CHAPTER 2

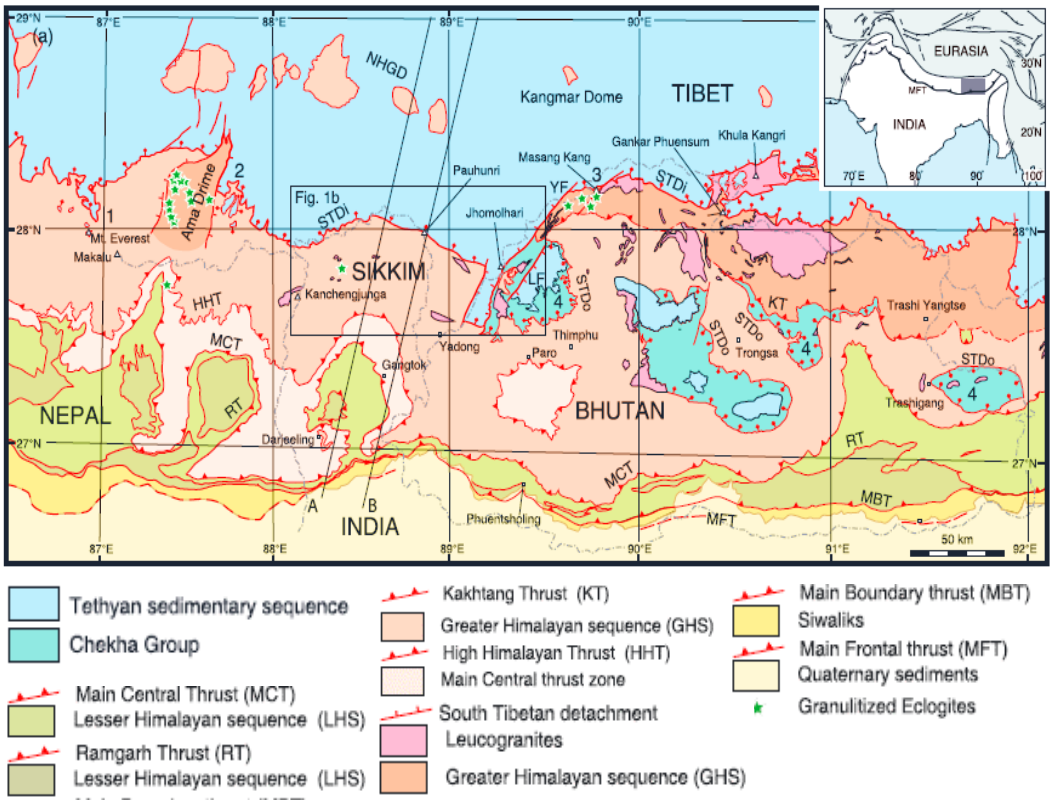
Geography of Eastern Himalayas

GEOGRAPHY OF EASTERN HIMALAYAS

The eastern Himalayas span an area of approximately 122,802 square kilometres, extending from 26°40' - 29°30'N and 88°2' - 97°5'E. Within its borders are the Kingdoms of Sikkim and Bhutan, as well as the North-East Frontier Agency (excluding the Lohit Frontier district to the south of the Lohit River and Tirap) and the Darjeeling district (excluding the Siliguri sub-division) of West Bengal.

The international boundary with the Tibetan Plateau is defined by the Himadri Mountains in the north, which corresponds to the Mc-Mohan line in the north-east of Arunachal Pradesh and the east of Bhutan. This traverses the crest of the Himalayan Range until it reaches the Brahmaputra River's major bend, where the river exits from its Tibetan path into the Assam Valley. The Sangalila Range, on the other hand, runs across the eastern Himalayas from west to east and south to east. The area is defined by this range, which separates the Kingdom of Nepal from the Assam – Burma Mountains and the Lohit River (Singh, 1971) (Figure 2.1).

Figure 2.1: Geological Map of Eastern Himalayas



Source: Kellett et. al.,2013

Its uniqueness as a physical entity is distinguished by significant differences in both political and physical elements. Therefore, the eastern Himalayan domain was partitioned into three geographical regions:

a) The Darjeeling and Sikkim Himalayas,
b) Bhutan Himalayas
c) The Assam Himalayas.

a) Darjeeling and Sikkim Himalayas

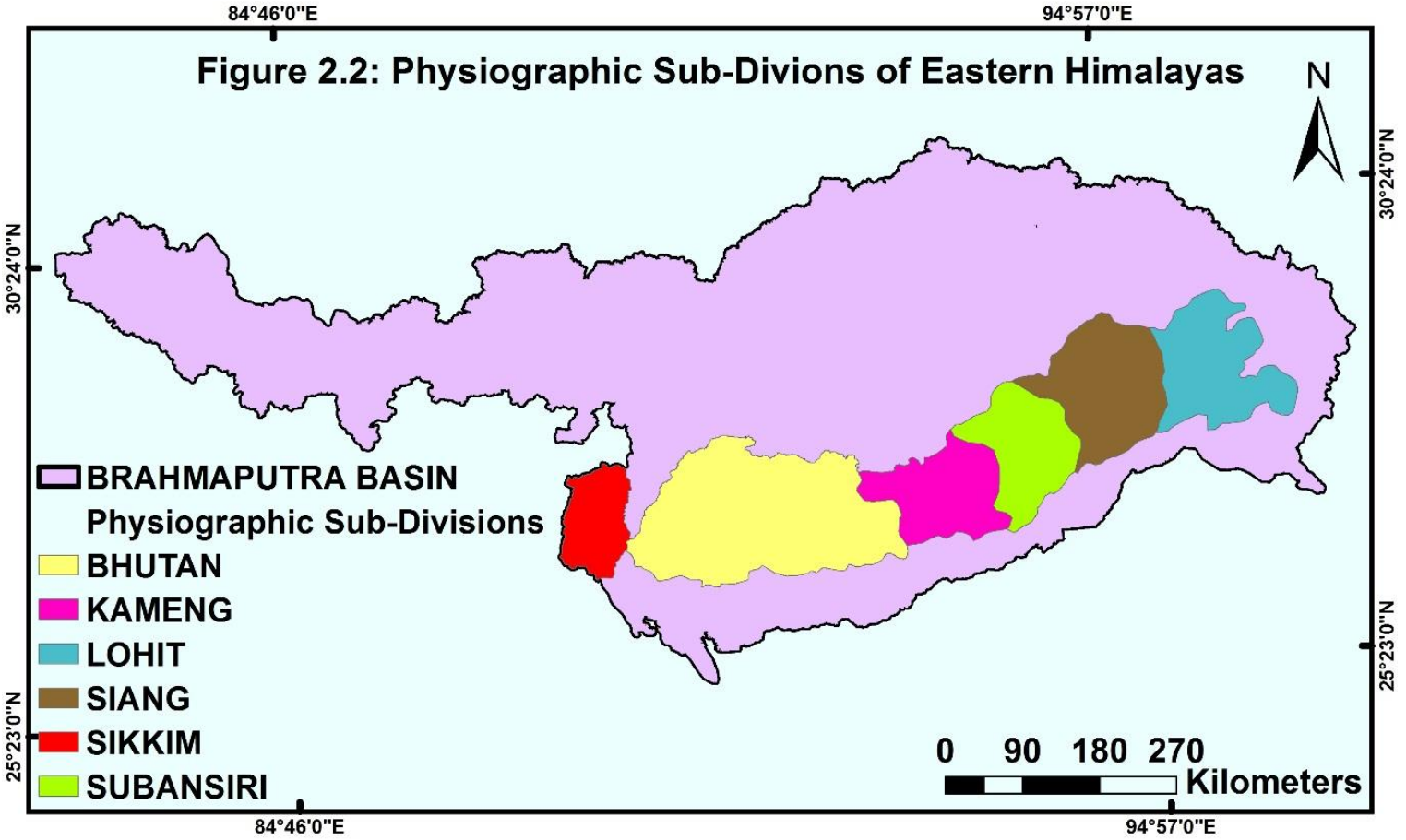
The Darjeeling and Sikkim Himalayas are positioned between the Rajmahal Hills (Bihar) and the Shillong Plateau (Assam), separated by an alluvial gap. The unimpeded moisture-laden southwest monsoon has resulted in specific geographical peculiarities in this area.As a result, the monsoons have a significant influence on the mountains and even the central part of Sikkim and its surroundings get 200 inches of rain every year. On the other hand, River Tista along with its tributaries have deeply incised the gneissic rocks in central Sikkim.

Sikkim, which is contained within the Tista basin and separated from India by forest-clad mountains and Tibet by the Great Himalayan range, has a distinct geographical personality that serves as the foundation for recognising it as a separate province.

b) Bhutan Himalayas

Bhutan Himalayas has a distinct geographical and cultural identity within the Eastern Himalayan domain. Snow-capped mountains reach heights of more than 7500 metres in certain areas of northern Bhutan that are part of the Great Himalayas, whereas high valleys at 3500 metres are used for grazing during the summer months (Karan, 1966).

Thus, the fundamental rationale for selecting Sikkim and Bhutan as the study region for the current study was that the political divisions in the Eastern Himalayas aligned with the physical divisions as seen in Figure 2.2.



Source: Computed

SIKKIM:-

2.1:- Introduction of Sikkim

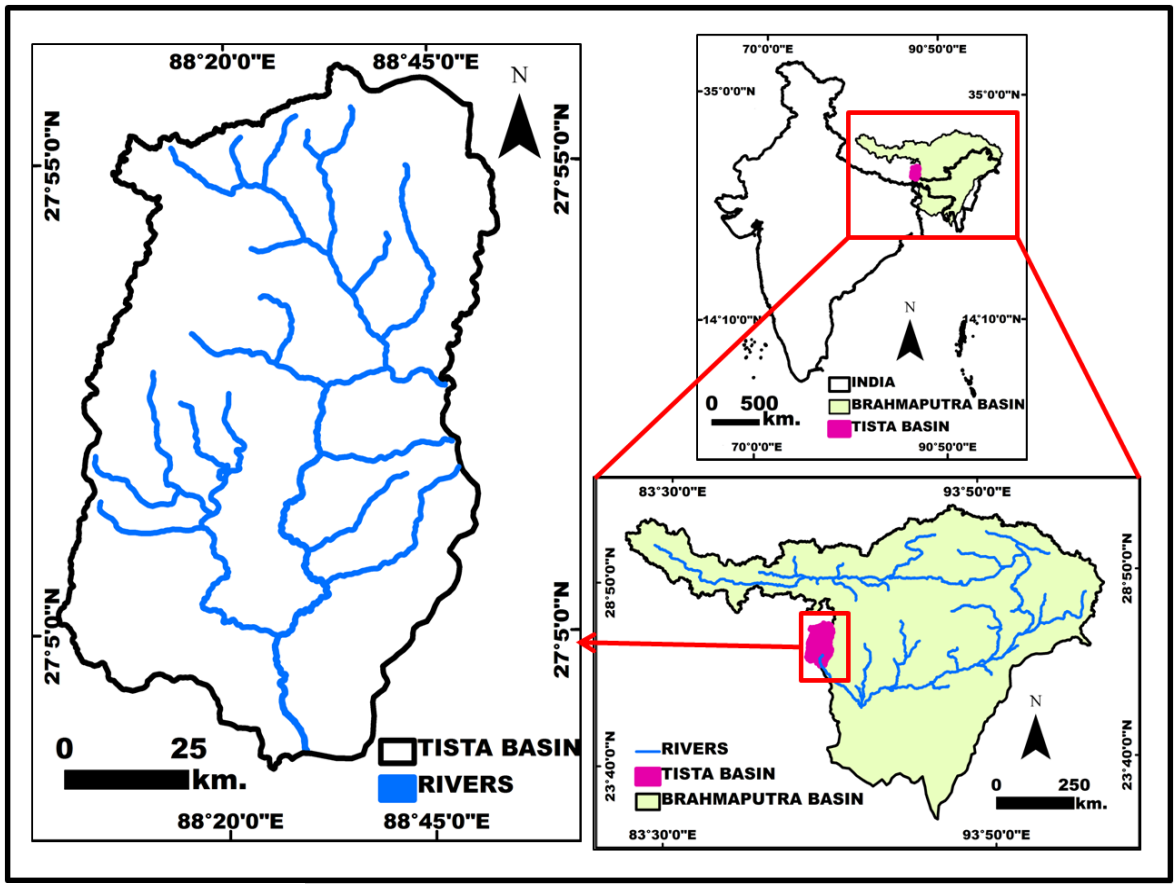
Sikkim is the 22nd state in India that was reorganised in 1975. The name was derived from the Tibetan names "Drenjong, Demojong and Demo Shong," meaning “The Valley of Rice” Sikkim's true essence lies in its lofty mountains with no flat piece of land. The boundaries of the state are defined by rivers and mountains (Sarkar & Lama, 1986). Nepalese, followed by Bhutias and Lepchas, are the main inhabitants of this region (DCH: Sikkim, 2011).

Location and Geographical Extent

The north-eastern hilly and landlocked state of Sikkim is situated between 27°04'46" to 28°07'48" North latitude and 88°00'58" to 88°55'25" East longitude (DCH: Sikkim, 2011) (Figure 2.3). Sikkim is the least populated (0.05%) (India Census, 2011) and the second smallest state of India (after Goa) with an area of approximately 7096 km^2. The north-south and east-west dimensions of the state are 112 km^2 and 64 km^2 respectively. The state is divided into four districts namely: - (a) East (b) West (c) North and (d) South. Their respective headquarters are in Gantok, Gyalshing, Mangan and Namchi respectively.

Sikkim is bordered by the lofty Himalayas and the Tibetan Plateau in the north, the Chumbi Valley and the Kingdom of Bhutan in the east and the southern portion is bordered by the Darjeeling district of West Bengal. The north-western portion, however, is bordered by the Kingdom of Nepal.

Figure 2.3: Location Map of the Study Area - Sikkim



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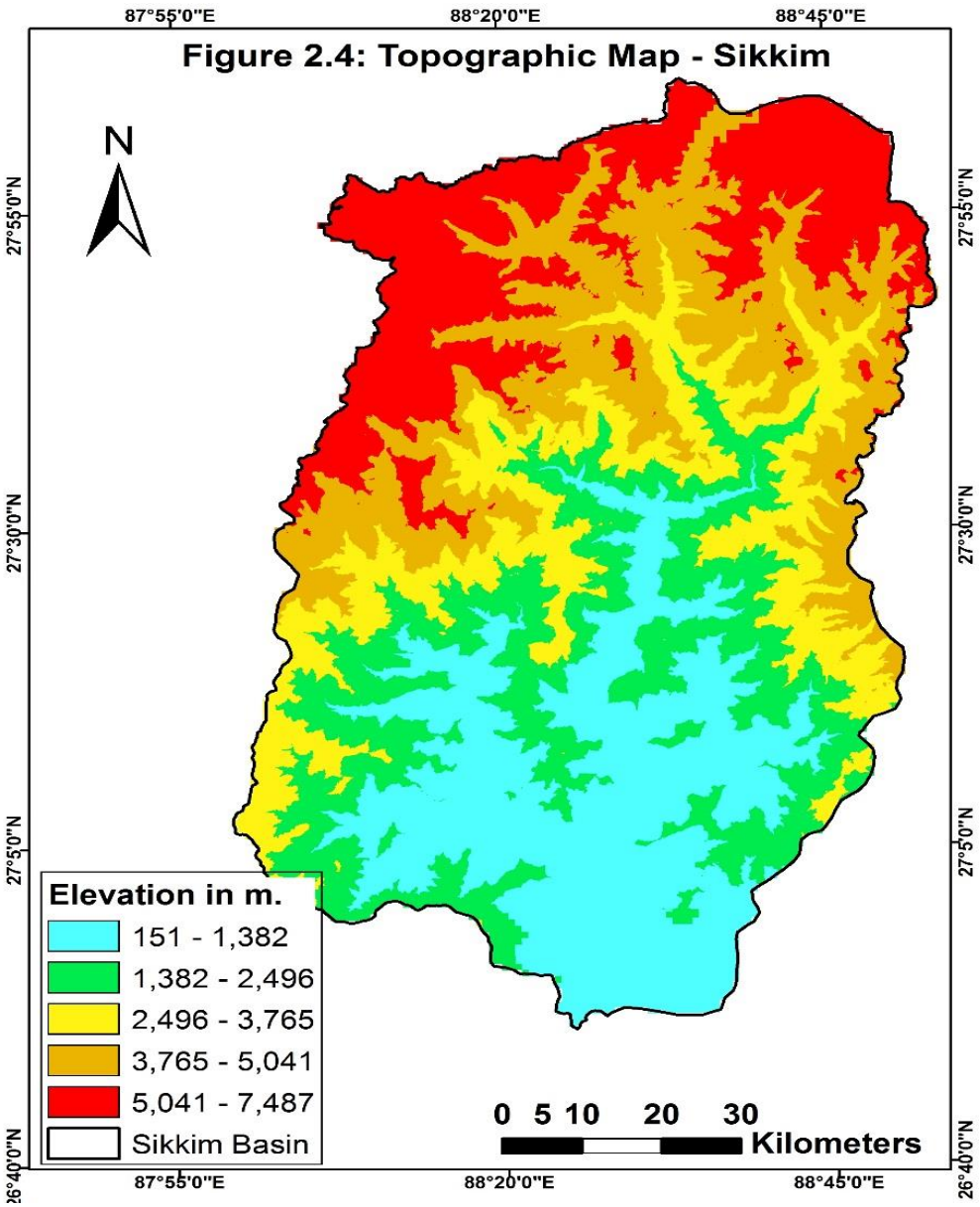
2.2:- Physical Setup of Sikkim

Physiography and Geomorphology

The Sikkim Himalayas, corresponding to the state of Sikkim, is situated at the western end of the Eastern Himalayas. Therefore, it is an important component of the lesser and Greater Himalayas. Sikkim is characterized by the most harsh and inhospitable natural landscape due to its daunting physical characteristics. Sikkim's physiographic divisions are not well demarcated, owing to the compound terrain and the consequence of dynamic geomorphic evolution. The base of Sikkim commences at a low elevation of <300 meters and rises to the height of 8,598 meters approximately (Figure 2.4)(Pradhan, Sharma, et al., 2004). The plains in the southern part rise sharply to the north and to the north-west, where the world's third highest mountain, Kanchenjunga (8,598 meters), is located (DCH: Sikkim, 2011). This region has the most remarkable glaciers, such as the Zemu Glacier, which marks the origin of the Tista River (Raina, et al., 1973). The Rathong Glacier, on the other hand, situated in the western part of Sikkim, is the source of the second most significant river, i.e. Rangit (a tributary of Tista) (Joshi, 2004). In fact, these rivers are seasonal and



Source: Computed, SRTM DEM

are fed by glacial melt water as well as monsoonal rains. In general, except for the two major ranges of Sikkim, i.e. the Singalila and Chola ranges, the mountain ranges run in the east-west direction (Abdullah, 2020). They run more or less in the north-south direction, primarily due to the southern slopes of the Himalayas. There is another mountain range that runs through the central part of Sikkim that divides the valleys of the Tista and Rangit rivers in the north-south direction. The significant and noteworthy peaks of this ridge are Maenam (3,139 meters) and Tendong (2,639 meters) (Sarkar and Lama, 1986). The whole region is essentially an enclosed basin between two transverse ridges that are parallel and deeply intersected, namely the Donkhya Range in the east and the Singalila Ridge in the west, defining the borders between Tibet and the Kingdom of Nepal. These two ridges have a

length of around 144 kilometres. Donkyala (5,520 metres), Jelep La (4,380 metres), Kangra La (4,809 metres) and Nathula (4,392 meters) are some of the renowned mountain passes in the north and east regions of Sikkim that attract visitors, merchants, pilgrims, etc. (Kumar and Singh, 2001).

Table 2.1 illustrates the land elevation profile of Sikkim, spanning from the Lower Hills with altitudes ranging from 270 to 1,500 metres to the snowbound sections of very high mountains barren of vegetation with permanent snow cover reaching up to 8,580 metres.Between these two extreme ends lie the Mid Hills (1,500 metres – 2,000 metres), the Higher Hills from 2,000 to 3,000 metres and the Alpine zone which is situated above 3,900 metres and is bestowed with scarce vegetation which completely disappears in the upper reaches.

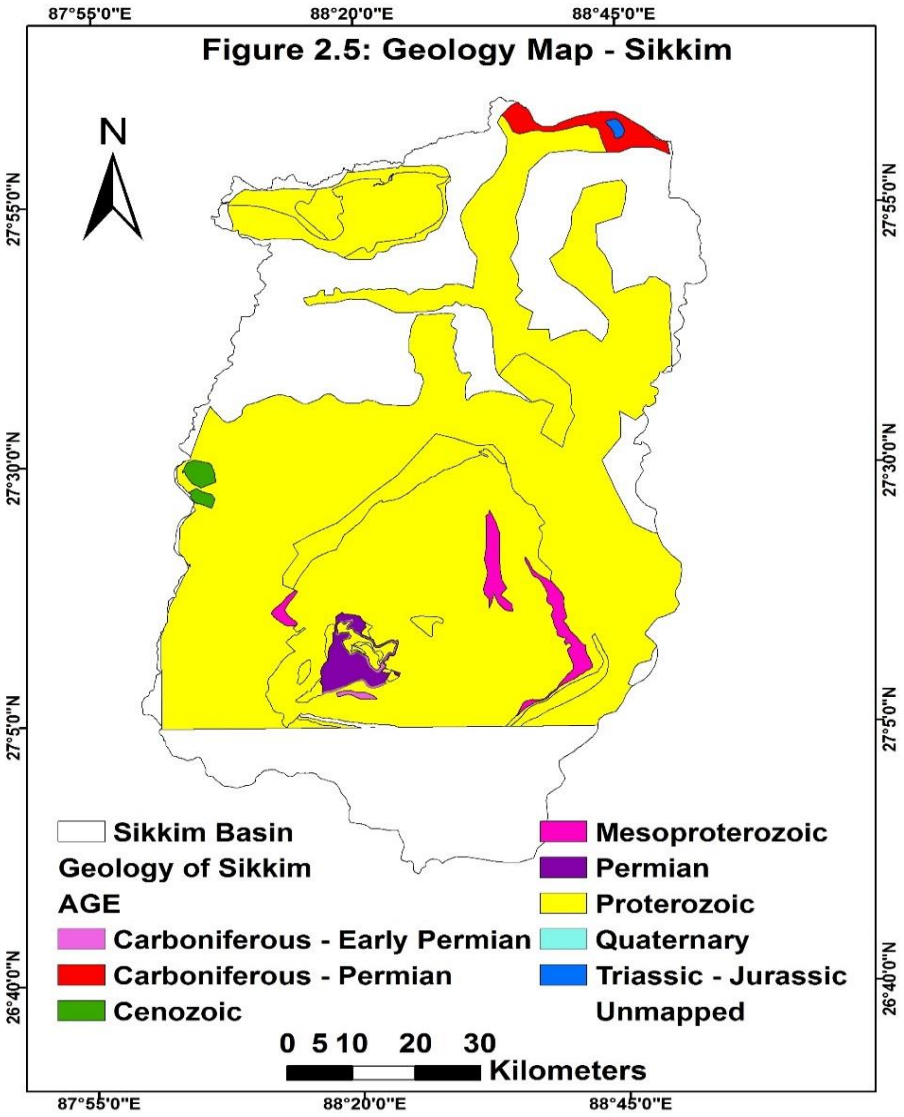
Table 2.1 Sikkim: Profile of Land Elevation

Type of Land	Level of Elevation (Altitude in meters)
Lower Hills	270 meters to 1,500 meters
Mid Hills	1,500 meters to 2,000 meters
Higher Hills	2,000 meters to 3,000 meters
Alpine Zone	Above 3,900 meters with vegetation
Snow Bound land	Very high mountains, without vegetation and with perpetual snow cover up to 8,580 meters.
Source: Sikkim – A Statistical Journal, 2013 (Draft)	

Geology

Sikkim Himalayas is the present day representation of the Tethys Sea of the geological past i.e. of the “Paleozoic Age”. A substantial portion of Sikkim's geology consists of Precambrian rocks, which indicate an area with younger age rocks than other places with rocks such as half – schistose and gneissose, which are older in origin. The major portion of the north-eastern and western Sikkim constitutes of hard massive gneiss rocks that resist denudation. The southern and the central region is pre-dominantly composed of relatively soft thin slate sedimentary, meta-sedimentary and half- schistose rocks which are prone to erosion and weathering by the running water (Kumar and Singh, 2001). Slope instability which is the major cause of landslides is caused by a variety of variables, the most important of which are rainfall, seismic activity and anthropogenic

activities. These areas are low in elevation. Despite the fact that these places are vulnerable to landslides, this region is densely inhabited. Thus, the physical setup of the state on the whole is governed by three important physical aspects i.e. its geological structure, the south flowing rivers and the frequent landslides (Figure 2.5).



Source: Computed (from Diva - GIS)

Soils

Soils present in distinct landforms are studied in terms of composition, physical and chemical qualities. The soils found in the Eastern Himalayas, particularly in the Sikkim region vary with the altitudinal variations. They significantly change from north to south, where the northern region of Sikkim has mountainous skeletal soil with very thin layer of the top soil. Whereas, towards the extreme south at the foot hill zone, where the rivers

debouch, the gravelly-sandy soil along with some alluvial soil in the river beds can be noticed (Sarkar and Lama, 1986).

Table 2.2 Major Physiographic Units and Dominant Soils Found in Sikkim

Sl. No.	Physiographic Units	Area (ha)	% of TGA	Dominant Soils (Subgroup)
1	Summit and ridge (<30%)	31459.45	4.43	Typic Haplumbrepts Typic Hapludolls Pachic Haplumbrepts Typic Udorthents
2	Side slope of hills	213100.01	30.03	Typic Hapludoll
2.1	Very steeply sloping (>50%)			Entic Hapludolls Dystric Eutrochrepts Lithic Cryorthents
2.2	Escarpments (>50%)	30480.73	4.30	Typic Udorthents Entic Hapludolls Umbric Dystrochrepts
2.3	Steeply sloping (30 - 50%)	214641.28	30.24	Umbric Dystrochrepts Typic Hapludolls Typic Argiudolls Cumulic Haplumbrepts Entic Cryumbrepts
2.4	Moderately steep sloping (15-30%)	16024.82	2.26	Fluventic Eutrochrepts Mollic Udarents Typic Argiudolls Cumulicapludolls
3	Valleys (15-30%)	9683.36	1.37	Typic Haplumbrepts Aquic Udorthents Cumulic Hapludolls
4	Rocky cliffs and Precipitous slope	85700.29	12.08	Lithic Udorthents Lithic Haplumbrepts
5	Glacier/Perpetual snow	108510.06	15.29	

Source: SOER, 2007,TGA = Total Geographical Area

The soil of this area is derived from half - schistose and Gneissose, which gives rise to the sandy soil in the upper part of the foothill zone and clayey in the lower parts. The soil developed from these rock types is brown in colour and has a texture that varies from loamy sand to silty clay loam. This soil is poor in lime, manganese, phosphorous and also has low nitrogen content. But on the other hand it is quite rich in potassium (SOER, 2007). The soil of the entire state is acidic in nature with a pH ranging from 4.3 to 6.4. It is also

rich in organic matter content (0.36% to 5.61%) with a mean value of 2.74% (Sikkim-A Statistical Journal, 2013 (Draft)). This kind of soil is most suitable for deciduous and evergreen forests.

In the state of Sikkim, 78 soil families were defined and mapped into 69 mapping units in accordance with the physiographic sequence of the terrain features. It was affirmed that the soils of Sikkim belong to 3 orders, 8 suborders, 12 broad groups and 26 subgroups. It has been found that Inceptisols was the most prevalent soil type (42.84 per cent) followed by Entisols and Mollisols occupying 42.52 per cent and 14.64 per cent respectively. Table 2.2 depicts the key physiographic units and dominating soils found in Sikkim.

Drainage

The term drainage here does not only mean to describe an area with the help of its rivers and tributaries, but understand and state the resources from where the river gets its perennial waters. Hence, a brief description of the rivers, glaciers and the lakes of Sikkim is undertaken here.

Rivers

The state of Sikkim gives an impression of a horseshoe shape pattern which is deduced from the mountains that surround the state from all the three sides. This kind of structure gives rise to a particular drainage pattern that acts as a watershed for the two most important rivers to the state namely: Tista and Rangit. The River Rangit joins the River Tista near the boundary between Sikkim and West Bengal (Figure 2.6).

The Tista River originates in the north-eastern corner of the state as Chhombo Chhu from the glacial lake Khangchung Chho at an altitude of 5,280 meters. This glacial lake is located at the snout of the Tista Kangse Glacier that descends from the north-west where the Pauhunri mountain peak (7,056 meters) lies. Many scholars (DCH, 2011) are also of the belief that Tista River has its source in the Tista Khangse glacier and Chho Lhamo Lake. The river receives water from a number of tributaries on either side of its course along its traverse from its sources to the plains. The tributaries that flow on the eastern banks are shorter in length but greater in number. While the tributaries on the western flank are lengthier and have wider drainage areas, resulting in much more flow to the main Tista channel. On the other hand, the left bank tributaries, as opposed to right bank, originate from semi-permanent and much smaller snow-fields (SOER, 2007). The river has 315 kilometers long course and flows through the states of Sikkim and West Bengal. It eventually enters Bangladesh at Fulcherry where it flows into the river Brahmaputra

(HWRIS). The River Tista on its course is fed by rivulets like Goma Chhu and Lachen Chhu that arise in the Thangu, and the Donkia-La ranges respectively. From the origin to the plains the Tista River receives a number of tributaries on both sides of its course. Thus, this addition of water makes the river swift, swollen, muddy and dangerous. (SOER, 2007). Therefore, it can be rightly said that, approximately 95% of the total area of the state of Sikkim is drained by the single major river i.e. the River Tista. Even during the dry season, Tista runs through a 175 kilometer river length, dropping nearly 3,300 metres in elevation along the way. Thus, making the river an ideal and reliable source for development of Hydropower projects (Chatten Micro Mini HEP (100 KW), Lachung Micro Mini HEP (200 KW), LLHP Small HEP (I) (12 MW), URHP (8 MW), etc.) (SOER, 2007).

The River Rangit a right bank tributary of the River Tista originates from the Rathong glacier, south of the Kanchenjunga ranges. It meets the river Tista at Melli near the Tista Suspension Bridge,which connects Kalimpong with Darjeeling. One of the tributaries of Rangit is Ramam River (Bhatt, 2005).

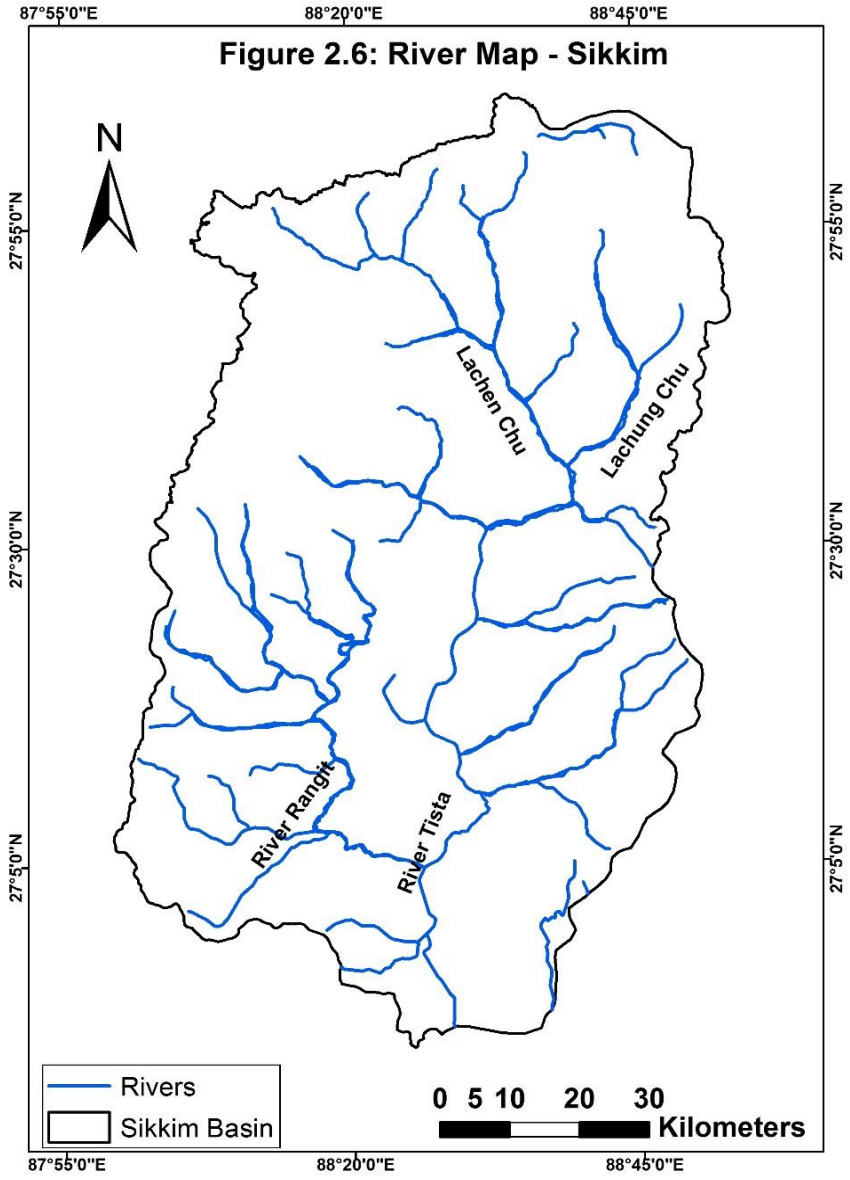
Table 2.3 represents the Catchment Area of the River Tista in the hilly regions of Sikkim and West Bengal and the plains of West Bengal and Bangladesh. The highest catchment area was recorded in Sikkim (6,930 sq. kilometers), followed by the West Bengal plains (2,104 sq. kilometers). However, out of a total drained area of 10,155 sq. kilometers, River Tista drained the by far the most mountainous region in India (8,051 sq. kilometers).

The Table 2.4 shows the Left-bank tributaries such as Lachung, Chhu, Rangpo Chhu, Dik Chhu, etc. which are shorter in length and larger in number. Whereas, the longer tributaries draining a larger area are the Right-bank tributaries namely Zemu Chhu, Rangyong Chhu and Rangit.

Table 2.3 Catchment Area of Tista River

Geographical Region	Political Region	Area (in sq.km.)	Area (in sq.km.)
Hilly Region	(i) Sikkim	6,930	**8,051**
	(ii) West Bengal	1,121	
In Plain	(i) West Bengal	2,104	**4,108**
	(ii) Bangladesh	2,004	
		Total in India :	**10,155**
		Total in Bangladesh :	**2,004**
		Total :	**12,159**

Source: SOER, 2007



Source: Computed

Table 2.4 Major Tributaries of Tista River			
Sl. No.	**Left-bank Tributaries**	**Sl. No.**	**Right-bank Tributaries**
1	LachungChhu	1	ZemuChhu
2	ChakungChhu	2	RangyongChhu
3	DikChhu	3	Rangit River
4	Rani Khola	4	
5	RangpoChhu	5	
Source: SOER, 2007			

Glaciers

Glaciers are an important perennial source of water and they provide abundant fresh water to the mighty rivers Tista and Rangit. A significant portion of the state of Sikkim consisting of the total ice and permanent snow cover is estimated to be 145.05 cu. kilometers that lies above the permanent snow line which is at about 5,000 meters Above Sea Level (ASL) (SOER, 2007). Extensive areas of Sikkim especially the northern, southern and the eastern parts remain snow bound throughout the year. Whereas, the rest of the areas lying below his elevation are habituated. (Subba, 2008).

There are a huge number of small or medium sized glaciers in Sikkim who have their sources in the permanent snow fields. Some of the important glaciers of Sikkim are listed in the Table 2.5 below. The Northern district of Sikkim is clearly seen here as the most glaciated region among the four districts of Sikkim, with significant glaciers such as Zemu, Lonak, Talung and others found here. Rathong, on the other hand, was the only large glacier in western Sikkim.

Table 2.5 Major Glacier of Sikkim

District	Names of Glaciers
West	Rathong
North	Zemu, Lonak, Hidden, Talung, North Lonak, South Lonak, TistaKhangse
Source: Sikkim-A Statistical Journal 2013 (Draft)	

Lakes, Springs and Waterfall

The state of Sikkim is blessed with a number of lakes which are quite unexpected in such a rugged terrain. According to the published reports of the Government of Sikkim (sikkim.nic.in), there are approximately 180 perennial lakes at different altitudes. These lakes are a major environmental asset and an important component of the Sikkim Himalayas. They not only enrich the natural resources of the region but are also valuable aesthetic spots acting as tourists' attraction points and are a major contributor to the revenue of the state. These water bodies are natural and mostly a result of glaciation. Numerous small glacial lakes are found at the heads of the gorges, while on the other hand large lakes are found at comparatively lower elevations.

Sikkim has about 227 high altitude lakes (wetlands) that are small and shallow in nature. Most of them are fed by the glacial water and are treated as holy. These lakes are

usually referred to as Chhokha or Tso or Chhona (in Bhutia), Pokhari or Jheel or Tal (in Nepali) and Chho (in Lepcha). Table 2.6 mentions the major lakes of Sikkim where the Western district of Sikkim has the maximum number of lakes followed by the Eastern and the Western districts.

Table 2.6: Major Lakes of Sikkim

District	Names of Lakes
West	Khe-cheod-Palri (Khecheoperi), Lam Pokhari, LaxmiPokhari, MajurPokhari, Dud Pokhari, Samiti Lake, Ram- Laxman (Twin Lake)
North	Gurudungmar, Cholamu, SimaChoka
East	Changu (Tsomgo), Bidang Cho, Menmecho
Source: Sikkim-A Statistical Journal 2013 (Draft)	

The presence of springs is a common feature of the Himalayan geo-hydrology. Apart from springs being a source of water for the local population, they act as an important indicator for the status of underground water and water table across the mountains.

Thus, the number of seasonal springs locally known as "mulphutnu" increase in the monsoon season and decrease during the drier spells. Sikkim is also known for its numerous natural hot springs which are locally termed as "Tatopani or Tsha-Chhu". They have great therapeutic value owing to the presence of fluorides and sulphur which is known to have bounteous medicinal properties for curing skin diseases. The temperature of water in these hot springs range between 45°C to 70°C. Some of the major hot springs of this region are Polok, Borong and Reshi (Sherpa, et al., 2013). Table 2.7 lists the names of the major hot springs in the four districts of Sikkim. Southern district of Sikkim has more number of hot springs as compared to the other districts. These hot springs attract a lot of tourism from around the world.

Waterfalls that make Sikkim more picturesque are mostly perennial in nature and abound mostly in the northern region of the state. The maximum number of waterfalls can be observed between Dzongu and the road between Lachung and Mangan. Most of these waterfalls are snow fed and ultimately drain into either of the major Rivers i.e. Tista or Rangit. They not only act as a tourist attraction site for trekking, but are also are conducive for setting up of the hydro power projects as they fall from a great height (mapsofindia).

Some of the important waterfalls in Sikkim are Kanchendzonga, Rimbi, Naga, Rukshyot and Bhim Nala.

Table 2.7: Major Hot Springs of Sikkim	
District	**Names of Lakes**
West	Phurchachu (Reshi),
North	Yumthang
East	YumeySamdong
South	Borong, Ralong
Source: Sikkim-A Statistical Journal 2013 (Draft)	

Climate

In terms of climate, Sikkim experiences extreme temperatures with summer in the foothills and cold winter in the high mountains. The state's climate has been typically categorized into tropical, temperate and alpine regions. In the deep valleys, with an elevation of up to about 1500 metres, the sub-tropical form of climate prevails. The Temperate Region continues above this up to about 4000 metres after which the Alpine climate zone starts and stretches up to 5000 metres beyond which the perpetual snow-bound zone begins (Bhatt, 2005).The principal aspect regulating the state's climate and environmental patterns is altitude. The increase in altitude is marked by the decrease in the temperature. The climate is cold and humid for most of the period in a year as precipitation occurs every month. Sikkim is located in the direct path of the monsoon and also because of its proximity to the Bay of Bengal, the region is subject to heavy rainfall. The mean annual precipitation varies from1250 mm in the snow fed areas and it approximates to 2,500 mm in the rain fed catchment zones which is the highest in the Eastern Himalayan region. The intensity of rain varies from drizzling showers in the low altitudes to torrential rains in the higher altitude areas. The high rainfall density thus induces severe soil erosion and regular landslides. The annual monsoonal rainfall is spread during the months of May to October with the pre-monsoonal showers in April-May and the monsoonal rains from the month of May up to early October. In most of the places the month of July is recorded as the wettest month. The average number of rainy days varies from 100 days at Thangu to 184 days at Gangtok with 2.5 mm or more rainfall. On the other hand, for an individual station the highest annual rainfall may even exceed 5000 mm. in Sikkim. The South-West

monsoonal rainfall recedes from the south to north as opposed to the distribution of the winter rainfall (SOER, 2007).

The temperature changes with the slope and altitude. The mean temperature ranges from 4.5 °C to 18.5°C in the lower altitudinal areas, while it varies between 1.5°C and 9.5°C in the higher altitudinal zones with biting cold encounters in the winter months at high altitudes. The maximum temperature is typically recorded in July and August and the minimum in December and January. As recorded by the Metrological Station at Gangtok, the temperature in the lower altitudes fluctuates between 22° C to 23°C in July and August to a minimum of 3°C to 5°C in the months of December and January and is even recorded below freezing points at higher altitudes in the winter season (MOEF).

Fog is a regular feature in this region between May and September. Snowfall is common in high altitude areas during winters. The Sikkim climate ranges from the Sub-Tropical warm climate in the valleys to cold temperatures in the upper reaches of the Alpine ice.

BHUTAN:-

2.3:- Introduction of Bhutan

The Kingdom of Bhutan, the world's only Buddhist kingdom, has stunning scenic beauty that is unmatched. It is better known to people as "DrukYul" or "Druk," meaning "The Land of the Thunder Dragon" (Sinha, 2001). Bhutan is classified as one of the smallest nations in Asia (having a 133rd rank), both in terms of area and population. Bhutan has a population of approximately 779,666 people (2017) (estimated on the basis of the population of 634,982 in 2005 as predicted by the National Statistics Bureau, 2010 (NSB)).

Location and Geographical Extent

The enclosed autonomous Kingdom of Bhutan stretches from 26°45' to 28°30' north latitude and 88°45' to 92°10' east longitude (Fraser, et al., 2001). Bhutan is located on the southern slopes of the Eastern Himalayas. It has a 470 kilometres long boundary with the Tibetan region of China to the north and the north-west. Bhutan, on the other hand, shares 605 kilometres of boundary with the Indian states of Sikkim, West Bengal, Assam and Arunachal Pradesh, which are respectively situated to the west, south-west, south-east and east. Bhutan has a territorial area of almost 38,394 square kilometres which can be

compared to Switzerland in terms of form and area. With its compact form, Bhutan has an overall length of 170 kilometres north-south and almost 300 kilometres east to west (Phuntsho, 2013) (Figure 2.7).

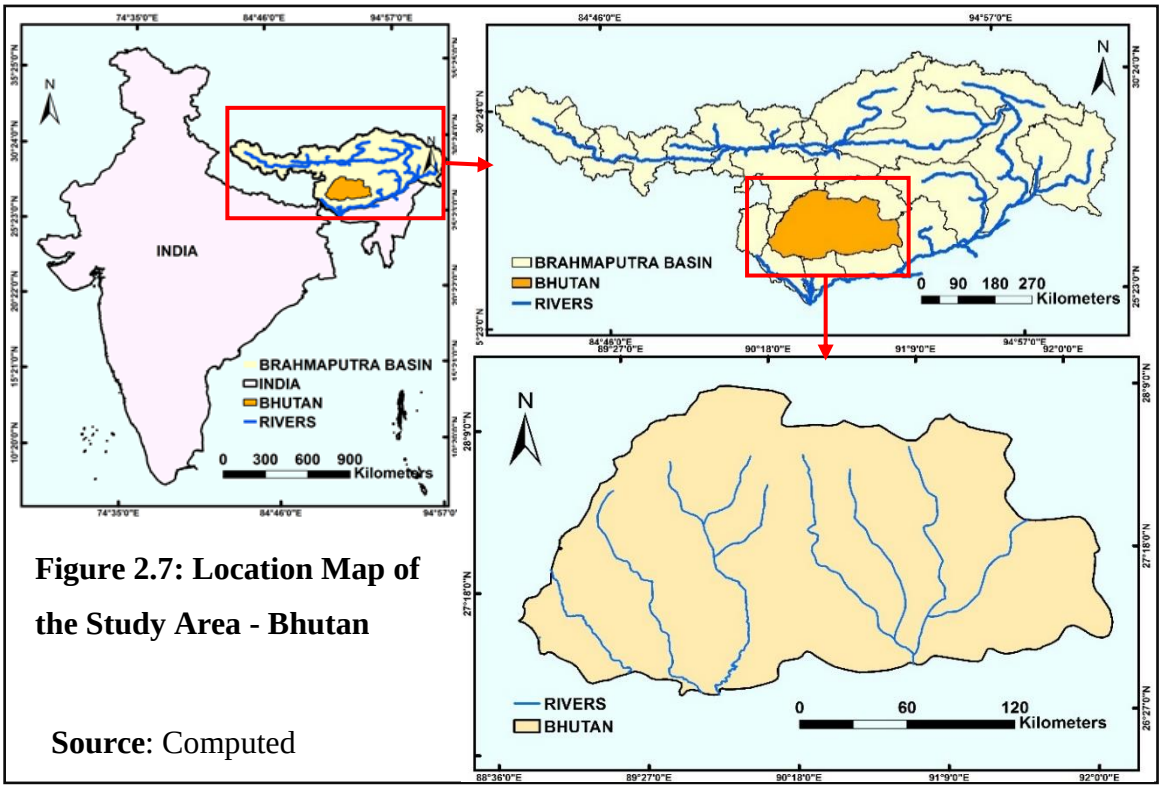


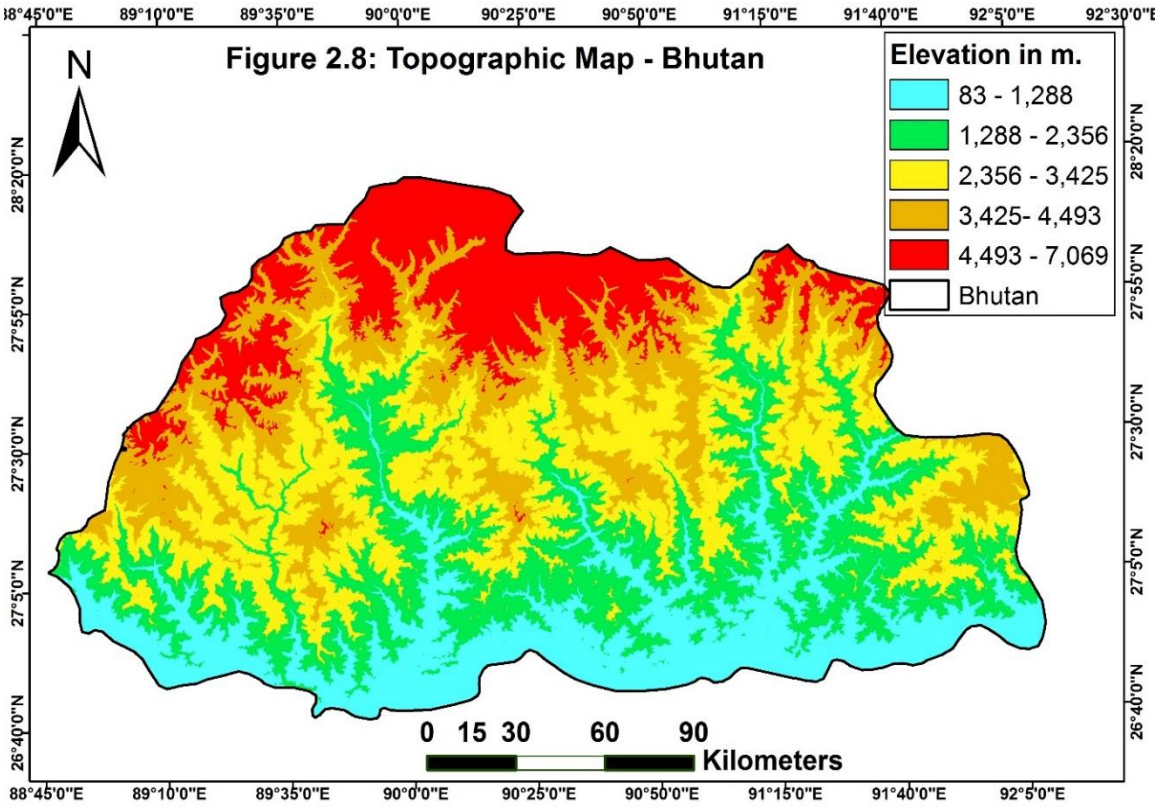
Figure 2.7: Location Map of the Study Area - Bhutan

Source: Computed

2.4:- Physical Setup of Bhutan

Physiography and Geomorphology

The tiny nation of Bhutan is blessed with both high and rugged mountain reliefs. While the nation is described as having hilly and mountainous characteristics, it is endowed with physical diversity. This heterogeneity is in the peaks that climb northward to 7,500 metres and southward to 200-300 metres in the plains. This marks the frontier from which the Himalayan Mountains rise sharply from the North Indian Great Plains (National Environmental Secretariat Planning Commission, 1992). Bhutan's highest point is 7,314 metres above the mean sea level that overlooks the valley of Chumbi in the west. Apart from this, Bhutan has nineteen other peaks that reach 7,000 metres in height (NSB, 2010) (Figure 2.8).



Source: Computed, SRTM DEM

According to Alam and Tshering (2004), Bhutan can be physiographically stratified in three main zones from the south to the north:

a) The Southern Himalayan foothills
b) The Inner Himalayas
c) The Higher or the Greater Himalayas

a) The Sub-Himalayas or the Himalayan Foothills :-

This narrow 20 kilometres foothill region rises gently from the plains of Bengal-Assam in India to a height of approximately 1,500 metres. In Bhutan, this expansion of India's Bengal-Assam plains, better known as the "Duar Plains," has a width of around 12 to 16 kilometres. The foothill zone marks the point of origin of several streams that flow for a short distance before vanishing into the bordering areas in the porous and pebbly areas.

In addition, the “Bhutan Duars” are subdivided into the northern and southern sections. Gravels, pebbles, boulders, etc. with low sub-soil water constitute the northern section, whereas, the southern portion has relatively rich soil and even well-defined channels with less erosive capacity for slow flowing streams.

b) The Inner Himalayas or the Middle Ranges :-

They consist of higher mountains, which eventually climb up to 3,000 metres. These ranges from watershed between the major rivers and they pass from north-west to south-east direction in western Bhutan and from north-west to south-west in eastern Bhutan. There were eight major though narrow valleys in the area, namely, Ha, Paro, Thimbu, Punakha, WangdiPhodrang, Tongsa, Bumthang and TasHigong. These valleys form the country's economic and cultural heartland. Although these ranges do not have glaciers at present, their traces can be seen in the form of moraines present in some of the summits and upper slopes.

c) The Great Himalayas :-

With its chain of high peaks, the northern most region of Bhutan consists of the major Himalayan ranges. In this area, the western and easternmost ends of the Himalayan ranges have towering glaciated peaks, including Chomolhari (7,272 metres) and Kula Kangri (7,497 metres). Popular characteristics of this region are glaciers and moraine zones (Dubey, 1978).

Geology

Prior to the geological sub-divisions of any region, structural and stratigraphical aspects need to be considered. The geology of Bhutan is quite fragile and therefore is needed to be managed and preserved.

In contrast to its relatively young and less stable southern fringe, the northern and central regions of Bhutan are more stable.

The geological setting of the Himalayas of Bhutan from south to north is as follows:-

a) The Indian Shield
b) The Lower Himalayas
c) The Higher Himalayan Crystalline and
d) Tibetan Series (Bisht, 2008)

The Main Boundary Thrust (MBT), which is the active thrust fault, separates the Indian Shield from the Lower Himalayas. The rocks are thrown over the Indian Shield alongside this active fault because of India's collision with Asia.

On the other hand, the Lower Himalayas and the Higher Himalayan Crystalline (HHC) are segregated by the Main Central Thrust (MCT). This "dead" thrust was once thought to be the ancient counterpart of the MBT. About 20 million years ago (Ma), there was a major displacement along this thrust, which contributed to the original thickening of the continental thrust. Over MCT lies the Kakhtang thrust, which is also marked as the second main thrust. It carries the deep portions of the crust that the deeper section of the HHC represented. In comparison to this thrust, the South Tibetan Detachment System, which resembles the MCT, covers practically the whole length of the Himalayas (STD). This differentiates the HHC from the Tibetan Sequence and consists of a series of normal faults descending moderately to steeply down to the north in reference to the HHC (Daniel, et al., 2003).

The most recent upliftment of the Himalayas happened as a result of thrusting along the MBT. Earthquakes in the neighboring Trashigang area were periodically caused by the vibrations associated with this fault. It was observed that deep portions of the HHC and its bounding structures, i.e. the MCT and the STD, were discovered as a consequence of the upliftment that occurred through the MBT. The cover rocks of the underlying Indian Shield and the highly deformed and thermally altered (i.e. metamorphosed) overlying HHC was separated by the slightly wrapped and northwards dipping MCT. Therefore, this plane connected the rugged topographical terrain of the Himalayas and formed an intersection line that can be traced over the surface of the earth.

This line of intersection was seen in many places: - as it crossed the road quite a few times near Barshong, crossed the pass between Kanglung and Barshong, goes under the road from Kanglung to Trashigang, and even crossed Gamrich about 2 kilometres below Rolong. Thus, after passing several valleys, rivers and highways, this intersecting line continued through Bhutan, Nepal, Ladakh and through the Kashmir Valley. It eventually entered Pakistan in the north-west direction and has its branches in the Northern Frontier of India on the eastern edge (NSB, 2010; Daniel, et al., 2003).

Figure 2.9 depicts the geology of Bhutan. This map has been taken from Greenwood et al., 2016. They have compiled this map from the previous work and studies conducted by scholars like Chambers et al., 2011; Long et al., 2011a, b; Warren et al., 2011; Grujic et al., 1996, 2002, 2011; Chakungal et al., 2010; Tobgay et al., 2010; Long & McQuarrie, 2010; Kellett et al., 2009, 2010; Mc Quarrie et al., 2008; Hollister & Grujic, 2006; Richards et al., 2006; Daniel et al., 2003; Edwards et al., 1999; Edwards et al., 1999; Wu et al., 1998; Davidson et al., 1997; Bhargava,1995; Swapp & Hollister, 1991 and Gansser, 1983.

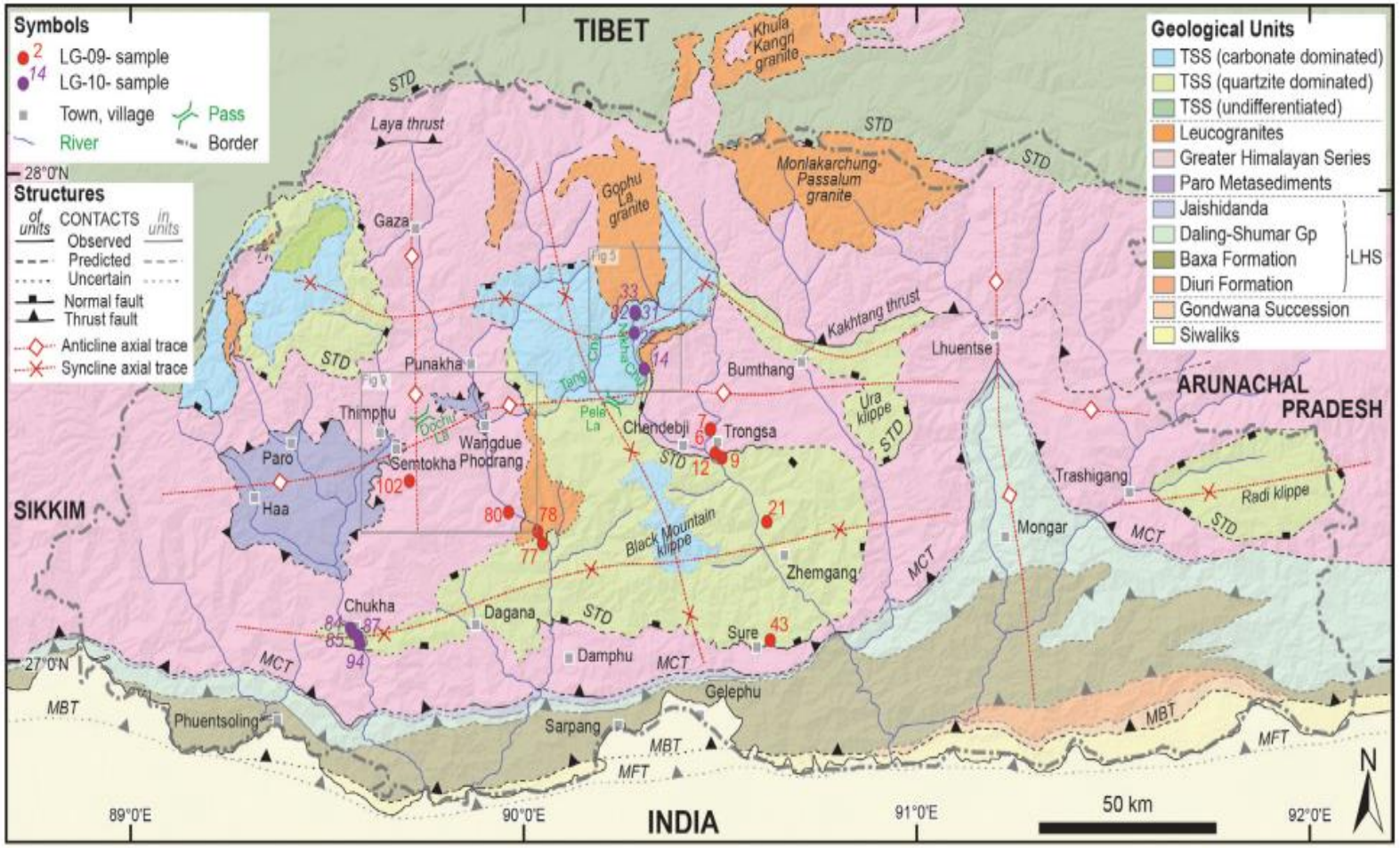


Figure 2.9: Geology of Bhutan

Source: Greenwood et al., 2016

Soils

The soils of the Bhutan Himalayas are divided into separate regions, i.e. the temperature zones of the Mesothermal, Microthermal and Tundra. The high and steep slope is distinguished by azonallithosols (shallow rocky ground) in the Great Himalayas. Whereas, the gentler slopes and foothill areas of the Inner Himalayas had shallower zonal soils.

Red or yellow soils are found in the lower slopes of the tropical deciduous and sub-tropical moist forest cover. Whereas, ash like brown or grey podzolic forest soils and mountain meadow soils are found at higher altitudes, i.e. in temperate coniferous and alpine vegetation zones.

Immature azonal soils with low profiles are not differentiated into various regions. The rich alluvium carried down by the rivers found in the Duar region, on the other hand, is split into two age groups. The first is the "Older Alluvium", which appears above the flood plain level in the higher fields. It consists of brown argillaceous loams with permeable nodular kankars (limestone). The "Younger or Newer Alluvium", on the other side, was largely limited to the current flood plains. In contrast to the older alluvium, it was light brown in colour, with clayey and loamy texture with more sand and less clay content.

Flanking the "Alluvial Duars" along the foot of the Himalayas is the "Bhabar Region", composed of and shingles. In this region, the stream tended to vanish and to reappear like springs in the Duars. Coarse gravels and boulders that are mixed with the ferruginous sand and clay are often filled in large areas of this region. This type of soil supports thick Sal forests in this area.

Going farther into higher elevations, the soil becomes sparse, immature, sandy and light with no humus material. These conditions are dominant in the lower ranges and in the foothills of the mountains with high rainfall, particularly where the parent material consisted of poorly clustered conglomerates with soft sandy beds (RGoB, 2000a).

The Temperate climatic region, which is between 1,500 and 3,600 metres, had both altitudinal and geological influences in its development. The flora of this area varies from the Sal Forests of the Sub-Himalayas to the Pine Mixed with Conifers and Magnolias, Oaks, Laurels and Rhododendrons. In addition to the transition in vegetation, the red or yellow soils of the pine trees have been taken over by the high altitude brown or grey (excessively leached) soils of the Podzolic Forest and the Mountain Meadows. On the other hand, at an altitude of 3,900 metres, the soils are usually frozen for a significant part of the year.

According to research by various scientists (RGoB, 2000b), it was inferred that very little was understood about the genetic association, structure and physical properties of Bhutan Himalaya soils. Systematic soil surveys do show a wide range of soil types, ranging from extremely fertile soils in valleys such as Paro and Thimpu to scant soils in the Higher Himalayas, where the survival of specialized flora was also difficult.

The south facing slopes of the Inner Himalayan range consist entirely of bare rocks. On the other side, the northern slopes are either covered with glacial and fluvio-glacial deposits or rain-washed soils which are usually used for agricultural purposes at higher altitudes (>2,000 metres). The higher valleys of the Inner Himalayas are frequently obstructed by drifting gravel and small rocks, which are the remains of glacial moraines carried down from above the snow line.

Drainage

Integrating all water supplies, such as high-altitude wetlands, glacial lakes amalgamated with snow, ice, streams, rivers and ground water. Bhutan has one of the largest per capita supply of water in the world. An average water flow of 2,238 m3/s was observed in Bhutan. The country produced approximately 70,572 million cubic metres of water per year, which totals to 94,500 m3 of water per person per year, making it the highest in the region. Bhutan's water supplies consist of ice, glacial and high-altitude wetlands; rivers and river basins; and groundwater and reservoirs (Water, 2016).

Rivers

Bhutan's fast moving rivers serve as the region's major form of water resources. On one side, due to the altitudinal differences, these profoundly incised swift flowing rivers formed as a blessing for the setting up of hydropower schemes. Whereas, on the other hand, small but perennial streams help in irrigating Bhutan's agricultural lands.

All the rivers of Bhutan have turbulent flow and rapidly changing gradient which flows between the high rocky mountains with their channels confined in the narrow valleys. While the alluvium from these rivers increase the soil's productivity. As they advance into the plains, the alluvium brought down by them increase the soil productivity and at the same time they pose serious dangers and flood threats in this area.

Nearly all of Bhutan's large rivers (with the exception of Manas and Chobhrak) pass through the narrow foothills of the mountains from the southern part of the Great Himalayas, emerging through the “Duars” and eventually culminating itself in the

Brahmaputra River. Whereas, the Manas and Chobhrak rivers are on two of the major roads linking eastern Bhutan to Lhasa, the capital of Tibet (Karan & Jenkins, 1963).

Basically, Bhutan has four major river systems:—

a) The DrangmeChhu
b) The Puna Tsang Chhu also called the Sankosh
c) The Wang Chhu
d) The TorsaChhu or AmoChhu

These rivers and their tributaries have a combined length of approximately 7,200 kilometres (Dubey, 1978) (Figure 2.10).

a) The Drangme Chhu:-

Rising from the Indian state of Arunachal Pradesh, it is the biggest river system flowing in the south-western direction. The DrangmeChhu basin consists of three main tributaries, the DrangmeChhu, MangdeChhu and ChamkarChhu, which stretch across the eastern part of Bhutan and drain the valleys of Tongsa and Bumthang. DrangmeChhu was called ManasChhu in the Duars, where eight other tributaries join the river. (Savada, 1993).

b) The Puna Tsang Chhu or Sankosh:-

The river that rises as Mo Chhu and Pho Chhu from the north-western part of Bhutan is a snow fed stream. These two streams flow farther south to Punakha, where they come together to form the Puna Tsang Chhu. From this point, the river begins its journey to the Indian state of West Bengal, covering a total length of 1,810 kilometres. Sankosh, with all its tributaries, is the second largest river system in Bhutan.

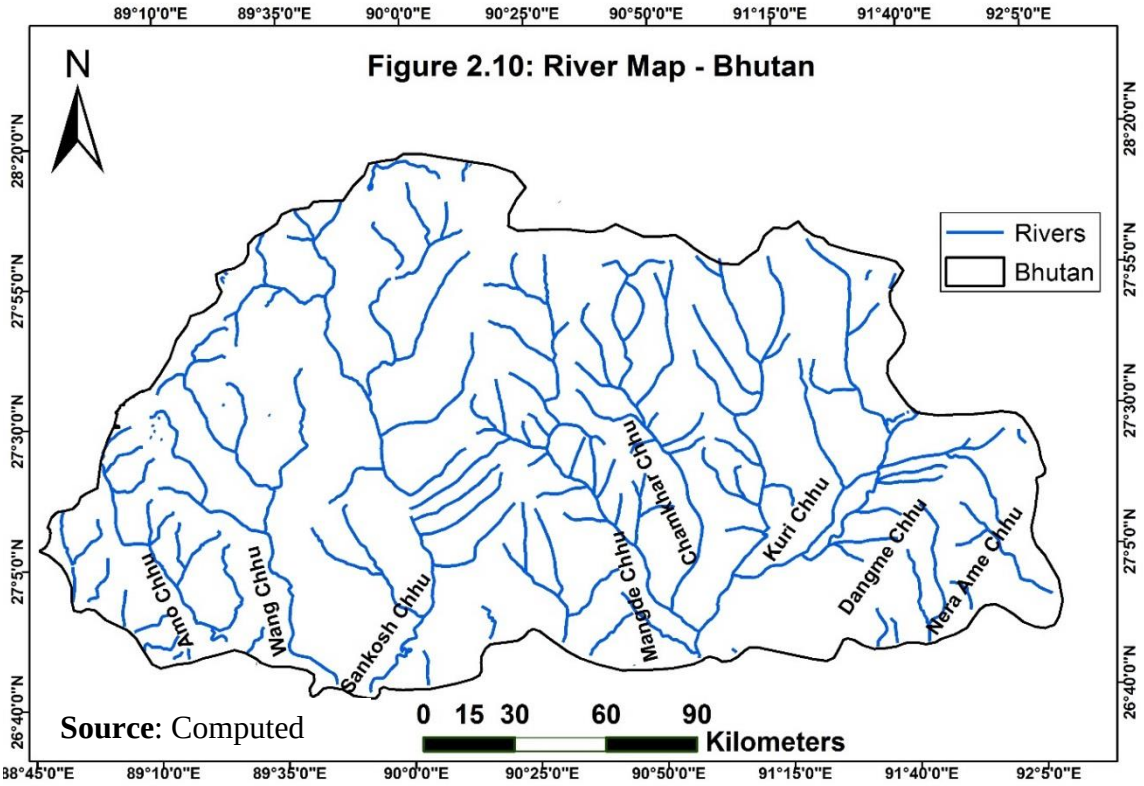
c) The Wang Chhu or Raidak:-

With a course of 610 kilometres in Bhutan, this river flows through western-central Bhutan in the south-easterly direction. On the way to the “Duars” the Ha, Paro and Thimpu valleys of Bhutan are drained and eventually debouches in West Bengal.

d) The Torsa Chhu or Amo Chhu:-

Torsa Chhu rises in Tibet and reaches the Kingdom of Bhutan via the Chumbi Valley. In its northern reaches, it is also regarded as Amo Chhu. It passes

through western Bhutan, following a narrow valley between steep mountains. This river has a rapid flow even during the winter season, with an average depth of at least 1 metre. It has a wide course near Phuntsholing in Bhutan, after which it enters India as a wide, braided channel. Torso Chhu and its tributaries measure a combined length of 310 kilometres in Bhutan. (Dubey, 1978; NSB, 2010).



An estimate by Dubey (1978), indicates there were about 32 rain fed or non-perennial rivers in this region. They run a cumulative length of 1,270 kilometres in the state, marking their roots in the Lesser Himalayas. They are distinguished by broad river beds and shallow depths of flow. During the rainy season, the river is torrential and lean at other times of the year.

Glaciers:-

Glaciers occupy nearly 10% of the total surface area of northern Bhutan. They serve as an important and sustainable source of water and contribute to the Bhutan Rivers (NSB, 2010). Every year, melted water from the glaciers brings millions of litres of fresh water to Bhutan and downstream areas. This region's waterways are potentially hazardous and

vulnerable to flooding and associated disasters. This happens as the monsoonal rainwater also feeds these rivers along with the glacial melt water.

The glaciers appear to move under their own weight, i.e. when the snow piles on the glaciers and the ice compresses, which deforms the glacier and eventually slides. As a result, the acceleration in the south (i.e. 10-20 metres per year) is sluggish relative to 100-200 metres per year in the north. This sluggish movement of glaciers on the southern side of the Bhutan Himalayas may have been due to the dwindling supply of snow and ice, as well as to the rocks and gravel that lie on top of these glaciers.

The northern glaciers of Bhutan, with an elevation of 7,000 metres, form essentially in the plateau region, and then drop down to the steep hillsides in long glacier tongues. The glaciers on the southern side of Bhutan form only on the mountains and cling to their steep rock walls, which shower a lot of 'debris' on them.

Some early snowfall at higher elevations occurs in early October, while snowfall is a typical occurrence for areas above 3,000 metres elevation from the months of November to March. Dry spells then continue until June, followed by monsoonal rains. Therefore, the glacial ice begins to melt and glaciers in the southern part shrink in size relative to the glaciers in the north, have a colder climate and intermittent supply of fresh snow that delays the process of glacier melt (Bisht, 2008).

Lakes and Springs:-

Lakes:-

Bhutan is blessed with >59 natural lakes covering a total area of approximately 42.5 square kilometres. Many of these lakes are situated at an altitude of 3,500 metres. In Dagala in Thimpu district, an observation by some surveyor as stated by Bisht in 2008 revealed that, along with their yaks, the Drukpa tribesmen migrate to places around the lakes for grazing at around 3,500 metres for 3-4 months when the region became ice free Bisht, 2008. There are four lakes in Bhutan situated at an altitude below 2,000 metres. (Table 2.8)

Table 2.8 Lakes of Bhutan Located Below 2,000 metres Altitude			
Lake	**District**	**Surface Area (sq. km)**	**Altitude (metres)**
Hoko Tso	Punakha	0.6	1,829
Luchika	WangdiPhodrang	0.025	1,830
Buli	Shamgong	0.02	1,372
Gulandi	Diapham	0.01	366
Source: Bisht, 2008			

Glacial Lakes:-

In Bhutan, glacial lakes are also present in addition to the high altitude wetlands. These are created when glaciers melt and their water is stored over time in the depressions near the glaciers, making them a type of natural reservoirs. (Water, 2016).

Particularly in this area, it was observed, that in the last few decades the glacier lakes were rapidly forming on the surface of glaciers covered by debris. The lake deposits retained under fluvio-glacial terraces and moraines were proof of their recent formation (Gansser, 1983). According to Water, 2016 there were approximately 2,674 glacier lakes in Bhutan then.

Springs:-

A number of natural springs exist in the southern part of the country, especially in the Kanglung, Chirang and Sarbhang areas (Dubey, 1978). Wangchuk et al. reported 10 hot springs (Tsha Chhu), 17 medicinal water or mineral springs (Sman Chhu) and 17 holy spring waters (Sgrub Chhu) in 2021, making a total of 44 springs in Bhutan, by field surveys.

Climate:-

Bhutan's diverse pattern of climate patterns can be accounted for in its different altitudinal and micro-climatic regions. (Alam and Tshering, 2004). The temperate climate prevails in the central mountain valley region, i.e. from an altitude of 1,535 metres to 2,155 metres. The weather is exceptionally cold in the rest of the country.

The extreme maximum temperature recorded at Phuntsholing (37.2°C) in south-western Bhutan and the extreme lowest temperature was recorded at Drukgyel Dzong (-8.2°C) in western central Bhutan. The geographical temperature range thus shows that the

mountainous regions of central, western central and northern Bhutan are distinguished by low temperatures and high temperatures in the southern valleys (Quadir, etal., 2007). The climate of Bhutan is therefore as diverse as its altitudinal variations. Monsoons influence Bhutan as well as other Asian countries. In particular, western Bhutan is affected by the monsoon rains, as it brings 60 to 90 percent of the total precipitation to the region (NSB, 2010).

The fundamental elements of the weather, such as temperature, pressure, precipitation and wind, differ with the altitude transition, but temperature was the primary parameter that had been taken to define the three climate zones. Climate sub-divisions from south to north were as follows:-

a) The hot and humid subtropical Duars and the foothills zone.
b) The cool temperate region of the Inner Himalayas that has a micro-thermal climate. This classification in particular is a tricky one, as the winters range from moderate to cool while the summers are warm and wet.
c) The Great Himalayan tundra region, above 4,585 metres, remains covered with snow almost throughout the year (Bisht, 2008).
    a) The first climatic sub-division, i.e. the humid sub-tropical type of climate, is, in particular, the upward expansion of the climate existing in the Assam-Bengal plains. This form of climate is present at an altitude of between 1,200 and 1,500 feet, with annual rainfall estimated at 80 inches.
    b) To the north of this subtropical belt, the temperature of the region is changes considerably. The Inner Himalayan ranges have micro-thermal climates where the winters range from relatively cold to severe (5 °C to 8 °C) while the summers are mild (10 °C to 22 °C) and bring rain (1500mm to 2000mm) (SASCOF-1, 2010). Products that thrive in lowlands, such as rice, bananas and oranges, are highly productive within this region. Lower areas and valleys are ideally suited for intensive cultivation. While at about 3,000 metres above sea level, the winters are moderately cold, the summers are short and cool, and grain farming is not successful.

        The narrow valleys that border the craggy slopes of the Inner Himalayan ranges form the lower zone of the micro-thermal Himalayan climate. Broad leaved trees are located on the southern fringes of the mountains that appear to resemble those of the Humid Sub-Tropical region. Whereas, in less moisture laden areas such as the valley regions, scrub forests or short grasses are prevalent.

c) In the upper reaches of the micro-thermal climate region, which is more than 3,000 metres above the mean sea level, the winters are severe and the summers are brief and cold. This upper micro-thermal climate area differs from the lower zone in two respects:-firstly, in this zone, frost is a constant characteristic that is rare below 3,000 metre elevation. Secondly, this region is characterised by traditional farming in which hardy crops such as barley and potato are cultivated that can withstand freezing conditions.

This region extends up to approximately 4,500 metres, which is typically defined as the upper limit of agriculture and the growth of natural trees. The estimated location of the trees and the snow line is largely based on, and thus varies with, the rainfall. For instance, the snow lines are typically higher in the drier areas and the tree lines are lower. The Alpine Grasslands region is, the wider in dry areas and the narrower in wet areas. This highland or better known as the Tundra region of the Great Himalayas, had some ancient frontier settlements where the native Bhutanese people reside with extremely cold winters and cool summers. The livelihood of these people depends on the herding of yak and sheep and as discussed earlier, the cultivation of potatoes and barley. This area has temperatures ranging from 1°C to 7°C with an average of 15 inches of precipitation during the year. Therefore, the altitudes above 4,500 metres above mean sea level represent the true climate of the alpine tundra (Karan, 1967).

Resume

This chapter contains a detailed description of the "Study Area," where the "Geography of the Eastern Himalayas" has been investigated and the reasons for selecting Bhutan and Sikkim for this specific research have been explained. For these places, the "physiography, geology, drainage, etc" have all been extensively examined. The first aim of the research, "The Glacier Inventory," is covered in the next chapter.