Morphometric Analysis of Manali Watershed of Beas River Basin for Watershed Management

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ABSTRACT

This study is focused on the morphometric analysis of relative parameters of Digital Elevation Model (DEM) and satellite imagery for Manali watershed in the Kullu district of Himachal Pradesh. Morphometric analysis of linear, areal and relief aspects helps in understanding the drainage pattern, elongation ratio, bifurcation ratio and other geo-hydrological parameters of watershed which are further useful for watershed management. Hydrology tool of ArcGIS software was used to delineate watershed and perform morphometric analysis over SRTM DEM at 90m resolution. The present study reveals that morphometric analysis technique is more methodical and meticulous compared to other available techniques. Land use map, Soil parent material map, Slope map and Aspect map along with morphometric analysis of the study area are also helpful for planners and decision makers for natural resource management and watershed management leading to sustainable development of the study area.

Keywords: *Remote Sensing, ArcGIS, DEM, Morphometric Analysis and Watershed Management.*

1. Introduction

The general public today is now experiencing the GIS revolution. This leads to huge changes in life giving rise to new methodologies, especially with respect to earth assets mapping and observations (Singh et al., 2012). The depleting quality and quantity of water and other natural resources have become one of the prime concerns of today. In India, especially, the rising levels of pollution in the rivers and other water bodies have alarmed the authorities as well as the citizens. These water bodies need to be managed and kept safe. The remote sensing and GIS sectors have a lot to contribute to this noble cause.

This research paper gives an insight about the Manali watershed of river Beas basin. Watershed management refers to the term used to describe the process of applying land use practices and water management practices to guard and develop the quality of water and other natural resources in a watershed by handling and managing these resources in a comprehensive way. This process should be well planned and well implemented in order to avoid complications. A comprehensive planning process includes all affected municipalities located in the watershed. Runoff form of rainwater can reach various places and cause pollution. Watershed management helps to regulate pollution by identification of various kinds of pollution and taking significant steps to manage it. Watershed management is also useful in promoting collaborations among the affected parties or municipalities in the watershed. One issue to note is that the decisions and actions of the upstream municipalities can affect the downstream ones. Therefore, comprehensive planning is required in order to provide equal resources and rights to all the associated municipalities.

In India, major resources of water supply are the rivers coming from the mountains. These rivers need to be managed and a planned watershed management system should be present in order to preserve them. Advancement of a drainage framework and the flowing pattern over reality estates are influenced by several variables (Abrahams, 1984; Horton, 1945; Leopold et al., 1953). They need to be constantly checked and assessed on their soil erosion levels, safety and other parameters such as permeability, groundwater infiltration, runoff etc. This is done through a morphometric analysis. Morphometric analysis is a quantitative description and analysis of landforms that may be applied to a drainage basin and large regions basically. Evaluation of the qualities of the drainage basin utilizing quantitative morphometric investigation can give data about the hydrological idea of the rocks uncovered inside the drainage basin (Revitt et al., 2010). In respect to drainage basins, there have been many developed measures that define various aspects like valley side, relief area and other variables. Attempts are being made to statistically correlate these parameters that describe drainage basin characteristics. It is very useful in understanding and predicting the geo-hydrological behavior of the drainage basin which involves the climatic conditions, geology and the structural aspects. It helps in determining the control of flow of runoff water and also it foresees the upcoming floods, if any, along with its intensity.

Morphometric analyses and their portrayal have been performed since the mid-nineties for linear, aerial and relief aspects along with elucidation of their interrelationship with reference to vegetation, soil and water management (Horton, 1945; Magesh et al., 2011; Smith, 1950; Strahler, 1957). Morphometric analysis widely uses remote sensing and Geographic Information System (GIS) techniques for determination of this statistical description of various drainage basins. These techniques use aerial photographs and satellite imagery have become a convenient tool for this sector of operation. However, traditionally GIS was used only in mapping and related engineering activities in watershed management. GIS, when used with digital elevation data, improve overall watershed operation and also deliver a visual illustration of the watershed's reaction to the surrounding conditions and also give corrective measures. GIS tools also help the operators to concentrate more on modelling and refinement of analysis and prediction of trends rather than the tedious work of setting up models and gathering appropriate data.

The traditional methods for watershed planning involved manual data collection and predictions and decisions based on hard copies of aerial maps. This was a hectic, tedious and laborious task. Further, it also did not ensure accuracies in the tasks performed and predictions made. The chances of errors were high. On the contrary, GIS based approach starts with a digital illustration of the Digital Elevation Models (DEMs). Digital elevation models are the essential information utilized in the investigation of catchment topography (Maathis, 2006; Moore et al., 1991). They are easily available and accessible in both public as well as private organizations. In GIS based approach, the computer evaluation becomes easier and more accurate. Instead of sending a survey crew to the site, the assumptions can be verified and various investigations can be made by the desktop evaluation itself. There is also better display of images. There are many aspects that were not noticed in the traditional 1-D, 2-D images. With 3-D images, every aspect and parameter can be critically evaluated. GIS is now used in day-to-day tasks of watershed engineers. This technology has given an opportunity to engineering projects with increased accuracy and the flow of information within a large community among the technical and non-technical parties in a precise format. The accessibility and flexibility of GIS based model have provided an appropriate method for morphometric analysis and watershed management. The present study deals with the morphometric analysis of Manali watershed of river Beas which provides the geo-hydrological behavior of the basin. Further, this study could easily be used by decision makers for sustainable development.

2. Study Area

In this study, the area considered is the Manali watershed of Beas river which comes under Kullu district in the Himachal Pradesh. It is located at the coordinates with latitude 32.2396N and longitude 77.1887E. The average mean sea level (AMSL) height is between 1247m to 6002m with the total area of about 1098.79 square kilometers (Figure1). The Manali watershed basin is one of the valleys of Kullu district and it lies to the north. The climate of this region is generally cool in the winter (within −7 to 15°C) with snowfalls and slightly hot in summer (within 10 to 30°C) which makes the annual average temperature pleasant and also attracts the tourists. The average annual rainfall is 1411.1mm rainfall. The slope of this area is steep in the outside hilly region and at the central valley region it is gentle and the direct of slope is southward. The lithological types of this area include banded gneisses, schists, quartzite, granite, phyllites, volcanic and mylonites. The Soil surface texture is sandy, loamy and loamy skeletal. The main crops of this region are paddy, maize, kodra and salyara.

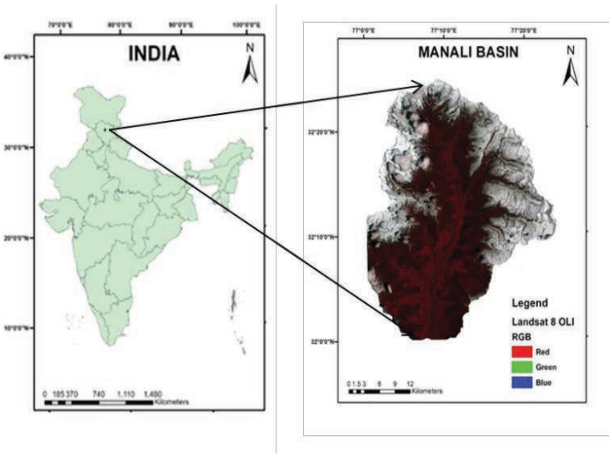

Figure 1: Map of the study area of Manali watershed in the Beas river basin.

3. Methodology

Morphometric analysis gives the precise and methodical information about the watershed. There are different formulae for different parameters which are used in this study. These formulae are mentioned in Table.1. The satellite data and Digital Elevation Data (DEM) required for the morphometric analysis are downloaded from the source USGS (https://earthexplorer.usgs.gov/). Satellite data of Landsat 8 Operational Land Imager (OLI) of date (21/05/2019). Landsat 8 OLI has a spatial resolution of 30m and has 11 bands in total. DEM data of Shuttle Radar Topographic Mission (SRTM) of 23/09/2014 have been used here for drainage flow, stream order, slope and aspect. It has a resolution of 90m. The software used here are Arc GIS (10.3.1) and ERDAS Imagine (2014). All these data are brought into the spatial domain (Arc GIS and ERDAS Imagine) to prepare different maps and conduct the morphometric analysis. ERDAS Imagine software has been used for the image classification purpose such as image stacking and then for supervised classification. For image stacking, 4 bands (2-Blue, 3-Green, 4-Red and 5-NIR) out of 11 bands have been used. In supervised classification method, Maximum Likelihood classification (MLC) algorithm is used along with supervised editor tool for taking control points. For this LULC map, six different classifications have been created (dense forest, shrub land, fallow land, ice cover, water bodies and built-up area). As noted earlier, Arc GIS software has been used to prepare different maps and morphometric analysis of Manali basin.

Table 1. Parameters for computation of morphometric analysis.

S.No.	Parameters	Formulae
1	Stream order (U)	Hierarchical rank
2	Stream length (L_u)	Lengthofthestream
3	Mean stream length (L_{sm})	$L_{sm}=L_u/N_u$
4	Stream length ratio (R_L)	$R_L=L_u/(L_u—1)$
5	Bifurcation ration (R_b)	R_b) = Nu/Nu + 1
6	Mean bifurcation ratio (R_{bm})	R_{bm}=averageofbifurcation ratios of allorder
7	Drainage density (D_d)	$D_d= L_u/A$
8	Drainage texture (T)	$T=D_d \cdot F_s$
9	Stream frequency (F_s)	$F_s= N_u/A$
10	Elongation ratio (R_e)	$Re=2\sqrt{(A/\pi)}/L_b$
11	Circularity ratio (R_c)	$R_c= 4\ \pi\ A/P^2$
12	Form factor (F_f)	$F_f= A/L^2$
13	Relief	$R=H—h$
14	Relief Ratio	$R_r=R/L$

Table 2. Linear Aspect of the Manali Watershed.

Stream order (w)	No. of streams (Nu)	Bifurcation ratio (RbF)	Mean bifurcation ratio (Rbm)	Total length of streams (km)	Mean length of streams (km)	Length ratio (RL)
1	364			381.5		
2	155	2.35		187.9		0.49
3	115	1.35	2.1	132.65	1.06	0.7
4	27	4.26		26.29		0.2
5	64	0.42		41.32		1.57
Total			Total	769.67		

4. Results and Discussion

The results of this study give the morphometric analysis of Manali watershed of AMSL from 1247m to 6002m shown in Figure 2 at three different aspects (Linear, Areal and Relief) which is helpful in watershed management. These aspects can be defined on the basis of different parameters which are given in Tables 2-4.

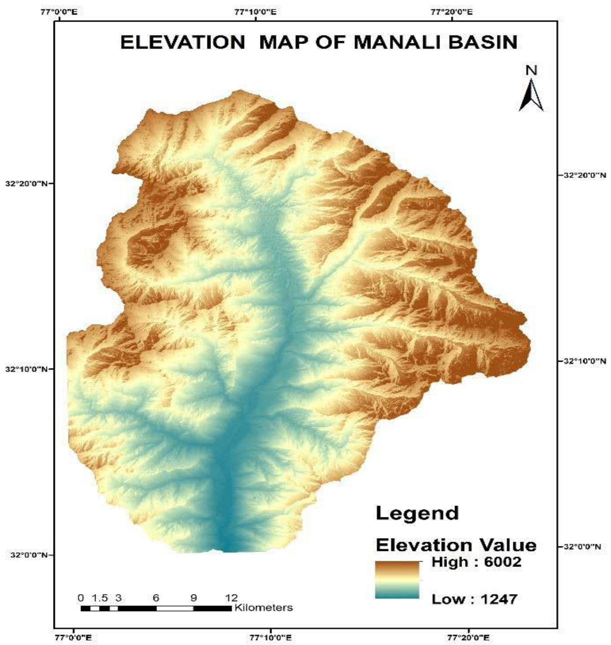

Figure 2: Elevation Map of Manali watershed of Beas river basin.

Through these analyses we can understand the drainage flow, soil permeability, slope etc. Variables controlling groundwater storage are different in different place and most of these components depend on the accompanying parameters such as (1) rainfall availability (2) drainage characteristics for runoff (3) soil permeability and (4) slope which helps in runoff and flow energy. Therefore, morphometric analysis plays an important role in watershed management. Detail for parameters are given below.

A. Stream Order and Number of Streams

Stream Order measures the size of the stream or we can say that number of branches in a stream. In this study, the Manali watershed contains stream order of 5th which is calculated by using (Strahler method) in Arc GIS Software shown in Figure 3.

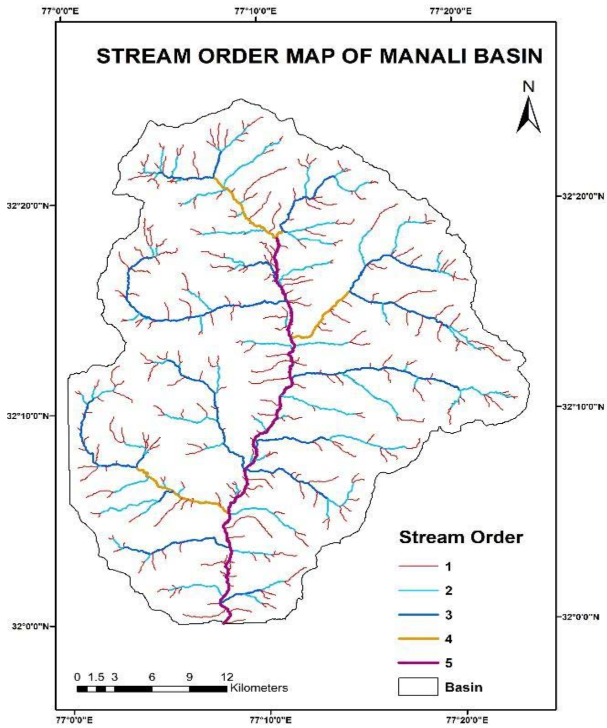

Figure 3: Stream Order Map of Manali watershed of Beas river basin.

Table 3. Areal Aspect of the Manali Watershed.

Basin area (km2)	Perimeter (km)	Length(km)	Form factor	Elongation ratio (Re)	Circularity ratio (Rc)	Drainage density (km)	Stream Frequency	Drainage Texture
1098.79	154.47	44.56	0.55	0.42	0.57	0.7	0.67	0.47

Table 4. Relief Aspect of the Manali Watershed.

Height of basin mouth (z) m	Maximum height of the basin (Z) m	Total basin relief (R) m	Relief ratio
1247	6002	4755	106.71

Number of streams (Nu) represents the total number of streams in watershed. In this Manali watershed basin, there are 725 streams in total as shown in Table 2. The drainage pattern of this Manali watershed is dendritic pattern which by a long shot, the most widely recognized. These are created in regions where the rocks (or unconsolidated material) underneath the stream has no specific texture or structure and can be eroded equally easily in all directions. Through morphometric analysis of these two parameters, we came to know that stream number increases as the stream order decreases except for the 4th stream order.

B. Stream Length, Mean Stream Length and Stream Length Ratio (RL)

Generally, the stream length of the Watershed decreases as the stream order increases. It also happens in Manali watershed as shown in Table 2 except for the 4th order.The total length of the stream is 769.67 km. Mean stream length helps in calculating the stream length ratio.

C. Bifurcation Ratio (RbF) and Mean Bifurcation Ratio (Rbm)

The bifurcation ratio is the ratio of the number of stream segments of given order to the number of segments of next higher order. In this Manali Watershed region, the range of bifurcation is between 0 to 4.5 which means there is minimum structure disturbance. The mean bifurcation ratio is 2.1. The bifurcation ratio is of central significance in drainage basin examination as it is the chief parameter for connecting the hydrological characteristics of a watershed under topological and climatic conditions. It helps in interpreting the shape of the basin and deciphering the run off behavior. Higher the values of bifurcation ratio, higher the flood risk.

D. Drainage Density (Dd) and Drainage Texture (T)

Drainage density is the total length of the stream per unit area. Here the value of drainage density of the basin is 0.7. Higher value of drainage density indicates low permeability, less runoff high vegetation & low relief and lower value of drainage density indication high permeability, more runoff, low vegetation & high relief. Drainage texture also plays an important role in defining drainage density. According to Smith 1950, the drainage texture is classified in to 5 classes (Smith, 1950). The Drainage texture less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture (Singh et al., 2014). It is observed that drainage texture equal to 0.47 indicates the presence of very low resistant permeable material with high relief. Drainage density also depends on other factors like climate, rainfall, vegetation, rock and soil type.

E. Stream Frequency (Fs)

According to Horton (1932), stream frequency means the total number of streams per unit area. In this study, the value of stream frequency is 0.67

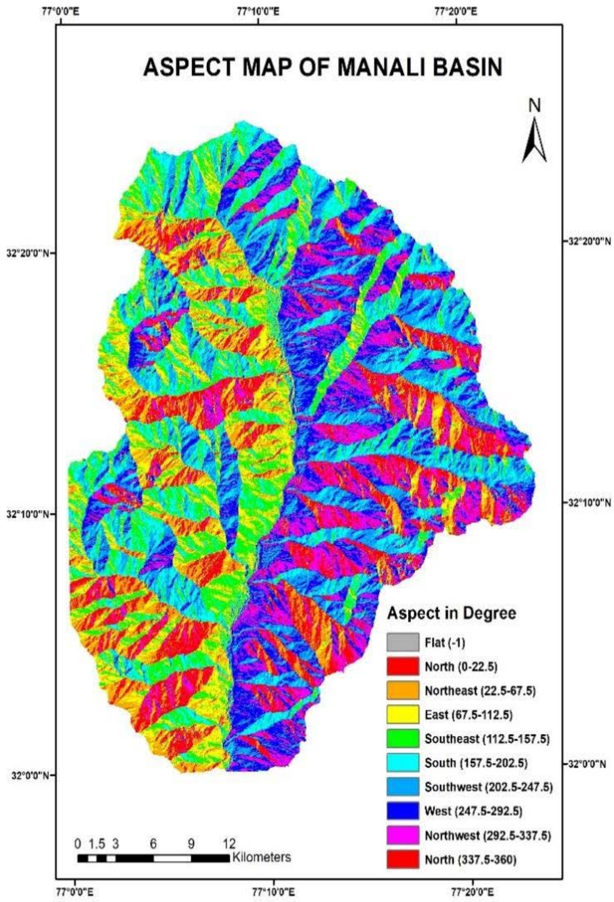

Figure 4: Aspect Map of Manali watershed of Beas river basin.

which means positive correlation with the drainage density which is 0.7, since the stream frequency is directly related to drainage density.

F. Elongation Ratio (Re)

Elongation ratio denotes the ratio of diameter of a circle of the same area as the basin to the maximum basin length as suggested by (Schumm, 1956). Elongation ratio has been classified into 3 types; a) circular (>0.9), (b) oval (0.9–0.8) and (c) elongated (<0.7). For Manali watershed of Beas river basin, the value of elongation ration is 0.42 which means that the basin is elongated in shape with high relief.

G. Circulatory Ratio (Rc)

According to Miller (1953), the circulatory ratio is the ratio of basin area to the area of a circle having the same perimeter as the basin (Miller, 1953). The formula of circulatory ratio is $Rc = 4 \pi A/P2$. Here the value of circulatory ratio is 0.57 which indicates that the basin is elongated in shape. The increased runoff (Rc) is influenced by slope of the basin, LULC and length & frequency of the stream.

H. Form Factor (Ff)

Horton (1932) derived form factor as a ratio of basin area to the square of basin length. It shows the flow intensity of a basin for a required area. The value of Ff should always be less than 0.7854. Smaller the value of Rf, more elongated is the basin. Basins with high Ff experience larger peak flows of shorter duration and elongated basin with low Ff experience lower peak flows of longer duration. In this study, the value of form factor is 0.55 which implies that the basin is elongated and has lower peak flows of longer duration at the center where the Beas river is flowing. On the other hand, there is larger peak flows of shorter duration at the outer part where there is a hilly region.

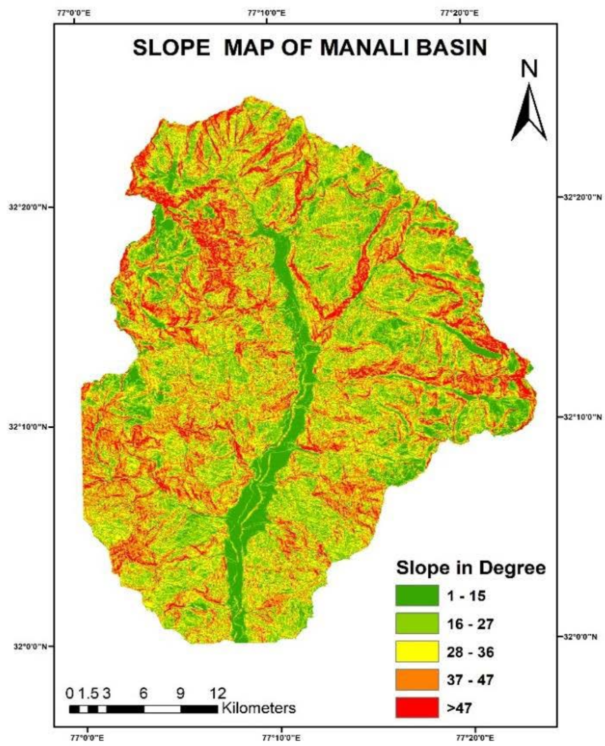

Figure 5: Slope Map of Manali watershed of Beas river basin.

I. Relief (R) and Relief ratio (Rr)

Relief is the difference between the maximum height of the basin and the height of the basin mouth (Schumm, 1956). Here the basin relief is 4755m. The relief ratio is the difference of total basin relief and basin length. For Manali watershed basin, the value of relief ration is 106.71 which confirms the steep slope in major region of the basin. Relief ratio infers potency of erosion process by consideration of overall steepness of the basin.

J. Aspect Map

Aspect shows the direction of the slope. As of now, the direction of slope at 00 is north, at 900 it is east and so on. For this study, the direction of slope is south facing as shown in Figure 4. This indicates the slope having higher vegetation cover and higher moisture content as compared with the north facing slope.

K. Slope Map

Slope defines the steepness of the area. In this Manali watershed, the maximum height is 6002m whereas the minimum value is 1247m. Here the slope is divided in to 5 classes as shown in Figure 5; 00-150 gentle, 160-270 moderate, 270-360 steep, 360-470 very steep and >470 very very steep. Gentle slope is good for ground water infiltration having less runoff whereas steep slope or higher slope category has bad ground water infiltration with more runoff.

L. Land Use and Land Cover Map

LULC has a great effect on ground water infiltration. Through LULC change analysis, one can easily understand the groundwater gain and loss for the future use. The LULC map of Manali watershed basin is prepared by using Landsat 8 OLI Data of date (21/5/2019). The LULC map contain 6 classes as shown in Figure 6. This LULC map helps in understanding the hydrological condition of watershed. The LULC classification is prepared by supervised classification method. Here the Maximum Likelihood Classification (MLC) algorithm is used. The control points are created by using supervised editor tools in ERDAS Imagine software. Accuracy assessment gives the overall classification accuracy value 87.5% and overall kappa statistics values 0.8476. These numbers indicate that the accuracy of classification is reasonably good. The estimated area of each class is shown in Table 5.

Table 5. Different classes of LULC.

LULC Classes	Area (km)	Area (%)
Dense Forest	322.51	29.35%
Shrub Land	169.89	15.46%
Fallow Land	110.74	10.08%
Water Body	40.21	3.66%
Ice Cover	451.16	41.06%
Built-Up Area	4.28	0.39%
Total	**1098.79**	**100%**

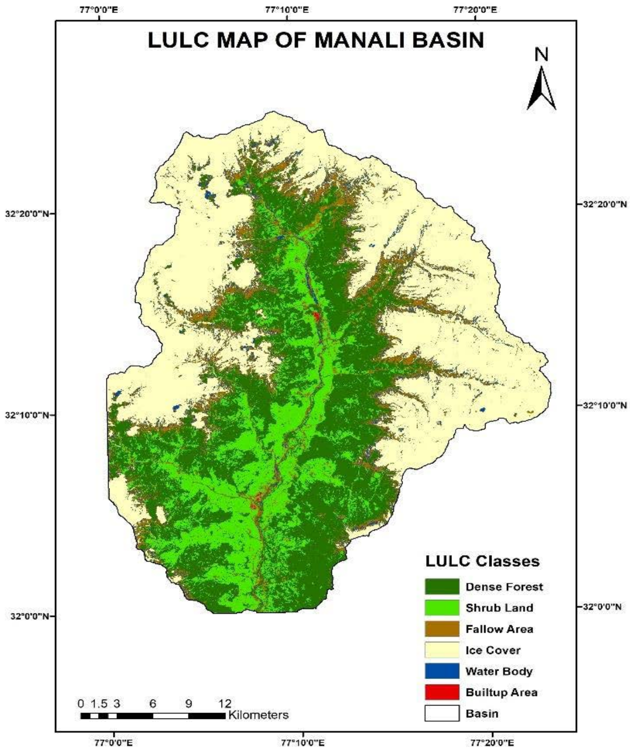

Figure 6: LULC Map of Manali watershed of Beas river basin.

M. Soil Parent Material Map

Integrated watershed management basically means the management of water-vegetation-soil. Therefore, soil plays an important role in watershed management. The permeability and porosity of soil affects the groundwater infiltration. The underlying geological material in which soil horizons form is the parent material. The soil parent material map is prepared by using NRSC India soil data which contain parent material types of entire India. The Beas valley consists of 5 types of parent materials as shown in Figure 7. These types are named as Glacial, Colluvium, Glaciers & Rock Outcrops, Rock Outcrops and Sandstone. In this map, the material colluvium is situated at the foot of the steeps or hills whereas Glacial, glaciers & rock outcrops, and rock outcrops are at the hilly region and rock outcrops. Sandstones are located at the basin.

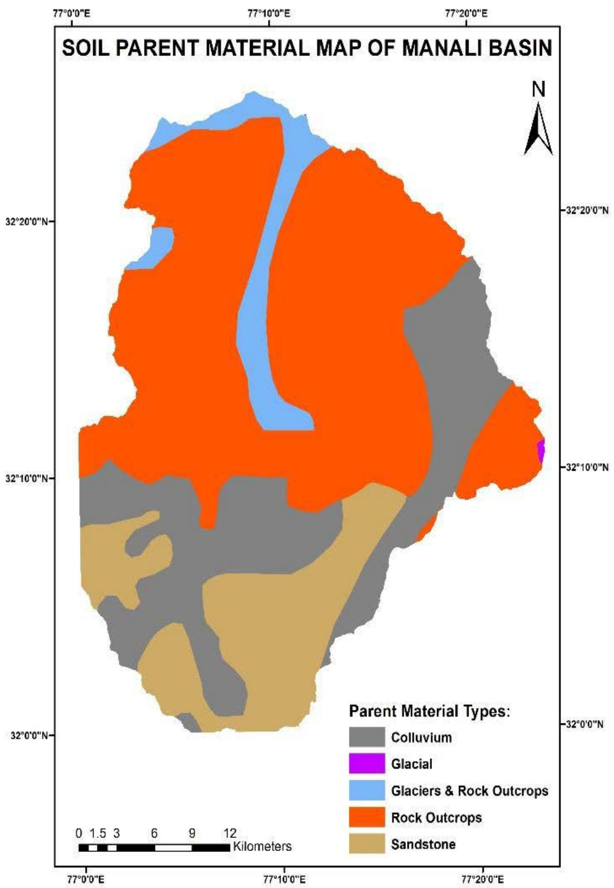

Figure 7: Soil Map of Manali watershed of Beas river basin.

5. Conclusions

Manali watershed of Beas river Basin has steep slope at the hilly region and gentle slope at the center (valley). This watershed basin is elongated in shape. Use of Remote Sensing, GIS and DEM data are useful methods for hydrological analysis of watershed. The morphometric parameters can easily explain the geology, groundwater runoff, rock permeability, groundwater infiltration of any region. At the same time, slope, aspect, LULC and soil map can also provide effective information. This study will be useful for micro level management of watershed for sustainable development. These results can also be examined for the site suitability analysis of the area with respect to water and soil protection structures advancement.

These parameters can be coordinated with other topical data viz., LULC, slope along with drainage, aspect and soil data in the GIS to find the suitable location. It also helps in identification of site having soil and water preservation structures (nala, bund, check dam, and permeation tank, energize shaft, and so on) in the region, which may be used for the overall development and management of groundwater.

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