

STUDY ON WATERSHED ANALYSIS AND SEDIMENT REGIME IN THE SIWALIK REGION OF NEPAL

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ABSTRACT:

Wide spread damage due to floods is one of the very common water induced natural disasters in Nepal that account for heavy losses during the monsoon period every year. Perennial rivers that flow through Siwalik area transport heavy sediments loads than rivers located in other areas during rainy season due to very fragile geology of the Siwaliks. Investigating the sediment production and transportation regime in the Siwalik regions of Nepal, drainage analysis was conducted. Satellite data was used in identifying the changes of land coverage, floodplain and river channels. Reasons for these changes were examined with field observation and aerial photograph interpretation. These series of studies evidently showed the crucial causes of the massive sediment production were due to intense erosion that led by the fragile geology, intense rainfall, lack of vegetative coverage, exploitation of lands due to human activities and root morphologies of the indigenous vegetation.

1. INTRODUCTION

Nepal is a mountainous country; approximately 86 percent of the area is characterized by steep hills and mountains. Elevation ranges from 70 m to 8849 m within a radius of less than 200 km. The country comprises five distinct physiographic regions distributing E-W belt form north to south: the High Himalayas (23.7% of the total area), the High Mountains (19.7 %), the Middle Mountains (29.5 %), the Siwalik (12.7 %) and the Terai (14.4 %). All the regions are stretched in a E-W direction and arranged collaterally form north to south.

The southern belt of the Terai region, the Siwalik region, is composed of north dipping interbedded sandstone, silt stone, shale and weakly/unconsolidated conglomerates. It has a subtropical climate and dominated by Sal (*Shorea robusta*) forests. The soils (*red laterite* soil) are highly vulnerable to water erosion, and flash floods occur frequently in the low-lying areas during monsoon, causing massive sediment production.

Due to the clearance of a total of 103,968 ha of forest in Siwalik hills and Terai plains under the government's resettlement programmes from the 1950s to the mid. 1980s, and an introduction of modern healthcare and a malaria suppression programmes, unpredictable growth of population, which led to increasing demand for fuelwood, timber, fodder and agricultural land (Awasthi *et al.*, 2002). These factors caused the decline of the forest cover, accelerating erosion process and producing huge mass of sediments from the Siwalik Hills resulting severe flood-induced deterioration on the nation's exclusive granular plains, the Terai. Controlling high sediment production in the Siwaliks and protecting cultivable lands in Terai region from floods are the most prominent concerns to Nepal.

While implementing sediment control measures, understanding the characteristics of a watershed is inevitable. The main objective of this study is to illustrate the characteristics of sediment regime of Thadokhola watershed, one of the typical watersheds of the Siwalik region by analysing its

geomorphometric parameters incorporated with land-use/land-cover changes within the watershed.

2. MATERIALS AND METHOD

2.1 Study Area

The study area, Thadokhola watershed, derives from its river Thadokhola, one of the tributary of Rapti River, lies in the central part of the Siwalik regions. Thadokhola river could be considered as wadji, as water flow in the upper reach is visible only during the intense rainfall period of monsoon (wet season). Water is only visible at downstream (near the confluence with Rapti River) during the dry season. The channel bed is covered by highly porous materials: sand, silts, gravels/cobbles and boulders. Occurrences of frequent floods at downstream are very common during the high rainfall period. The southern (upstream) border of the Thadokhola watershed adjoins with the Parsa Wildlife Reserve. The slender-shaped (form factor is 0.14) watershed has total area of 14.10 km² and elevation varies from 400 to 740 m (Figure 1). The width of Thadokhola river bed varies from 50 to 210 m and average channel gradient is less than 3 degrees.

Thadokhola watershed is a remote hilly area having neither access to roads nor infrastructures. People residing in the watershed rely fully or partially on traditional agriculture. Large areas of cultivated lands (mostly rice fields) and vegetable farms are located near and around the settlements (mud and brick houses with thatched roof). Settlements are mostly concentrated at middle to lower part of the watershed.

Surface erosions on cultivated lands, bank cuttings, aggradations of channel bed, formations of small fans and talus near/around river trunks, and expansion of floodplains are prevalent over the watershed. Few gabions (0.5m width, 1.0m in height), set up along the river banks are the one and only sediment control and flood protection measures existing in the

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site. Excluding gabions, ditches, installed mainly for irrigation purposes, are seen at the site. The completely/partially damaged gabions and ditches at the site display the impacts of flood events occurring in the monsoon.

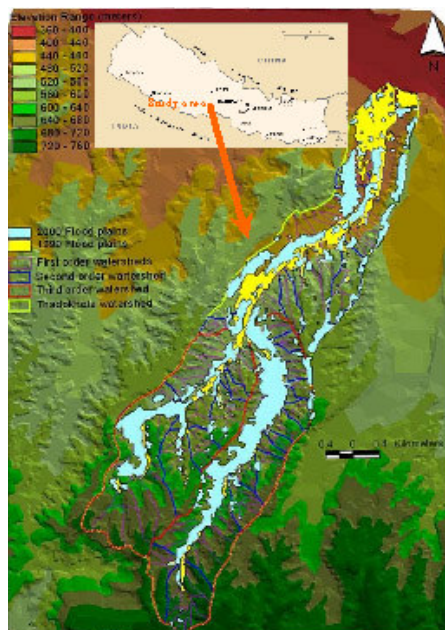


Figure 1. Location of Study Area

2.1 Geomorphometric Parameters and Land Use/Land Cover Classification

In this study 1988 dated Landsat 5 TM and three Landsat 7 TM images taken 1999, 2000 and 2003 were used to investigate landuse/land cover changes in the study area. The images were geo-referenced and ortho-rectified, using topographic map, aerial photograph and field observations. A hierarchical classification of four Landuse/land cover classes within the watershed was performed by unsupervised multitemporal classification by means of the ISODATA (Iterative Self Organizing Data Analysis Technique) algorithm in Erdas Imaging 8.4 environment. ISODATA, a clustering method, classify pixels iteratively, redefine the criteria for each class, and classifies again, so that the spectral distance pattern in the data gradually emerge. The convergence threshold was set as 0.95 pixels and the number of iteration was 24. Four land cover types, class 1: mix of cultivated land and settlements; class 2: mix of sparse forest, vegetable farms and settlements; class 3: mix of flood plains, eroded and depleted lands; and class 4: dense forest, were classified. Where, classes 1, 2, 3 and 4 will be refer as cultivation land, sparse forest, floodplains/eroded lands and dense forest, respectively. An example of image classification for the year 2003 is given in Figure 2.

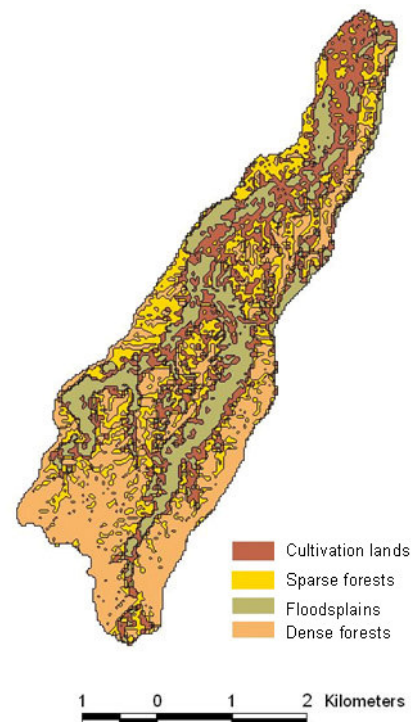


Figure 2. Classification Results of Image taken in 2003

Digital data for deriving geomorphometric parameters: drainage area, stream length, altitude difference, numbers of streams, drainage density and bifurcation ratio, were prepared from topographical map of scale 1:25,000 (Figure 3). Sub-watersheds were delineated on the topographical map according to Strahler branch ordering method. Delineated topographical map was then scanned, digitized and produced DXF (Digital Exchange) files by AutoCAD 2000 software, and performed spatial analysis in ArcView 3.1 desktop environment. For the generation of DEM, contour lines were scanned from 1:25,000 scale topographical map having contour interval of 20 m. Altitude differences, watershed areas and stream lengths within the watersheds were measured directly from the topographic map. Digital planimeter (X-PLAN 360) was used for area and stream length measurement. Areas of the watershed were also calculated from the GIS software (ArcView). The difference in values obtained from manual and automated measurements are shown in Table 1. The total difference in whole Thadokhola watershed is approx. 0.10 km², whereas, total differences in first, second and third watersheds are 0.03, 0.07 and 0.11 km², respectively. Here, all the geomorphometric parameters: watershed area, stream frequency and drainage density those implicated in watershed areas, were calculated from the automated values.

The difference values in these two measurements are considered due to the errors exerted during. These are; re-delineation, re-alignment and re-arrangement of watersheds while interpreting and digitizing into the AutoCAD and ArcView environment and errors governed by the thickness of watershed boundaries drawn on topographic map (watershed boundaries were delineated by 0.3 to 0.5 mm ball pens). From this, it could be mentioned that doing spatial measurement on map, especially in measuring comparatively small watershed area of less than 1 km² (1:25,000 scale of standard topographic map) needs very fine and precise workmanship. High possibilities of occurring human errors, difficulties in re-checking or verifying outcomes,

and inefficiency in measuring several hundreds of small sub-watersheds are considered to be the main delimits of manual measurements.

Additionally, manually delineated watershed was compared with an automated one. An automated delineation of the watershed was performed by means one of the widely used scripts in ArcView. The comparison of an automated and manually delineated whole Thadokhola watershed is given in Figure 4. An automated delineation for the whole watershed (14 km²) is very similar to that of manually produced watershed. Where brown color represents the automated Thadokhola watershed and Opaque represents the manually produced Thadokhola watershed. Unfortunately, for the small sub-watersheds (lower than TOWs) having an area approx. less than 0.1 km², the script did not found worthy. The automated small sub-watersheds were not resembled with manually produced one. The script might not be compatible for the small watersheds. Further study on this using several such scripts need to be experimented.

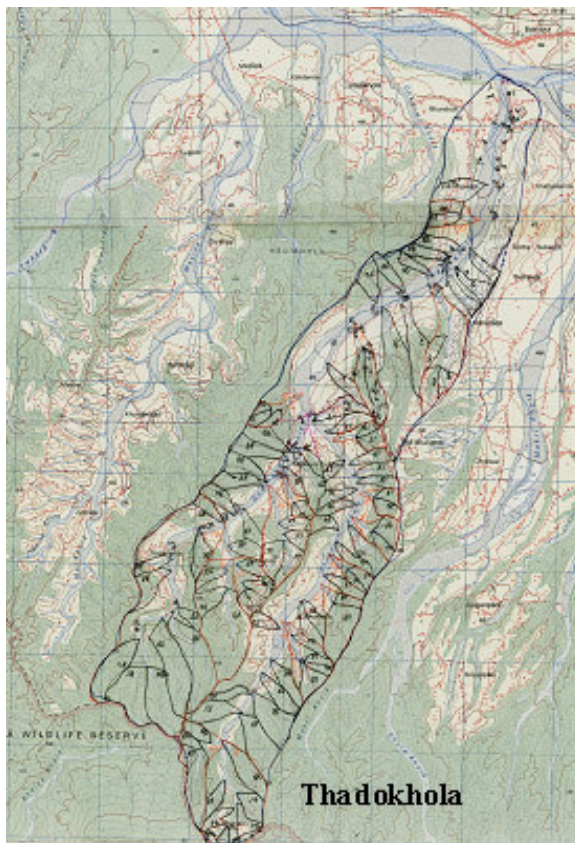


Figure 3. Manual Sub-water Delineation on Topographical Map

3. RESULTS AND DISCUSSION

3.1 Geomorphometric Parameters

Thadokhola watershed is a four order watershed, comprises 101 first order (total area 7.16 km²), 17 second order (5.96 sq.km) and 2 third order watersheds (9.14 km²). First order watersheds (FOW) attribute approx. 51 %, 60% and 66% of its total area to whole, third order watershed (TOW) and second order

watersheds (SOW), respectively. Similarly, SOWs attributes 42% of total area to whole and 56 % to the TOWs, whereas, only 65% of total area of TOWs attribute to the whole Thadokhola watershed.

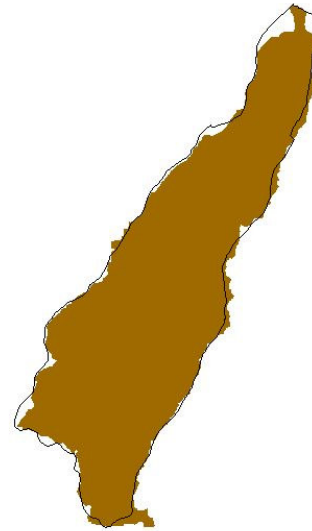


Figure 4. Comparison of Automated and Manually Delineated Watersheds

	Watersheds				Thadokola Total
		First Order	Second Order	Third Order	
Area calculated in ArcView	Average	0,07	0,35	4,57	14,10
	Min	0,01	0,07	4,57	
	Max.	0,47	2,16	4,57	
	St. Dev.	0,07	0,49	0,00	
	Total	7,16	5,96	9,14	
Area Measured by Planimeter (X-PLAN 360)	Average	0,07	0,35	4,52	14,00
	Min	0,01	0,07	4,51	
	Max.	0,44	2,12	4,52	
	St. Dev.	0,07	0,48	0,00	
	Total	7,19	5,89	9,03	

Table 1. Comparisons on Automated and Manual Measurements of Watershed Area

In comparing to other watersheds in Siwalik region, Thadokhola watershed has properties of larger sub-watershed area, longer stream length, higher drainage density and gentle stream slope (Shrestha, 2001). High drainage density suggests the occurrence of high erosion rates in lower order watersheds. Larger area, longer stream length and gentle slope gradient of higher order watersheds infer the mitigation of sediment transportation. This presumption was verified by field survey carried out during the dry season of 2000. Sediments from lower order watersheds were deposited at/near the branch points of higher order watersheds forming small fans and talus. Thus, if secondary sediment transportation from the higher order watersheds is controlled, volume of downstream sediment supply will be lessened significantly.

Stream orders	First Order	Second Order	Third Order	Fourth Order
Numbers	101,0	17,0	2,0	1,0
Average stream length (m)	453,0	1899,5	24019,9	65505,3
Average area (km ²)	0,1	0,3	4,6	14,1
Average altitude difference (m)	87,9	113,5	260,0	360,0
Average drainage density (km/km ²)	7,8	6,8		4,7
Stream frequency (nos. stream/km ²)	14,1	2,9	0,2	0,1
Bifurcation ratio	5,9	8,5	2,0	-

Table 2. Statistical Data on Geomorphometric Parameters of Thadokhola Watershed

3.2 Landuse/landcover Classification

The landuse/landcover change from 1988 to 2003 within the study area is shown in Figures 5 to 8. In general, areas under floodplains/eroded lands have increased whereas those under rain-fed cultivation land and sparse forest have decreased within the study area. The expansion of floodplains/eroded lands and dense forest from 1988 to 2003 were 0.8 and 0.9 km², respectively (Figure 5). The increase in dense forest area mostly due to implementation of hill community forestry, integrated soil conservation and watershed management programme and an operational forest management plans after the government intervention for integrated landuse and natural resources management.

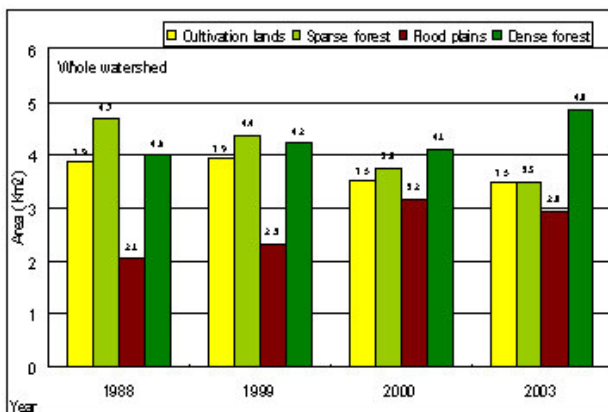


Figure 5. Changes in Landuse/landcover in Whole Watershed

Landuse/landcover has undergone significant alteration and transformation in 2000. Specifically increase in floodplains/eroded lands observed between 1999 and 2000. There is a 143 days difference between the dates of the images taken 1999 and 2000 (November 4, 1999 and February 16, 2000). This is highly significant in compare to the changes occurred between 1988 and 1999. It is assumed that an intense rainfall might have occurred during September, 1999 to March,

2000, and depleted cultivation lands and sparse forest floors resulting increase in class 3 areas (rainfall data is unavailable). This period accords with post harvest and plant dormancy time, thus might have enhanced erosions.

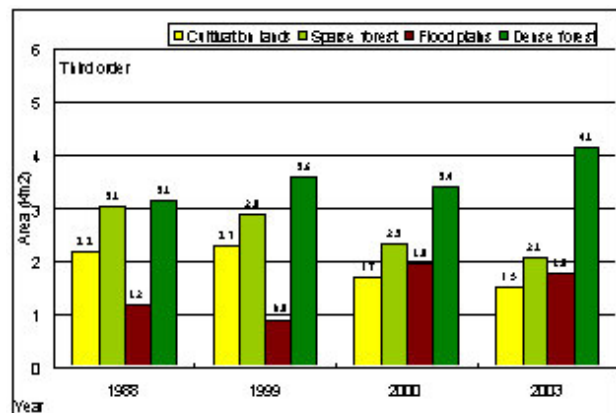


Figure 6. Changes in Landuse/landcover at Third Order Watershed

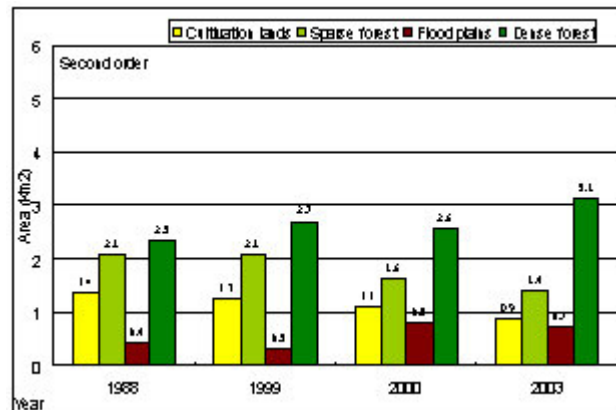


Figure 7. Changes in Landuse/landcover at Second Order Watershed

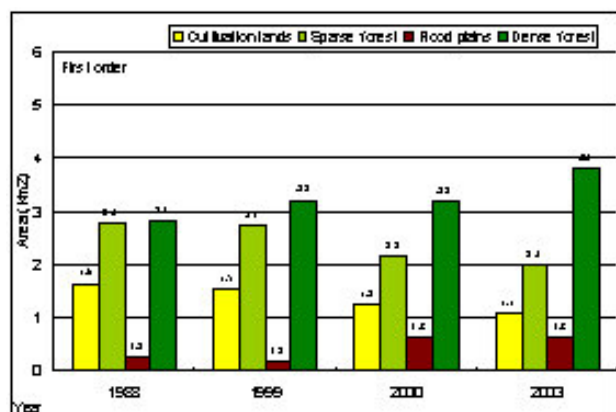


Figure 8. Changes in landuse/landcover at first order watershed

In the year 2003, cover classes 2 and 3 were decreased and cover class 4 was increased. Cover class 1, in whole watershed remain unchanged, whereas, it was observed decreasing in all sub-watersheds. This reflects the occurrence of abandonment of

rained cultivation lands and settlements in the area. The reasons for the abandonment of agricultural lands might be due to: 1) migration of dwellers; 2) low production from the lands; and 3) shifting cultivation. It is very common practice seen in Nepal (Awasthi *et al.*, 2002).

Similarly, in 1999, all the landuse/landcover classes excluding class 3 had increased by 0.2 km² in whole watershed, whereas, class 3 in TOWs, SOWs and FOWs had decreased by 0.3, 0.1 and 0.1 km², respectively. This is because of the significant expansion of floodplains near the confluence with Rapti River, which does not attribute/share to any sub-watershed (Figure 1). The percentage areas of class 3 contributed from FOWs, SOWs and TOWs to whole watershed, are 6.7 %, 8.6 % and 37%, respectively, in 1988; and 10.8%, 10.5% and 40%, respectively, in 2003. These results suggest the development and expansion of landuse/landcover class 3 areas (mostly floodplains) are predominantly larger in higher order watersheds, which cover main channel and tributaries. Two third order watersheds which are derived from two main tributaries of Thadokhola River, Bhundrun and Goganghari, occupies whole channel area of these two tributaries. Thus, it is obvious that TOWs comprise larger area of floodplains. In contrary to that SOWs covers only few portions of these two tributaries since SOWs contribute only 56% of its total area to TOWs, thus have less floodplain areas in compare to TOWs.

The dynamics of expansion and contraction landuse/landcover class 3 are mostly due to the internal trading among the landuse classes: cultivation lands, sparse forest and floodplains. Specifically, expansion and development of new floodplains are observed in the rice fields that were cultivated along the river banks, and some parts of sparse forests.

Development of floodplains/eroded lands is hardly seen on dense forests. The reasons for expansion of landuse/landcover class 3 are mainly because of soil erosions taken place on both cultivated lands and on sparse forest floors. The red soil of the study area is very susceptible to rain and wind erosion. From the field survey, it was confirmed that the sparse forest floors are very poorly vegetated. Collection of litters for composts, fuels and fodders, and damage to understudy vegetation due to grazing, have impaired the surface of forest floor from resisting erosive forces exerted during rainy period. Furthermore, the root morphology of sal (*Shorea robusta*), which is the main component of forest in the study area, has extremely low effects in protecting surface erosion. Sal possess stake-like main root which is very thick and strong enough to penetrate hardpans of red soils (*Laterite soil*) but, it has enormously few lateral and fine/hair roots which are very useful in protecting surface erosions (Shrestha *et al.*, 2001).

4. CONCLUSION

The geomorphometric analyses revealed that the watersheds are susceptible to surface erosion, but inert to sediment transportation. Landuse/landcover changes incorporated with geomorphometric parameters analysis is useful in investigating watershed characteristics, in which a wide variety of analytical results can be effectively integrated using GIS for explaining the current situation and proposing future plans for integrated soil conservation and watershed managements. The ability of GIS to integrate the digital maps of land use derived from interpretation of satellite images with DEM also provides a new opportunity for analysing patterns of long term landuse

dynamics with respect to the geomorphometric characters. Furthermore, several similar studies on different parts of Siwaliks need to be carried out in order to have conclusive characteristics of whole Siwaliks regions.

4. REFERENCES

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