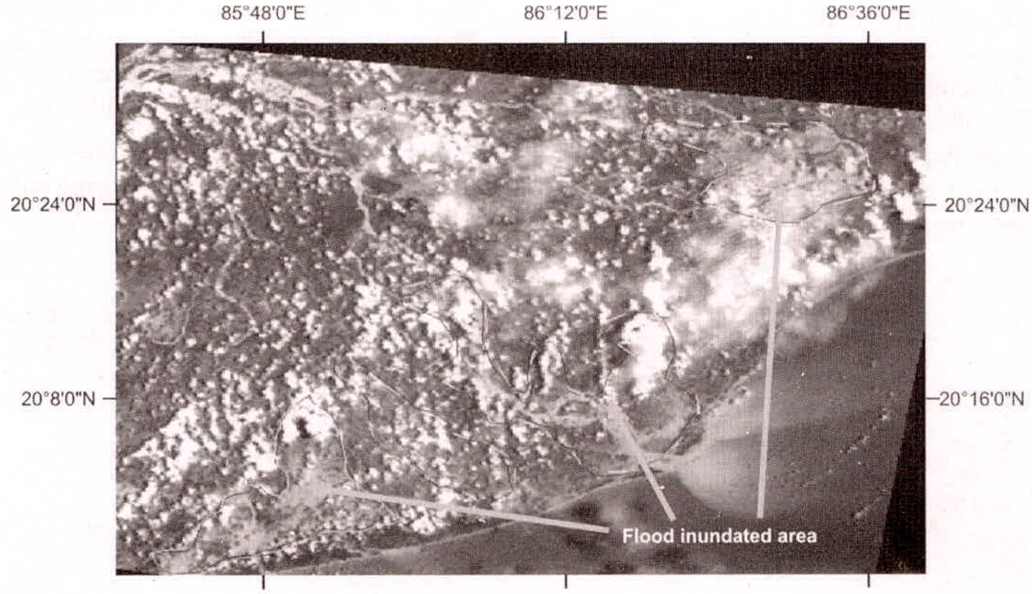


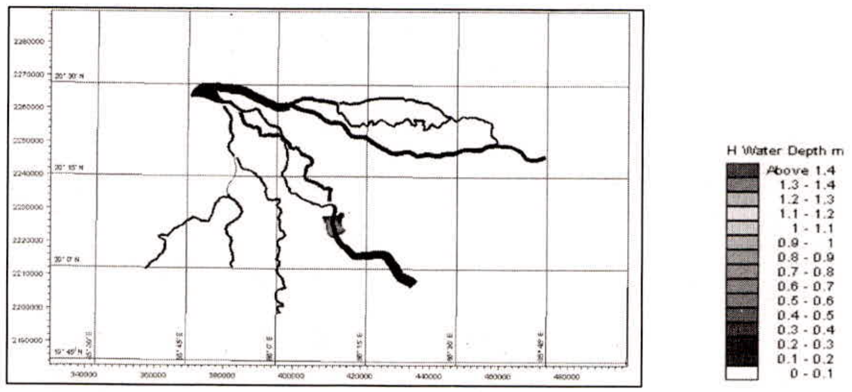
Fig. 10: IRS-1D WiFS image of 31st July, 2001 showing flood inundation in the study area

Figures 11(a)-(b) show the calibrated flood inundation extent and the flooding depth at different dates from the commencement to the recession of flooding for the year 2001. From Figure 11(a), it is observed that the flood inundation in the floodplain commences from the 2nd week of July, 2001. The initiation of flooding is observed in the river Devi and subsequently in the river Mahanadi and its tributaries. It is also observed that the inundation due to floods continue till the first week of August and the maximum flooding extent is observed on 23rd July, 2001. There are three main flood causing rivers in the Delta area and they are the Mahanadi, the Devi and the Kushabhadra. The flooding is observed only at the downstream end of these rivers and this is due to the low lying topography in these areas.

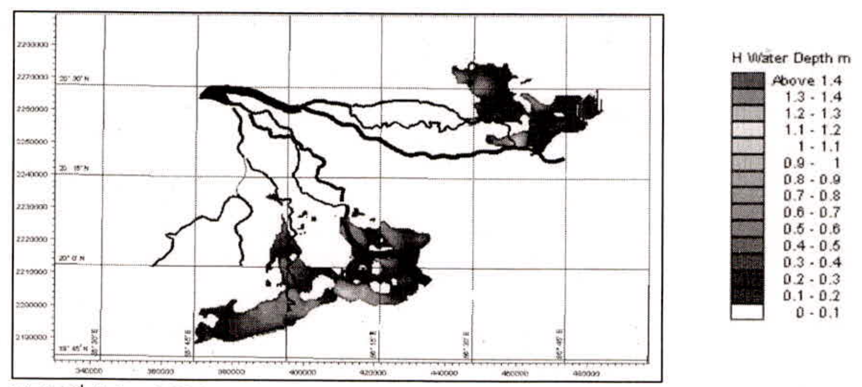
The flooding depth at various locations of the floodplain varies from 0.6 to 1.5 m. The maximum flooding extent is observed to occur on 23rd July, 2001 and the maximum flooding depth obtained is 1.45 m. As the flood inundation recedes, the flooding depth decreases. The maximum inundation extent obtained using MIKE FLOOD is about 723.1 km^2 on 23rd July, 2001 while the maximum inundation extent reported by the SWRD and UNDP is 685.2 km^2 as stated earlier. Also, the flood inundation extent obtained using MIKE FLOOD for 31st July, 2001 is 601.8 km^2 while the corresponding inundation extent obtained from the WiFS image of 31st July, 2001 is 589.6 km^2. The spatial variation of the simulated flood inundation is also observed to be in reasonable agreement with that obtained from the remote sensing data (Figure 12). Thus, it is observed that during the calibration of MIKE FLOOD, there is a reasonably good agreement between the simulated and observed/reported flood inundation extent.

Validation of MIKE FLOOD Results for the Year 2003

The calibrated setup of MIKE FLOOD is validated for the year 2003 using the data on maximum flood inundation extent reported by SWRD and UNDP. Figures 12(a)-(b) show the flood inundation extent and flooding depth simulated using the calibrated MIKE FLOOD setup at different dates from the commencement to the recession of flooding for the year 2003. The delta region of Mahanadi River basin was reeling under floods from the last week of August, 2003 which continued till the first week of September, 2003 (UNDP, 2003).

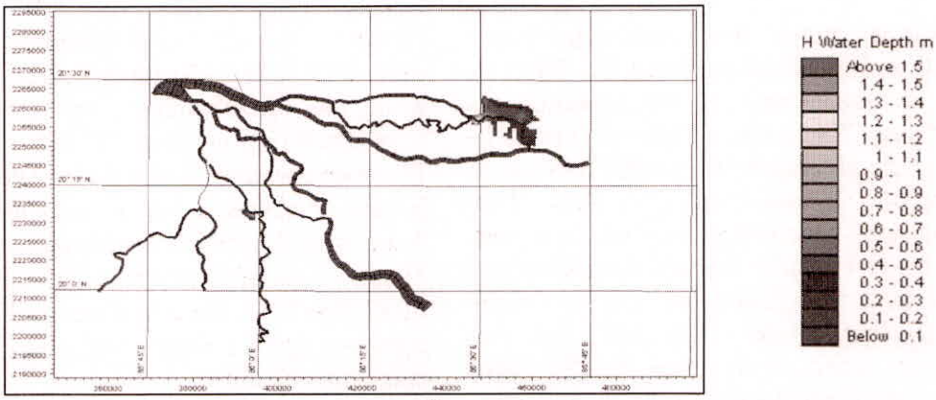


(a) 13th July, 2001

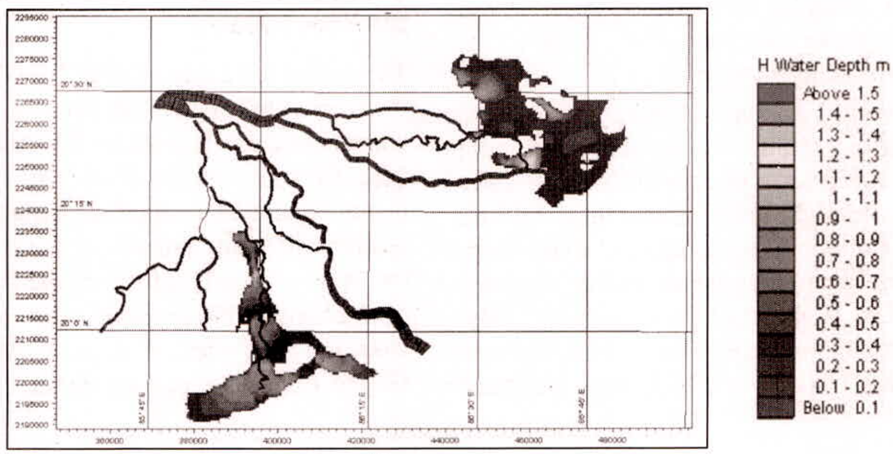


(b) 23rd July, 2001

Fig. 11(a)&(b): Flood inundation extent and depth obtained from MIKE FLOOD for (a) 13th (b) 18th (c) 21st and (d) 23rd July, 2001



(a) 27th August 2003



(b) 4th September 2003

Fig. 12(a)&(b): Flood inundation extent and depth obtained from MIKE FLOOD for (a) 27th August (b) 4th September, 2003

From Figure 12(a), it is observed that the initiation of flooding in the delta region for the year 2003 is caused at the tail end of the joining point of the rivers Chitrotpala and Mahanadi. For the year 2003, the rivers causing floods in the delta region are the Mahanadi and the Kushabhadra. The maximum inundation extent obtained using MIKE FLOOD is about 514.7 km^2 on 4th September, 2003 while the maximum inundation extent reported by the SWRD and UNDP is 550.0 km^2 as stated earlier. Thus, it is observed that there is a reasonably good agreement between the simulated and reported flood inundation extent during the validation of MIKE FLOOD.

The calibrated and validated MIKEFLOOD model may be used to simulate the flood inundation for different extreme flood events for the delta region of Mahanadi River basin in Orissa. Subsequently, this information may be used to develop the flood hazard and risk zone maps for the floodplains of the study area.

CONCLUSIONS

This study aimed at developing a calibrated and validated coupled 1D-2D hydrodynamic model, MIKE FLOOD setup for simulating the flood inundation extent and flooding depth in the delta region of Mahanadi River basin. The performance of the 1D MIKE11 model during calibration and validation was found to be satisfactory. The calibrated Manning's n values for the different rivers were found to be between 0.03 and 0.04. The simulated water levels at all gauging sites for the year 2001 and 2002 were found to be in close agreement with the observed values.

The performance of the coupled 1D-2D hydrodynamic model, MIKE FLOOD in simulating the flood inundation extent and flooding depth during the process of calibration and validation was also found to be satisfactory. During the calibration process, the average Manning's n for the floodplain which was initially estimated as 0.05 based on the landuse of the study area obtained from IRS-1D LISS-III data was also found to be the calibrated Manning's n value. The actual flood inundation extent obtained from the IRS-1D WiFS data of 31st July, 2001 was very effective in calibrating the MIKE FLOOD model. The calibrated MIKE FLOOD model setup was also found to simulate the flood inundation extent with a reasonable accuracy for the year 2003 during the validation process. This calibrated and validated MIKE FLOOD model may be used to simulate the flood inundation extent and flooding depth in the floodplains caused by floods of different magnitudes in the delta region of the Mahanadi River basin for development of flood hazard and risk zone maps.

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