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Temporal Variability of Hydrological Characteristics in the Lower Balason River, Darjeeling District, West Bengal, India

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Abstract

As the Balason river debouches onto the Terai plains, the fall in gradient and incompetence provides greater scope for the water to spread laterally. Thus, along the lower course, the river attains the braided pattern and the increment in the size of bars downstream has also restricted the free passage to an excessive amount of run-off due to heavy and concentrated rainfall causing flood. In this paper, the authors have attempted to describe the seasonal as well as annual variability of morphological as well as hydraulic characteristics of the lower Balason river for which the data on discharge, water level and velocity collected from the CWC Gauging & Discharge (G&D) Site has been computed and analyzed from 2007 to 2010. The cross-sections along the entire lower course have been surveyed at 1 km interval both during pre-monsoon and post-monsoon periods from 2008 to 2010 with respect to the CWC Bench Mark (119 m). Although the low channel flow during non-monsoon period reduces the transporting capacity, yet due to frequent outburst of monsoon peak flows increments the channel run-off and capacity inducing varied bed erosion. Such act of river is also encouraging the anthropogenic control in the form of bed materials extraction and human encroachment of flood plains and banks.

Introduction

Fluvial processes of a river are a dynamic phenomenon controlled by several factors, some of which are independent in nature and therefore, cannot be regulated by the available technologies. Balason, an important right bank tributary of Mahananda river is noteworthy for its dynamic fluvial characteristics, sometimes causing devastating floods, erosion and sedimentation which are primarily controlled by its discharge, bed load and the abrupt changes in its gradient in which the channel adjusts itself (Jana and Dutta, 1997). The fluctuating discharge, excessive bed load supply from its upper catchments and highly erodible banks have resulted in braided nature with sandy filled bars at lower plain.

In its lower course the river bed has been gradually elevated, restricting the free passage to an excessive amount of run-off due to heavy and concentrated rainfall causing flood. Till date, the dynamic nature of Balason river has not got much importance in the fluvio-geomorphic studies of the region. Some sporadic attempts have been done by Basu & Sarkar, 1990, De & Basu, 1998, Jana & Dutta, 1997, Starkel & Basu, 2000, Lama, 2003. De, (1998) has made a detailed study of the fluvial dynamics of Balason river in a quantitative way and also examined the progressive changes in hydrological parameters between 1989 and 1993.

Similarly, Lama (2003) has studied the environmental geomorphology of the Balason Basin in which the analysis of its forms and processes during 1998 – 2001 have been carried out. The quantitative characteristics of the long and cross profiles of the Balason river has been studied by De (2010) to follow the exact sequence of activities along the long profile of the river from its source to the confluence by fitting the exponential curves. Bhattacharya (1993) carried out a comprehensive study on the problem of management of the Rakti basin which is an important tributary joining the Balason river at its lower course.

Objectives and Methodology

In this paper, the authors have attempted to describe the seasonal as well as annual variability of morphological as well as hydraulic parameters such as Cross-sections, Discharge (Q), Velocity (v), Water level, Bed heights and Flow characteristics with the help data collected from the CWC Gauging & Discharge (G&D) Site, located near Matigara (N.H 31) from 2007 to 2010. The cross-sections along the entire lower course has been surveyed at 1 km interval both during pre-monsoon and post-monsoon periods from 2008 to 2010 starting from below Panighata bridge (Dudhia Bazar) till Naukaghat bridge with respect to the CWC Bench Mark (119 m). The analysis of discharge and water level hydrographs and rating curves on daily and monthly basis and correlation of discharge with water level and velocity along with analysis of peak flow, flood frequency and return period analysis (has been) have been prepared to bring out the probable temporal variability in hydrological condition prevailing in the lower Balason river.

The Study Area

The Balason basin has its source from Lepchajagat on the Ghum-Simana ridge (2361 m) which is the major right bank tributary of Mahananda river covering an area of 367.42 km^2. The Balason being a perennial river has a total length of about 48.4 km of which 24.27 km is in the hills and remaining 24.13 km flows in the plain region. The right bank tributaries of Balason river are Pulungdung Khola, Rangbang Khola, Marma Khola, Manjwa Jhora and Dudhia Jhora. The left bank tributaries are Bhim Khola, Rangmuk Khola, Pachhim Khola, Rinchigtong Khola and Ghatta Hussain Khola. At an altitude of 305 m, Balason river starts its lower course (Fig.1) and from this area onwards mostly transportation and deposition by the river could be noticed. In its lower course, the river is joined by Rakthi khola, Rohini Khola, Panighata Khola, Chenga, Manjha, etc. It finally joins the Mahananda river near Siliguri town (latitude 26°48´37˝N and longitude 88°18´30˝E).

Cross-sections of the Lower Balason river

The cross-sections along the lower course of Balason is typical braiding type with a number of water covered channels that are separated by sand bars, mud-flats of vegetated islands (De, 2010). The width (w) of the cross-sections increases as the river moves downstream with occasional narrowing at few sections due to deposition of bars and also concentration of channel flow over same segments thus increasing channel velocity also. The channel mean depth (d) is also variable, which is largely controlled by frequent changes in bars and flow conditions. The unstable bars and frequent diversions of flow due to its braiding nature and extraction of bed materials from the river bed are also changing the channel mean depth in entire lower course. In the surveyed cross-sections along the lower course of Balason river, there is no marked annual changes in its width and mean depth (Fig.2). The width ranges from maximum of 702.600 m (21 km downstream) to minimum of 202 m (below Matigara Bridge) with channel widening at an average rate of 2.100 m (1 km below Panighata bridge), 1.270 m (8 km downstream) to 0.640 m (22 km downstream) during 2008 to 2010. From the surveyed cross-sections, the annual average width varies between 337.833 m (below Panighata Bridge) to 206.333 m (below Matigara bridge) and 580.333 m (below Naukaghat bridge). In case of channel mean depth, the value ranges from 1.530 m (4 km downstream) to 0.380 m (20 km downstream). The annual variation in mean depth is 0.692 m (below Panighata Bridge) to 0.811 m (below Matigara bridge) and 0.697 m (below Naukaghat bridge).

In the surveyed cross-sections along the lower course of Balason river, there is no marked annual changes in its width and mean depth (Fig.3). The width ranges from maximum of 702.600 m (21 km downstream) to minimum of 202 m (below Matigara Bridge) with channel widening at an average rate of 2.100 m (1 km below Panighata bridge), 1.270 m (8 km downstream) to 0.640 m (22 km downstream) during 2008 to 2010. From the surveyed cross-sections, the annual average width varies between 337.833 m (below Panighata Bridge) to 206.333 m (below Matigara bridge) and 580.333 m (below Naukaghat bridge). In case of channel mean depth, the value ranges from 1.530 m (4 km downstream) to 0.380 m (20 km downstream). The annual variation in mean depth is 0.692 m (below Panighata Bridge) to 0.811 m (below Matigara bridge) and 0.697 m (below Naukaghat bridge).

The variations of cross-section width and mean depth ratio (w:d) along the lower Balason river during 2008-2010 (Fig.4) shows that the value ranges between 0.001 to 0.005. At segments (14 km to 16 km below) where the banks are exposed and also the continuous extraction of bed materials from the river bed as well as adjacent floodplains, inducing the frequently shifting of channel flow, thus increase the width as well as mean depth. But at segments, where channel flow has been concentrated over same portions mostly due to increase in the bar height or reduction in channel competence and where artificial bank protection structures are present, there exists low w:d, since the channel has little scope for widening and also the depth also remains almost the same.

The trend in cross-sectional area along the entire lower Balason river (Fig.5) reveals that at few segments (3 km to 8 km downstream) the area reduces from 318.420 m^2 to 269.083 m^2 and also at segments below Matigara bridge (18 km to 20 km downstream) with an area of 153.488 m^2. As compared to the segments with no restrictions in its flow, there exists marked reduction in the cross-sectional area below the bridges (233.939 m^2 below Panighata Bridge and 167.044 m^2 below Matigara Bridge) as channel is being constricted causing retention of flow and also narrowing channel width. Moreover, such disturbance has resulted in deposition in the form of channel bars of considerable sizes (Tamang and Mandal, 2010). Hence, the segments (1 km, 2 km and 9 km to 17 km downstream) and also at the confluence with Mahananda (21 km and 22 km downstream), there have been less disturbances.

The wetted perimeter of surveyed cross-sections ranges from 339.552 m (below Panighata Bridge) to 207.955 m (below Matigara Bridge) and 581.728 m (below Naukaghat Bridge). The maximum wetted perimeter (703.848 m) prevails near the confluence with Mahananda river (21 km and 22 km below) and minimum (203.800 m) at 18 km downstream (Matigara Bridge). Along the entire lower course, segments (2 km to 9 km below, 15 km and 18 km downstream) with narrow channel width and divisions of channel flow have reduced its mean depth resulting into lower wetted perimeter (359.423 m to 348.504 m, 246.833 m and 207.955 m respectively). Although, there does not exists any noticeable variations in annual trend of wetted perimeter during 2008 2010 (figure 3.5), only at 2 cross-sections (1 km and 2 km downstream), the concentration of main flow over same portions allow down cutting which in turn increases the channel mean depth (454.317 m and 359.423 m respectively). In other segments, the trend is almost similar with no or slight variations annually.

The analysis of correlation (Fig.6) between average annual cross-sectional area and its corresponding width (w) along the lower course of Balason river shows that the values of correlation co-efficient (r) varies from +0.6723 in 2008, +0.69997 in 2009 to +0.5233 in 2010. The values of correlations co-efficient (r) with channel mean depth (d) varies from +0.52293 in 2008, +0.49831 in 2008 to 0.45226 in 2010. The result show the decreasing trend annually as the bars condition changes frequently with splitting of main channel flows, high under cutting at few segments and construction of artificial bank protection structures thus narrowing the cross-section widths. Besides, the unscientific method of extraction of bed materials directly from the river bed (is disturbing) disturbs not only the channel form but results into local steeper gradients, thus, increasing stream power and consequent bed erosion (Kondolf, 1994).

Daily Discharge Hydrograph

The daily discharge hydrograph of the Balason river (Fig.7) reveals that almost every year the river attains the peak flows during monsoon period (June to October) concentrated within a few well defined spells. During 2007, there existed more than 5 peak flows (above 200 $m^3 s^{-1}$) ranging from the maximum of 439.6 $m^3 s^{-1}$ on 07-09-2007 to the minimum of 210 $m^3 s^{-1}$ on 02-08-2007 (Fig. 7A). In 2008, similar amount of peak flows were noticed but its intensities ranged from 210.800 $m^3 s^{-1}$ 24-07-2008 and maximum of 354.200 $m^3 s^{-1}$ on 19-08-2008 (Fig.7B). The occurrences in peak flow were slightly reduced during 2009 and 2010 with 2 and 4 peak flows but its intensities were almost similar to annual peak flow trends (Fig.7C & D). The maximum peak discharge was recorded as 309.200 $m^3 s^{-1}$ on 20-09-2009 and the minimum peak of 215.200 $m^3 s^{-1}$ on 16-08-2009. For 2010, the maximum peak discharge was 320.700 $m^3 s^{-1}$ on 12-07-2010 and minimum peak discharge was 204.600 $m^3 s^{-1}$ on 21-07-2010. Thus, it may be said from the analysis of daily discharge hydrograph of Lower Balason river that there exists few spells of peak discharges during the monsoon period almost every year (2007 to 2010), which directly reflects the nature of monsoon rainfall associated with the number of successive rain-storms. Moreover, the sudden increment in discharge during the late-monsoon period often invites devastating floods along the lower reaches of the river (Lama, 2003).

Mean Monthly Discharge Hydrograph

The mean monthly discharge hydrograph of lower Balason river during 2007 to 2010 shows some variations in terms of crest, rising and recession of its limb depending upon the channel run-off and infiltration capacity of the watershed (Morisawa, 1968). In 2007, two crest or peak during the months of July (100.543 $m^3 s^{-1}$) and September (117.892 $m^3 s^{-1}$) could be observed and there existed sudden rising and recession immediately before and after it reaches to the crest (Fig.8A). Such condition signifies that the high monsoon rainfall during that period has abruptly increased the river run-off with consequent reduction in its absorption capacity. The situation during 2008 and 2009 was almost similar with only a single crest (August with 121.460 $m^3 s^{-1}$ in 2008 and 94.430 $m^3 s^{-1}$ also in the month of August, 2009) (Fig. 8B & C). After the crest has been attended, in both the year there were abrupt recession of its limb, signifying the continuous fall in the amount of rainfall in its catchment. In 2010, the trend was slightly different as the hydrograph crest had expanded for two months (July and August) with mean monthly Q of 102.310 $m^3 s^{-1}$ and 97.300 $m^3 s^{-1}$ respectively (figure 8D). Here, the peak Q has been attended in both the months with 320.700 $m^3 s^{-1}$ on 12-07-2010 and 244.900 $m^3 s^{-1}$ on 19-08-2010.

Water Level Fluctuations

During 2007, the annual mean water level was 121.359 m with maximum water level of 122.410 m on 07-09-2007 and the minimum of 121.000 m on 30-12-2007 & 31-12-2007. The mean water level during monsoon period was 121.546 m and during non-monsoon period was 121.223 m, so the annual mean water level varied from +0.187 m to -0.136 m (Fig.9A). In 2008, the annual mean water level was 121.329 m with maximum water level of 122.400 m on 07-09-2008 and the minimum of 121.030 m on 23-04-2008. The mean water level variation from annual mean water level was +0.297 m

(121.608 m) for monsoon period and -0.149 m (121.128 m) for non-monsoon period (Fig.9B). For 2009, the mean annual water level was 121.144 m with maximum water level of 122.150 m on 20-08-2019 and minimum water level of 120.780 m on 28-12-2009. The mean water level variation from annual mean water level was +0.203 m (121.347 m) for monsoon period and -0.147 m (120.997 m) for non-monsoon period (Fig.9C). During 2010, the annual mean water level was 120.893 m with maximum water level of 121.940 m on 12-07-2010 and the minimum of 120.660 m on 24-03-2010. The mean water level during monsoon period was 121.090 m and during non-monsoon period was 120.760 m, so the annual mean water level varied from +0.197 m to -0.133 m (Fig.9D).

Velocity Fluctuations

During 2007, the maximum velocity (v) was 2.171 m s^{-1} on 27-07-2007 and the minimum velocity was 0.204 m s^{-1} on 07-04-2007 with mean annual velocity of 0.623 m s^{-1}. The mean velocity of monsoon period was 0.932 m s^{-1} which was +0.309 m s^{-1} excess from annual mean velocity and the mean velocity of non-monsoon period was 0.390 m s^{-1} which was -0.233 m s^{-1} deficient (Fig.10A). In 2008, the maximum velocity was 1.952 m s^{-1} on 03-08-2008 and the minimum velocity of o.231 m s^{-1} on 26-01-2008 with mean annual velocity of 0.569 m s^{-1}. The mean velocity variability during monsoon (0.855 m s^{-1}) and non-monsoon (0.364 m s^{-1}) period from mean annual velocity was +0.286 m s^{-1} and -0.205 m s^{-1} (Fig.10B). For 2009, the maximum velocity was 3.587 m s^{-1} on 16-08-2009 and the minimum velocity was 0.174 m s^{-1} on 09-05-2009 with annual mean velocity of 0.599 m s^{-1}. The mean velocity variability was +0.244 m s^{-1} and -0.176 m s^{-1} during monsoon period with 0.843 m s^{-1} and non-monsoon period with 0.423 m s^{-1} (Fig.10C). In 2010, the annual mean velocity was 0.590 m s^{-1} with the maximum velocity of 1.694 m s^{-1} on 12-07-2010 and the minimum velocity of 0.164 m s^{-1} on 10-04-2010. The variability of mean velocity was +0.318 m s^{-1} during monsoon period with 0.908 m s^{-1} mean velocity and -0.237 m s^{-1} during non-monsoon period with 0.353 m s^{-1} of mean velocity (Fig.10D).

Bed Height Variability

The variability of Bed height of the lower Balason river has been calculated from the Water level and Hydraulic Mean Depth (HMD) data collected from CWC G&D Site, Matigara during 2007 to 2010.

Bed Height = Water Level - Hydraulic Mean Depth

In figure 11, the daily bed heights above and below the annual mean has been plotted to show the variations of bed heights in both monsoon and non-monsoon period from 2007 to 2010. During 2007, the annual mean bed height was 120.954 m with the annual maximum of 121.213 m on 15.06.2007 and the minimum was 120.745 m on 29.07.2007. The mean bed height varied from 120.933 m during monsoon period to 120.969 m during non-monsoon period (Fig.11A). In 2008, the annual mean bed height was 120.968 m with the maximum bed height of 121.345 m on 06-07-2008 and minimum bed height of 120.686 m on 24-06-2008. The mean bed height from monsoon period was 121.047 m and for non-monsoon period the mean bed height was 120.913 m (Fig.11B). For 2009, the annual mean bed height was 120.767 m with the maximum bed height of 121.072 m on 07-09-2009 and the minimum bed height of 120.508 m on 28-12-2009. The mean bed height varied from 120.813 m during monsoon period to 120.734 m during non-monsoon period (Fig.11C). During 2010, the annual mean bed height was 120.460 m with the maximum bed height of 120.898 m on 18-07-2010 and the minimum bed height of 120.213 m on 23-09-2010. The mean bed height varied from 120.465 m during monsoon period to 120.457 m during non-monsoon period (Fig.11D).

The variability shows that the trend of increasing or decreasing the bed height has no rhythm and almost throughout the year the bed height remains more or less same with only slight increase during monsoon period. The annual mean bed height variation were +0.014 m, -0.201 m and -0.307 from 2007 to 2010 which may be attributed to the bed lowering or incision due to anthropogenic factors rather than natural.

Discharge - Water Level Relation

To study the relationship between the daily volume of water and corresponding water level at CWC G&D Site, Matigara from 2007 to 2010 the rating curve has been used (Fig.12). The correlation co-efficient values (r) of 0.916 for 2007, 0.887 for 2008, 0.855 for 2009 and 0.913 for 2010 and the values for coefficient of determination (r^2) are calculated 0.852 for 2007 its value will be, followed by 0.759 for 2008, 0.797 for 0.834 for 2010. Thus from these analysis, we may state that the water level or Gauge height of lower Balason river has positive correlation with total volume of water passing through the CWC G&D Site, Matigara which is largely dependent upon the rainfall intensities over its upper catchment. Although due to the location of the CWC G&D Site, the actual volume of water does not reach till that point since the river after entering into the lower course adjusts within its wide flood plains composed mainly of sand, silt and gravels (Lama, 2003).

Peak flow Characteristics

With high annual rainfall intensities (above 2000 mm) in its upper catchments the nature of flow in the lower course of Balason river during monsoon period are coupled with few spells of peak flows inducing floods in its lower reaches. During 2007, the peak flow spell was attained 5 (five) times out of which 2 spells continued for more than a day. The first peak flow spell occurred from 26-07-2007 to 29-07-2009 with maximum peak discharge of 356.700 $m^3 s^{-1}$ (Fig.13A). Another peak flow spell also remained for 4 (four) days from 05-09-2007 to 08-09-2007 with the maximum peak discharge of 439.600 $m^3 s^{-1}$ (Fig.13B). In 2008, only a single peak flow spell could be noticed which occurred from 18-08-2008 to 20-08-2008 with maximum peak discharge of 354.200 $m^3 s^{-1}$ (Fig.13C). During 2009 the peak flow spells occurred during 19-08-2009 to 21-08-2009 with maximum peak discharge of 309.200 $m^3 s^{-1}$ (Fig.13D). In 2010 the peak flow spell occurred during 11-08-2010 to 14-08-2010 with maximum peak discharge of 320.700 $m^3 s^{-1}$ (Fig.13E).

Monthly Peak flow Characteristics

The monsoon period (June to October) carries more than 90% of the total annual volume of water as the river follows the rainfall pattern, the analysis of the peak flow during this period reveals the formation of short steep rise in discharge and consequent water level due to high low storage capacity during high intensity rainfall (Starkel and Basu, 2000). Such conditions favours the occurrences of floods in its lower reaches (1998, 2002). During 2007 to 2010, the peak flow characteristic clearly shows the frequent rising and falling of flow discharge within a single monsoon month (Fig.14). The variation in total discharge in a single month from June to October were 5.26%, 26.96%, 22.52%, 30.59% and 6.48% respectively of the total annual discharge of 2007. In 2008 the variations were 7.37%, 23.73%, 37.34%, 10.82% and 5.19% respectively of the total annual discharge. The variations in total monthly discharge from annual total discharge were 6.69%, 22.33%, 33.83%, 14.85% and 9.20% respectively during 2009 and 8.81%, 29.83%, 28.37%, 16.54% and 7.53% respectively during 2010. Thus it may be noticed that annual peaks mostly reaches during the month of August showing several peak flows causing channel modifications and floods.

Flood Frequency

Flood frequency analysis of the lower Balason river has been attempted in order to estimate the flood of various return period at CWC G&D Site, Matigara. Once a return period flood magnitude relationship is fitted to a data series, flood magnitude may be worked out of any return periods. For analysis of flood frequency two types of data series are computed, namely, Annual Peak flood series (AP) and Partial duration series (PD) (Chow, 1964). Annual peak flood series is the highest annual discharge of each year. The major disadvantage of this using this series (AP) for analysis is that the second or third highest events in a particular year may be higher than some of the annual peak floods and still they are totally disregarded in this analysis. Such a disadvantage is remedied by using partial duration series (PD) for all the events above a certain threshold value in the analysis, which can be used in this study. All the flood events more than 150 $m^3 s^{-1}$ magnitudes collected from CWC G&D Site, Matigara has been considered for analysis using partial analysis series. The extreme value distribution introduced by Gumbel (1941) based on frequency factor (K) has been used for the flood frequency analysis of the lower Balason river in which the general equation used is as follows:

$X = x + K,$

where, X = the flood magnitude of a given return period (T) x = the mean of the annual peak flood seriesK = the frequency factor.

Again, $K = (y_T \ y_n)/\delta_n$

where $y_T = -\ln\ln (T/T-1)$ y_n = Expected mean δ_n = Standard deviations of reduced extremes to be found from Gumbel's table. The frequency factor (K) has been determined based on the values obtained from Gumbel's table:

$y_n = 0.5268$ and $\boldsymbol{\delta_n} = 1.0754$

Based on the above, the flood discharge for different periods has been calculated and given in Table 1 and 2 for CWC G&D Site, Matigara. The flood frequency analysis based on Gumbel's method show that the return period for the maximum peak Q of 1037.350 $m^3 s^{-1}$ is predicted to be more than 1000 years and also the annual average peak Q (330.903 $m^3 s^{-1}$) is predicted to occur after almost every year which has been clear from the previous sections. Although the above analysis shows the frequency of occurrences of peak Q as a very rare event, but it might not be the actual scenario as the total volume of the water could not always pass through the channel where site for observation is located.

Conclusions

The analysis of the hydrological characteristics in lower Balason river considering its morphological and hydraulic characteristics shows that the river adjusts within the changing fluvial conditions through the scouring and filling phenomenon. However, the effects of anthropogenic disturbances like construction of bridges, embankments and artificial bank protection structures could be clearly seen in its form and processes. Besides, the channelization of the river flow due to extraction of bed materials from the river bed and adjacent flood plains and terraces is also largely hampering the morphological characteristics of the river. The hydraulic parameters characterised by high rainfall intensities with fluctuating discharge and surface run-off proves that the river is(still) active in its fluvial processes. Although the low channel flow during non-monsoon period reduces the transporting capacity the frequent outburst of monsoon peak flows increments the channel run-off and capacity inducing varied bed erosion. The channel flow at lower reaches also migrates frequently abandoning the pervious path. Such act of river is also encouraging the anthropogenic control in the form of bed materials extraction and human encroachment of flood plains and banks.

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Table – 1: Details of Annual Peak Discharge of the lower Balason river at CWC G&D Site, Matigara

Year	Peak Q ($m^3 s^{-1}$)(x)	(x – mean)	(x – mean)^2	(x – mean)^3
1989	378.100	-10.215	104.356	-1066.039
1990	415.200	26.885	722.779	19431.579
1991	903.800	515.485	265724.317	136976778.560
1992	182.600	-205.715	42318.848	-8705641.101
1993	251.300	-137.015	18773.235	-2572223.297
1994	173.400	-214.915	46188.653	-9926655.269
1995	619.600	231.285	53492.541	12371998.023
1996	472.000	83.685	7003.103	586051.504
1997	312.900	-75.415	5687.491	-428924.703
1998	364.700	-23.615	557.690	-13170.096
1999	510.800	122.485	15002.464	1837569.968
2000	216.400	-171.915	29554.924	-5080948.110
2001	315.200	-73.115	5345.870	-390865.693
2002	152.000	-236.315	55844.994	-13197035.155
2003	1050.000	661.685	437826.438	289702987.413
2004	330.300	-58.015	3365.793	-195268.009
2005	202.700	-185.615	34453.097	-6395027.254
2006	409.700	21.385	457.299	9779.127
2007	439.600	51.285	2630.105	134883.719
2008	354.200	-34.115	1163.864	-39705.758
2009	309.220	-79.095	6256.091	-494828.356
2010	320.700	-67.615	4571.850	-309127.695
Total	8542.940			
Mean (x)	388.315			

Source: Computed by the authors based on data collected from CWC G&D Site, Matigara

Table – 2: Predicted Flood Discharge for different Return Periods after Gumbel

Sl. No.	Return Period (Year)	y_T	K	Q ($m^3 s^{-1}$) X_T
1	2	0.367	-0.123	375.889
2	10	2.250	1.760	566.337
3	25	3.199	2.709	662.320
4	50	3.902	3.412	733.422
5	100	4.600	4.110	804.018
6	1000	6.907	6.417	1037.350

Source: Computed by the authors based on data collected from CWC G&D Site, Matigara)

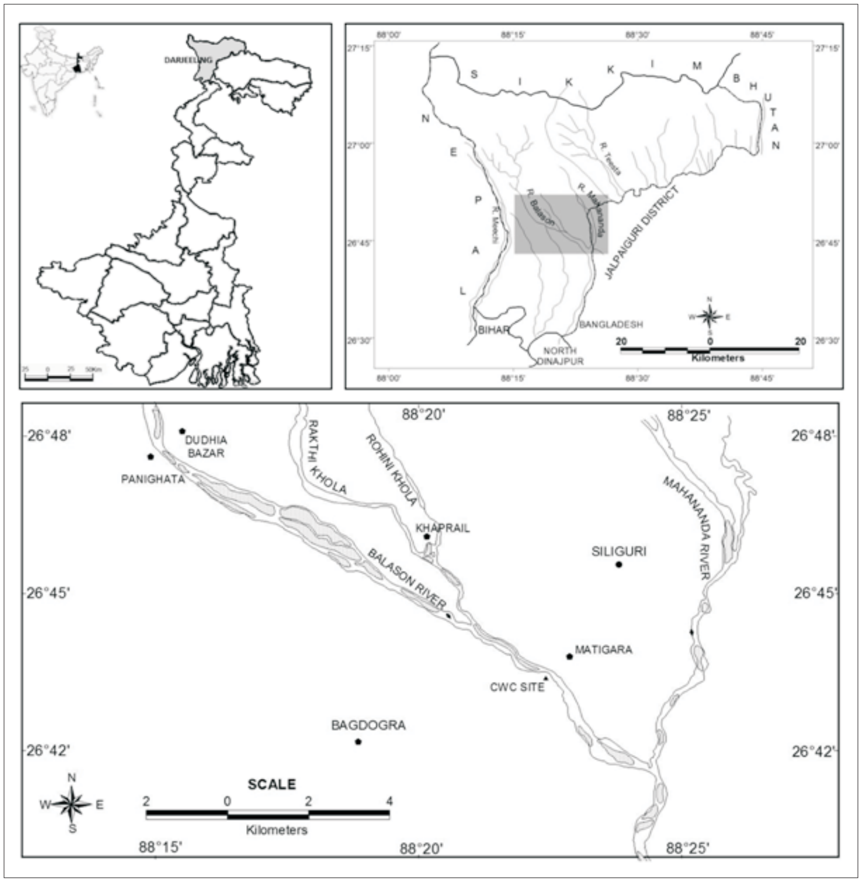


Fig. 1: Location of the Study area (showing the lower course of Balason R. with its two major tributaries, Rakthi and Rohini Khola).

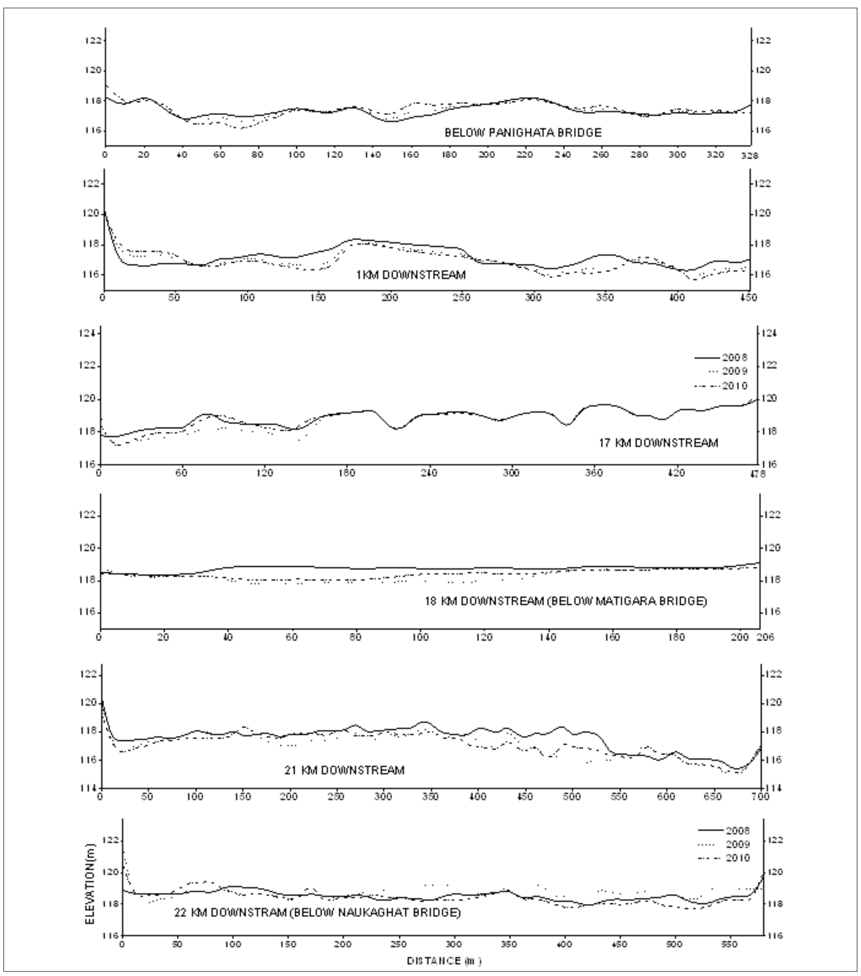


Fig. 2: Cross-sections along the Lower Course of Balason R. (showing Fluctuations in Bed Elevation during 2008, 2009 and 2010

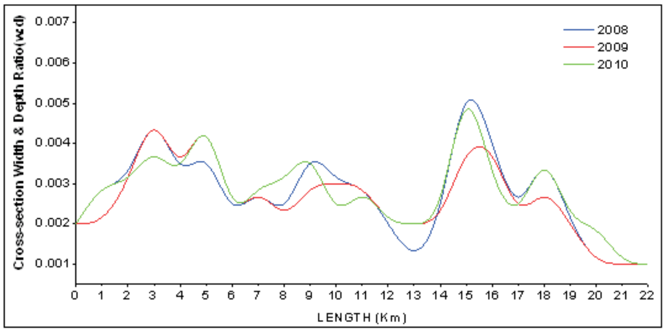


Fig. 3: Annual Changes in Cross Section Width-Mean Depth Ratio along the Lower Balason R., 2008 - 2010

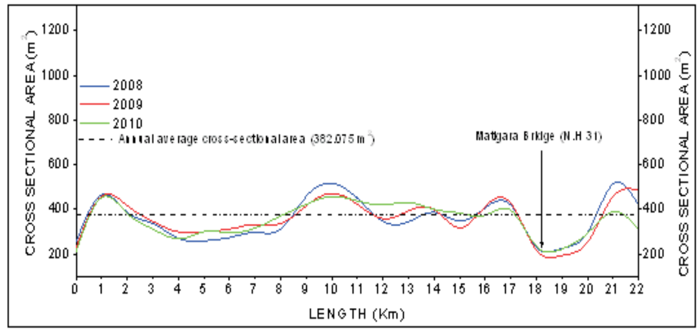


Fig. 4: Annual Changes in Cross-sectional Area along the Lower Balason R., 2008 - 2010

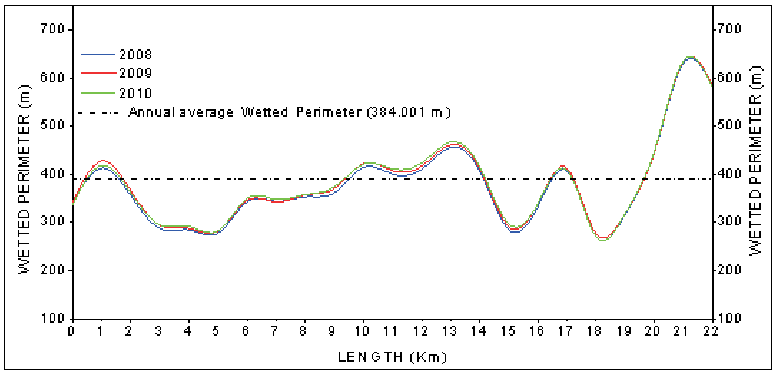


Fig. 5: Annual Changes in Wetted Perimeter along the Lower Balason R., 2008 - 2010

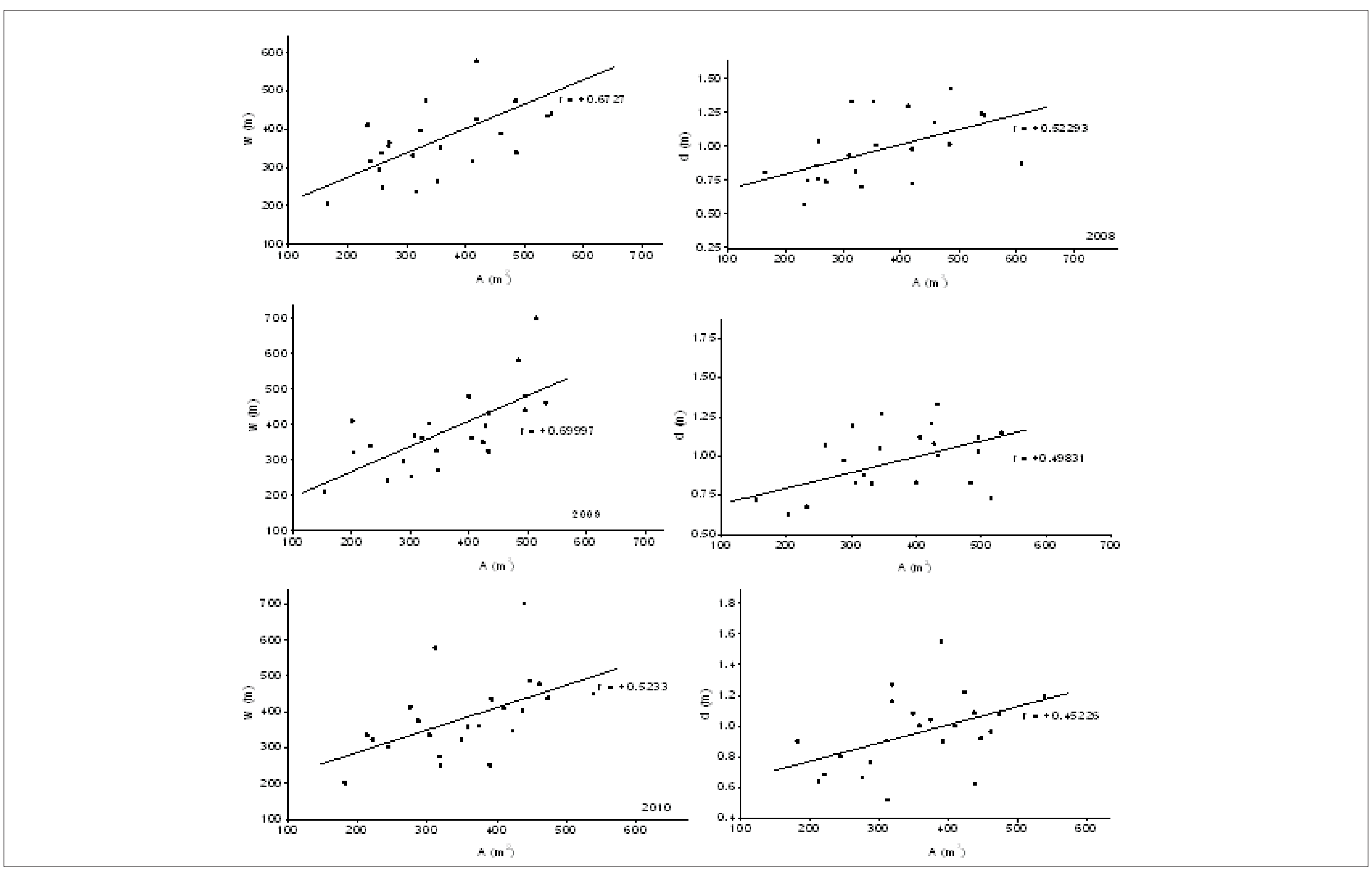


Fig. 6: Relation between Cross-sectional Area and Width and Depth along the Lower Balason R. , 2008 - 2010.

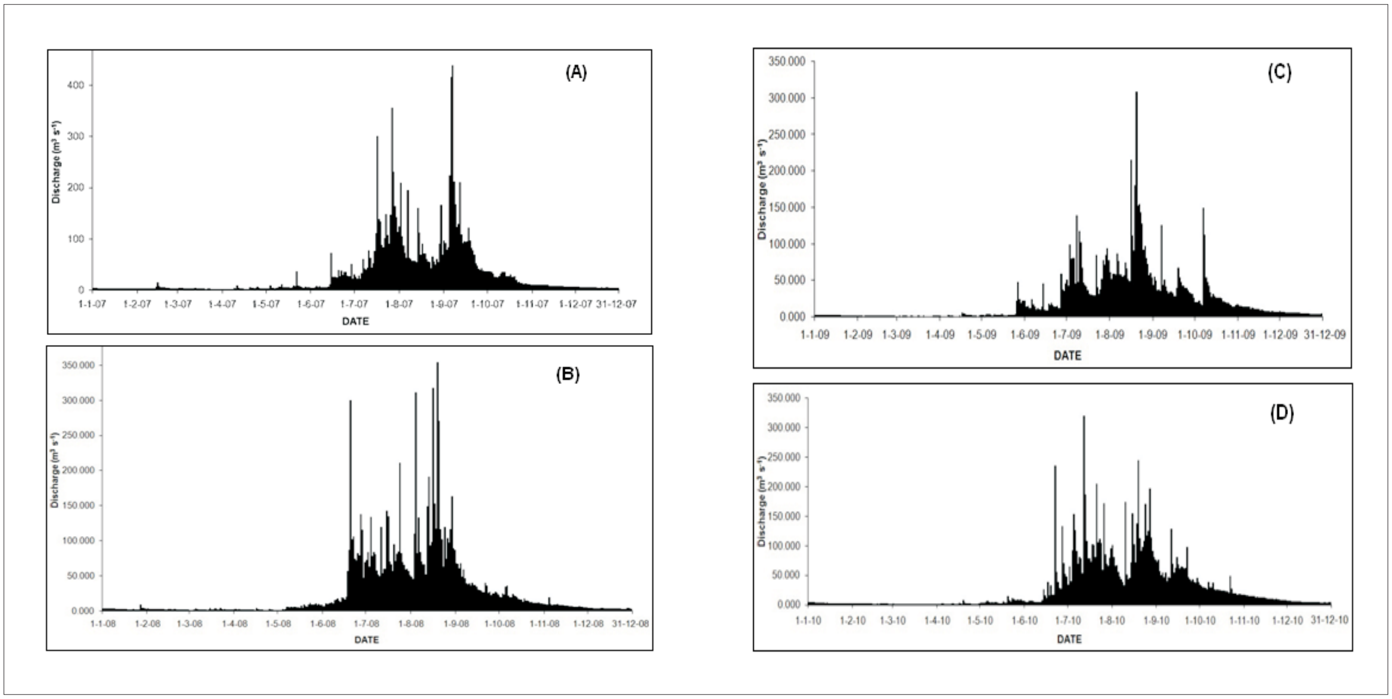


Fig. 7: Daily Discharge Hydrographs of Lower Balason R., 2007 - 2010.

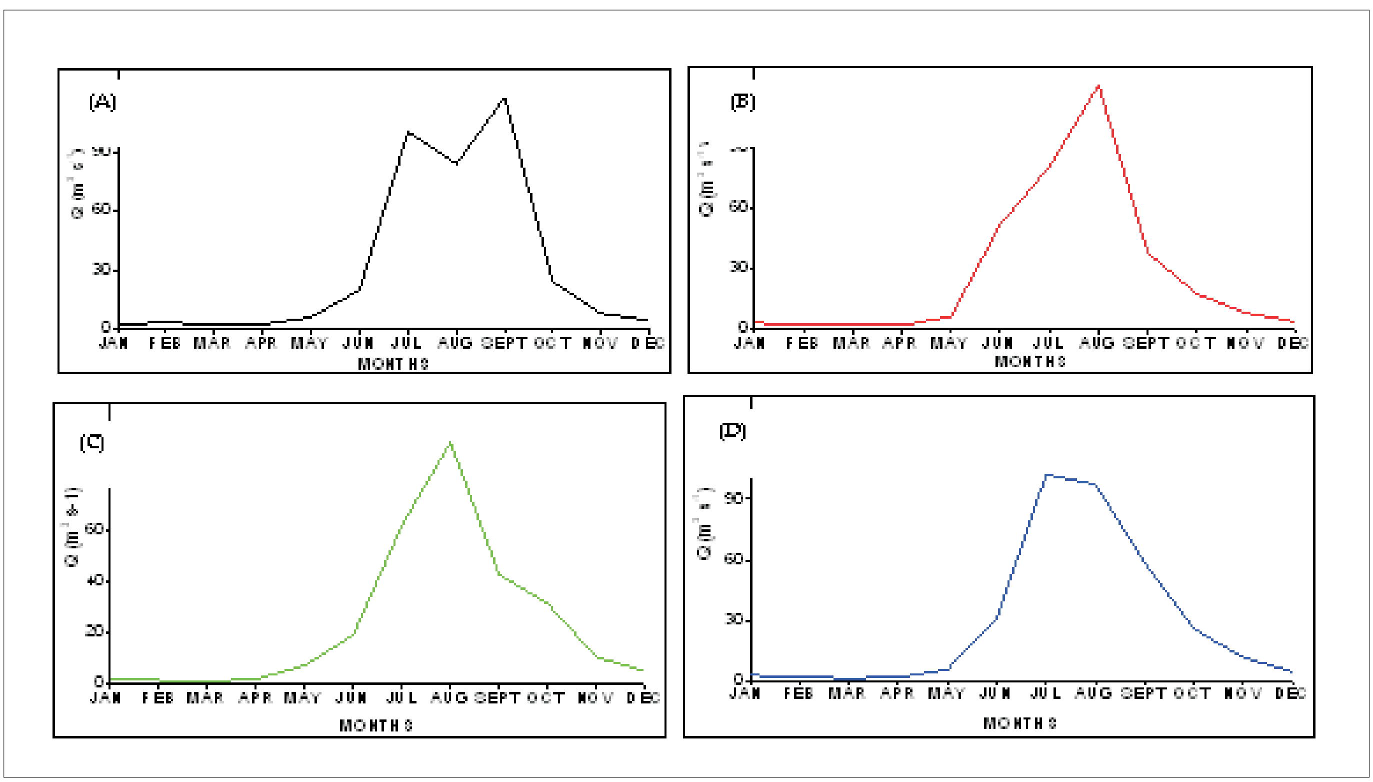


Fig. 8: Mean Monthly Discharge Hydrographs of the Lower Balason R., 2007 - 2010.

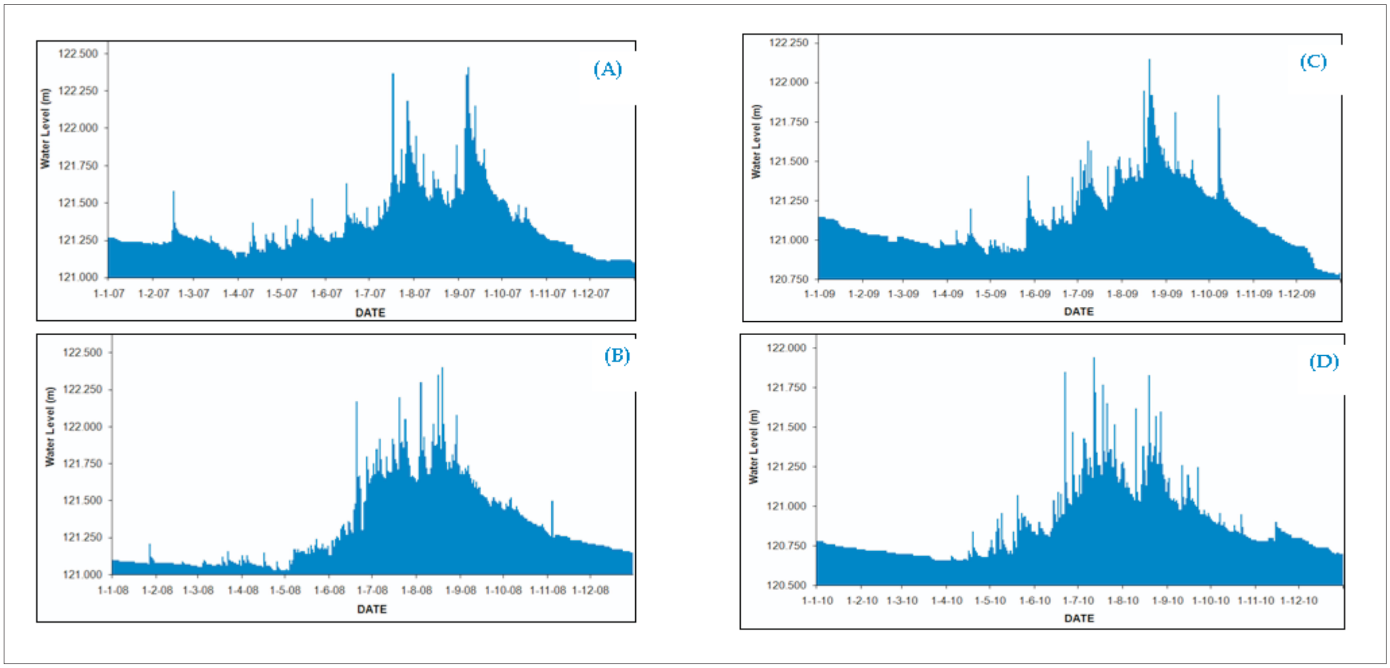


Fig. 9: Daily Water Level of the Lower Balason R., 2007 - 2010

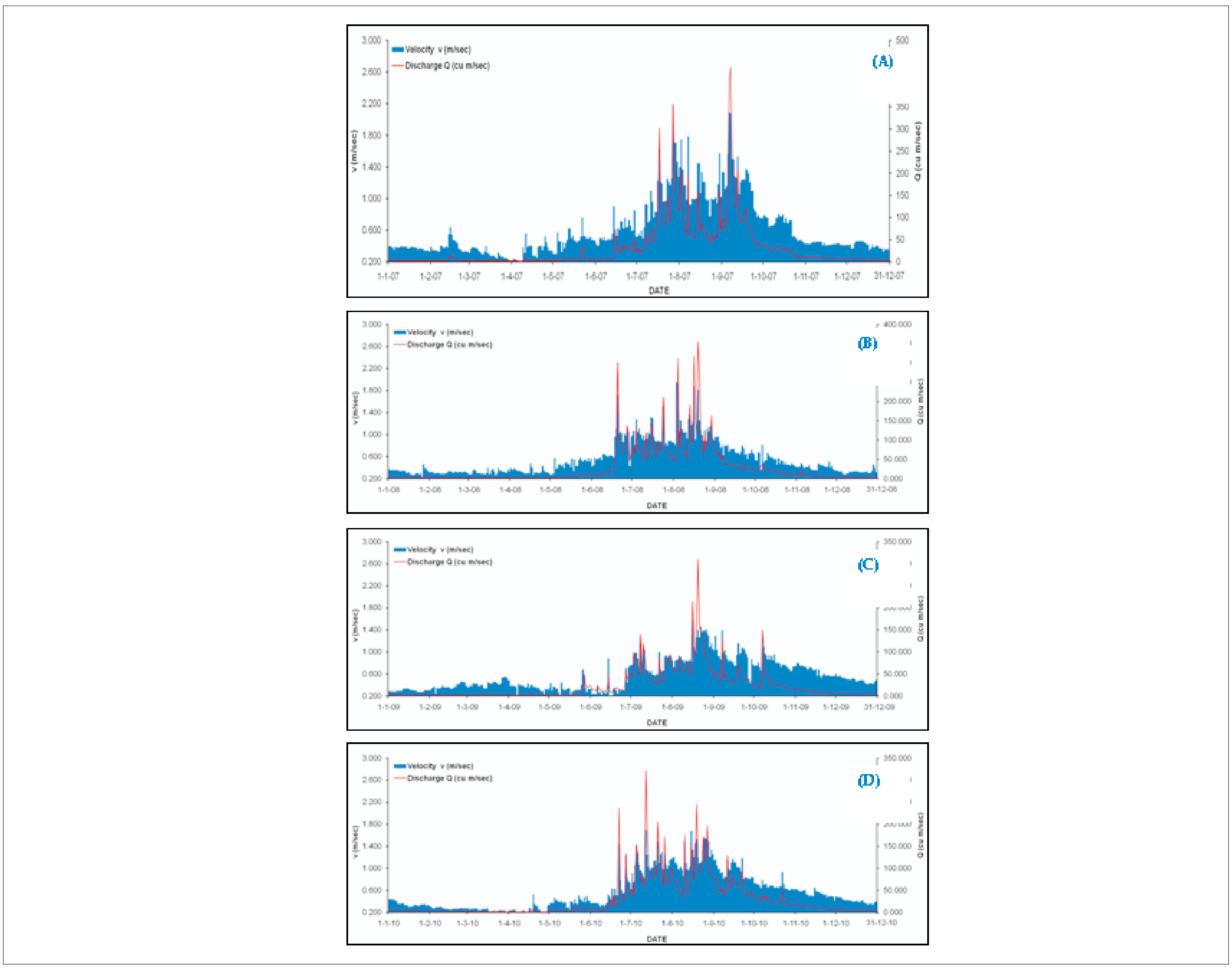


Fig. 10: Distribution of Daily Mean Velocity of the Lower Balason R., 2007 - 2010.

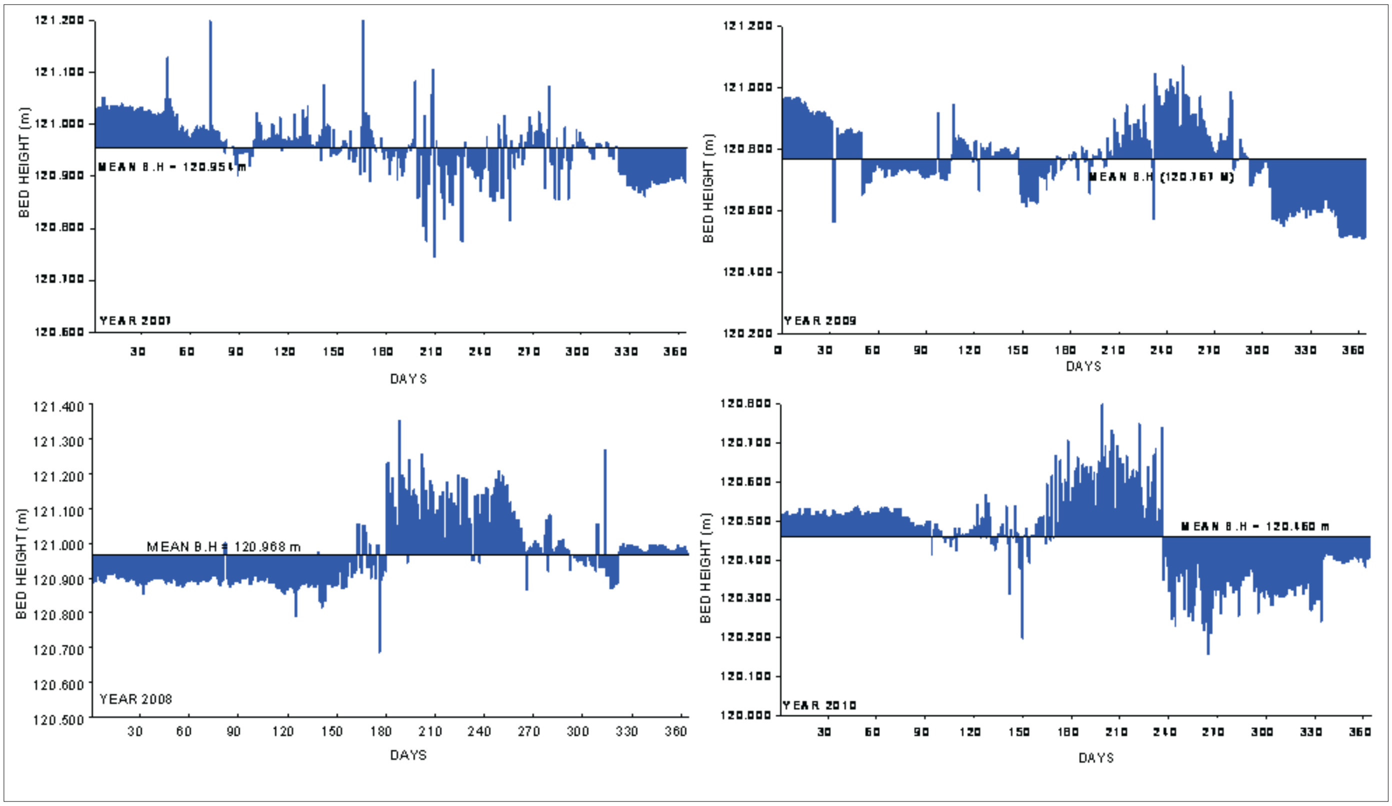


Fig. 11: Distribution of Daily Bed Height of the Lower Balason R., 2007 - 2010.

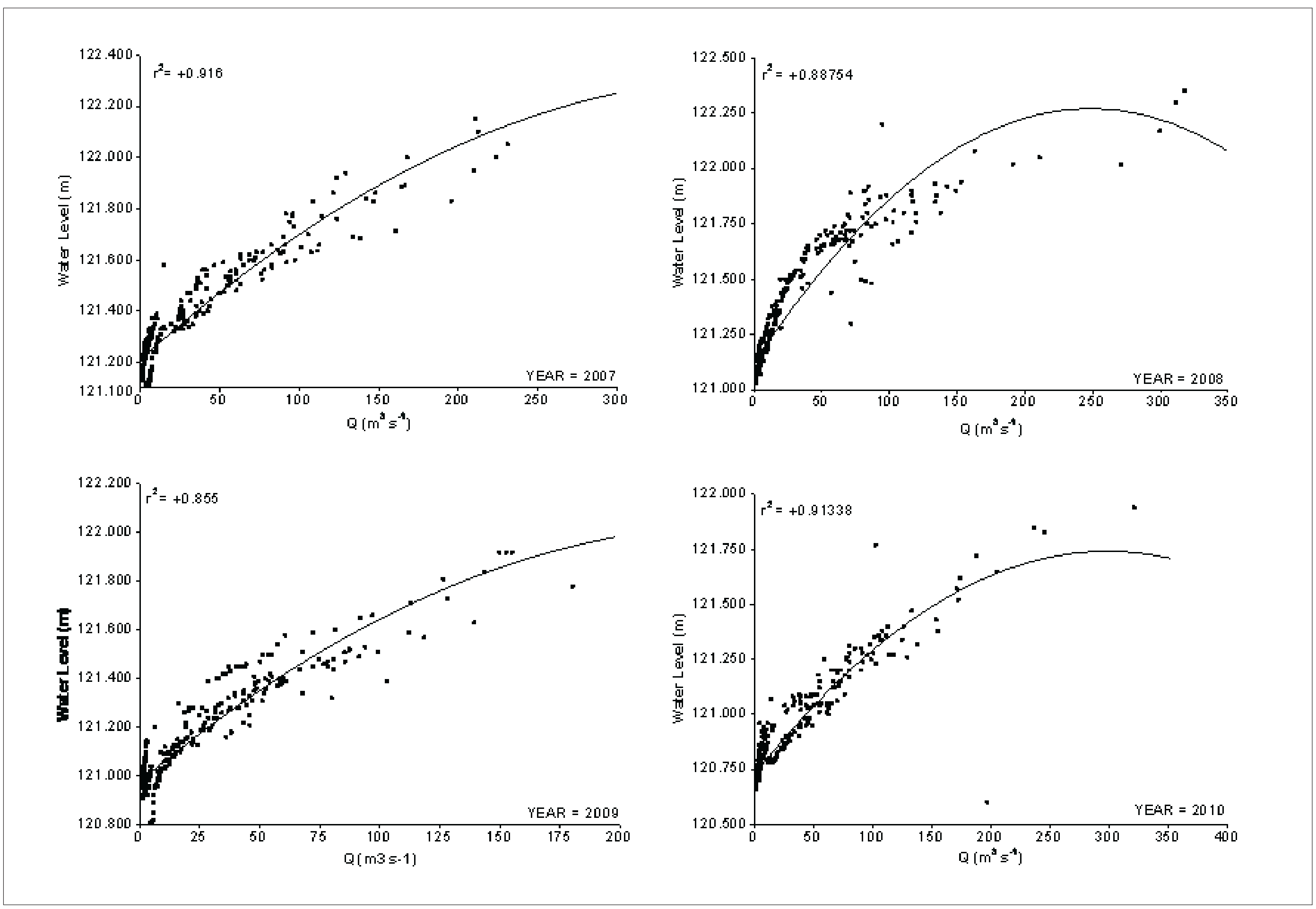


Fig. 12: Discharge - Water Level Rating Curves of the Lower Balason R., 2007 - 2010

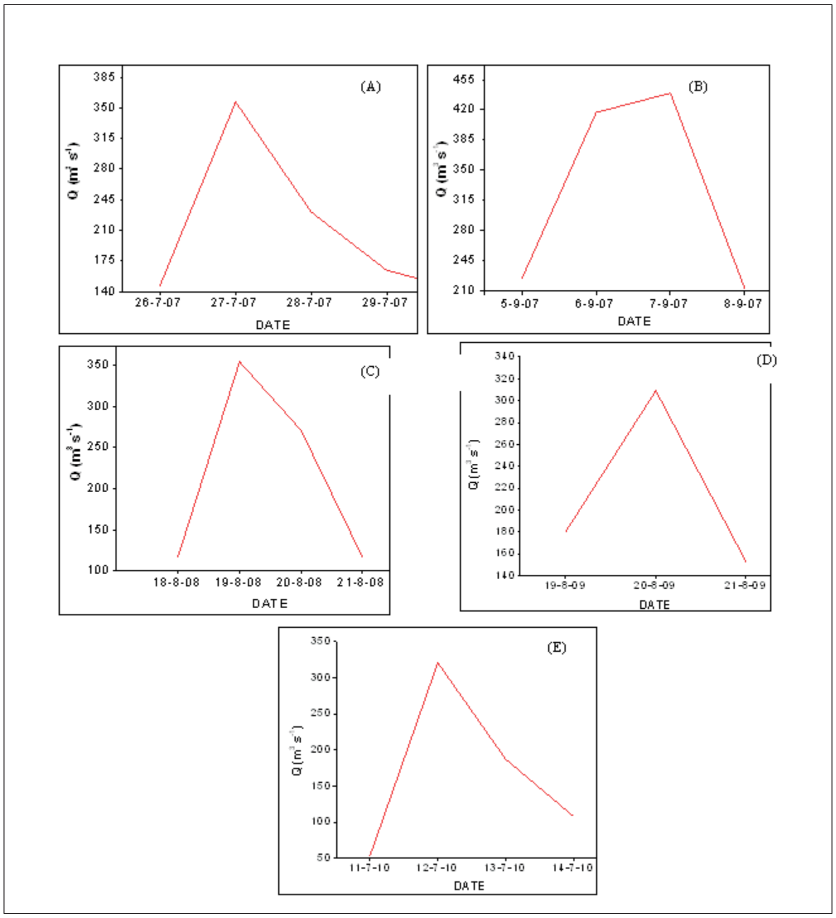
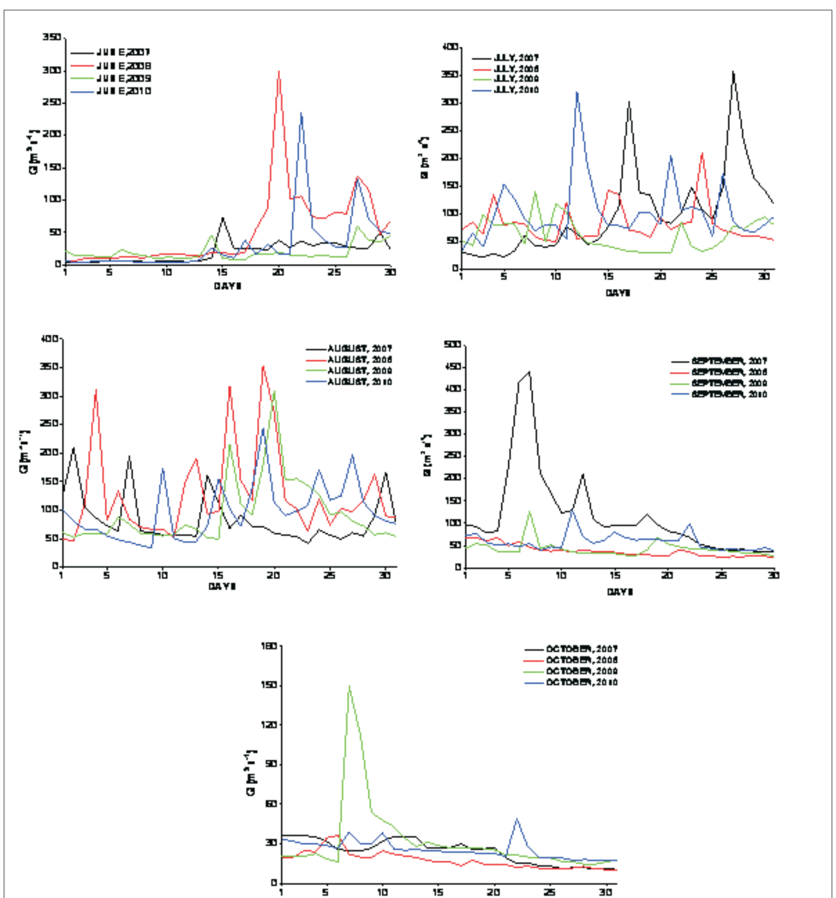


Fig. 13: Peak flow Hydrographs showing the Peak Discharge of the lower Balason R., 2007 - 2010.

Fig. 14: Monsoon Peak Discharge (June October) at CWC G&D Site, Matigara,1989 - 2010



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