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Impact of Climate Change on Glacier in Dhauliganga River Basin: A Geospatial Investigation

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ABSTRACT

Glacier lake outburst is a recent incident that increases in higher glacier regions. Repeatedly Outbursts of glacier-originated lakes are prime factors for the loss of human lives as well as huge damage to local infrastructure in hilly terrain, which is recognized as hazards or natural calamities or disasters. Dhauliganga River basin is located in Uttarakhand mainly in the Chamoli district. The said research paper addresses how glacier lakes are formed and why these are busted. Data and information about the climatic condition and physical and cultural characteristics of the study area are collected from secondary sources e.g., IMD web portal, news articles, electronic media, census reports, and maps downloaded from USGS that are mapped by the QGIS software. In this research work, the area of a particular glacier zone is measured through the Google Earth software, and the measurement of the area of water bodies e.g., glacial lake with the temporal scale by Normalised Difference Water Index (NDWI), a remote sensing application. On 7th February 2021, a massive lake outburst happened in Uttarakhand, Chamoli district. Two power projects totally collapsed, many people died, and some are missing. Somehow, behind the occurrence of the glacier lake outburst (GLOF) global warming is one of the reasons for it. Anthropogenic activities influence the cause of temperature increase and climate change.

INTRODUCTION

Temperature increases are stimulated to lead to major environmental changes in ocean and mountain regions, e.g. major changes in glacial extent, ice and snow cover, permafrost, and vegetation. According to the IPCC (2007), climate change is a change in the state of the climate. This change can last for decades. Nowadays, among the most sensible, dramatic incident is climatic change, basically global warming. The great Himalayan glaciers are considered the third pole of the world as well as recognized as the source of freshwater from Asia. These glaciers are recognized to be sensitive indicators of climate (Houghton et al. 2001; Solomon et al. 2007; Mohd Ramiz et al. 2020).

At present, the impact of climate change on the world's glaciers is significant. The Indian Himalayan System consists of 9575 glaciers spread over an area of about 40000 km² and which is the source of 2000 km³ of fresh water. Major glacier-hydrological changes have taken place in glacial and periglacial mountain regions in response to climate change due to their higher level of sensitivity (Barry, 1990, Couture and Pollard, 2007, Maland Singh, 2013). Global climate change is the main cause of ice melting of surface and sub-surface ice. Glacial de-buttressing, slope failures and glacial lake outburst flood (GLOF), and some geomorphological processes affect newly formed deglaciated foreland, periglacial and low-lying regions. All these failures often lead to disaster in human life. Climate change has moved glaciers in the hilly region to form lakes. As its water level rises, it floods which is having a huge impact on the environment.

The Dhauliganga River basin is held in the northeastern part of Uttarakhand, mainly in the Chamoli district. Some parts of the said river basin area are extended to the Pithoragarh and Bageswar districts of Uttarakhand, India, and some very small parts extended to Tibet (occupied by China) country. The river basin area extends from latitude 30°15'36.00" north to 31°0'0.00" north and longitude 79°33'0.00" east to 80°15'0.00" east. Near Joshimath Town, the Dhauliganga river confluences with the main river, Alaknanda (K Jain et al., 2012). The initial water source of the Dhauliganga River is mainly from east Kamet and Raikanha glacial, melting water of these glacial flows through the Basudhara Tal and falls into the Alakananda River. The 84.3 km long Dhauliganga River assists to drain about 3024sq km catchment area. Analysis of the present situations of glaciers due to climate change and the probability of GLOF (Glacier Lake Outburst Flood) and its effects on the Dhauliganga River basin.

MATERIALS AND METHODS

As the study is based on secondary data, all work was done by using various web portals, QGIS 3.6.2 software, Google Earth software, and others internet sites. Satellite images of the years 1974, 2000, 2010, and 2020 are downloaded from USGS earth explorer. Various types of remote sensing index databases are used to do the said research work, e.g. to assess the land use land cover, supervised classification (maximum likelihood method) is being applied. As well as, to study the snow cover, the measurement of glacier zone are entertained by the Normalised Difference Snow Index (NDSI) method. According to Hardy & Burgan (1999) and K Jain et al. (2012), Normalised Difference Vegetation Index (NDVI) is used to determine vegetation cover and delineate the vegetation zone by the model of G J Laidler et al. (2007). The Normalized Difference Water Index (NDWI) model by Mc Feeters (1996), is used for glacier lake identification and New glacier lake formation.

In addition, the digital elevation model (DEM) map and stream ordering map are prepared from the Landsat-1 image of 1974, Landsat-5 image of 2000, Landsat image – 5 of 2010, and Sentinel Image of 2020. The stream-ordering map has been sketched as per Strahler model (1952). Climatic data from Mukteshwar station from 1980 to 2020 has been collected to compare climatic conditions and world temperature data is collected from 1897 to 2020 to know the trend of climate change worldwide. To know human activities in this area, the population trend from 1991 to 2011 has been analyzed using the data of the census handbook, and settlement trends were analyzed by MS Excel software.

RESULTS AND DISCUSSION

Climate

In the Garhwal region, the Dhauliganga River is situated where the famous Chipko movement happened. Dhauliganga river basin also experienced a monsoonal climate, like other areas of India. The highest annual temperature is about 15.45°c in 1999 found from the collected 123 years of temperature data similar to the world's other region temperature increasing trend is positive (Figure 1a). Most of the rainfall happens in July and August about 277.7mm and the lowest rainfall occurs in dry mostly in November about 10.9mm (Figure 1b). After analysis of 30 years of monthly rainfall data and yearly rainfall data, the trend is decreasing. Mukeswar station is the closest weather station to the river basin so collecting data on rainfall chooses this station is easy to work (Figure 1c).

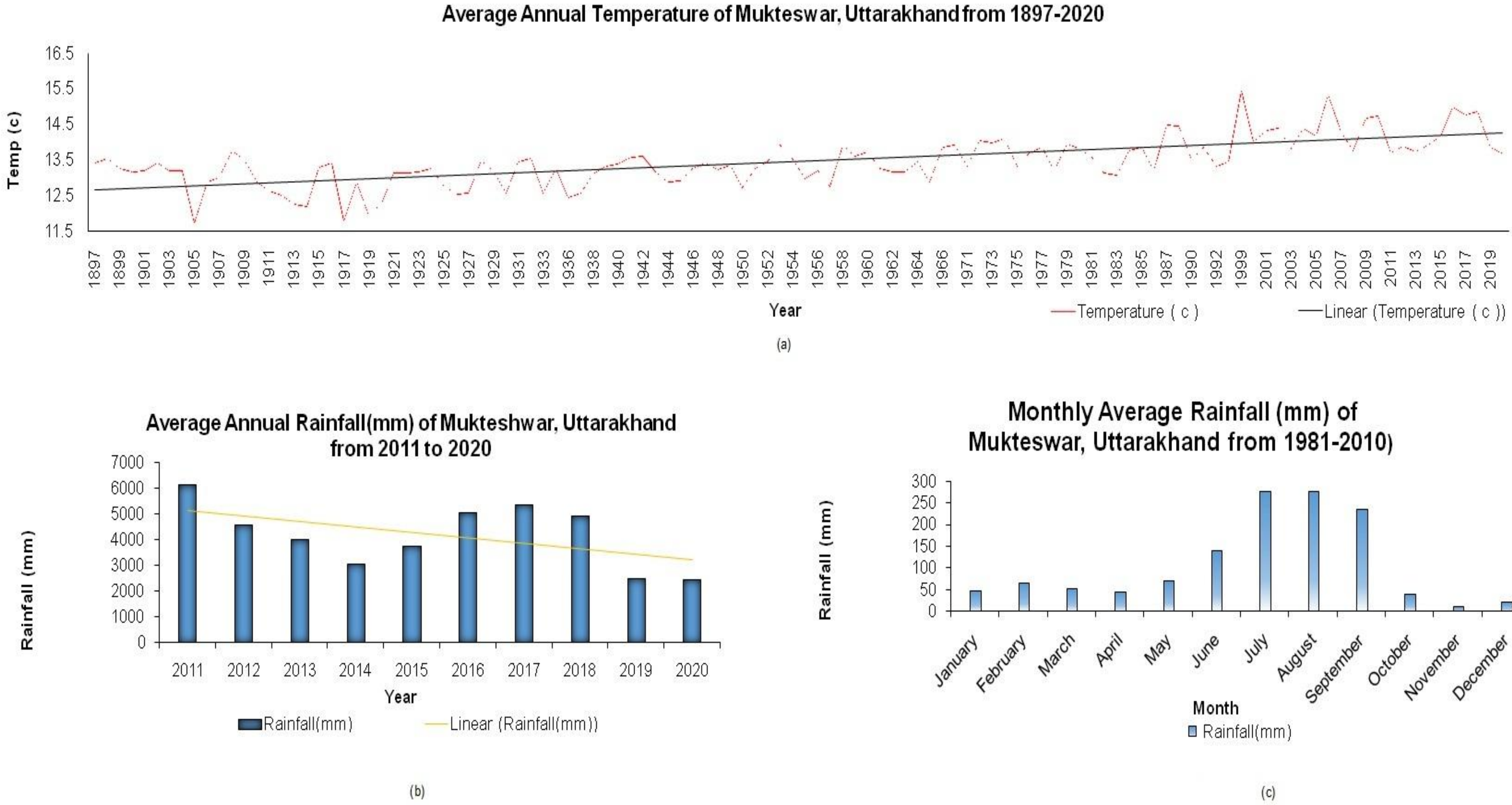

Figure 1. Climate Change in Study Area (a) Average annual Temperature since 1897, (b) Average Annual Rainfall in mm since 2011, (c) Monthly Average Rainfall in mm from 1981-2010

Physiographic Scenario

In this basin area, the highest elevation is 7816mt Nanda Devi peak situated extremely Southeast is the second highest mountain in India after Kanchenjunga lowest elevation is 1624mt (approx.) situated where Dhauliganga and Alokananda meet at Visnuprayag near Jashimath town. Dhauliganga River is the main river of this study which flow middle of the study area from northwest to south. On the right-hand side of the river Amrit Ganga, Kasa gad flow from northwest to the east, and some tributaries flow northwest to southeast like Jumma gad, Oti gadhera. On the left-hand side Girthi Ganga originated from Bhimagroar Glacier which as flows east to west and Bagini nala, Gannakhuni Nala, Tolma gad flows from east to west which is the subsequent River. Rishiganga River originates from Dakshini Rishi Glacier flowing from southern east to northern west. Ronti Gangs (obsequent stream) flow south to north and meet Rishi Ganga near Nanda Ghunti. A stream-order map of the study area is drawn according to Strahler's model (1952).

Based on the number of headwater tributaries, the said river basin is regionalized in different segments. A stream without upstream tributaries is recognized as the first-order stream and when two first-order streams confluence then the second-order stream originates. As per Strahler's model (1952), a higher-order stream strats his journey after the confluence of the previous-order river. However, lower order river confluences with higher order, then the higher order should be maintained, according to his model. In the Dhauliganga River Basin, streams are ranges from the first order to the sixth order. About 481, 105, 27, 8, 3, 1 stream as 1st order, 2nd order, 3rd order, 4th order, 5th order, and 6th order is tracked in respectively and 6th order stream is the main River of Dhauliganga River. Bifurcation Ratio (Rb) is defined as the ratio of the number of stream branches of a given order to the number of stream branches of the next higher order. This can be expressed by:

$$\text{Bifurcation Ratio (Rb)} = \frac{Nu}{Nu+1} \quad \text{(after Strahler 1952)} \quad \ldots\ldots \quad 1$$

Where,

Rb =Bifurcation Ratio,

Nu = Number of stream of given order,

Nu+1 = Number of stream of next higher order.

After calculating bifurcation ratio (Rb) of the Dhauliganga River Basin is 3.498 which means the area is a higher drainage density and also suggests the area is technically active.

Normalized Difference Water Index (NDWI)

Due to Global warming, glaciers of the Himalayan region are retreating and forming glacial lakes behind the end moraine. It is necessary to monitor these glacial lakes consistently to save properties and lives downstream from Probable disastrous glacial lake outburst floods (Lalan Kumar Jha, Deepak Khare, 2016). According to Huggel et al. (2002), the research work introduces the Normalised Difference Water Index (NDWI) of McFeeters (1996) to delineate the glacial lake in the study area. The Normalised Difference Water Index (NDWI) is computed and mapped by the following equation:

$$\text{Normalized Difference Water Index (NDWI)} = \frac{\text{Green-NIR}}{\text{Green+NIR}} \quad \text{(after Feeters 1996)} \quad \ldots\ldots \quad 2$$

Where,

Green = Pixel values of the visible green reflectance of Green band of satellite imagery

NIR = Pixel values of the NIR reflectance of NIR band of satellite imagery

Here the minimum NDWI value is -0.6966209, maximum NDWI value is 0.3323442. The deep blue color represents the deep water body which means a large amount of water is accumulated in these regions. Through the computation and mapping of the normalized difference water index (NDWI), several numbers of glacial lakes are been identified in 2020. However, it's problem to identify the newly originated lakes due to their little water accumulation.

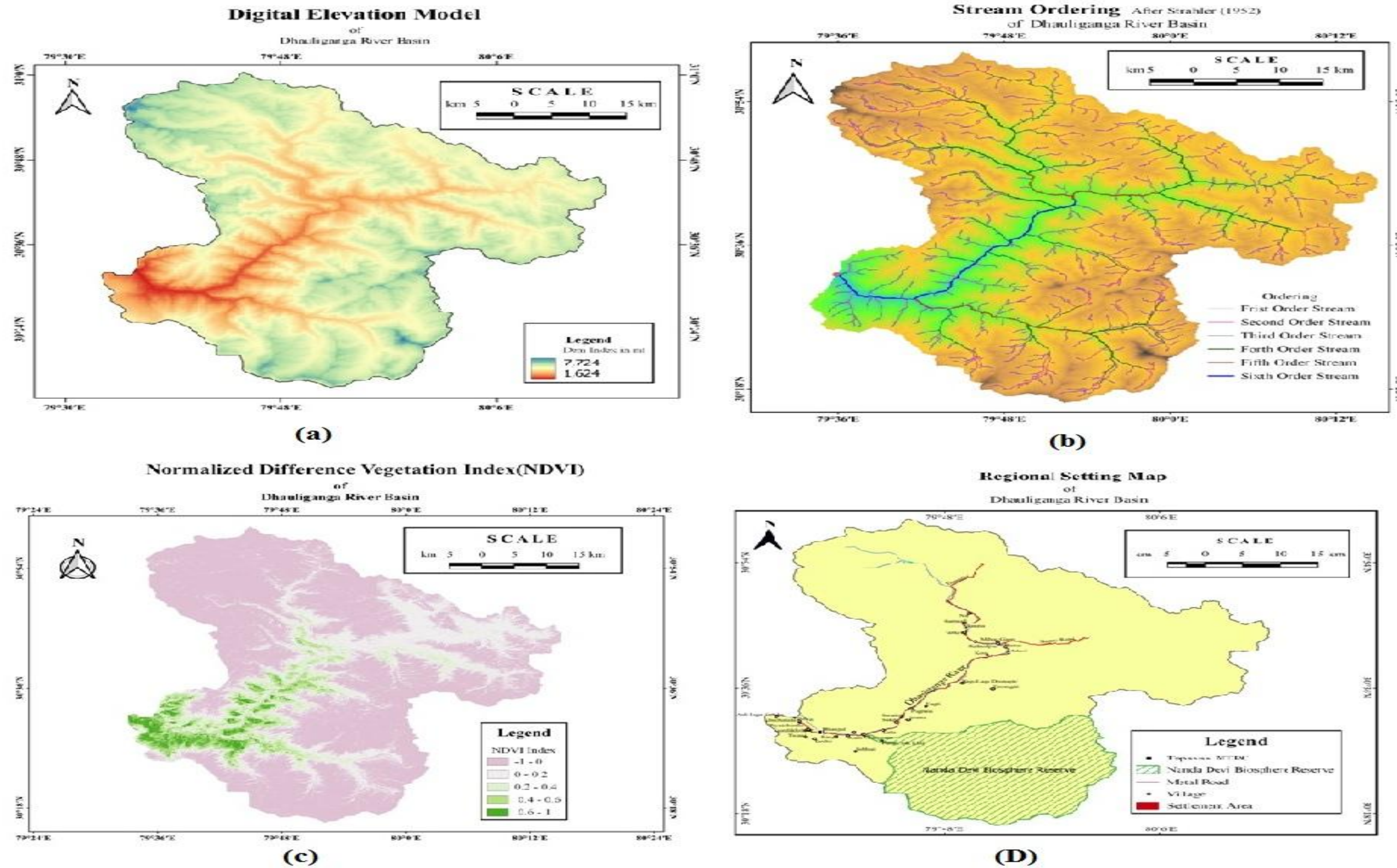

Figure 2. Physical Cultural Setup (a) DEM (b) Stream Ordering (c) NDVI (d) Regional Setup

Normalized Difference Vegetation Index (NDVI)

The NDVI has been used widely to examine the relation between spectral variability and the changes in vegetation growth rate. It is also useful to determine the production of green vegetation as well as detect vegetation changes (G. Meera Gandhi et al. 2015). The Normalised Difference Vegetation Index (NDVI) is applied in the said research work to detect the vegetation cover area and its' change detection from year to year. The said index database is computed by the following equation:

$$\text{Normalized Difference Vegetation Index (NDVI)} = \frac{\text{NIR-Red}}{\text{NIR+Red}} \quad \text{(after Laidler et al. 2007)} \quad .... \ 3$$

Where,

NIR= Pixel values of the NIR reflectance of NIR band of satellite imagery

Red = Pixel values of the visible red reflectance of Red band of satellite imagery

NDVI is the most important vegetation index used in satellite assessment and vegetation cover monitoring, which has become popular in the last two decades. The map shows the Normalised difference vegetation index of the Dhauliganga river basin in the year 2020 (Figure 2c). As per the Earth Observatory website of NASA, values below 0.1 represents the barren rock region, and values between 0.2 to 0.3 indicate the grassland, as well as the shrub. In addition, values between 0.6 to 0.8 address the temperate to tropical rainforest. The barren rock area of the Dhauliganga River Basin scored 0 and the temperate forest scored above 0.8 on the Normalised Difference Vegetation Index (NDVI) map. This map, clearly figures out that the vegetation cover is not the same in the whole basin area. Vegetation cover is higher beside the river because of soil moisture and sediment availability. Other areas are highly elevated and covered by snow, because of this the region in less vegetation cover and the NDVI value is zero (0).

The study area is part of the Himalayan Mountains, high snow cover areas do not have vegetation. Below the high snow cover region, the tundra forest is located and the low altitude areas where the river flows temperate forest has located. From the map of the normalized difference vegetation index (NDVI) of the study area in 2020, it has been observed that about 62 percent of the basin area is covered by barren rock with occasional snow cover, about 7 percent of the area is covered by grassland or shrub and only 2.4 percent of the area is covered by temperate forest (Figure 2c).

Glacier Movement

In the Dhauliganga river basin, two types of glaciers are recognized viz., one is mountain glacier and another is valley glacier. The Mountain Glaciers stream in high mountainous regions and sometimes its' headward extension up to the peaks. According to the National Snow and Ice Data Centre (NSIDC), valley glaciers are characterized by long glacier streaming channels. Sometimes, in high latitude regions, the tongue-shaped valley glaciers are flowing down to the sea, beyond the snowline. Most of the glaciated area situated in the northwest, east, and southeast Raikhana and East Kamet glaciers are located in the extreme Northwest part of the basin. The maximum number of glaciers found eastern part of the basin is Nanda Devi, Biagini, Rhamani, Changabang, Uttar Rishi, Siraunch, Jidier, Najgaon, and Bhilmagroar glacier. Dakshini Nanda Devi and Dakshini Rishi glaciers are situated extreme southeastern part and Ronti, Nanda Ghunti, Bethartoli, and Trisul glaciers are located in the extreme southern part of the basin. Most of the high peaks are found in the Trisul glacier and its' associated area (Figure 3c). After comparing the glacier zoning area 2021 (Figure 3d) to 2005 (Figure 3c), a huge amount of ice is melted due to temperature increases.

Normalized Difference Snow Index (NDSI)

The snow cover itself is a surface condition that affects radiation and water balance determinations that are input to the hydrological cycle and climatic studies (Cess et al., 1991; Cohen, 1994; Cohen & Entekhabi, 2001; Douville & Roger, 1996; Foster et al.,1996, Stieglitz, Ducharne, Koster & Suarz, 2001; Yang et al., 1999, V. V. Salomonson & I Appel, 2013). NDSI values for rock and vegetation are negative, for clouds close to 0.2, and snow and water above 0.4 (Kulkarni et al., 2002; Smriti Basnett & Anil Kulkarni, 2012).

$$\text{Normalized Difference Snow Index (NDSI)} = \frac{\text{Green-SWIR}}{\text{green-SWIR}} \quad \ldots\ldots \quad 4$$

Where,
Green = Pixel values of the visible green reflectance of Green band of satellite imagery
SWIR = Pixel values of the SWIR reflectance of SWIR band of satellite imagery

This NDSI map (Figure 3b) of 2020 shows the highest NDSI value 0.969086 which represents high snow cover area and the lowest value is – 0.6086 which represents rock and vegetation or less snow cover zone. In the year 2020, around 55 percent area falls under the high NDSI value that is 0.6 to 1, which means more than half area is high snow cover. A Low NDSI value between – 1 to 0, covers around 31 percent of the said region that is covered by rock and vegetation.

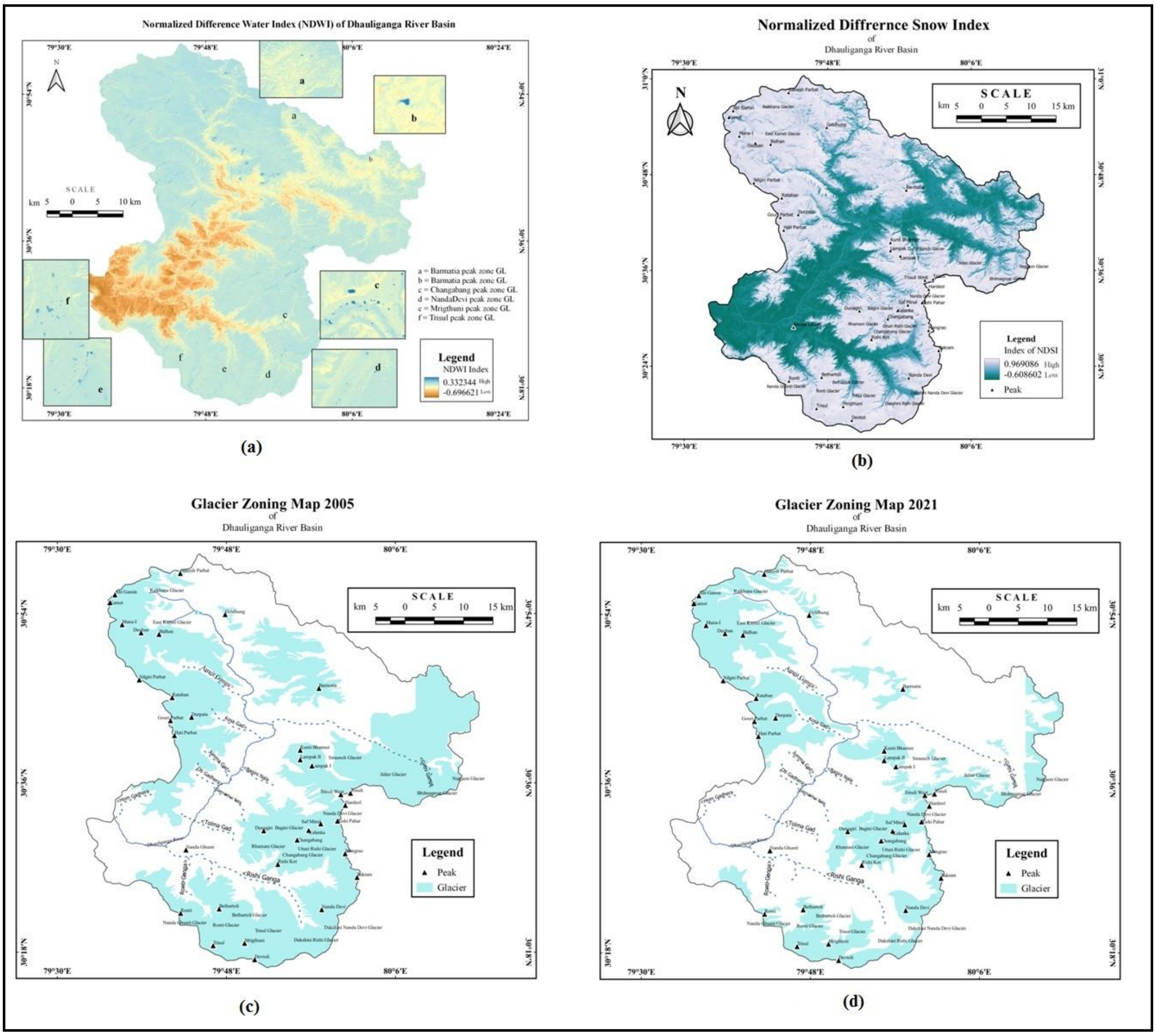

Figure 3. (a) NDWI (b) NDSI (c) Glacial Zoning Map in 2005 (d) Glacial Zoning Map in 2021

Cultural Characteristics

A settlement is a habitat of people and it may be a small village in a remote region as well as may be a large city. According to Matt Rosenberg (2018), the morphology of settlement is shaped by the physical element viz., terrain, climatic condition, situation of the river, water availability, soil, and building materials availability. In the said river basin, settlements are very low due to the rough and steep terrain area. There has no urban center in the aforesaid study area, only rural settlements exist. Almost all the settlements have been settled along the narrow part of the river valley for river occurs fertile land that is a very good pronouncing factor for cultivation and good for irrigation purposes, transport facilities, etc (Figure 2d).

The Chamoli district is situated at the heart of the Himalayas, in the Garhwal division. The district of Chamoli is Uttarakhand's second biggest area (Deep Mala Bhardwaj & Anupam Pandey, 2017). Chamoli is the main settlement area in the Dhauliganga River Basin area. In the said study area, most of the settlements are compact to semi-compact in nature some are linear and dispersed type settlements (Figure 2d). Generally, the settlement area increases here rapidly in some villages like Auli Laga Salud, settlement area is 24447sq mt in 2004-2005 and that increases to about 190503 sq mt in the year 2020-2021. Topoban, Chamoli, Buras, Khundikhola, Lata, Payaichormi, Subhai, Suki, Tugari, Bhangul, Bampa, Bilagar, Dunagiri, Fagti, Farkya, Gahar, Gamsali, Jugajuchaklata, Juwagar, KagaLaga Dronagiri have experienced the settlement expansion, etc (Table 1).

Table 1. Settlement Area (sq mt) of Dhauliganga River Basin (2004 - 2005 to 2020 – 2021)

Village	Area (sq mt)		Village	Area (sq mt)	
	2004-2005	2020-2021		2004-2005	2020-2021
Aulilagasalude	24447	190503	Kurchoi	5352	9740
Bampa	14110	21071	Lata	23213	40321
Bhangul	5060	18480	Mahargaun	3334	4264
Bilagar	3258	13014	Malari	16263	20434
Buras	4885	25786	Mirg	39029	71196
Chamtoli	28384	82079	Niti	9546	15711
Dunagiri	11346	11703	Pagrasu	4684	8274
Fagti	2413	3238	Pang chaklata	8245	12035
Farkya	9660	13763	Payaichormi	1340	12050
Gahar	3383	5494	Rainichaklata	9361	30102
Gamsali	31439	47487	Rainichaksubhai	3433	10829
Jugajuchaklata	NA	3480	Rewalchakkurkuti	342	1664
Juwagwar	822	3323	Ringi	9477	16670
Kagalagadonagiri	1730	6180	Subhai	14400	35423
Kailashpur	5867	14356	Suki	12307	27894
Karchi	24388	34793	Suraitota	16455	20876
Khnchatala	4976	13800	Topoban	46604	173339
Kosa	6879	12584	Tolma	4445	6453
Kundikhola	6891	24963	Tugasi	27629	57412

Source: Census Report

Settlement areas are experiencing expansion due to the development of socioeconomic facilities like well communication and transportation. In addition, due to the growth of tourism industries in the study area, settlements are facing expansion. Some of the reasons are intermigration from one village to another village for more facilities (Table 1). There Topoban NTPC is a big reason for settlement growth day by day due to village-to-village migration from other villages. Settlement area measured through Google earth. Niti village is located at a higher altitude in the basin area and Mirg, Kanchatala, Topoban, and Bhangul are lower-altitude villages in this area. Settlements are connected by the metal roadway parallelly going with the Dhauliganga River. From this research work, it has been envisaged that settlements of the study are developed based on River.

Population

In general, a Population is a group of individuals of the same species within a community (Mayhew, 2009, 394; Yadav, Pandey Arvind Singh D.C., 2017). In other words, 'population' mean the people living within a political or geographical boundary (en.wiktionary.org, 2017; Yadav, Pandey Arvind Singh D.C., 2017). The population of any area is of utmost importance regarding the use of resources mostly. Without the presence of the human population, the physical environment would not be worked upon to be transformed into a cultural environment. The transformation of the physical environment into a cultural environment is a significant process and happens due to Human actions (Shipra Basu, 2017). The total population of Chamoli District is about 3.92 lakh according to the 2011 census. In the Dhauliganga river Basin, the rural population mostly inhabits lower-altitude villages.

Population Growth (1991 to 2011)

According to the census report, the most populated center is Topoban, with about 735 (in 1991), and grows to 1064 (in 2011).

Table 2. The total population in Chamoli district's some village in the years 1991, 2001 & 2011

Village	Total Population			Village	Total Population		
	1991	2001	2011		1991	2001	2011
Aira	16	9	21	Kosa	123	194	302
Aulilagasalud	0	22	2	Kundikhola	229	233	180
BadalGaitha	20	1	0	Kuraipani	0	0	28
Bampa	97	74	192	Kurchoi	306	391	429
Barhgaon	755	825	167	Lamtoli	0	0	0
Bhalgaon	155	205	167	Lata	348	342	305
Bhangul	186	195	241	Longsagari	75	67	100
Bilagar	104	121	97	Mahargaon	29	26	269
Chamtoli	67	78	122	Malari	564	434	1933
Dhak	227	359	422	Mirg	334	362	451
Dronagiri	160	89	92	MoranaChakSubhai	0	23	23
Fagti	0	0	0	Niti	123	98	47
Farkiagaon	113	251	197	Pagrasu	90	94	56
Gahar	45	51	50	Pang chakLata	104	105	125
Gamsali	208	147	383	Payachormi	122	134	134
Garpak	49	33	66	Raigari	79	88	97
Gurguti	0	18	250	Rainichaksubhai	149	153	258
Jalam	409	315	224	Rainichaklata	98	153	145
Jugajuchaklata	40	32	36	RewalChakKurkuti	0	23	0
Jumma	214	98	78	Ringi	213	278	273
Juwagwar	113	78	59	Subhai	405	526	569
Kagalagadronagiri	72	58	97	Sukhi	121	163	174
Kailashpur	143	245	158	Topaban	735	793	1064
Karchi	216	277	328	Tolma	155	145	429
				Tugasi	147	192	230

Source: District Handbook

The population increase in Farkiagaon, Mahargaon, Kailashpur, Malari, Kosa, Dronagiri, Tugasi, Chamoli, Payachormi, Ringi, Pang Chak Lata, Subhai, Rainichaksubhai, Gamsali, Bampa, Sukhi, Tolma, Raini Chak Lata, Bhangul, Gahar, Karchi, Gurguti, Garpak, Longsagari, Bhalgaon, Kuraipani, Dhak, Aira, Raigari, Mirg, Kurchoi. However, population decrease in some villages, are Niti, Bilagar, Kundikhola, Khanchatala, Auli Laga Salud, Lata, Jugajuchak Lata, Jalam, Jumma, BadalGaitha, Juwagwar. Lamtoli and Fagti where the total population was zero (0) (Table 2). Topoban, Subhai, Malari, etc villages' population is higher due to urban facilities viz., well-metalled roads, water availability from the river, and riverine productive fertile land. Topoban NTPC is one of the reasons for the higher population in Topoban village (Table 2). However, the reorganization of the total population has increased over the years and further rural populations are increasing in the next census year. Dhauligang river basin is a hilly region here population is not like plain land. Population growth is not increased much in remote villages because of interrupted communication, transportation, and other facilities. Only riverside roads are mettle otherwise inter villages roads are unmetalled.

Population Density

The distribution and density of the population of any area are directly influenced by several environmental factors viz., physical, socioeconomic, cultural, and political factors that govern the population density in different segments of the India and World. A large portion of the said river basin comes under the Chamoli district of Uttarakhand and a very small portion stretches into the Pithoragarh and Bageshwar districts of Uttrakhand, India, and in Tibet (occupied by China). Uttarakhand is a Himalayan state and the physical environment in most cases is the prime factor for the distribution and density of the population. The said basin region contains few populations compared to other hill districts of Uttarakhand. This is because of the impassable physical and socio-economic environment for high altitude. Population density is the ratio between the population and area of a particular settlement.

Table 3. Population Density Dhauliganga River Basin Area, Uttarakhand

Village	2011	Area (hector)	Pop density	In No. of Person	Village	2011	Area (hector)	Pop Density	In No. of Person
Aira	21	146	0.143836	0	Kundikhola	180	576	0.3125	0
Aulilagasalud	2	121	0.016529	0	Kuraipani	28	101	0.277228	0
Badal Gaitha	0	41	0	0	Kurchoi	429	377	1.137931	1
Bampa	192	1393	0.137832	0	Lamtoli	0	17	0	0
Barhgaon	167	625	0.2672	0	Lata	305	2381	0.128097	0
Bhalgaon	167	178	0.938202	1	Longsagari	100	419	0.238663	0
Bhangul	241	4720	0.051059	0	Mahargaon	269	1684	0.159739	0
Bilagar	97	292	0.332192	0	Malari	1933	269	7.185874	7
Chamtoli	122	312	0.391026	0	Mirg	451	216	2.087963	2
Dhak	422	272	1.551471	2	Morana Chak Subhai	23	148	0.155405	0
Dronagiri	92	26593	0.00346	0	Niti	47	12852	0.003657	0
Fagti	0	224	0	0	Pagrasu	56	258	0.217054	0
Farkiagaon	197	2217	0.088859	0	Pang Chak Lata	125	3775	0.033113	0
Gahar	50	636	0.078616	0	Payaichormi	134	226	0.59292	1
Gamsali	383	1170	0.32735	0	Raigari	97	416	0.233173	0
Garpak	66	1120	0.058929	0	Raini Chak Lata	258	143	1.804196	2
Gurguti	250	7	35.71429	36	Raini Chak Subhai	145	232	0.625	1
Jalam	224	15436	0.014512	0	Rewal Chak Kurkuti	0	948	0	0
Jugajuchaklata	36	50	0.72	1	Ringi	273	2266	0.120477	0
Jumma	78	659	0.118361	0	Subhai	569	756	0.752646	1
Juwagwar	59	3322	0.01776	0	Sukhi	174	445	0.391011	0
Kaga Laga Dronagiri	97	1582	0.061315	0	Tolma	1064	208	5.115385	5
Kailashpur	158	6265	0.025219	0	Topoban	429	534	0.803371	1
Karchi	328	190	1.726316	2	Tugasi	230	297	0.774411	1
Kosa	302	2063	0.146389	0					

Source: Researcher's Computation

The settlements of the Dhauliganga river basin are located in the Chamoli district of Uttarakhand. population density of Chamoli is 49 persons per sq. km. The said district ranked 9th in population density out of the state of Uttarakhand. Consequently, it is clear that there the population is very low compared to others. The total population of our study area was 8070 in 1991, very slowly increasing to 8663 in 2001, and in 2011 it increased to 11095. Settlements of the basin region experience the inclination or decline of the population with the changing condition of physical and cultural setup. In the village of the lower portion of the river basin, the population gradually increases. Mainly because of exciting of Topoban NTPC and Joshimath town as the development of socio-economic, and transportation conditions. It accelerates village-to-village or urban migration. The density of the population is too low in these types of regions, comparatively. The highest population density is 36 persons/sq km which is Gurguti village (Table No. 3). Most of the villages' population density is zero (0) are Aira, Auli Laga Salud, Badal Gaitha, Bampa, Barhgaon, Bhangul, etc, and are examples of seasonal villages. These villages are situated at high elevations. Some of the villages' population densities are one (1) to two (2) are Jugajuchaklata, Karchi, Kurchoi, Mirg Payaichormi, Rainichak Lata, Rewal Chak Subhai, Subhai, Topoban and Tugasi, and population density is 5 to 7 persons/sq km villages are Tolma and Malari (Table No. 3). The population density has increased a lot in 2011 compared to previous population census as because of tourism, developed of Topoban NTPC.

Location of Power Project in Study Area

The Rishi Ganga small Hydro Project (production capacity 13.2 MW), a small hydroelectric Power Project is located (latitudinal location 30°28'03" N to longitude 79° 43' 50" E) at the1975 m altitude above the mean sea level (MSL) at the Dhauliganga river basin. In addition, Tapovan Hydro-Electric Power Dam (latitudinal location 30° 27' 37.55" N and longitude 79° 37' 41.62" E) is being constructed by the name of Tapovan Vishnugad project at the1794 m altitude above the mean sea level (MSL). On 07 Feb 2021 around 10:30 hrs, local time, a catastrophic flash flood occurred in the Dhauliganga River (a tributary of the Ganga River) near Rini village at 2000m above mean sea level (MSL) (Dwivedi et al., 2021) and damaged the Rishi Ganga small Hydro Project and a part under construction Tapovan Hydro-Electric Power Dam.

Compare Landuse/Landcover Maps in the Year of 1974, 2000, 2010 & 2020

The term land cover refers to the biophysical envelope of an area and land use indicates human activity on the surface of the Earth. Land cover is the combination of natural and man-made features of the earth's surface. Land use and land cover are prime components to understanding the interrelationship between the environment and human activities. In this research work, land cover maps of 1974, 2000, 2010, and 2020 are presented to detect changes and also try to assess the tendency of changes. From the map land cover map of 1974, it is envisaged that about 29 percent area is covered by natural vegetation but in the year 2000, it declined by 13 percent. Due to social forestry from the government and NGO initiatives, forest cover is positively sustained and increases by about 37 percent of the total region.

At present time, by the name of development work huge account of the forest is cut down in Chamoli and Uttarkashi. Observed that a large part of these districts fall under perpetual snow cover areas and alpine pasturelands therefore, forest cover is less (Vishwambhar Prasad Sati,2019). Barren land has increased due to deforestation. In 1974, barren land covered about 17% of the basin area is increased in 2020 by 36%. In the years, 2000 and 2010 the barren land area was about 28 and 27 percent. Due to the melting with global warming, the glacier-covered area has been decreasing and transformed into rocky barren land. In 1974, the glacier cover area and melting of glaciers area were 35 percent and 19 percent, in 2000 these areas were about 22 percent and 38 percent. The lowest glacier cover area has been observed in the year 2010 about 12 percent area when the flowing ice area was about 27 percent. In 2020, the glacier cover area has increased from the year 2010 which is around 20 percent, and the melting ice area or occasional ice area is increased to 34 percent.

Global Temperature Changing Trend from 1880 to 2020

Today, the world population is approximately 7 billion and grows by nearly 80 million people each year (Sajjad et al., 2009; Omvir Singh et al., 2013). The dramatic acceleration of urban growth is a universal phenomenon in most countries of the world (Xu et al., 2010; Omvir Singh et al., 2012). Assessing the impacts of urbanization and land use change on mean surface temperature is a challenging task. Several studies have attempted to assess the effect of urbanization and industrialization on temperature trends (Chung et al., 2004; De and Prakash Rao 2004; Gadgil and Dhorde 2005; Kumar et al., 2005; Dash and Hunt 2007; Dhorbe et al., 2009; Sajid et al., 2009; Tigga and Hema Malini 2011; Omvir Singh, 2012). The world is getting warmer. Since the industrial revolution, unscientific and unethical human activities have caused an excessive increase in global temperature. The following time series illustrates the changes in global temperature from 1880 to 2020. This temperature trend graph was conducted by the secondary data that is acquired by the scientists at Goddard Institute for Space Studies (GISS), NASA.

According to the graph, the global temperature rises more than 1°C since 1880. In 1880 the average temperature was 13.73°C which increased in the year 2020 by 15.2°C. The average rate of increase since 1981 (0.18°C/0.32°F) has been more than twice that rate (Rebecca Lindsey & LuAnn Dalhman, 2021). Global temperature is a popular criterion for measuring the state of the world's climate.

Growth of Glacier Lakes in Term of Area (sq mt)

GLOF is a phrase used to describe a sudden release of a significant amount of water retained in a glacial lake, irrespective of the cause (Emmer, 2017). Glacial lake outburst flood (GLOF) is a sudden exogenetic activity of a significant water discharge from the glacial-originated lake, irrespective of the natural cause.

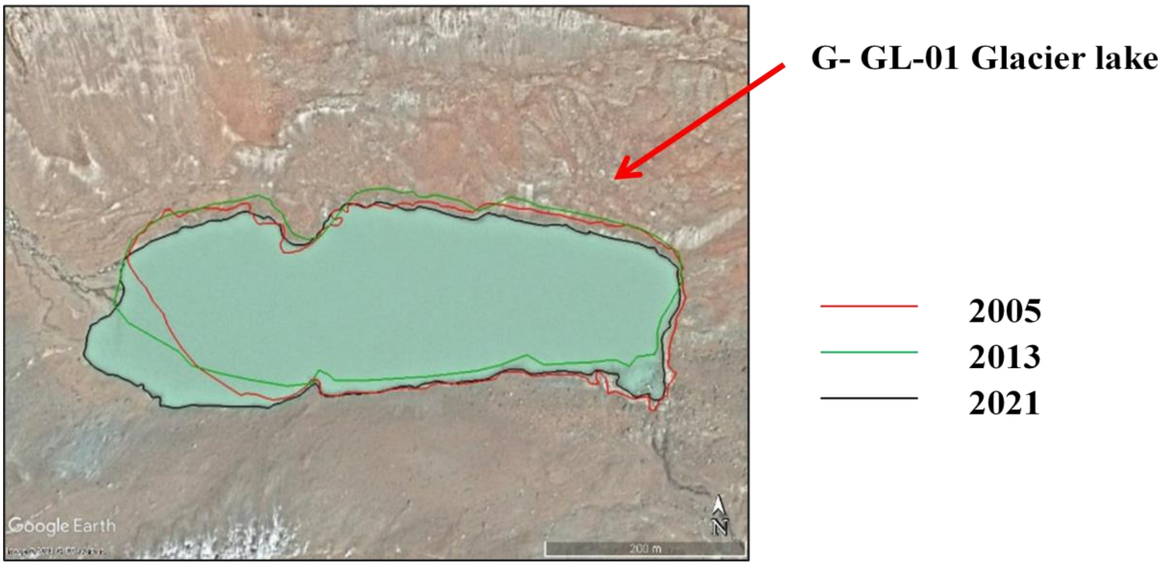

Figure 4. Glacier Lake

Table 4. Measurement of Glacier Lake Area (2005, 2013, 2021)

Name of GL	Area in sq.mt			Name of GL	Area in sq.mt		
	2005	2013	2021		2005	2013	2021
Auli Lake		3841	4758	*CH-GL-05*			1040
B-GL-01	3894	671	1377	*CH-GL-06*			547
B-GL-02			7631	*CH-GL-07*			1347
B-GL-03			3214	*CH-GL-08*			2691
B-GL-04			1854	*DG-GL-01*			5279
B-GL-05			24072	*DG-GL-02*			1913
B-GL-06	9295	11520	3396	*DG-GL-03*			940
BT-GL-01			59865	*DG-GL-04*			1209

Name of GL	Area in sq.mt			Name of GL	Area in sq.mt		
	2005	2013	2021		2005	2013	2021
BT-GL-02	4476	5211	5197	*G-GL-01*	77507	75175	80324
BT-GL-03	2466	5109	3571	*GP-GL-01*	20594	12767	16117
BT-GL-04	1275	1401	1581	*GP-GL-02*	8830	4142	3883
BT-GL-05			4819	*KB-GL-01*		14308	6444
BT-GL-06		1128	3853	*KB-GL-02*		795	2242
BT-GL-07	1414	1892	1465	*M-GL-01*			1915
BT-GL-08		1157	3219	*M-GL-02*		2682	6452
BT-GL-09	1485	5764	5567	*NDG-GL-01*		41046	40874
BT-GL-10	39032	6846	53568	*ND-GL-01*			6476
BT-GL-11	23390	12961	29819	*ND-GL-02*			2389
BT-GL-12			11948	*ND-GL-03*			1940
CH-GL-01			1879	*ND-GL-04*			1738
CH-GL-02			2165	*ND-GL-05*			541
CH-GL-03			971	*ND-GL-06*			5877
CH-GL-04			452				

Source: Researcher's Computation #GL = Glacial Lake

GLOFs are characterized by extreme peak discharges, often several times over the maximum discharges of hydro meteorologically induced floods, with an exceptional erosion/transport potential; therefore, they can turn into flow-type movements (Emmer, 2017). Table number four represents the growth of the Glacier lakes area in the years 2005, 2013, and 2020. The names of these lakes are given according to the mountain peak name like G-GL means Geldhung glacial lake (Figure 3a & Figure 4). The largest Glacier lake in this region is G-GL- 01(80324 sq mt) in 2021 (Table 4). Many lakes are newly developed, these lakes did not exist in 2005 and 2013 but in 2021 these lakes have been identified by Google Earth. After analyzing the changes in the growth of Glacier lakes it is envisaged that overall tendency towards increasing Glacier lake area. The lakes are situated in front of glaciers and the lake area and water volume are increasing due to the retreating of the glaciers by melting in the present time. But some lakes are decreasing for low water supply. The number of such lakes increases in the present compared to the past (Table 4). Climate change is the main reason for such lake formations much more the past in recent times. Auli Lake is an artificial lake, located in our study area.

GLOF Effect on the Environment

The temperature of the Himalayas has been increasing at the rate of 0.15°C to 0.60°C per decade. The Central and Eastern Himalayas have a high proportion of lakes in direct contact with debris-covered parent glaciers, possibly accelerating glacier mass loss and lake growth (C. Song et al., 2017). In the present global warming era, this type of glacial-originated lakes is developed.

The transboundary effects of an event of glacial lake outburst flood (GLOF) are the prime factor of the consequence of loss of lives and huge destruction of infrastructure viz., houses, roads, basic service centers, bridges, agriculture fields, hydro-electric power stations as well as forest. Risky GLOF areas require regular monitoring of glaciers and glacial lakes and the spread of early warning mitigation measures. In the short term, glacial lake outburst floods (GLOFs) are major cryosphere hazards and a potential risk for local communities as lakes are formed and grow due to deglaciation (Emmer and Vilímek, 2013; Carrivick and Tweed, 2016; Carey et al. 2017; Emmer 2018; Rasul and Molden, 2019; Schmidt et al., 2020). This type of sudden incident greatly influenced the environment and socioeconomic condition in their associated region. Socioeconomic effects are the death of human life and mental impacts on their family members, damages to property and infrastructure and the unemployment rate also increase. One GLOF was described from Nyoma in the Changthang area in eastern Ladakh in 1971, which caused 13 to 16 fatalities. Another GLOF happened in Domkhar in 2003, which destroyed farmland and infrastructure (Ikeda et al. 2016; Schmidt et al 2020).

From the standard newspapers, it was reported that a glacial lake outburst (GLOF) struck in the form of an avalanche and deluge due to broke off a portion of the Nanda Devi glacier at Chamoli, Uttarakhand on 7th February 2021. From the standard newspapers, it was reported that a glacial lake outburst (GLOF) struck in the form of an avalanche and deluge due to broke off a portion of the Nanda Devi glacier at Chamoli, Uttarakhand on 7th February 2021. The sudden incident triggered widespread large-scale devastation and panic in the Chamoli. As per the news article in The Hindu (February 23, 2021), the power project of NTPC (Rishi Ganga Hydel Project and the Tapovan-Vishnugad hydel project) was highly devasted and laborers are trapped in a tunnel in Tapovan. Over 32 people die and 190 people are still missing.

After the 7 February deluge according to one estimate Dhauliganga and Rishi Ganga river beds are risen by a few meters, especially in the Topoban area. It is noticed, a considerable rise in river beds after the floods which is a big issue before us, said a top NTPC official (Social News.XYZ February 21, 2021). The Times of India reported (on February 14, 2021) that a joint team of the Defence Research and Development Organization (DRDO) and Dehradun Wadia Institute of Himalaya Geology (WIHG) explored a 350 meters long glacial lake, like a football ground. They researched that the lake is formed due to the water of the Rishiganga River being choked by heavy boulders of rock. Near Rishiganga, a massive chunk of the Nanda Devi glacier broke down in the Raunthi River, and occurred a massive wave of water in the lake and the lake was outbursted. Huge amounts of water, rocks, boulders, and mud streamed downward and washed out the river-adjacent settlements and projects. Mr. Kalachand Sain, Director of Dehradun Wadia Institute of Himalaya Geology (WIHG) said that the research team collected the sample of ice mass for further study.

Prediction of Flood Zone in Dhauliganga River Basin

Flood inundation mapping (FIM) is a map of flood prediction. It sketches the effects of flood with the help of DEM of a particular area. Flood levels are simulated with the height of the water level and measures whether it does devastate the infrastructure viz., buildings, roads, rail tracks, airports, etc, or not. FIM provides important information, like the depth and spatial extent of flooded zones, required by the municipal authorities to inform the citizens about the major flood-prone areas and adopt appropriate flood management strategies (Sanat Nalini Sahoo and Pekkat Sreeja, 2017).

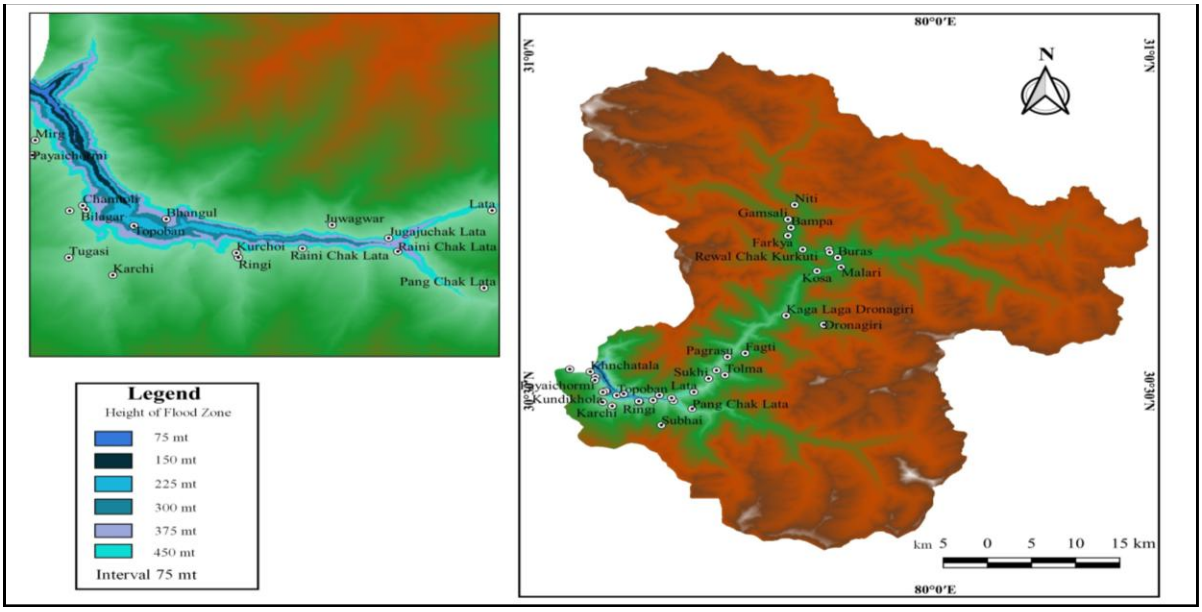

Figure 5. Prediction Map of Flood Zoning of Study Area

The Dhauliganga river basin belongs to the great Himalayan region. The Inundation flood map (Figure 5) is help to assess the effects of that's kind of sudden massive flood on land cover and land use of the study area. The lowest altitude of the study area is 1674 meters. For Inundation flood map range or interval of flood height 75 meters than the lowest altitude has been taken. If the water is raised 150 meters from the lowest altitude no human settlements or Villages will be affected but if it is raised to 300 meters from than lowest altitude the village of Topovan will be collapsed. The village Bhangul is located at 375 meters from the lowest altitude and 450 meters from the lowest altitude Chamtoli, Bilagarh, and Rainichalklata, villages are located. If the release of water rises to 450 meters from the lowest altitude then mentioned villages will be collapsed.

CONCLUSION

In this particular study, we sought to find how climate change is contributed to glacier lake formation and GLOF-like situations. Based on the method in this study were able to establish a relation between temperature increase and glacier lake formation. Also predicted flood effects on land use and land cover of this particular study area. The mean annual temperature trend of the study area from 1897 to 2020 has increased. The area of glacier lakes have been increased and many new glacier lakes are also formed in 2021. Here can say due to temperature increases area of glacier lakes has increased and new glacier lakes have been created. The population of the study area has been increased in 1991 total population was 8663 which increased to 11095 in the year 2011. The settlement also increased with the increasing population which resulted in changes in landscape because of increasing human activities, vegetation cover has decreased, and not only vegetation cover but also land cover areas changed. Increasing land use patterns like settlement, road, or transportation networks have contributed to temperature change. The development of settlements indicates not only local popular are increasing but also growing of the tourism industry.

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