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REMOTE SENSING AND GIS APPLICATION BASED WATERSHED DELINEATION AND CLASSIFICATION IN THE GORI GANGA RIVER, KUMAUN HIMALAYA

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Abstract

Present research paper is an attempt to delineation and classification of the Gori Ganga watershed, Kumaun Himalaya, Uttarakhand (India). The present study watershed and sub-watershed delineation and classification based on remote sensing and GIS techniques, and Cartosat-1 satellite image of 2008. The Gori Ganga watershed is divisible in to 9 sub-watersheds, size of these sub-watershed varies in between 83.97 km^2 (viz., Baram sub-watershed) and 794.97 km^2 (viz., Gori Ganga sub-watershed). There are total 168 villages situated in 8 sub-watersheds in which those number of villages varies in between 1 (viz., Gori Gad, Lwan Gad and Ralam Gad sub-watershed) and 95 (viz., Gori Ganga sub-watershed). In the entire watershed total number of streams is 17645 and total length of these streams is 8561.62 km.

Keywords: *DEM, Stream Network, Stream Ordering, Watershed Delineation*

INTRODUCTION

In earlier days, watershed delineation work was done manually using topography sheets. GIS tools are being widely used for delineation of watershed area and identifying stream network. The watershed classification approach used by WSCP- Watershed Classification Project (Thomas, 1997) was based on a methodology that was developed and applied in Thailand in the 1980's. The approach used statistical analysis to establish relationships between a numbers of variables (like slope, elevation and landform etc.) derived from topographic maps and the watershed classes (Breu, 2005). The need for watershed management is important and is most likely to achieve a positive and measurable impact in watershed. Watershed classification is one approach that can help to identify critical watersheds by mainly using static criteria (Heinimann et al., 2005). It should be noted that methods to classify watersheds differ around the world, as the method will depend on the intended use of results. For instance, the classification of a watershed for the purpose of measuring snow cover, snow line, vegetation cover, vegetation line, timber line and dynamics as well as hydropower generation etc. (Banerjee et al., 2017). Watershed delineation is a method of dividing a landscape into different watershed and sub watershed classes on the basis of selected topographic features. It describes the potential topographic soil erosion risk of a landscape on the basis of its physical and environmental features. A geographical area separated by surrounding ridges is a hydrological unit defined as a watershed within the basin all land area contributed its runoff to a common point (Kumar et al., 2015). As water tends to move downwards by the forces of gravity, the common point is normally situated in a watercourse at the bottom of the basin (Wilson et al., 2012).

According to Natural Resources Conservations Service (NRCS, 1995), a hydrological unit is defined as "an area of land, above or upstream from a specific point on a stream, which is defines by a hydrologic boundary that includes all the source areas that could contribute surface water runoff, directly or indirectly to the designated outlet point". A hydrological unit is synonymous with a basin, river basin, drainage basin, catchment area and watershed. The most commonly used terms are basin, catchment and watershed. In the Glossary of Geographical terms, a basin is "the whole tract of a country drained by a river and its tributaries" (Stamp and Clark, 1981). The term watershed also refers to a water divide between two drainage basins (Shanley and Peters, 1988). The Encyclopedia of Geomorphology relates the term catchment with hydrologists, who use it in connection with water supply (Fairbridge, 1968). Larger Watershed also contains smaller watersheds, called sub-basins. The termed using for a boundaries between two basins are drainage divides. The outlet is the point on the surface where water of rivers flows out of a basin area. It is the lowest point along the boundary of a watershed.

Accurate watershed delineation plays an important role in the management of the watershed. The delineated boundary helps in management efforts, analyzing and in drawing appropriate conclusions (Savant et al., 2002). Delineating catchment areas by employing GIS and DEM is being preferred to manual techniques due to the improved accuracy, less duplication, easier map storage, flexibility and simplicity in data sharing, timeliness, greater efficiency and higher product complicity. GIS tools can be automated in implementation of various practical applications of watershed delineation (Fattah et al., 2017). Arc GIS hydrological tools used to describe the physical components of a basin by identifying sinks, calculating flow direction and accumulation, stream order, delineating watershed and creating stream network (Pareta et al., 2012; Woodrow et al., 2016). Presenting a case study by simple application of GIS as a tool of watershed delineation and drainage extraction like watershed boundary, flow direction, flow accumulation, flow length, stream ordering can be done by using hydrological tools (Alqaysi et al., 2016). The watershed is a hydrologic unit that is used to be modeled as it is considered fundamental to hydrologic designs and it is used to aid in the study of the movement, distribution, quality and quantity of water in an area (Bajjali, 2018). The algorithms are essentially raster based; the products (watershed polygons, drainage link network and tabular attribute information defining watershed linkages) can readily be converted to vector form (Jenson, 1988). Flow routing algorithms use DEM to estimate the direction of the down slope redistribution of topographically driven overland flow passing through each grid cell in the digital elevation model (Woodrow et al., 2016). The various morphometric parameters of a watershed area like as stream order, stream length, mean stream length, stream length ratio and areal aspect describes like as stream frequency, drainage density, drainage texture, from factor circularity index and length of the overland flow (Kumar et al., 2016).

METHODOLOGY

The literature suggests that watershed can be of various sizes depending upon the size of stream, drainage density and its distribution. The size of watershed is governed by the order of stream or river in question or the confluences of the stream or river likes dams, barrages etc. the size of the watershed is important for land and water resources development. Normally a watershed describe with pour point and drainage line. Total area of the water flowing are given to an outlet point or more often known as pour point. Pour point is the center point at where the river water flows out of the basin area. This is the lowest point in elevation along the boundary of the drainage lines.

Delineation of watershed depends on the drainage pattern of the watershed.

The processing steps includes removal of artificial depressions/sinks by an iterative process, superimposition of existing drainage in DEM, then generation of flow direction from each cell and calculate of flow accumulation by accumulating the weight for all cells that flow accumulation by accumulating the weight for all cells that flow into each down slope cell and derivation of stream network using threshold on flow accumulation value (Hutchinson et al., 2008). Then next step, automatic delineation of watershed is carried out by interactively selecting an outflow point on the stream network. The size of the watershed generated is collected by the number of cells that needs to flow into a cell to classify it as a stream. If we want to create different sizes of watersheds we can achieve it giving different threshold values while building the stream network. In addition to the delineation of watershed a table containing channel length, channel slope, channel slope length, channel width and channel depth is generated for each watershed.

LOCATION AND EXTENT

The study area, viz., the Gori Ganga watershed (Kumaun Himalaya) (Fig. 1) extends between $29^0$45’0’’N to $30^0$35’47’’N latitudes and $79^0$59’33’’E to $80^0$29’25’’E longitudes, and encompasses an area of about 2191.63 km^2. The altitude of the Gori Ganga watershed varies between 626 m and 6639 m. The Gori Ganga watershed has 168 villages and total population is about 40616 as per 2011 censes (Parihar et al., 2021). Gori Ganga watershed spreads in three Tehsils, i.e., Munsyari, Dharchula and Didihat and in one Sub-Tehsil known as Bangapani. Munsyari remains one of the last accessible hill stations by motor road in the region. There are many tribes in this watershed which are Bhotiya, Barpatiya and Anuwal Samuday. Three main valleys, i.e., Gori Ganga valley, Ralam valley and Johar valley are famous valleys in the study area.

WATERSHED ANALYSIS

A watershed is the area of land where all of the water that falls in it and drains off from it, goes into the same place or common outlet. Watershed also defined by topographic divides between two adjacent catchment basins, such as a mountain ridge. A large watershed may cover an entire stream system and within the watershed, there is smaller watershed, one for each tributary in the stream system. In the present study delineation of watershed was done by area based and point based method. The selected point may be an outlet, a gauge station or a dam site. Point based automated process follows a series of steps, starting with a filled DEM. Figure-2 depicts the flow chart of the research methodology used for delineation of watershed boundary. Gori Ganga watershed is located in Kumaun Himalayan region in Uttarakhand. The watershed lies in north-western part of the Pithoragarh district.

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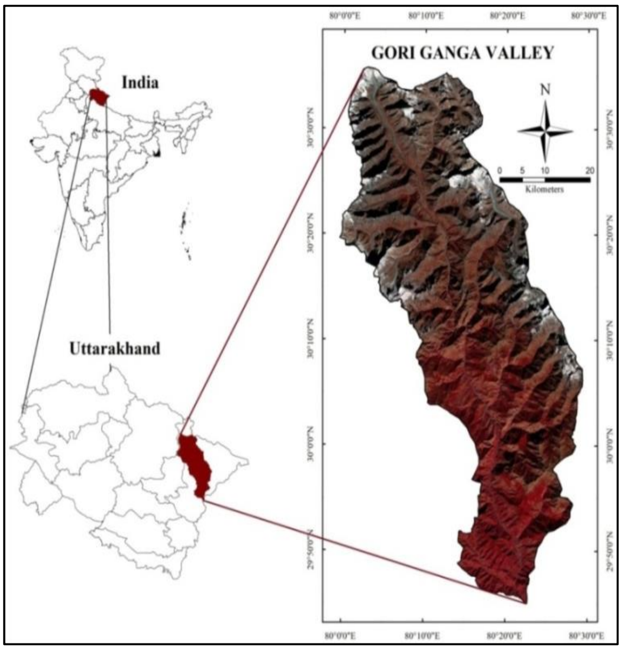

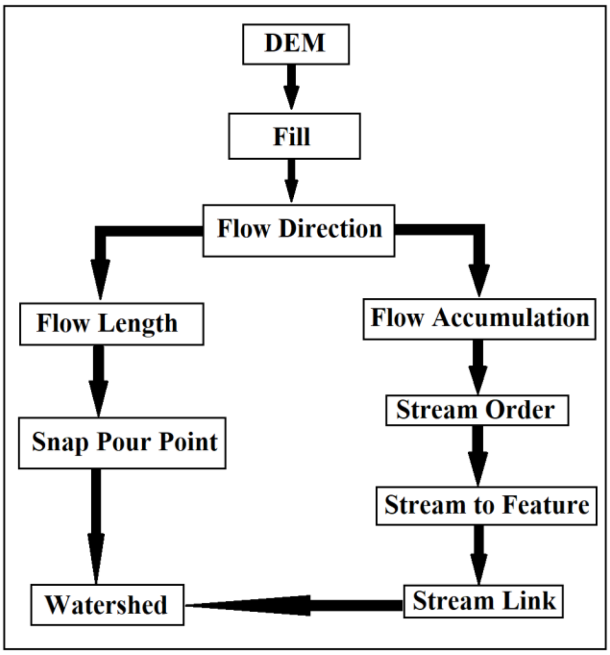

Figure-1: Location map of the Gori Ganga watershed, higher Himalayan region Kumaun Himalaya (Uttarakhand).
Figure-2: Methodological flow chart for watershed delineation (*after Breu, 2000*).

PREPROCESSING IN DIGITAL ELEVATION MODEL (DEM)

Preprocessing the DEM is one of the important step need to be carryout for first step in automatic extraction of drainage networks and delineation of watersheds. During DEM generation using the spatial interpolation method, artificial spurious depressions get generated. O'Callaghan (1984) has suggested that smoothing a DEM prior to analysis reduces the size and the number of sinks. According to Band (1986) it increases the elevation of sink cells until a down slope flow path to an adjacent cell becomes available under the assumption that flow may not return to the sink cell. First the sinks are identified and the cells contributing flow to the sinks are delineated. Using Cartsat-1 satellite data DEM for the study area was generation through Arc GIS software (Fig. 3).

FILLED DEM

Fills sinks in a surface raster to remove small imperfections in the data. A filled DEM or elevation raster is void of depressions. A depression is a cell in an elevation raster that are surrounded by higher elevation values and thus presents an area of internal drainage. A common method to remove depression is to increase its cell value to the lowest overflow point out of the sink. Figure-3 depicts the Cartsat-1 satellite data based DEM for the study area which was generated through Arc GIS software. Considering the basic fact that water flows downhill, grids with a higher value will flow to grids with lower values. Generally, landscapes will have low points or depressions that do not drain. These depressions will cause errors in future steps, as a continuous flow network is required (Jenson and Domingue, 1988).

FLOW DIRECTION

The single direction flow direction method was originally described by O'Callaghan (1984). Main applications of flow direction grids are automated delineations of stream lines and catchment boundaries. Flow direction grids are well suited in calculation of convergent flow for various

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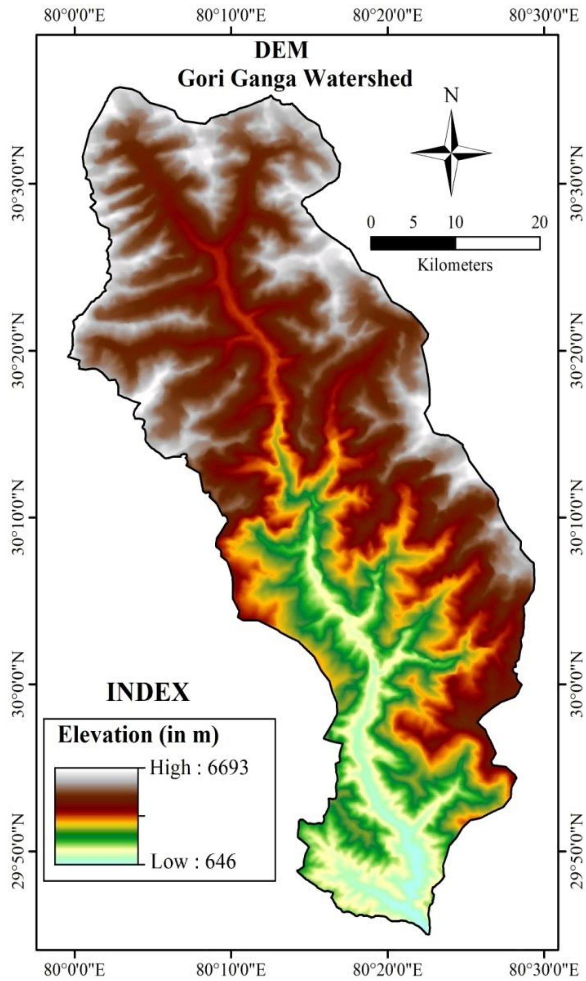
hydrological modeling applications associated with stream flow (Hutchinson et al., 2008).

The flow direction is obtained by checking the elevation difference with the 8 neighboring cells. The D8 flow direction grid defines the flow direction for each cell in a DEM as the direction towards one of its eight adjacent or diagonal neighbors with the steepest downward slope. Figure-4 depicts distribution of flow directions which is based on flow direction grid (Garbecht, 1997). Garbrecht (1997) and ESRI flow direction grid (D8) is an integer raster where values indicated (Fig. 5) coding from center: 1- East, 2- Southeast, 3- South, 4- Southwest, 5- West, 6- Northwest, 7- North, 8- Northeast.



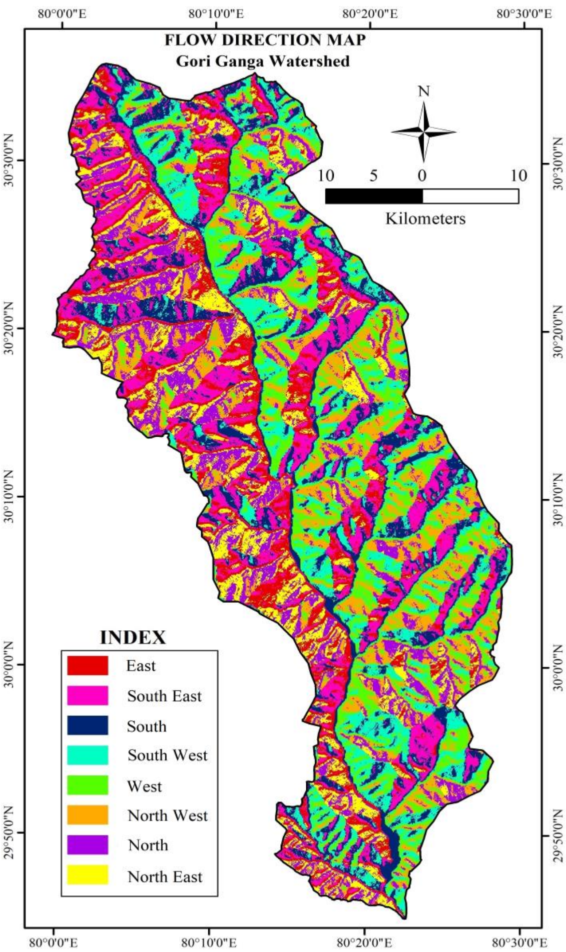


Figure-3: DEM of the Gori Ganga watershed *(based on Cartosat-1 satellite data).*
Figure-4: Flow directions map of the Gori Ganga watershed *(based on Cartosat-1 satellite data).*

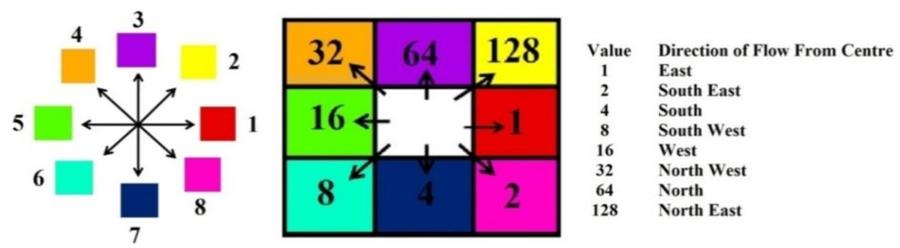


Figure-5: Raster value represents flow direction from the centre *(after Garbrecht, 1997).*

FLOW ACCUMULATION

According to O'Callaghan (1984), interactively looking at each cell and tracing the flow paths directed toward that cell, the number of cells, or contributing area, may be found in each cell. To increase the efficiency of flow accumulations, the matrix may be updated while operating in these recursive calls, allowing for each cell to be visited only once (Tribe, 1992).

Flow accumulation represents the total contributing numbers of stream pixels summed at the target pixel based on flow direction raster (8 directions). A flow accumulation raster records how many upstream cells with contribute drainage to each cell. Eight different colors represent each flow accumulation range as shown in Figure-6.

Stream network can be driven from a flow accumulation raster and derivation based on threshold accumulation value. For example, value 500; mean that each cell of the drainage network has a maximum of 500 contributing cells. A higher value will result in a less dense stream network and fewer internal watershed then lower value. For the best cells seems capture the stream network in the area set threshold values between 100 to 500. Figure-7 is showing the stream network based on a threshold value of 500 cells.

STREAM ORDERING

Stream ordering map (Fig. 8) was prepared following by Strahler method (1964) using DEM with the help of Arc GIS tool. It is found that the Gori Ganga river is 7th order stream (Plate-1). There are as 14374 first order streams, 2033 second order streams, 1093 third order streams, 110 fourth order streams, 28 fifth order streams, 6 sixth order streams and 1 seventh order stream Table-1 contains the number and length of different order streams. The length of the first order streams is about 5572.10 km, second order streams is about 1746.61 km, third order streams is about 611.26 km, fourth order streams is about 291.73 km, fifth order streams is about 184.42 km, sixth order streams is about 66.37 km and seventh order streams is about 89.13 km. The total numbers of streams in the Gori Ganga watershed at 17645 and the total length of all these streams is about 8561.62 km (Table-1).

Table-1: Stream numbers and length of different order streams, numbers and lengths in the Gori Ganga watershed (based on Cartosat-1 satellite data).

Stream order	Number	Stream length (km)
First	14374	5572.10
Second	2033	1746.61
Third	1093	611.26
Forth	110	291.73
Fifth	28	184.42
Sixth	6	66.37
Seventh	1	89.13
Total	**17645**	**8561.62**

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Plate-1: Gori Ganga River at different places of the study area: (A) terminal of Milam glacier and origin place of the Gori Ganga River, (B) at Rilkote, (C) near Dhapa village, (D) at Devi Bagar, (E) at Fagua Bagar and (F) at Ghatta Bagar.

STREAM LINK

Once a stream network is established, stream links are defined as the un-branched segments between junctions in the stream. Interior links have a junction at each end and exterior links, or first order streams occur where a stream is initiated at the upstream end and a junction is at the downstream end (Mark, 1984).

A watershed may then be delineated as the area draining to a given stream link or set of adjacent stream links. A stream link raster therefore resembles a topology-based stream layer: The intersections or junction are link nodes and the stream sections between junctions are link reaches. Figure-9 is depicting the stream links in the study area.

SUB-WATERSHED DELINEATION

A watershed describes an area of land that contains a common set of streams and rivers that all drain into a single larger body of water, such as a larger river, a lake or an ocean (https://water.usgs.gov/edu/watershed.html). A watershed can cover a small or large land area. Small watersheds are usually part of larger watersheds (https://oceanservice.noaa.gov /facts/watershed.html).

AREA WIDE SUB-WATERSHED DELINEATION

Area wide watershed delineation was done for the study area as presented in Figure 10. For this operation flow direction and stream link both raster inputs were used. A denser stream network will have more, but smaller watershed. The missing areas around the rectangular border are areas that don't have flow accumulation values higher than the specified threshold value.

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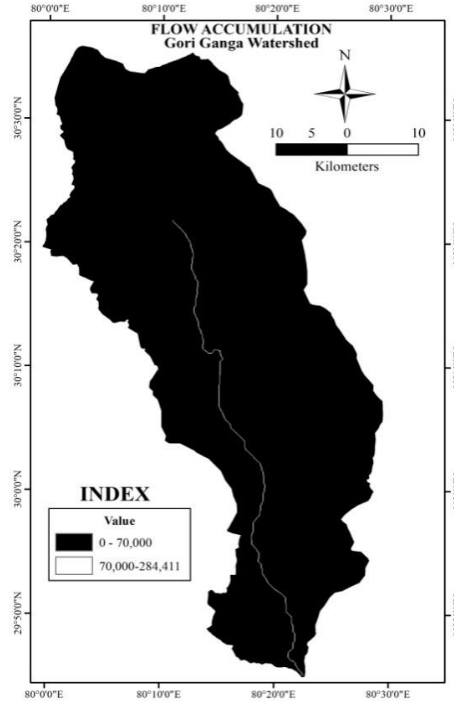
POINT BASE SUB-WATERSHED DELINEATION

The selection of pour points for watershed delineation is the final step. All the water of the watershed flows through the pour point. The pour point defines the lowest point in watershed and must be located on a flow accumulation cell. The chosen pour points will be the basis for the watershed or sub-watershed delineation. Example of point-based watershed delineation is presented in Figure-11 and area of these sub-watersheds is registered in Table-2. Distribution of villages in these sub-watersheds is presented in Table-3 while Figure-12 presented distribution of villages in these sub-watersheds. Examples of some important river valleys and river confluence point in the study area are presented in Plate-2. A brief account of these sub-watersheds is presented below.



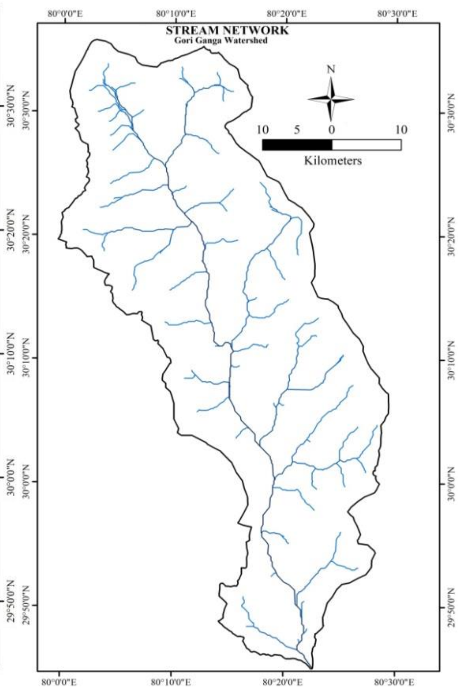
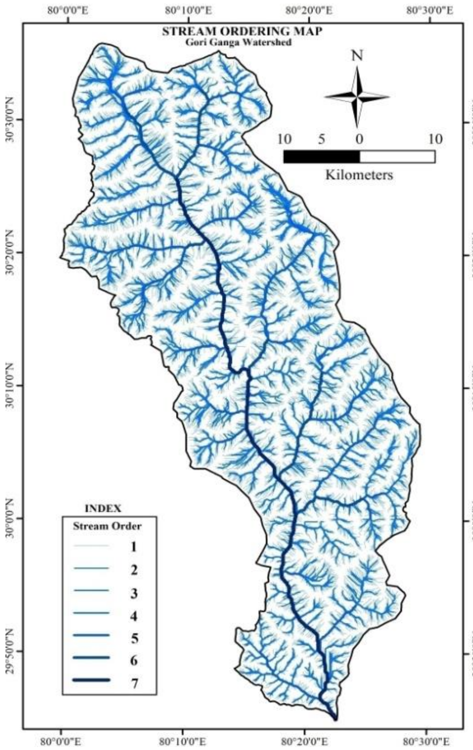


Figure-6: Flow accumulation map of the Gori Ganga watershed (based on Cartosat-1 satellite data).
Figure-7: Stream network map of the Gori Ganga watershed (based on Cartosat-1 satellite data).



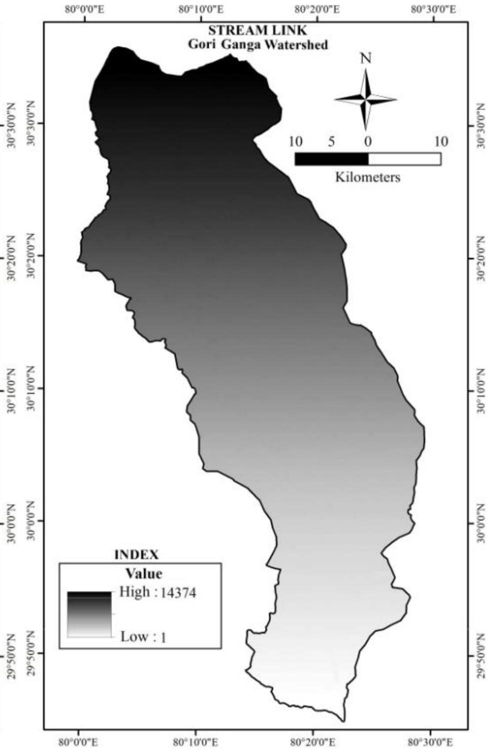
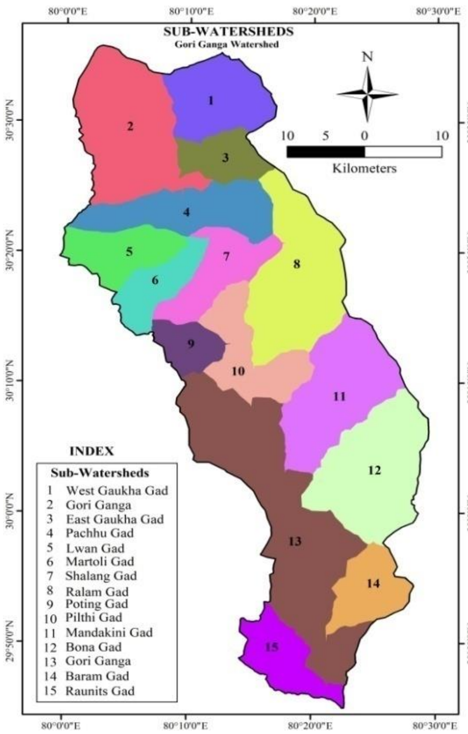


Figure-8: Stream ordering map of the Gori Ganga watershed Kumaun Himalaya (based on Cartosat-1 satellite data).
Figure-9: Stream link map of the Gori Ganga watershed (based on Cartosat-1 satellite data).



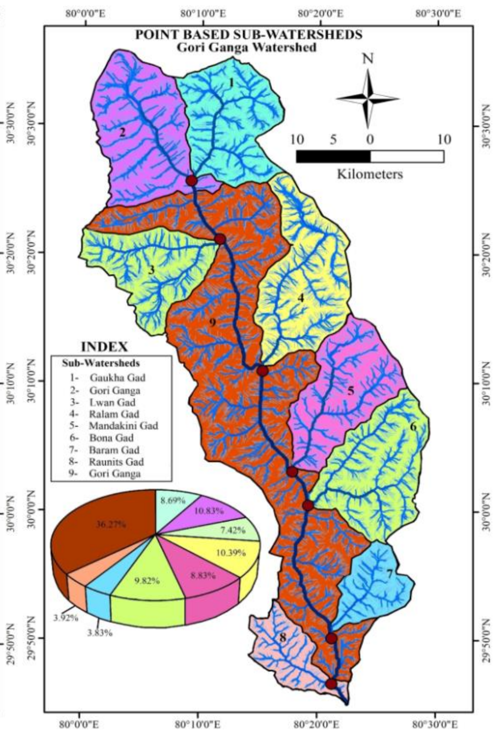


Figure-10: Area wide sub-watersheds of Gori Ganga watershed (based on Cartosat-1 satellite data).
Figure-11: Point-based sub-watershed map of Gori Ganga watershed (based on Cartosat-1 satellite data).

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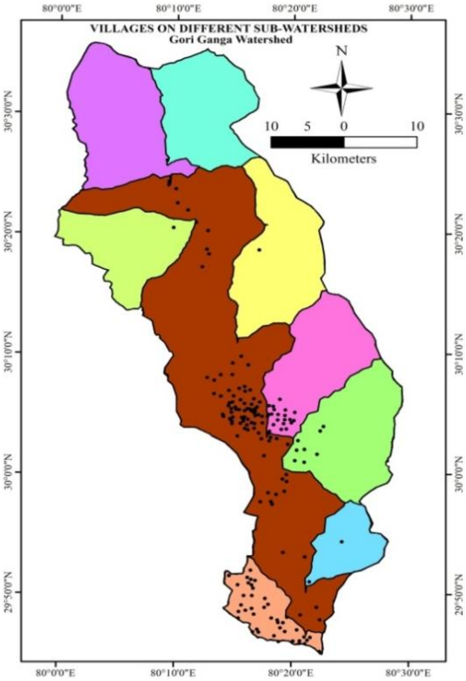

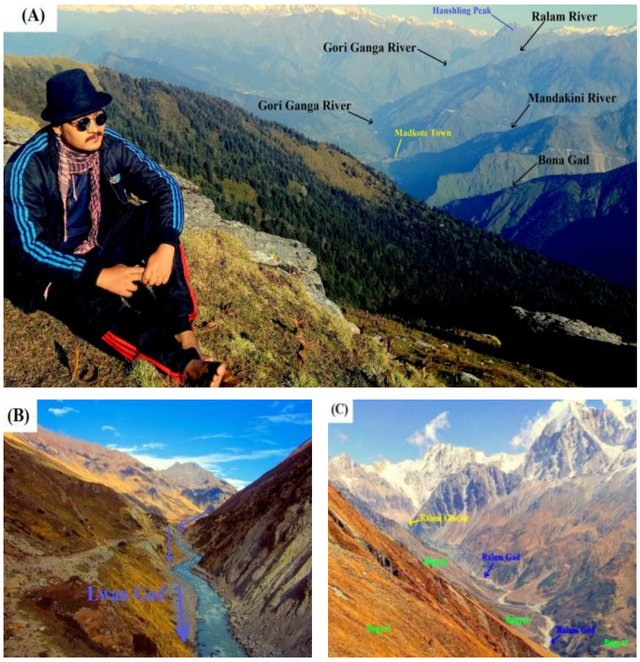

Figure-12: Distribution of villages in sub-watersheds of the Gori Ganga watershed (based on Cartosat-1 satellite data, COI 2011).

Plate-2: Gori Ganga River valley and tributaries rivers in the study area: (A) Gori Ganga valley near Chhipla Kedar Bugyal, (B) Lwan Gad valley and (C) Ralam Gad valley.

Table-2: Distribution of area under point based sub-watersheds in the Gori Ganga watershed (based on Cartosat-1 satellite data)

S. N.	Name of sub-watershed	Area		S. N.	Name of sub-watershed	Area	
		in km^2	in %			in km^2	in %
1	Goukha Gad	190.51	8.69	6	Bona Gad	215.15	9.82
2	Gori Ganga	237.31	10.83	7	Baram Gad	83.97	3.83
3	Lwan Gad	162.53	7.42	8	Raunits Gad	85.91	3.92
4	Ralam Gad	227.82	10.39	9	Gori Ganga	794.97	36.27
5	Mandakini Gad	193.46	8.83		Total	2191.63	100

Table-3: Distribution of number and percentage of villages in the sub-watersheds of the Gori Ganga watershed (*based on COI, 2011*).

S. N.	Sub-watershed	No. of villages		S. N.	Sub-watershed	No. of villages	
		Number	%			Number	%
1	Goukha Gad	0	0	6	Bona Gad	8	4.76
2	Gori Ganga	1	0.60	7	Baram Gad	2	1.19
3	Lwan Gad	1	0.60	8	Raunits Gad	39	23.21
4	Ralam Gad	1	0.60	9	Gori Ganga	95	56.54
5	Mandakini Gad	21	12.5		Total	168	100

Goukha Gad sub-watershed: This sub-watershed encompasses an area about 190.51 km2 which accounts for 8.69% of the total study area (Table-2 and Figure-11).

Gori Ganga sub-watershed: This sub-watershed is part of Milam glacier and the Gori Ganga River originates from this sub-watershed near Milam village. This sub-watershed encompasses an area about 237.31 km2 which accounts for 10.83% in the total study area (Table-2 and Figure-11). This sub-watershed has only 1 village that name is Milam (Table-3 and Figure-12).

Lwan Gad sub-watershed: The Lwan Gad is the western side tributary of Gori Ganga River. This sub-watershed encompasses an area of 162.53 km2 which accounts for 7.42% in the total study area (Table-2 and Figure-11). This sub-watershed is named after Lwan village which has only 1 situated village (Table-3 and Figure-12).

Ralam Gad sub-watershed: The Ralam Gad sub-watershed lies in the eastern part of the Gori Ganga River. This sub-watershed encompasses an area of 227.82 km2 which accounts for 10.39% in the total study area (Table-2 and Figure-11). This sub-watershed has only one village which name is Ralam (Table-3 and Figure-12).

Mandakini Gad sub-watershed: The Mandakini Gad sub-watershed also lies in the eastern part of the Gori Ganga River. This sub-watershed encompasses an area of 193.46 km2 which accounts for 8.83% in the total study area (Table-2 and Figure-11). This sub-watershed has 21 villages. These are Phapa, Wadni Dhar, Bhatkura, Dhuratoli, Dhauliua Dunga, Chulkot, Bothi, Chhija, Ringu, Khata, Gaila Malla, Sana, Dobari Narki, Baiga, Gaila Talla, Rapti, Ropar, Walthi, Dolma, Morpatta, Ghatdhar and Ritha (Table-3 and Figure-12). This watershed has five roads. These are Madkote to Chulkote, Pithoragarh to Munsyari, Walthi Bona, Walthi to Gaila and Basantkote to Chulkote Road. The total length of these roads is about 22.54 km. In this sub-watershed there are four watermills which are located at Ropar, Dobari, Rapti and Khata villages.

Bona Gad sub-watershed: The Bona Gad sub-watershed encompasses an area of 215.15 km2 which accounts for 9.81% in the total study area (Table-2 and Figure-11). This sub-watershed has 8 villages. These are Bindi, Lodi, Bona, Tomik, Tanga, Pharwakot, Nirtoli and Bata (Table-3 and Figure-12). This sub-watershed has seven roads. These are Tanga Road, Pithoragarh to Munsyari, Walthi to Bona, Sera to Sirtola, Seraghat to Lodi, Bindi Road and Balibagar to Pharwakot Road. The total length of these roads is about 21.40 km. In this sub-watershed there are four watermills which are located at Pharwakot, Bindi, Bona Gad and Bona.

Baram Gad sub-watershed: The Baram Gad sub-watershed encompasses an area of 83.97 km2 which accounts for 3.83% in the total study area (Table-2 and Figure-11). This sub-watershed has 2 villages. These are Baram and Kanar (Table-3 and Figure-12). This sub-watershed has three roads. These are Baram to Kanar, Pithoragarh to Munsyari and Baram to Goge. The total length of these roads is about 14.91 km. There are two watermills in the study area which are located at Baram and Kanar.

Raunits Gad sub-watershed: The Reunits Gad sub-watershed lies in the western part of the Gori Ganga River. This sub-watershed encompasses an area of 85.91 km2 which accounts for 3.91% in the total study area (Table-2 and Figure-11). This sub-watershed is densely populated area and has 39 villages. These are Tham, Garjiya, Dewal, Chamlekh, Kuta, Basaur, Khetar Bhandari, Raitoli, Dhaniya Khan, Dhunga, Barigaun, Jogyura, Lohargaun, Jamtari, Bankoo, Pamsyari, Hunera, Khoja, Doonakot, Humkapita, Mahargari, Bora Gaun, Koonia, Barna Airi, Khetar Kanyal, Kauli Kanyal, Baya Gaun, Kaindi, Panthali, Sinquali, Garsoli, Mirthi Biniya, Bichhata, Sirtoli, Khariyani, Chhabbisa, Nakote, Matayula and Darti (Table-3 and Figure-12). There are two roads. These are Pithoragarh to Munsyari and Dharchula Jauljibi Road. The total length of these roads is about 5.31 km. In this watershed there is one watermill which is located at Bari Gaun.

Gori Ganga sub-watershed: The Gori Ganga sub-watershed encompasses an area of 794.97 km2 which accounts for 36.27% in the total study area (Table-2 and Figure-11). This sub-watershed is also highly inhabited and has 95 villages. These are Martoli, Tola, Rilkote Old, Laspa, Khilanch,Dhapa, Ugarali, Suring, Bachhepur, Harkot, Uchhaiti, Imla, Josha, Alam, Khartoli, Madarma, Darma, Mawani Dawani, Porthi, Seeling, Sirtola, Sain Polo, Saimat, Zimiya, Sera, Mani Dhami, Basantkot, Umadada, Pyangti, Dhunamani, Kultham, Dheelam, Dumar Talla, Sainar, Jalath, Dumar Malla, Darkot, Phalyati, Shankh Dhura, Bunga, Sarmoli, Jaiti, Namjala, Ranthi, Darati, Gopal Bara, Diya Walla, Dadabisa, Diya palla, Minal Gaon, Buie, Pato, Leelam, Ghorpatta Malla, Jaduk, Barniya Gaon, Telkot, Teli, Akhoriya, Sela, Khasiya Bara, Dhamikura, Kawa Dhar, Kaiti, Cheti Chimla, Sera Surai Dhar, Sela Chital, Sella Malla, Charkham, Ghor Patta Talla, Sebila, Papri, Mana Chulankar, Matena, Matyali, Malupati, Bhadeli, Chauna, Kholi, Pachhu, Bilju, Burphu, Mapa, Ganghar, Kotal Gaon, Kanalka, Lumti, Quiri, Metali, Toli, Bangapani, Payya Pori and Garali (Table-3 and Figure-12). This watershed has 26 roads and total length of these roads is about 208.52 km. In this watershed there is 21 watermills which is located at Garali, Umargada, Sera, Dhoonamani, Golma, Imla, Josha, Mtyani, Harkote, Talla Ghorpatta, Dhapa, Syannar, Sain, Quiry, Sain Polu, Jimighat, Gopal Bara, Basantkote, Bachchepur, Jara Jibli and Jara.

CONCLUSION

Based on the study on the delineation and classification of watershed area of the Gori Ganga watershed, the following may be conducted: Using pour point technique of GIS, the Gori Ganga watershed is divisible in to 9 sub-watersheds. The size of these sub-watershed varies in between 83.97 km2 (viz., Baram sub-watershed) and 794.97 km2 (viz., Gori Ganga sub-watershed). There are total 168 villages situated in 8 sub-watersheds in which those number of villages varies in between 1 (viz., Gori Gad, Lwan Gad and Ralam Gad sub-watershed) and 95 (viz., Gori Ganga sub-watershed). There is no village's in the Goukha Gad sub-watershed area. There are 7 sub-watersheds (viz., Goukha Gad, Gori Ganga, Lwan Gad, Ralam Gad, Bona Gad, Mandakini Gad and Gori Ganga) which are glacial fed and remaining two sub-watersheds (viz., Raunits Gad and Baram Gad) are non-glacier fed. In all the watershed total number of streams is 17645 and total length of these streams is 8561.62 km. Remote sensing and GIS are very useful techniques for watershed analysis. This technique very helpful in delineation of watershed and determination of stream network analysis through DEM.

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