CHAPTER 4

Sediment Distribution: Nature, Extent and Mechanism

4.1 Introduction

Self-formed streams receive their sediment supply almost entirely from upstream (fluvial) sources, the local bed, and erosion of banks composed of sediment transported under the current transport regime. Stream morphology and sediment sizes are exclusively controlled by the interaction between flow and sediment. Consequently, the streambed does not contain particles larger than that can be moved during the highest floods. The transport of sediments downstream is dependent on the characteristic of the supply catchments (geology, soil, topography, and land use), the type of sediment being released and the hydrology of the river (Ankers et al, 2003).

Coarse material transported by a river (bed load) commonly is moved by rolling, sliding, or bouncing along the channel bed. There is a large amount of uncertainty in the process of calculating annual rates of bed load transport. How much coarse material is moved, how long it remains in motion and how far it moves depends on the size, shape, and packing of the material and the flow characteristics of the river. Downstream movement commonly occurs as irregular bursts of short-distance movement separated by longer periods when the particles remain at rest. Because bed load changes from hour to hour, day to day, and year to year, estimating annual bed load rates is a dynamic process involving careful examination.

The Balason river is noteworthy for its transporting capacity of huge volume of coarse materials as bed load. The catchment characteristics with high rainfall intensities, and decreasing vegetative coverage inducing surface run-off and occasional landslides have incremented the delivery of colluvial masses including big boulders and gravels causing aggradations in middle and lower reaches of the Balason river (Starkel and Basu, 2000) (plate 4.2C). In its lower course, the decrease in the flow velocity of the river with
subsequent fall in the gradient and braiding nature, the competency and transportation ceases and the assorted deposition of the load carried by the river begins (plate 4.1A & B).

In this chapter the sediments size, characteristics and its distribution along the lower course of the Balason river have been studied based on the field surveys and analysis of nature, extent and mechanism with the help of data on surface sediment distribution and suspended sediment collected by the researcher from 2008 to 2010 and also recorded at CWC G&D Site, Matigara. Such analysis have been validated and properly interpreted following the literatures available and its relationship with the fluvial characteristics of the lower Balason river.

4.2 Sediment sources

The sediment sources in the Himalayas are widely considered to be the glacial debris and landslides but there are only few data available on the relative contribution of sediments from either source. In some parts of the Himalayas visual observations suggests that glacial debris is the major source materials while in other parts landslides appear to be the major sources (Jhonson and Collins, 1983). Quaternary sediments in the eastern Himalayan foothills un-conformably overlie the Siwalik group of rocks and older metamorphic units like Daling group or Darjeeling Gneiss near the mountain front (Acharrya and Shastry, 1979). Three distinct groups of Quaternary sediments occur in the eastern Himalayan foreland in the Darjeeling and Jalpaiguri districts of West Bengal, India (Chakraborty and Ghosh, 2010). These are: (a) coarse gravely piedmont sediments lying close to the mountain front and at places extending few kilometres inside the mountain valleys; (b) pebbly, coarse to fine sand and mud related to the mega fans and (c) gravel, sand and clay deposited in the modern river valleys (Shukla et al, 2001). The fact that these thick beds overlies the northward dipping Siwalik (Pliocene Pleistocene) strata at the base of the eastern Himalayas indicates that the boulder formation originated sometimes in the Pleistocene after the uplift, tilting and partial denudation of the Siwalik (Basu and Sarkar, 1990). It is thus evident that during the Pleistocene, when the higher parts of the Darjeeling
Himalayas were experiencing widespread glaciations, the Manebhanjyang-Sukhiapokhari-Ghoom range was subject to periglacial conditions. During this period, Balason, the main stream, together with its tributaries Rakthi and Rohini, brought down a great volume of periglacial debris and solifluction materials which eventually were deposited as coalescing alluvial fans at their outlets (Kar, 1962, 1969). Such sediments have become finer grained and more rounded with greater quartz and mica composition as the river settles its load after the erosional threshold ceases. The occurrence of cobbles, gravels and boulders with subordinate amount of sand, silt and some clay in the Balason-Rakti-Rohini fan has been deposited by the intermittent flash floods, stream action, stream floods and mass-movements (Basu and Sarkar, 1990).

4.3 Study of the coarse sediments (>2 mm) in the lower Balason river

The river bed sediment distribution analysis is essential for understanding the hydraulics and other river characteristics such as bed-load transport rate, sediment budget, and habitat description. Accurate sediment sampling can be an important component of identifying changes in bed composition due to varied flow conditions and environmental factors.

In this section, the researcher has attempted the coarse sediment sampling following the Grid sampling method of Wolman (1954) at an interval of 1 km along the lower course of Balason river during pre-monsoon and post monsoon periods from 2008 to 2010. Since the river bed is mostly composed of boulders, gravels and pebbles which are extensively lifted along the entire lower Balason, hence the researcher in this study has considered only a single grid of 1 m\(^2\) over reaches where the bed material extraction has not been carried. Within the grid prepared, the sediments intermediate axis is measured in mm (figure 3.2) and the process is repeated until the desired number of samples have been sampled and measured, with 100 samples being the generally accepted guideline (plate 4.1D, E & F). The obtained sizes were arranged in a frequency distribution table with a Wentworth scale showing only class limits. The mean of all the sample sizes from each grid are further used to represent the mean coarse sediment distribution at each site (1 km interval) along the lower course of the Balason river.
Figure 4.2 The different axis of the pebbles used for measuring its size.
The study of coarse sediments reveals that the sediments ranging from boulders (512 - >4096 mm) in its upper segment, Cobbles (96 – 128 mm) and gravels (12 – 96 mm) in middle segment and sand and silt (2 – 12 mm) are distributed unevenly throughout the lower course of Balason river (figure 4.3). The segments upto 4 km downstream of the Panighata bridge has un-assorted boulders with largest diameter of more than 1.5 m and plenty of medium and small diameter boulders. The presence of such boulders indicates the river’s competency to transport sediments from its upper sediment sources as well as the intensity of extreme floods carrying heavy debris flow. Below these segments upto the Matigara Bridge (18 km downstream) the cobbles and gravels (32 – 256 mm) are found in large quantities mixed with coarse sand with medium boulders (512 – 1024 mm). In this segment of the lower Balason river there is maximum extraction of bed materials and due to this the sorting of coarse sediments are also hampered. Mostly the cobbles and gravels are extracted which are river processed and readily available for construction purposes. Although the extent of bank failure in this segment indicates the river’s adjustments as the deficit sediment are being added to the river from such exposed banks. In the segment below Matigara bridge till the confluence with Mahananda river the coarse sediments also decreases in size with ample of medium to small gravels (12 – 96 mm). The coarse sand is abundantly available and decrease in the amount of cobbles and gravels reveals that the river starts depositing the finer sediments.
suspended sediments in the form of sand, silt and clay. Also few boulders (512 – 1024 mm) are scattered along this segment probably brought down during extreme flood time.

4.3.1 Study of the distribution of mean coarse sediments (D_{50}) in the lower Balason river during 2008 to 2010

The analysis of the mean coarse sediments (D_{50}) in each site along the lower course of the Balason river, which has been calculated based on the mean diameter (D_{50}) of the total samples of each grid shows that it ranges from largest 319.323 mm to smallest of 36.755 mm (figure 4.4). The mean coarse sediment for the entire lower Balason river was 134.892 mm, 130.383 mm and 136.728 mm during 2008, 2009 and 2010. The variation of mean coarse sediments in different sites of 1 km interval during pre and post monsoon from the annual D_m shows that the upper segments (up to 8 km below) and segments near Matigara bridge (18 km below) had maximum of 86.356 mm (7 km below, 2008) and minimum of 32.002 mm (18 km below, 2010). Although such changes in D_m could not be directly related to channels annual adjustments but it was noticed that mostly sections with maximum human interferences (boulder lifting activities) shows that the coarse surface sediments are lifted and also bed and bank erosion is prevalent. Hence it could be ascertained that despite of river’s own adjustment under human interferences, the competency and sorting of coarse sediments is highly uneven along the lower course of Balason river.
Figure 4.4 The distribution of the mean sample diameter ($D_{50}$) of the coarse sediments (>2 mm) at sites (1 km interval) along the lower course of Balason river during 2008 to 2010 (Refer Appendix C table 4.1, 4.2 and 4.3).
4.3.2 Study of the relationship between fall or settling velocity (m s\(^{-1}\)) and the distribution of the coarse sediments

Fall or settling velocity is a function of density, shape, size, roundness and surface texture of the sediment particles and specific weight and viscosity of the water and it determines the terminal rate of settling of particles under varied flow condition. This influences the sediment particles mode, rate and distance of transport by shearing forces of the flow (Dietrich, 1982). Considering the coarse sediments as spherical particles, an attempt has been made to estimate the fall velocity of the sampled coarse sediments with respect to its diameter (mm) and water temperature (°C) along the lower course of Balason river during 2008 to 2010. The formula used for calculation of fall velocity (\(w\)) is as follows:

\[
\begin{align*}
\text{w} & = \left(\frac{4}{3}\right)\frac{(gd_m/C_D)}{\left(\frac{(\gamma_s - \gamma)/\gamma}\right)}^{1/2} \\
\text{w} & = \text{fall velocity (m s}^{-1}\text{)} \\
g & = \text{gravitational acceleration (m s}^{-3}\text{)} \\
d_m & = \text{sediment diameter (mm)} \\
C_D & = \text{Drag Coefficient (dimensionless)} \\
\gamma_s & = \text{Specific weight of the particles (kN m}^{-3}\text{)} \\
\gamma & = \text{Specific weight of the water (kg m}^{-3}\text{)}
\end{align*}
\]

In this estimation of fall velocity (m s\(^{-1}\)) certain parameters has been taken as constant based on hypothetical assumptions provided in several related literatures. The water temperature of 20°C and the mean flow velocity and depth has been estimated from the data collected from CWC G&D Site. The assumed values considered for these parameters are as follows:

\[
\begin{align*}
g & = 9.81\text{ m s}^{-3} \\
\gamma_s & = 26.0\text{ kN m}^{-3} \\
\gamma & = 9.789\text{ kN m}^{-3}\text{ for 20°C} \\
C_D & = 24/R + 2 \text{ (Rubey, 1933)}
\end{align*}
\]

Again, R = Reynolds number of sediment particles has been calculated based on the formula:
\[ R = \frac{(p \cdot V \cdot h)}{\mu} \]

where

- \( p \) = Density of the sediment particles (kg m\(^{-3}\))
- \( V \) = Mean flow velocity (m s\(^{-1}\))
- \( h \) = Mean flow depth (m)

The estimated fall or settling velocity (w) reveals that the larger sized boulders (> 4096 mm) which are common till sites 3 km below Panighata Bridge may have been transported by the river during extreme flood events as debris flow with fall velocity of more than 20 m s\(^{-1}\) (Refer Appendix B table 4.4, 4.5 and 4.6) (plate 4.2A & B). Similarly, the medium and smaller sized boulders (256 – 1024 mm) and cobbles (64 – 256 mm) almost available till Matigara Bridge (18 km downstream) may have been transported during flash floods occurring once or twice a decade (Starkel & Basu, 2000) with fall velocity between 5 – 3 m s\(^{-1}\). The remaining sites till the Naukaghat Bridge (22 km downstream) having plenty of gravels and coarse to fine sands may be transported during the annual peak flows from upper segments which are being settled as flow retreats with fall velocity below 2 m s\(^{-1}\).

![Graph](image-url)
Figure 4.5 The estimated fall or settling velocity (m s\(^{-1}\)) of the annual mean coarse sediments (D\(_{50}\)) sampled during 2008 to 2010 (Refer Appendix C table 4.4, 4.5 and 4.6)

4.4 Study of the Suspended sediments of the lower Balason river

The amount and type of solid particles carried by the river flow shows the relative contribution of the surface run-off and its catchment characteristics
(Morisawa, 1968). The lower Balason river with deforested catchment and high surface run-off brings down huge loads of suspended particles during monsoon periods with its flow in the form of sand, silt and clay which are being deposited on its entire lower course before it mixes with Mahananda river. In this section, the researcher has attempted to calculate the total suspended load (metric tons) based on the data collected from CWC G&D, Matigara (plate 4.2D, E & F). In the analysis of suspended sediment, the particles have been classified on the basis of its grain size, which are as follows:

i. Coarse (coarse to medium sand) with diameter of 2.00 - 0.20 mm
ii. Medium (fine sand) with diameter of 0.02 – 0.075 mm, and
iii. Fine (silt and clay) with diameter <0.075 mm

Figure 4.6 The total suspended load (M.T) of lower Balason river from 1989 – 1990 to 2010-2011 (Refer Appendix C table 4.7).

In figure 4.6, the annual total suspended load in metric tons has been estimated along with its proportion during monsoon and non-monsoon periods. It could be clearly seen that the monsoon periods contribute more than 90% of the total annual suspended load carried by the river. The maximum annual suspended load was estimated 2153895 M.T during 1991-92 and the proportion of monsoon suspended load was 2151205 M.T which was 99.88% of the total annual load and for non-monsoon period it was only 2690 M.T. The minimum annual suspended load was estimated 195095 M.T
during 1997-98 and the contribution of monsoon suspended load was 188857 M.T which was 96.80% of the annual total and for non-monsoon period it was 6238 M.T. During non-monsoon due to nil to few low intensity rainfall and consequent non occurrence of the surface run-off, the suspended load carried by the river is very minimal. The maximum non-monsoon suspended load was estimated at 38670 M.T during 2000-01 and its contribution to annual total 399448 M.T was 9.68%.

4.4.1 Study of the relationship between discharge (m$^3$ s$^{-1}$) and Suspended Sediment Load (M.T) during monsoon period (June – October) of the lower Balason river during 2007 to 2010

Since during monsoon period the suspended load carried by the lower Balason river contributes more than 90% of the total annual load as high rain intensity and consequent high saturation of soil profiles and also high gradient of the bed rocks in its upper catchment accelerates surface as well as sub-surface run-off (Starkel & Basu, 2000). An attempt has been made by the researcher to estimate the relationship with the help of coefficient of correlation between discharge and suspended load during monsoon period from 2007 to 2010.
The relationship between the total daily suspended load (M.T) and mean discharge (Q) during monsoon periods of the lower Balason river are highly correlated as the values of coefficient of correlation ($r^2$) is 0.93318 in 2007, 0.92571 in 2008, 0.95371 in 2009 and 0.9372 in 2010 (figure 4.7). Such correlation clearly states that during monsoon periods with the increase in discharge due to high intensity rains, river energy also increases and consequently the load of suspended particles in its flow fluctuates thereby incrementing the channel competency.

4.4.2 Study of the Suspended Sediment Concentration (g l$^{-1}$) (SSC) of the lower Balason river during 2007 to 2010

In rivers the concentration of suspended particles depends on the water’s flow rate, turbidity, soil erosion, land use changes, impoundment on upstream river and several other factors. The SSC (g l$^{-1}$) of the lower Balason river shows the overall effects of such factors which greatly contributes to the total SSC. During 2007 to 2010, the estimation of total monthly SSC (figure 4.8) based on the data collected from CWC G&D Site, Matigara reveals that the
maximum SSC were 145.671 g l\(^{-1}\), 79.728 g l\(^{-1}\), 83.364 g l\(^{-1}\) and 114.098 g l\(^{-1}\).

The proportions of coarse, medium and fine particles in total SSC were 28.51%, 21.02% and 50.45% of the total SSC during 2007 - 2010 (Table 4.8). Such grains proportion of suspended load shows the actual competency of the river flow which has been largely controlled by anthropogenic effects, soil erosion, surface runoff etc on the lower Balason river.

<table>
<thead>
<tr>
<th>YEARS</th>
<th>COARSE (g l(^{-1}))</th>
<th>MEDIUM (g l(^{-1}))</th>
<th>FINE (g l(^{-1}))</th>
<th>TOTAL SSC (g l(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>38.492</td>
<td>32.928</td>
<td>74.179</td>
<td>145.671</td>
</tr>
<tr>
<td>2008</td>
<td>24.948</td>
<td>16.871</td>
<td>37.909</td>
<td>79.728</td>
</tr>
<tr>
<td>2009</td>
<td>22.556</td>
<td>13.760</td>
<td>47.048</td>
<td>83.364</td>
</tr>
<tr>
<td>2010</td>
<td>34.578</td>
<td>25.341</td>
<td>54.179</td>
<td>114.098</td>
</tr>
<tr>
<td>MEAN</td>
<td>120.574</td>
<td>88.900</td>
<td>213.315</td>
<td>422.861</td>
</tr>
</tbody>
</table>

(Computed by the researcher based on data from CWC G&D Site, Matigara)

Table 4.8 The total monthly SSC (g l\(^{-1}\)) of lower Balason river from 2007 to 2010.
Figure 4.8 The total monthly SSC (g l⁻¹) of lower Balason river from 2007 to 2010 (Refer Appendix C table 4.8, 4.9, 4.10 and 4.11).
4.4.3 Study of the total Run-off (million m$^3$) and Suspended Sediment Concentration (g l$^{-1}$) of the lower Balason river during 2007 to 2010

The analysis of the daily run-off (million m$^3$) and SSC (g l$^{-1}$) of the lower Balason from 2007 to 2010 has been attempted to shows that the SSC fluctuates with river run-off (figure 4.9). During the monsoon period (June to October) the increase in river discharge causing maximum run-off and consequently high SSC could be noticed. During non-monsoon period (November to May), the SSC also recedes but sometimes late monsoon rainfall largely contributes to the SSC with increase in river discharge and consequent runoff as could be noticed in 2010.
4.5 Study of the daily Suspended Sediment Yield (ha 300 km² d⁻¹) of the lower Balason river during 2007 to 2010

Suspended sediment yield (SSY) refers to the rate delivery of eroded soil particles brought down by the river with its flow (Reddy, 2008). An estimate has been made by the researcher in this section about the suspended sediment yield of the lower Balason river based on the sediment run-off data collected from CWC G&D, Matigara during 2007 to 2010 (figure 4.10). In order to estimate SSY, the following formula and parameters has been used:

\[
SSY = \frac{[(Qs \times 300)}{(A/300)]
\]

where

Qs = Suspended sediment run off (ha m /10³)
A = Total Basin area (km²)

Again, Suspended sediment discharge (Qs) has been calculated with the help of following formula

\[
Qs = \frac{[(Q \times 0.0864)/10] \text{ where, } Q = \text{ discharge (m³ s⁻¹)}}
\]
(Estimated by the researcher based on data collected from CWC G&D, Matigara)

**Figure 4.10** The total daily suspended sediment yield (ha 300 km$^2$ d$^{-1}$) of lower Balason river from 2007 to 2010.
4.6 Conclusions

The analysis of surface coarse sediments and suspended sediments of the lower Balason river and its relation with discharge, run-off and fall or settling velocity reveals that during hyperconcentrated flows occurring very rarely, the efficiency of sediment delivery by linear erosion and mass movement causes substantial transformations in the channel geometry. The annual flow with normal peak discharge (below 500 m$^3$ s$^{-1}$) does not greatly result the sediment transportation with only substantial change in sediment distribution. The suspended sediment yield rate also fluctuates with fluctuation in channel flow and surface run-off.

References


Plate 4.1 The sediment distribution along the lower Balason river starting from unassorted boulders in its upper piedmont segments (A), followed gravels and coarse sand in its middle segments (B) and the finer sediments mostly sand in the lower reaches (C) transported by the river during monsoon flows; grid sampling (D) and samples collected (E & F) for measuring its size (diameter).
Plate 4.2 The larger boulders in the middle segments brought during extreme flood flows (A & B) scattered over river bed; loose soils in its upper catchment (C) adding suspended load to the river, and the monsoon flows carrying large quantities of suspended load (D, E & F) in the lower Balason river. (Photographs by the Researcher)