Analysis of Channel Geometry and Sediment Transport in Palung and Chitlang Watersheds Using GIS

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ABSTRACT

Channel geometry and sediment transport have been analyzed using Geographic Information System and statistical methods in Palung and Chitlang sub-watershed of Kulekhani watershed located in the Central Hills of Nepal, which covers 87.9 sq. km of land surface.

The study demonstrates that the channel geometry and sediment transport changes abnormally in downstream distance for both rivers, though there are some controlling factors i.e. lithology, land use, climate, vegetation cover etc.

Key words: Channel geometry, discharge, GIS, landscape, River morphology

1. INTRODUCTION

Nepal has high-energy environment because of seasonal monsoon precipitation, weak and active geology, and high relief but there is absolute lack of information on the channel geometry and river behavior in the context of Nepal. There is absolute lack of study on the relationship between hydraulic variables, which is essential in designing hydraulic structure and development of water resources. Water resources development or management represents an attempt to meet an existing or potential demand for water or related resources, such as energy and food (Alford, 1991). The study of the channel behavior is one of the most significant aspects of the water resources management.

Mountain streams are similar in their dynamics and form to stream in other parts of the World. Present environment is characterized by one of the high relief, tectonic activity and intensive land use provides great volumes of both water and sediment to the channels but does not force them to behave in an abnormal way. It is evident that the process in change in channel hydraulics varies with time and space (Caine and Mool, 1980).

River channel is the most dynamic component of the landscape. Dramatic change in channel morphology and river behavior occurs as a result of upstream control due to the change in climate and land use, and downstream influences due to change in base level. The relief, lithology, structure, climate and hydrology as well as vegetation cover also controls the actual erosion rate in an area (Chorley et al, 1984).

River hydraulics is a comprehensive study of the behavior of flow in natural channels, which require the knowledge of hydrology, geomorphology, and sediment transportation etc (Chow, 1986).

Hydraulic Geometry is the analysis of the interdependence of hydraulic variables of stream channels, where, channel width, depth, slope, velocity, sediments or particle's size, channel roughness and stream discharges are studied (Leopold, 1993).

The sediment loads of Himalayan Rivers are amongst the highest in the World, resulting in problems such as the siltation of reservoirs, blockage of river channels, water pollution and degrading of aquatic environment. In a rain-fed river system, the major sources of sediments are considered to be landslides and intensively cultivated hill slopes but little is known about the characteristics of the sediments from these sources, movements into the river system or transport down to the rivers (Johnson and Collins, 1996)

The channel morphology and river behavior is controlled by the relief, lithology, geology, climate and land use and land cover. Relief is an index of potential energy and lithological variation determine the erodibility of the surface materials and infiltration capacity. The geology controls the pattern of drainage and the climate controls both the runoff and vegetation. River hydraulics is a comprehensive study of the behavior of flow in natural channels, which require the knowledge of hydrology, geomorphology, and sediment transportation etc.

Stream channels are among the most dynamic components of the landscape. Through them, energy and mass are transferred from one location to another. It is evident that the process in change in channel hydraulics varies with time and space. This study aims to evaluate the similarity and differences in different variables of channel geometry of Palung and Chitlang Rivers as compared to other areas. The general objective of this paper is to analyze the hydraulic geometry and sediment transport of river channels in terms of river morphology. The specific objectives are;

i. To study the relationship among the hydraulic variables of channels and variation of these variables from one place to another and from one river to another.

ii. To study the change in channel behavior in down stream direction and their controls.

iii. To discuss the type of sediments transported and deposited by streams in downstream direction.

2. THE STUDY AREA

The Palung and Chitlang River basins are located in southwest of Kathmandu Valley within the outer Himalayan Mountain. It covers the surface drainage area of 87.9 sq. km (65.1 sq. km of Palung River basin and 22.8 sq. km of Chitlang River basin). These are the sub-catchments of Kulekhani watershed. Geographically it is extended from 85^0 01' 15" East to 85^0 12' 30" East longitude and 27^0 35' 00" North to 27^0 41' 35" North latitude. Figure 1 shows the location map of study area.

The elevation of the watersheds ranges from 1510 m to 2540 m above mean sea level. The length of main channel of Palung River is 15.953 km and Chitlang River is 9.730 km. The drainage density of Palung watershed is 5.084 km/km^2 and Chitlang is 4.119 km/km^2, and drainage frequency is 14 No/km^2 in Palung and 8 No/km^2 in Chitlang basin.

The mean annual temperature of this area is 17.9^{0}C and an average annual precipitation is about 1635mm. The drainage area comprises different land use categories i.e. forest, cultivation, shrub land, settlement, grass land, sand and water bodies. Cultivated land constitutes the largest land use categories. In Palung basin, it covers 54 % of total basin area and forest area covers 34 % of the total basin area. In Chitlang basin forest area comprises the largest land use category; it covers 60 % of the total basin area. Similarly cultivated land covers 35.5 % of the total basin area.

According to slope categories, about 46 % of total basin area is under the moderate slope (5°-30°) and 35 % area is under steep slope (more than 30°) of the study area. Climatologically, 63% of total basin area is under warm temperate zone and 37% area is under cool temperate zone.

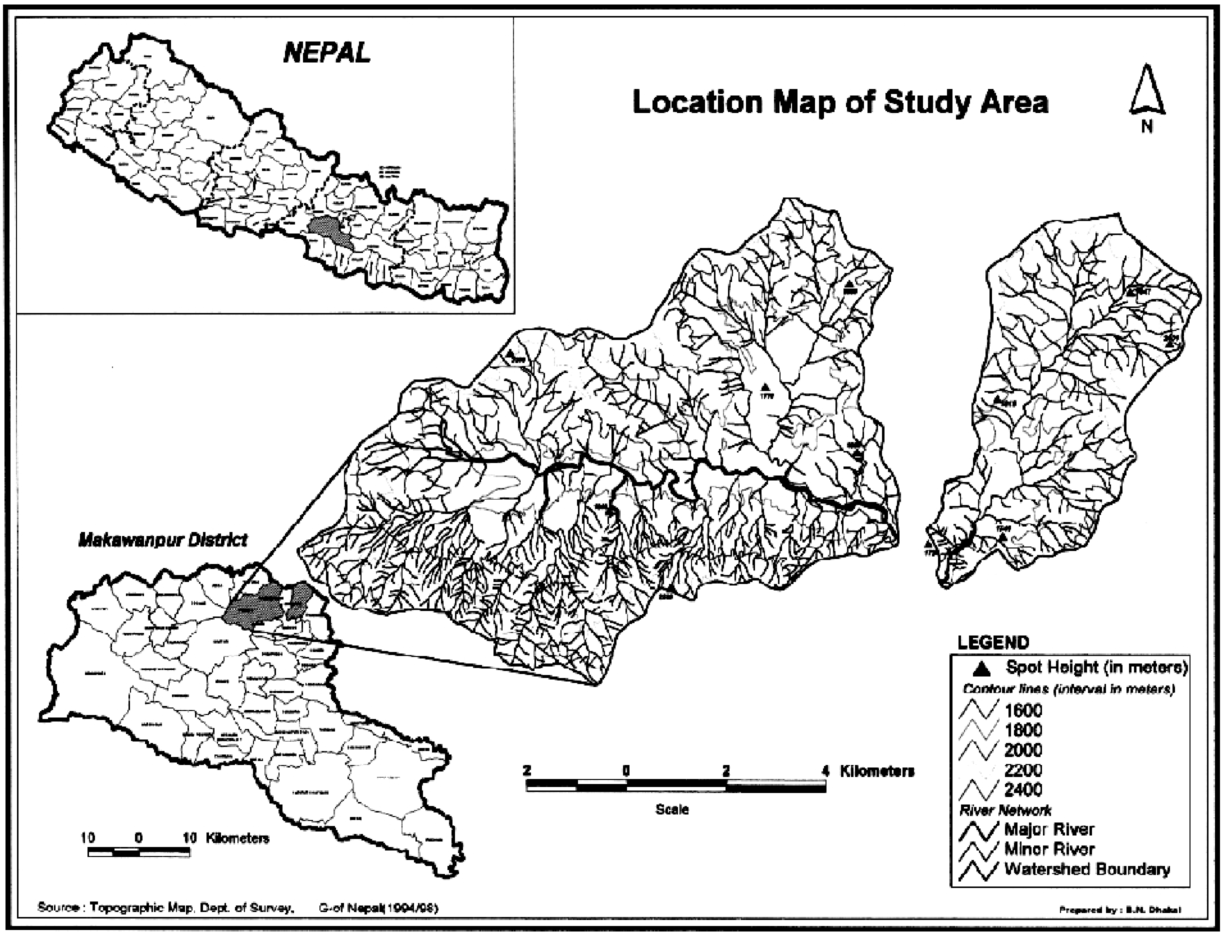

Figure 1: Location map of study area

3. METHODOLOGY

The collected data and information were analyzed by using different statistical formula, Arc INFO 3.5.1 and Arc View 3.2 Geographic Information System (GIS) software and other Computer Software programs. Beside these, cartographic and descriptive methods were also adopted.

For the flow hydraulics, some parameters tractive force or shear stress, stream power, stream power per unit area, Froude number and Reynolds numbers for both channels in each site have been calculated. The regression model was used to define the interrelationship of variables in downstream distance and stream slope with particles diameter. Correlation coefficients were tested at significance level (α) = 0.01. To define the shape factor, Sphericity (ψ), Flatness (Fw) and Elongation (Es) values were calculated based on three diameters of the sediment measured in each survey site along both channels. Similarly the regression was used to define the interrelationship of shape factors. The channel flow parameters and sediment parameters are calculated using the following equations.

i. *Channel Capacity* (C) = WxR
where W = width of channel (m)
R = mean depth (as hydraulic radius) (m)

ii. *Stream discharge* (Q) = 0.85 x A x v
where A = cross-sectional area (m^2)
v = mean velocity (m/sec)

iii. *Tractive share stress* (T_c) = γds
where γ = weight of water (1 Nm^{-3})
d = mean depth s = slope

iv. *Stream power* (W_c) = γdsv
where γ = tractive force
d = depth of water s = slope
v = mean velocity.

v. *Froude Number* (Fr) = $v/(gd)^{1/2}$ where
v = water velocity (ms^{-1})
g = gravitational constant (9.80665ms^{-2})
d = water depth (m)

vi. *Reynolds numbers* (Re) = du*/v
where d = particle size (cm)
u* = shear velocity $(\gamma/\rho)^{1/2}$
ρ = water density
v = Kinemetic viscocity
(0.013 cm^2 s^{-1})

vii. Sphericity (ψ) = (BC/A^2) 1/3

viii. Flatness (Fw) = (A + B)/2C

ix. Elongation (Es) = B/A
where A = Long axis length of sediment (mm)
B = Intermediate length of sediment (mm)
C = Short axis length of sediment (mm)

4. NATURE AND SOURCES OF DATA

This study is based on both primary and secondary sources of data. Primary data were collected from the field measurement. Field survey was carried out for 21 days during January-February, 1997 to obtain data on hydraulic variables. Channel width, depth, stream slope, water discharge and particle size were measured by using simple instruments and method like measuring tape, Abney label, scale, stopwatch, cockball etc. For the discharge measurement float method was adopted. Similarly, sediment deposited along the River course was sampled for the sediment survey, where 30 particles (boulders) with different size were taken randomly for measurement in each survey station. In this study, the diameter (a = longest, b = intermediate and c = shortest) of 20 particles deposited by recent flows at a station and of 10 particles that had moved in the past were measured. Measured values are presented on the table 1 and 2 under the column iv, v, vii, x and xi respectively. ARC INFO 3.5.1 and Arc View 3.2 GIS software was used to generate data on basin characteristics like stream distance, basin area, channel width and depth ratio, and map layers like geology, contour, rivers, land use, climate and slope. Statistical formula was applied to calculate channel capacity, velocity, tractive force, stream power, Froude number, Reynolds number and presented on table 1 and 2. Basic geometric properties of drainage system have been explored according to the devices formulated by Horton and Strahler (Strahler, 1968).

For the secondary information, Hydro-meteorological data were taken from the Climatological Records (1971-1993) of Nepal (DHM, 1997) and Stream Flow Records (1963-1978) of Nepal (DHM, 1997), published, by the Department of Hydrology and Meteorology, Government of Nepal.

Information on drainage network, relief and land use pattern were compiled from the topographic sheets prepared by Department of Survey, Government of Nepal (1994/98) at the scale of 1:25000. Geological map prepared by the Department of Mines and Geology (1984) at the scale of 1:250000 were used to identify geology of study area and Land Capability Map prepared by the Land Resources Mapping Project (LRMP, 1978/82) at the scale of 1:50000 were used to extract slope and climate zone of study area. Besides these, various documents and reports were collected and reviewed. These maps were digitized using GIS software and necessary data were generated.

The hydraulic geometry and hydraulics of flow in Palung and Chitlang Rivers are presented in Table 1 and 2 respectively. Table 3 presents morphometric parameters for both rivers.

Table 1: Hydraulic Geometry and Hydraulics of flow in Palung River.

Station	Distance (km)	Basin Area (km^2)	Channel Width W(m)	Mean Depth R(m)	W/R	Slope S(°)	Channel Capacity C(m^2)	Velocity V(m/sec)	Discharge Q(m^3/sec)	Particle Size F (cm)	Tractive Force (T_c)	Stream Power (W_c)	Froude Number (Fr)	Reynolds Number (Re)
A	2.091	2.713	1.2	0.1667	7.1986	0.675	0.2000	0.4400	0.0750	58	0.1127	0.0496	0.3438	15.130
B	3.072	4.711	1.9	0.1170	16.2393	0.760	0.2223	0.6000	0.1130	49	0.0889	0.0534	0.5601	11.252
C	3.405	4.948	2.6	0.1160	22.4138	1.027	0.3016	0.4615	0.1180	47	0.1191	0.0550	0.4327	12.604
D	3.982	5.287	4.5	0.1257	35.7995	0.424	0.5656	0.3478	0.1670	43	0.0534	0.0186	0.3129	7.721
E	4.579	5.552	3.7	0.1769	20.9158	0.991	0.6540	0.3051	0.1690	34	0.1754	0.0535	0.2316	11.065
F	4.892	5.716	3.8	0.1543	24.6273	0.824	0.5863	0.3143	0.1600	32	0.1269	0.0399	0.2558	8.858
G	5.113	5.794	4.0	0.1050	38.0952	0.781	0.4200	0.4348	0.1600	34	0.0820	0.0357	0.4285	7.565
H	5.486	8.889	8.0	0.0700	114.2857	1.257	0.5600	0.4400	0.2100	39	0.0880	0.0387	0.5312	8.990
I	6.025	17.01	8.5	0.0671	126.6766	1.600	0.5704	0.4795	0.2324	38	0.1072	0.0514	0.5915	9.668
J	6.578	17.16	6.8	0.1619	42.0012	0.869	1.1009	0.2408	0.2254	40	0.1408	0.0340	0.1905	11.663
K	6.901	18.34	4.9	0.1628	30.0983	1.402	0.7977	0.3792	0.2571	37	0.2285	0.0866	0.3000	13.743
L	7.242	18.53	5.8	0.0900	64.4444	1.271	0.5220	0.5524	0.2450	34	0.1144	0.0632	0.5880	8.936
M	7.494	19.43	5.0	0.1189	42.0521	0.754	0.5945	0.5263	0.2659	35	0.0897	0.0472	0.4872	8.145
N	7.801	19.65	7.0	0.1467	47.7164	1.213	1.0269	0.3307	0.2887	36	0.1783	0.0590	0.2754	11.812
O	8.296	20.12	5.8	0.1478	39.2422	0.991	0.8572	0.3673	0.2680	37	0.1467	0.0539	0.3049	11.012
P	8.898	20.57	6.3	0.0928	67.8879	0.942	0.5846	0.6479	0.3220	34	0.0876	0.0568	0.6784	7.819
Q	9.259	20.82	6.5	0.1017	63.9135	1.339	0.6612	0.5906	0.3320	35	0.1379	0.0814	0.5905	10.099
R	10.886	27.86	6.7	0.1273	52.6316	1.150	0.8529	0.6438	0.4670	37	0.1461	0.0941	0.5768	10.989
S	11.281	31.24	5.8	0.1406	41.2518	1.351	0.8155	0.6813	0.4720	32	0.1905	0.1298	0.5793	10.853
T	11.884	31.71	4.0	0.2925	13.6752	0.991	1.1700	0.4800	0.4800	30	0.2904	0.1394	0.2832	12.562
U	12.673	32.11	10.6	0.0914	115.9737	2.824	0.9688	0.6131	0.5049	33	0.2570	0.1576	0.6490	12.999
V	13.198	59.24	5.6	0.2513	22.2841	1.130	1.4070	0.5385	0.6439	46	0.2836	0.1527	0.3432	19.035
W	13.529	59.48	9.2	0.1886	48.7805	0.795	1.7350	0.3717	0.5481	54	0.1503	0.0559	0.2730	16.267
X	14.151	59.77	8.7	0.2038	42.6889	0.824	1.7726	0.3670	0.5530	36	0.1681	0.0617	0.2595	11.469
Y	14.391	59.92	6.2	0.1930	32.1244	0.839	1.1966	0.5349	0.5440	37	0.1619	0.0866	0.3880	11.569
Z	14.693	61.00	9.2	0.3059	30.0752	1.280	2.8143	0.2704	0.6468	28	0.3917	0.1059	0.1561	13.617
A'	15.244	64.88	9.7	0.1436	67.5487	1.235	1.3926	0.5800	0.6866	29	0.1778	0.1031	0.4881	9.502
B'	15.635	65.05	4.8	0.3538	13.5669	0.933	1.6980	0.4694	0.6770	19	0.3303	0.1550	0.2519	8.485
C'	15.953	65.10	4.5	0.2895	15.5440	0.713	1.3028	0.5800	0.6423	10	0.2068	0.1199	0.3439	3.534

Table 2: Hydraulic Geometry and Hydraulics of flow in Chitlang River.

Station	Distance (km)	Basin Area (km^2)	Channel Width W(m)	Mean Depth R(m)	W/R	Slope S(°)	Channel Capacity C(m^2)	Velocity V(m/sec)	Discharge Q(m^3/sec)	Particle Size F (cm)	Tractive Force (T_c)	Stream Power (W_c)	Froude Number (Fr)	Reynolds Number (Re)
A	1.886	1.625	1.2	0.0580	20.6897	0.445	0.070	0.4055	0.0240	31	0.0258	0.0105	0.5377	3.869
B	2.652	2.928	1.8	0.1280	14.0625	0.754	0.230	0.5263	0.1030	29	0.0965	0.0508	0.4698	7.000
C	3.146	7.040	2.4	0.1360	17.6471	0.941	0.326	0.5144	0.1427	30	0.1280	0.0658	0.4454	8.340
D	3.421	8.793	4.3	0.1110	38.7387	0.543	0.478	0.6103	0.2479	31	0.0603	0.0368	0.5850	5.915
E	3.563	9.108	3.3	0.1364	24.1934	0.877	0.450	0.6427	0.2459	33	0.1196	0.0767	0.5557	8.868
F	3.944	9.299	3.2	0.1625	19.6923	0.795	0.520	0.5882	0.2600	35	0.1292	0.0760	0.4649	9.776
G	4.236	11.426	4.5	0.1589	28.3197	0.869	0.715	0.4828	0.2934	39	0.1381	0.0667	0.3638	11.262
H	4.269	12.585	4.0	0.1750	22.8571	0.869	0.700	0.5659	0.3367	37	0.1521	0.0861	0.4320	11.213
I	4.802	12.832	3.3	0.1979	16.6751	0.795	0.653	0.5728	0.3179	36	0.1573	0.0901	0.4112	11.095
J	5.092	13.029	4.9	0.1260	38.8889	1.235	0.617	0.6593	0.3460	31	0.1556	0.1026	0.5931	9.502
K	5.316	13.181	4.8	0.1622	29.5931	0.727	0.779	0.4919	0.3260	33	0.1179	0.0580	0.3900	8.805
L	5.566	13.409	4.6	0.1778	25.8718	0.733	0.818	0.5093	0.3540	38	0.1303	0.0664	0.3857	10.659
M	5.839	13.528	5.5	0.1654	33.2527	0.625	0.910	0.4789	0.3700	45	0.1034	0.0495	0.3760	11.244
N	6.003	13.671	4.3	0.1525	28.1967	1.632	0.656	0.6836	0.3810	40	0.2489	0.1701	0.5590	15.507
O	6.242	14.823	4.2	0.1900	22.1053	0.854	0.798	0.5789	0.3900	41	0.1623	0.0940	0.3107	12.835
P	6.452	15.071	6.3	0.1075	58.6047	0.681	0.677	0.6261	0.3604	39	0.0732	0.0458	0.6098	8.199
Q	6.719	15.413	4.7	0.1379	34.0827	0.649	0.648	0.6667	0.3670	36	0.0895	0.0597	0.5733	8.369
R	6.896	18.287	3.9	0.2172	17.9558	1.213	0.847	0.5182	0.3700	34	0.2635	0.1365	0.3551	13.562
S	7.343	18.579	5.8	0.1661	34.9187	0.869	0.963	0.5150	0.4220	30	0.1443	0.0743	0.4035	8.855
T	7.536	18.706	4.8	0.2005	23.9402	0.625	0.962	0.5313	0.4350	24	0.1253	0.0666	0.3789	6.601
U	7.785	18.935	5.0	0.1994	25.0752	0.916	0.997	0.5339	0.4520	25	0.1827	0.0975	0.3818	8.303
V	8.024	19.020	5.6	0.1745	32.0917	0.839	0.977	0.5432	0.4510	28	0.1464	0.0795	0.4152	8.325
W	8.355	21.161	7.6	0.1179	64.4614	0.754	0.896	0.6124	0.4660	30	0.0889	0.0544	0.5695	6.950
X	9.130	22.447	5.8	0.1788	32.4385	1.072	1.037	0.5469	0.4820	25	0.1917	0.1048	0.4130	8.505
Y	9.340	22.593	4.7	0.2072	22.6834	1.017	0.974	0.5514	0.4560	27	0.2107	0.1162	0.3868	9.630
Z	9.730	22.800	4.8	0.2155	22.2738	0.824	1.034	0.5432	0.4776	17	0.1776	0.0965	0.3737	6.567

Source: Field survey, 1997 & Statistical calculation

Table 3: Morphometric parameters for two river basins.

Parameters	Palung River	Chitlang River
Total basin area (km^2)	65.100	22.800
Basin perimeter (km)	37.734	21.345
Main stream length (Km)	15.950	9.730
Basin length (km)	13.540	8.070
Basin width (km)	4.810	2.830
Basin slope (Sb)	0.467	0.493
Differences in elevation (m.)	1030	1015
Basin shape (Rf)	0.355	0.350
Relief ratio (Rr)	0.076	0.126
Mean stream slope (Sc)	0.065	0.104
Sinuosity Index (Si)	1.347	1.278
Drainage density (Dd)	5.084	4.119
Drainage frequency (Fd)	14.316	8.728
Elongation ratio (Re)	0.194	0.256
Circularity ratio (Rc)	0.575	0.629
Compactness coefficient (Cc)	1.319	1.261
Ruggedness number (HD)	5.240	4.180

Source: Field survey & Topographic Maps (*complied with application of GIS*)

5. RESULTS AND DISCUSSION

Relationship between stream slope and stream discharge for both rivers is obtained by the regression modeling as presented in following equations:

For Palung River, $S = 1.2469\ Q^{0.1757}$

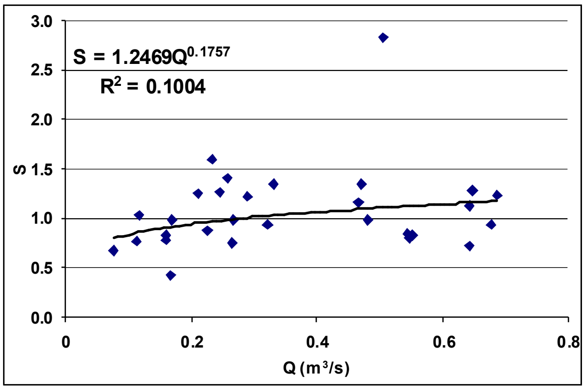

Figure 2a: Stream slope in Palung River

For Chitlang River, $S = 1.0345\ Q^{0.1923}$

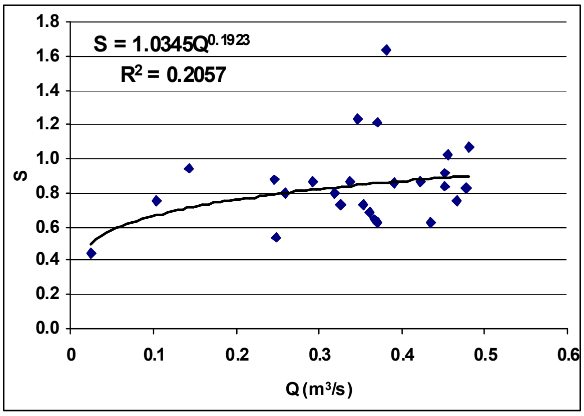

Figure 2b: Stream slope in Chitlang River

Water discharge increases in both channels in downstream direction; it ranges 0.075 m^3/sec to 0.687 m^3/sec along Palung River and 0.024 m^3/sec to 0.482 m^3/sec along Chitlang River. It is seen that the stream slope also increases in downstream direction for both rivers.

Similarly, relationships among the different parameters of flow hydraulics are the following.

Palung River

$T_c = 4.9177\ d^{-0.5961}$

$W_c = 4.9626\ d^{-0.7334}$

$V_c = 0.5873\ d^{-0.0441}$

Chitlang River

$T_c = 0.6074\ d^{-0.2712}$

$W_c = 0.2300\ d^{-0.2052}$

$V_c = 0.3777\ d^{-0.1159}$

Where, T_c = boulder shear stress
W_c = stream power
V_c = mean velocity

Particle's size decreases in downstream direction along both channels but there are abnormal changes in particle size in some sections. Intermediate diameter ranges 10 cm to 58 cm in Palung River and 17 to 31 cm in Chitlang River.

Figure 3a indicates that there is abnormal change in particle size near the 5th and 13th km distance from origin along the Palung River. Figure 3b indicates that there is abnormal change in particle size near the 3rd, 5th and 7th km distance from origin along the Chitlang River in downstream direction due to local obstacle of landslide and irrigational dam construction. Figure 4 represents the changing scenario of particle sizes along the main channels in downstream direction.

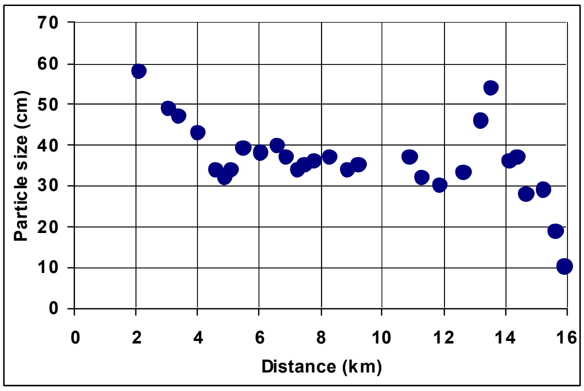

Figure 3a: Particle size in Palung River

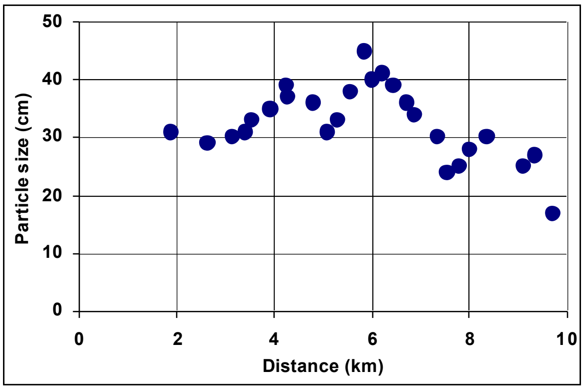

Figure 3b: Particle size in Chitlang River

The channel size changes in downstream direction in the both channels, where the width along Palung River ranges from 1.2 m to 10.6 m and mean depth ranges from 0.06 m to 0.35 m. The width along Chitlang River ranges from 1.2 m to 5.3 m and mean depth ranges from 0.05 m to 0.22 m. Capacity (cross-sectional area) in Palung River ranges from 0.2 m^2 to 2.8 m^2 and in Chitlang River it ranges from 0.07 m^2 to 1.04 m^2. Figure 5 shows the Channel cross-section for both rivers and figure 6 shows the hypsometric curve for both rivers.

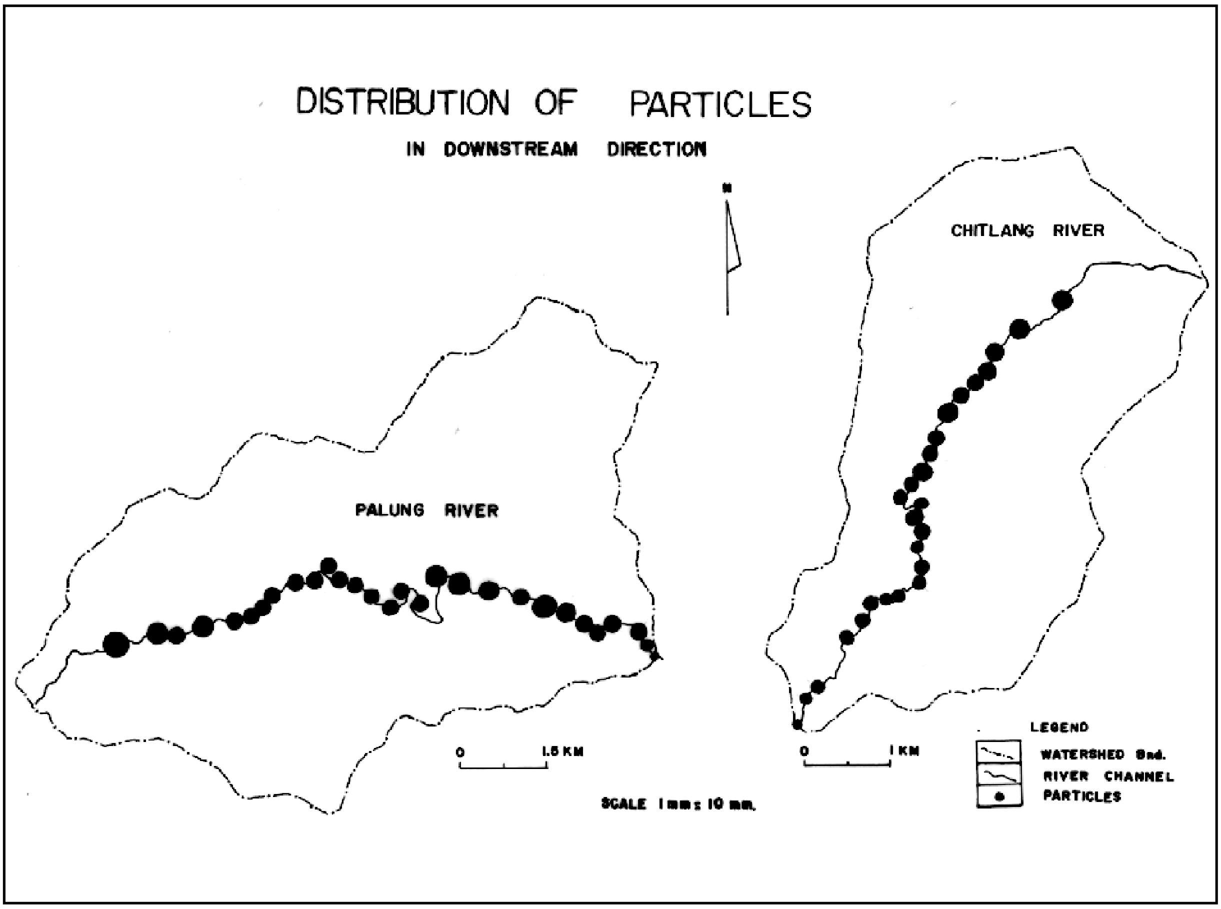

Figure 4: Distribution of particles in downstream direction

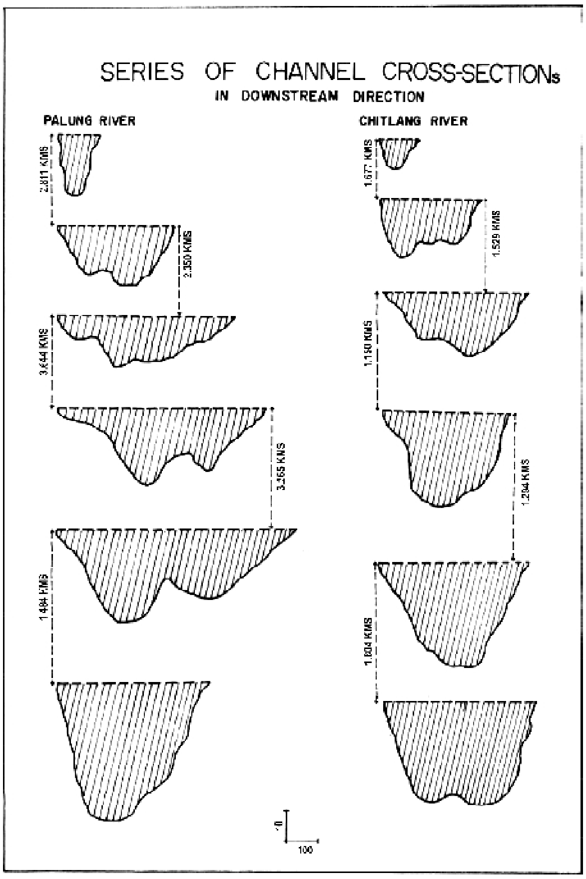

Figure 5: Series of channel cross-sections in downstream direction

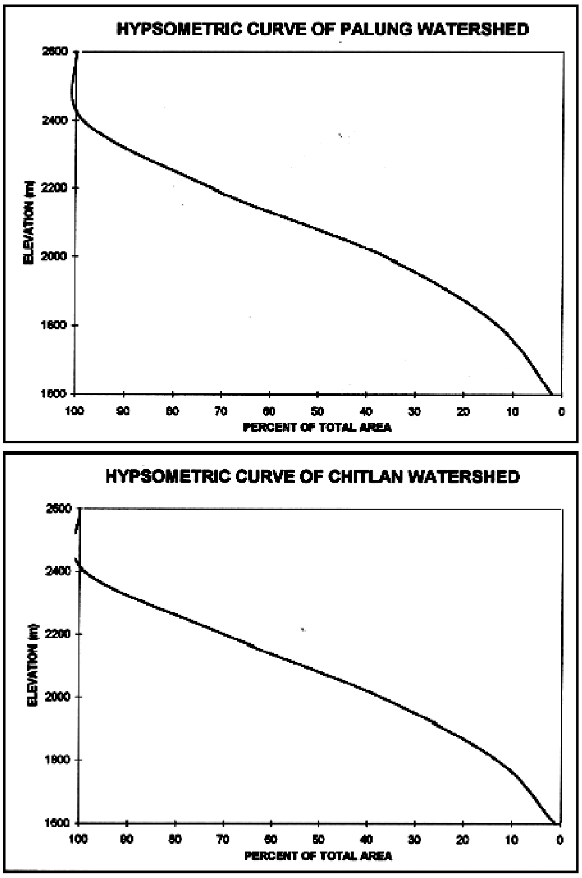

Figure 6: Hypsometric curve of Palung and Chitlang Rivers.

6. CONCLUSION

Though there are abnormal changes in different parameters such as stream slope and particle size along downstream distance, water discharge is increasing with increasing in downstream distance of channel and particle's size is decreasing with increasing downstream distances. Hence, it is concluded that these streams are similar in their dynamics and form to streams in other parts of the World. Further, it is noted that present environment is characterized by one of the high relief, tectonic activity and intensive land use. This provides a great volume of both water and sediment to the channels which forced them to behave in an abnormal way. Some of the physical controls i.e. geological structure on channel bed and landslide contribute large boulder to the channels which caused irregular change in particular size. Other human factors also play important role in creating irregularities in channel hydraulics and water and sediment discharge. These include division of water for irrigation and water mills, abstraction of gravels and rocks from the river bed and other river training activities in this area.

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