INFLUENCE OF SAND BAR BEHAVIOUR ON CHANNEL CHANGES ALONG KALIGANDAKI RIVER, NEPAL

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ABSTRACT

The main aim of this paper is to calculate morphological changes and its effects on floods, and to propose countermeasures. The countermeasures deal with channel changes in order to change river morphology and solve inundation problem in the Jomsom area of the Kaligandaki river. The area around Jomsom is surrounded by steep slopes in the middle of Himalayan Mountain. Steep slope and rainfall cause landslide and debris flow. This study therefore applies two-dimensional depth integrated hydrodynamic model including flow, sediment transport and morphological change namely Nays 2DH. In order to examine whether simulated results represent actual phenomena, different sediment supply condition as well as flow discharge are implemented. The meander part of this study reach is prone to deposition of fine sediment, which cause clogging of river channel. The clogging cause overtopping from the river banks resulting all area of the Jomsom is inundated. This study proposes the river training works. The simulated results after the work shows less deposition and less inundation.

Keywords: Sediment supply, Bed deformation, Inundation area, flow pattern, countermeasures.

INTRODUCTION

The Jomsom area is surrounded by High Mountain with steep slopes. Because of that steep topography, mountainous area are prone to landslides and debris flow. Sometimes there is possibility of flash flood when high rainfall occurs .Basically landslides and debris flow which keep supplying large amount as well as fine sediment from the upstream. When large amount of sediment supply occurs, then there will be massive morphological change as well as inundation problem. This study evaluates such changes using numerical simulations of a two-dimensional integrated depth model, including flow, sediment transport, and morphological change. This model is nays 2DH proposed by Shimizu et al (2014), which can be operated in iRIC. The output of the simulation model shows that the main reason for the flooding is the accumulation of fine sediments in the meander channel. Such problem cause the clogging of river channel. Due to clogging problem there will be rise in a water level which passes through the bank and all area get inundated. Therefore this study proposed the river training works as straight dredged channel in clogged portion of the river. Then this study also evaluated the effectiveness of river training by simulation of the model. The result of river training work shows less deposition as well as less inundation that means the river training works is functioning well to meet our requirements.

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THEORY AND METHODOLOGY

To complete the objective of study, the numerical simulation; Nays 2DH, is implemented.

The depth integrated mass conservation equation for flow pattern in Cartesian coordinate system is described as:

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}(uh)+\frac{\partial}{\partial y}(vh)=0 \tag{1}$$

The x and y components of momentum conservation equations for flow pattern are described as:

$$X: \frac{\partial uh}{\partial t}+\frac{\partial uuh}{\partial x}+\frac{\partial uvh}{\partial y}=-gh\frac{\partial}{\partial x}(h+Z_b)-\frac{\tau_x}{\rho}+\frac{1}{\rho}\left\{\left(\frac{\partial}{\partial x}(h\sigma_{xx})+\frac{\partial}{\partial y}\left(h\tau_{yx}\right)\right\}\right. \tag{2}$$

$$Y: \frac{\partial vh}{\partial t}+\frac{\partial vuh}{\partial x}+\frac{\partial vvh}{\partial y}=-gh\frac{\partial}{\partial y}(h+Z_b)-\frac{\tau_y}{\rho}+\frac{1}{\rho}\left\{\left(\frac{\partial}{\partial y}\left(h\sigma_{yy}\right)+\frac{\partial}{\partial x}\left(h\tau_{xy}\right)\right\}\right. \tag{3}$$

Where, h is the flow depth, t is the time, u and v are the component of depth averaged flow velocity along x and y direction respectively, g is the acceleration due to gravity, Z_b is the bed elevation, ρ is the mass density of water, σ_{xx}, σ_{yy}, τ_{yx} and τ_{xy} are the depth-averaged Reynold's stresses, τ_x and τ_y are the x and y component of bed shear stress (τ_b).

Following equation describes the mass conservation equation of suspended sediment.

$$\frac{\partial \bar{c}h}{\partial t}+\frac{\partial r_1\bar{c}uh}{\partial x}+\frac{\partial r_1\bar{c}vh}{\partial y}=\frac{\partial}{\partial x}\left(h\in_x\frac{\partial \bar{c}}{\partial x}\right)+\frac{\partial}{\partial y}\left(h\in_y\frac{\partial \bar{c}}{\partial y}\right)+E_i-D_i \tag{4}$$

Where, $\bar{c}$ is the depth averaged sediment concentration, r_1 is the correction factor, $\in_x$ and $\in_y$ are the x and y component of dispersion coefficient respectively, E_i is the erosion rate and D_i is the deposition rate of suspended sediment in each grid.

Mass conservation equation of bed sediment (equation of bed elevation)

$$\frac{\partial z_b}{\partial t}+\frac{1}{1-\lambda}\sum i\left(\frac{\partial q_{bix}}{\partial x}+\frac{\partial q_{biy}}{\partial y}+E_i-D_i\right)=0 \tag{5}$$

Where, q_{bix} : Bed load transport rate in x-direction for grain size d_i, q_{biy} : Bed load transport rate in y-direction for grain size d_i and λ: porosity of bed sediment .

Generally, river channels are composed of non-uniform sediment. For the non-uniform sediment case,

Bed load discharge were evaluated by following equation given by Ashida and Michiue (1972) modified Egiazaroff's formula

$$q_{b*i}=17\rho_i\tau_{*ei}^{\frac{3}{2}}\left(1-\frac{\tau_{*ci}}{\tau_{*i}}\right)\left(1-\frac{u_{*ci}}{u_*}\right) \tag{6}$$

Where, τ_{*ci} is the non-dimensional critical bed shear stress for the particle size, d_i and $\tau_{*cm}$is non-dimensional critical bed shear stress for the mean size, d_m and ρ_i is the fraction of particle size class, d_i, in the surface of bed load layer.

The equilibrium concentration of suspended load at reference level was evaluated using Lane and Kalinske's equation as following:

$$q_{ss}=5.55P_{mk}\left[\frac{1}{2}\frac{u_*}{W_0}\exp\left(-\frac{w_0}{u_*}\right)\right]^{1.61}\ w_0r_b \tag{7}$$

Where, q_{ss} : Suspended sediment transport rate, P_{mk} : Fraction of sediment size class in bed load layer, u_* is the shear velocity, W_0 is the fall velocity of suspended sediment.

Figure 1 shows the methodology of this study.

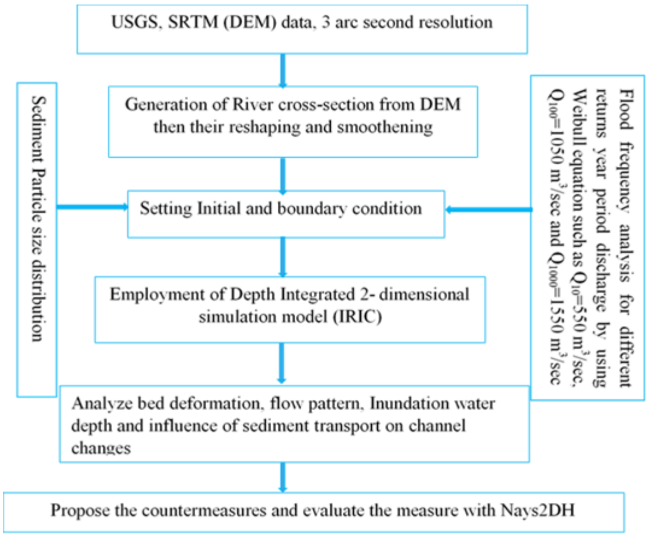


Figure 1 Methodology of the study

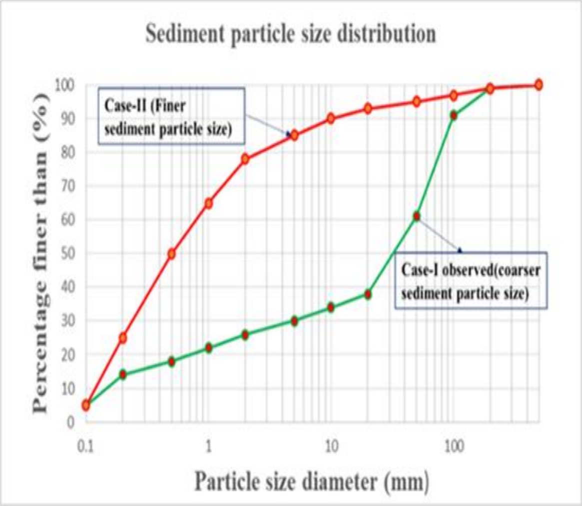


Figure 2 Sediment particle size for both Cases

SEDIMENT CONDITION

One of main purpose of this study is to simulate the upstream sediment condition of landslides and debris flow which supplies large amount of fine sediment. Two sediment supply cases such as Case-I and Case-II were considered along with the steady discharge Q_{10}=550 m^3/sec, Q_{100}=1050 m^3/sec and Q_{1000}=1550 m^3/sec. Table 1 shows the initial and boundary condition of sediment supply that we assumed for this study. Figure 2 shows the different sediment particle size distribution for both cases. Case-I illustrates what was observed on the actual river bed. On the other hand, Case-II represents sediment supplies from the slopes. They are not exists on the main stream since they are easily transported to downstream by the flow. They can be seen at the slope, river side bank or area, wherever the dead water zone exists, but not necessary in the main channel.

Table 1Initial and boundary condition of sediment

	Case-I	Case-II
Initial condition (in entire calculation condition)	Observed sediment particle size.	Finer sediment particle size.
Upper Boundary condition	No particle size distribution changes with time	

RESULT AND DISCUSSION

Inundation area with different discharge and sediment supply condition

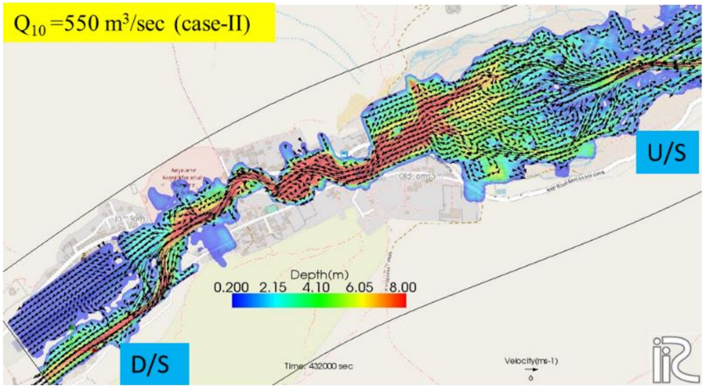


Figure 3.a Inundation area for Q_{10}=550m^3/sec (case-II)

Figure 3.a shows the 5days simulation result with discharge Q_{10}=550 m^3/sec with Case-II. Blue color shows the water depth up to 0.2 m whereas red color shows water depth equal or more than 8 m. later this simulation output is going to compared with Q_{1000}=1550 m^3/sec with Case-I. Generally less discharge cause less inundation whereas high discharge cause high inundation.However from the figure 3.a & 3.b, it is clearly seen that there is no such difference in inundation. Therefore it can be concluded that sediment particle size is playing an important role for inundation. At a same time, when comparison of

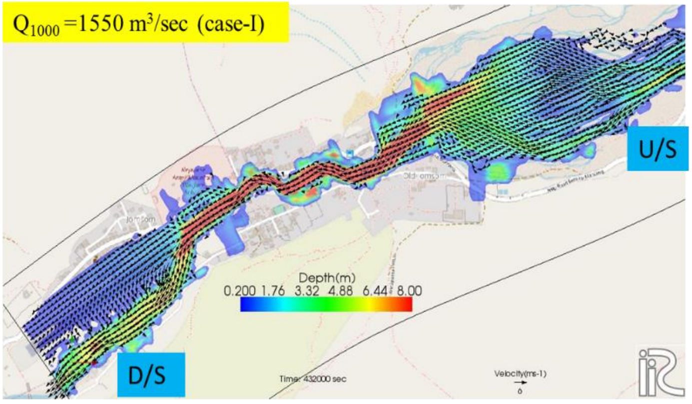


Figure 3.b Inundation area for Q_{1000}=1550m^3/sec (case-I)

numerical simulation of both cases of sediment supply with same discharge Q_{1000}=1550 m^3/sec with Case-I and Case-II of sediment supply. It is found that there is much difference in inundation .Figure 4.a shows the simulation result of Case-I and Figure 4.b shows the result of Case-II. From figure 4.a it can be observed that the inundation area as well as inundation water depth is in the acceptable range. Whereas from figure 4.b, the inundation area and inundation water depth is beyond the acceptable limit. From the result it is concluded that in case of Case-II, clogging by the fine sediment occurs resulting the rise in water level and inundation occurs.

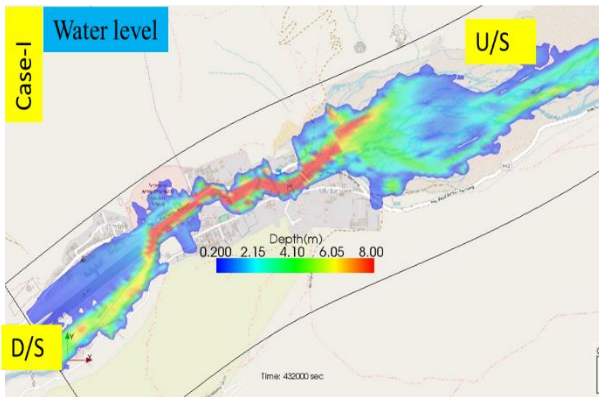


Figure 4.a Inundation area for Q_{1000}=1550m^3/sec (case-I)

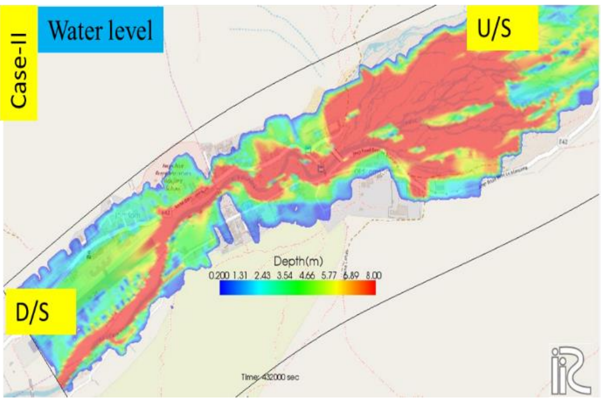


Figure 4.b Inundation area for Q_{1000}=1550m^3/sec (case-II)

Sediment transport rate

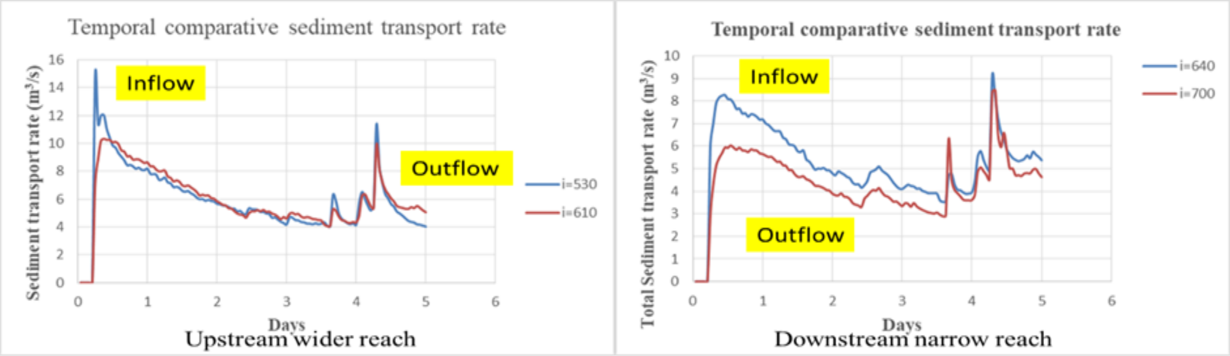


Figure 5 Sediment transport rate on upstream wider and clogging section of study reach.

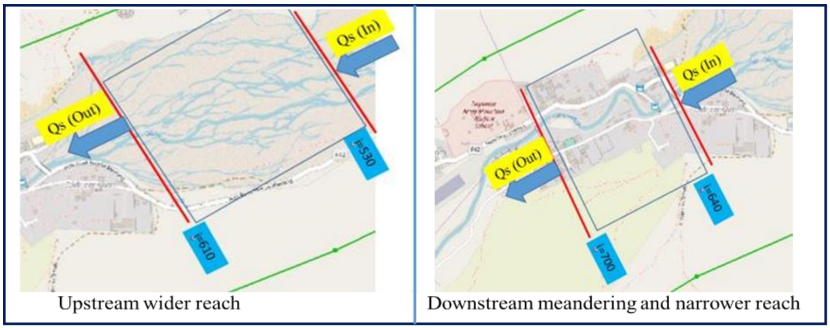
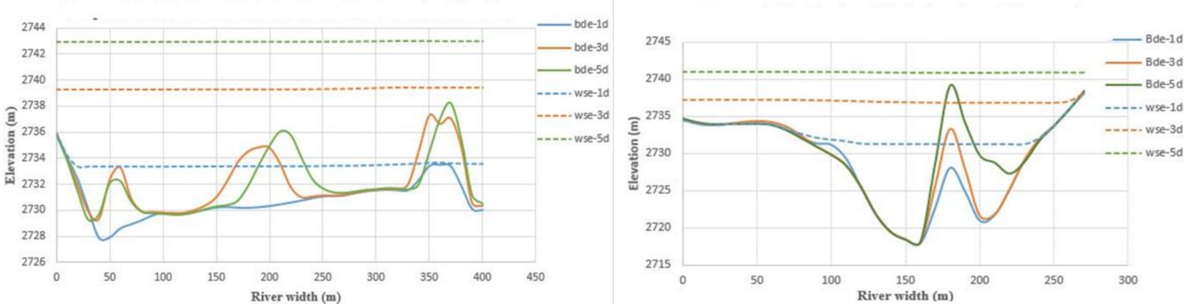


Figure 6 Location of upstream wide and downstream clogging section

Figure 6 shows the actual location of upstream wider reach and meander and clogging section of the study reach. The model calculates the sediment transport rate in every location of the river. This study calculates the total sediment transport rate in two section one in upstream wider reach and another in downstream narrow part of the study reach as shown in figure 5. In upstream, i=530 represents the inflow upward river section whereas i=610 represents the downward outflow of river section. The inflow rate is higher than outflow at earlier stage of simulation. So, most of the sand bar forms at this stage. In downstream reach i=640 represents the inflow upward river section whereas i=700 represents the downward outflow of river section until 3.5 days of simulation there is only deposition. This is because of the clogging section. The physics behind this output is sediment budgeting. Form the sediment budget, it can be calculated that whether the section is erosion dominant or deposition dominant. In downstream meander part $q_{b(in)} >> q_{b(out)}$, that means inflow is larger than outflow resulting deposition of fine sediment.

Formation of sand bar and change in water surface elevation (WSE)



a. upstream *b. clogging part*

Figure 7 Timely changes of bed elevation (bde) and water surface elevation (WSE)

Figure 7.a & 7.b shows the change in bed elevation and WSE at (Q_{1000}=1550 m^3/s with Case-II) of upstream wider reach and downstream clogging portion. In both figure bde-1d, bde-3d & bde-5d represents the bed elevation on 1day, 3day and 5 day respectively. On similar way represents wse-1d means water surface elevation after one day simulation and so on. Figure 7.a shows that formation and shifting of sand bar towards the right bank of river with passes of time. Multiple channels ae formed in between large sand bars. The bifurcation of channel directs the flow towards the bank and resident area. And figure 7.b represents the downstream narrower and clogging part .from figure 7.b it is clearly seen that there is deposition of fine sediment in the middle part of the river channel which is really the clogging part. Figure 6 shows the actual location of river.

Determination of vulnerable location of study reach

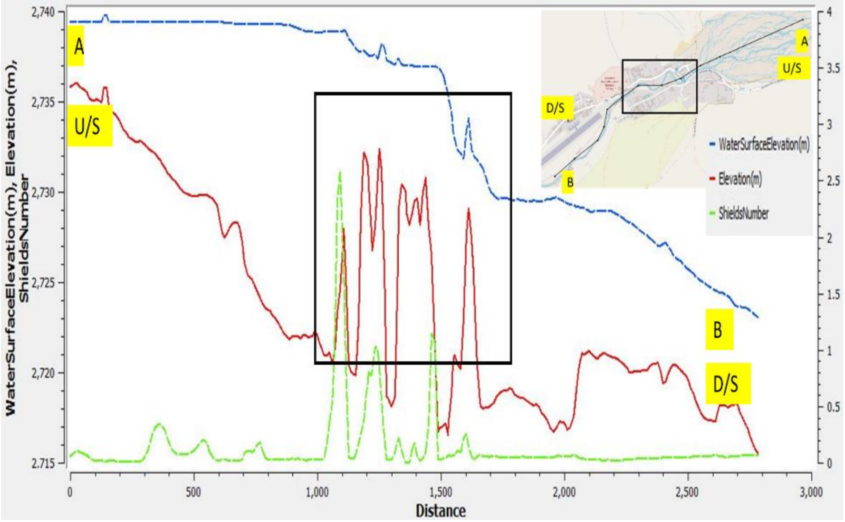


Figure 8 Temporal distribution of bed elevation, WSE and non-dimensional bed shear stress at the end of 5 days simulation

Figure 8 represents the temporal distribution of bed elevation, WSE and non-dimensional bed shear stress at the end of 5 days simulation. Red line shows bed elevation, Blue line shows WSE and green line shows the shield number. When sediment budget is disbalanced then there is either erosion or deposition. The area under black circle shows huge deposition that means the inflow is greater than outflow of sediment at that section. Figure shows huge deposition of fine sediment on the black circle causes clogging in river channel. Due to that clogging, water level increases behind the clogged part. Then the water level rises and starts to overtop the both bank of the river resulting the inundation extent.

River training works

Figure 9 shows the simulation results of inundated area along with water depth with proposed river training works. The comparison of this result in those presented in Figure 4.b (without river training works), it can be revealed that the proposed river training works seems to be efficient in reducing the inundation in surrounding localities of the river channel .

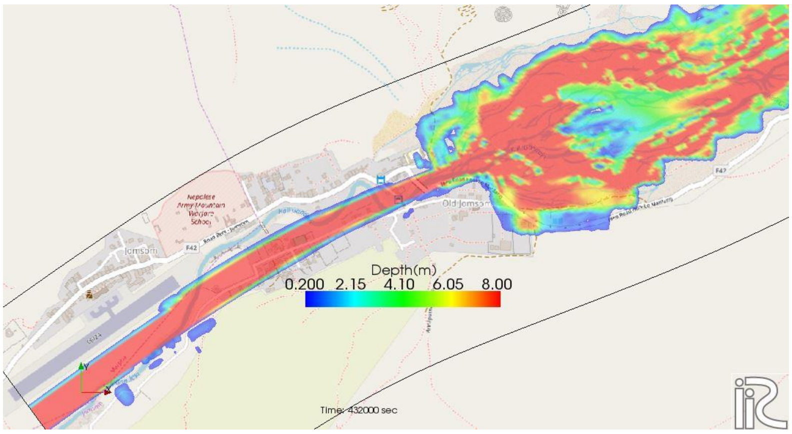


Figure 9 Elimination of inundation area after river training works.

CONCLUSION AND RECOMMENDATION

From this study following conclusion are listed

1) It is found that finer sediment supply condition caused by landslide and debris flow from upstream tributaries causes massive change in morphology and inundation problem in the study area.
2) The reason of change in morphology and inundation is due to deposition of fine sediment in meander part of the study area, which is also described as clogging part or clogging section.
3) To eliminate such problems, river training works is proposed and effectiveness of the works also evaluated through numerical simulation.

This study proposes river training works by straightening the channel throughout the length which is very costly to construct and operate. Cost of construction and operation may be reduced by training the clogging portion only. Effectiveness of this type of improvement may be investigated in the future study.

ACKNOWLEDGEMENT

I am highly indebted to my supervisors Dr. Atsuhiro Yorozuya, Associate Professor, Prof. Shinji Egashira, Research and training advisor, ICHARM, PWRI and Dr. Daisuke Harada, Associate Professor for their precious guidance, valuable suggestion and most importantly constant encouragement brought this research to this shape.

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