CHAPTER IV

ANALYSIS AND INTERPRETATION

4.1INTRODUCTION

Hydrometeorology is a branch of meteorology and hydrology that involves the transfer of water and energy between the land and the lower atmosphere**.** It deals with problems involving the hydrologic cycle, the water budget, and the rainfall statistics of storms. Other concerns of this branch of science include the determination of rainfall probabilities, the space and time distribution of rainfall and evaporation, the recurrence interval of major storms, snow melt and flood event. The hydro-meteorological parameters represent and exhibit the nature of the environment of a river basin. Various climatic variables such as rainfall, temperature, wind direction and evapo-transpiration together with physiographic factors such as drainage pattern, slope and aspect factors play significant role in the Hydrometeorology of a river basin. High mountain areas play a most decisive role in the areal distribution of precipitation and thus the water resources of the continents. As a result of the forced orographic lifting of the advective air masses or of the enhanced convective activity in the elevated source areas of sensible heat and water vapour, most of the earth's mountain regions are extraordinarily rich in water resources and in many of the world's long river systems the water flow originates mainly from high mountain areas which provide a dependable source of water supply for our societies (Lang, 1996). In our study area the hydrometeorological parameters like temperature, rainfall and water flow are analysed with the help of available data.

4.2 MATERIAL AND METHODS

The data are collected from various government departments and published research papers, reports etc. for the stations viz. Chauldhoaghat and Dam site of the eastern Himalayan region and Rudraprayag and Joshimath of the western Himalayan region. These comprise Survey of India toposheets, daily discharge data, daily rainfall data, mean monthly temperature data, mean annual flow data, monthly rainfall data and monthly temperature data etc. The study is based on geospatial as well as conventional database. The IHA (Indicators of Hydrologic Alteration) software is used to generate few graphs on relevant themes.

4.3 ANALYSIS OF HYDROMETEOROLOGICAL PARAMETERS OF THE SUBANSIRI AND THE ALAKNANDA BASINS

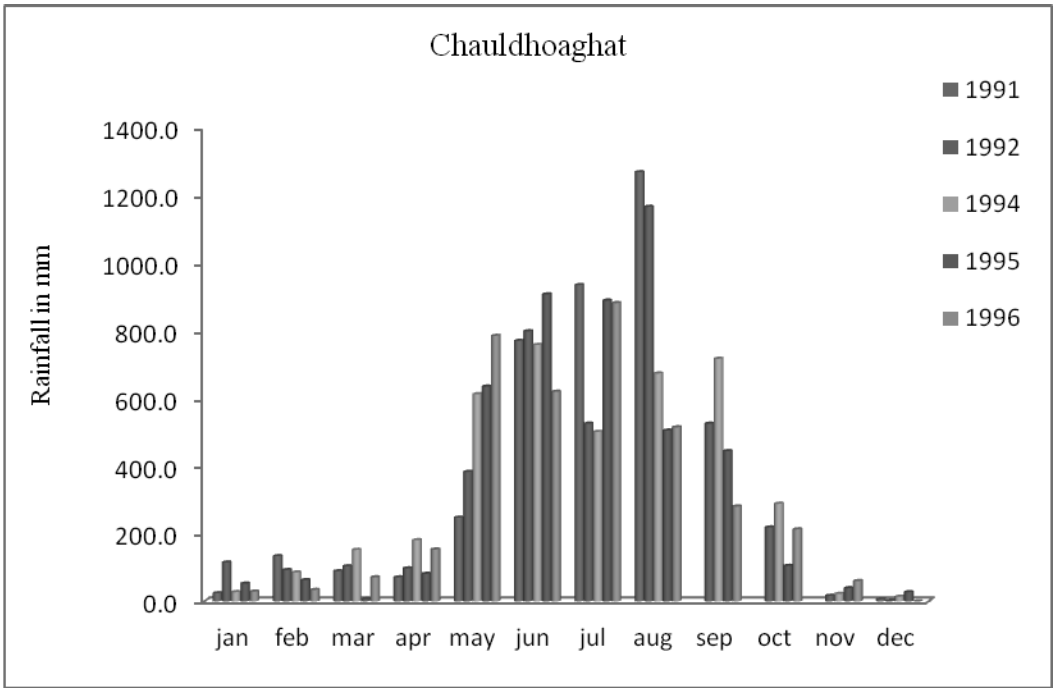
For the hydrometeorological comparison, data on rainfall, temperature and discharge are taken mainly from two gauging stations viz. Chauldhoaghat and Dam site of the Subansiri basin in eastern Himalayas, while similar data from the stations viz. Rudraprayag and Joshimath are analysed for the Alaknanda basin of western Himalayas (Data in Table I - XIII in Appendix 2).

For investigation of rainfall in the Subansiri basin, data from Chauldhoaghat and North-Lakhimpur stations are analysed for the years 1992-96. On the other hand, for the Alaknanda basin, rainfall and temperature data available for Rudraprayag and Joshimath are analysed for the years 2004-07. Rainfall data of the period 2007-09 were also available for the North-Lakhimpur station.

Mean monthly, maximum and minimum temperature data are analysed from North-Lakhimpur station for the years 1992-96.

Water discharge data from the stations Chauldhoaghat and Dam site are analysed to obtain the hydrographs, environmental flow components and annual flow duration curve for the years 1992-96. On the other hand, annual flow data of the period 1971-2003 are used to draw the mean annual, maximum annual and minimum annual hydrographs.

From the rainfall investigation (Figures 4.1, 4.2, 4.3a, 4.3b and 4.4) it is revealed that the rainfall is highly seasonal and dominated by monsoon in Subansiri river basin. Based on the investigation it is seen that the rainfall is comparatively more in the stations of Subansiri basin of eastern Himalaya than the stations of the Alaknanda basin of western Himalaya. The seasonality of rainfall pattern is also more pronounced in case of the Subansiri. It is seen that the temperature is relatively more (Figures 4.5, 4.6) in the Alaknanda basin compared to the Subansiri basin and the temperature decreases as the altitude increases.



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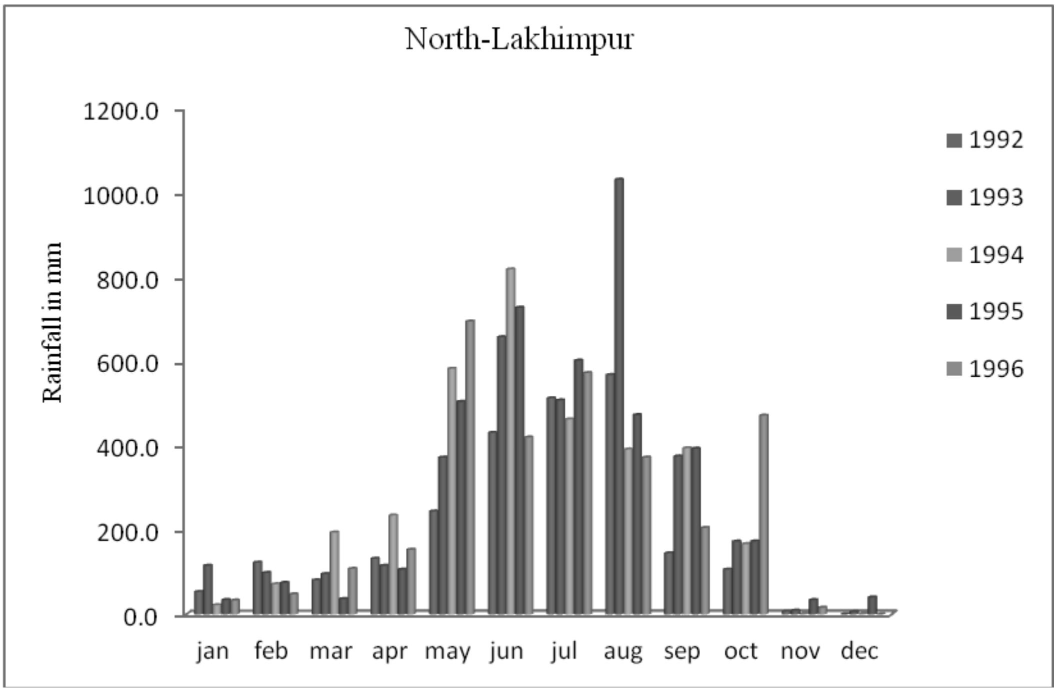
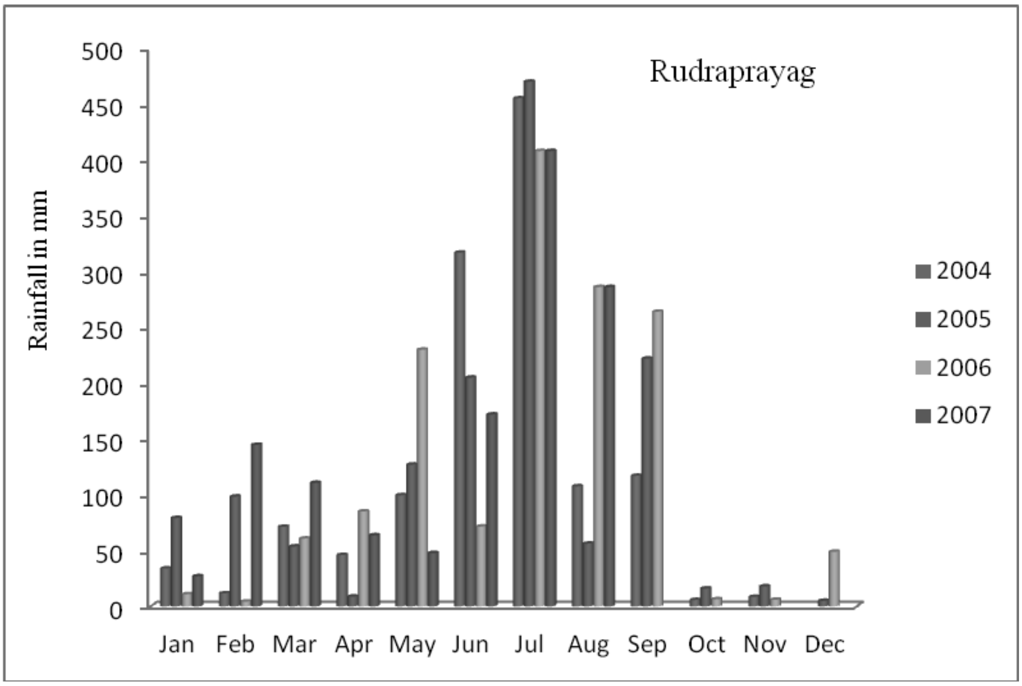


(b)

Figure 4.1: Monthly total rainfall (mm) at (a) Chauldhoaghat and (b) North-Lakhimpur from 1992 to1996



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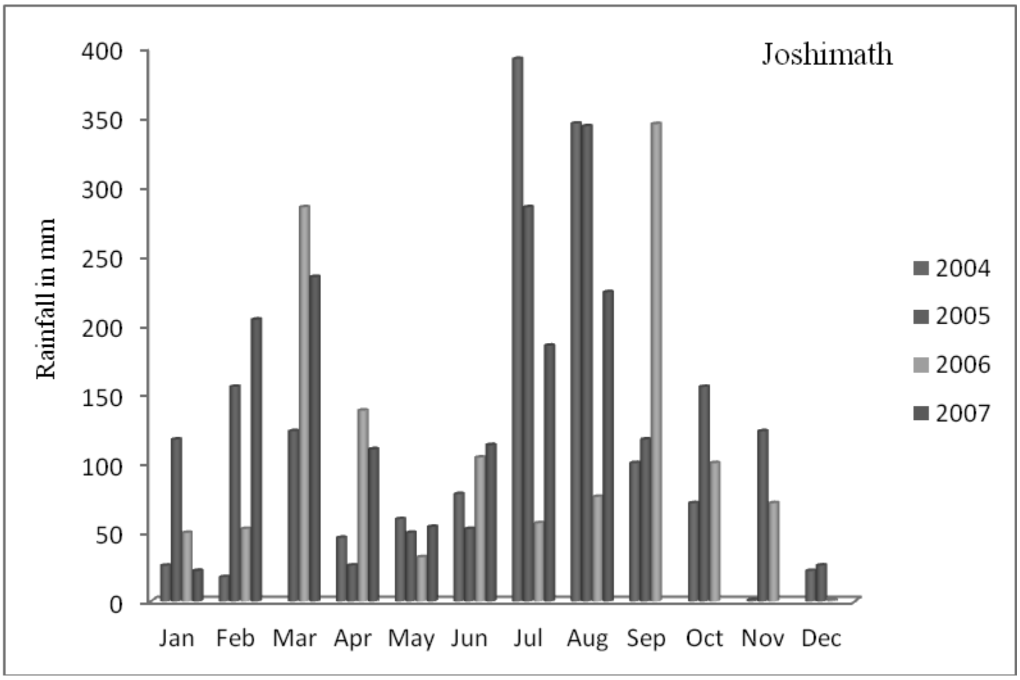


(b)

Figure 4.2: Monthly total rainfall (mm) at (a) Rudraprayag and (b) Joshimath from 2004 to 2007

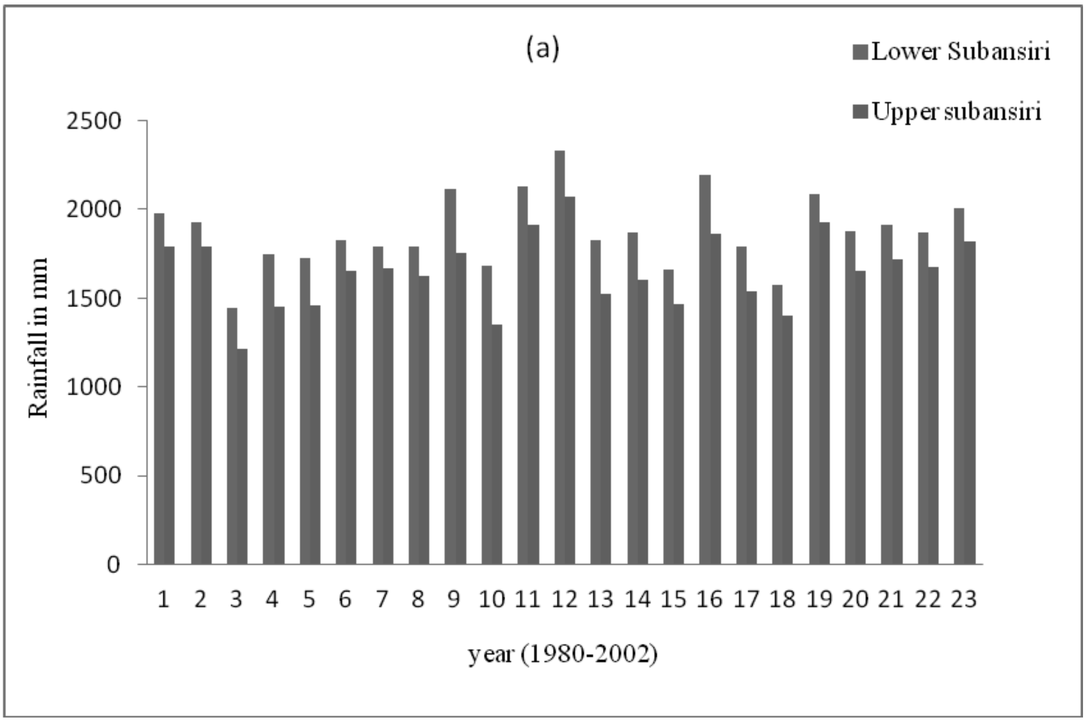


Figure 4.3(a): Annual rainfall (mm) in the districts of the Subansiri basin

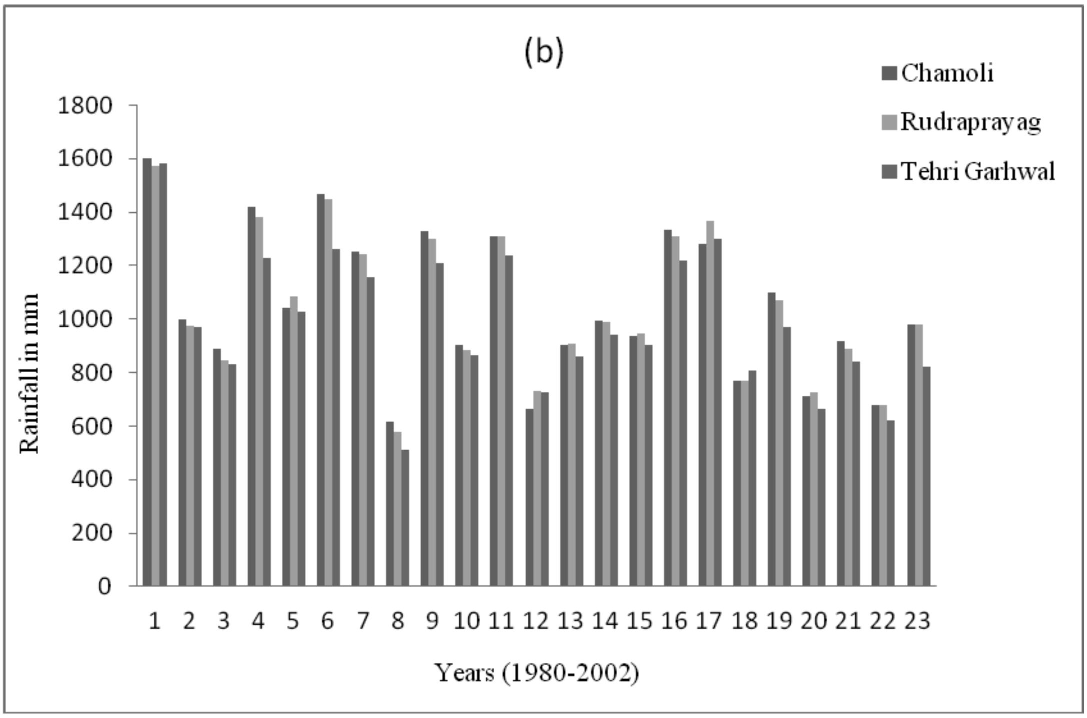


Figure 4.3(b): Annual rainfall (mm) in the districts of the Alaknanda basin from 1980 to 2002

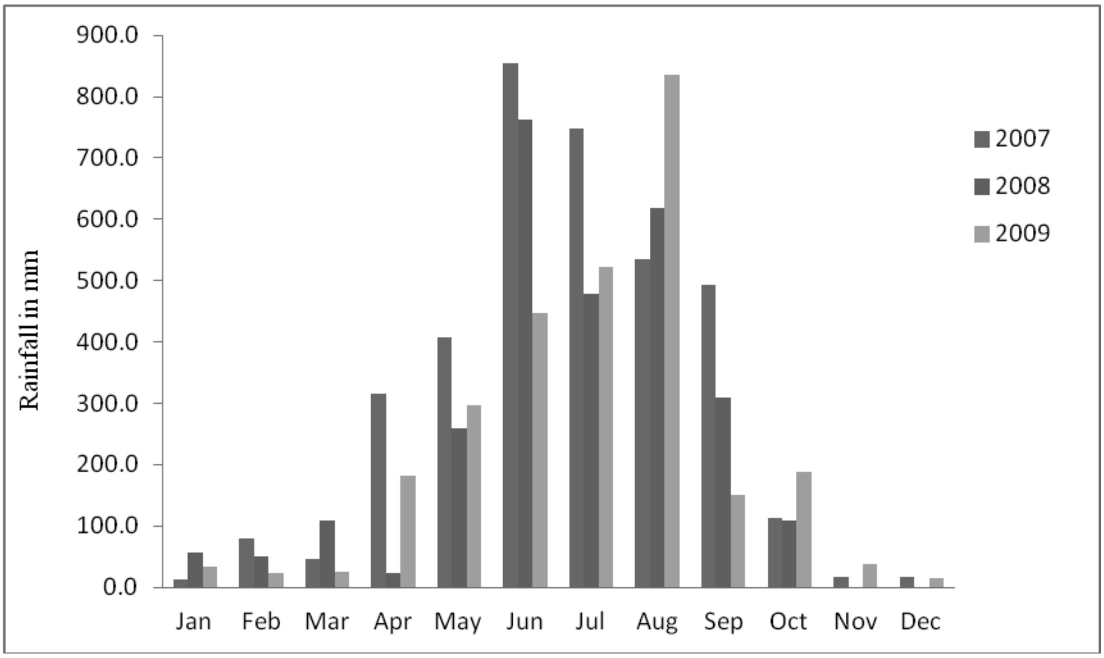


Figure 4.4: Monthly total rainfall (mm) at North-Lakhimpur from 2007 to 2009

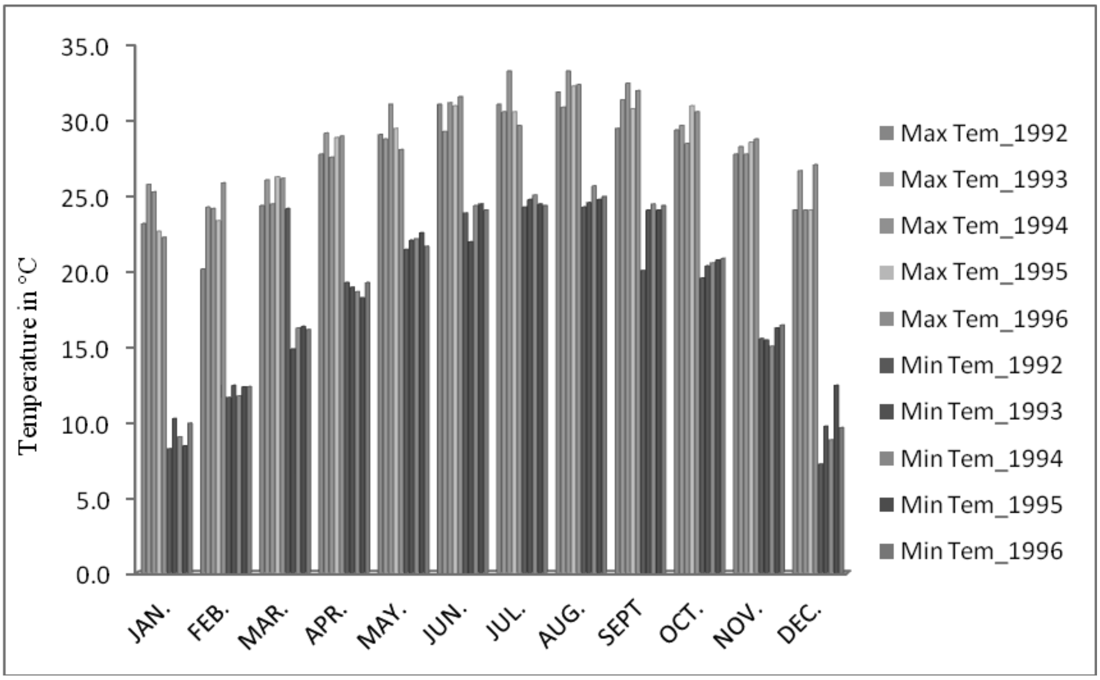
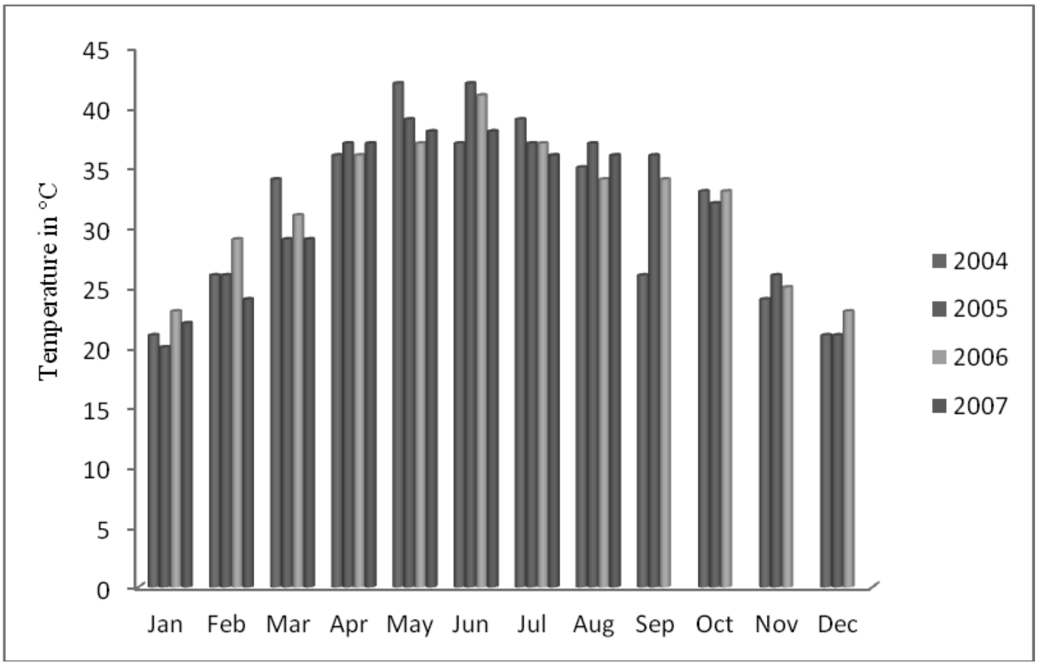
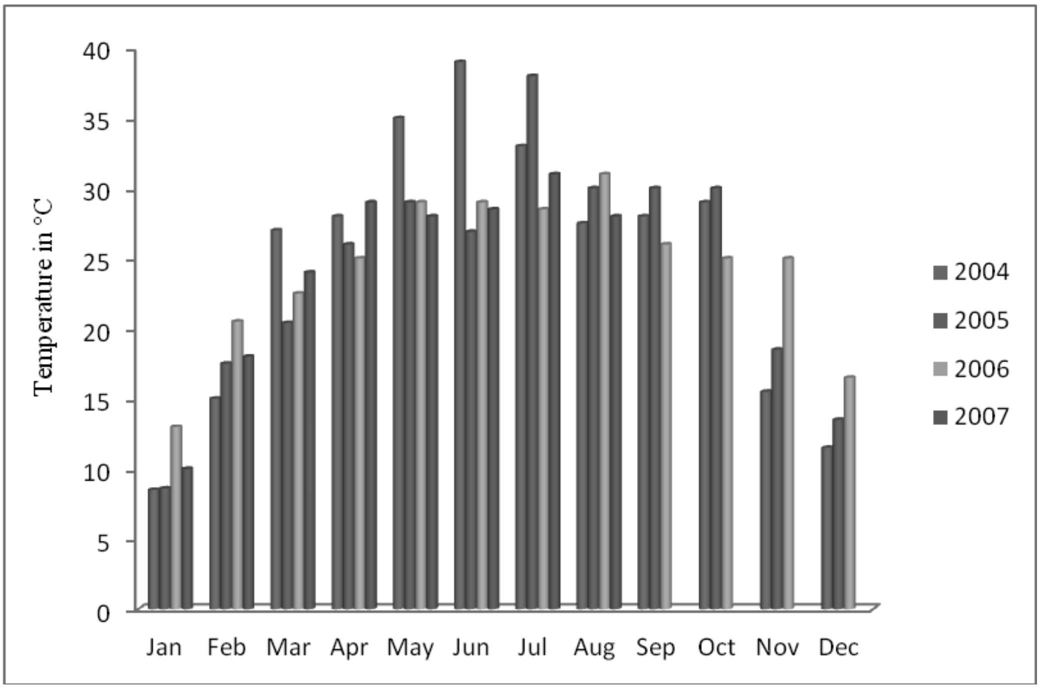


Figure 4.5: Mean Monthly maximum temperature and minimum temperature (°C) at North-Lakhimpur from 1992 to 1996



(a)



(b)

Figure 4.6: Mean Monthly temperature (°C) at (a) Rudraprayag and (b) Joshimath from 2004 to 2007

The hydrographs (Figure 4.7) of both the stations viz. Chauldhoaghat and Dam site indicate significantly high flow peaks during the monsoon period and more flow at the downstream station Chauldhoaghat than the Dam site of Subansiri basin of eastern Himalayas. Based on the available data comparison of flow with rainfall is shown in the Figure 4.8 at the station Chauldhoaghat and dam site for the year 1996. Both the two graphs are synchronizing in nature. On the other hand, the mean annual, maximum annual and minimum annual flow investigation of the stations viz. Rudraprayag and Joshimath shows (Figure 4.9) that the flow at Rudraprayag is more than that of Joshimath of Alaknanda basin of western Himalayas.

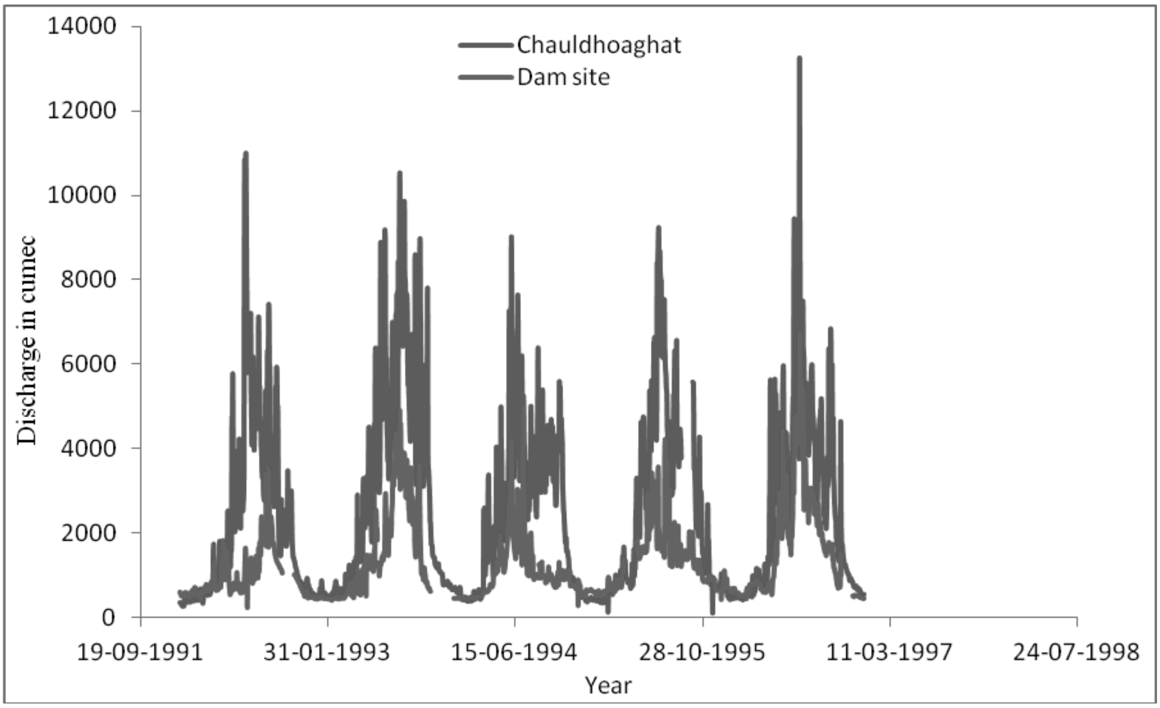


Figure 4.7: Hydrographs at Chauldhoaghat and Dam site

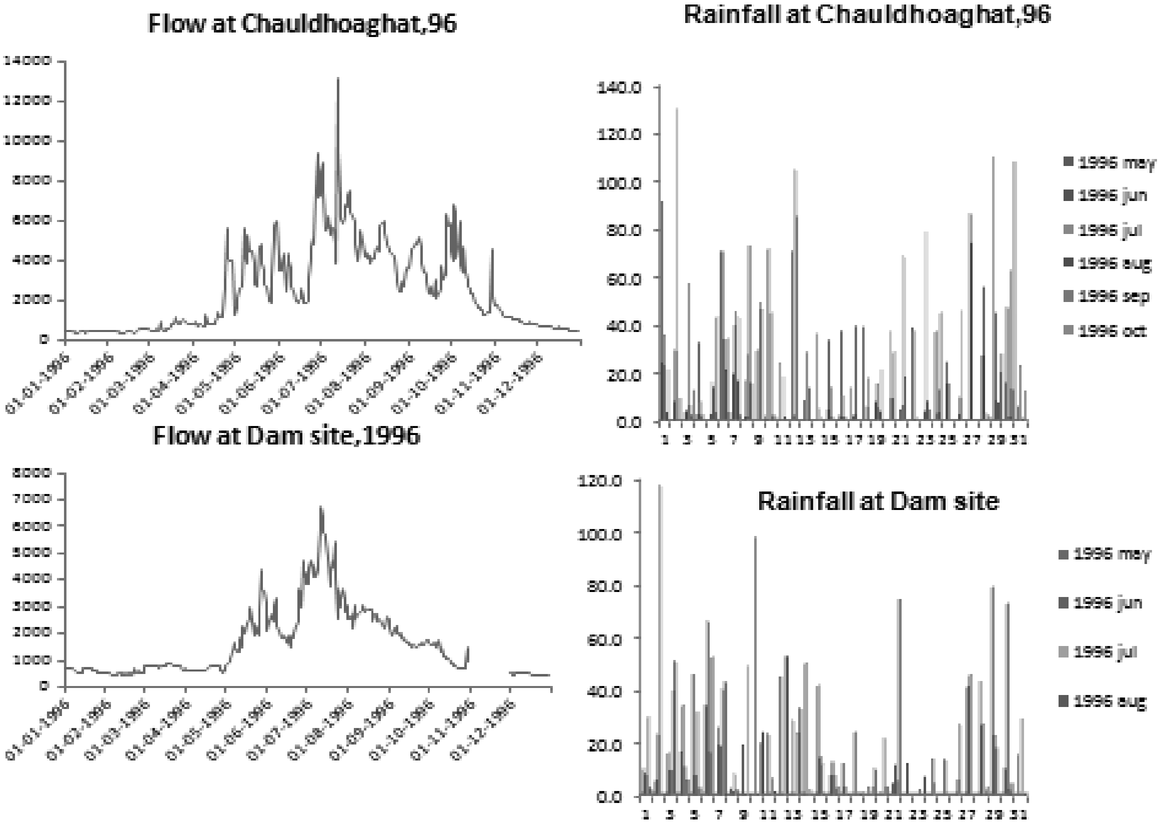
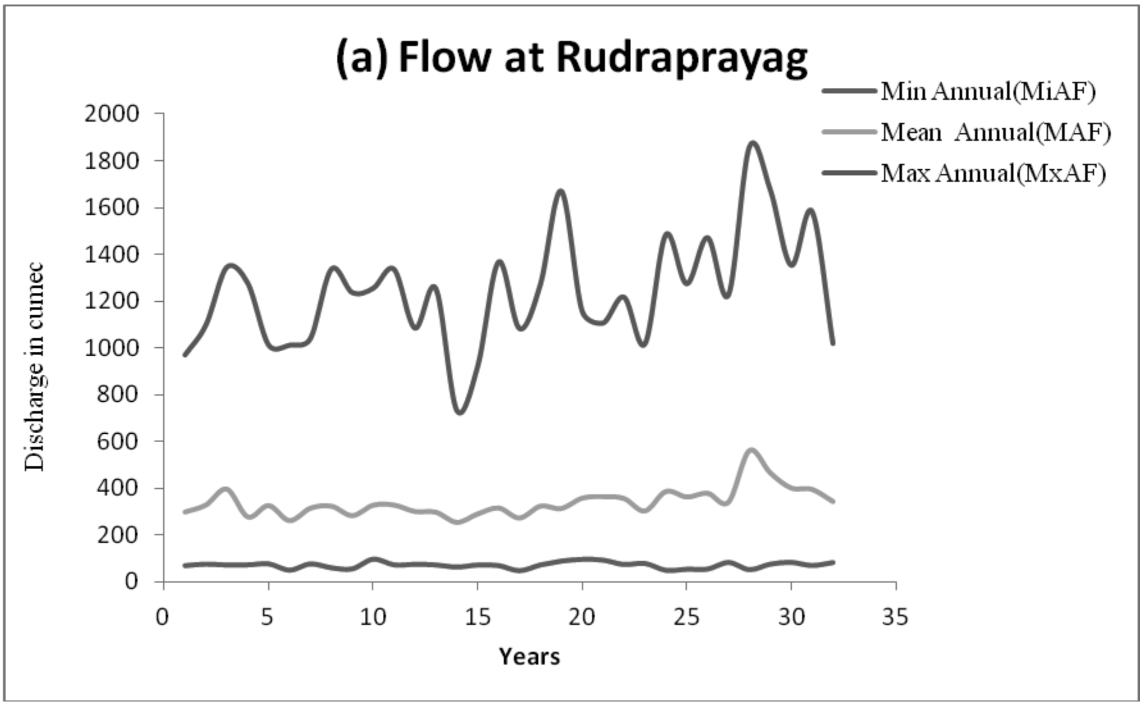


Figure 4.8: Comparison of flow with rainfall at Chauldhoaghat and Dam site in 1996

In Chauldhoaghat relatively small floods were observed in 1992 and 1993 while in the dam site such small floods occurred in 1993 and in 1994. But in the year 1996 large floods (Figure 4.10) were common in both the stations. The environmental flow component analysis also shows the high flow pulses during the monsoon period in both the stations and extreme low flow during the pre and post monsoon period. The annual flow duration curves (Figure 4.11) show that the 75% dependability exceeded 1000 m^3/s in Chauldhoaghat but less than 1000 m^3/s in case of Dam site.



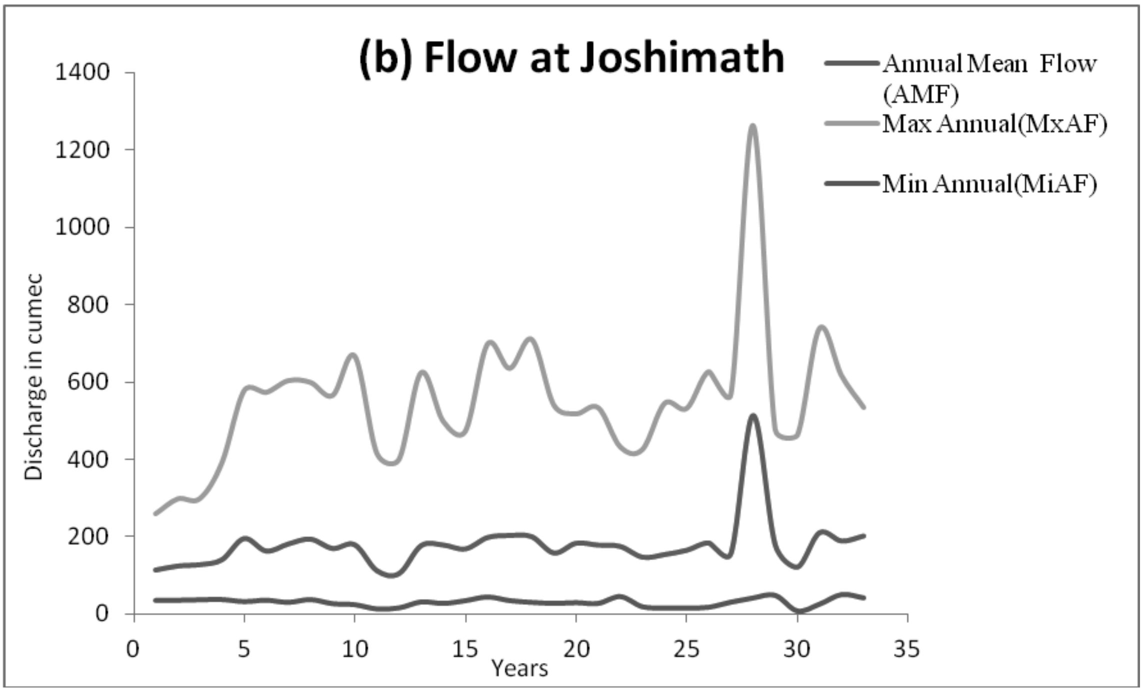


Figure 4.9: Mean Annual, Maximum Annual and Minimum Annual flow (m^3/s) at (a) Rudraprayag and (b) Joshimath from 1971 to 2003

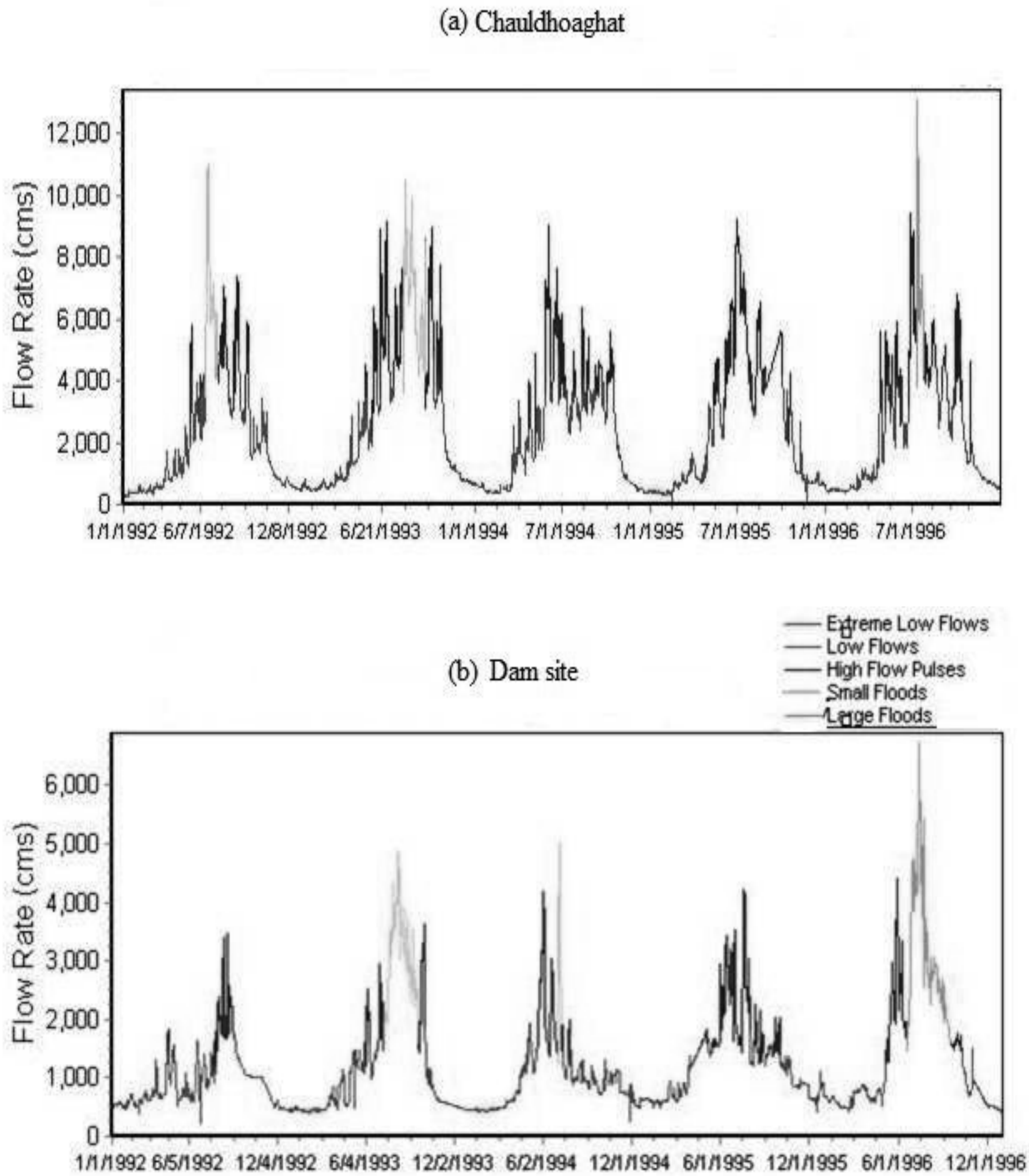


Figure 4.10: Environmental Flow components of the Subansiri river at (a) Chauldhoaghat and (b) Dam site

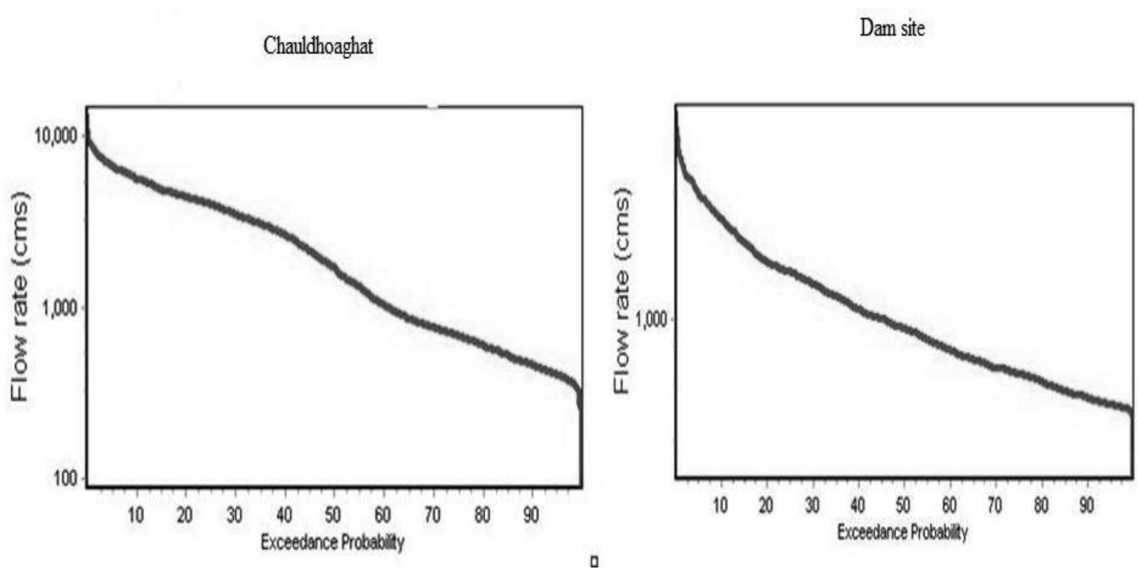


Figure 4.11: Annual flow duration curves of Subansiri river at Chauldhoaghat and Dam site from 1992 to 1996

The above investigation shows that the monsoon rainfall is more dominant in the eastern Himalayan region than in the western Himalayan region, while the temperature is comparatively high in the stations of the Alaknanda basin of western Himalaya. The comparison of flow patterns in the two rivers show that relatively high flows characterize the Subansiri basin as against the Alaknanda basin of western Himalaya for the same season. The high flow in the Subansiri basin may be primarily due to the intense monsoon rainfall in the eastern part of the Himalayas, accentuated further by unique physiographic and ecological setting (Devi and Goswami, 2014).

In the high mountain elevations an increasing amount of precipitation is accumulated as temporary snow cover or, above the climatic snow line, forms perennial snow fields and glaciers. This naturaly stored water feeds the river flow with melt water, often during the same season that purely rainfed rivers are at minimum flow. Lack of gauge stations in the high altitude causes uncertainity of the vertical gradients in precipitation and these types of gauge stations may strongly affected by the systematic wind-induced error (Lang, 1996).

4.4 ANALYSIS OF SELECTED ENVIRONMENTAL PARAMETERS OF WATER QUALITY

Water quality parameters of river water provide us the concept of the suitability of the utilization of the water body and how it is affected by the biotic and abiotic factors of its surrounding. Testing of Water quality parameters are essential tasks in present times because of the tremendous growth of population, land use change as well as urban development. It is important for evaluating management strategies for a watershed. Changes of water quality may occur due to the construction of dams and natural disasters.

In this chapter a few parameters of water quality of the Subansiri river in eastern Himalaya and the Alaknanda river of western Himalaya have been analysed to observe the difference between the water quality of the two opposite parts of the Himalayas. Keeping this issue in mind, few samples of water have been collected in the monsoon season from the accessible as well as comparable locations of both the river basins. Standard methodologies (APHA, 1995) were adopted to analyse the data and got the values for the samples. The results of the analysis are compared with the drinking water quality standards such as WHO and BIS.

4.4.1 Significance and methodology of the parameters tested

pH: The balance of positive hydrogen ions (H+) and negative hydroxide ions (OH-) in water determines how acidic or basic the water is. It determines which ions with a positive or negative electrical charge dominate. The pH scale ranges from the 0 to 14. River water in areas not influenced by pollution generally has a pH in the range 6.5-8.5 (Hem, 1991). pH is measured by pH meter provided with a pH electrode. pH meter is calibrated against standard buffer solution. The samples are taken in a beaker and the electrode of the pH meter is dipped into it and the pH is recorded.

Electrical Conductivity: It is a measure of ability of water to pass an electrical current. Pure water is a poor conductor of electricity. Presence of acids, bases and salts in water make it relatively good conductor of electricity. Such substances are called electrolytes and electrolytes in a solution dissociate into cations and anions and impart conductivity. Thus higher the concentration of electrolytes in water the more is its electrical conductance and lesser the resistance. It is claimed that, other things being equal, the richer a body of water in electrolytes the greater is its biological productivity.

Conductance is the reciprocal of the resistance involved and the unit of measure of conductance is reciprocal ohm designated as mho or Siemens (S). As conductivity varies with temperature, it is conveniently reported at 25° C. Conductivity is measured with the help of a digital conductivity meter. Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows (AHEC/2011).

The calculation of Conductivity is

EC (S) = OEC x CC x TF at 25° C

Where, EC = electrical conductivity

OEC= observed conductance

CC = cell constant (supplied by the manufacturer)

TF = temperature factor

Turbidity: Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. It refers to the clarity of water. Turbidity in water is caused by suspended matter such as clay, silt, organic matter, phytoplankton and other microscopic organisms. It is actually an expression of the optical property (Tyndall effect) that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample.

Turbidity, when caused largely because of phytoplankton, is considered as an index of productivity. But on the contrary, when causes because of suspended matter other than phytoplankton, it restricts the light penetration in water resulting in reduced primary production (by photosynthesis). The instrument used was Nephelometer (turbidimeter). The volumes were calibrated with respect to a set of formazine suspensions of known turbidity and are given in nepheloturbidity units (NTU). The calculation for measuring turbidity is Turbidity, NTU = Nephelometer reading x 0.4 x dilution factor.

Total Solids (TS): A well mixed sample is evaporated in a weighted dish and dried to constant weight in an oven at 103 to 105 ºC. The increase in weight over that of the empty dish represents the total solids. It is calculated as

TS mg/L = (A-B) x 1000/sample volume (ml)

Where A= weight of dried residue + dish (mg)

and B= weight of the dish (mg)

Total Dissolved Solid (TDS): It refers to the total amount of all inorganic and organic substances that are dispersed within a volume of water. High TDS typically indicate hard water and may have bitter or salty taste. Though TDS is generally not considered as health hazard, still further testing may be warranted, as water with a high TDS concentration may indicate elevated levels of ions that do pose a health concern, such as aluminium, arsenic, copper, lead, nitrate and others (Bruvold and Ongert, 1969, WHO, 1989). It is calculated as

TDS mg/L= (A-B) x 100/sample volume (ml)

Where A= weight of dried residue + dish (mg)

and B= weight of the dish (mg)

Total Suspended Solid (TSS): It can be calculated by the difference between the total solids and total dissolved solids. It is responsible for turbidity.

TSS= TS-TDS

Total Hardness: Total hardness is defined as the sum of the calcium and magnesium concentrations in the water sample and is expressed as milligram calcium carbonate per litre. Total hardness of the water samples was determined by EDTA coplexometric titration using erichrome black T indicator. Ethylenediaminetetraacetic acid (EDTA, sodium salt) forms a chelated soluble complex when added to a solution of certain metal cations. If a small amount of a dye such as erichrome black T indicator is added to an aqueous solution containing calcium and magnesium ions at pH of 10.0± 0.1, the solution becomes wine red. If EDTA is added as a titrate, due to its stronger affinity towards Ca^{++} and Mg^{++}, the former complex is broken down and a new complex of blue colour is formed, thus marking the end point of the titration.

Hardness as mg/L $CaCO_3$=ml EDTA used x1000/ml sample

Classification of Hardness:

Concentration of $CaCO_3$

0 to 60 mg/L --------------------------- Soft water

60 to 120 mg/L-------------------------- Moderately hard water

120 to 180 mg/L------------------------- Hard water

>180 mg/L------------------------------- Very hard water

(a) (b)

Plate 4.1: Water sampling and recording GPS coordinates at (a) Chauldhoaghat, Subansiri river and at (b) Srinagar, Alaknanda river

Nitrate: Nitrate (NO_3^-) is colourless, odourless and tasteless and so it is undetectable without laboratory testing. Nitrate reacts with phenol disulfonic acid to form a nitro-derivative which develops a yellow colour in alkaline medium. The concentration of nitrate can be determined colorimetrically, since the colour so formed obeys the Beer's law.

Sulphate: Sulphate ($SO_4^{- -}$) is widely distributed in nature. It is measured by Turbidimetric method. Sulphate is precipitated in the form of barium sulphate by adding barium chloride in hydrochloric acid medium. The concentration of the sulphate can be determined from the absorbance of light on a spectrophotometer at 420 nm wavelength by barium and then measuring it with the help of a standard curve.

Phosphate: it is occured in natural water. The phosphates (PO_4^{---}) in water react with ammonium molybdate and form complex heteropoly acid, which gets reduced to a complex of blue colour in the presence of $SnCl_2$. The absorption of light by this blue colour can be measured at 690 nm and the concentration of phosphates is calculated. 50 ml water sample is taken in a conical flask after filtration and 2 ml ammonium molybdate and 5 drops $SnCl_2$ are added to the sample. A blue colour appears and the absorbance is measured at 690 nm by spectrophotometer to have the standard curve to calculate the phosphate concentration.

Chloride: Chlorine, in the form of chloride (Cl^-) ion is one of the major inorganic anions in water. Natural fresh waters, in general, have low chloride concentration, often less than that of bicarbonates and sulphates. High concentration of chloride in natural fresh waters is considered to be an indicator of pollution due to organic wastes of animal origin as animal excreta has high quantity of chlorides along with nitrogenous wastes. Chloride content above 250 mg/l makes water salty in taste; however, a level up to 1000 mg/l is safe for human consumption. Chloride is determined by titration with standard silver nitrate solution using potassium chromate as indicator. It is called Argentometric method. Silver nitrate reacts with chloride to form very slightly soluble white precipitate of AgCl. At the end point when all the chlorides get precipitated, free silver ions react with chromate to form silver chromate of reddish brown colour.

$$\text{Chloride (mg/L)} = V \times N \times 35.457 \times 1000/S$$

Where, V= volume of titrate (ml)

N= normality of titrant

S= volume of sample (ml)

Sodium: Sodium (Na^+) is the sixth abundant element in most natural waters. This cation occurs generally in lower concentration than calcium and magnesium in fresh waters and makes its way in water through weathering of rocks. High sodium content in the form of chloride and sulphate makes the water salty in taste and unfit for human consumption. High sodium content in irrigation water causes puddling of soil. As a result, water intake of soil is reduced and it becomes hard in which germination of seed becomes difficult. It is measured by using Flame Photometer. The filter is set at 589 nm.

Potassium: This cation occurs in natural waters in far lesser concentration than calcium, magnesium, and sodium. Though found in small amounts it plays a vital role in the metabolism of freshwater environments and considered to be an important micronutrient. Potassium (K^+) is measured by using Flame Photometer. The filter is set at 769 nm and the same procedure as of Na^+ is followed for K^+ determination. Finally standard curve is prepared using standard potassium solutions and result of K^+ content is expressed in mg/l.

Calcium: Calcium (Ca^{++}) is found in great abundance in all natural waters and its source lies in the rocks from which it is leached. Its concentration varies greatly in natural waters depending upon the nature of the basin. Calcium is an important micronutrient in aquatic environment. Being an important contributor to hardness in water it reduces the utility of water for domestic use.

Calculation for calcium, mg/L= A x 400.8/ ml of sample

Where, A= Volume of EDTA used.

Magnesium: Like calcium, magnesium is also found in all natural waters and its source too lies in rocks. It is generally in low concentration than calcium. Magnesium (Mg^{++}) is a necessary constituent of chlorophyll without which no ecosystem could operate. Its high content reduces the utility of water for domestic use, while a concentration above 500 mg/L imparts water an unpleasant taste and renders it unfit for drinking purpose. High concentration of magnesium also proves to be diuretic and laxative. Calculation

Magnesium (mg/L) = (T-C) x 0.244

Where, T = total hardness (mg/L as $CaCO_3$)

C = Calcium hardness (mg/L as $CaCO_3$)

Table 4.1 Analysis of water quality for selected environmental parameters

Parameter	Sample No.	Elevation in (m)	Subansiri River (values)	Elevation in (m)	Alaknanda River (values)
pH	1	86.258	7.35	534.619	7.61
	2	88.392	7.32	535.838	7.70
	3	92.964	7.35	632.460	7.94
Conductivity (µS/cm)	1	86.258	139.2	534.619	173
	2	88.392	170	535.838	158
	3	92.964	158	632.460	141.1
Turbidity	1	86.258	344.64	534.619	78
	2	88.392	394.6	535.838	62
	3	92.964	395.2	632.460	464
Total Solid (TS) in mg/l	1	86.258	980	534.619	260
	2	88.392	740	535.838	290
	3	92.964	920	632.460	530
Total Dissolve Solid (TDS) in mg/l	1	86.258	134	534.619	90.5
	2	88.392	116	535.838	110.43
	3	92.964	150.47	632.460	147.49
Total hardness (mg/l)	1	86.258	42	534.619	40
	2	88.392	46	535.838	43
	3	92.964	54	632.460	88

Table 4.1 Contd.

Parameter	Sample No.	Elevation in (m)	Subansiri River (values)	Elevation in (m)	Alaknanda River (values)
Ca^{++} (mg/l)	1	86.258	20.04	534.619	28.86
	2	88.392	18.44	535.838	30.02
	3	92.964	19.23	632.460	57.71
Mg^{++} (mg/l)	1	86.258	19.79	534.619	22.42
	2	88.392	14.77	535.838	24.71
	3	92.964	12.79	632.460	26.84
K^+	1	86.258	2.06	534.619	2.58
	2	88.392	1.62	535.838	2.72
	3	92.964	1.73	632.460	3.34
Na^+	1	86.258	1.26	534.619	7.74
	2	88.392	0.90	535.838	7.77
	3	92.964	0.77	632.460	6.21
Cl^- (mg/l)	1	86.258	80.94	534.619	93.72
	2	88.392	58.22	535.838	99.4
	3	92.964	65.32	632.460	139.16
SO_4^{--}(ppm)	1	86.258	32.12	534.619	11.03
	2	88.392	33.41	535.838	9
	3	92.964	34.39	632.460	10.78
PO_4^{---} (ppm)	1	86.258	0.08	534.619	2.78
	2	88.392	0.07	535.838	3.40
	3	92.964	0.08	632.460	3.06
NO_3^- (ppm)	1	86.258	0.61	534.619	4.51
	2	88.392	0.11	535.838	1.56
	3	92.964	0.88	632.460	4.56

4.4.2 Analysis of water quality results

From the foregoing analysis (Table 4.1) of collected water samples, it is found that there is similar trend in case of the pH, electrical conductivity and K^+ in both the basins of eastern and western Himalayas. But the other parameters show dissimilarities in both the eastern and western Himalayan rivers. From the table 4.1 it is observed that the pH value ranges between 7.32 - 7.94 in both the basins indicating the slightly basic nature of the river water and no influence of pollution (Hem, 1991). The results are further demonstrated graphically in Figure 4.12. A comparative study of selected water quality parameters of the two rivers representing western and eastern Himalayas has been carried out by Devi and Goswami, 2015.

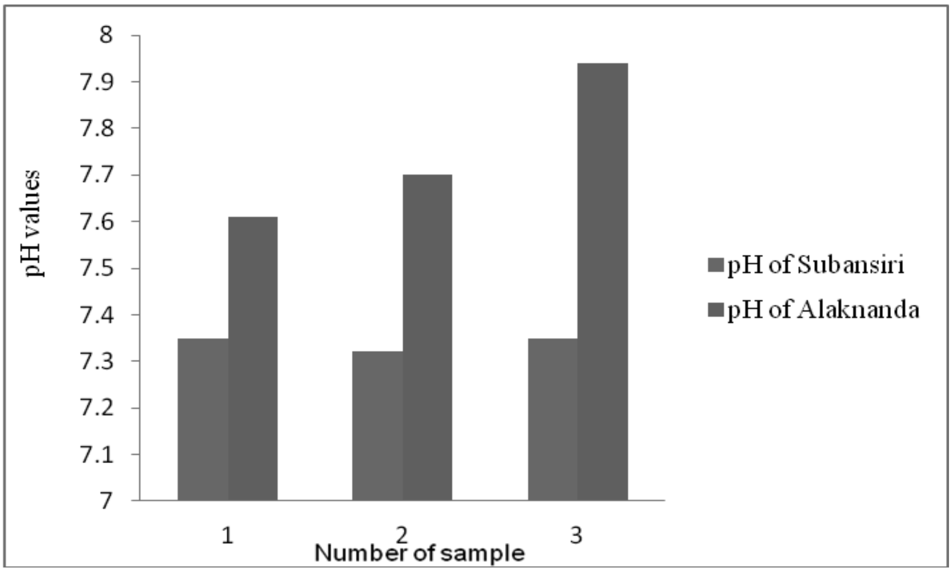


Figure 4.12: pH of the Subansiri and Alaknanda rivers at selected locations

Electrical conductivity (EC) lies in the range of 139.2 – 170 µS/cm in the Subansiri river while the EC range is 141.1 - 173 µS/cm in the Alaknanda river (Figure 4.13). The maximum limit of EC in drinking water is prescribed as 1500 µS/cm. Conductivity in streams and rivers is affected by the geology of the area through which the channel flows. If the area has granite bed rock then conductivity tend to have a lower value as granite is composed of more inert materials that do not ionize when exposed to water. Streams that flow through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when come in contact of water (AHEC/2011). Conductivity is found to be high in case of both the eastern and western Himalayan rivers which may be due to the clayey texture of soils present in both the rivers.

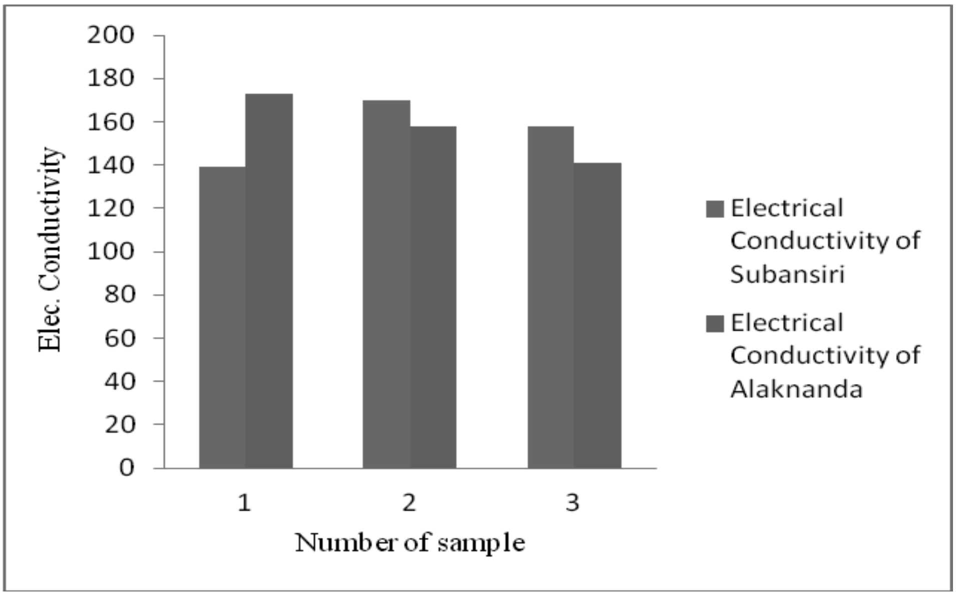


Figure 4.13: Electrical Conductivity of the Subansiri and Alaknanda rivers at selected locations

Turbidity is much more in case of the Subansiri basin than the Alaknanda basin (Figure 4.14). The EPA drinking water standards specify a maximum turbidity value of 1NTU and BIS permissible limit as 10 NTU. But the sample collected from the Rudraprayag of Alaknanda basin shows a high value being 464 NTU which may be due to the muddy rain water flowing down at that time from the hills and also due to the high velocity of the flowing water.

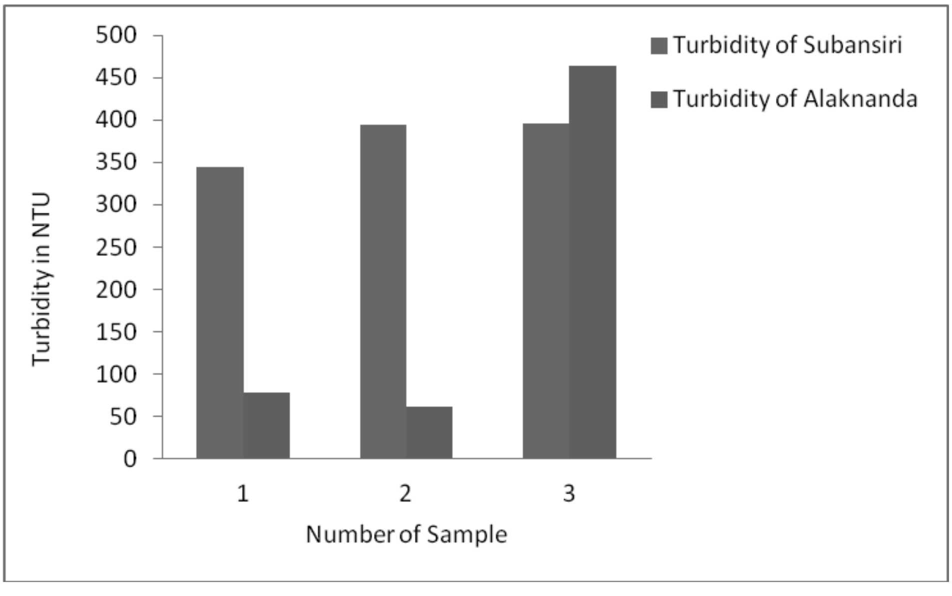


Figure 4.14: Turbidity of the Subansiri and Alaknanda rivers at selected locations

Total Solid (TS) ranges in between 740 - 980 mg/l in the water of Subansiri river while it is found to be 260 - 530 mg/l in case of the Alaknanda river which is comparatively much less than the Subansiri river (Figure 4.15).

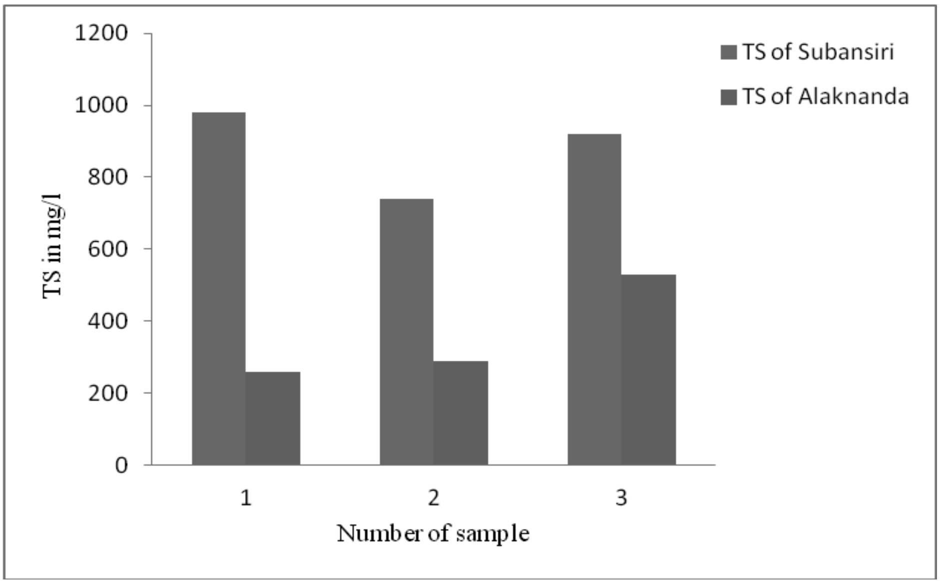


Figure 4.15: Total Solid (in gram) of the Subansiri and Alaknanda rivers at selected locations

Total Dissolved Solid (TDS) is found to be in the range between 116 – 150.47 mg/l in the Subansiri river while it varies in between 90.5-147.49 mg/l in the Alaknanda river (Figure 4.16) which is comparatively less than the Subansiri river of eastern Himalaya. The maximum permissible limit for TDS in BIS permissible limit is 500 mg/l and the highest desirable limit is 2000 mg/l. Hence, both the rivers have the TDS values within the permissible limit. The primary source of water in Uttaranchal for rivers is rainfall and snowmelt, which makes their composition an important component of river water chemistry. Total dissolved solids in Himalayan Rivers ranged from 35-151 mg/l, (Krishnaswami and Singh, 2005 in Semwal and Akolkar, 2006) which is similar in case of the Subansiri and the Alaknanda river basins.

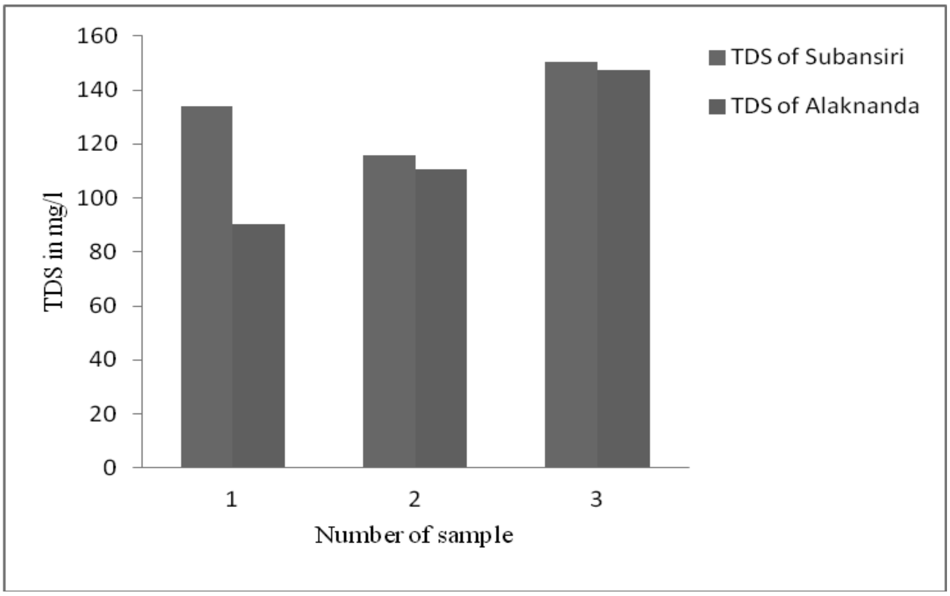


Figure 4.16: Total Dissolved Solid (in gram) of the Subansiri and Alaknanda rivers at selected locations

Total Hardness lies in the range of 42 - 54 mg/l in the Subansiri river while it is 40 - 88 mg/l in the Alaknanda river which is comparatively higher than the Subansiri river (Figure 4.17) but within the BIS (1991) permissible limit of 600 mg/l. Table 1 shows the Ca^{++} ranges in between 18.44 -20.04 mg/l in the Subansiri river of eastern Himalaya while it is 28.86 - 57.71 mg/l in the Alaknanda river which is comparatively higher than the Subansiri river (Figure 4.18). The permissible limit for Ca^{++} as per BIS is 200 mg/l. Mg^{++} varies in the Subansiri river in the range of 12.79 - 19.79 mg/l which is comparatively less than the Alaknanda river (22.42 - 26.84 mg/l) of western Himalaya (Figure 4.19). A concentration up to 30 mg/l is recommended for magnesium in drinking water.

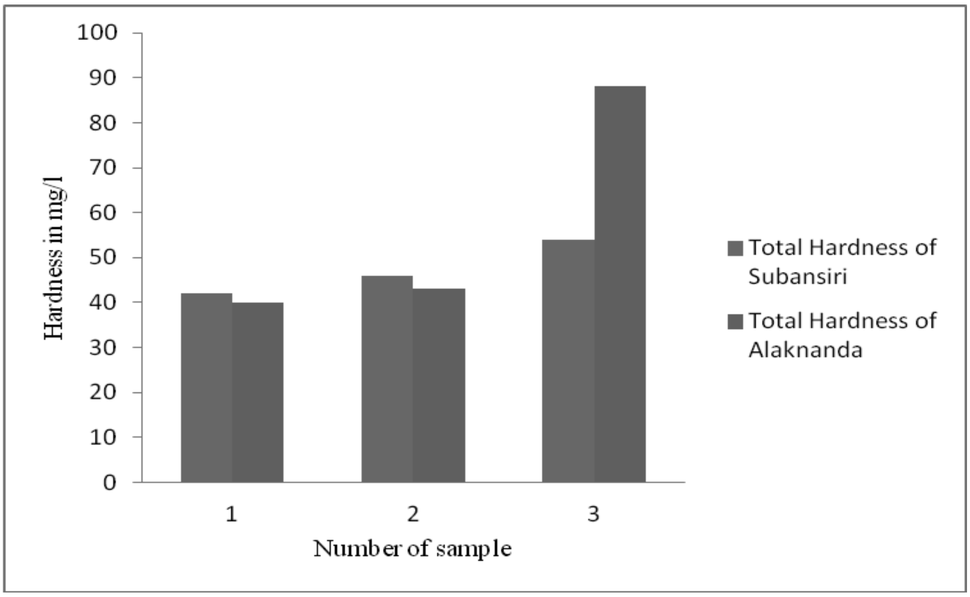


Figure 4.17: Total Hardness of the Subansiri and Alaknanda rivers at selected locations

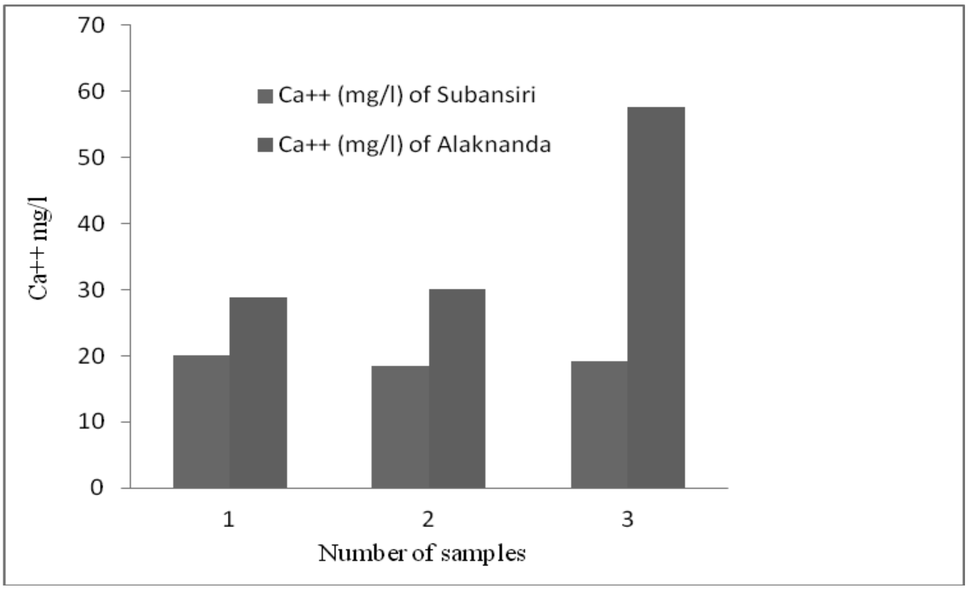


Figure 4.18: Ca^{++} (mg/l) of the Subansiri and Alaknanda rivers at selected locations

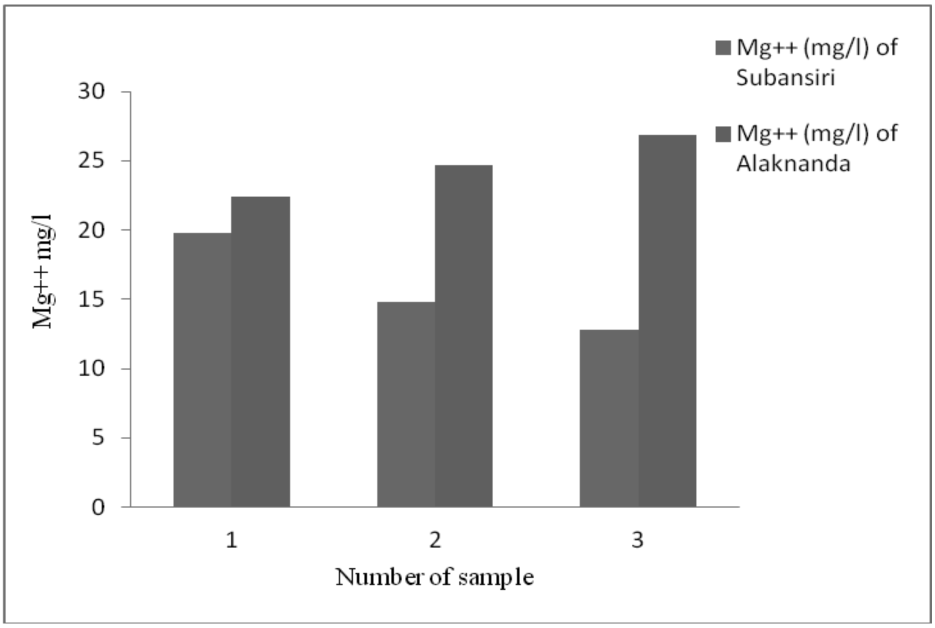


Figure 4.19: Mg^{++} (mg/l) of the Subansiri and Alaknanda rivers at selected locations

K^{+} value ranges in between 1.62 - 2.06 in the Subansiri river while it is 2.58 - 3.34 in the Alakanda river which is comparatively higher than the Subansiri river (Figure 4.20). Na^{+} ranges in between 0.77 - 1.26 in the Subansiri river while it varies in between 6.21 - 7.77 in the Alaknanda river and it is comparatively much higher than the Subansiri river (Figure 4.21).

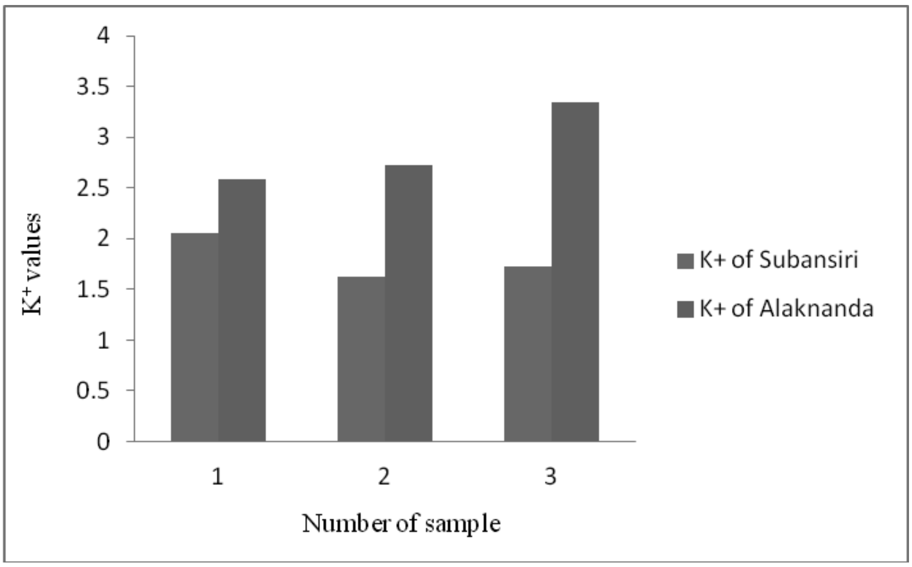


Figure 4.20: K^{+} of the Subansiri and Alaknanda rivers at selected locations

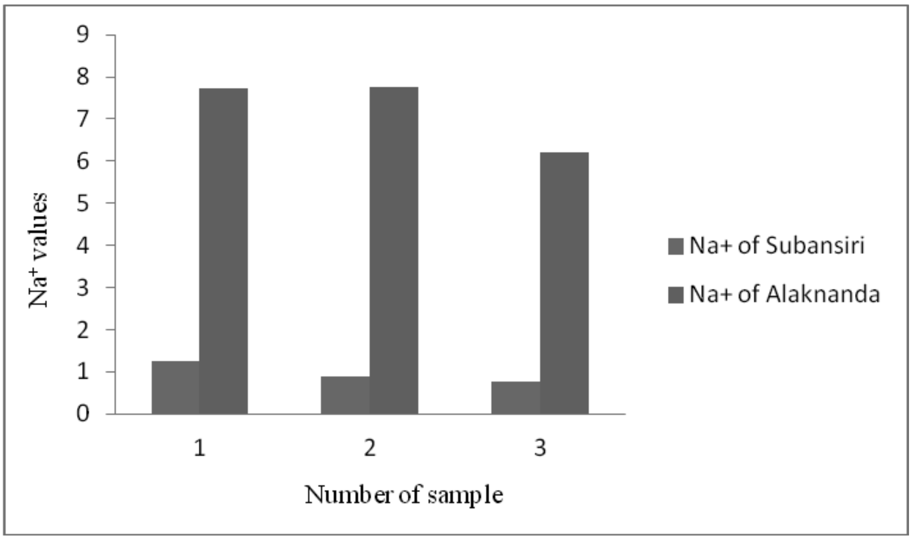


Figure 4.21: Na^+ of the Subansiri and Alaknanda rivers at selected locations

Cl^- value ranges in between 58.22 - 80.94 mg/l in the Subansiri river which is found to be comparatively less than the values in the Alaknanda river ranging in between 93.72 - 139.16 mg/l (Figure 4.22). WHO (2008) guide lines suggest the permissible limit in ground water is 600 mg/l.

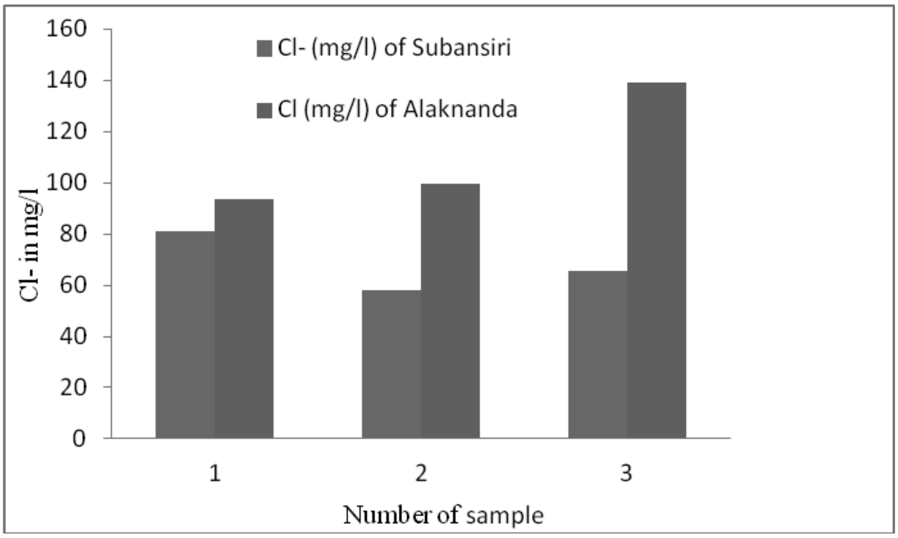


Figure 4.22: Cl^- (mg/l) of the Subansiri and the Alaknanda rivers at selected locations

SO_4^{--} values show a range between 32.12 - 34.39 ppm in the Subansiri river while these show the comparatively lower figures in case of the Alaknanda river where the range is between 9 - 11.03 ppm (Figure 4.23). The recommended upper limit for sulphate in drinking water is 250 mg/l. The main source of phosphorus in the environment is from soil and rock weathering. Phosphate occurs in traces in most of the natural waters.

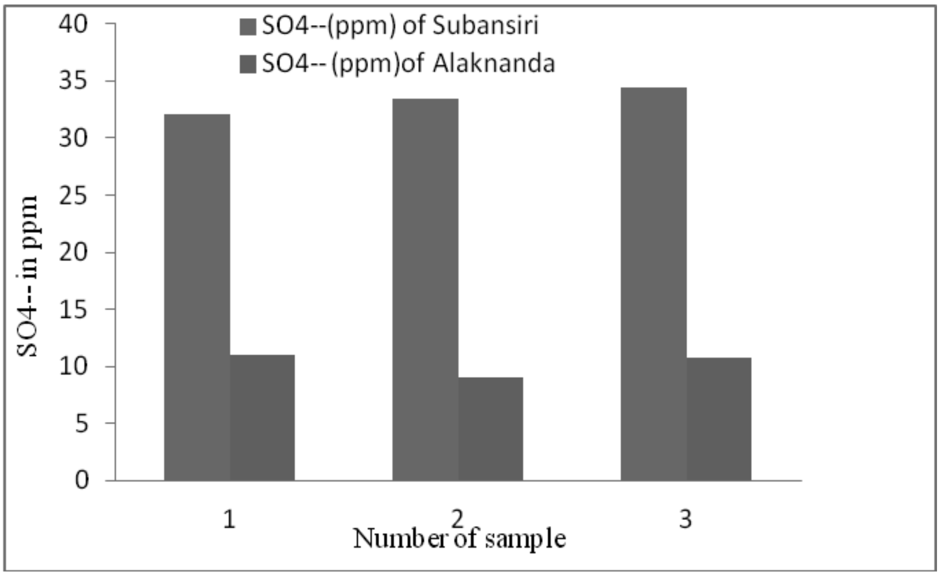


Figure 4.23: SO_4^{--} of the Subansiri and the Alaknanda rivers at selected locations

PO_4^{---} is observed to be comparatively higher in the Alaknanda river (2.78 - 3.40 ppm) than the Subansiri basin (0.07 - 0.08 ppm) (Figure 4.24).

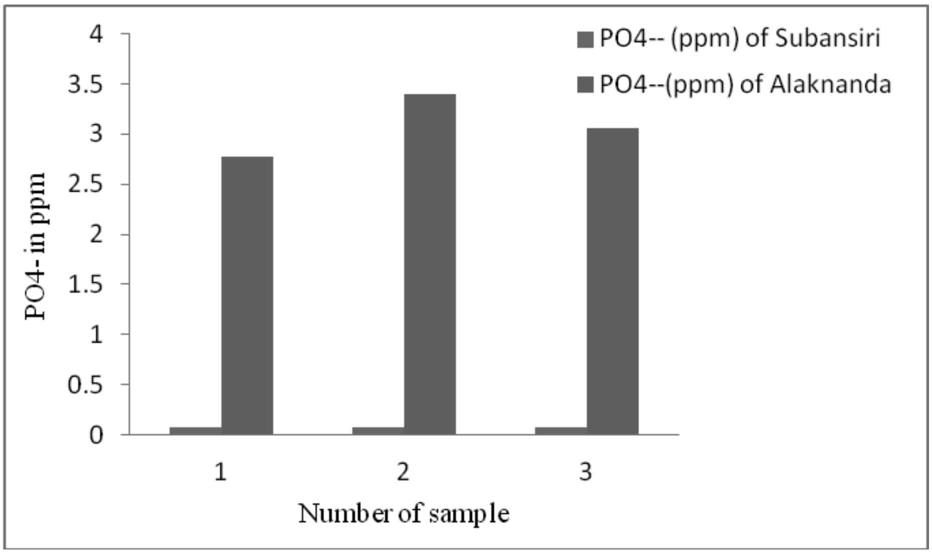


Figure 4.24: PO_4^{---} of the Subansiri and the Alaknanda rivers at selected locations

NO_3^- ranges in between 0.11 - 0.88 ppm in case of the Subansiri river while it is 1.56 - 4.56 ppm in the Alaknanda river (Figure 4.25) indicating anthropogenic activity near the sampling site and flow of nutrients from the watershed. A high level of nitrate (>45 mg/l) in drinking water can cause methenoglobinemia or blue baby syndrome in infants and gastrointestinal cancer in adults (Mc Donald and Key, 1998).

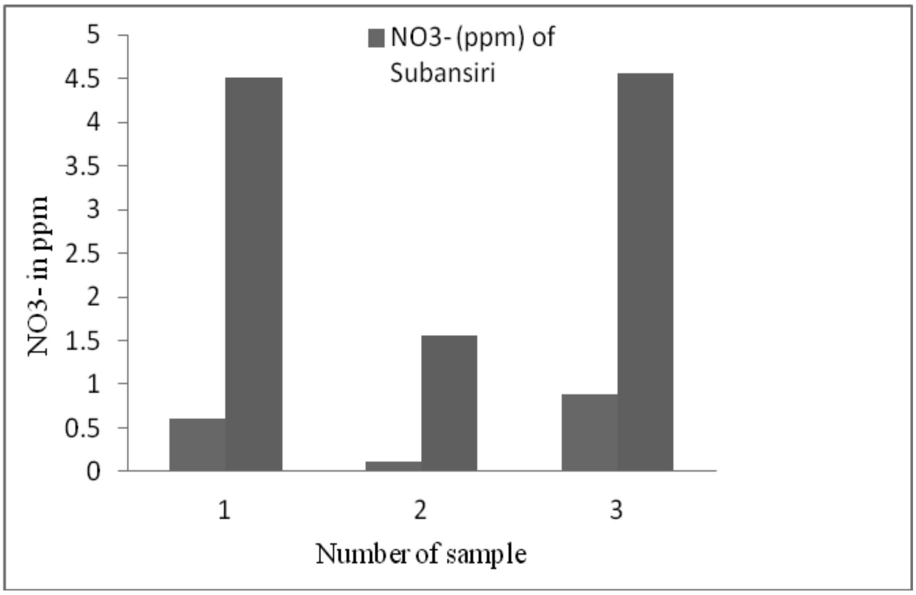


Figure 4.25: NO_3^- (ppm) of the Subansiri and Alaknanda rivers at selected locations

4.5 MORPHOMETRIC STUDY

4.5.1 Introduction

Geomorphology is the study of the formation of terrain or topography of the earth's surface. According to Clarke (1996), Geomorphometry is the measurement and mathematical analysis of earth's surface configuration, and dimensions of its landforms**.** Morphometric analysis of a river basin provides a quantitative description of the drainage system, which is an important aspect of the characterization of basins (Strahler, 1964). The development of a drainage system over space and time is influenced by several variables such as geology, structural components, geomorphology, soil and vegetation of an area through which it flows (Magesh et al., 2013). Various hydrological phenomena can be correlated with the physiographic characteristics of a drainage basin such as size, slope, shape of the drainage basin, density, size and length of the contributories; etc (Rastogi et al., 1976). Morphometric analysis using Remote Sensing technique has emerged as a powerful tool in recent years (Rudraiah et al., 2008). Study of morphometric parameters provides significant information about the geology, hydrology, soil and vegetation cover of a river basin. It helps in targeting ground water potential, environmental impact assessment and watershed management.

This study is significant in the sense that it reveals selected hydrological aspects of the upper catchment of the Subansiri basin. The intense spell of heavy rainfall in the upper reaches as well as in lower part of the Subansiri basin during the months June through September, due to the prevailing south westerly monsoons, creates severe flood in the lower part of the basin (Gogoi and Goswami, 2013). The study of the upper catchment is important to understand the flood hazard scenario of the lower Subansiri basin which suffers three to four waves of flood havoc each year. Morphometric analysis of a river basin provides a quantitative description of the drainage system which is an important aspect of its characterization. Morphometric analysis helps to understand various hydrologic phenomena of a river basin. The morphometric studies are carried out taking two case studies viz. the analysis of the relief, slope and aspects of both the Alaknanda and the Subansiri basins of eastern and western Himalayas and the another study is the analysis of Linear aspects (drainage network), Areal aspect (basin geometry) and Relief aspects (measurement involving heights) of four small catchments taking two from each eastern and western Himalayan basins. Gayung and Sipu subbasins of the Subansiri and Bhardari Gad and Kyar Gad subbasins of the Alaknanda basin are taken as the representative basins to study the parameters related to linear, areal and relief aspects.

4.5.2 Case Study 1

The study area comprises of the Subansiri river basin of eastern Himalaya and the Alaknanda basin of western Himalaya (Figure 4.26). The entire Subansiri basin covers an area of 38051.56 sq.km, the extension of which in India is 26.57°N to 28.40° N and 92.42°E to 94.47°E and the Alaknanda basin is bounded between 30° 0' N- 31° 3' N and 78°37'E - 80°2' E with a basin area 10936.35 sq.km.

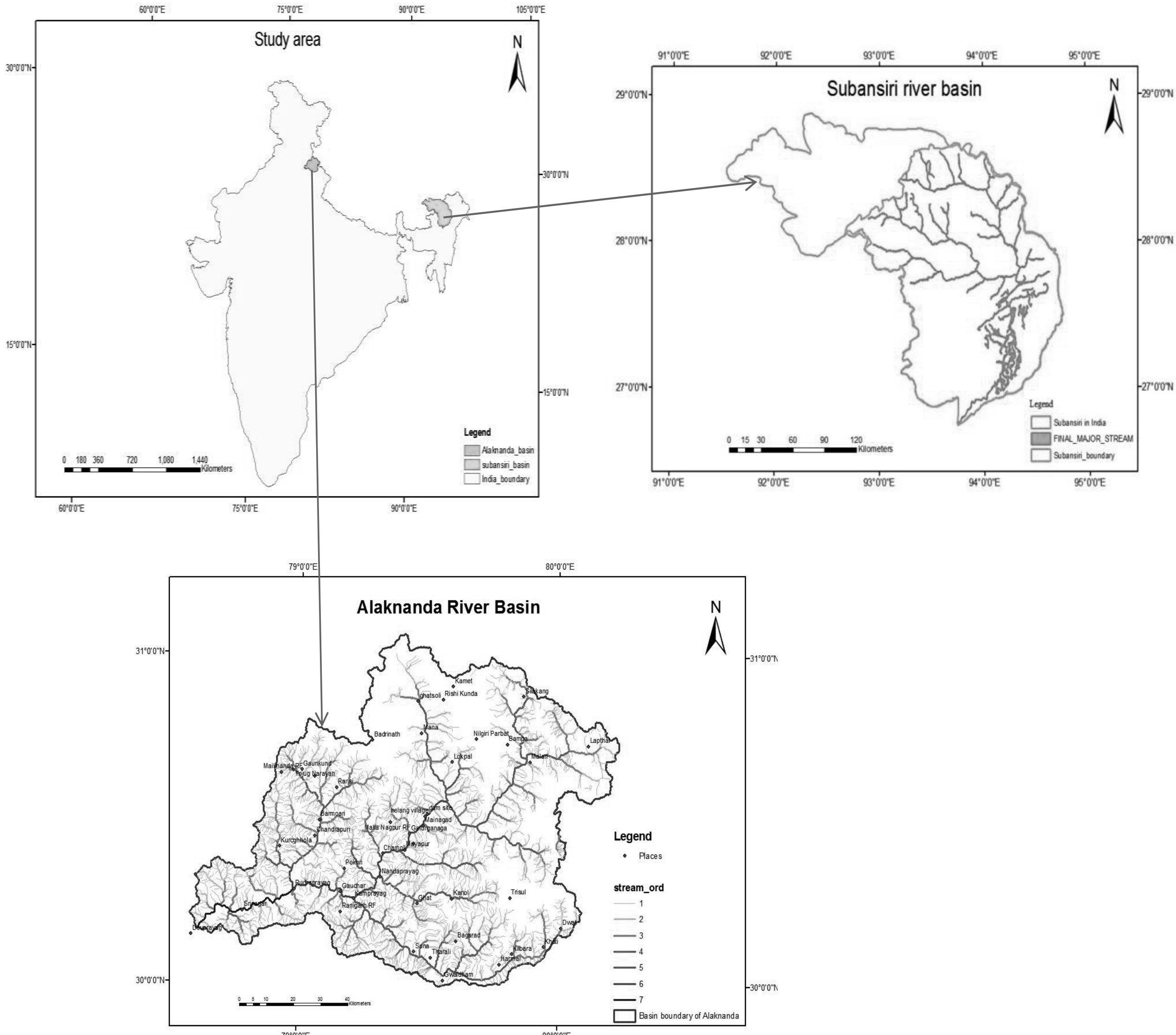


Figure 4.26: The study area of the case study 1

4.5.2.1 Database and Methodology

The data used for the study of the selected basins are Survey of India 1:50,000 scale toposheets No. 83 I/2 to I/16, 83 E/1 to E/16, 83 H/1 to H/16, 53N/1 to N/15 and India and Pakistan 1:250,000 toposheets No. NH 44-5, 6 and ASTER GDEM of 30 m resolution. These toposheets are geometrically rectified, georeferenced and digitized to delineate the watershed boundaries. These are projected to the regional projection (WGS 1984 UTM Zone 46 N and 44N for the Subansiri and the Alaknanda basins respectively). Stream orders are assigned following Strahler (1964) stream ordering technique. Digital Elevation Model is prepared for each watershed under GIS platform using standard procedures to derive relief, aspect and slope maps for both the watersheds using ERDAS 9.1and ArcGIS 9.3 software.

4.5.2.2 Relief of the Subansiri and the Alaknanda Basins

Relief refers specifically to the quantitative measurement of vertical elevation change in a landscape. It is the difference between maximum and minimum elevations within a given area, usually of limited extent**.** The relief of the Subansiri basin of eastern Himalaya varies between 29 m to 7,174 m; on the other hand it varies between 454 - 7799 m in the Alaknanda basin of western Himalaya (Figure 4.27 & 4.28). In case of Subansiri basin, the relief ranging from 29-1000 m covers the highest area of the basin, i.e. 27.85%, and the elevations ranging from 7000-8000 m account for the lowest area coverage of 0.0003%. On the other hand, in case of Alaknanda basin, the relief ranging from 1000-2000 m covers the highest area of the basin i.e. 21.19%, while between 7000-8000 m it covers the lowest area of 0.059% (Table 4.2). It is observed from the statistics that most of the basin areas of the Subansiri river and of the Alaknanda river lie in the relief range of 1000-5000 m accounting for 63.83% and 77.17% of the total basin area respectively. The Percentages of area covering different relief categories are graphically represented in Figure 4.29.

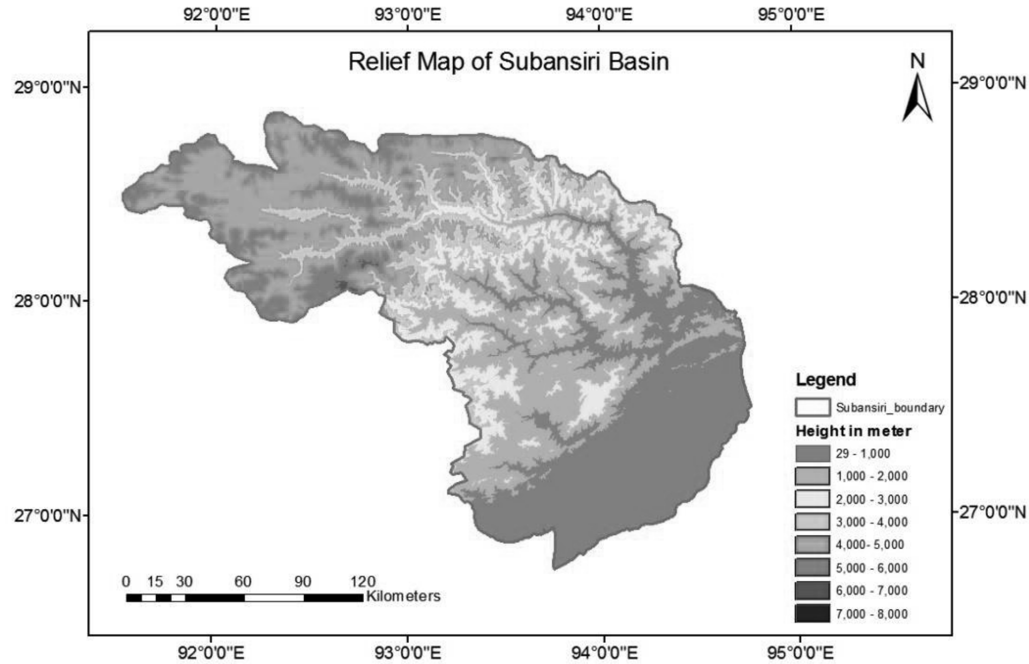


Figure 4.27: Relief Map of the Subansiri river basin

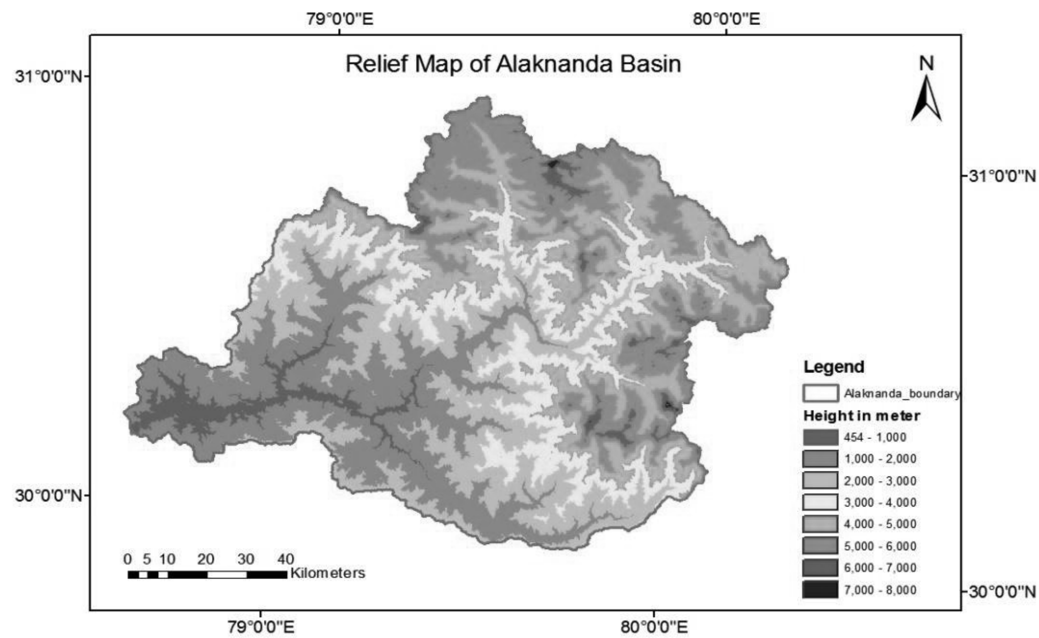
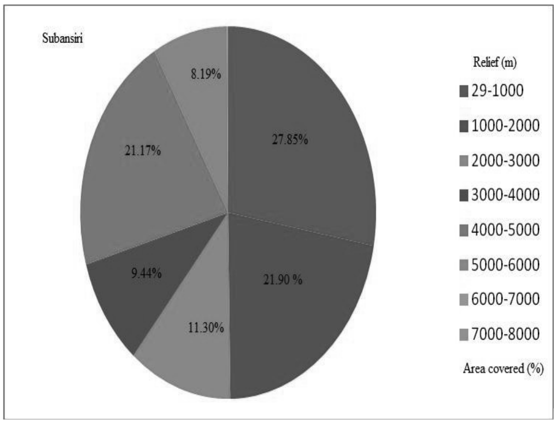


Figure 4.28: Relief Map of the Alaknanda river basin

Table 4.2: Relief characteristics of the Subansiri and the Alaknanda basins

Heigtht in meters Subansiri Basin (m)	Percentage of area (%)	Height in meters Alaknanda Basin (m)	Percentage of area (%)
29-1000	27.85	454-1000	3.45
1000-2000	21.90	1000-2000	21.19
2000-3000	11.30	2000-3000	20.93
3000-4000	9.44	3000-4000	14.68
4000-5000	21.17	4000-5000	20.37
5000-6000	8.19	5000-6000	17.51
6000-7000	0.13	6000-7000	1.79
7000-8000	0.0003	7000-8000	0.059



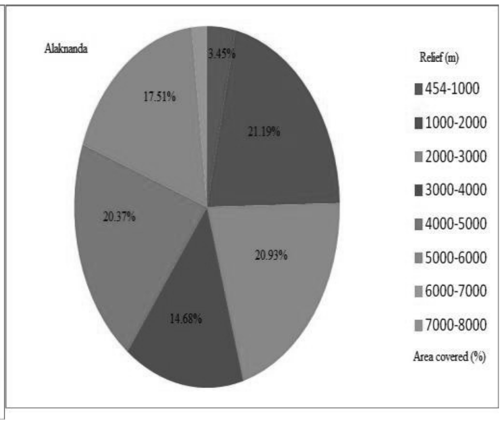


Figure 4.29: Graphical presentation of relief characteristics of the Subansiri and Alaknanda river basins

4.5.2.3 Slope (or Gradient)

The measures of slope as hydrologic parameters are also very important. The slope of a terrain refers to the amount of inclination of physical feature, topographic landform to the horizontal surface. Hill slopes become steeper with increasing relief. The slope maps (Figure 4.30 & 4.31) for both the Subansiri and Alaknanda basins are derived from the ASTER GDEM using the aspect and slope tool in ArcGIS 9.3 Spatial analyst module. The slopes are classified under nine different classes for both the basins ranging between 0-90 degrees. It is revealed from the Table 4.3 that the slope ranges between 0-89 degree for the Subansiri basin and 0-82 degree for the Alaknanda basin. In case of the Subansiri basin, gentle to steep slopes (0-23 degree) cover 48.87% of the basin area, while it is 31.75% for the Alaknanda basin. On the other hand, extremely steep slope (23-35 degree) covers 30.92% in the Subansiri basin, while it is 31.38% for the Alaknanda basin.

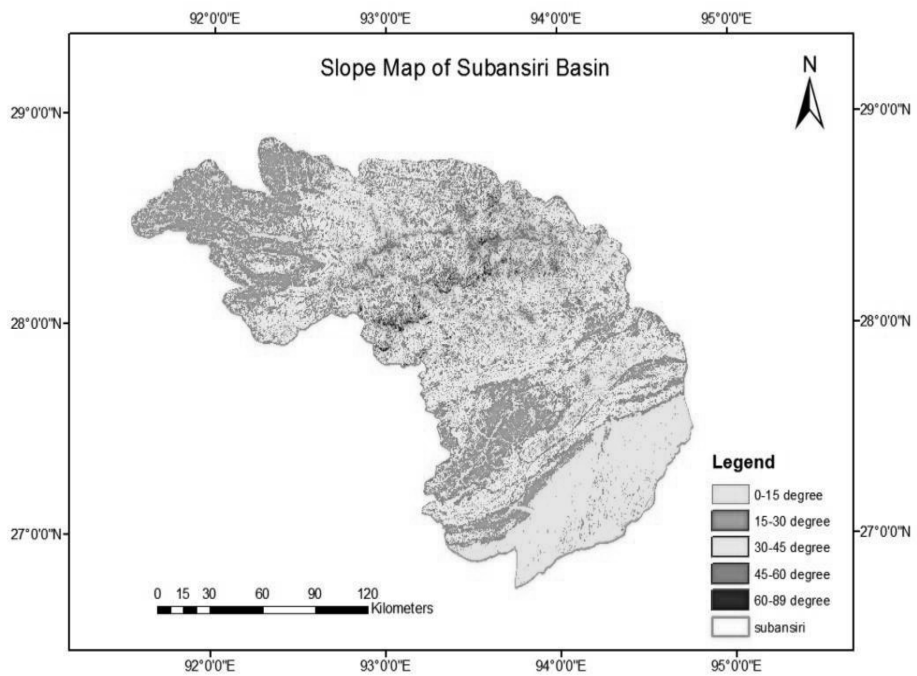


Figure 4.30: Slope Map of the Subansiri river basin

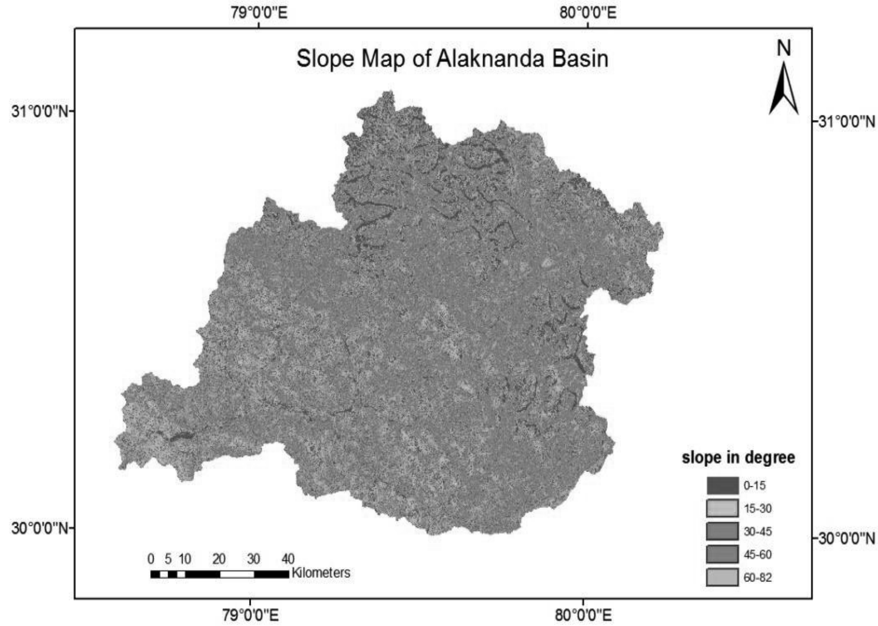


Figure 4.31: Slope Map of the Alaknanda river basin

The distribution of different categories of slopes in the Subansiri and the Alaknanda river basins are shown in table 4.3 and Figure 4.32.

Table 4.3: Slope categories of the Subansiri and the Alaknanda basins

Serial number	Slope (in degree)	Percentage of area covering different slopes of the Subansiri basin	Slope (in degree)	Percentage of area covering different slopes of the Alaknanda basin
1	0-8	15.96	0-10	6.90
2	8-16	15.96	10-17	10.93
3	16-22	16.94	17-23	13.91
4	22-29	16.36	23-29	15.61
5	29-35	14.56	29-34	15.77
6	35-42	10.74	34-40	14.42
7	42-50	6.48	40-46	11.54
8	50-65	2.45	46-54	7.57
9	65-89	0.54	54-82	3.33

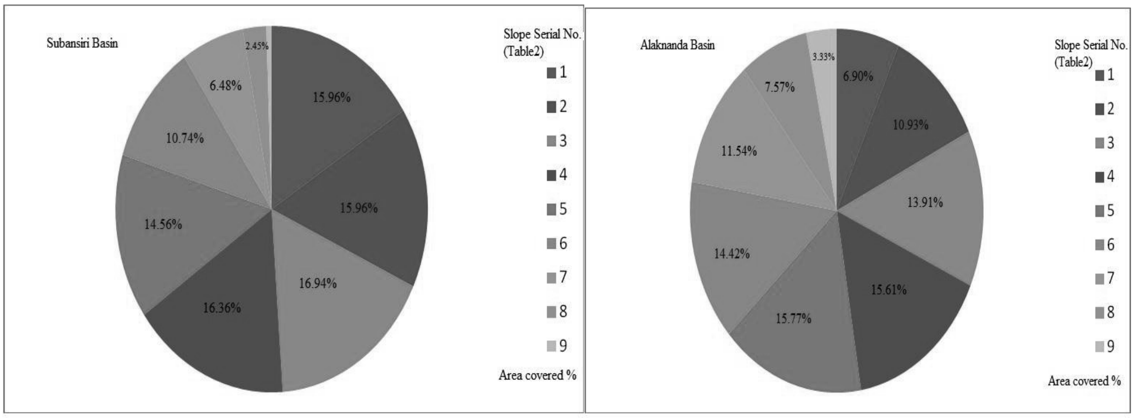


Figure 4.32: Graphical presentation of different slope categories in the Subansiri and the Alaknanda river basins

4.5.2.4 Aspect

The aspect of a terrain is the direction to which it faces. Aspect influences vegetation type, precipitation patterns, snow melt and wind exposure. Aspect can also have a strong influence on temperature. This is because aspect affects the angle of the sun rays when they come in contact with the ground, and therefore affects the concentration of the sun's rays hitting the earth. The aspect of a slope can make very significant influence on the local climate. For example, because the sun's rays are in the west at the hottest time of day in the afternoon, in most cases a west-facing slope will be warmer than a sheltered east-facing slope (unless large-scale rainfall influences dictate otherwise). This can have major effects on altitudinal and polar limits of tree growth and also on the distribution of vegetation that requires large quantities of moisture. Aspect maps of the Subansiri basin and the Alaknanda basin are shown in Figure 4.33 and 4.34 respectively.

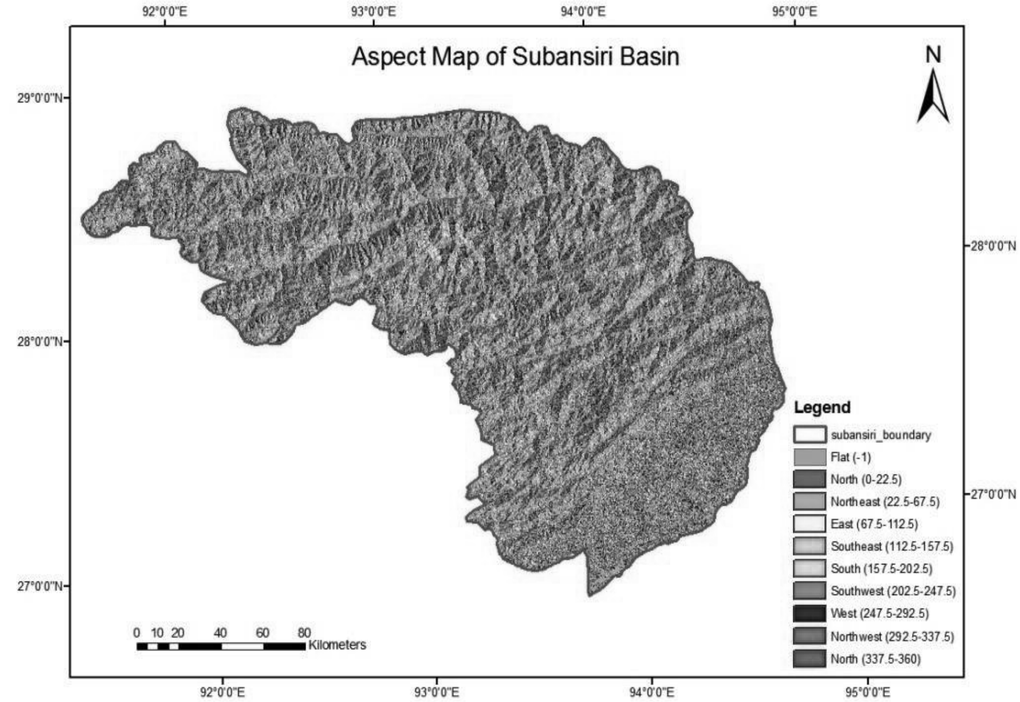


Figure 4.33: Aspect map of the Subansiri river basin

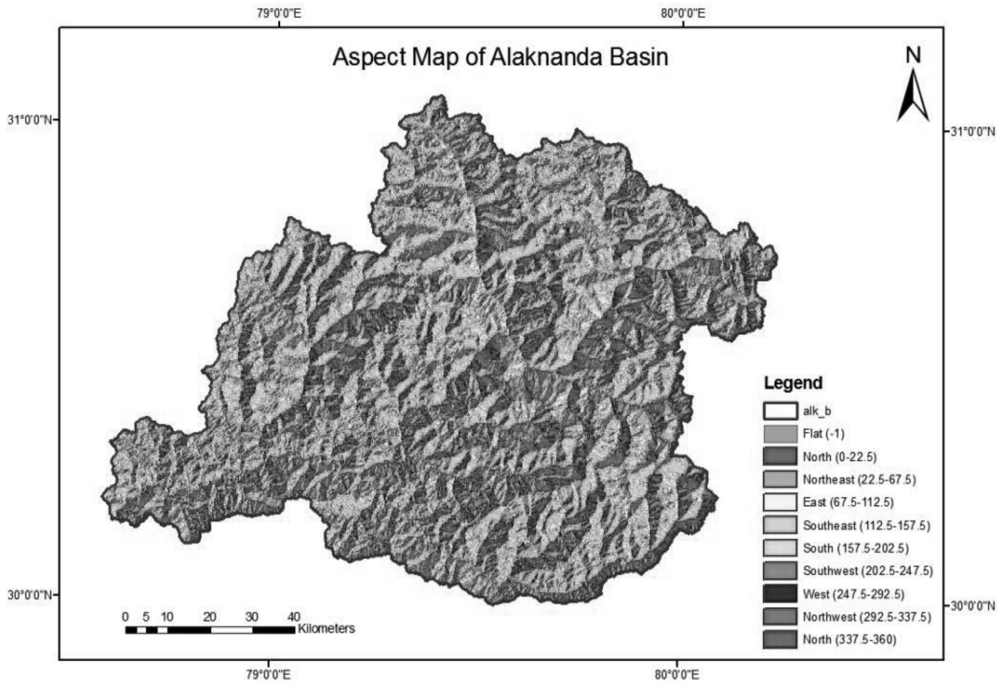


Figure 4.34: Aspect map of the Alaknanda river basin

4.5.2.5 Discussion

It is observed from the study that both the two basins viz. the Subansiri and the Alaknanda have contrasting features in regard to their relief, slope and aspect conditions. These differences reflect the contrasting geographical, hydrometeorological and denudational characteristics of the study areas representing opposite extremities of the Himalayan arc (Devi and Goswami, 2015). The results of the study may prove useful in understanding the regional physiography and structure of the great Himalayan arc and the dominant geographic processes operating on them.

4.5.3 Case Study 2

4.5.3.1 Introduction

This case study is to compute the morphometric parameters of the Gayung and Sipu subbasins of the Subansiri basin considering them as the representatives of the Subansiri river basin of eastern Himalayas and the Bhardari Gad and Kyar Gad sub basins of the Alaknanda basin considering them as the representatives of the Alaknanda basin of western Himalayas using Remote Sensing and GIS techniques (Figure 4.35).

The morphometric analysis of a drainage network includes the following:-

(a) Linear aspects (drainage network)

(b) Areal aspect (basin geometry)

(c) Relief aspects (measurement involving heights)

4.5.3.2 Study Area

Both the two subbasins of the Subansiri are located in the upper part of the Subansiri basin and lie in Arunachal Pradesh of Northeast India. The Gayung subbasin extends from 93°58'55"E to 94°14'45" E longitude and 27°26'0" N to 27°34'45" N latitude (Figure 4.36). On the other hand, the Sipu subbasin extends from 93°56'0"E to 94°13'15" E longitude and 27°29'15" N to 27°37'25" N latitude (Figure 4.37). The Gayung and the Sipu subbasins cover an area of 104.34 sq. km. and 248.66 sq. km. respectively. On the other hand two small subbasins of the Alaknanda basin are taken as the representative basins from the western Himalaya based on the available toposheets of Survey of India. The Bhardari Gad subbasin extends in between 78º51'22" E - 78º56'45" E longitude and 30º15'10" N - 30º21'38" N latitude (Figure 4.36) while the extension of the Kyar Gad subbasin is 79º7'54" E - 79º14'50" E longitude to 30º30'45" N - 30º33'52" N latitude (Figure 4.37) covering an area of 36.38 sq.km. and 42.70 sq.km. respectively. The drainage network of (a) Gayung subbasin of the Subansiri basin and (b) Bhardari Gad subbasin of the Alaknanda basin is shown in Figure 4.36. The drainage drainage network of (c) Sipu subbasin of Subansiri basin and (d) Kyar Gad subbasin of Alaknanda basin is shown in Figure 4.37.

4.5.3.3 Database and Methodology

The data used for the morphometric analysis of the basins are the Survey of India (SOI) Toposheets numbering 83E/14, 83E/15, 83I/2, 83I/3 of 1:50,000 scale covering the Gayung and Sipu subbasins of Subansiri basin of eastern Himalayas while the SOI toposheets used for the Bhardari Gad and Kyar Gad subbasins of western Himalaya are- 53 J/15 and 53 N/2 of 1:50,000 scale. Satellite based data from ASTER GDEM of 30m resolution is also used to derive relief, aspect and slope maps of the basins. ERDAS 9.1 software is used to georeference and sub-set the toposheets and the streams are digitized with the help of ArcGIS 9.3 software. The morphometric parameters like stream number, stream order, stream length, bifurcation ratio, elongation ratio, form factor and circulatory ratio etc. have been analysed using the standard formulae given in the table.

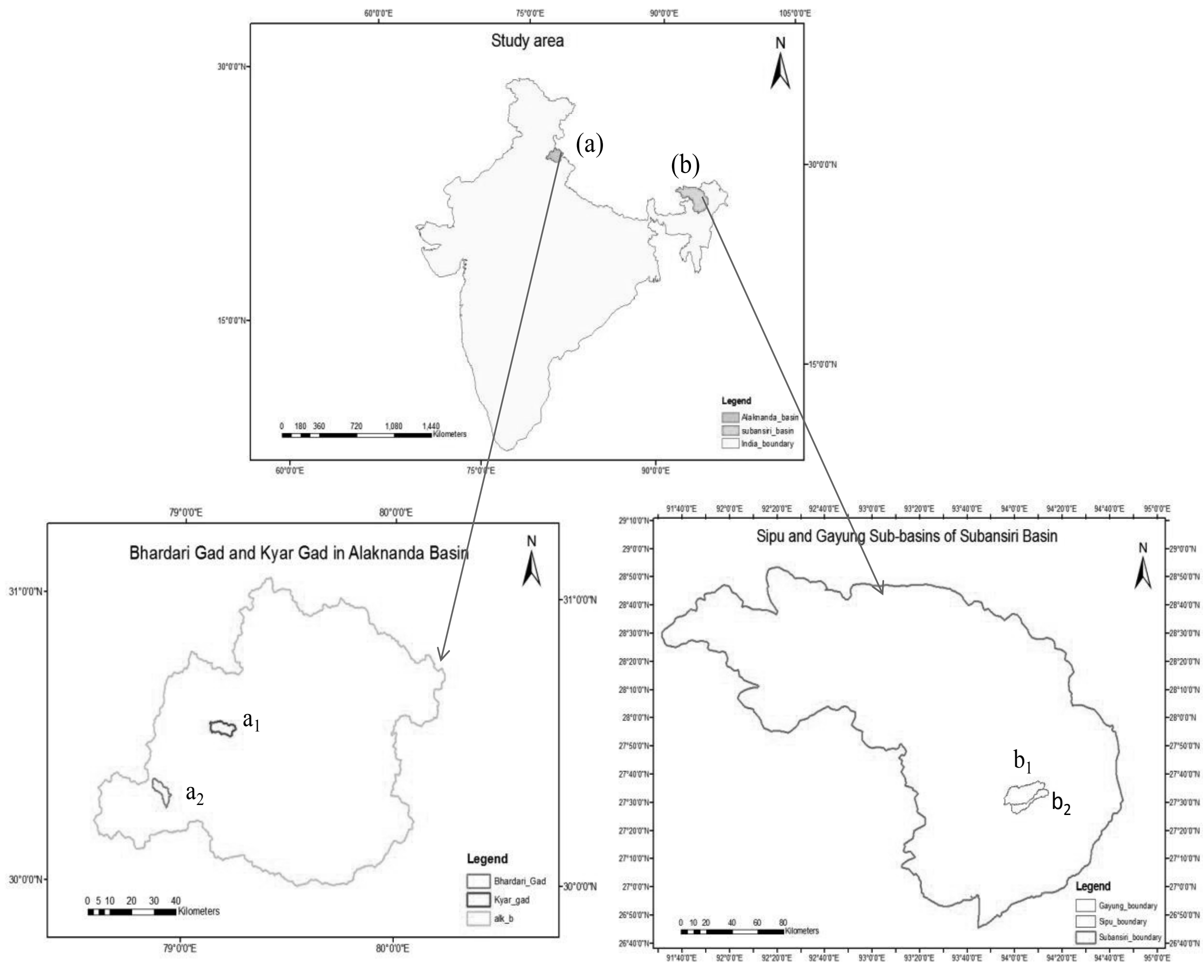
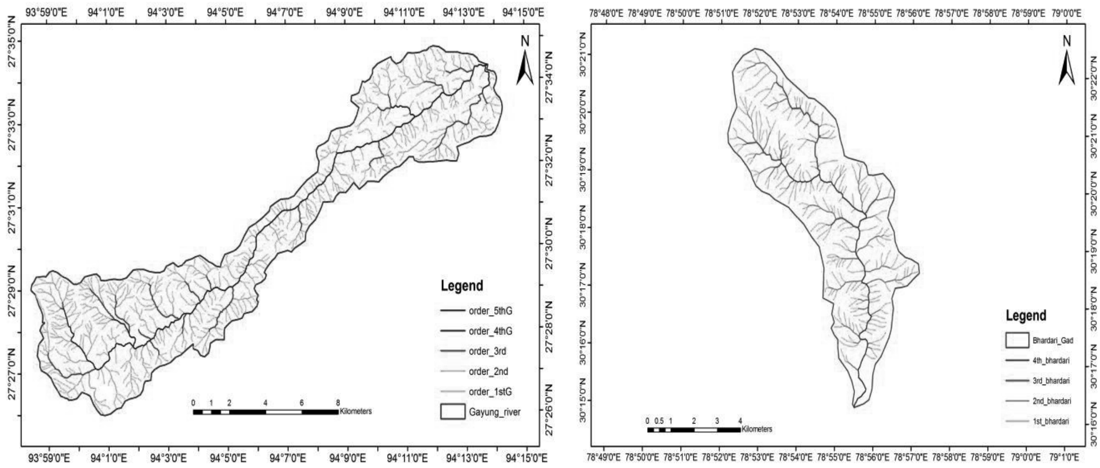


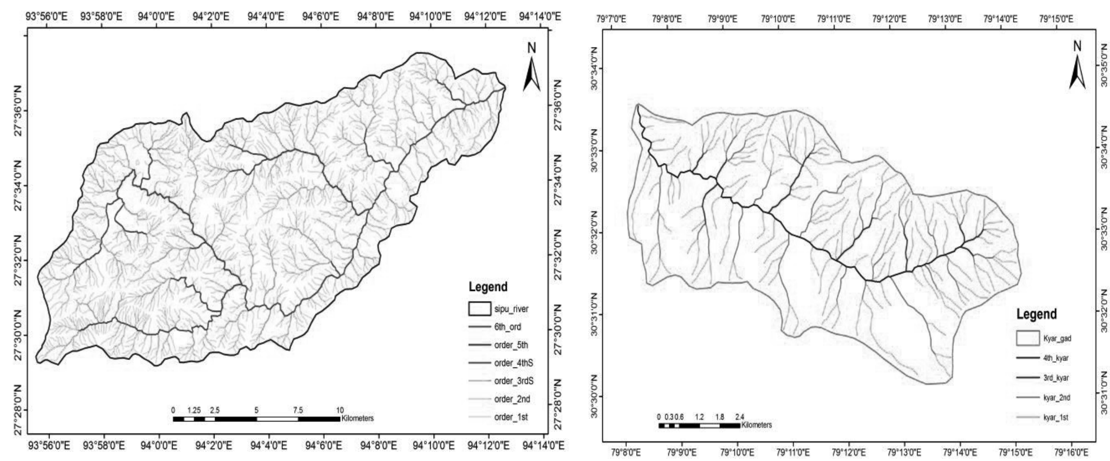
Figure 4.35: Location of the study basins: a_1 and a_2 show the Kyar Gad and Bhardari Gad subbasins of the Alaknanda basin (a) while $b_1$and b_2 represent Sipu and Gayung subbasins of the Subansiri basin (b)

4.5.4 ANALYSIS OF MORPHOMETRIC PARAMETERS



(a) (b)

Figure 4.36: Drainage network of (a) Gayung subbasin of Subansiri basin and (b) Bhardari Gad subbasin of Alaknanda basin



(c) (d)

Figure 4.37: Drainage network of (c) Sipu subbasin of Subansiri basin and (d) Kyar Gad subbasin of Alaknanda basin

Table 4.4: Linear aspects of the Gayung subbasin of the Subansiri basin

Stream order u	No. of Stream segment	Stream length (km)	Bifurcation ratio (Rb)
1	493	222.52	
2	104	67.46	1st/2nd order=4.74
3	22	30.38	2nd/3rd order=4.73
4	4	11.75	3 rd/4th order=5.5
5	1	25.89	4th/5th order=4
Total	Nu =624	Lu =358	Mean = 4.74

Table 4.5: Linear aspects of the Bhardari Gad subbasin of the Alaknanda basin

Stream order u	No. of Stream segment	Stream length (km)	Bifurcation ratio (Rb)
1	201	83.83	
2	41	24.37	1st/2nd order=4.90
3	6	8.06	2nd/3rd order=6.83
4	1	2.06	3 rd/4th order=6
Total	Nu =249	Lu =118.32	Mean = 5.91

Table 4.6: Areal and relief aspects of the Gayung and Bhardari Gad subbasins of the Subansiri and the Alaknanda basins respectively

Parameters	**Symbol/Formulae**	**Gayung (value)**	**Bhardari Gad (value)**
Area of the basin(sq.km)	A	104.34	36.37
Perimeter of the basin(km)	P	75.40	31.96
Basin Length (km)	L	28.19	12.36
Drainage density (Dd)	Dd= Lu/A	3.43	3.25
Stream frequency (Fs)	Fs=Nu/A	5.98	6.65
Texure (T)	$T=N_1/P$	6.54	3.19
Circularity Ratio(Rc)	$Rc= 4\ \pi A/P^2$	0.23	0.45
Elongation Ratio(Re)	$Re= (4A/\pi)^{0.5} / Lb$	0.41	0.55
Form Factor	$Ff = A/Lb^2$	0.13	0.24
Relief ratio	Rc = (Hmax-Hmin)/Lb	0.091	156.88

Nu= Total no. of streams of all orders, Lu= Total stream length of all orders

N_1= = Total no. of 1st order streams, $\pi = 3.14$

Table 4.7: Linear aspects of the Sipu subbasin of the Subansiri basin

Stream order u	No. of Stream segment	Stream length (km)	Bifurcation ratio(Rb)
1	1188	515.15	
2	285	172.37	1st/2nd order=4.6
3	68	79.34	2nd/3rd order=3.79
4	11	34.99	3 rd/4th order=6.18
5	3	27.41	4th/5th order=3.67
6	1	24.36	5th/6th order=3
Total	Nu =1556	Lu =853.62	Mean = 4.25

Table 4.8: Linear aspects of the Kyar Gad subbasin of the Alaknanda basin

Stream order u	No. of Stream segment	Stream length (km)	Bifurcation ratio(Rb)
1	141	97.12	
2	34	23.7	1st/2^{nd} order=4.15
3	9	8.03	2^{nd}/3^{rd} order=3.78
4	1	12.3	3 rd/4^{th} order=9
Total	Nu =185	Lu =141.15	Mean = 5.64

Table 4.9: Areal and relief aspects of the Sipu and Kyar Gad subbasins of the Subansiri and the Alaknanda basins respectively

Parameters	**Symbol/Formulae**	**Sipu (value)**	**Kyar Gad (value)**
Area of the basin(sq.km)	A	248.66	42.70
Perimeter of the basin(km)	P	80.02	31.52
Basin Length Lb (km)	L	31.16	11.73
Drainage density (Dd)	Dd= Lu/A	3.43	3.31
Stream frequency (Fs)	Fs=Nu/A	6.26	4.33
Texure (T)	$T=N_1/P$	14	4.47
Circularity Ratio(Rc)	$Rc= 4\ \pi A/P^2$	0.49	0.54
Elongation Ratio(Re)	$Rse= (4A/\pi)^{0.5} / Lb$	0.57	0.63
Form Factor	$Ff = A/Lb^2$	0.26	0.31
Relief ratio	Rc = (Hmax-Hmin)/Lb	0.091	256.44

Nu= Total no. of streams of all orders
Lu= Total stream length of all orders
N_1= = Total no. of 1^{st} order streams, $\pi = 3.14$

Table 4.10 Comparison of morphometric parameters of subbasins of the Subansiri and the Alaknanda basins

Name of Parameters	Subansiri basin		Alaknanda basin	
	Gayung subbasin	Sipu subbasin	Bhardari Gad subbasin	Kyar Gad subbasin
% of 1st order Streams	79%	76%	80.72%	76.23%
Bifurcation ratio	4.74	4.25	5.91	5.64
Drainage density	3.43	3.43	3.25	3.31
Stream frequency	5.98	6.26	6.65	4.33
Texture	6.54	14	3.19	4.47
Circulatory ratio	0.23	0.49	0.45	0.54
Elongation ratio	0.41	0.57	0.55	0.63
Form factor	0.13	0.26	0.24	0.31
Relief ratio	0.091	0.091	156.88	256.44

4.5.4.1 Stream order

Stream order is defined as a measurement of the position of a stream in the hierarchy of tributaries (Leopold et al., 1964). Based on the Strahler (1964) system of stream ordering, the first order streams are those that don't have any tributaries. The existence of more first order streams in a basin indicates complex hilly and compact nature of bed rock lithology (Magesh et al., 2013). Moreover the presence of large number of streams in the basin indicates that the topography is still undergoing erosion and at the same time, less number of streams indicates mature topography. In the study, it is seen that the first order streams dominate both subbasins of the Subansiri basin, the percentage being 79% in Gayung and 76.3% in Sipu, while the corresponding figures are 80.72% and 76.23% in Bhardari Gad and Kyar Gad subbasins of the Alaknanda basin. The larger numbers of first order streams indicate lower intensity of permeability and infiltration. Predominance of first order streams further indicates that there is a possibility of flash floods after heavy rainfall in the downstream areas (Chitra et al., 2011).

4.5.4.2 Stream number

Generally it is seen that the number of streams gradually decreases as the stream order increases. Table 4.4 and Table 4.7 show the total number of streams of different orders which are digitized independently for the Gayung and Sipu of the Subansiri basin and Bhardari Gad and Kyar Gad (Table 4.5, 4.8) subbasins of the Alaknanda basin.

4.5.4.3 Stream Length

The stream length of various orders has been measured from the topographical map. The total stream length of Gayung basin is 358 km and it is 853.62 km for Sipu basin (Table 4.4 & 4.7). On the other hand, total stream length of Bhardari Gad subbasin is 133.71 km and it is 144.15 km for Kyar Gad subbasin (Table 4.5 & 4.8). Streams with relatively short lengths are representative of area with steep slopes and fine texture, whereas longer lengths of stream order are generally indicative of low gradients (Strahler, 1964). Stream length is indicative of chronological developments of the stream segments including interlude tectonic disturbances (Magesh et al., 2013).

4.5.4.4 Bifurcation ratio (Rb)

Horton (1945) introduced the term Bifurcation ratio to express the ratio of the number of streams of any given order to the number in the next lower order. It is a dimensionless property related to branching pattern of a drainage network. The low Rb value indicates poor structural disturbances and the drainage patterns have not been distorted (Strahler, 1964); whereas the high Rb values indicates high structural complexity and low permeability of the terrain. The mean Bifurcation ratios for Gayung and Sipu subbasins are 4.74 and 4.25 respectively while the bifurcation ratios are 5.91 for Bhardari Gad and 5.64 for Kyar Gad subbasins of the Alaknanda basin respectively. The mean Rb value characteristically ranges between 3.0 and 5.0 for a basin when the influence of geological structures on drainage network is negligible (Vestappen, 1983).

4.5.4.5 Drainage Density (Dd)

It is an important indicator for analysis of river basin. It is defined as the total stream length in a given basin to the total area of the basin (Strahler, 1964). Drainage density gives a significant idea about the landscape evaluation processes. It indicates the closeness of the spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. Drainage density depends upon both climate and physical characteristics of the drainage basin. High drainage density indicates weak or impermeable sub-surface material, sparse vegetation and fine texture and mountain relief. Low density leads to coarse drainage texture (Strahler, 1964). High densities can also indicate a greater flood risk. High drainage densities also mean a high bifurcation ratio. A low Dd indicates permeable sub-surface strata and has a characteristic feature of coarse drainage which generally shows values less than 5.0 (Magesh et al., 2013). The drainage densities (Table 4.6 and 4.9) for both the subbasins of the Subansiri basin are found to have same value of 3.43 which indicates permeable sub- surface strata with coarse drainage texture and lower flood risks while the values of drainage densities are found to be 3.25 for Bhardari Gad and 3.31 for Kyar Gad catchments of the Alaknanda basin of western Himalayas.

4.5.4.6 Basin Length (Lb)

Lb determines the shape of the basin. High basin length indicates elongated basin. The Lb values for the study area are 28.19 km and 31.16 km for the Gayung and Sipu catchments respectively, both having elongated shapes. On the other hand the values of basin lengths are 12.36 km for Bhardari Gad and 11.73 km for Kyar Gad indicating comparatively less elongated shape than the Gayung and Sipu subbasins (Table 4.6 and 4.9).

4.5.4.7 Stream Frequency (Fs)

It is the ratio of total number of stream segments of all the orders in the basin to the total area of a basin. The rock structure, soil property, vegetation cover and rainfall influence the stream frequency of a basin. High densities or frequencies indicate greater flood risk while low Fs indicating a higher recharge of groundwater. The values of the Fs (Table 4.6 and 4.9) for the study area are 5.98 and 6.26 for the Gayung and Sipu basins respectively indicating the greater flood risk, while stream frequencies are 6.65 and 4.33 for Bhardari Gad and Kyar Gad catchments depict the comparatively less flood risk and higher recharge of ground water of the drainage area than the Gayung and Sipu subbasins of eastern Himalayas.

4.5.4.8 Drainage Texture (T)

Drainage texture is a product of stream frequency and drainage density (Smith, 1950). According to Smith (1950) classification the range of texture 4 or below 4 indicates coarse texture of a basin, Texture in the range, 4-10 indicates intermediate, while above 10 is fine and above 15 is ultra fine (bad topography). In case of Gayung, the drainage texture value 0f 6.54 indicates intermediate texture and for Sipu, it is 14 which indicates characteristics of fine texture of the drainage, while in case of Bhardari Gad catchment T 3.19 indicates coarse texture and 4.47 for kyar Gad indicates intermediate texture of the drainage (Table 4.6 and 4.9).

4.5.4.9 Form Factor (Ff)

Form factor is calculated from Horton's (1932) formula. Ff is smaller for long-narrow basin, for circular basin Ff is intermediate and it is greater than 0.78 for a perfectly circular basin. Short-wide basin has the largest form factor. The basin with high form factor value has high peak flow for a short duration whereas elongated basin with low form factor will have a flatter peak flow of longer duration. Flood flows in elongated basins are easier to manage than that of the circular basin (Nautiyal, 1994). The calculated values of form factor (Table 4.6 and 4.9) for the Gayung and Sipu catchments are 0.13 and 0.26 while it is 0.24 for Bhardari Gad and 0.31 for Kyar Gad catchments of the Alaknanda basin which reveal the characteristics of much narrower and elongated basin with flatter peak flow for a long duration.

4.5.4.10 Circularity ratio (Rc)

It is the ratio of the area of a basin to the area of a circle having the same circumference as the perimeter of the basin. The low, medium and high values of the circulatory ratio are indication of the youth, mature and old stages of the life cycle of the tributary basin (Magesh et al., 2013). This parameter is influenced by the lithological characteristics of the basin. The Rc (Table 4.6 and 4.9) is found to be 0.23 and 0.49 for the Gayung and, Sipu subbasins of eastern Himalayas respectively which justifies the elongated shapes and youth stages of development of the basins. On the other hand, it is found that the comparatively higher Rc values of 0.45 and 0.54 for Bhardari Gad and Kyar Gad catchments respectively of western Himalaya indicates the comparatively mature stage of development of the basins.

4.5.4.11 Elongation ratio (Re)

Elongation Ratio (R_e) is expressed by the equation $R_e = 2/L_m(A/\pi)^{0.5}$ Where L_m is the maximum length of the basin parallel to the principal drainage lines. It is negatively correlated with peak discharge. It is a measure of the shape of the river basin and it develops on the climatic and geologic types. Elongation ratio ranges from 0.6-0.8 over a wide variety of climatic and geologic regimes which indicates the regions of high relief and steep ground slope. If the Re (Table 4.6 and 4.9) values are close to 1.0, then the basins have very low relief with circular shape. It is found to be 0.41 and 0.57 for Gayung and Sipu catchments of the Subansiri basin respectively while in case of western Himalayan catchments these were found to be 0.55 for Bhardari Gad and 0.63 for Kyar Gad catchments respectively indicating their high relief with steep slope and elongated in shape of the basins.

4.5.4.12 Relief ratio (Rh)

Basin relief is an important factor in understanding the denudational characteristics of the basin (Sreedevi et al., 2009). The relief ratio Rh is defined as the total relief of the catchment and the longest dimension of the basin parallel to the principal drainage line and it is given by-

$$Rh = (Hmax-Hmin)/Lb$$

Relief ratio normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin. It is noticed that higher values of Rh indicate steep slope and high relief, while the lower values may indicate the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope (Jasrotia et al., 2012). The higher the relief, the steeper the slopes and the greater the energy available to move flows through the catchment. Catchments with the highest relief ratio have shorter lag time and time of rise, as well as higher peaks and flow velocities. The relief ratios of the Gayung, Bhardari Gad, Sipu and Kyar Gad subbasins are shown in the table 4.6 and 4.9.

4.5.4.13 Relief

Relief refers specifically to the quantitative measurement of vertical elevation change in a landscape. It is the difference between maximum and minimum elevations within a given area, usually of limited extent**.** The relief maps of the Gayung and Bhardari Gad, Sipu and Kyar Gad are shown in the Figure 4.38 and 4.39.

4.5.4.14 Slope (or gradient)

The measures of slope as hydrologic parameters are also very important. The slope of a terrain refers to the amount of inclination of physical feature, topographic landform to the horizontal surface. Hill slopes become steeper with increasing relief. The slope elements, in turn, are derived from the ASTER DEM using the aspect and slope tool in ArcGIS 9.3 Spatial analyst module. In case of Gayung and Bhardari Gad, Sipu and Kyar Gad are shown in the Figure 4.40 and 4.41.

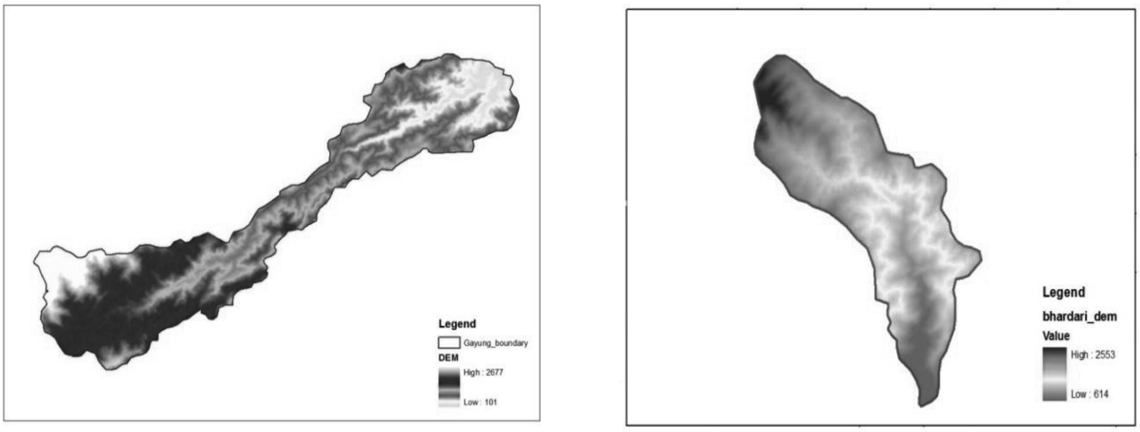


Figure 4.38: Relief maps of Gayung and Bhardari Gad subbasins

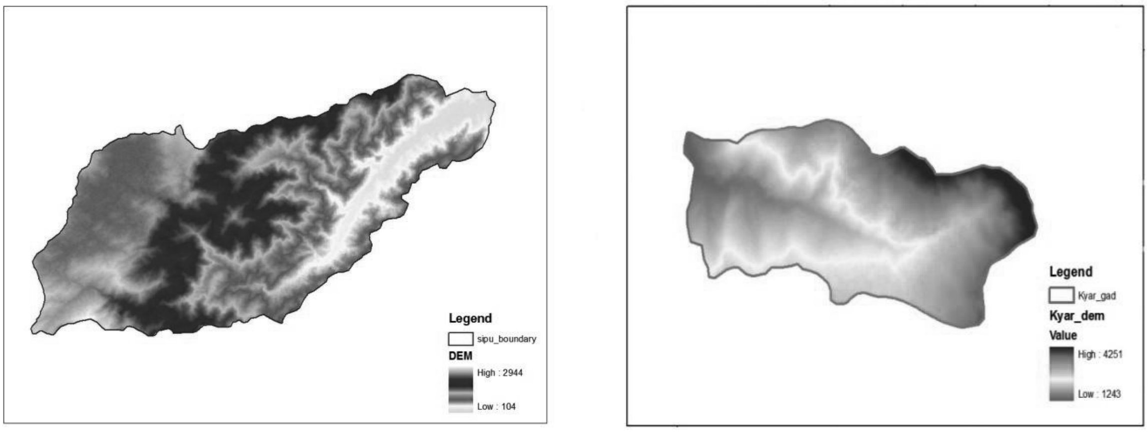


Figure 4.39: Relief maps of Sipu and Kyar Gad subbasins

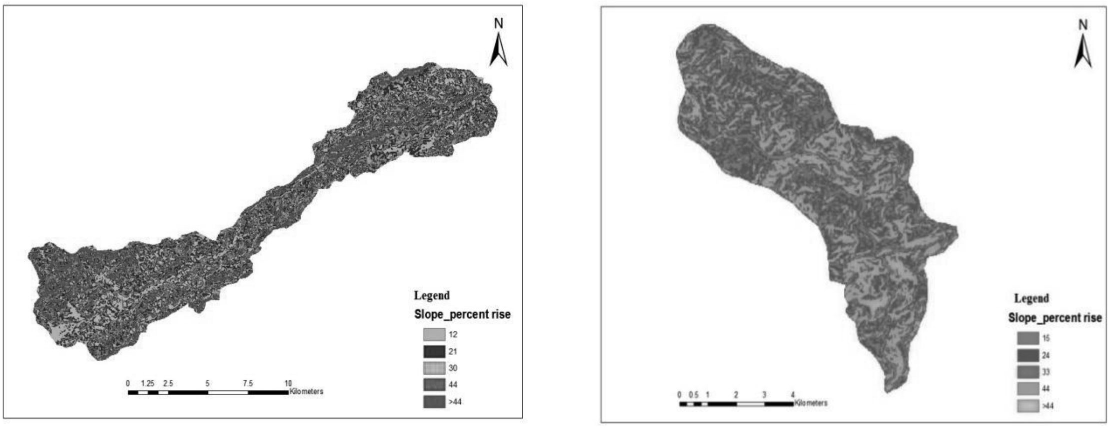


Figure 4.40: Slope maps of Gayung and Bhardari Gad subbasins

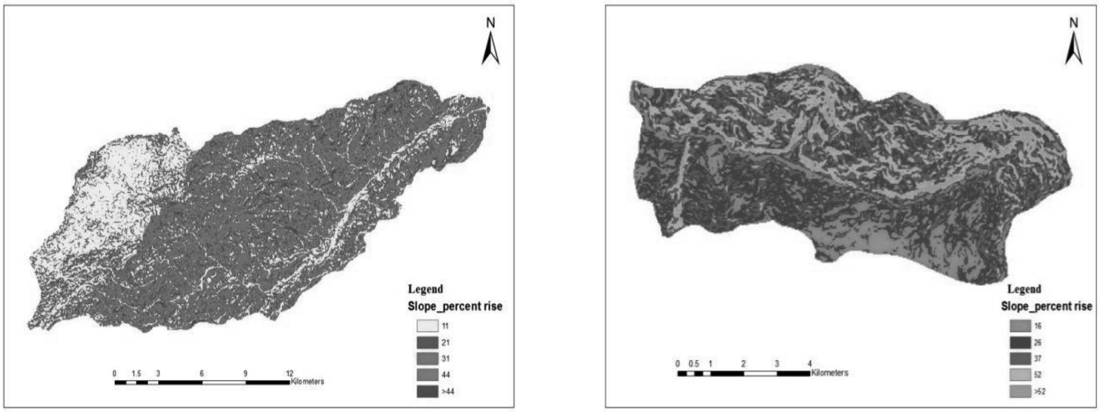


Figure 4.41: Slope maps of Sipu and Kyar Gad subbasins

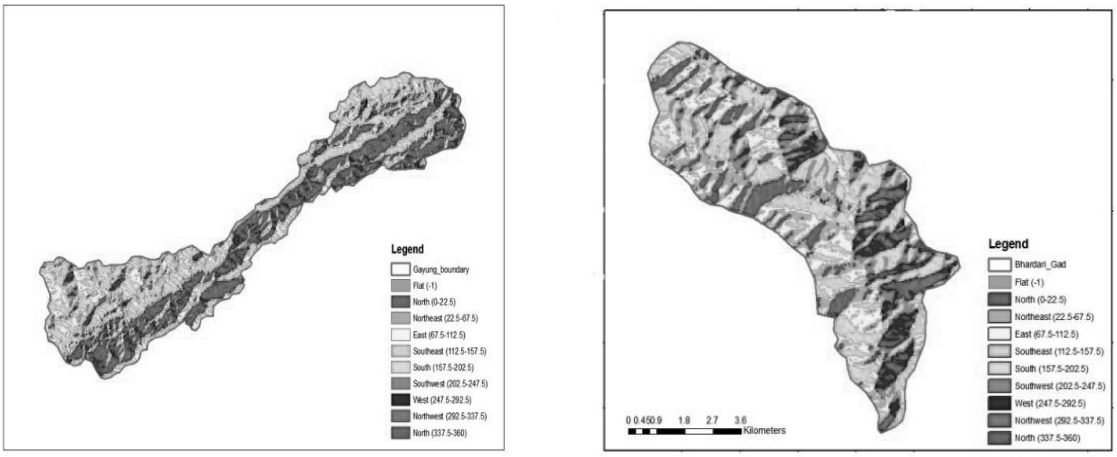


Figure 4.42: Aspect maps of Gayung and Bhardari Gad subbasins

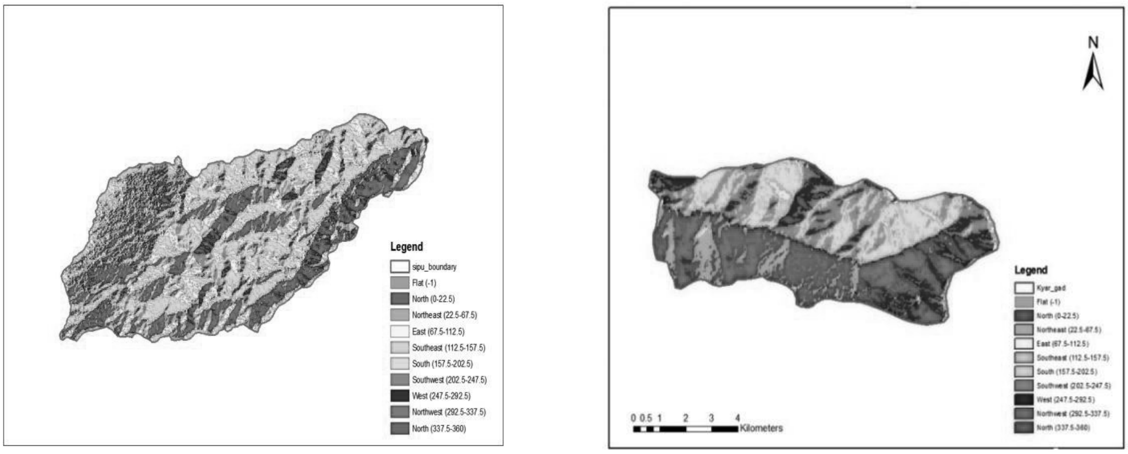


Figure 4.43: Aspect maps of Sipu and Kyar Gad subbasins

4.5.4.15 Aspect

The aspect of a terrain is the direction of the slopes to which it faces. Aspect influences vegetation type, precipitation patterns, snow melt and wind exposure. The aspect map of Gayung and Bhardari Gad, Sipu and Kyar Gad are shown in the Figure 4.42 and 4.43. It is derived from the ASTER DEM of the area.

4.5.4.16 Results and Discussion

It is revealed from the above analysis (Study 2) that both the subbasins viz. Gayung and Sipu of the Subansiri basin are first-order-dominated subbasins with large number of fingerling streams (Table 4.10). This condition is same for the Bhardari Gad and Kyar Gad subbasins of the Alaknanda basin of western Himalaya. The bifurcation ratios are high for all the catchments of eastern and western Himalayas. Still, analysis of most of the morphometric parameters indicates the youth and immature topography of the eastern Himalayan basins undergoing erosion while comparatively mature and stable development is seen in case of the western Himalayan subbasins. Both the subbasins of eastern Himalayas have elongated shapes, high reliefs, steep slopes with high drainage densities and high bifurcation ratios indicating the structural complexity and low permeability of the terrain; hence low recharge of ground water and greater flood risks than the western Himalayan subbasins (Devi and Goswami, 2015). Therefore, remote sensing data coupled with GIS techniques are useful tools for geo-spatial analysis and better understanding of the hydrologic scenario of a basin having complex and hilly terrain. It further helps in hazard management of the basin.

4.5.5 LAND USE, LAND COVER (LULC) CHANGE DETECTION OF THE SUBANSIRI AND THE ALAKNANDA BASINS

4.5.5.1 Introduction

Land use and land cover is an important component in understanding the interactions of the human activities with the environment and thus it is necessary to be able to simulate changes (Gajbhiye and Sharma, 2012). Land use and vegetative cover play an important role in watershed runoff and stream flow discharge patterns over time, including peak flows. Increased human interventions have caused rapid transitions in land cover, adversely affecting the watershed processes and hydrological cycle in the long run (Dadhwal et al., 2010).

The forests of Himalaya have a pervasive influence on the ecosystems, environment and the lives of people. During the period (1967–1997) the forest cover in Garhwal Himalaya has altered drastically due to increasing population pressure (both human and animal), increased agricultural activities and extraction of natural resources (Wakeel et al. 2005, in Yu et al., 2007).

In the mountains, the terrain complexity complicates the interpretation of spectral signatures, which are influenced by elevation, aspect, and slope; this could lead to similar objects showing different reflectance and/or the different objects presenting the same reflectance, especially in dark shadow areas (Li 2004, in Yu et al., 2007).

In mountainous terrain, environmental vulnerability is strongly related to forest cover change. During 1976 and 1990 environmental vulnerability in the sub-watershed was relatively low due to maintenance of various protection measures. However, the growing population pressure, expanding agriculture and increasing forest resources extraction exerted acute pressures on both forests and the environment. This has resulted in the depletion of forest cover and deterioration of surrounding environment (Yu et al., 2007).

4.5.5.2 Methodology

The Remote Sensing technology along with GIS is a perfect tool to identify, locate and map various types of lands associated with different landform units. LANDSAT imageries (Figure 4.44 and 4.45) of the year 2000 and 2014 for the river Subansiri and of 2000 and 2013 (Figure 4.50 and 4.51) for the river Alaknanda were used for interpretation of land use/land cover and field study. Digital data were imported into the image processing system and enhancement was performed. Separately from making observation on the individual bands, FCC was generated using bands 2, 3 and 4 by transmission blue, green and red combination. Image classification procedures are used to classify multispectral pixels into different land cover classes. The input for the classification is multispectral bands and textural patterns computed from the multispectral data. Primary methods are supervised and unsupervised classification. The classes were generated by the unsupervised classification based on spectral properties, taking Isodata algorithm with hundred (100) classes, iteration six (6) for accurate classification. The classified map is validated with the imagery using visual interpretation technique and finally a classified map was prepared.

4.5.5.3 Land Use /Land Cover Analysis of the Subansiri basin

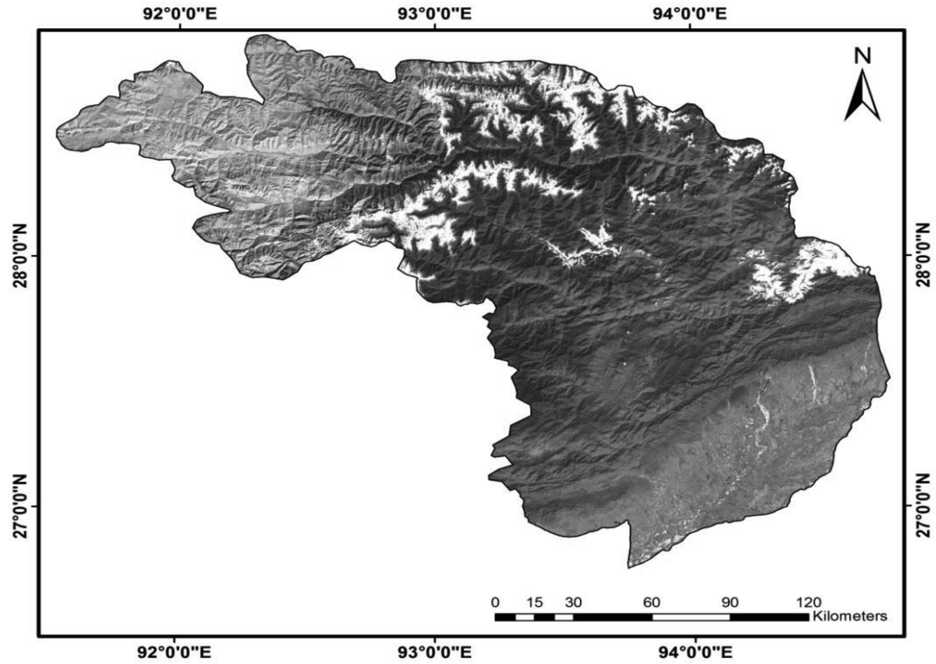


Figure 4.44: Satellite view (LANDSAT) of the Subansiri basin, 2000

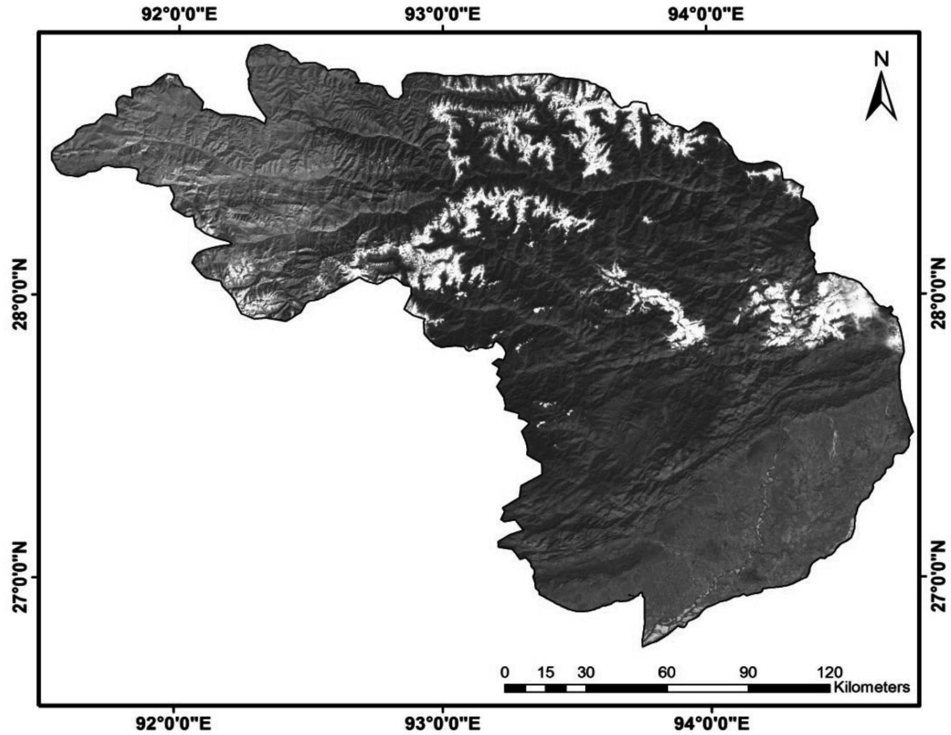


Figure 4.45: Satellite view (LANDSAT) of the Subansiri basin, 2014

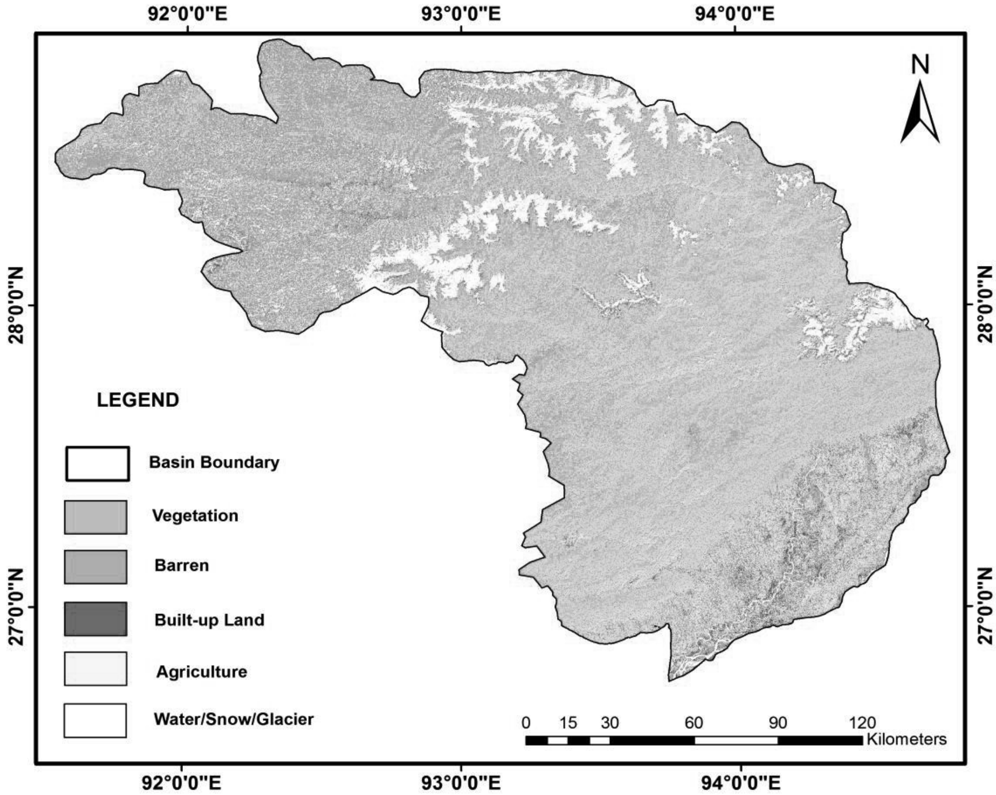


Figure 4.46: LU/LC map of the Subansiri basin, 2000

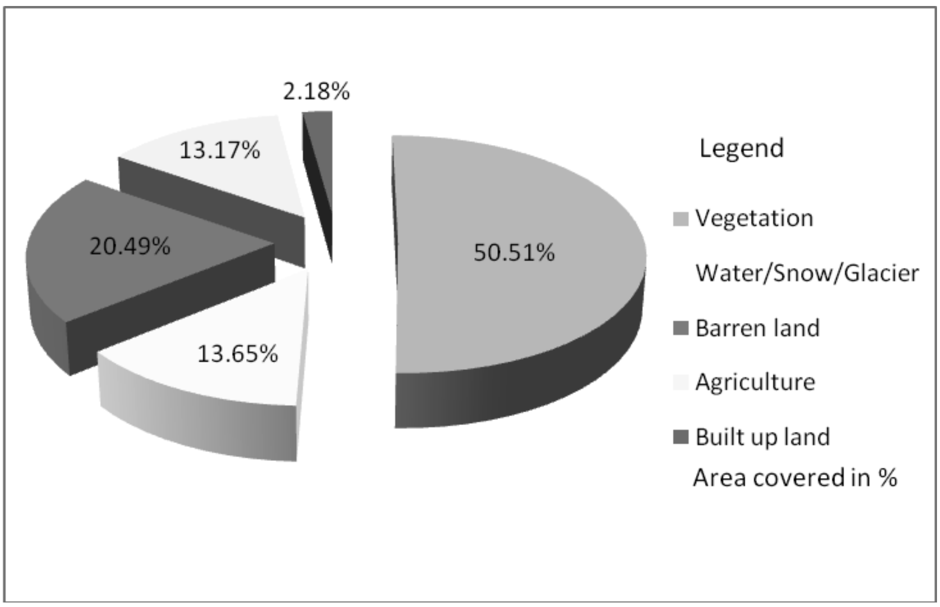


Figure 4.47: Graphical presentation of LU/LC pattern of the Subansiri basin, 2000

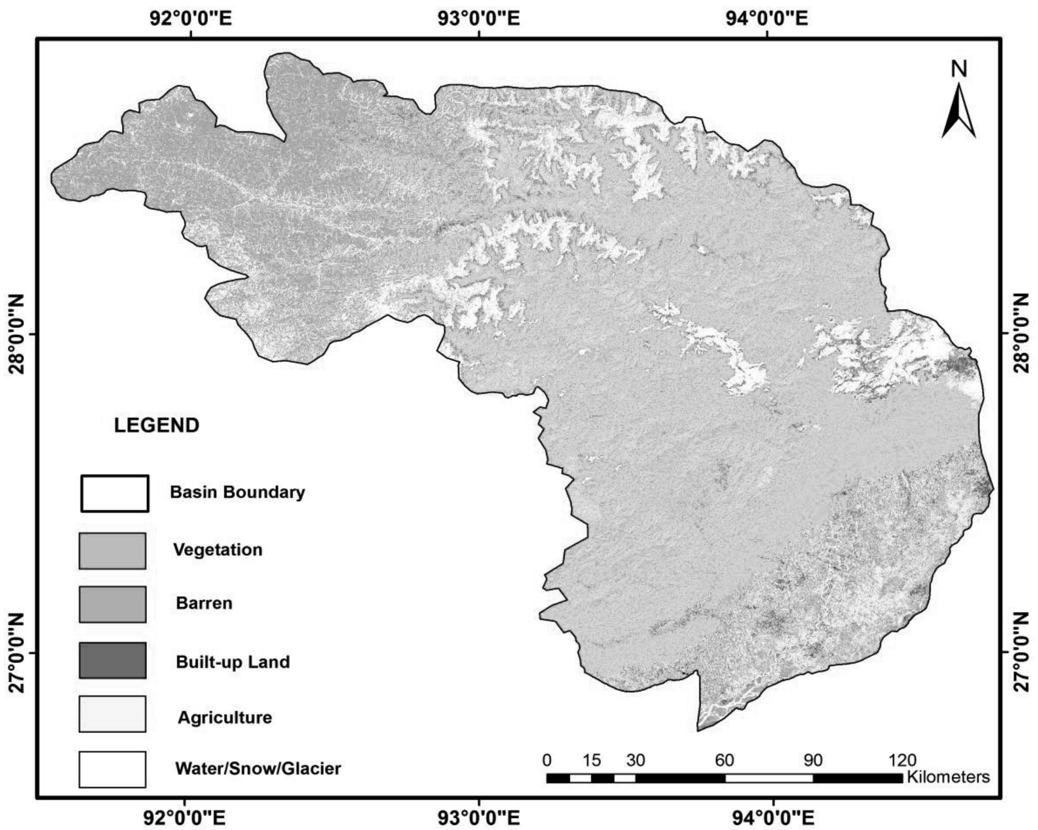


Figure 4.48: LU/LC map of the Subansiri basin, 2014

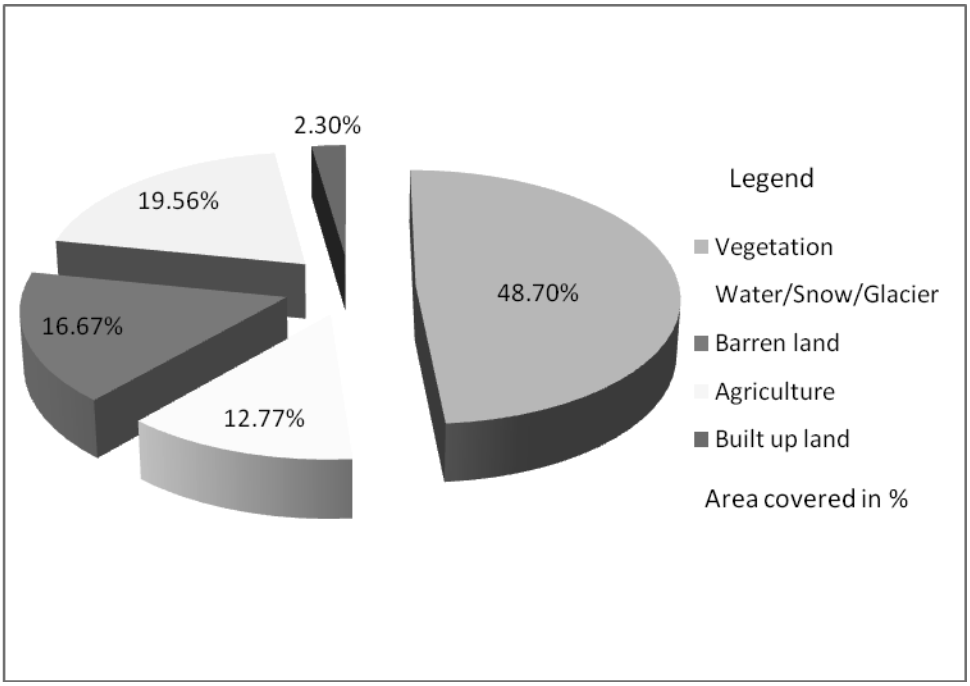


Figure 4.49: Graphical presentation of LU/LC pattern of the Subansiri basin, 2014

Table 4.11: Changes of Landuse/Landcover pattern in Subansiri basin, 2000 and 2014

LU/LC Class	Area in square km		% of Total Area		Change	
	2000	**2014**	**2000**	**2014**	**Sq.km.**	**%**
Vegetation	18175.58	17525.17	50.51	48.70	-650.41	-1.81
Water/Snow/Glacier	4910.76	4595.59	13.65	12.77	-315.17	-0.88
Barren land	7374.35	5996.74	20.49	16.67	-1377.61	-3.82
Agriculture	4737.63	7036.70	13.17	19.56	2299.07	6.39
Built-up land	784.74	828.79	2.18	2.30	44.05	0.12

From the LU/LC table (Table 4.11) of 2000 and 2014, it is seen that the vegetation cover and barren land have declined from 18175.58 sq. km. to17525.17 sq.km. and from 7374.35sq.km. to 5996.74 sq.km. respectively in the Subansiri basin. The area covered by Water/Snow/Glacier is calculated to be 4910.76 sq. km. in 2000 while it is 4595.59 sq. km. in 2014 showing a negative change. Agricultural area increases from 4737.63 sq. km. to 7036.70 sq. km and Built-up land slightly increases from 784.74 sq. km. to 828.79 sq. km (0.12%) in 14 years.

4.5.5.4 Land Use /Land Cover Analysis of the Alaknanda basin

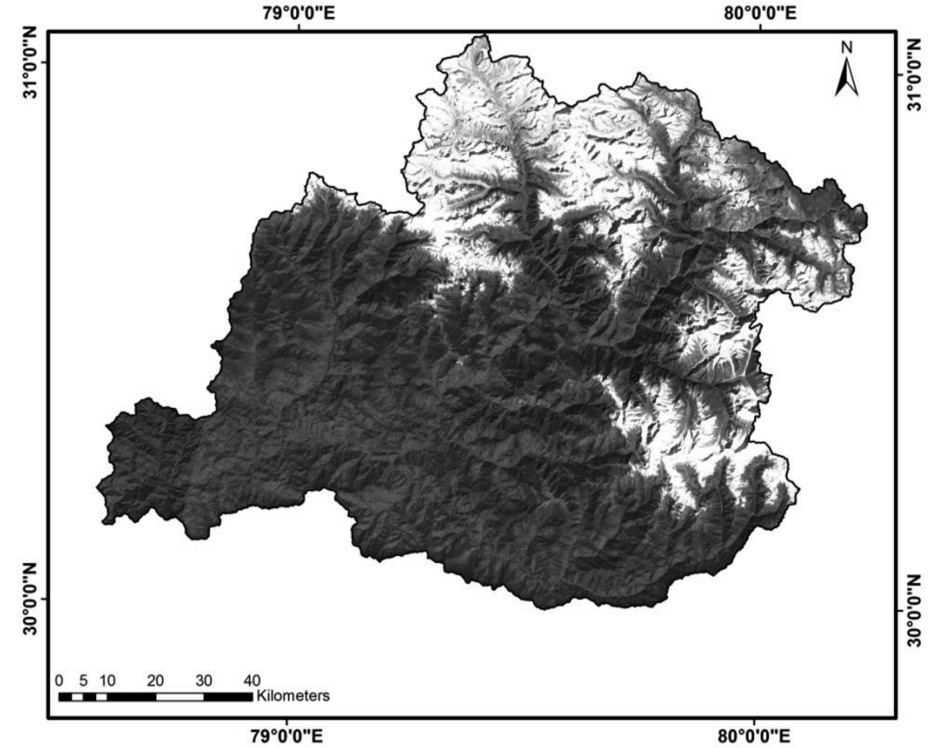


Figure 4.50: Satellite view (LANDSAT) of the Alaknanda basin, 2000

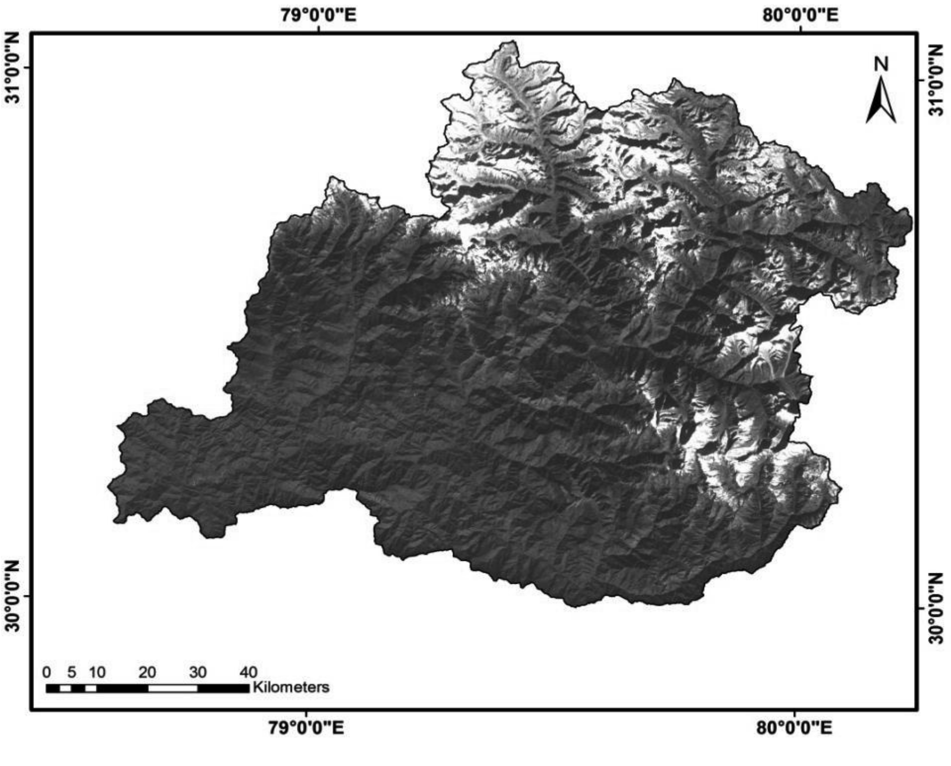


Figure 4.51: Satellite view (LANDSAT) of the Alaknanda basin, 2013

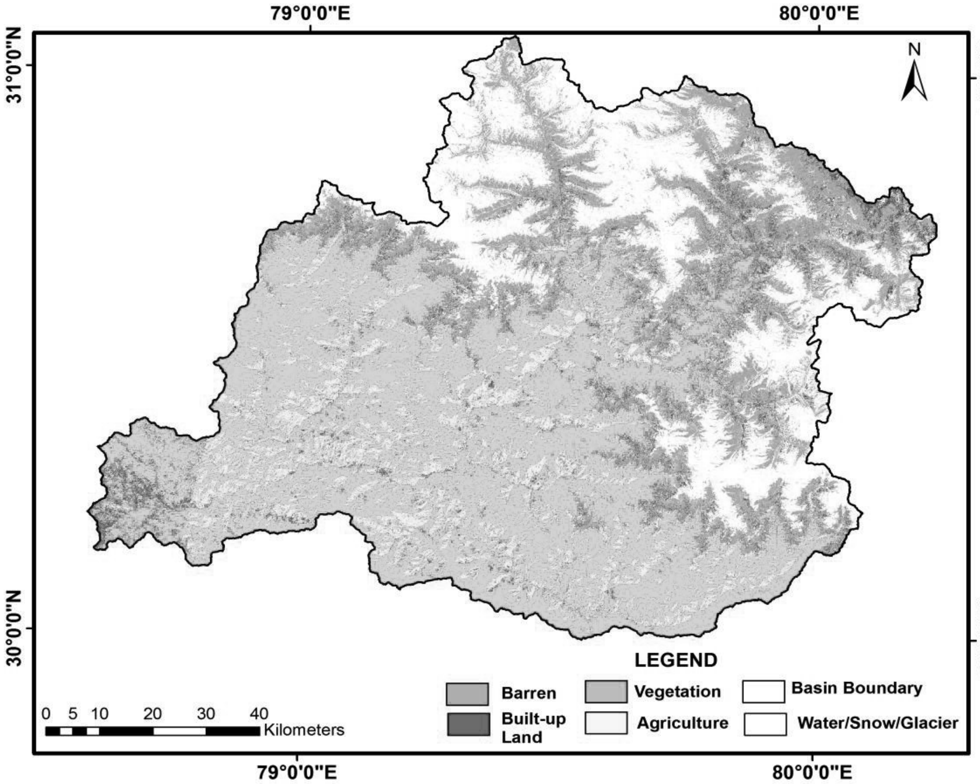


Figure 4.52: LU/LC map of the Alaknanda basin, 2000

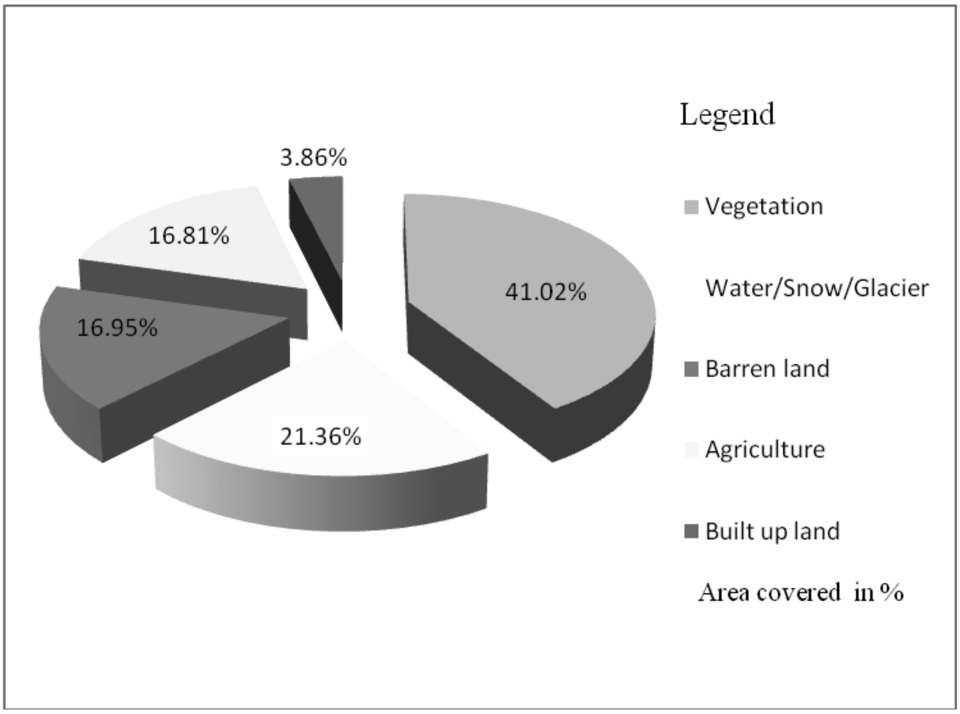


Figure 4.53: Graphical presentation of LU/LC pattern of the Alaknanda basin, 2000

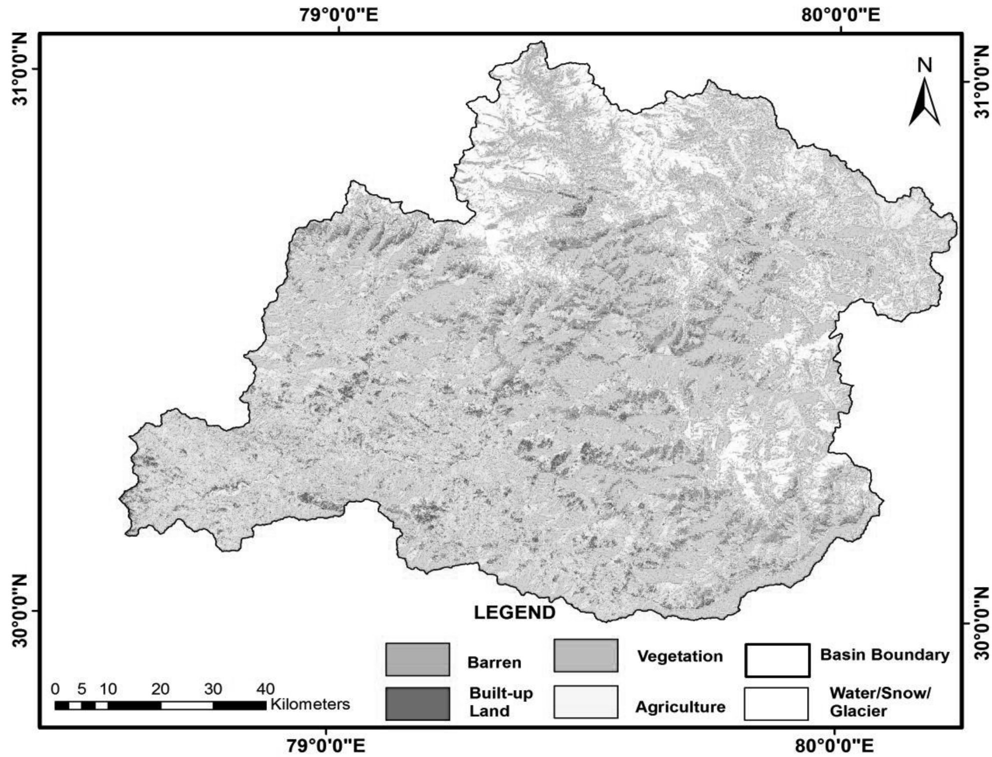


Figure 4.54: LU/LC map of the Alaknanda basin, 2013

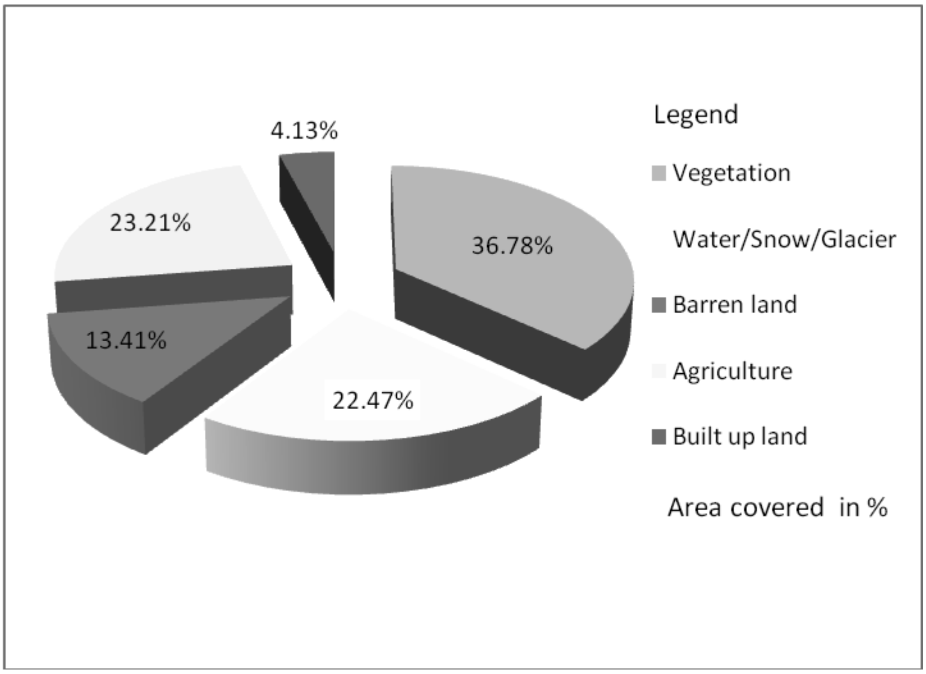


Figure 4.55: Graphical presentation of LU/LC pattern of the Alaknanda basin, 2013

Table 4.12: Changes of Landuse/Landcover pattern in Alaknanda basin, 2000 and 2013

LU/LC Class	Area in square km		% of Total Area		Change	
	2000	**2013**	**2000**	**2013**	**Sq.km.**	**%**
Vegetation	4483.1	3975.69	41.02	36.78	-507.41	- 4.24
Water/Snow/Glacier	2334	2428.79	21.36	22.47	94.79	1.11
Barren land	1852.6	1450.02	16.95	13.41	-402.58	-3.54
Agriculture	1837.4	2509.24	16.81	23.21	671.84	6.40
Built-up land	422.23	446.17	3.86	4.13	23.94	0.26

In case of the Alaknanda basin, table 4.12 shows that the vegetation cover has declined from 4483.1 sq. km. to 3975.69 sq. km. and barren land from 1852.6 sq. km. to 1450.02 sq. km. in 13 years. But the Agricultural area increases from 1837.4 sq. km. to 2509.24 sq. km. and built-up land from 422.23 sq. km. to 446.17 sq. km. in the basin. Water/Snow/ Glaciers have increased from 2334 sq. km. to 2428.79 sq. km. in 13 years.

Table 4.13: LU/LC Change detection in the Subansiri and the Alaknanda basins

LU/LC Class	% of Total Area in Subansiri		% of Total Area in Alaknanda		% change of area in Subansiri basin in 14 years	% change of area in Alaknanda basin in 13 years
	2000	**2014**	**2000**	**2013**	**2000-2014**	**2000-2013**
Vegetation	50.51	48.70	41.02	36.78	-1.81	- 4.24
Water/Snow/Glacier	13.65	12.77	21.36	22.47	-0.88	1.11
Barren Land	20.49	16.67	16.95	13.41	-3.82	-3.54
Agriculture	13.17	19.56	16.81	23.21	6.39	6.40
Built-up land	2.18	2.30	3.86	4.13	0.12	0.26

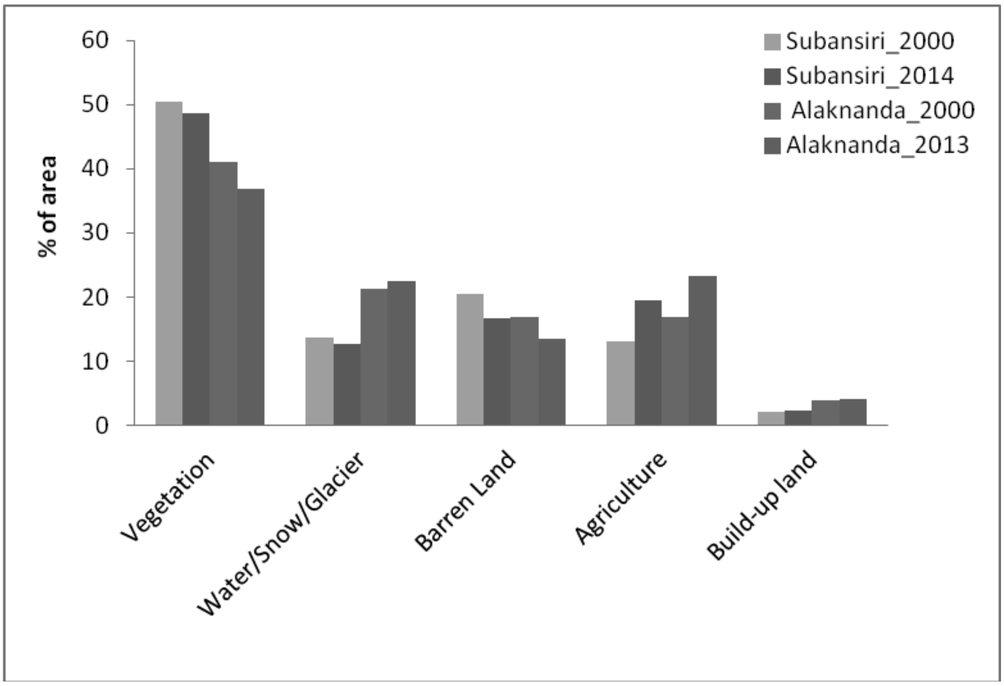


Figure 4.56: Graphical presentation of LU/LC categories of Subansiri and the Alaknanda basins, 2000 - 2014

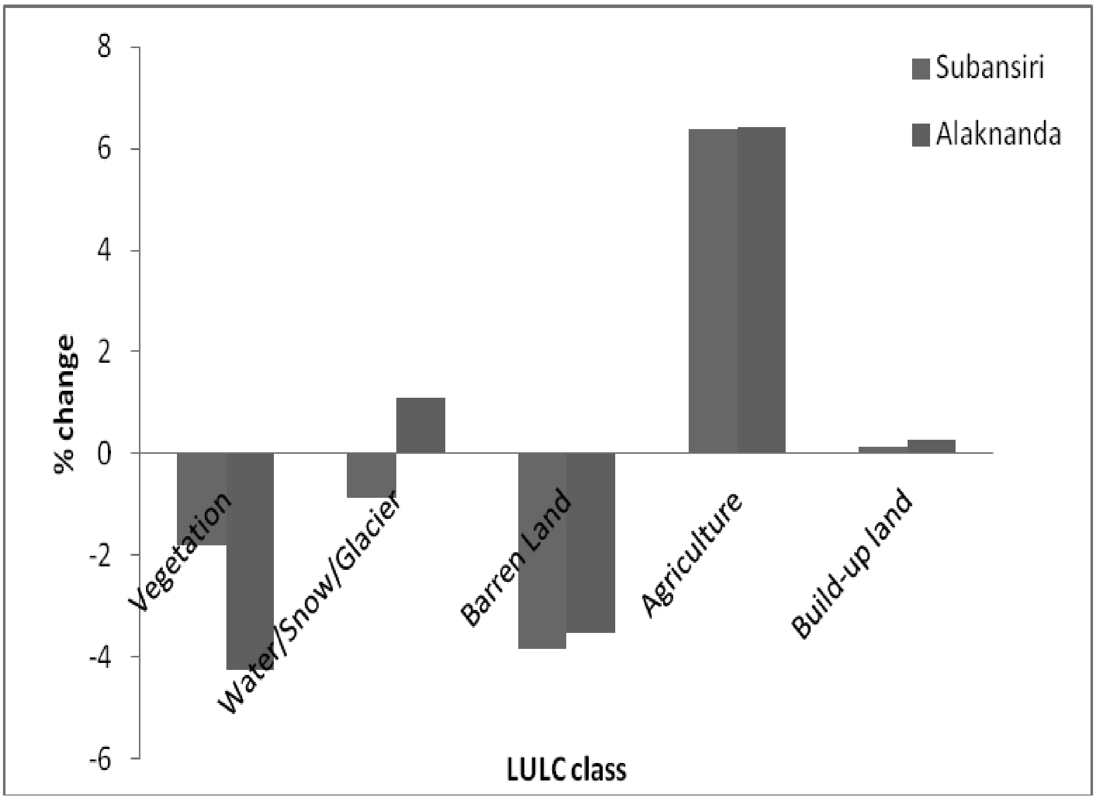


Figure 4.57: Graphical presentation of LU/LC change detection of the Subansiri and the Alaknanda basins

4.5.6 THE NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) OF THE SUBANSIRI AND THE ALAKNANDA BASINS

4.5.6.1 Introduction

The Normalized Difference Vegetation Index (NDVI) is based on the property of the leaves of green vegetation to absorb incident solar radiation in the red (RED) spectrum band through the chlorophyll and scatter in the near-infrared (NIR) spectrum band through the spongy mesophyll. It is calculated as the difference between near-infrared (NIR) and visible (VIS) reflectance values normalized over the sum of the two (Eidenshink, 1992): NDVI= (NIR−VIS)/ (NIR+VIS)]

Normalized Difference Vegetation Index (NDVI) is generally recognized as a good indicator of terrestrial vegetation productivity, Environmental factors such as soil, geomorphology and vegetation all influence NDVI values. Variations in climatic factors, in particular precipitation and temperature, have a strong influence on variation in NDVI for a given site (Wang et al., 2003).

NDVI values close to zero generally corresponds to barren areas of rocks, sand or snow; low positive values represent shrub and grassland (approximately 0.2-0.4) while high index (values approaching 1) indicate temperate and tropical forest or crops at their peak growth stage.

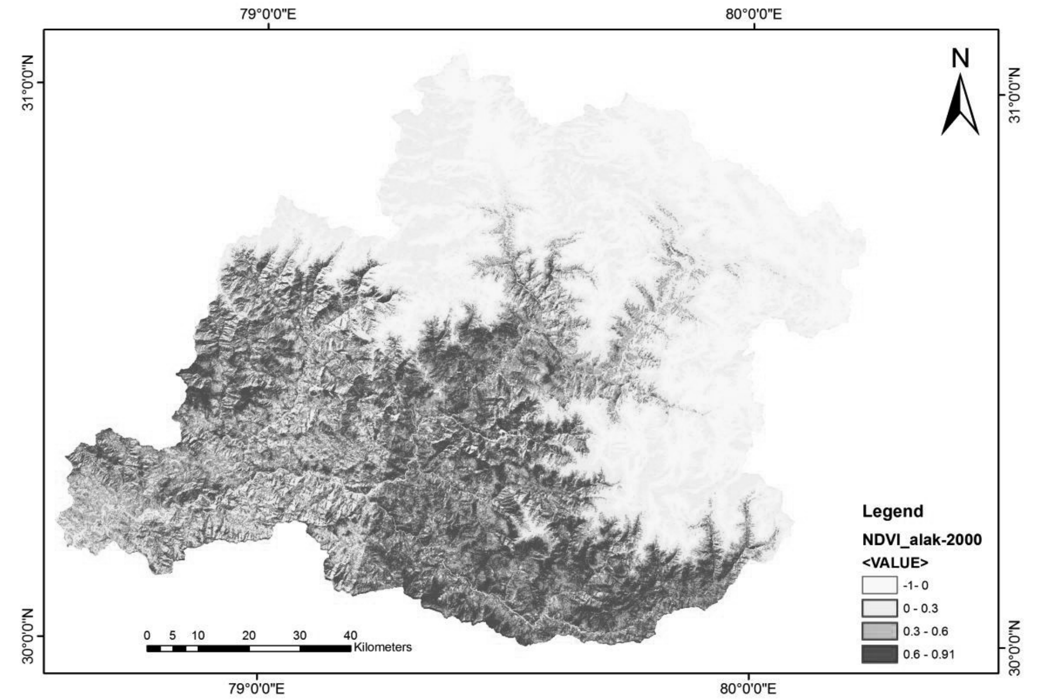


Figure 4.58: NDVI map of the Alaknanda basin, 2000

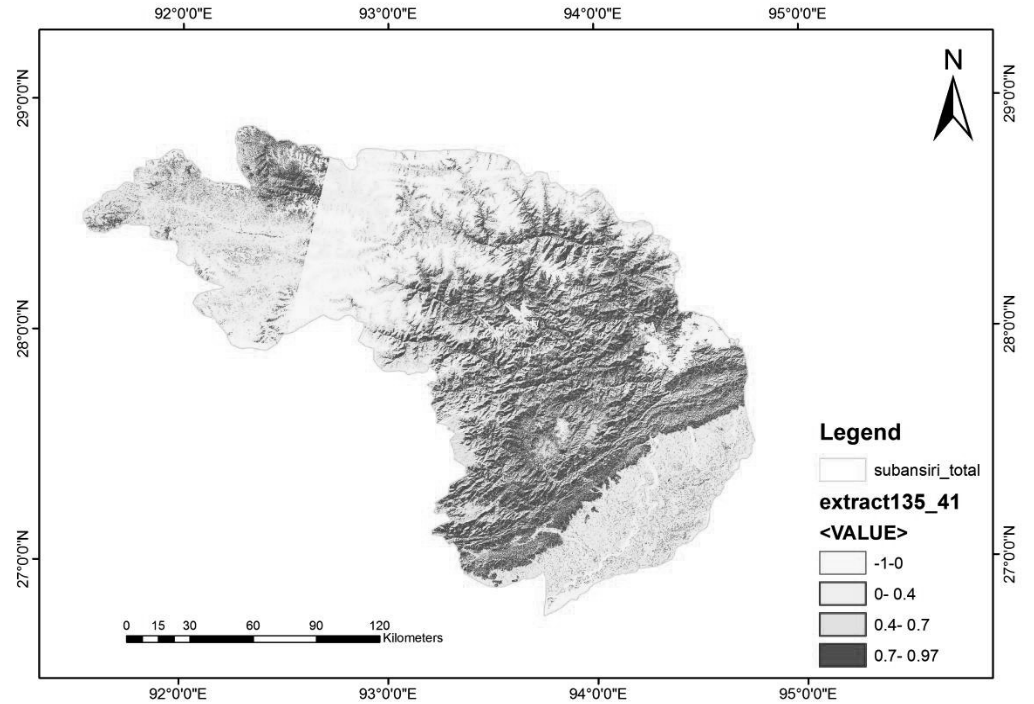


Figure 4.59: NDVI map of the Subansiri basin, 2000

4.5.6.2 Results and discussion

Land use/land cover (LULC) classes have been classified into five LULC categories in Level 1 classification. The land use/land cover maps of the Subansiri basin for the years 2000 and 2014 are presented in Figures 4.46 and 4.48, while the same of the river Alaknanda for the years 2000 and 2013 are presented in the Figures 4.52 and 4.54. The graphical representations of the LULC maps are given in the Figure 4.47 and 4.49 for the Subansiri while the same for the Alaknanda in Figure 4.53 and 4.55. The related calculations for the Subansiri and the Alaknanda are presented in table 4.10 and table 4.11 respectively.

From the LU/LC analysis of the Subansiri basin, it is observed that the vegetation cover has declined by 1.81% in 14 years. Water/Snow/Glacier areas have also decreased by 0.88% and there is a negative change of barren land by 3.82%. But there is a positive change of agriculture and built-up area by 6.39% and 0.12% respectively. Reasons for the negative change in forest cover in Subansiri basin in Arunachal Pradesh is primarily due to shifting cultivation practices and biotic pressure (Final report of CWC, 2014).

From the statistics (Table 4.13) and graphs (Figure 4.56 and 4.57) in the Alaknanda basin, it is observed that vegetation has declined from 41.02% in the year 2000 to 36.78% in 2013, while there is a positive change in case of agricultural practices by 6.4%. There is negative change in barren land (3.54%) and positive change in built-up land (0.26%). The decline in vegetation cover and barren land may be due to their conversion into agricultural land or built up area to meet the need of the raising population pressure and their livelihood. The water/snow/glacier class indicates the positive change by 1.11% which may be due to the seasonal variation.

For the study area the Subansiri basin and the Alaknanda basin of eastern and western Himalaya, NDVI is calculated for the year 2000 for both the basins. NDVI values are found to be 0.97 and 0.91 for both the Subansiri and the Alaknanda basins respectively indicating high vegetation index (Figure 4.58 and 4.59).