# PREDICTION OF SEDIMENT RUN-OFF PROCESSES IN WEST RAPTI RIVER BASIN, NEPAL


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## ABSTRACT

The present study focuses on the prediction of the sediment runoff processes in the West Rapti river basin using Rainfall-Runoff Inundation and Sediment Transport model (RRIS). Rainfall, topographic data, and Sediment distribution are the input for the model. Sediment distribution consisting of two cases: Case I before river bed armored condition and case II, armored river bed condition. The model is able to evaluate the sediment transport rate, Sediment volume, sediment concentration, sediment yields, bed elevation changes, and particle size distribution at the assigned location of the river. The model predicted that high sediment concentration occurred in the upstream area compared to the downstream area. High deposition of sediment occurred in the region consisting of the wide valley. Higher sediment yield observed in the smaller catchment area, compared to the larger catchment area. From the study, it can be concluded that the West Rapti river is a medium sediment transport river compared with that of Japan.



**Key Words:** Rainfall runoff inundation and sediment transport model, Sediment transport rate, Armor condition, Sediment yield, West Rapti river basin


## INTRODUCTION

West Rapti river basin lies in the mid-western part of Nepal. Jhimruk khola, Lungri river, Madi river, Arun Khola, Arjun Khola and Dundung khola are the major tributaries of West Rapti river.(refer to figure 1) West Rapti river is a class II river basin and discharges in river is generated by the monsoon rainfall and groundwater. The total basin area of West Rapti River is about 6,700 $Km^2$. About 65 percent of the basin area lies in the mountainous region. The river has relatively higher slope of 1/105 in upstream area and lower slope of 1/900 in the downstream area. The basin consists of the wide valley with narrow and step channels along the river as shown in figure 7. The basin has average annual rainfall of about 1,500 mm. Based on the measured data at Kusum hydrological observation station (HOS) (refer to figure 1), the average and maximum discharge have been found 136 $m^3/s$ and 7279 $m^3/s$.

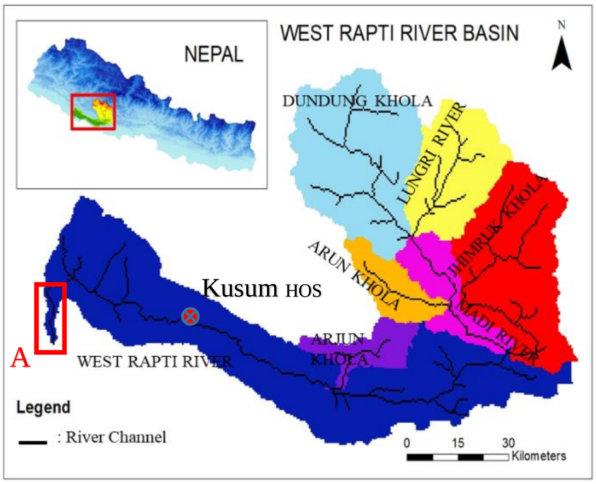


Figure 1: West Rapti river basin and its tributaries.

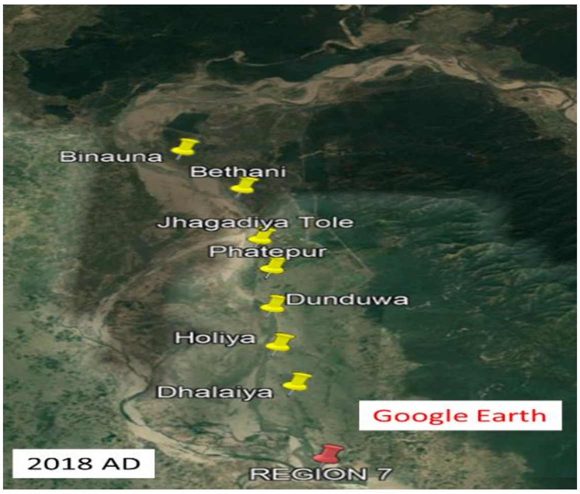


Figure 2: Villages frequently affected by flood which are located in A in figure 1

Floods are the most severe problem in the lower reach of the basin. Every year villages such as Holiya, Phatepur, Binauna, Bethani, Dunduwa and Dhalaiya of the Banke district (refer to figure 2) suffered

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from the flood and inundation because of the breaching of the embankment and bank erosion resulting due to large accumulation of sediment in the river causing substantial river course changes. The main objective of this study is to establish a numerical model for evaluating the sediment transport processes in the West Rapti river basin using two cases. Case I, before river bed armored condition and case II, river bed armored condition. Case I occurs when there is sediment supply from slope to river in the mountainous area and sediment distribution becomes the composition of the finer to coarser particles. Case II occurs when there is small or medium flood in river and no sediment supply from slope to the river. In that condition, bed material consists of coarser particles due to washing out of finer particles. In order to obtain the sediment transport rate, bed elevation changes, and particle size distribution at the assigned sediment out location, RRIS model is run several times using rainfall, topographic data, sediment distribution, and parameter setting.

## THEORY AND METHODOLOGY

For the calculation of the rainfall runoff process, the model uses the 2 –D kinematic wave approximation for calculating flow in slope where as the model uses the 1 D kinematic wave model for flow calculation in river. The model uses the discretize form of mass conservation of flow as under in equation 1.

$$\frac{\partial h^{i,j}}{\partial t} + \frac{q_x^{i,j-1} - q_x^{i,j}}{\Delta x} + \frac{q_y^{i-1,j} - q_y^{i,j}}{\Delta y} = r^{i,j} - f^{i,j} \qquad (1)$$

Where, h, r, f are water depth, rainfall intensity and infiltration depth respectively at grid cell i, j. $q_x^{i,j}$, $q_y^{i,j}$ - are x and y direction discharges at grid cell (i, j).

$$q_x = \begin{cases} -k_a h \dfrac{\partial Z_b}{\partial x}, & (h \le d_a) \\ -\dfrac{1}{n}(h-d_a)^{5/3}\sqrt{\left|\dfrac{\partial Z_b}{\partial x}\right|}\, sgn\left(\dfrac{\partial Z_b}{\partial x}\right) - k_a h \dfrac{\partial Z_b}{\partial x}, & (h > d_a) \end{cases} \qquad (2)$$

$$q_y = \begin{cases} -k_a h \dfrac{\partial Z_b}{\partial y}, & (h \le d_a) \\ -\dfrac{1}{n}(h-d_a)^{5/3}\sqrt{\left|\dfrac{\partial Z_b}{\partial y}\right|}\, sgn\left(\dfrac{\partial Z_b}{\partial y}\right) - k_a h \dfrac{\partial Z_b}{\partial y}, & (h > d_a) \end{cases} \qquad (3)$$

Where, Ka: lateral saturated hydraulic conductivity, $d_a$: Soil depth times the effective porosity. $q_x$ and $q_y$ are the discharges in x and y direction. The first part of equation 2 and 3 ($i.e\ h \le d_a$)explains about the discharge due to saturated sub surface flow condition while as second part($i.e\ h > d_a$) explains about discharge due to surface flow in addition to the first part.

Figure 3 shows the relationship among flow field (shear velocity) sediment transport and river bed elevation changes. As the water flow increases in the river channel, increasing shear velocity takes place. Increasing in shear velocity cause the sediment mobility in the river which are in function of bed load, suspended load and wash load. This sediment transport cause river bed elevation changes.

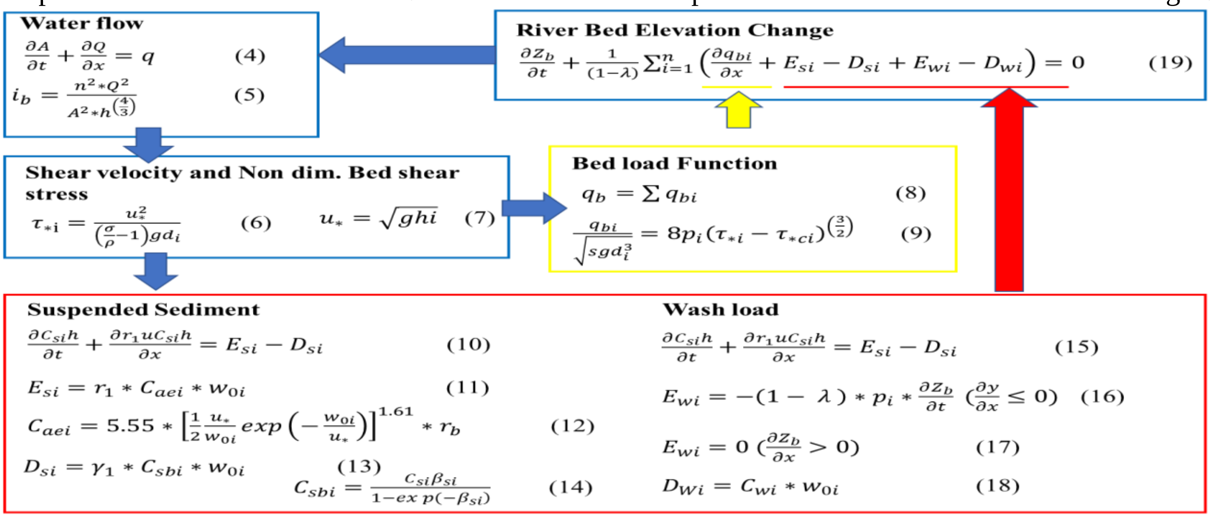


Figure 3: over all sediment transport processes.

Equation 4 and 5 shows the 1 D Mass and Energy conservation equation for channel flow. Where, A, Q, q, $i_b$, and h are cross-sectional area, water discharge, lateral inflow in unit length, river bed slope and depth of water respectively. n denotes the Manning's roughness coefficient.
Equation 6 and 7 explains about the non- dimensional bed shear stress($\tau_{*i}$) as well as shear velocity($u_*$) which are the most influencing factors contributing the sediment transport in the river. Shear velocity is proportional with the flow depth and river bed slope. Flow depth is influenced by the flow discharge and width of the channel. Bed shear stress dependent on the shear velocity which causes the sediment transport in the channel. So, shear velocity is the key term connecting the sediment transport and flow discharge.
In the model, bedload transport rate ($q_b$) which is in the function of $\tau_{*i}$ and particle size distribution ($d_i$) is calculated by the Meyer-Peter and Muller's formula as shown by the equation 9. Where, $\tau_{*ci}$ : Non-dimensional critical bed shear stress for initiating bed sediment transport, $p_i$: Sediment size distribution of size class i.
Suspended sediment transport rate is explained by the equation 10, 11, 12, 13 and 14. Equation 10 states about how the suspended sediment transported by the flow. $E_{si}$ and $D_{si}$ are erosion and deposition rate of suspended sediment calculated by equation 11 and 13. Where, $r_1$: Coefficient of suspended sediment transport, $w_{0i}$: Settling velocity for each sediment particle calculated by Ruby's equation, $C_{sbi}$: Equilibrium concentration of suspended sediment at a reference level of size class i and $C_{aei}$: Equilibrium concentration of suspended sediment calculated by Lane and Kalinske's equation.
Wash load transport rate is calculated in the model by equation 15, 16, 17 and 18. Equation 15 states about the convection of wash load by the flow. $E_{wi}$ and $D_{wi}$ are erosion and deposition rate of wash load calculated by equation 16, 17 and 18. Where, $\frac{\partial Z_b}{\partial t}$: Decreasing rate of bed elevation, $C_{wi}$: Sediment concentration of wash load.
The transport of the bed load, suspended sediment, and wash load causes the riverbed elevation changes which are evaluated based on the sediment continuity equation stated by equation 19. Thus the river bed changes lead the watercourse changes and direct the flow.
The particle size distribution in the model is evaluated by the equation 20.

$$\frac{\partial p_i}{\partial t} = \frac{1}{1-\Lambda}\left(\frac{\partial q_{bi}}{\partial x} + E_{si} - D_{si} + D_{wi} - E_{wi}\right) - \frac{\partial Z_b}{\partial t}\frac{f_i}{\delta} \quad (20)$$

Where, $p_i$ particle size of size class i, $\delta$ bed load layer thickness (first layer).

## MODEL SET UP

1. For the topographic file of the study area, DEM data downloaded from the USGS website. DEM, Flow direction and Flow accumulation of the basin are delignated as shown in figure 4, 5 and 6. Those are converted into ASCII files for model use.

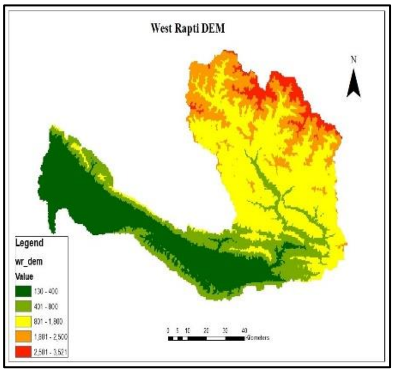

Figure 4: DEM

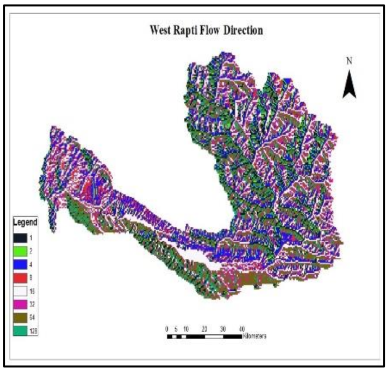

Figure 5: Flow direction

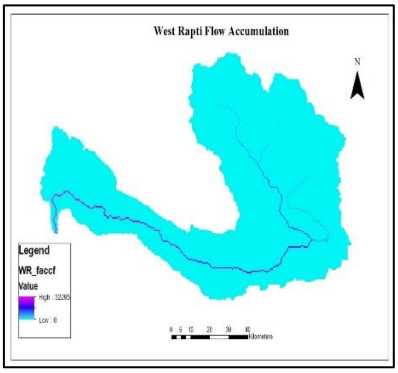

Figure 6: Flow accumulation

2. River width has been made on the basis of measured river width about seventy locations in the google earth because of unavailability of ground measurement data. Then river width of each grid cell is obtained by the interpolation.
3. The rainfall event from 10th to 18th August of 2014 is used for the simulation. Ground gauge daily rainfall data is converted into hourly rainfall data by applying factor obtained from hourly GS map data as below:
   Daily to hourly Factor (for each hour) = GS Map (each hour rainfall) / GS Map (sum of rainfall in 24 hours)

Ground rainfall (hourly) =Ground rainfall (Daily)* Daily to hourly Factor (for each hour)

4. Basin is divided into seven different regions based on the fact that production of sediment, transport of sediment and topography. Figure 7 shows the sediment regions with the main river channel. Also, figure 7 indicates the wide valley (Yellow circled) and step and narrow channel (Red circled). Two cases of sediment distribution is applied to the study. The case I, before river bed armored condition and Case II, Armored river bed are shown in figure 8 and 9 respectively.

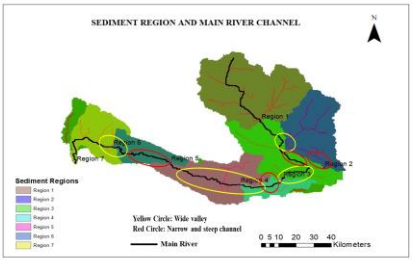


Figure 7: Sediment Regions

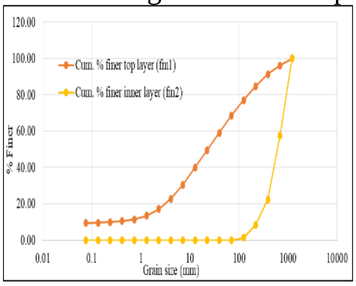


Figure 8: Particle size (case I)

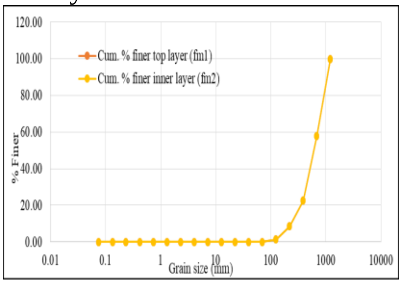


Figure 9: Particle size (case II)

5. Before the actual flood simulation, the model is run with the dummy flood event in order to ensure the river bed smoothing caused by high fluctuation of shear velocity and sediment sizes.

## RESULTS AND DISCUSSION

RRI model calibration is conducted for the period from 10th to 18th August 2014 based on the measured discharge at Kusum HOS. Thus those calibrated parameters are used for the RRIS model simulations.

- River bed changes (Region 7)

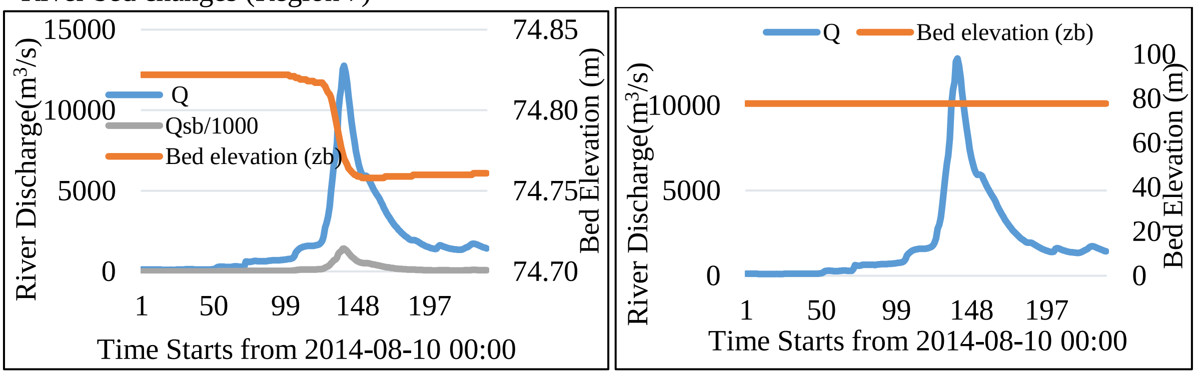


Figure 10: Temporal changes of flow discharge and river bed. (Case I and Case II)

In case I of figure 10, the increase in the discharge and increase in bedload transport rate caused the river bed erosion while as in case II, no river bed changes noticed.

- Sediment Transport rate (Region 7)

Figure 11 shows the graph in between sediment transport rate and water discharge at region 7 where Qsb, Qss, and Qsw represents the bed load, suspended load and wash load transport rate respectively. In case I, whenever the increase in discharge took place, increase in sediment transport rate observed. Bed load domination has been observed in case I. In case II, no sediment transportation observed. The reason is that new sediment supply in case I and armored river bed condition in case II.

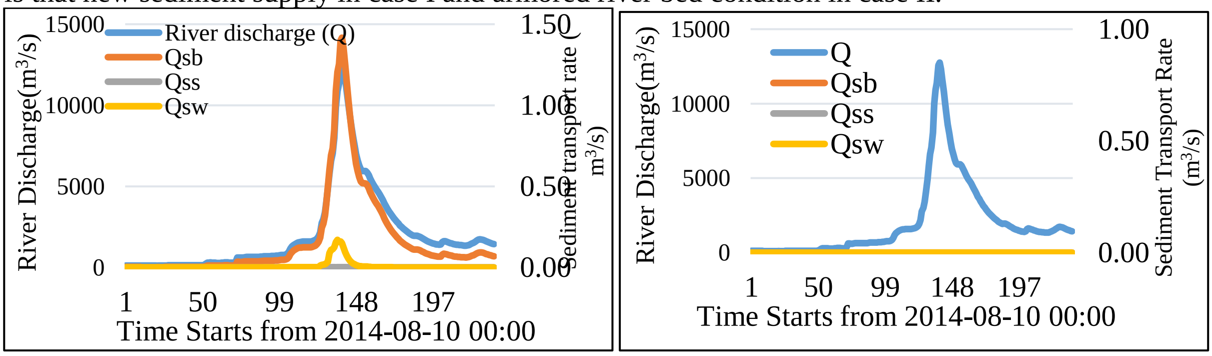


Figure 11: Temporal changes of flow discharge and sediment transport rate. (Case I and Case II)

- Particle size distribution (Region 7)

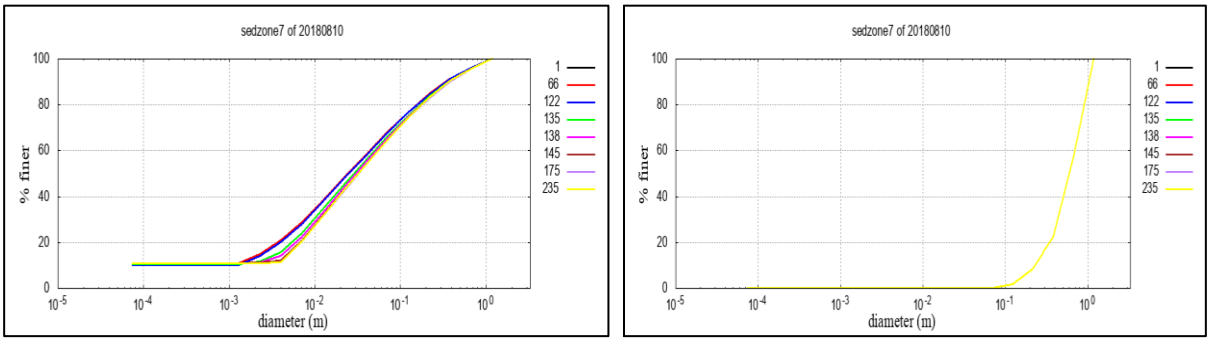

Figure 12: Temporal changes in sediment size distribution. (Case I and Case II)

Figure 12 shows the sediment size distribution of zone 7 at different simulation time step for both cases. During the peak discharge condition in case I, (138th hour) coarsening of the particle noticed. In the final hour of the simulation further coarsening noted due to the washout of lower size particles and in the meantime particle size less than 1mm has been increased. But in case II, no change in particle size distribution observed because of no sediment transport and armored condition.

- Sediment concentration in the basin.

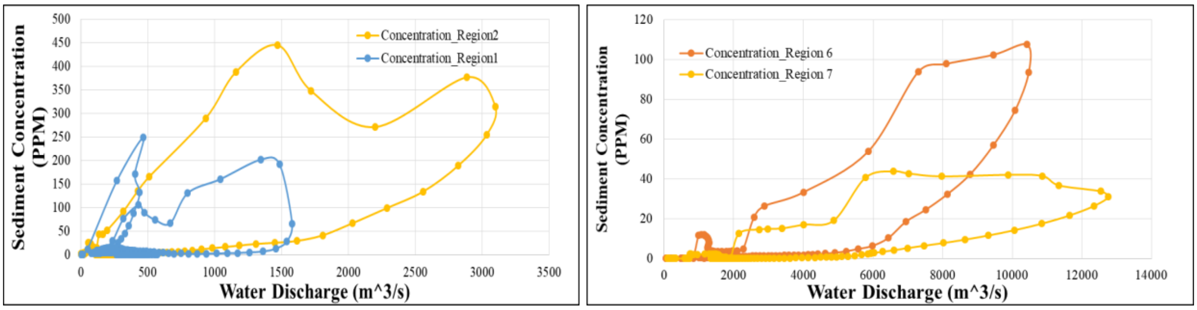

Figure 13: Sediment concentration in the basin (case I)

Figure 13 shows the relation between sediment concentration in PPM with the flow discharge in Region 1, 2 and Region 6, 7. Both the figure shows that the concentration increases during the rising period of flood and decrease in the recession of flow. So from the results, it has been clear that the upstream region has higher sediment concentration than the far downstream regions.

- Sediment volume in the basin

Table 1: Sediment volume in the basin

| **S.N** | **Water Volume (M. m$^3$)** | **Sediment Volume (m$^3$)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Case I (Before Armored Condition)** | | | | **Case II (Fully Armored Condition)** | | | |
| | | **Bed load** | **Suspended Load** | **Wash Load** | **Total Sediment** | **Bed load** | **Suspended Load** | **Wash Load** | **Total Sediment** |
| Region 1 | 243.8 | 624,377.5 | 66.41 | 2,406.67 | 626,850.57 | 24,307.70 | 0.00 | 0.00 | 24,307.70 |
| Region 2 | 235.1 | 331,672.9 | 60.29 | 9,705.07 | 341,438.30 | 37,090.97 | 0.00 | 0.00 | 37,090.97 |
| Region 3 | 708.2 | 370,733.7 | 68.81 | 10,413.81 | 381,216.31 | 7,979.68 | 0.00 | 0.00 | 7,979.68 |
| Region 4 | 809.7 | 121,851.6 | 47.12 | 6,391.73 | 128,290.48 | 66.95 | 0.00 | 0.00 | 66.95 |
| Region 5 | 1094.8 | 101,976.4 | 26.82 | 8,619.18 | 110,622.44 | 134.33 | 0.00 | 0.00 | 134.33 |
| Region 6 | 1298.7 | 211,162.4 | 56.65 | 10,726.43 | 221,945.44 | 377.97 | 0.00 | 0.00 | 377.97 |
| Region 7 | 1730.1 | 141,285.5 | 34.35 | 6,853.30 | 148,173.18 | 0.00 | 0.00 | 0.00 | 0.00 |

Table 1 shows the water volume and the accumulated sediment in all the seven regions for both cases. In case 1, about 586,000 m$^3$ sediment retained in the region 3. This large quantity of sediment deposition in region 3 is due to the wide valley in region 3. When we compare about the input and output at region 7 then about 819,000 m$^3$ sediment deposited in the basin. In case II, as the river bed is armored condition, the composition of the higher size sediment particles are difficult to transport resulting in the less transportation of sediment.

From both cases, it can be concluded that sediment transport is higher before the armoring process of the river and then sediment transport is less after armoring process due to washing out of the finer size of sediments.

- Catchment area and sediment yields.

In figure 14, Line 1 indicates the maximum sediment discharge while as line 5 indicate the minimum sediment discharge. Line 2, 3 and 4 falls in a range between maximum to minimum sediment discharge. The blue dots (case I) in the figure represents the per cubic meter sediment yield per square kilometer in a year. Region 1 has a small catchment area compared to region 7 however the sediment yield has been observed around 800 cubic meters per square kilometer per year. And at region 7 sediment yield has been observed around 20 cubic meters per square kilometer per year. So the results say that the lower catchment area has higher sediment yield and higher catchment area has lower sediment yields. The reason is that higher catchment area consists of the larger flat area for sediment storage resulting less yield of sediment. Based on this chart, it is concluded that West Rapti river falls on medium sediment transporting river.

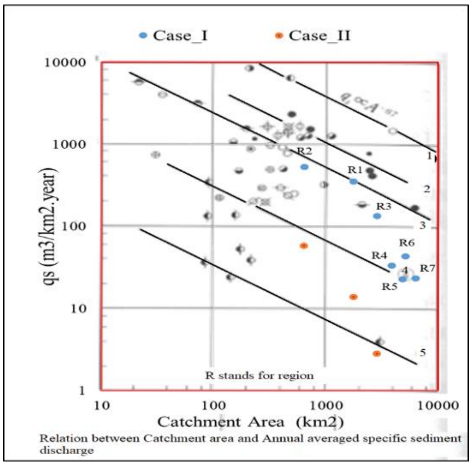


Figure 14: Relation between catchment area and sediment yields.

## RECOMMENDATIONS

The model is able to access the sediment transport processes in the study area such as bed load, suspended sediment and wash load transport rate, river bed changes, and particle size distribution in the assigned locations. So, it is recommended to pay attention to the sediment discharges along with the flow discharge in designing the River Infrastructures even if the riverbed is armored.

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