UGC Approved Journal

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified

Vol. 4, Issue 7, July 2017

Derivation of the Topographic Characteristics of Sutlej Catchment in Nari Khorsum, Tibet

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Abstract: Accurate representation of topographic characteristics of catchment is a prerequisite for delineating stream network, watersheds and management of water resources of in any river system. In this the study satellite imagery based Digital Elevation Model has been used for derivation of the topographic characteristics of Sutlej river's catchment in Tibetan Highlands. D8 algorithm has been invoked for carrying out hydrological and spatial analysis in the ArcGIS environment. The relief of catchment ranges from 2551 m to 7156 m and it was found that almost 65% of the catchment is situated in the elevation range 4500 m to 5500 m.

Keywords: Digital Elevation Model, Topographic Characteristics, Eight Flow Direction Algorithm, Delineating of Watershed and Stream Network.

1. INTRODUCTION

Accurate representation of topographic characteristics of catchment is a prerequisite for delineating stream network and watersheds of in any river system. This information is essential for management of water resources. Historically, stream network was delineated from topographic maps. Currently satellite imagery based Digital Elevation Models (DEM) are used for extraction for drainage characteristics. DEM is a raster dataset where each cell is assigned an elevation value corresponding to its locations.

2. OBJECTIVE

The objective of this study is derivation of the topographic characteristics and watershed boundary of Sutlej river in the Nari Khorsum province of Tibet using satellite imagery based DEM and computerized spatial analysis.

Date Set

There are many sources of satellite imagery based elevation data sets of various spatial resolutions. Among these, Shuttle Radar Topography Mission's SRTM DEM and optical imagery based Advanced Space borne Thermal Emission and Reflection Radiometer's ASTER Global DEM are important. SRTM DEM data has a spatial resolution of 90 meters while the ASTER DEM has a spatial resolution of 30 meters. Since ASTER DEM has a finer spatial resolution, it was used for extracting the drainage network of Sutlej and its tributaries draining the western-Tibetan plateau, trans-Himalayan and the Himalayan mountain ranges.

The ASTER DEM is distributed by the NASA's Earth Observing System Data Information System (EOSDIS) and the Land Processes Distributed Active Archive Center (LPDAAC) of the United States. Each ASTER GDEM tile represents an area of 60- x 60-kilometers. Following ASTER GDEM v2 tiles, released in 2011 by NASA, were downloaded from the Earth Explorer website http://earthexplorer.usgs.gov/.

ASTGTM2_N30E076_dem, ASTGTM2_N30E077_dem, ASTGTM2_N30E078_dem, ASTGTM2_N30E079_dem, ASTGTM2_N30E080_dem, ASTGTM2_N30E081_dem, ASTGTM2_N31E076_dem, ASTGTM2_N31E077_dem, ASTGTM2_N31E078_dem, ASTGTM2_N31E079_dem, ASTGTM2_N31E080_dem, ASTGTM2_N31E081_dem, ASTGTM2_N32E076_dem, ASTGTM2_N32E077_dem, ASTGTM2_N32E078_dem, ASTGTM2_N32E079_dem, ASTGTM2_N32E080_dem, ASTGTM2_N32E081_dem.

3. STUDY AREA

The Sutlej river rises from lake Rakastal in the Tibetan Plateau at an elevation of about 4,572 m and forms one of the main tributaries of Indus river. After travelling about 322 km in north-westerly direction in the Tibetan province of Nari-Khorsan, Sutlej enters Himachal at Shipkila and flows in the south-westerly direction through Kinnaur, Shimla, Kullu, Solan, Mandi and Bilaspur districts and covers another 322 km up to Bhakra gorge, where the 225.55 meters (740 ft) high straight gravity dam (Bhakra/Govind Sagar) has been constructed. In Nari Khorsan province of western

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Tibet, Sutlej has created an extraordinary canyon, comparable to the Grand Canyon of Colorado. Present study confines itself to the catchment of river Sutlej in Tibet.

4. METHODOLOGY

The main steps involved in extraction of drainage characteristic from DEM include: mosaicing the DEM tiles and their processing using D8 (Eight Flow Directions) algorithm. This processing was carried out using ESRI's ArcGIS v.10 software's Spatial Analyst and Hydrology tools (ESRI, 2005; Merwade, 2012).

Mosaicing and Reprojection

Above referred ASTER GDEM tiles were mosaiced or stitched together (Figure 1) and re-projected to Universal Transverse Mercator Projection (Zone 44). The mosaiced DEM's spatial extent covers the catchments of Sutlej, Beas, Jhelum and Yamuna rivers. For the purposes of this study the catchment of Sutlej river needs to be isolated and rest of the areas need to be pruned.

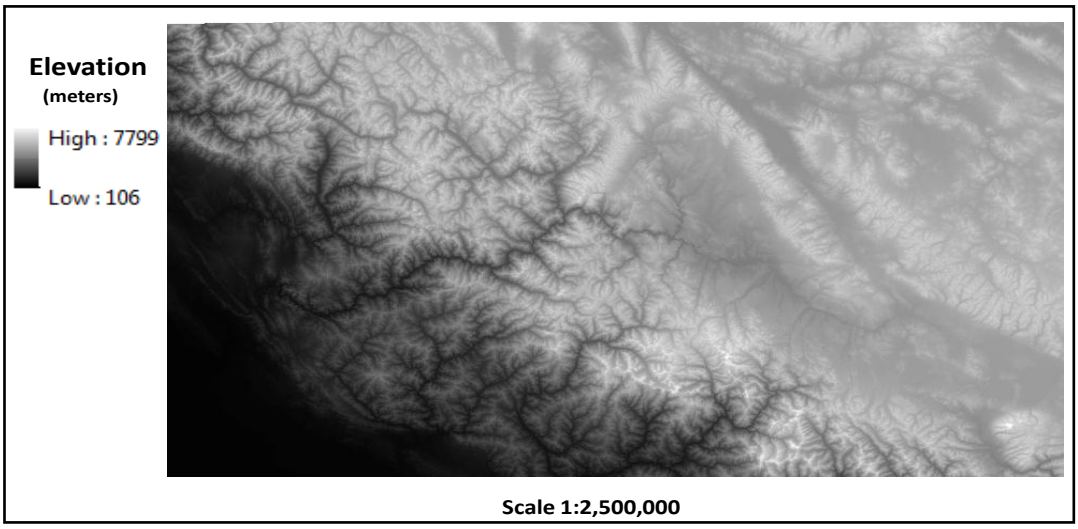

Figure 1: ASTER GDEM Tiles Mosaic

Eight Flow Direction Algorithm

The eight flow directions method was introduced by O'Callaghan and Mark (1984). It is based on the concept of local drainage directions; each cell in a DEM is assigned a drainage pointer to one of the eight neighboring cells in the direction of the steepest slope. This approach specifies flow directions by assigning flow from each cell to one of its eight neighbors, either adjacent or diagonal, in the direction with steepest downward slope (Tarboton, 1997). As the flow of water is traced downhill from a point, a counter is incremented for all the downstream points through which the water flows (Jones, 2002). The drainage network is defined by the relative counts wherever the upstream drainage area exceeds a specified threshold. These pointers define a tree-like drainage network that extends to an every cell in the DEM. The important steps involved in invoking the D8 algorithim are: sink filling; identification of flow direction; calculation of flow accumulation; stream definition; and isolation of watershed of interest.

Depression Filling

The D8 approach to extract drainage network sometimes encounters roadblock due to the presence of depressions in DEMs. Depressions or Sinks are cells which have no neighbors at a lower elevation and consequently, have no down slope flow path to a neighboring cell. If cells with higher elevation surround a cell, the water is trapped in that cell and cannot flow. Sinks include both flat and depressional areas. Sinks may arise from input data errors as most satellite imagery based DEMs also contain vertical errors (Martz and Garbrecht, 1998). The Fill-Sink function of ArcGIS Hydrology tool set fills the sinks/depressions in the DEM and makes it drainable.

Drainage directions

In the following step, the Flow Direction function of ArcGIS Hydrology tool box was invoked to compute drainage directions based on the steepest decent of each cell. This results in a network of drainage directions extending to every cell in the raster.

Flow Accumulation

The flow accumulation is the amount of rainwater that drains through a given point (cell) from all upward locations connected to that point by an uninterrupted chain of drainage directions.

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Flow accumulation is quantified on the basis of Flow-direction raster data set created in previous step.

Stream Network

Stream network was derived from the flow accumulation raster. A stream is formed when an area of certain threshold drains to a point and channelization occurs in places where there is significant enough flow. Different thresholds like 1 km^2, 5 km^2, 25 km^2, 50 km^2 etc. can be used to derive the stream network. Since the watershed of Sutlej is very huge and spreads across Tibet, Himachal Pradesh, and Punjab, a relatively large threshold 40km^2 was used for delineation of stream network.

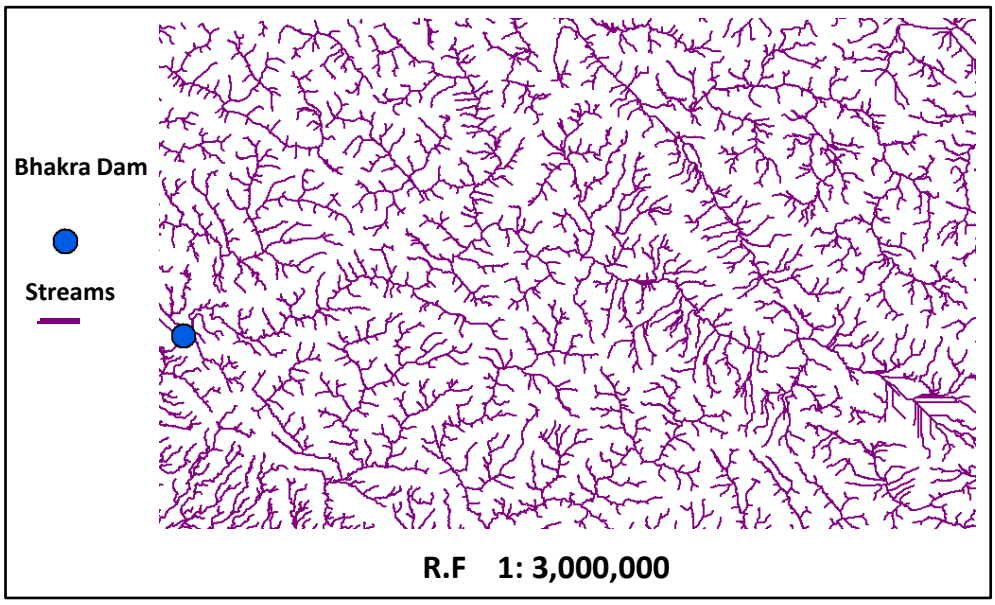

Figure 2: Stream Network Extracted from ASTER GDEM.

Catchment of Sutlej River

For the purposes of this study the watersheds of tributaries of Sutlej above the Bhakra dam site were needed. It is assumed that the outlet for Sutlej is the Govind Sagar lake behind Bhakra dam. A 'point' shape file was created for the Bhakra dam and was treated as the "Pour Point." This is displayed by a yellow symbol in Figure 3.

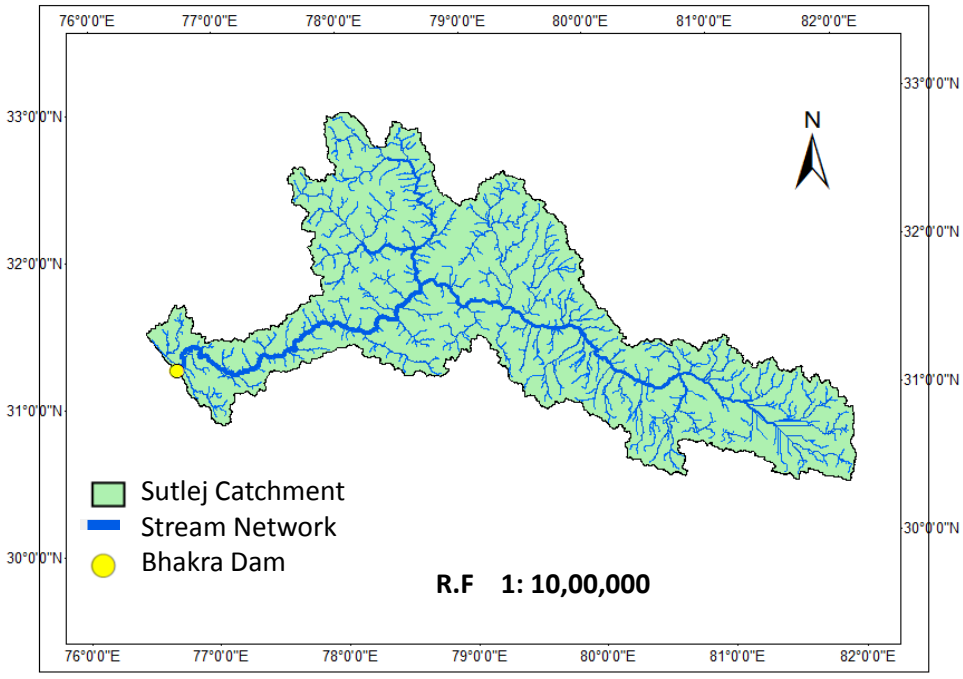

Figure 3: Catchment of Sutlej upstream of Bhakra dam.

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Drainage area upstream of this place is catchment of Sutlej river. Pour Point vector layer along with the Flow Direction raster was processed by the Watershed tool of Hydrology tool kit to obtain catchment area of Sutlej river. The total area drained by Sutlej up to the "Pour point" is 52221 km^2.

Bifurcation of Catchment of Sutlej in Tibet and India

Sutlej enters Indian territory after gathering the waters from western Tibet near Shipki La Pass. Here it meets Sutlej's largest northern tributary Spiti at Khab. Spiti drains the cold arid districts Lauhal and Spiti in Himachal Pradesh. A Pour Point shape file for Khab was created for bifurcation of Sutlej rivers Indian and Tibet catchment (Figure 4 and Figure 5).

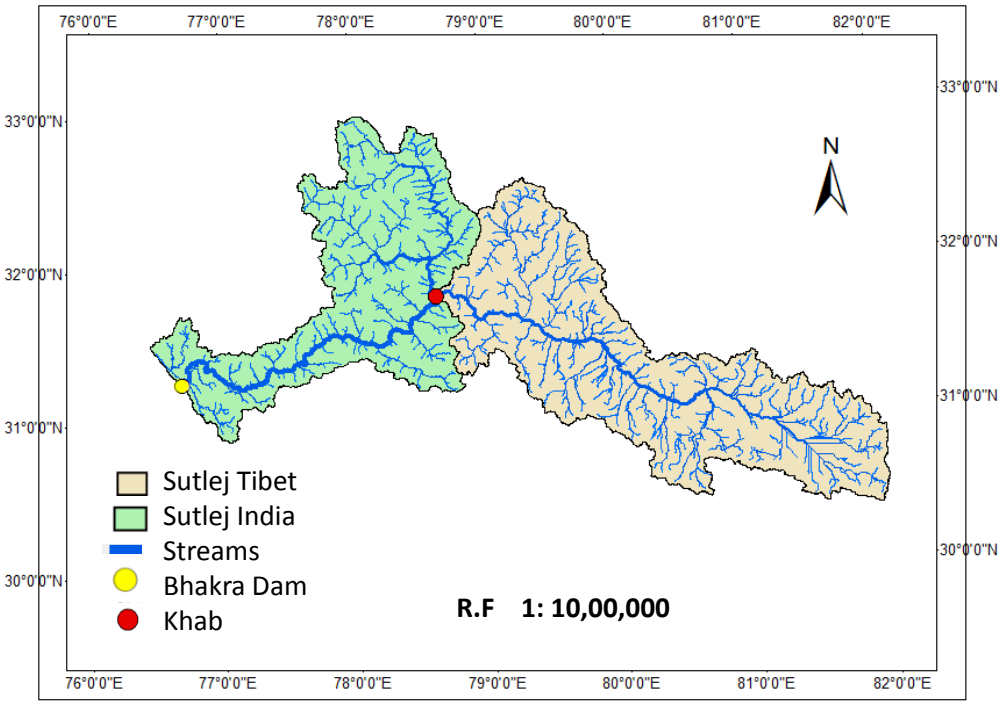

Figure 4: Catchment of Sutlej (Tibetan and Indian part).

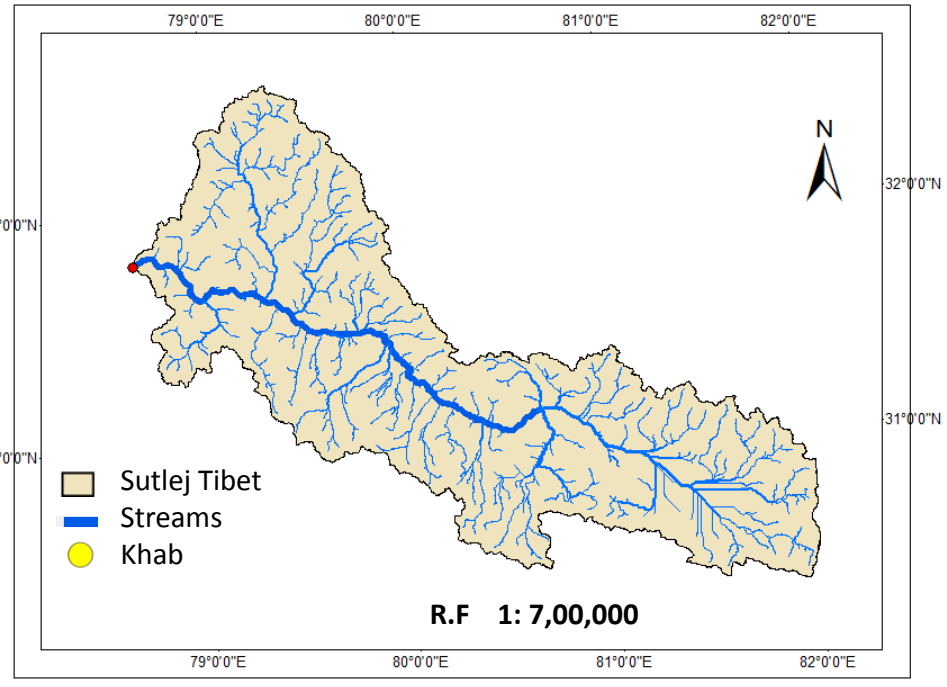

Figure 5: Catchment of Sutlej in Tibet.

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Digital Representation of Topography of Sutlej's Entire Catchment

Using the Sutlej Catchment layer as a mask, the Digital Elevation Model of Sutlej's catchment was extracted for a better comprehension of flow regime of the entre basin (Figure 6). Similarly Digital Elevation Model of Sutlej's Tibetian catchment was extracted.

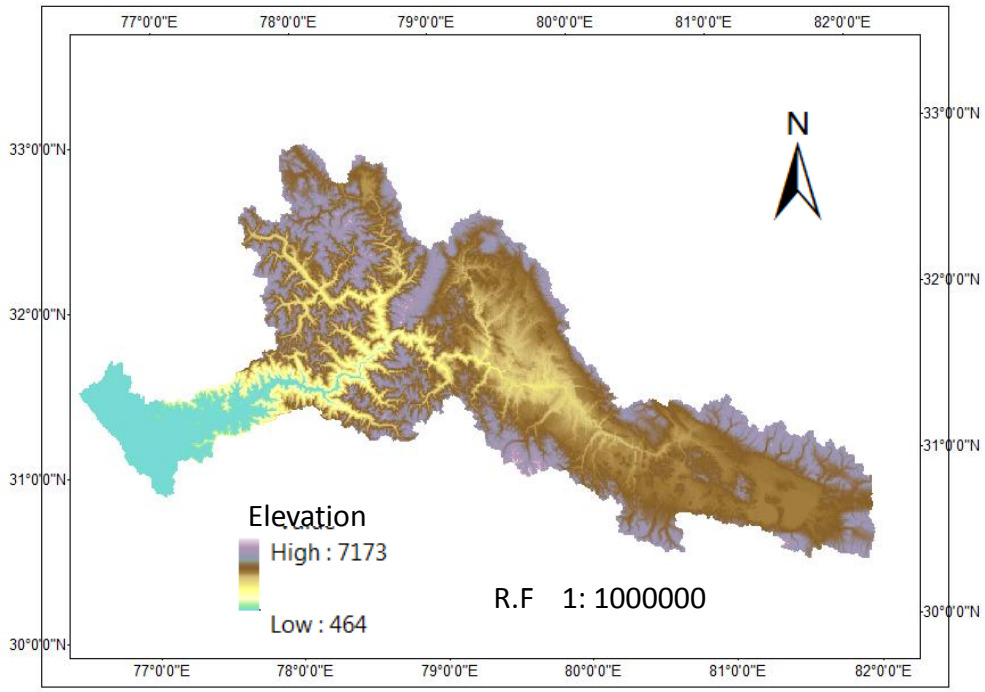

Figure 6: Digital Elevation Model of the area drained by Sutlej.

Digital Representation of Topography of Sutlej's Tibetian Catchment

Using the watershed of Sutlej upstream of Khab as a mask, the Digital Elevation Model of Sutlej's Tibetian catchment was extracted for a better comprehension of flow regime of the basin (Figure 7). The total area drained by Sutlej in Tibet (upto Khab) is 29676 sqkm.

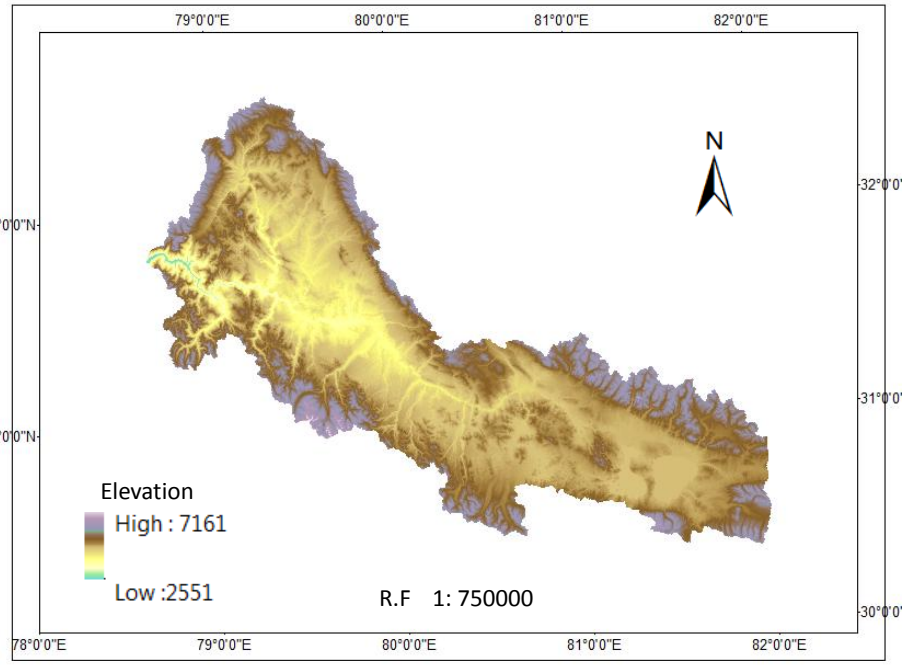

Figure 7: Digital Elevation Model of the area drained by Sutlej in Tibet.

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The relief of catchment ranges from a low of 2551 m to 7156 m. The catchment area was further classified into four elevation zones (Table 1 and Figure 8). It is amply clear that almost 65% of the catchment is situated in the elevation range 4500 m to 5500 m and the mean elevation of the catchment is 4516 meter.

Table 1: Zonal Elevation Characterstics of Sutlej Catchment in Tibet

Elevation Zone	Area (sq km)	Relief Range (m)	Mean Elevation (m)	Median Elevation (m)
2551 - 3500	170	949	3277	3325
3500 - 4500	6339	999	4208	4246
4500 - 5500	20040	999	4872	4803
5500 - 7551	3125	1655	5707	5667
	29676		4516	

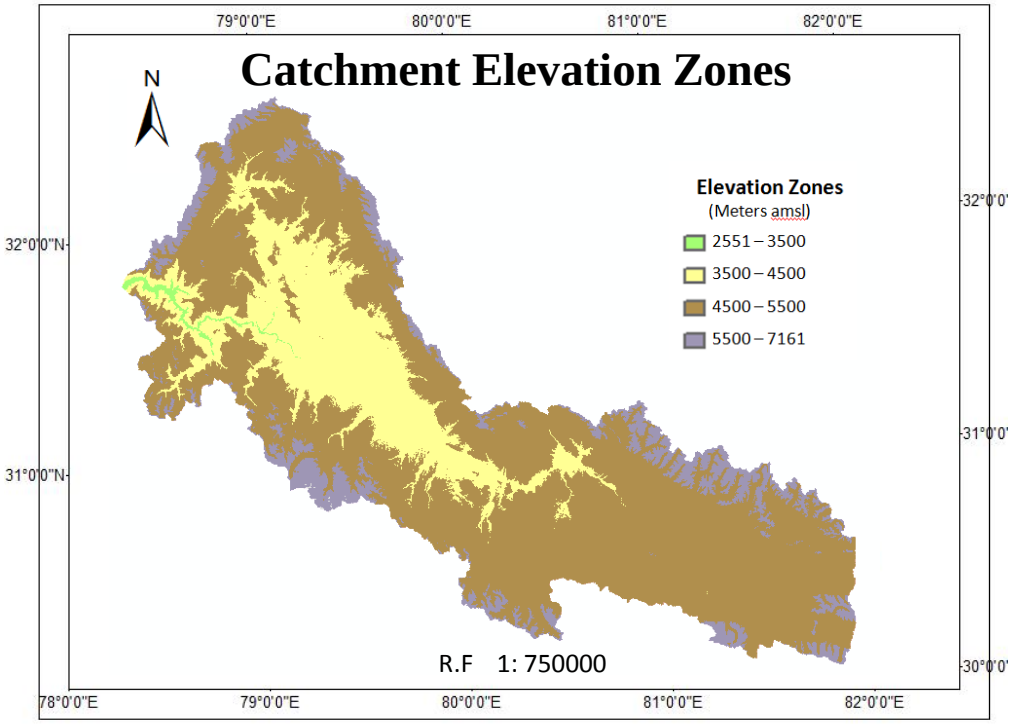
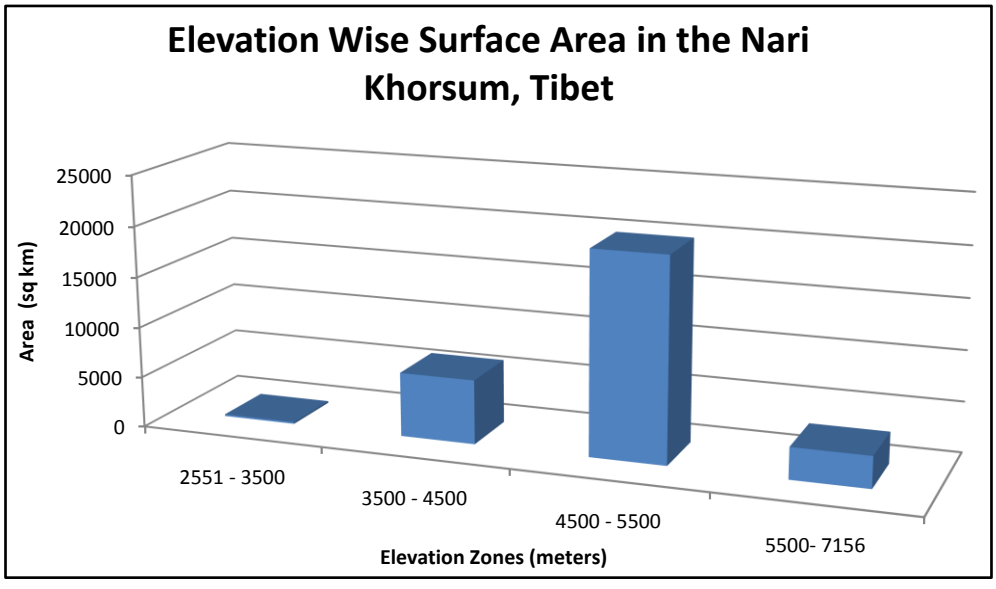


Figure 8: Catchment Elevation Zones in Nari Khorsum, Tibet.



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5. CONCLUSION

The Sutlej River is a very important river draining the north-western Himalayan, trans Himalayan ranges and eastern Tibetan plateau. It important to understand and delineate the topographic characteristics like watershed, streams and, drainage network of river's catchment for modeling of hydrological processes lie rainfall-runoff and snowmelt runoff from the catchment and planning of water resources.

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