Applicability of Stream Order Data for Morphometric Analysis and Sub-watershed Prioritization

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KEYWORDS

Morphometric Analysis, Watershed planning and management, Sub-watershed prioritization, GIS, Kailash Khola, Stream order, Spatial data

ABSTRACT

Sub-Watershed management and planning is integration of both technical and social aspects. Physical assessment of sub-watershed includes among many other bio-physical parameters, the morphometric analysis. The current study examines the applicability of existing stream order digital data for morphometric analysis and sub-watershed prioritization of Kailash Khola watershed. The study is based on secondary data and desk study and uses GIS data produced by Survey Department of Nepal and GIS tool for the analysis. Three linear and three aerial/shape parameters are taken for the morphometric analysis and simple ranking method based ob calculated value is applied for sub-watershed prioritization. Technological tools like GIS and Remote Sensing has aided for spatial analysis using morphometric method. The study show that variation is found in vulnerability of sub-watershed in terms of linear and aerial morphometric parameters. The finding show that western part of the watershed is relatively vulnerable in terms of potential soil erosion and flooding. The study concludes that the importance of readily available stream order digital data and GIS tool and technology in identifying and analyzing priority sub-watershed is reasonable. However, it is realized that spatial data at more finer spatial scale will improve the analysis and provide better analysis result and exemplify local problems in the area of topographical variation. The study suggest that, introduction of stream order data set finer scale or will allow analysis to be performed at much greater so that more localized effect of drainage morphometry in varying topographical landscape of the country could be assessed.

Introduction

Different analytical approach to watershed management is in practice such as watershed management as a process of planning and implementation, as a planned system of management measures and implementation or as a set activities for specific management tasks (FAO,1986). A standard process of watershed management begins with the problem identification such as land and water resources degradation leading to resource management task. In this setting, assessment of drainage, geomorphology, physiography, soil and land use - land cover is one of the important step of watershed planning and management. The potential role of spatial information in improving natural resources depletion and land degradation problem is realized for long (Sugarbaker, 2000). In recent years, with the advent of application-ready geospatial data and tools like Remote sensing and GIS, spatial assessment of resources has become simple and universal for watershed planning and management. Morphometric analysis using various linear, aerial and relief parameters is one of the important tool utilized for assessment of watersheds for soil conservation and water resource management at micro level. The morphometric analysis of watershed gives quantitative description of the hydrological system which is significant to understand the structural, lithological, geomorphological aspects of the watershed (Strahler,1964). Previously, morphometric parameters were measured manually but nowadays GIS provide flexible environment and powerful tools for integrating, manipulating and analyzing such spatial information. It aids on the challenges of understanding the hydrological behavior, environmental management and public policies (Martins and Gadiga, 2015). Several studies have been carried out using GIS and morphometric analysis to understand the watershed dynamics and their usefulness in watershed prioritization and management in terms of soil erosion, flood hazard risk and landslide studies, groundwater potential assessment and natural resource management(Biswas et. al., 2014). However, base line spatial data is prerequisite for carrying out morphometric analysis in GIS environment. River network, watershed boundary or contour/ elevation/DEM data for watershed boundary delineation are basic requirement. In this context, the present study is an attempt to explore the efficacy of digital spatial data layer from Survey Department of Nepal in order to assess watershed condition based on morphometric analysis.

Study Area

Kailash Khola watershed is selected as a study area. It lies in the Achham district of far western development region of Nepal and occupies 224 Km2 area. The Kailash river flows from east to west indicating slope gradient of the region. Sub-tropical climate is found in the lower western part of the watershed whereas upper eastern part has temperate climate. Average annual rainfall of the area is 130mm. The elevation ranges from 657m to 3163m with average elevation of 1665m. Most part of the watershed has steep slope and more than 80% of the area lies above 30 percent slope. Agriculture is dominant land cover occupying 49.7% of the total area followed by forest with 47%. Settlement concentration is higher regarding the settlement distribution within the whole district.

Data Base and Methodology

The present work is based on use of existing application ready spatial data for morphometric analysis of Kailash Khola watershed. To assess the morphometric conditions, secondary GIS data sources such as contour and spot height data from 25000 scale and river network data of 100,000 scale digital topographic maps were compiled. Watershed and sub-watershed boundaries were delineated using these base data in GIS platform to carry out watershed and sub-watershed level morphometric analysis. Morphometric analysis starts with the stream ordering and sub-watershed delineation. In Kailash Khola watershed, stream order up to level five is identified and total of 12 sub-watersheds are delineated. After stream ordering and sub-watershed boundary generation, various morphometric parameters were calculated using standard method for the analysis. The basic, linear and aerial morphometric parameters such as area, perimeter, basin length, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, and compactness coefficient were computed based on the methods suggested by Horton (1945), Miller (1953), Schumn (1956) and Strahler (1964). Definitions of these morphometric parameters are as following:

Stream order is defined as a measure of a position of a stream in the hierarchy of tributaries (Strahler, 1964). Stream order of the river data is based on the hierarchical ranking of Strahler. Basin length refers to the aerial distance between the watershed inlet and outlet point (Schumm, 1956). Bifurcation Ratio refers to the number of streams in a low order to the number of streams in the next high order (Horton, 1945). Drainage density is the ratio of the total length of the streams of all orders of basin to the area of the basin (Horton, 1945). Stream Frequency is the total number of stream segments of all orders per unit area (Horton, 1945). Form factor is the ratio of basin area to the square of basin length. For perfectly circular basin the value of form factor would always be 0.7854 (Schumm, 1956). Circulatory ratio is the ratio of basin area to the area of circle having the same perimeter as the basin (Miller, 1953). Compactness Coefficient is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed (Horton, 1945).

Each parameter is ranked as per the calculated values. Linear parameters value such as of bifurcation ratio, drainage density and stream frequency have positive relationship with erodibility hence, higher rank is assigned for higher value for linear parameter. In contrast, aerial or shape parameters have inverse relationship with the erodibility and lower the value, more will be the erodibility. Therefore, higher values are assigned lower rank in case of aerial parameter. The compound value is calculated summing all individual parameter rank and the sub-watershed with lowest compound value has been given highest priority.

Result and Discussion

Morphometric Analysis

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms (Clarke, 1966). It is the measurement of the surface form of a drainage basin, and of the arrangement and organization of the associated river network. It is carried out through measurement of linear, aerial/shape and relief aspects of basin and slope contributions. It provides information about the basin characteristics in terms of slope, topography, soil conditions, runoff characteristics and surface water potential etc. The Morphometric characteristics of different sub-watersheds indicate their relative characteristics with respect to hydrologic response of the watershed.

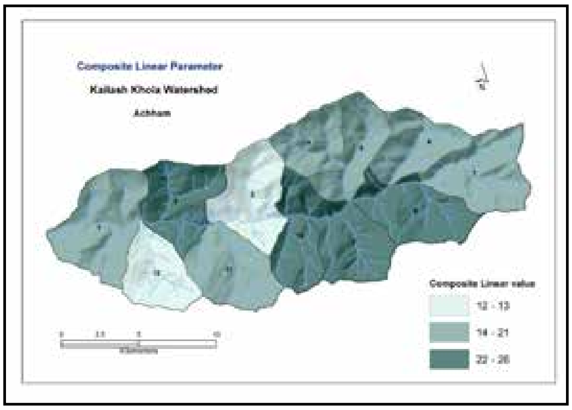
Linear parameters:

Linear parameter includes, drainage density, bifurcation ratio and stream frequency. In general, lower drainage density is found to be associated with regions having highly permeable subsoil material and high value of drainage density is noted for the regions of weak or impermeable subsurface materials (Nag, 1998; Pidwirny, 2006). The drainage density (Dd) of Kailash Khola is 1.45 and sub-watershed number 4 has the lowest calculated Dd value (1.28) indicating low runoff and high permeability whereas sub-watershed number 2 has the highest Dd value (1.67) suggesting high runoff and low recharge. However, relative relief and slope steepness largely controls the drainage density. Stream frequency on the other hand reflects the texture of a stream network and reflects the bedrock properties such as fracture density and infiltration. Though sub-watershed number 1 is the largest in size, sub-watershed number 6 has the highest stream frequency suggesting impermeable sub-surface material and low infiltration. Similarly, the lower bifurcation ratio values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Strahler,1964). Sub-watershed number 9 has the highest bifurcation ratio among other 12 sub-watersheds of Kailash Khola indicating high runoff, low recharge and mature topography whereas sub-watershed number 3 has the lowest value indicating structurally less disturbed sub-watershed but higher risk of flooding. However, compound linear parameter value shows that sub-watershed number 8 is most vulnerable and sub-watershed number 12 is the least vulnerable in terms of erodibility. Details of calculated values of linear parameters are provided in the table 1 and composite linear value is plotted in figure 1.

Table 1: Linear Morphometric Paramters

Sub-watershed	Area Km^2	Perimeter Km	Stream Count	Basin Length	Bifurcation Ratio	Drainage density	Stream Frequency	Linear Parameter
1	25.95	22.32	68	8.40	1.07	1.42	2.62	20
2	19.41	19.45	67	7.12	1.03	1.67	3.45	22
3	20.51	20.44	61	7.35	0.82	1.44	2.97	13
4	13.88	15.15	31	5.89	1.26	1.28	2.23	18
5	14.96	20.23	53	6.14	1.92	1.47	3.54	21
6	15.76	17.85	69	6.33	1.02	1.66	4.38	18
7	22.03	20.89	61	7.65	1.01	1.48	2.77	18
8	21.02	22.34	58	7.45	1.27	1.49	2.76	26
9	18.43	17.57	39	6.91	2.66	1.31	2.12	25
10	16.53	20.45	34	6.50	1.01	1.45	2.06	24
11	20.58	18.23	43	7.36	0.71	1.38	2.09	17
12	15.86	16.98	34	6.35	0.69	1.30	2.14	12
Total	224.94	231.90	621	28.63	1.29	1.45	2.76	

Figure 1:Composite Linear Parameter



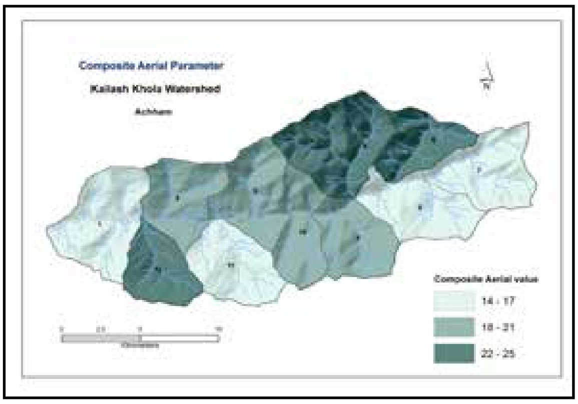
Aerial parameter:

Aerial or Shape parameter includes form factor (Rf), Compactness coefficient (Cc) and Circulatory ratio (Rc). Form factor is inversely related to the shape of the watershed. Smaller the value of form factor, more elongated and irregular will be the shape and watersheds with high-form factors experience larger peak flows of shorter duration and hence difficult to manage the floods. Among 12 sub-watersheds of Kailash Khola, there is not much variation and most of them reflects elongated shape. Sub-watershed number 1 has the lowest value indicating more elongated and irregular shape and low peak flow of longer duration. Whereas sub-watershed number 4 and 5 tend to be relatively circular suggesting high peak discharge and caution for flood management. Compactness coefficient value is associated with erosion assessment. Higher coefficient values denote more elongate watershed and slow discharge with potential of less erosion, while lower values indicate less elongation and faster peak discharge with potential of high erosion. Sub-watershed number 5 of Kailash Khola has the highest value indicating less erosion potential in the area whereas sub-watershed number 11 has high erosion potential. Similarly, circularity ratio indicates the potential of erosion and flood hazard. Higher the value, faster is the runoff and more is the possibility of erosion and flooding. The calculated Circulatory Ratio value is lowest for sub-watershed number 5 (0.46) indicating more elongated and irregular shape and low peak flow of longer duration with less potential of erosion and flood, whereas the highest value is of sub-watershed 11(0.78) suggesting relatively circular shape, high runoff and faster peak discharge with potential of erosion and flooding. Detail aerial parameter values are listed in table 2 and composite aerial parameter value is plotted in figure 2.

Table 2: Aerial Morphometric Parameters

Sub-Watershed	Form Factor	Compactness Coefficient	Circulatory Ratio	Composite Linear Value	Composite Aerial Value	Compound Value
1	0.37	1.24	0.65	20	14	34
2	0.38	1.24	0.65	22	19	41
3	0.38	1.27	0.62	13	18	31
4	0.4	1.15	0.76	18	25	43
5	0.4	1.48	0.46	21	24	45
6	0.39	1.27	0.62	18	23	41
7	0.38	1.26	0.63	18	15	33
8	0.38	1.37	0.53	26	16	42
9	0.39	1.15	0.75	25	20	45
10	0.39	1.42	0.5	24	21	45
11	0.38	1.13	0.78	17	17	34
12	0.39	1.2	0.69	12	22	34

Figure 2: Composite Aerial Parameter



Morphometric prioritization of sub-watershed of Kailash Khola is carried out combining three linear and three aerial/shape parameters. Linear parameters have a direct relationship with erodibility and the aerial/shape parameters have an inverse relation with linear parameters. Composite value of linear and aerial parameters are ranked and compound factor value is calculated and all sub-watersheds are grouped into three priority classes namely, Low, Moderate, and High (Figure 3). Lowest calculated compound factor value is for sub-watershed number 3 (31) followed by sub-watershed number 7 (33) and sub-watersheds 1, 11 and 12 (34) with High priority. Highest value is calculated for sub-watersheds 5, 9 and 10 (45) with Low priority. Result of prioritization of sub-watershed shows that sub-watershed 3 and 7, followed by 1, 11 and 12 are more susceptible to soil erosion as per morphometric analysis. Therefore, immediate attention towards soil conservation measures is required in these sub-watersheds to preserve the land from future erosion and natural hazards. Among 12 sub-watersheds of Kailash Khola, relatively vulnerable sub-watersheds in terms of erosion and flooding are located in the western part and towards lower elevation whereas there is one vulnerable sub-watershed in the east. Middle part of the Kailash Khola watershed is relatively less vulnerable. Watershed management and planning at sub-watershed level should be focused at earliest towards western part of the watershed.

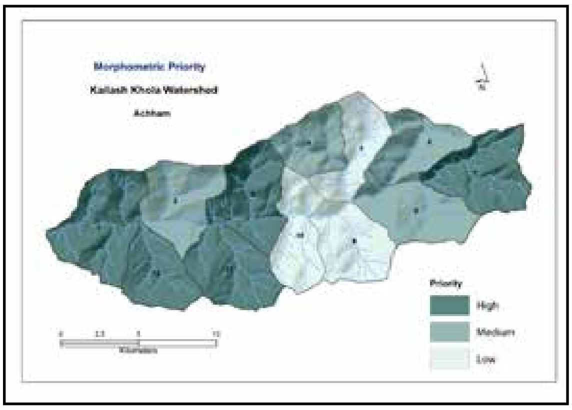


Figure 3:Morphometric Priority

Importance of stream order data

The current exercise demonstrate that taking some basic parameters, a problem area identification at first hand morphometric analysis could be carried out and based on the morphometric analysis. Identification of potential problem areas provides the basis for a targeted field assessment and using the data and maps created targeted field assessment could be conducted to verify and further describe erosion problem areas and key features. Finding sources of drainages and erosion areas is a critical step in developing comprehensive and effective solutions to erosion issues. Topography is the driving force behind surface water movement through watersheds, so the detailed river and elevation databases allow general users, managers, planners as well as hydrologists to predict the location and state of water related problems. The development of GIS capabilities and databases have greatly facilitated watershed research and planning efforts. GIS has enabled government agencies and private organizations to extend the delivery of their data from hardcopy maps to digital spatial data layer in various formats and scale. A good example of such is the digital topographical data of Survey Department of Nepal. Availability of such baseline digital data has impact beyond research as spatial analysis using these data influences planning, implementation and management of development projects for better interventions. However, it is realized that spatial data at more finer spatial scale will improve the analysis and provide better analysis result and exemplify local problems in the area of topographical variation. As depicted in figure 4, increasing aggregation consequently causes loss of information, complexities and incompleteness of information for decision making (Abson et al., 2012). As the stream order changes with the spatial detailing, all the morphometric parameters values will be changes and the prioritization of sub-watershed will ultimately change.

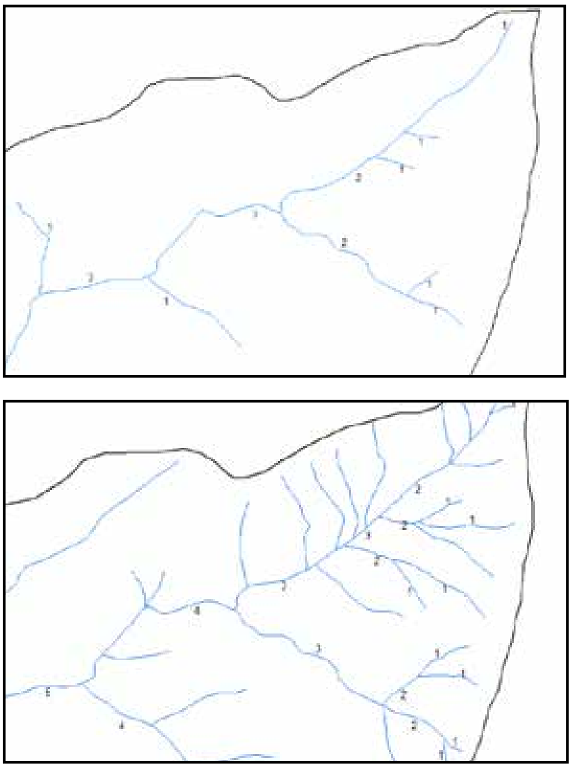


Figure 4:Effect of Scale on Spatial details

Stream order(Scale 1:100,000)

Conclusion

Number of studies reveal that the choice of data source and scale can impact analysis as they provide different results for the same geographical area. Number of morphometric analysis and prioritization of watershed and sub-watersheds have been carried out using existing DEMs such as ASTER, SRTM etc and creating streams, and watershed boundary. But using existing river data with stream order information such as one produced by Survey Department, aids morphometric analysis as well as prioritization. it also overcomes the problem of data unavailability at lower scale such as soil and geology for morphometric analysis and other land degradation assessment. This approach is simple to adapt and useful as it combines the best available information with the knowledge of users. Simple GIS techniques together with readily available stream order data and its interpretation offer a scope for determining the priority areas for watershed management and planning. It supports identification of sub-watersheds with relatively serious degradation problem for conservation activities according to level of need and degradation status. However, it is realized that spatial data at more finer spatial scale will improve the analysis and provide better analysis result and exemplify local problems in the area of topographical variation. The study suggest that, introduction of stream order data set finer scale or will allow analysis to be performed at much greater so that more localized effect of drainage morphometry in varying topographical landscape of the country could be assessed.

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