MAPPING DIGITAL DRAINAGE NETWORK USING GEOPROCESSING: A CASE STUDY OF KALI GANDAKI RIVER BASIN, NEPAL HIMALAYA

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ABSTRACT

The drainage network characteristics of watershed has a significant impact on mountain landscape. The Kali Gandaki River basin has various topographic variation with geomorphology to be crossed by the Sino-Nepal road corridor. In this research, the ALOS PRISM data is used to extract the watershed DEM, and then the drainage network is automatically extracted using geoprocessing methods. Digital water networks extracted from DEM of different filming years were compared. Automatic drainage extraction has high precision and details information than manual. The river morphology and local landscape has change over the years due to climatic changes, mountain hazards and human activities.

***Index Terms*—**DEM, Kali Gandaki River Basin, Drainage Network, Nepal-Himalaya

1. INTRODUCTION

The impact of climate change on water resources is considered one of the major challenges facing the Hindu Kush Himalayas[1–3], one of the most sensitive regions because of the highly diverse climate and topography[4]. The Kali Gandaki River basin lies in the western part of Nepal which has diverse topography and geomorphology. Pokhara-Korala road corridor is one of the major connecting road between Nepal and China under the broad umbrella of Belt and Road Initiatives taken by Chinese government. Apart from this, there are many hydropower stations in this watershed i.e Kaligandaki Hydropower Project (114 MW). Drainage network analysis is always important for infrastructure construction and understand the geomorphology. However, there are very few studies exist in this area. Therefore, an attempt has been done to analyze the drainage network typology and geometry using different Remote sensing (RS) and Geographic Information System (GIS) in this watershed. Drainage network topology and geometry form the basis of many hydrological and geomorphologic models. The digital basin feature is a digital representation of the characteristics of drainage networks. Accurate watershed boundaries extraction is depends on geomorphology, original maps, and measurement methods. Selecting a suitable grid-scale DEM to extract digital basin characteristics such as river network, slope, and watershed range is a basic task for establishing distributed hydrological modeling and in-depth research. In this research, ALOS PRISM data was used to generate Digital Elevation Model (DEM). Depressions in the DEM are identified and filled. The flow direction and catchment area are determined using the D8 algorithms[5]. Then, the Geoprocessing model is built to extract the digital basin feature. Finally, drainage network from different years are compared.

2. METHODS

2.1. Study Area And Data Sourse

Kali Gandaki River originates from the southern edge of the Tibetan Plateau. This river basin is bounded by Neogene extensional tectonics in the Tibetan Plateau and Himalaya, and rugged glacial topography with some gentle slopes (Figure 1). All of the tributaries originate from Himalayan glaciers. For local residents, the mountain disaster and flood risk have a profound impact on the production and daily life.

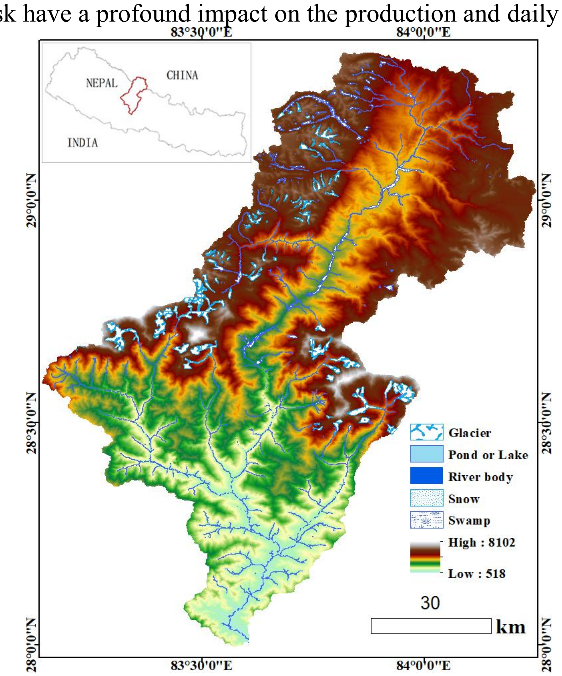

Figure 1: The map of the study area

River data in 2001 has been prepared by merging sheet-wise individual layers available from Survey Department, Nepal. A 12.5m resolution DEM data is processed using ALOS PRISM L1B2 data, shooting in 2016, to construct a digital drainage network model[6]. Three kinds of DEM (SRTM C-band, ALOS World 3D and ASTER GDEM Version 2) are used to compare the change of fluvial morphology[7].

Table 1: List of DEMs used for comparisons and geomorphic analyses.

Dataset	Type	Time	Source
SRTM1-V3	Radar / 30m	2000	https://earthexplorer.usgs.gov/
AW3D	Optical /30m	2006-2011	https://www.eorc.jaxa.jp/ALOS/en/aw3d/index_e.htm Commercial
GDEM2	Optical / 30m	2006-2011	https://earthexplorer.usgs.gov/
ALOS PRISM	Optical /2.5m	2016	https://auig2.jaxa.jp/openam/UI/Login

2.2. Processing Techniques

Based on the manually digitized watershed boundaries, a buffer zone of 20km in the periphery is established. DEM pretreatment and sag filling has been done in ArcGIS platform. The slope runoff simulation has been done to extract flow direction[8]. D8 algorithm is a single flow algorithm and follows the basic principle that there are only eight possible flows in a single grid. They are represented by eight valid signatures 128, 1, 2, 4, 8, 16, 32, and 64. The distance between the central grid and each adjacent grid is calculated. The grid with the largest distance is the outgoing grid of the central grid. If the cell size is 1, the distance between two orthogonal cells is 1, and the distance between two diagonal cells is 1.414. The algorithm is:

$$S = Z / D$$

Z is the height difference between the two grid cells, and D is the distance between the centers of the two grid cells (Figure 2).

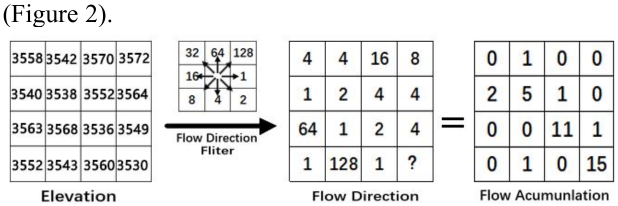

Figure 2: The basic principle of the D8 algorithm

After the flow direction calculation, upstream confluence matrix is calculated and then different critical support area (CSA) are set to extract the raster map of the river network. After that, the river network raster diagram is graded, segmented and vector river network is extracted. At the same time, according to the stream segment and flow direction, the hydrological response unit is extracted. River network has been classified based on Strahler grading[9]. Compared with Shreve grading[10], this algorithm has higher extraction efficiency and clearer expression of the result. Finally, the digital drainage model of the Kali Gandaki River is prepared (Figure 3). All processes can be implemented in the hydrological analysis module of ARC GIS, and scripted using Python language.

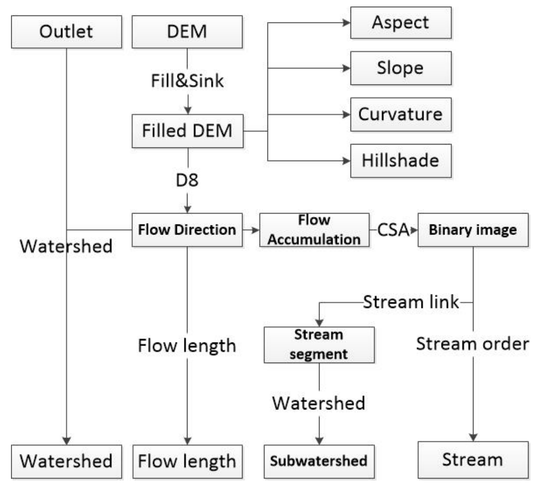

Figure 3: Methodology chart

The Python scripts developed for this study will be bundled into an Esri ArcGIS® toolbox for public download, making them readily accessible to other researchers.

3. RESULTS AND DISCUSSION

3.1. Digital Drainage

In order to extract drainage system more accurately, multiple critical support areas, ranging from 0.78 to 7.8 square kilometers, are set in this study to compare the extraction effect of river network under different catchment areas. The higher the density, the more fragmented the ground, the greater the average slope, the lower the stability of surface materials, and the formation of surface runoff, soil erosion intensified. It is found that the density of river network and river nodes are well correlated with the CSA (Figure 4). The relation between the density and the CSA can be well fitted (Figure 5) as the power function curve, the formula is as follows:

$$f(x) = 0.6585 \times x^{-0.4939} + 0.01563$$

Calculation of open street map drainage density is 0.33 km^{-1}. According to the results of the power function fitting, when the critical catchment area is 4.5 square kilometers, it is the closest to the actual river network density. The outputs from the model shows a good result with the existed watershed map and OpenStreet map. The drainage system of the Kali Gandaki River is oriented nearly in north-south direction. The Syang Khola, Lumbuk Khola, Panda Khola, Jhon Khola, Ghilumpa Khola, Narsing Khola, Tange Khola, Charan Khola, Dhechyan, Khola, Yak Khola and the Hyujun Khola are the main tributaries of the Kali Gandaki River. The watershed boundary is basically consistent with the factual drainage network and with better details.

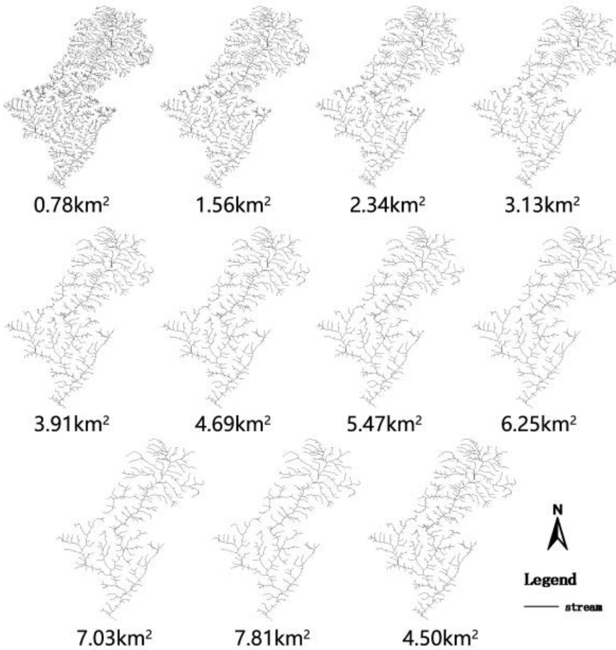

Figure 4: Drainage Network Extract by different CSA

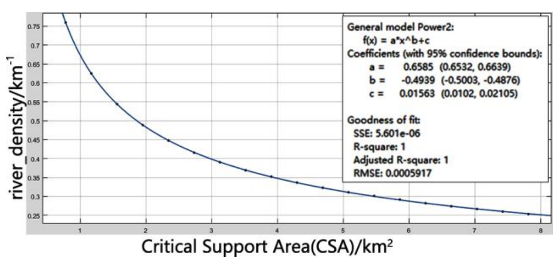

Figure 5: The best fitted curve

3.2. Testing And Comparison

In order to understand the changes of Kali Gandaki River, DEM data collected by ALOS PRISM in 2016 are resampled into DEM with a resolution of 30m, and SRTM, GDEM and AW3D30 data (30m resolution) were put into the model to extract their digital watershed information respectively (Table 2).

Table2. The drainage network characteristic

DEM	Length (km)	Subwatershed No.	Source No.	Area (km^2)	Density (km^{-1})	FDavg
SRTM	2388.44	1253	890	6958.53	0.34	1.30
GDEM	2404.80	1277	903	6962.75	0.35	1.27
AW3D	2330.35	1273	884	6957.78	0.33	1.27
ALOS	2259.22	1184	836	6956.81	0.32	1.34
FDavg:Average fractal dimension for selected area.						

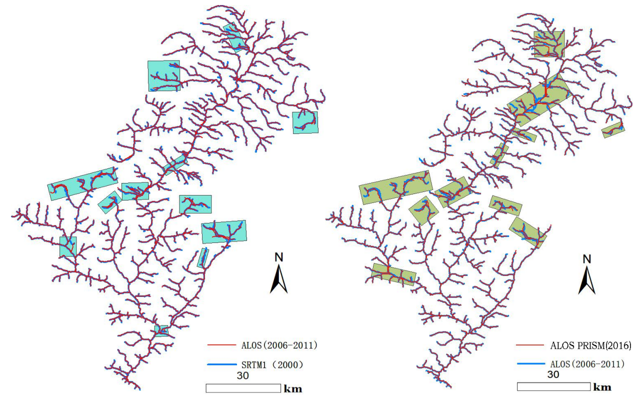

Figure 6: The contrast of drainage in SRTM1v3(2000) ALOS3D (2006-2011) and ALOS prism (2016)：In the box is the section with large deformation.

All processing share a same CSA, which is 5000 in raster calculation. The results show that the local rivers have undergone significant morphological changes in recent years, reflecting the active erosion activities (Figure 6). The Average fractal dimension is around 1.30 and shows an increasing trend, which means the watershed landform is in the infancy of erosion development. The river system is not fully developed, and the river erosion is severe[11-12].

4. DISCUSSION

Rising temperature, erratic rainfall and change in monsoon system in the Nepal Himalaya caused severe damage to local livestock systems and agriculture[1,13]. The pattern shows that the temperature rise is more active in high-elevation than in low-elevation resulting glacial melting in the Kali Gandaki river basin also. As temperatures warm and glaciers retreat, many existing glacial lakes are growing in size and new ones are forming[14,15]. As glaciers recede, glacial lake levels are rising at an alarming rate, and the threat of glacial lake outburst floods (GLOF) causing catastrophic damage to people and infrastructure downstream is growing[1]. These changes will also affect the shape and flow of future water networks, creating new challenges for local agricultural irrigation, production and domestic water use.

The Kali Gandaki river cuts across the >8000 m high peaks of Dhaulagiri and Annapurna, formed the world's deepest canyons in the gneiss of the greater Himalayas and the metamorphic rocks (mainly quartzite and schist) of the lesser Himalayas, where characterized by narrow terrain and discontinuous schistose sedimentary terraces. Natural disasters (such as landslide, collapse, glacial lake outburst, etc.) often interact with rivers, causing river diversion and landslide dam. This river basin also heavily affected by such kinds of hazards causing sediment deposition and change in local landscape. Anthropogenic activities i.e. road construction, improper agricultural practices have been largely affecting this river basin. Precipitation and snowmelt are the most important variables affecting the annual flow rate, and temperature is the most important variable affecting the flow timing. The runoff of the upstream and midstream of this river will increase by the most or by 60% to 100%[1]. The synergistic effect of temperature and precipitation will lead to the increase of river flow and sink flow, and the final outlet flow may increase by more than 50%[1]. Overall, local rainfall, snowmelt, runoff and river flows will continue to increase, and erosion may increase. The water network will not shrink in the future, but may expand, especially at high altitudes.

5. CONCLUSIONS

The utilization of GeoProcessing will help local water resources utilization and management, as well as flood disaster assessment and early warning. However, the formation of drainage network is the common result of a variety of natural and human factors within the basin. The presence of large flat areas in depressions and plains makes the spatial expression of topography and point elevation of DEM inaccurate. The excavation of artificial channels and canals will also affect the accuracy of extracting river network water system based on DEM to varying degrees. Climate change, mountain hazards and human activities have significant effects on the spatial and temporal changes of the water network in the Kali Gandaki basin.

6. ACKNOWLEDGEMENT

Funding: This work was supported by National Natural Science Foundation of China(grant number: 71841027) and Sichuan University Overseas Excellent Doctoral Research Funding Scheme(grant number: skyb201603)

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