# STUDY OF GLACIAL LAKES LOCATED IN SIKKIM HIMALAYAN REGION USING SATELLITE DATA ON ARC GIS

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OF

**MASTER OF TECHNOLOGY**

IN

**ENVIRONMENTAL ENGINEERING**

Submitted by

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## CANDIDATE'S DECLERATION

I, Manish Kumar Mishra, Roll No.2K17/ENE/008 of M.tech (Department of Environmental Engineering), hereby declare that the project Dissertation titled "STUDY OF GLACIAL LAKES LOCATED IN SIKKIM HIMALAYAN REGION USING SATELLITE DATA ON ARC GIS" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology in Environmental Engineering, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of my Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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# CERTIFICATE

I, hereby certify that the project Dissertation titled "STUDY OF GLACIAL LAKES LOCATED IN SIKKIM HIMALAYAN REGION USING SATELLITE DATA ON ARC GIS" which is submitted by Manish Kumar Mishra, Roll No. 2K17/ENE/008 (Department of Environmental Engineering), Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the Degree of Master of Technology, is a record of the project carried out by the Student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this University or elsewhere.

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Above all, I owe it all to my Almighty God for granting me the wisdom health and strength to undertake this research task and enabling me to completion.

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# ABSTRACT

Failures of glacial lake dams can cause outburst floods and represents a serious hazard. The potential danger of outburst floods depends on various factors like the lake's area and volume, glacier area change, morphometry of the glacier and its surrounding moraines and valley, and glacier velocity. Remote sensing offers an efficient tool for displacement calculations and risk assessment of the identification of potentially dangerous glacial lakes (PDGLs) and is especially helpful for remote mountainous areas.

In this study we will study about the change in number of the glacial lakes and the area of those lakes in the Sikkim Himalayan region with the help of remote sensing and Arc GIS.

# Contents

# CHAPTER 1

# INTRODUCTION

Glaciers are situated in the most famous and remote regions over Earth surface. These are enormous assortments of ice and compacted snow which gradually streams under the activity of gravity. Of the most part of the glaciers, it exists mainly over land surface while some parts are discovered exclusively over sea water too. Presence of ice sheet and ice snow is constrained by two geographic factors. One of them is high elevations and the other is high scope[1]. Antarctic ice sheet (13.5 million $km^2$) is situated in high southern most part. Greenland (2 million $km^2$) is the largest ice sheet in the northern most part of the earth. Sub polar to polar areas are assessed to contain 500,000 $km^2$ of glacier and snow[1]. The figure below demonstrates the heterogeneous spatial dissemination of glacier everywhere throughout the Earth. High altitude snow-capped glacier in Hindu Kush Himalaya, Kunlun Shan, Pamir and Tien Shan mountain reaches are regularly named as the water towers of the planet.[2]

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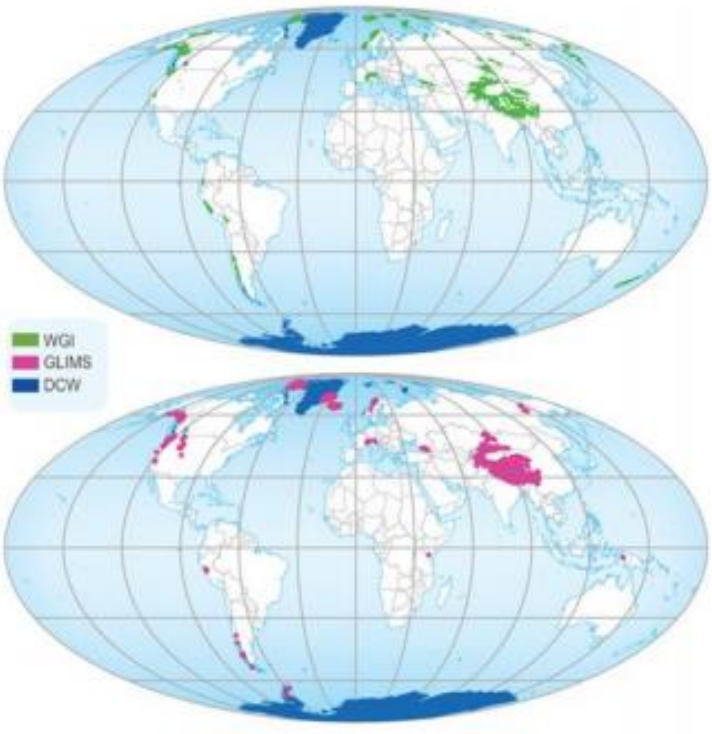


**Figure 1.1 Global Glacier Inventory** (https://nsidc.org/data/glacier_inventory/)

The figure above demonstrates the present century dissemination of glacier and snow over the world. Icy masses are a basic piece of the common hydrological cycle. The water vanished from the lakes, seas, ocean, streams and other water bodies when gather in environment at exceptionally low temperature result into the arrangement of snowflake or snow[2]. This snow experiences the procedure of glaciation to frame firm fundamentally solidified type of Glacier ice. The liquefy water from ice sheet ice in the long run streams into sea and in the course control the vitality parity of Earth. Himalayan icy masses framework for example has huge effect on atmosphere of the sub-landmass. It has been accounted for in IPCC report 2007 that southern Asia would have been 12°C without Himalayas.[3]

Major reasons to study glacier is that the glaciers are the fascinating elements of mother Earth. Glaciers are key indicator of climate change, and have always attracted scientists to study them. Academic reasons for studying glaciers are perhaps closely related to socially significant ones.

Ice sheets spread around 10 percent of the Earth, during the last ice age they secured one third of the Earth's surface. Investigation of such a huge bit of our planet can't be dismissed. Icy mass ice is the biggest repository of new water on the planet, putting away an expected 75 percent of the world's crisp water supply.[3] As indicated by U.S. Land study greatest of the polar ice tops, Antarctica glaciers are around 40 million years of age. This normal legacy of our own is assessed to contain around 29 million cubic kilometers of ice.

The Himalayan icy masses frameworks are most elevated of the icy masses present everywhere throughout the world. The word Himalaya is gotten from two Sanskrit words, -'Howdy mama' which means snow, and 'a-la-ya' which means dwelling place; it implies The Abode of Snow. This is the home of the wellspring of perfect and unadulterated water for right around 40 percent of the Earth's populace possessing Indian sub-mainland (UNEP, 2004. Monetary significance of icy mass lies in the way that ice sheets are potential hotspot for drinking water and water system. Streams with their starting point in mountain reaches encompassing Tibetan Plateau involve the biggest stream run-off from a specific area on the planet. Himalaya is the most youthful of all the mountain ranges and goes back their beginning from Tethys Ocean. Overflow from the Himalayan range is in this manner wealthy in minerals and natural mixes which consistently renew richness of the outwash fields. People have shrewdly restrained the capability of icy mass dissolve water for the most broadly utilized financial ware, control. Hydropower plants create power by the fundamental rule of electromagnetism. The potential vitality of the put away water in the repository is changed over into electric vitality. Alone in India Hydropower plants add to 37,367.4 MW of power age which relate to 21.53% of aggregate control utilization of the nation.[4]

A wide range of sorts of plant and creature species are found over the whole Himalayan mountain belt are jeopardized. Himalaya is characteristic territory to many imperilled creature species like Snow panther, Musk Deer, Himalayan Black Bear and some more.

India is a nation of social ceremonies and convictions. Individuals in India venerate nature and its endowments. Himalaya overall, a few of its pinnacles and its precipitous lakes are viewed as sacrosanct and what's more, revered.

## 1.1 GLOF- A GLACIER HAZARD

Because of quick rate of liquefaction of ice and snow conceivably brought knowledge about a dangerous atmospheric disaster in which a large portion of the Himalayan ice sheets have withdrawn abandoning various frosty lakes.[5] Glacial lake is characterized as water mass existing in an adequate sum and stretching out with a free surface in, under, next to, or potentially before an icy mass and beginning from icy mass exercises as well as withdrawing procedures of an ice sheet. IPCC in 2007 announced that with the expansion of temperature on Himalayan district between 1 to 6°C by 2100 the current inclusion of frosty ice and snow would diminish between 43 to 81 percent. Himalayan icy masses could shrivel from its present degree of 500,000 $km^2$ to 100,000 $km^2$ by 2030 deserting a lot progressively frosty lake in future.[5]

Burst or unexpected release of enormous volumes of water alongside trash from these lakes causes frigid lake upheaval floods (GLOFs) in valley downstream causing enormous harm to foundation (like dams, streets, neighbourhoods, ranches and so on), common assets (like woodlands), fauna and human life. So there is a solid need to screen these lakes for their arrangement, development and weakness.

## 1.2 RS & GIS IN GLOF STUDY

Himalayan elevated ice sheets have their snow line over 3800 meters structure m.s.l. Geographical investigation of ice sheets in this area accordingly is exceptionally troublesome considering the actuality that land field studies are risky and dangerous.

With the coming of room borne innovations like-Remote Sensing (RS) and Geographic Data System (GIS) it is presently conceivable to screen such blocked off spots all through the year. With further increment of remote detecting stages with improved spatial and worldly goals help customary perception and supervision of different properties of high ice sheets scilicet-ice degree, snow line, position of end, volume, icy mass parity.

# CHAPTER 2

# REVIEW OF LITERATURE

Glaciers are one of the most important constituent of a hydrological system. Around 10% of the world's land mass is covered with glacier. Glacier, ice caps and continental ice sheets are storage of fresh water, and it corresponds to three-quarter of world's total fresh water resources. They are unique source of fresh water for agriculture, industry and domestic use, an important economic component, yet they constitute serious natural hazards. As glaciers are natural component, they are directly affected by small climatic fluctuations at both local as well as global level but due to retreat of these glaciers glacial lakes are forming. Some studies on those lakes are shown below:

**J. Gabriel Campbell et. al (2016):**

They studied about the glaciers and glacial lakes and the potential of glacial lakes outburst floods due to global warming in the mountainous region of India, Pakistan and China/Tibet for the period of 2002-2015 in the paper named "Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOFs) Affected by Global Warming".. Data he used for his study are inventory of glaciers and glacial lakes are different type of satellite images, topographic maps and published maps, field report. Three main things are carefully taken (1) Changes in Terrestrial Ecosystems, (2) Human Dimensions of Global Change and (3) Climate Change and Variability. For this study he used Landsat 7 ETM+, IIRS LISS3 images, ASTER images were used. Shuttle Radar Topography Mission (SRTM) was used for the 3D applications. for the spatial and attribute database development and analysis. After the completion of his study he found that in Pakistan 5218 glaciers were identified among them 52 lakes are classified from which the potential threat of glacial lake outburst floods. In Sikkim Himalaya region 266 glacial lakes were identified out of which 14 were potentially dangerous glacial lakes.

**Julie Gardellea, Yves Arnauda, Etienne Berthier et. al (2011):**

They studied the evolution of glacial lakes along the Hindu Kush in the Himalayan mountain range, India, Nepal, Bhutan region for the period of 1990 – 2009. The data he used for the study are selected satellite images acquired between September and November (for the eastern part) and between June and October (for the western part). For each study site, a digital elevation model (DEM) of 2000 from the SRTM (Shuttle Radar Topography Mission) had also been downloaded. For this study spectral analysis has been carried out with one of the LANDSAT. Four bands in the VNIR and MIR (Middle Infra-Red) of ASTER data is used. A slope map is computed with a 3x3 pixels window using the SRTM DEM. In this study he found that Eastern sites show the largest glacial lake areas ($1.7*10^{-2}$ ha/ha for Western Nepal, $1.1*10^{-2}$ ha/ha Everest and $1.8*10^{-2}$ ha/ha Bhutan).Hindu Kush lake area has continuously decreased, for Garhwal sites, glacial lake expansion remains more or less the same in the 2000s and lake expansion rates are increasing in the Everest region.

**T. Bolch, M. F. Buchroithner, J. Peters, M. Baessler, and S. Bajracharya et. Al (2005):** They studied motion glacier and potentially dangerous glacial lakes in the Mt. Everest region and Nepal region mountainous range using space borne imagery for the period of 1962 - 2003. For this study ASTER DTM was generated in order to obtain information about the characteristics of the glaciers and their surroundings. Corona KH-4, Landsat MSS, Topographic map, Landsat TM, Landsat ETM+ for lake identification. Ikonos for glacier velocity. In this study glacial lakes were automatically identified using the Normalized Differenced Water Index. Since ASTER lacks a BLUE channel the GREEN channel was used instead. The displacement of the features was calculated using SSD3.0 (SAR Software Dresden, version 3.0). From this study it is found that proglacial and supraglacial lakes in the study region increased from 2 $km^2$ in 1962 to nearly 3.5 $km^2$ in 2003. Most of the increase is due to the development of the Imja Lake which began to grow after 1962 and covered an area of more than 0.9 $km^2$ in 2003.

**K. Babu Govindha Raj, S. N. Remya and K. Vinod Kumar et. al (2009):**

They studied the glacial lakes present in the Sikkim Himalayan range and their association with the hazards for the period of 1962-2008. For the purpose of his study the data he used are CORONA, Landsat MSS, TM and Resourcesat-1 (IRS P6) LISS III satellite data were used in this study. Apart from satellite data, ASTER digital elevation data (DEM) were also used. Declassified CORONA data of 1962 was used as the base data, it captured information of the Earth’s surface in panchromatic films. Supraglacial lake were identified at the snout of the glacier with the help of CORONA data. First occurrence of a separate lake is marked in the Landsat MSS data. The glacier boundary was also mapped from Landsat TM and

Resourcesat-1 LISS III data. The depth measurements of the lake were carried out using ASTER DEM. From the study he found that in 1977, the lake had an aerial extent of 17.54 ha and was attached to the glacier terminus. The lake areal extent was also mapped from temporal satellite data of 1989, 2002 and 2008. The lake area increased by an extent of 81.1 ha from 1977 to 2008. The areal extent of the lake was measured as 98.7 ha in 2008. Imja glacial lake in Nepal increased from a few small ponds in the 1950s to a single body of water with a surface area greater than 0.5 sq. km in 1984. The lake volume is 19.7 million m3 and lake depth is 20 m.

**Aparna shukla et. al. (2018):**

This study is done in the Sikkim and Eastern Himalaya of India for the period of 1975 to 2017 using Hexagon, TM, ETM+, and OLI images, respectively. First, a baseline data was generated for the year 2000 and then the multi-temporal lake changes were assessed. The annual mapping of glacial lakes was also performed for four consecutive years (2014–2017) to analyze their nature and occurrence pattern. This study reveals that there is continuous increase in the size and number of lakes in the study area. The total area of lakes showed rather significant increase of ∼24%, increasing from $25.17 \pm 1.90$ $km^2$ to $31.24 \pm 2.36$ $km^2$ between 1975 and 2017.

**Anil V Kulkarni et. al. (2016):**

This study is done in the Sikkim region glacial lakes and particularly 10 lakes and volume estimation is done for the period of 2001 to 2015. For this study COSI-Corr method and DEM and depth were used to estimate the bottom topography and overdeepening of the bed. To estimate the spatial distribution of ice thickness, the ‘Topo to Raster’ tool in ArcGIS was used. From this study The total volume of the nine lakes was estimated as $149 \pm 26$ million $m^3$ in 2001 and $246 \pm 44$ million $m^3$ in 2015. Therefore, increase in volume of the lakes from 2001 to 2015 was $97 \pm 17$ million $m^3$.

The accelerated changing of glacier has severe impact on human-being, vegetation patterns, natural disaster, water supplies and local climate (UNEP). Glacier length changes indicate the global climatic changes. The increasing mass loss and decline in glacier size in mountain and other regions contribute to sea level rise. The mass loss and change of length of glacier depends up on its geometry, and climatic variation. Various meteorological experiments have shown that the primary source for melting in glaciers is solar radiation, and losses of mass balance are due to temperature and precipitation.

Recently using various ground measurements, remote sensing and aerial photogrammetry a global scaled record of glacier is obtained. The trend obtained in this study shows that only a few glaciers are advancing. Temperate glacier with large accumulation and mass-balance are very active than continental glacier due to want of precipitation. Hence temperate glaciers are more sensitive to the changing climate than continental glacier sheets.

## 2.1 HIMALAYAN GLACIER STUDY OVERVIEW

Himalayan glaciers are the largest glacier in central Asia. In Himalayan mountain region, glacier covers approximately 30,000 $km^2$ which is about 17% of mountain area. Himalayan Mountain is located near tropic of cancer and receives more heat from solar radiation over any time period than other glaciers.[6] Therefore, Himalayan glaciers are more sensitive to climatic fluctuations than other mountain glaciers in the world. Most of the glaciers in this region are retreating and only some are advancing or are static causing long-term loss of fresh water storage. For example, Pandey et al. had referred to a loss of 20% in surface runoff in the Hunza and Shyock Rivers in Karakoram and Hindukush mountains since 1961. The high altitude of Himalayan glacier preserves its glacial existence in these mountain areas. Variable climatic change and terrain difference resulted into different glacier responses to same climatic changes in Himalayan area. The hydro-meteorology and the contribution of precipitation due to glaciations are controlled mainly by Indian monsoon and westerly, climatic regimes. Since the climate of Indian subcontinent is changing with year the formation of glacial lakes is also increasing day by day.[7] With the passing of time the number of glacial lakes and size of it are increasing. With this increase there are many hazards related to it that can be caused due to presence of glacial lakes.

## 2.2 TYPES OF HAZARDS

### 2.2.1 Glacier Floods

Generally, glacier floods represent the largest and most extensive glacial hazard, i.e., the hazard with the highest potential for disaster and damage (up to 102 mill. $m^3$ break-out volume and up to 104 $m^3$/s runoff). Glacier floods (in the Himalayas often termed Glacier Lake Outburst Floods, GLOF) occur in most glacierzed mountains of the world, e.g., in the Andes and in particular in Peru, in the Himalayas, Central Asia and in North America. In Switzerland they represent a highly relevant hazard potential as shown by a number of specific detailed studies. Glacier floods are triggered by the outburst of water reservoirs in, on, underneath and at the margin of glaciers. Most reservoir types develop slowly and two of them can be identified at the surface, a precondition which favors the application of remote sensing techniques for monitoring glacial and periglacial lakes. Outbursts of ice-dammed lakes are usually caused by mechanisms of dam floatation, enlargement of sub glacial drainage channels, or overspill. Ice dams, particularly when formed by ice avalanche deposits or by the fractured ice of surging glaciers, can also fail through a sudden break producing very high peak discharges. Lakes dammed by cold ice with subglacial permafrost have also been observed draining by dam overflow. Outbursts from moraine-dammed lakes can be triggered by overtopping, piping, slippage on steep slopes or a combination thereof, potentially initiated by an ice/snow jam. Bedrock-dammed lakes are commonly considered as safe from failure. However, impact waves from mass movements (e.g., ice avalanches, debris flows, rock falls) can cause dam overtopping which then may trigger a flood or debris flow.

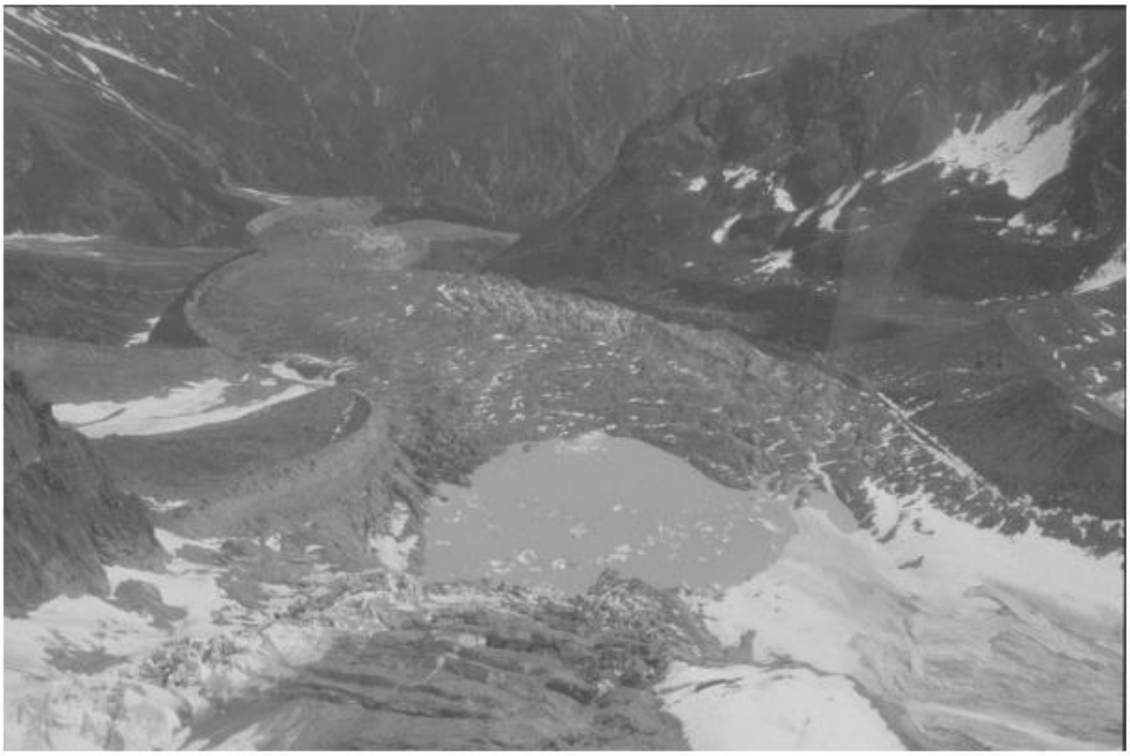

**Figure 2.2.1 Supraglacial 'Lago Effimero'** (Photo G. Mortara)

In contrast to glacier floods, whose effects are far-reaching, ice avalanches and the damage they cause are generally restricted to densely populated high-mountain regions, especially in the Alps. Nevertheless, in combination with other glacial hazards, ice avalanches can cause large-scale disasters. Ice avalanches are often triggered by breaking-off of ice from small and steep glaciers. The stability of such hanging glaciers is especially critical at altitudes and expositions where the firm is at the melting point due to percolating water.

**Figure 3 Deposits From the Ice Avala (https://wikivisually.com/wiki/Avala)**

In such cases, the vertical ice front of a hanging glacier typically consists of cold ice frozen to the underlying bedrock, which prevents failures of the ice mass. In fact, the geometry and thermal condition of the ice front is likely to be a key factor in the control of the stability of hanging glaciers. Disturbance of the equilibrium, e.g., by variations in firn accumulation or an increase in air temperature and melt water (possibly induced by climate change) may lead to hanging glaciers which are prone to failure.

Swiss glaciology traditionally plays a strong role in research and experience related to ice avalanches, since Switzerland is particularly vulnerable to such hazards. For this reason, detailed investigations of steep glaciers have been carried out in Switzerland partially accompanied by large-scale monitoring based on aerial photography. Worldwide, it is mainly the major ice avalanche catastrophes that draw public attention.

### 2.2.2 Glacier Clad Volcanoes

On a global level, glacier-clad volcanoes represent a further major glacier-related hazard. For instance, lahars (volcanogenic debris flows) can impact downstream areas at a distance of more than 100 km. The investigation of glacier-clad volcanoes was intensified and reinforced following the eruption of Mount St. Helens in 1980 and the Nevado del Ruiz catastrophe in 1985.

**Figure 2.2.3 Eruption of Popocatepetl Volcano** (https://en.wikipedia.org/wiki/Popocat)

In the case of Mt. St. Helens, glaciers have been found to react more elastically on long-term deformation than bedrock. Further studies also showed significant influence of ash cover on glacier mass balance and thus glacier changes. Eruption from the Nevado del Ruiz with a series of pyroclastic flows and surges melted parts of the summit ice cap and triggered large lahars having a total volume of about $9 \times 10^7$ $m^3$. More than 20,000 people lost their lives in the downstream areas.

Still, there are considerable gaps in the understanding of such hazards and related processes. In Mexico, a monitoring program has been focusing recently on the glaciers of Popocatepetl volcano since a new eruptive phase has been reached. Glaciers have been affected strongly by volcanic activity. Assessments of corresponding hazards have been made but dangerous or inhibited access conditions and the complexity of processes involved make them a special challenge.

# CHAPTER 3

# STUDY AREA

The investigation site is Sikkim a state of India. During the previous occasions Sikkim was otherwise called 'Basyul' which signifies 'the shrouded land'. The examination region nearly covers the whole Sikkim. The scope longitude of the locale approximates up to 27°34'27.39''N and latitude is 88°29'6.76''E with geological zone of 7096 $km^2$ establishing just 0.22% of aggregate land territory of India. Sikkim frames a piece of the Eastern Himalaya and it contains the Middle and Greater Himalaya. It has a human populace of 610,577 according to Census, 2011, which establishes just 0.05% of India's all out populace. The state is decently rectangular fit as a fiddle with a most extreme length from north to south of around 112 km and the greatest width from east to west of 90 km. The state is encircled by one of the most noteworthy mountain ranges from west, north, east and south-east. With Nepal to its west, the huge stretches of Tibetan Plateau flanking north east and the southern limit lying along India and Bhutan, Sikkim is a land bolted Indian Territory (Joshi H.G).

The Himalaya in Sikkim has rises going from 300 m to 8,600 m above Mean Sea Level (m.s.l.). Just about 66% of its landscape is unendingly secured with snow. Sikkim is a home for high mountain pinnacles including the third most noteworthy summit on the planet – Mt. Kanchenjunga (8,598 m) which is likewise the most noteworthy point in the nation.

## 3.1 CLIMATE

Sikkim is remarkable in light of the different climatic belts in its overall region. It tends to be extensively partitioned into sub-tropical, alpine and temperate zone from south to north concerning the altitudinal variety. The variety in elevation is to such an extent that one can move in all the climatic belts inside 60 minutes. As precipitation happens consistently, the atmosphere is for the most part cold and sticky. Moreover, because of its nearness with Bay of Bengal the territory gets substantial precipitation. North locale encounters lesser precipitation when contrasted with different regions. During April and May the Pre-monsoon (South-West) downpours win and the monsoon occurs from May and ended till the mid of October. Wonderful temperate is experienced by the populace possessing the mid and lower bit of the state. The high height locale in the extraordinary north experience gnawing cold temperature and for the most part stays occupied.

In the long periods of June and July the mountains in the north get warmed up making a convection cell. A low weight zone is made that draws dampness loaded air from the Bay of Bengal. The air chills off as it rises and condenses as downpour. The normal yearly precipitation is around 2,500 mm and the scope of precipitation differs from around 100 mm to 3,500 mm relying on the height and part of region. The mean yearly precipitation is least in Thangu (82 mm) and most extreme in Gangtok (3494 mm). In view of the precipitation circulation design, there are two most extreme precipitation territories (I) south - east quadrant, counting Mangan, Singhik, Dikchu, Gangtok, and Rongli and (ii) the south - west corner counting Hilley. In the middle of these two areas, there is a low precipitation region, i.e., Namchi. Precipitation here is about portion of that in the previous zones. Precipitation is substantial and well circulated during the months from May to early October. July is the wettest month in most of the spots. The intensity of precipitation during the southwest rainstorm season diminishes from south to north.

## 3.2 FLORA & FAUNA

The marshes in the south, 250 m to 1500 m, experience a tropical atmosphere; rich vegetation for example, figs, shrub, Sal trees and bamboos has been cleared in certain regions for cultivating. The calm timberland of oak, chestnut, maple, birch, birch, magnolia and silver fir overwhelms between 1500 m and 3500 m. Over 3500 m is the snow-capped zone where juniper, cypresses and rhododendrons develop. The interminable snowline lies at 3800 m. Lush woods spread 36% of the land; in excess of 4000 types of plant have been recorded in Sikkim. More than 600 species of orchids develop in Sikkim, Epiphytal and earthbound sorts, in the tropical and calm zones. 35 types of rhododendrons develop in calm and snow capped districts, their blossoming from May to August hues slopes.

**Table 3.2.1 Flora & Fauna in Sikkim** (Economic survey, govt. of Sikkim)

| | | | |
|---|---|---|---|
| Flowering plants: | 4500 | Butterflies: | 600+ |
| Rhododendrons: | 36 | Mountains and peaks: | 28 |
| Orchids: | 550 | Glaciers: | 38+ |
| Conifers: | 16 | Rivers and streams: | 104+ |
| Tree ferns: | 09 | Birds: | 550 |
| Primulas: | 30 | Oaks: | 11 |
| Medical plants: | 424 | Fishes: | 48 |
| Bamboo: | 28 | Lakes and wetlands: | 227 |
| Ferns and ferns allies: | 362 | Mammals: | 158 |

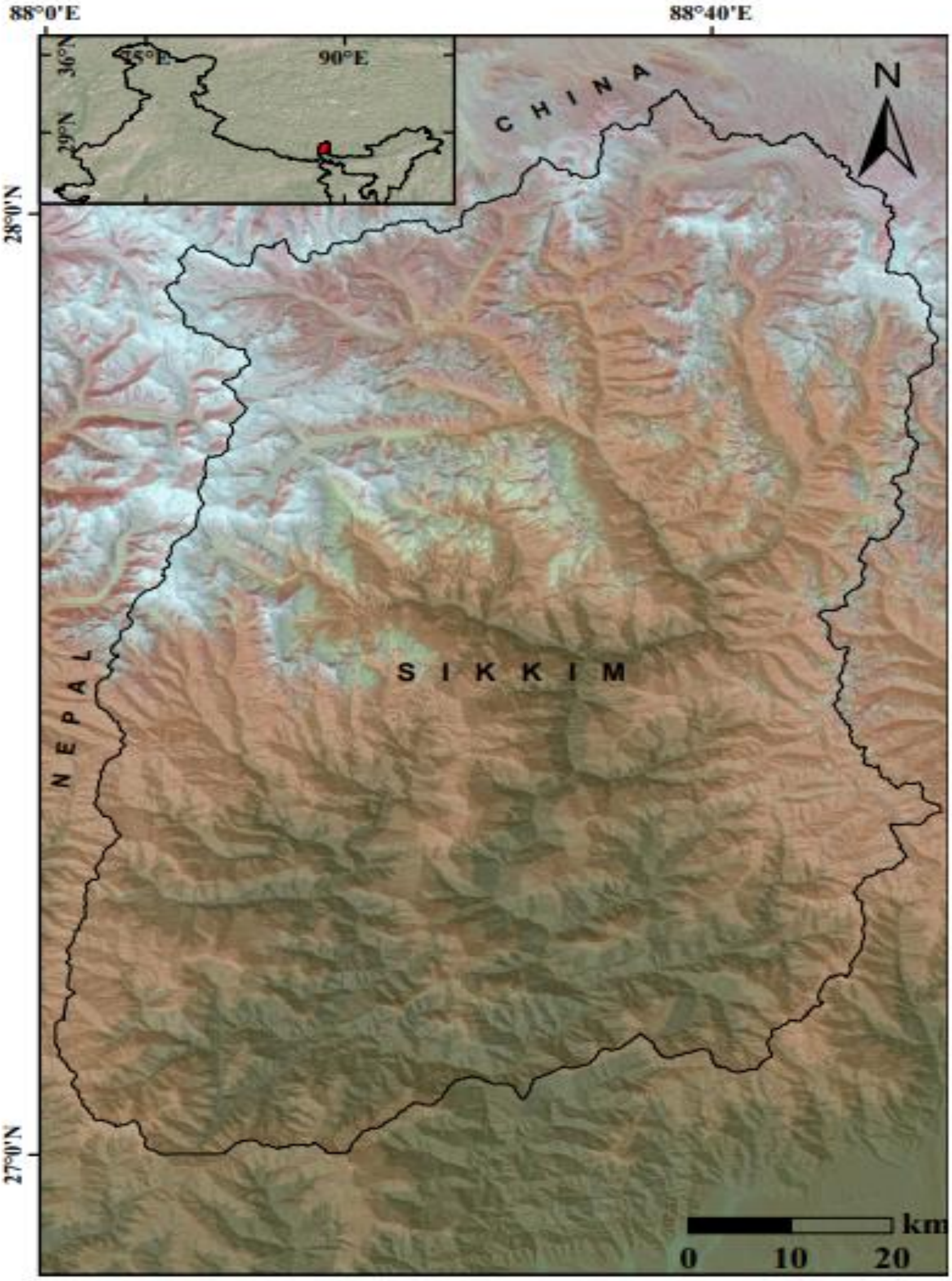


Figure 3.1 Sikkim Map (https://www.mapsofindia.com/sikkim/)

Figure 3.2 SOUTH LOHNAK LAKE (27°56'51"N 88°20'01"E)

## 3.3 ECONOMIC IMPORTANCE OF GLACIAL LAKES

Ice sheets framed lake bowls by gouging gaps in free soil or bedrock, by keeping material crosswise over streams beds, or by leaving covered pieces of ice whose dissolving molded lake bowls. All the more as of late, people and different creatures have made lakes and stores by damming waterways and streams.

Lakes continually experience transformative change, mirroring the progressions that happen in their watersheds. Most are bound to fill in with survives from lake living beings and with sediment and soil washed in by floods and streams. These slow changes in the physical and synthetic parts of a lake influence the advancement and progression of plant and creature networks. This normal procedure takes a great many years. Human exercises, be that as it may, can significantly change lakes, regardless, in only a couple of years.

Sikkim, a little state in the Eastern Himalaya has just regular inland wetlands having a place with the class lakes/lakes. The state has near 300 high elevation lakes which are essentially little and shallow. A large portion of it are nourished by icy masses and considered holy. The lakes are famously called as Chhokhaor Tsoor Chhona (in Bhutia), Chho (in Lepcha) and Pokhari or Jheel or Tal (in Nepali). The eastern piece of the state has novel structure of flower conveyance and faunal predominance. The whole lap of the Himalaya has abundant of water bodies as new water lakes credited by the ice sheets and perpetual snow topped mountains.

# CHAPTER 4

# DATA SOURCES

## 4.1 LANDSAT

The Landsat program is the longest-running endeavour for obtaining of satellite symbolism of Earth. On July 23, 1972 the Earth Resources Technology Satellite was propelled. This was in the end renamed to Landsat. The latest, Landsat 8, was propelled on February 11, 2013. The instruments on the Landsat satellites have procured a great many pictures. The pictures, filed in the United States and at Landsat getting stations far and wide, are a one of a kind asset for worldwide change research and applications in farming, cartography, geography, ranger service, provincial arranging, observation and training, and can be seen through the U.S. Land Survey (USGS) 'Earth Explorer' site. Landsat 7 information has eight ghostly groups with spatial goals going from 15 to 60 meters; the transient goal is 16 days. Landsat pictures are generally isolated into scenes for simple downloading. Each Landsat scene is around 115 miles in length and 115 miles wide (or 100 nautical miles long and 100 nautical miles wide, or 185 kilometers in length and 185 kilometers wide).

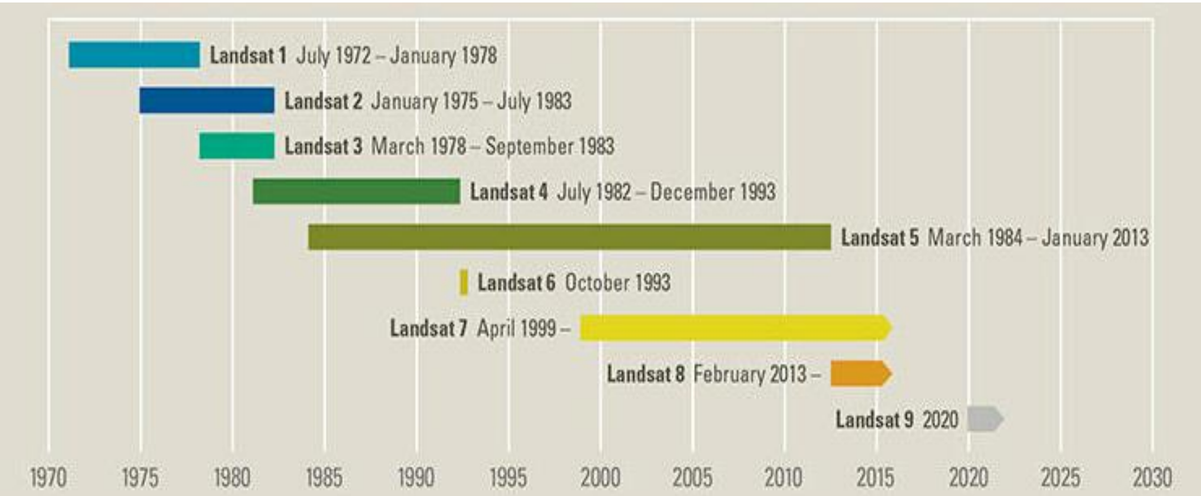


Figure 4.1 Landsat Launches (https://en.wikipedia.org/wiki/Landsat_program)

## 4.2 LANDSAT 7

Landsat 7 is the seventh satellite of the Landsat program. Propelled on April 15, 1999, Landsat 7's essential objective is to revive the worldwide file of satellite photographs, giving cutting-edge and sans cloud pictures. The Landsat Program is overseen and worked by the

USGS, and information from Landsat 7 is gathered and disseminated by the USGS. The NASA World Wind task permits 3D pictures from Landsat 7 and different sources to be unreservedly explored and seen from any point. The satellite's sidekick, Earth Observing-1, trailed by one moment and pursued the equivalent orbital qualities, yet in 2011 its fuel was exhausted and EO-1's circle started to degrade. Landsat 7 was worked by Lockheed Martin Space Systems Company. NASA will attempt to refuel it in 2020.

### 4.2.1 Specification

Landsat 7 was intended to keep going for a long time, and has the ability to gather and transmit up to 532 pictures for every day. It is in a polar, sun-synchronous circle, which means it filters over the whole earth's surface. With an elevation of 705 kilometers +/ - 5 kilometers, it takes 232 circles, or 16 days, to do as such. The satellite weighs 1973 kg, is 4.04 m long, and 2.74 m in width. In contrast to its ancestors, Landsat 7 has a strong state memory of 378 gigabits (approximately 100 pictures). The fundamental instrument on board Landsat 7 is the Enhanced Thematic Mapper Plus (ETM+).

### 4.2.2 Main features

- A "15 m (49 ft)" spatial resolution panchromatic band (band 8)
- Visible (reflected light) bands with 30 m (98 ft) of spatial resolution (bands 1-5, 7) in the blue, green, red, near-infrared (NIR) and mid-infrared (MIR) range.
- A 60 m spatial resolution heat infrared channel (band 6)
- Full opening, complete radiometric calibration of 5 percent

**Table 4.1.1 Landsat 7 Bands properties**

| BAND | SPECTRAL WAVELENGTH(µm) | DESCRIPTION | GROUND RESOLUTION |
|---|---|---|---|
| BAND 1 | .415-.515 | BLUE | 30m |
| BAND 2 | .525-.605 | GREEN | 30m |
| BAND 3 | .63-.69 | RED | 30m |
| BAND 4 | .75-.90 | NEAR IR | 30m |
| BAND 5 | 1.55-1.75 | SHORTWAVE IR | 30m |
| BAND 61 | 10.40-12.5(low gain TIR) | THERMAL IR | 60m |
| BAND 62 | 10.40-12.5(high gain TIR) | THERMAL IR | 60m |
| BAND 7 | 2.09-2.35 | SHORTWAVE IR | 30m |
| BAND 8 | .52-.90 | PANCHROMATIC BAND | 15m |

## 4.3 LANDSAT 8

Landsat 8 is a satellite started on February 11, 2013 for American Earth observation. It is the eighth Landsat satellite, the seventh to effectively achieve orbit. This is a cooperation between NASA and USGS, originally called the Landsat Data Continuity Mission (LDCM). NASA's Goddard Space Flight Center in Greenbit, Maryland development mission systems engineering and launch car acquisition while the USGS supplied ground systems development and will perform continuing mission activities.

The satellite was built by Orbital sciences Corporation, who served as the mission's prime contractor. The tools of the spacecraft were built by Ball Aerospace and the Goddard Space Flight Center of NASA, and its launch was ordered by the United Launch Alliance.

LDCM was checked out and verified by NASA during the first 108 days in orbit and operation were transferred from NASA to USGS on 30 May 2013 when LDCM was officially renamed LANDSAT 8.

### 4.3.1 Specification

- Collect and archive resolution (30- meter spatial resolution) multi spectral picture information providing seasonal coverage of worldwide land masses for at least 5 years;
- Ensure that Landsat 8 information is adequately compatible with previous Landsat missions information in terms of procurement geometry, calibration, coverage features, spectral features, output product quality, and information accessibility to allow land cover research and land use changes over time ;
- Distribute Landsat 8 information products in a non-discriminatory manner to the general public at no price to the consumer.

### Table 4.2.1 Landsat 8 Band Properties

| BAND | SPECTRAL WAVELENGTH(µm) | DESCRIPTION | RESOLUTION |
|---|---|---|---|
| BAND 1 | .43-.45 | COASTAL AEROSAL | 30m |
| BAND 2 | .45-.51 | BLUE | 30m |
| BAND 3 | .53-.59 | GREEN | 30m |
| BAND 4 | .64-.67 | RED | 30m |
| BAND 5 | .85-.88 | NEAR INFRARED | 30m |
| BAND 6 | 1.57-1.65 | SWIR 1 | 30m |
| BAND 7 | 2.11-2.29 | SWIR 2 | 30m |
| BAND 8 | .50-.68 | PANCHROMATIC | 15m |
| BAND 9 | 1.36-1.38 | CIRRUS | 30m |
| BAND 10 | 10.60-11.19 | THERMAL IR 1 | 100m |
| BAND 11 | 11.50-12.51 | THERMAL IR 2 | 100m |

# CHAPTER 5

# METHODOLOGY

## 5.1 ANALYSIS OF SATELLITE DATA

Using satellites namely Landsat 8 and Landsat 7, data was gathered from the USGS scheme and analyzed using ArcGIS 10.1. Steps engaged in the glaciers ' general evaluation are described below.

## 5.2 DATA COLLECTION

Medium resolution satellite sensors like LANDSAT enable glacier outline to be extracted at regional scales using semi-automated algorithms. In the visible (VIS) and near infrared (NIR) bands of the electromagnetic spectrum (.35-2.5 µm), optical sensors detect solar radiation reflected by the Earth's surface. Radiation emitted by the thermal infrared (TIR) surface (8-14µm) is registered by the sensor as brightness temperature. LANDSAT, together with ASTER, is one of the most frequently used glacier parameter monitoring tools due to its appropriate spatiotemporal and spectral resolution, low cost and close to worldwide coverage.

Remote sensing information in the form of a digital elevation model is freely accessible on the U.S. Geological Survey (USGS) website and can be accessed either by choosing the coordinates or by the place name. Select the time period from which to collect the information.

LANDSAT 8 and LANDSAT 7 are the sources of the pictures or information acquired, these pictures are downloaded using the USGS scheme. We should filter the information using months while downloading the picture and the following three requirements should be met:

- Minimum snow- At the end of the ablation period, specify a time frame.
- Minimal Clouds-Cloud coverage should be less than 10 percent of the data to be downloaded.
- Adequate contrast-Sensors are saturated in the visible bands, therefore low gain settings are suggested in those bands.

The images downloaded are regarded using ArcGIS in the form of distinct layers according to the satellite bands. Information is collected using the software's various instruments. The image is downloaded in the format of .tiff.

2000, 2005, 2010, 2012, 2016, 2017 and 2018 data are downloaded. The 2016, 2017 and 2018 data are from Landsat 8, while all other year data are from Landsat 7. Data management is also an important part of the project; with their name, data should be saved in different folders with proper classification.

## 5.3 ADDING DATA IN ARCMAP

The information gathered from the USGS scheme is stored in separate folders with correct classification as required. Data-containing folder contains various bands of data based on the satellite used; it might be LANDSAT 8 or LANDSAT 7. If the information acquired is from LANDSAT 7 then there will be 8 no bands and if it is LANDSAT 8 then there will be 11 bands.

Landsat 7's most significant band is band 5, 4, 3, and Landsat 8's band 6, 5, 4. The folder includes 1-11 bands of Landsat surface reflection and the metadata file. Each band is supplied as an picture of 16-bit grayscale.

Start a fresh blank ArcMap document and press the menu key to add it. Add only bands from the information folder that are the most significant band 2 to 6. Then load the map with band 4, 5, 6. Different ArcMap will be introduced to load all the varying years of information.

## 5.4 CREATING FALSE COLOUR COMPOSITES

The display colour assignment for any band of a multispectral image can be done in an entirely arbitrary manner. In this case, the colour of a target in the displayed image does not have any resemblance to its actual colour. The resulting product is known as a false colour composite image. There are many possible schemes may be more suitable for detecting certain objects in the image.

A very common false colour composite scheme for displaying a SPOT multispectral image is shown below:

R = XS3 (NIR band)

G = XS2 (red band)

B = XS1 (green band)

This false colour composite scheme allows vegetation to be detected readily in the image. In this type of false colour composite images, vegetation appears in different shades of red depending on the types and conditions of the vegetation appears in different shades of red depending on the types and conditions of the vegetation, since it has a high reflectance in the NIR band (as shown in the graph of spectral reflectance signature).

Clear water appears dark-bluish (higher green band reflectance), while turbid water appears cyan (higher red reflectance due to sediments) compared to clear water. Bare soils, roads and buildings may appear in various shades of blue, yellow or grey; depending on their composition. False colour composites (FCC) are useful to get a look at the terrain. Colour composite of layer 654 is created. The "composite bands" tool in the Arc toolbox combines (stacks) the multiple bands into the single raster dataset. There is a stepwise procedure to create FCC in ArcGIS.

### 5.4.1 Steps Performed For Creating False Colour Composite

Launch Arc toolbox then select → Raster → Raster Processing → Composite Bands.

Input Raster: choose band 6, 5 and 4 one by one for Landsat 8 and band 5, 4 and 3 for Landsat 7 in a sequence.

Output Raster: FCC_654.tif and navigate to the folder and save it there, do not change the root name, so as to avoid any confusion later.

For clouds add band 5 separately to the map and notice that clouds will be bright in this band this is because of spectral differences of clouds vs. ice/snow in near IR. The reflectivity of ice/snow drops in the NIR, while clouds are highly reflective in the near-IR. This is visible on band 5- ice/snow is black, and clouds are white. Band 5 can be used to mask clouds using thresholds the need to be selected on each satellite image.

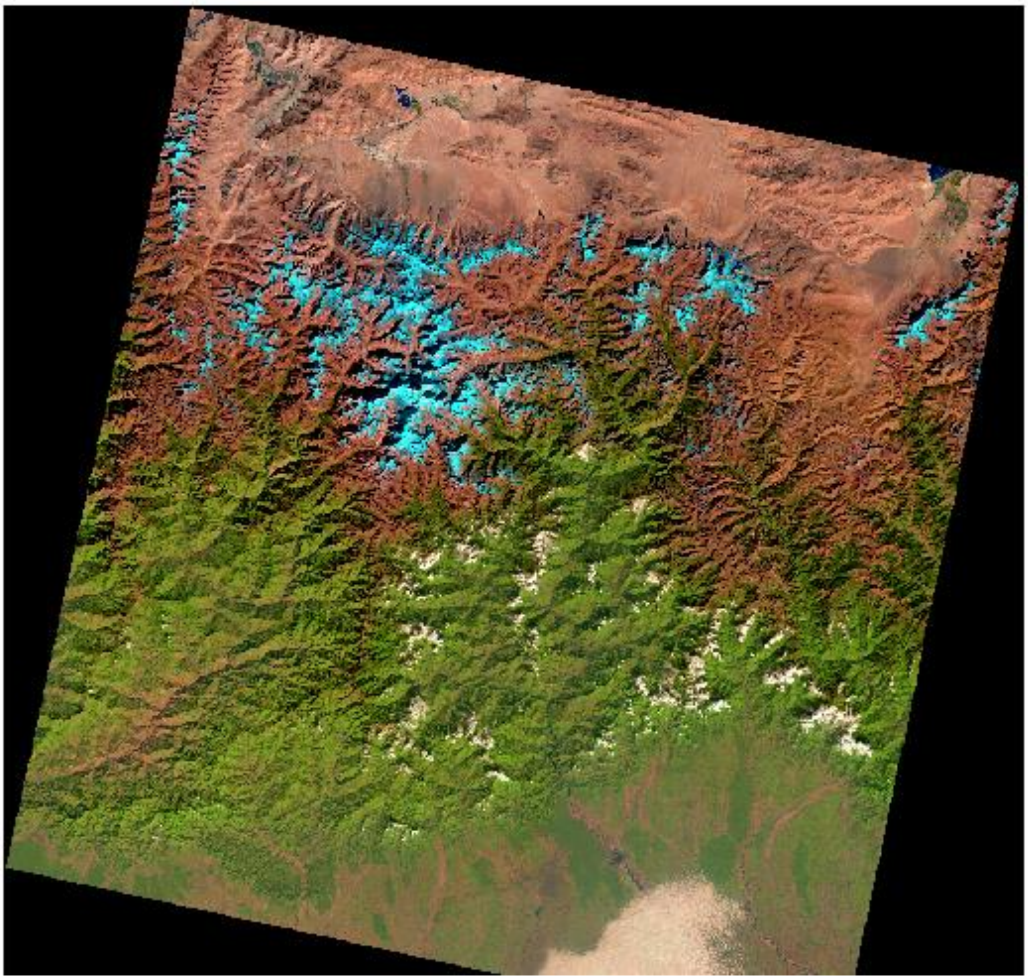

Figure 5.4.1 FCC of Sikkim of Year 2018

## 5.5 BAND RATIO METHOD

A band ratio is a new channel of data created by the division of two sets of band digital numbers for each pixel. It means dividing the pixels in one band by the corresponding pixels in a second band. The reason for this is twofold: One is that differences between the spectral reflectance curves of surface types can be brought out. The second is that illumination, and consequently radiance, may vary, the ratio between an illuminated and a not illuminated area of the same surface type will be the same and thus this will aid image image interpretation.

This creates a new set of data that may be used to highlight certain features. Logically, rationing may cancel out or reduce whatever is common in two images and exaggerate where they are different. Advantage of band ratio is that it is fast, simple and robust.

It also has some disadvantage, vegetation in shadows and shadows of mountains and some part of glaciers may be classified as glacial lakes.

### 5.5.1 Steps Performed For Making Band Ratio

For glacial lakes Normalized Difference Water Index (NDWI) is used as the band ratio.

In Arc Toolbox choose Spatial Analyst → Map Algebra → Raster Calculator.

In raster calculator window, for math algebra expression write expression as follows:

(float (Band 3) – float (Band 5)) / (float (Band 3) + float (Band 5))

In Environments set resolution to 30m.

Name the output as bandratio_5_6.tif and save it in the folder named 'band ratios' for the corresponding year.

Add the resulting image to the table of contents. The image is a grayscale with snow and ice appearing as white.

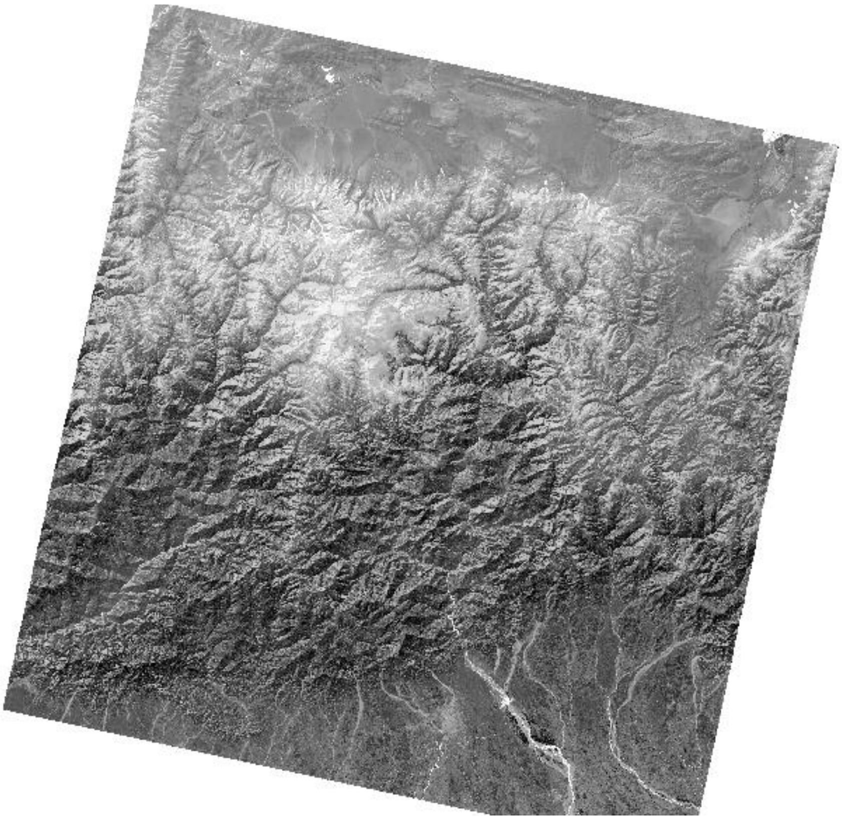

**Figure 5.5.2 NWDI of Sikkim of Year 2018**

## 5.6 FINDING THE THRESHOLD FOR LAKES

Using the "identify tool" from the main menu and scroll around the image to look for the edges of the water ( it is easily distinguished when we pass the threshold from bare land to water and values change sharply).

Image thresholding: Image thresholding (also called as image segmentation) consist of dividing an image into segments with similar spectral or texture characteristics, which corresponds to real real features. To find the threshold Identify tool is used and scrolled around the image to look for edges of the ice. Recommended values range from 0 to 0.2.

### 5.6.1 Steps Performed For Finding Threshold

In Arc Tool Box, choose Spatial Analyst → Map Algebra → Raster Calculator

To apply threshold, use the Raster Calculator with the expression:bandratio_5_6>X.X, where X.X is the threshold achieved from sensitivity analysis.

Set the output name as bandratio_5_6trX.X.tif so as to keep the track of different tests.

The output is a binary image with (0) for non- water and (1) for water. Different thresholds were tried from 0 to 0.2 and were saved with different names.

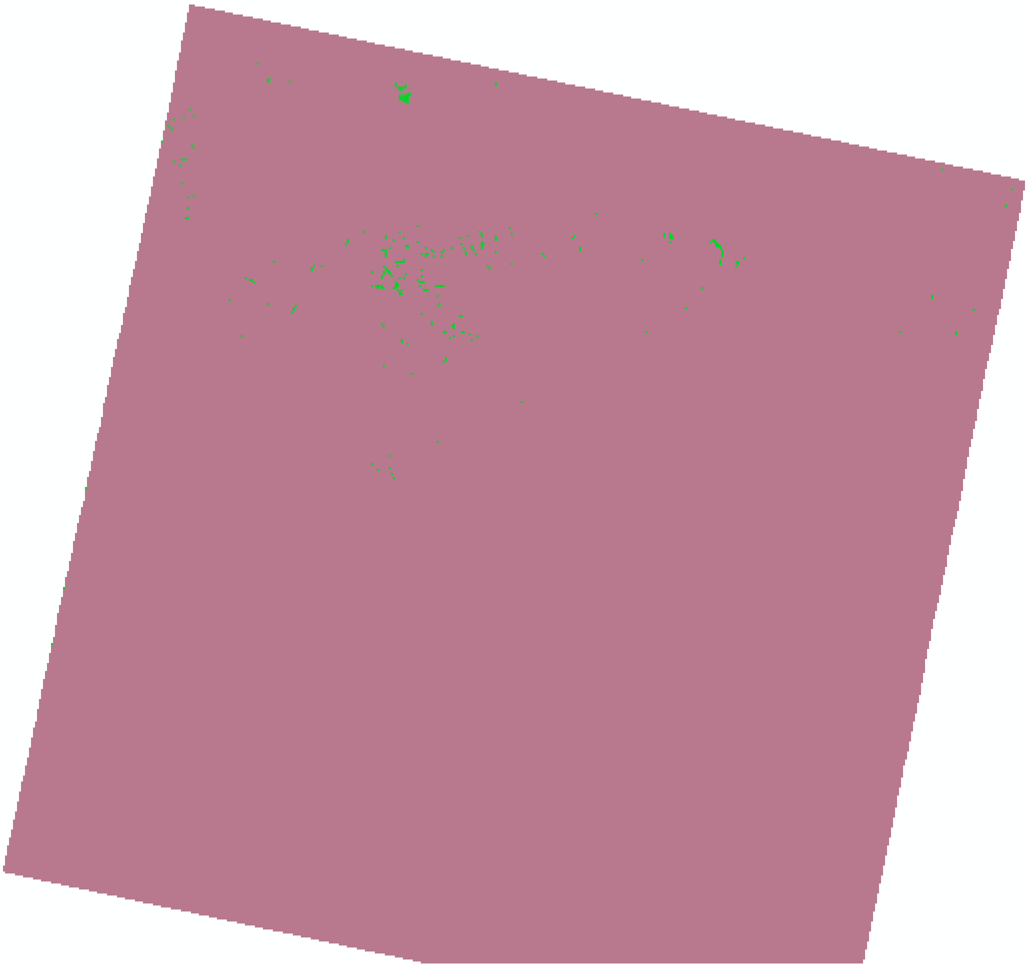

**Figure 5.6.1 Threshold of NDWI of Sikkim of Year 2018**

## 5.7 IMAGE FILTERING

Filters are defined as moving, overlapping neighbourhood statics, and are used to improve the quality of raster image by eliminating spurious data or enhancing the feature in data.

After delineation of ice and snow mass, filter is run to remove extraneous bits. Because while using band ratio method small lakes are also misclassified as lakes, and filter to remove these errors.

ArcGIS Spatial analyst provides two types of filter: low pass and high pass and both are based on focal functions with weighed kernel neighbourhoods.

- A low pass filter smooth's the data by reducing local variation, and works by calculating the average (mean) value for each 3x3 neighbourhood with the Mean statistic type of the Focal Statistics functions (or Focal Mean in Map Algebra). The effect is that the high and low values within each neighbourhood are averaged out.
- A median filter gets rid of the smaller, misclassified cells and smooth's the data.

### 5.7.1 Steps Performed For Image Filtration

Median filter 3X3 kernel size is applied for the assessment.

Go to Spatial Analyst → Neighbourhood → Focal Statistics

Input raster: bandratio_5_6trXX.tif

Output raster: bandratio_5_6trX.Xmed3X3.tif

Under the "statistics type" drop down menu choose "MEDIAN" and specify a 3x3 neighbourhood with units as cell.

In table of content right click on the filtered layer and export raster to save the final copy of the classification as lake.tif.

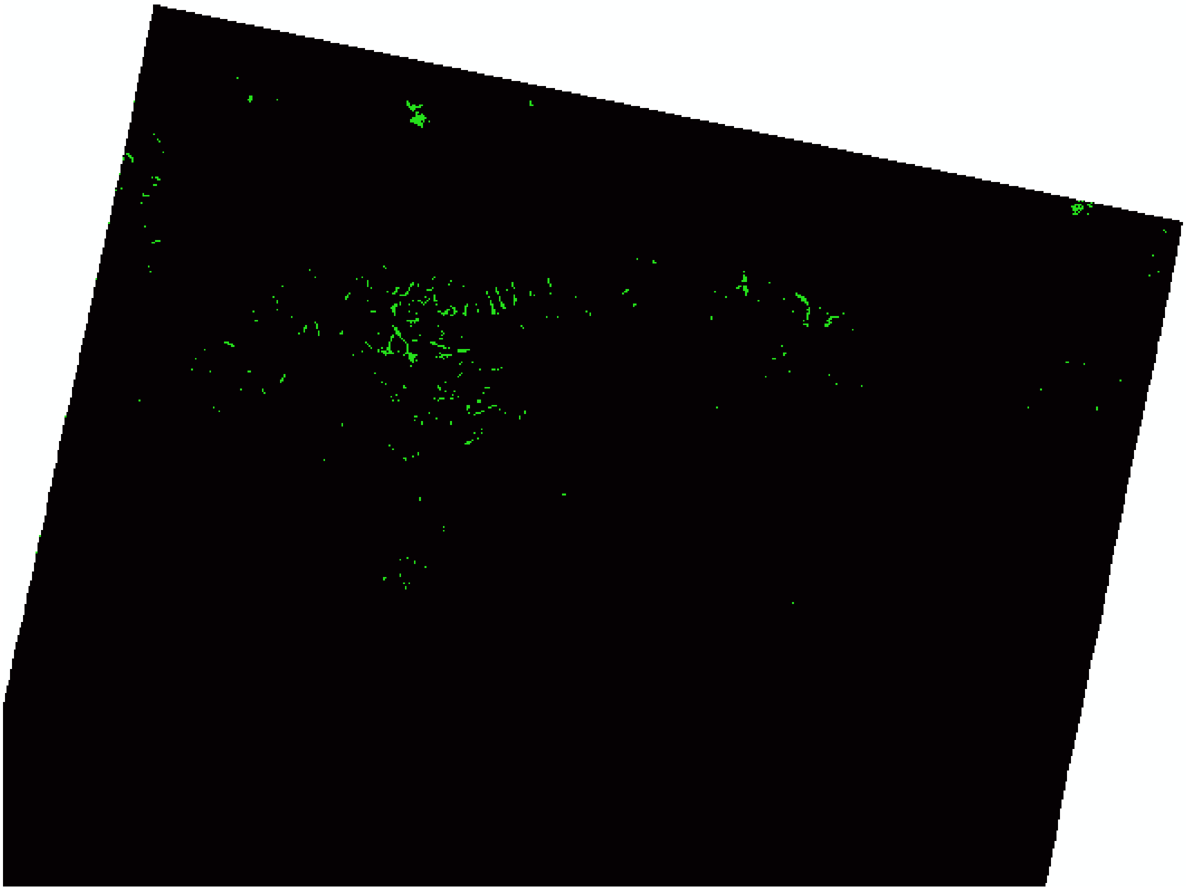

Figure 5.7.1 Image Filtration of Sikkim of Year 2018

## 5.8 RASTER TO VECTOR CONVERSION

In this step lakes are converted to polygon so as to calculate the area of lakes in the next step. These polygons can also be obtained directly with the data present on the GLIMS site but it's too complex as it gives the polygon of all the glaciers present on earth and hence area calculation for any specific area is very difficult. ArcGIS makes it simple to convert the raster into polygon and are easily obtained.

Steps performed for vector conversion

In Arc Tool Box, go to Conversion Tools → From Raster → Raster to Polygon.

Select the best filtered result, med 3X3 is selected as input and output is specified as raster lakes_2018_uned.shp and saved in the folder shapefile. Extension used for shape file is .shp.

The current file contains both the non-ice and ice, gridded by grid code 0 and 1. Polygons are edited further to remove the ice. From the main toolbar menu, Editor Toolbox is added and the newly created shape files are chosen for editing.

## 5.9 EXTRACTION

The Extraction tools allowed to extract a subset of cells from a raster by either the cells attributes or their spatial location and also to obtain the cells values for specific locations as an attribute in a point feature class or as a table.

The tools that extracted cell values based on their attribute or location to a new raster include the following:

- Extracting cells by attribute value (Extract by Attributes) is accomplished through a where clause.
- Extracting cells by the geometry of their spatial location requires that groups of cells meeting a criteria of falling within or outside as specified geometric shape (Extract by Circle, Extract by Polygon, Extract by Rectangle).
- Extracting cells by specific locations requires that you identify those locations either by their x,y point locations (Extract by Points) or through cells identified using a mask raster (Extract by Mask).

In this step area required for assessment was extracted from the over layer of the data collected from the satellite. In the thesis Sikkim Himalaya was the main point of focus so all the nearby area was removed with the help of extraction. Extraction by mask (Extracts the cells of a raster that corresponds to the areas defined by a mask) was the method used. Mask file was downloaded from the IMD data in the form of shapefile for Sikkim region. Extraction was done for getting the extracts for FCC, band ratio, threshold, filter and polygon images. Raster obtained after the extraction was used in calculating the area of all the polygons present in the focussed region. Extraction is basically done for getting the desired area on which we have to perform the study. The data or satellite images obtained from USGS are of larger area and study to be done is for specified areas.

### 5.9.1 Steps Performed For Extraction

In Arc Toolbox → Spatial Analyst Tool → Extraction → Extract by map.

Input Raster: bandratio_5_6trX.Xmed3X3.tif

Feature Mask Data: SikkimIMD.shp

Output Raster: bandratio_5_6tr_extract.tif

All these steps were performed to get the extracted raster’s of all the images formed through various above mentioned steps.

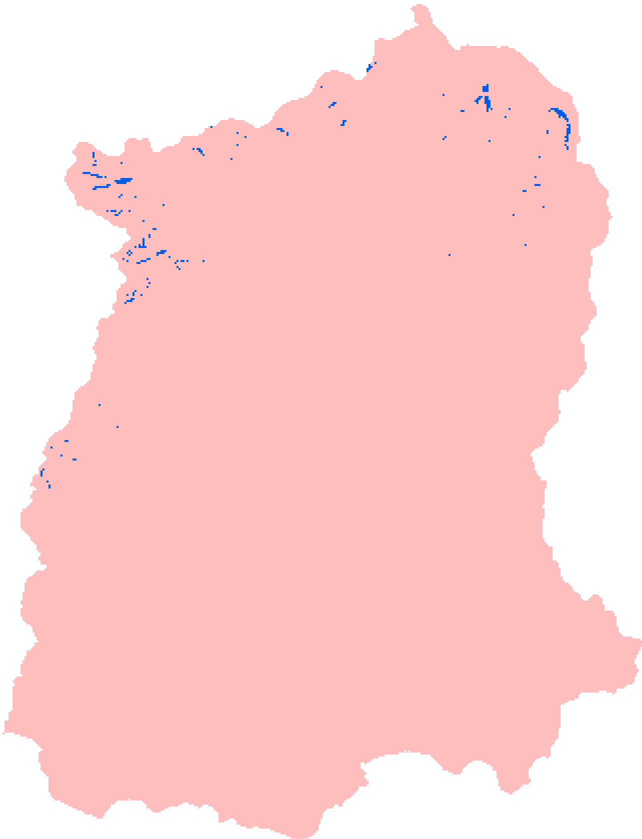

Figure 5.9.1 Extraction of Sikkim Lakes of Year 2018

## 5.10 AREA CALCULATION

Area is calculated from the polygons formed in the previous step. Area is calculated separately for all the years: 2000, 2005, 2010, 2012, 2016, 2017 and 2018. Calculation of area is the main objective of the work and then comparison is done on the basis of area change during these years.

Area is calculated with the help of specific functions of Arc Toolbox and used to calculate the area of all the polygons present in the Arc map.

### 5.10.1 Steps Performed For Area Calculation

In Arc toolbox → Utilities → Calculate area.

Input Raster: glaciers_2017_uned.shp

Output Raster: area_lakes_2017.shp

Then right click on the newly generated area file, choose the option editor toolbox → start editing then go back and click on :open attribute table" and new dialog box will open with list of all the lakes along with their lakes id and grid code. Grid codes are given as 0 and 1, the one with 0 are needed to be removed as they give the area which are not lakes.

In attribute table select the option "select by attribute" and select the "GRIDCODE" and write = 0, all the GRIDCODE with 0 will be automatically selected and apply this editing features and press "delete" all the lakes with grid code 0 will be deleted.

Export this attribute table to excel, in the form of text file and add the area of all the polygons.

**Figure 5.10.1 Area of Glacial Lakes of Sikkim of Year 2018**

## 5.11 ANALYSIS OF METEOROLOGICAL DATA

"Climate change" in the context of the intergovernmental climate change panel refers to a climate change that can be identified by changes in the mean and/or variability of its properties and that persists for an extended period of time, typically decades or longer. It relates to any climate change over time, either because of natural variation or because of human activity. As per the Climate Change Use Framework Convention of the United Nations, it relates to climate change that directly or indirectly attributes to human activity that alters the structure of the global atmosphere and is in relation to the natural climate variability observed over similar periods of time. Meteorological information plays a major role in glacier formation and ablation. The primary variables responsible for the modifications in glaciers are temperature and precipitation. Global warming is the primary factor for the rapid melting and retreat of glaciers in the Sikkim Himalayas.

In latest decades, climate variability has had significant effects on the lifecycle of the glacier in the Himalayan region. Many Sikkim Himalayan glaciers are leaving glacial lakes with growing intensity, which is in reality confirmed by the majority of researchers with the long-term impacts of climate change. Thinning and retreating glaciers in the Sikkim Himalayas led in the creation of fresh glacial lakes and the expansion of current ones owing to the accumulation of melt water behind loosely consolidated end moraine dams. Recent surveys conducted by Advanced Computing Development Centre (C-DAC), Pune and Sikkim State Council of Science & Technology, Gangtok, have shown that many natural lakes in the Sikkim Himalayan area have grown over the years revealing the effect of climate change on natural lakes and related dangers.

### 5.11.1 Steps Performed For Temperature And Rainfall Analysis

Temperature and rainfall information were acquired from the IMD site for an annual average period of 35 years from 1966-2000 and the graph was designed to observe rainfall and temperature variations during this period as the new variables play a very significant part in changing the region of glacial lakes.

### 5.11.2 Temperature Analysis

Data from the Indian Meteorological Department were gathered from 1966 to 2000 and graphs were used to observe the shift in mean mean rainfall and mean mean temperature. A chart has been plotted for each month and year to check or analyze the annual mean annual mean precipitation mean temperature change.

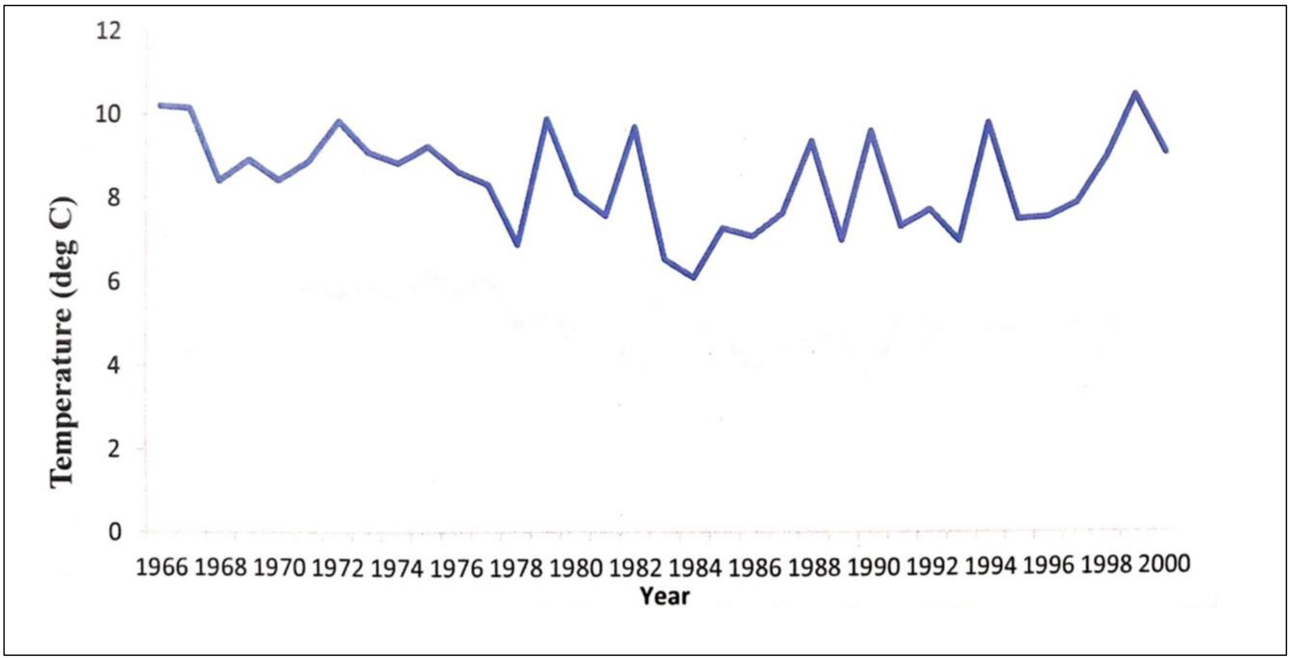


**Figure 5.11.1 Temperature Variation Graph of JAN from 1966-2000**

The minimum temperature was in 1983 was 6.5° C, while the maximum temperature was in 1999 was 10.5° C and the average temperature in that period was 8.41° C.

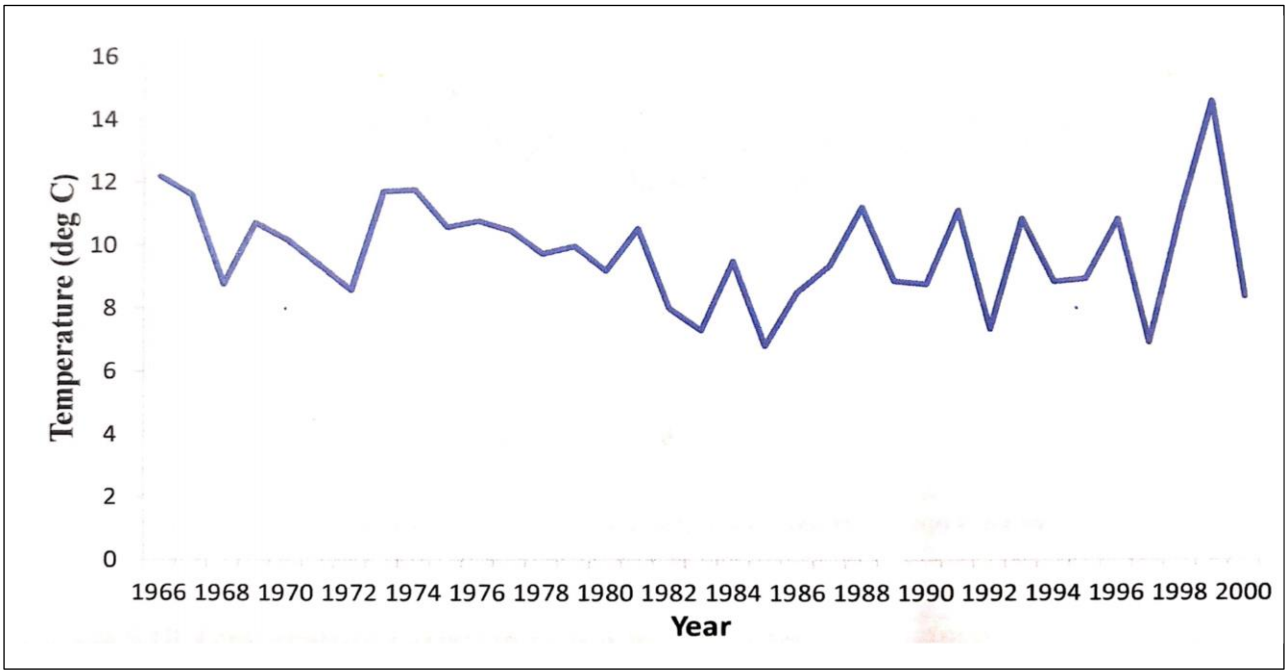


**Figure 5.11.2 Temperature Variation Graph of FEB from 1966-2000**

The minimum temperature was in 1985 was 6.75° C, while the maximum temperature was in 1999 was 14.55° C and the average temperature in that period was 9.77° C.

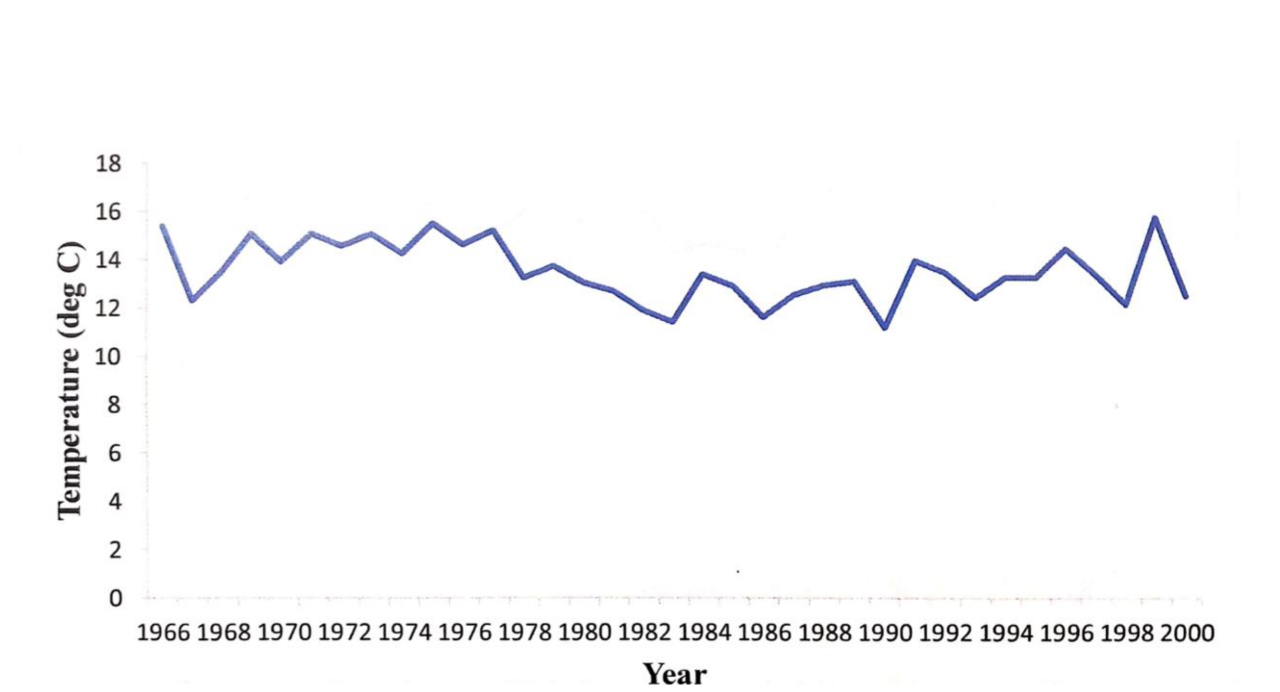


**Figure 5.11.3 Temperature Variation Graph of MAR from 1966-2000**

The minimum temperature was in 1990 was 11.2° C, while the maximum temperature was in 1999 was 15.75° C and the average temperature in that period was 13.51° C.

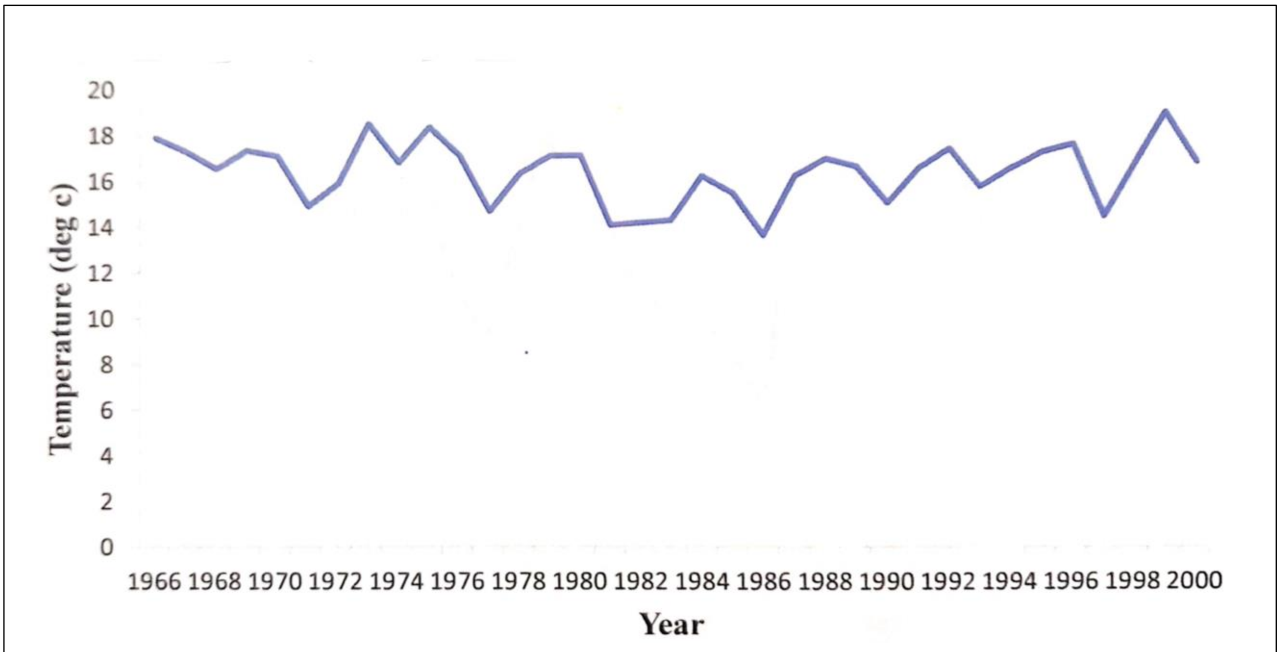


**Figure 5.11.4 Temperature Variation Graph of April from 1966-2000**

The minimum temperature was in 1986 was 13.5° C, while the maximum temperature was in 1999 was 18.75° C and the average temperature in that period was 16.29° C.

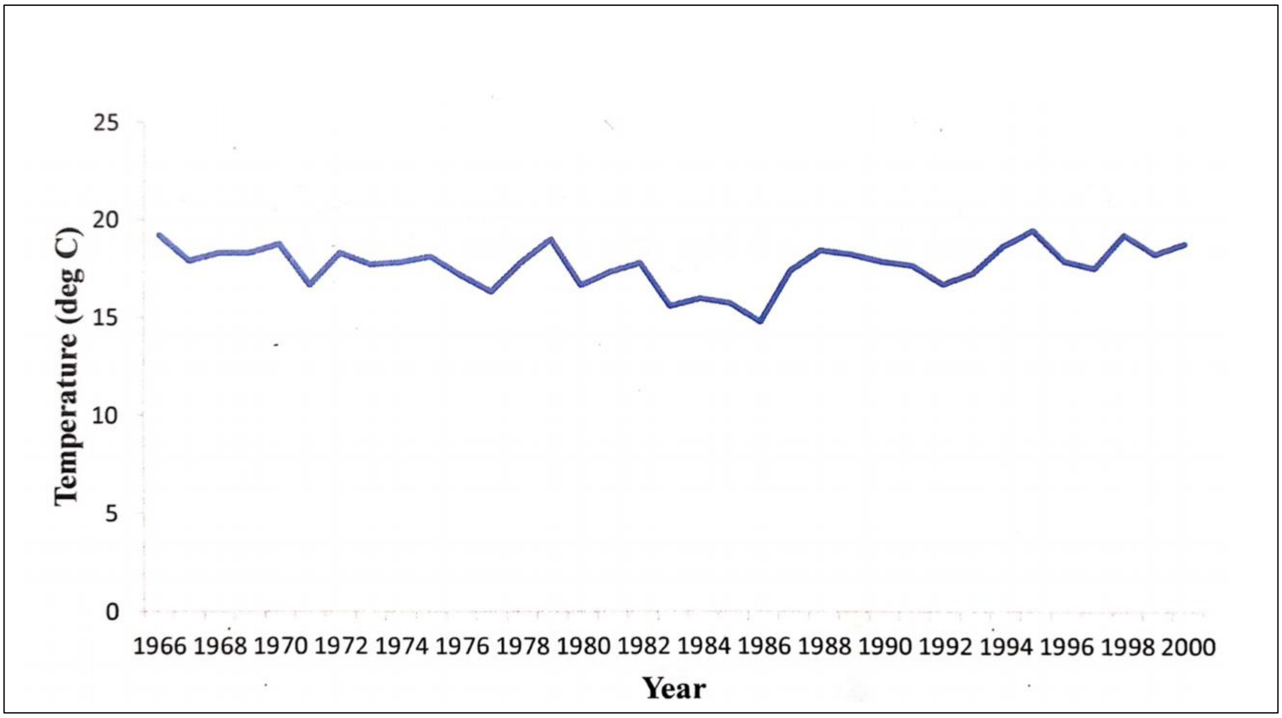


Figure 5.11.5 Temperature Variation Graph of MAY from 1966-2000

The minimum temperature was in 1986 was 13.5° C, while the maximum temperature was in 1999 was 18.75° C and the average temperature in that period was 16.29° C.

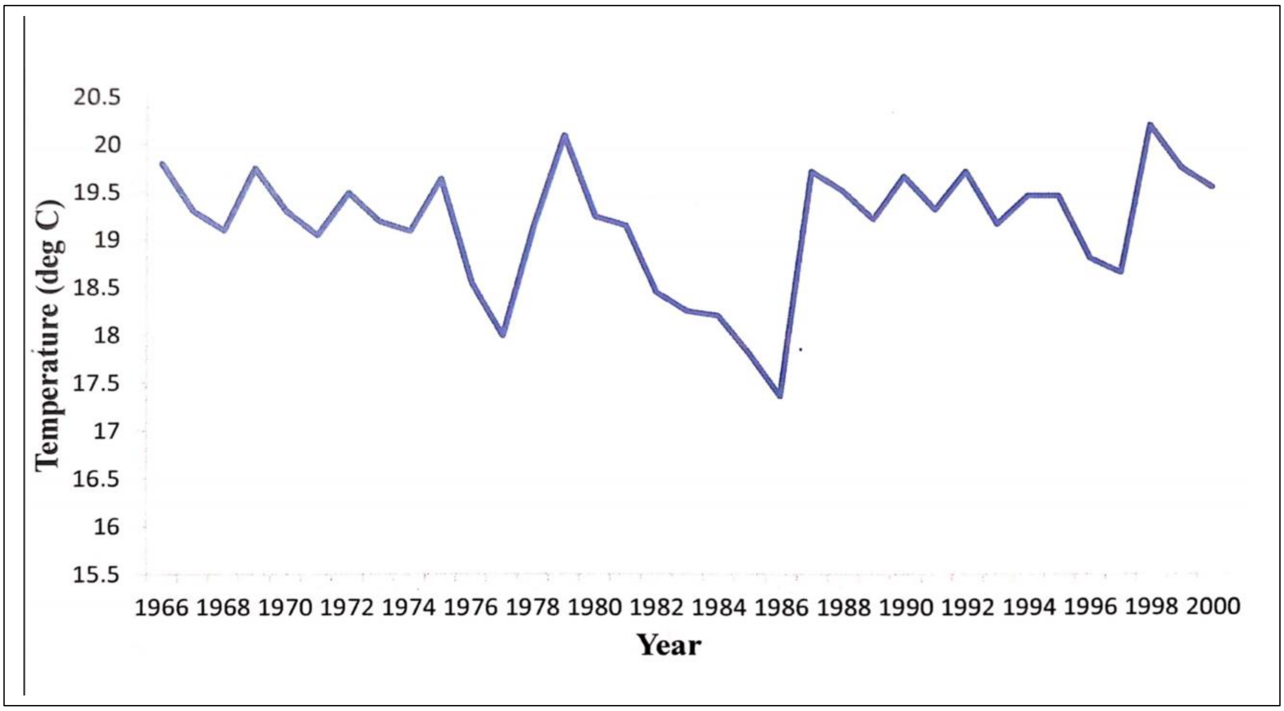


Figure 5.11.6 Temperature Variation Graph of JUNE from 1966-2000

The minimum temperature was in 1986 was 17.2° C, while the maximum temperature was in 1998 was 20.2° C and the average temperature in that period was 19.14° C.

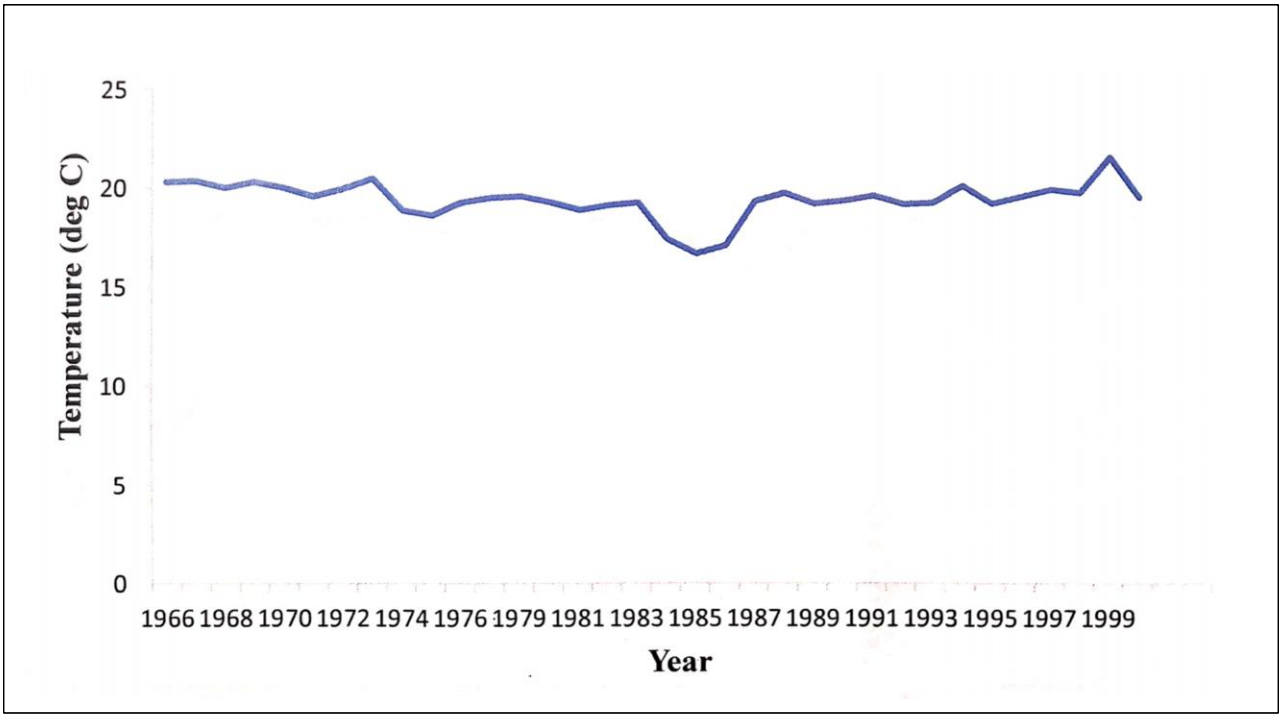


**Figure 5.11.7 Temperature Variation Graph of JULY from 1966-2000**

The minimum temperature was in 1986 was 17.1° C, while the maximum temperature was in 1998 was 21.5° C and the average temperature in that period was 19.39° C.

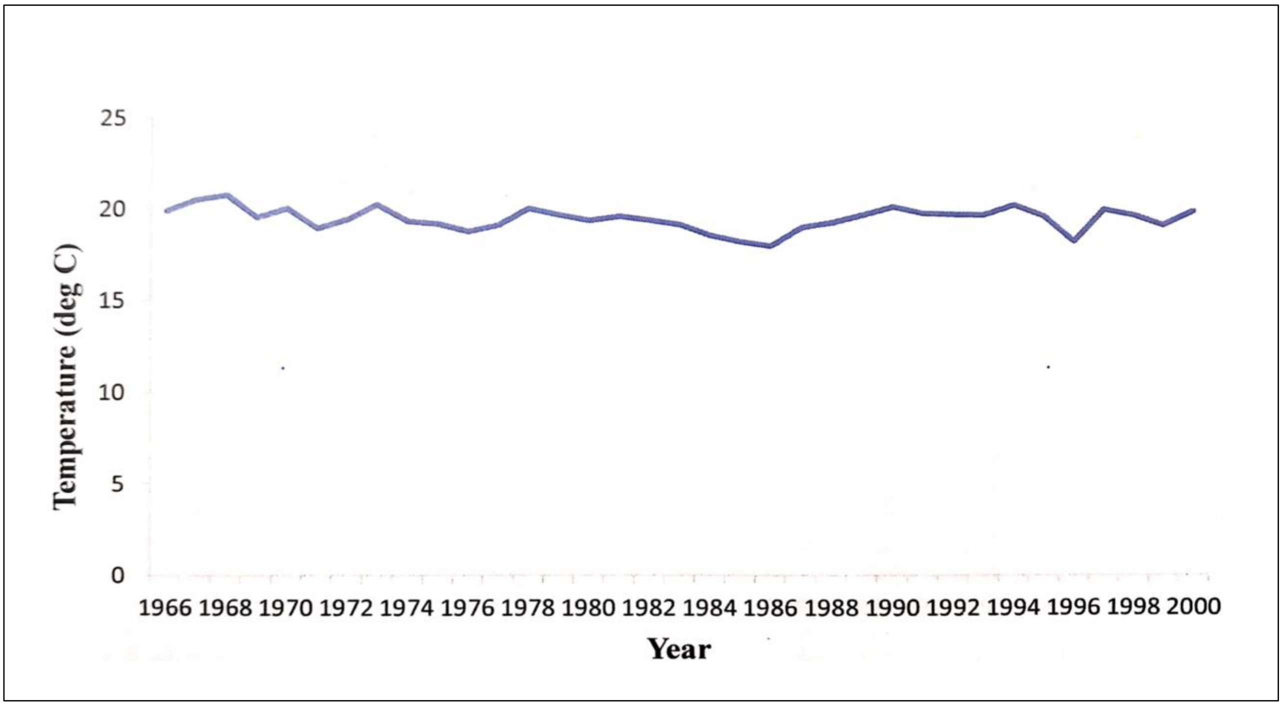


**Figure 5.11.8 Temperature Variation Graph of AUG from 1966-2000**

The minimum temperature was in 1986 was 17.9°C, while the maximum temperature was in 1994 was 20.1° C and the average temperature in that period was 19.4°C.

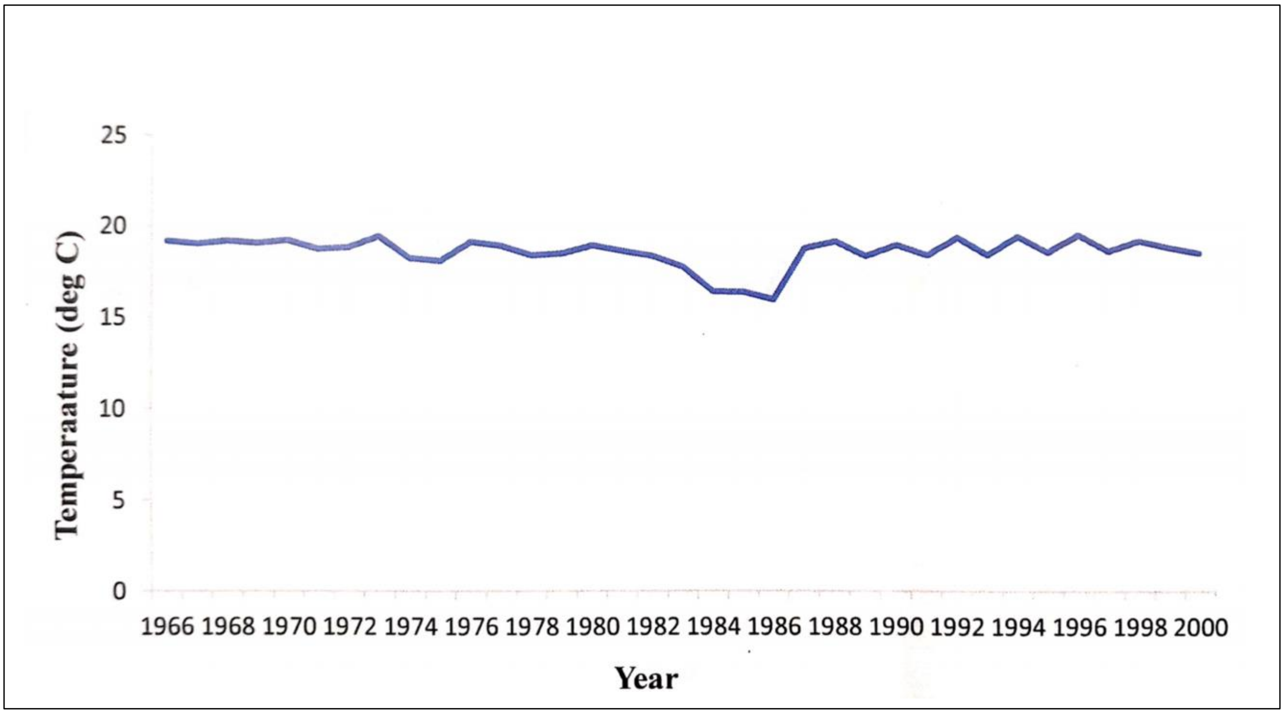


Figure 5.11.9 Temperature Variation Graph of SEP from 1966-2000

The minimum temperature was in 1986 was 16°C, while the maximum temperature was in 1994 was 19.4°C and the average temperature in that period was 18.5°C.

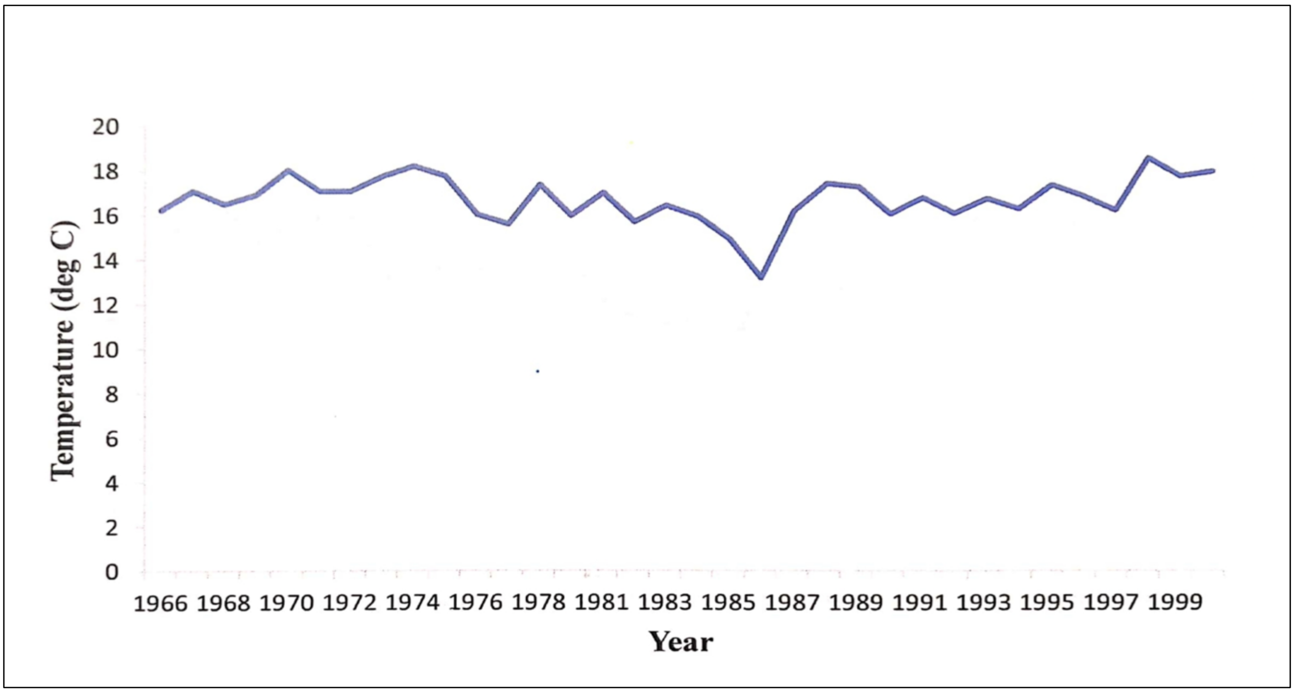


Figure 5.11.10 Temperature Variation Graph of OCT from 1966-2000

The minimum temperature was in 1986 was 13.1°C, while the maximum temperature was in 1998 was 18.3°C and the average temperature in that period was 16.6°C.

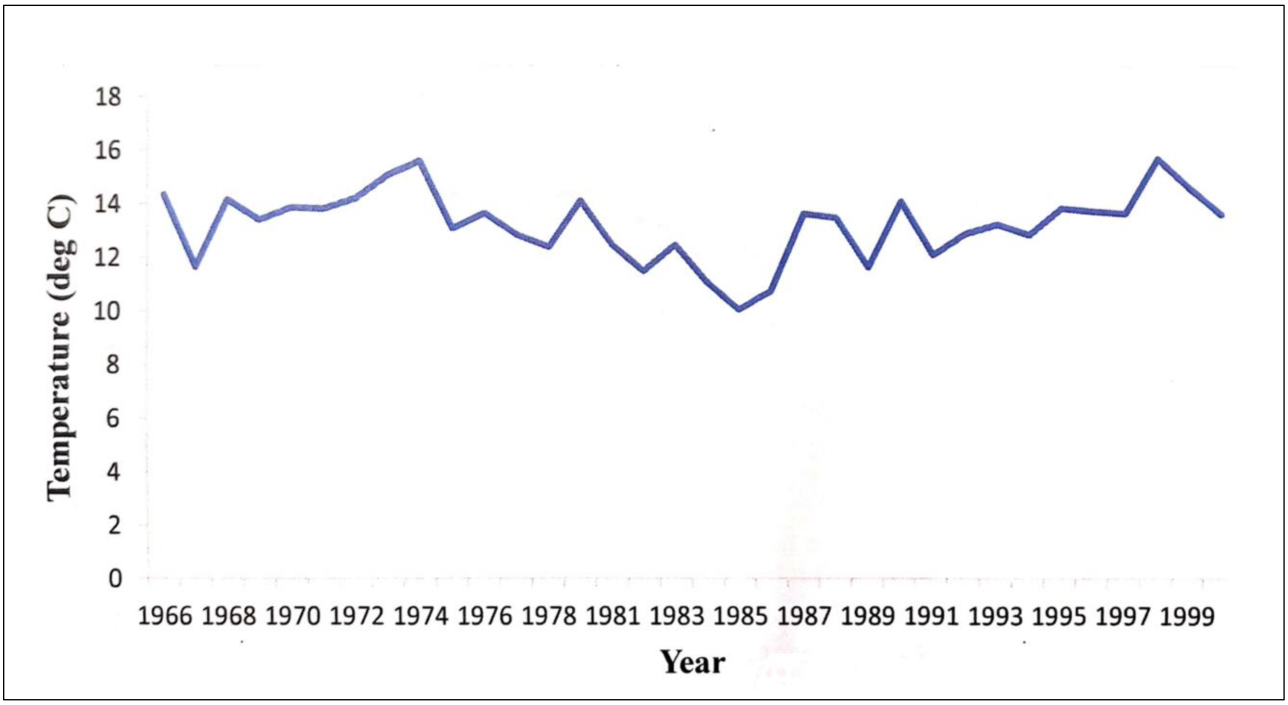


**Figure 5.11.11 Temperature Variation Graph of NOV from 1966-2000**

The minimum temperature was in 1985 was 10°C, while the maximum temperature was in 1998 was 15.7°C and the average temperature in that period was 13.2°C.

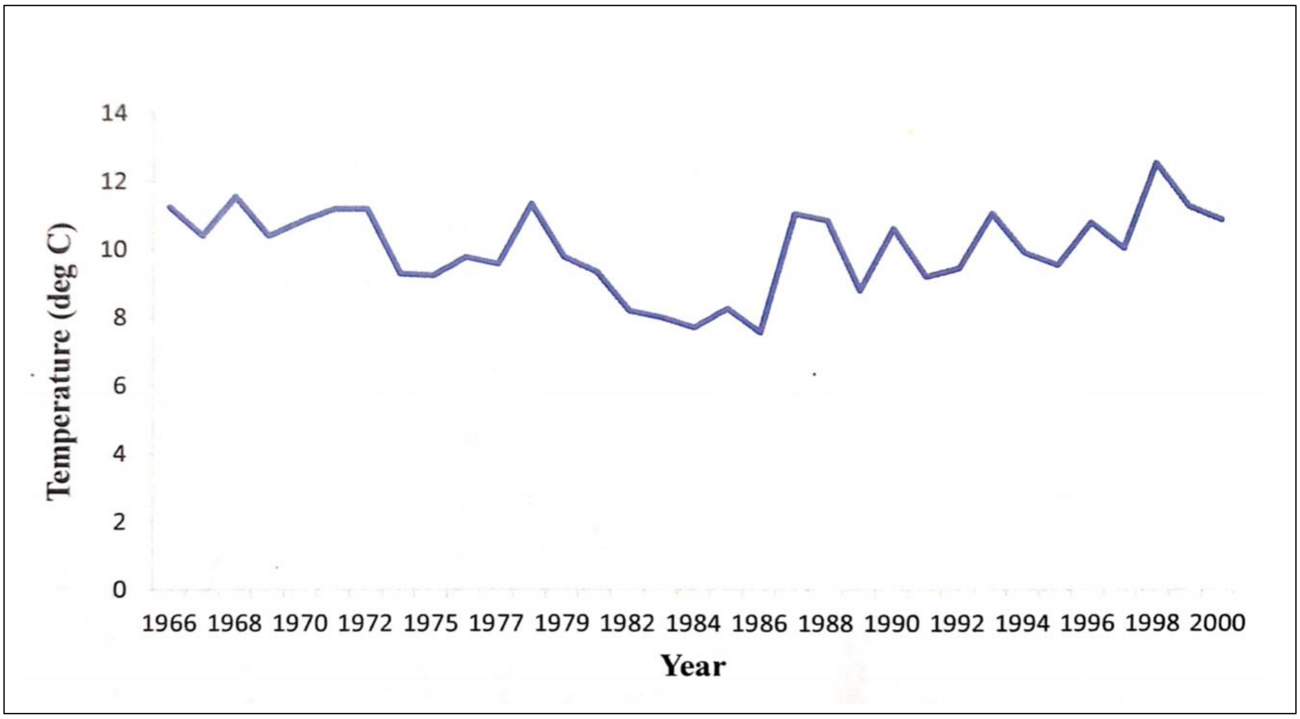


**Figure 5.11.12 Temperature Variation Graph of DEC from 1966-2000**

The minimum temperature was in 1986 was 7.5°C, while the maximum temperature was in 1998 was 12.5°C and the average temperature in that period was 10°C.

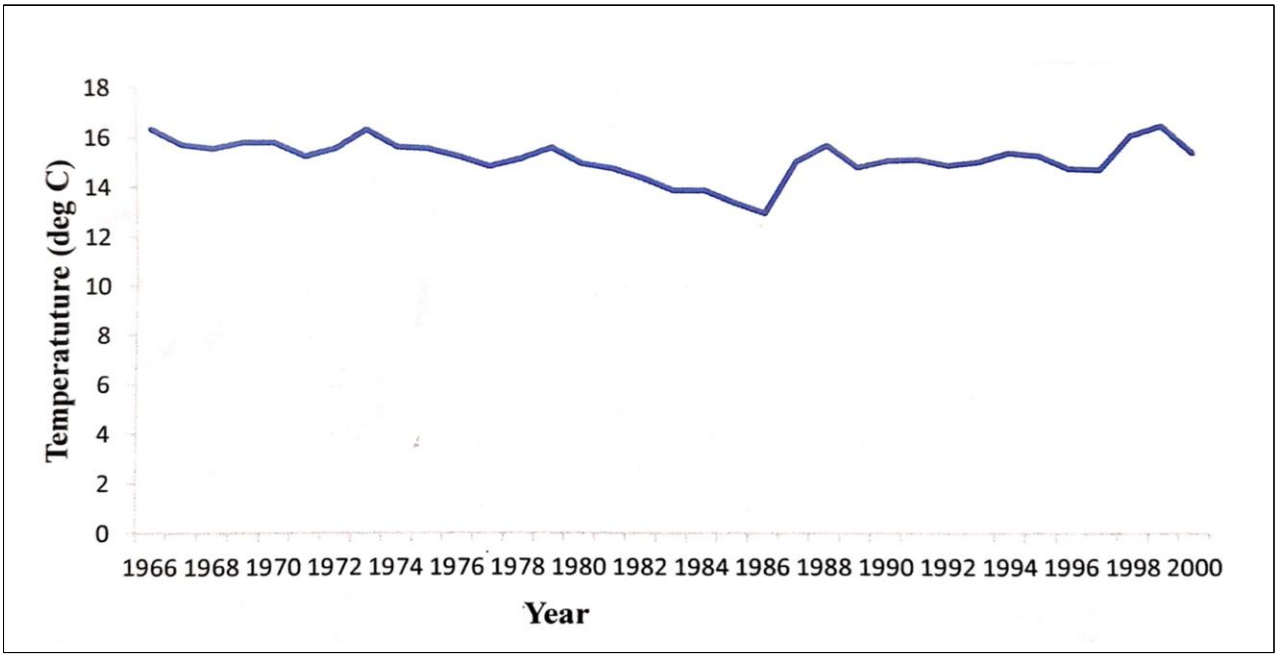


Figure 5.11.13 Annual Temperature Variation Graph from 1966-2000

The minimum temperature was in 1986 was 12.9°C, while the maximum temperature was in 1998 was 16.4°C and the average temperature in that period was 15.1°C

### 5.11.3 Rainfall Analysis

Rainfall data from the IMD system for the years 1966 to 2000 have been downloaded. Graphs are plotted separately for all the various months and years to analyze the rainfall variation.

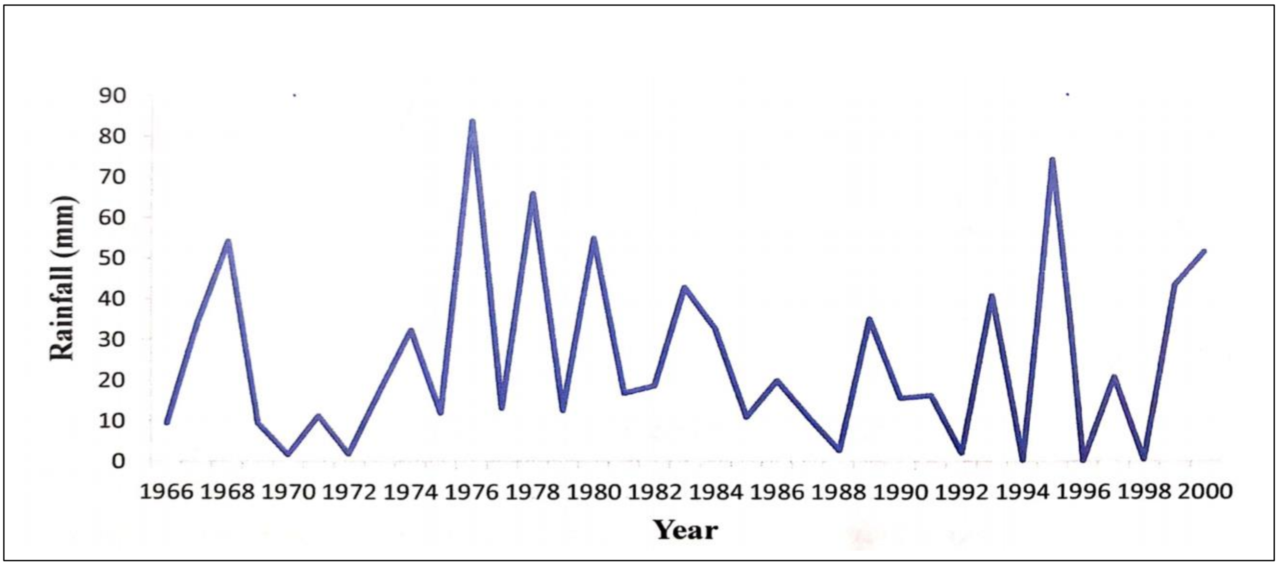


Figure 5.11.14 Rainfall Variation Graph of JAN from 1966-2000

The minimum rainfall was observed in 1969 as 0mm, while the maximum value of rainfall was observed in 1975 as 80.1mm and the average rainfall was 36.4mm during this time.

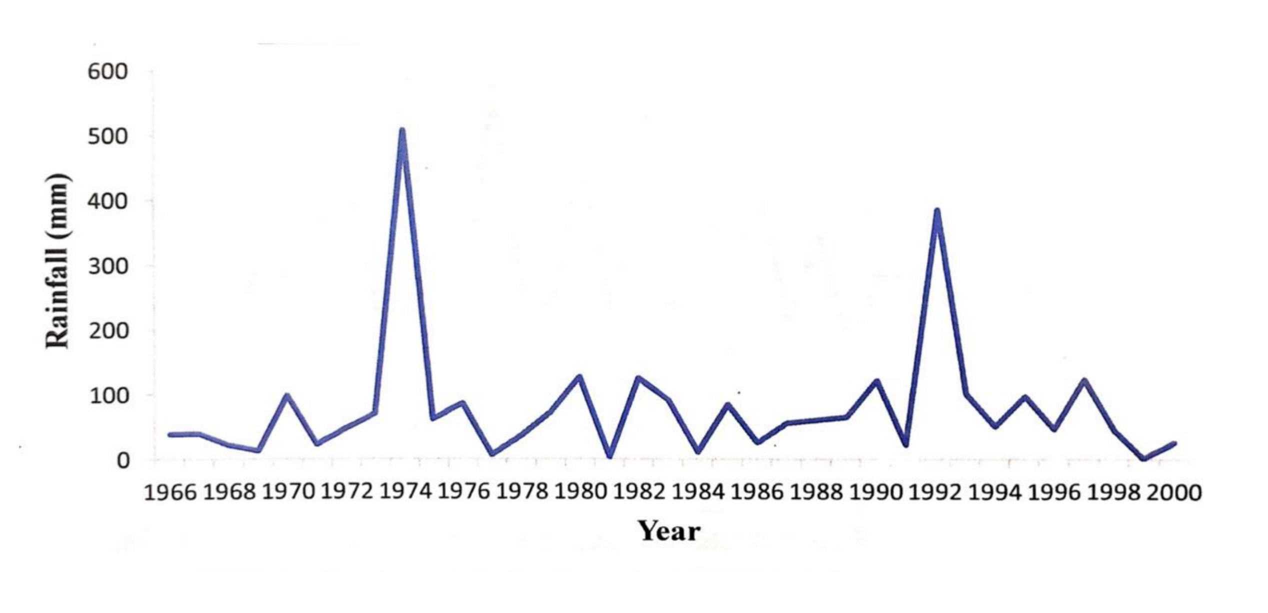


**Figure 5.11.15 Rainfall Variation Graph of FEB from 1966-2000**

The minimum rainfall was observed in 1969 as 1.2mm, while the maximum value of rainfall was observed in 1975 as 507.6mm and the average rainfall was 79.4mm during this time.

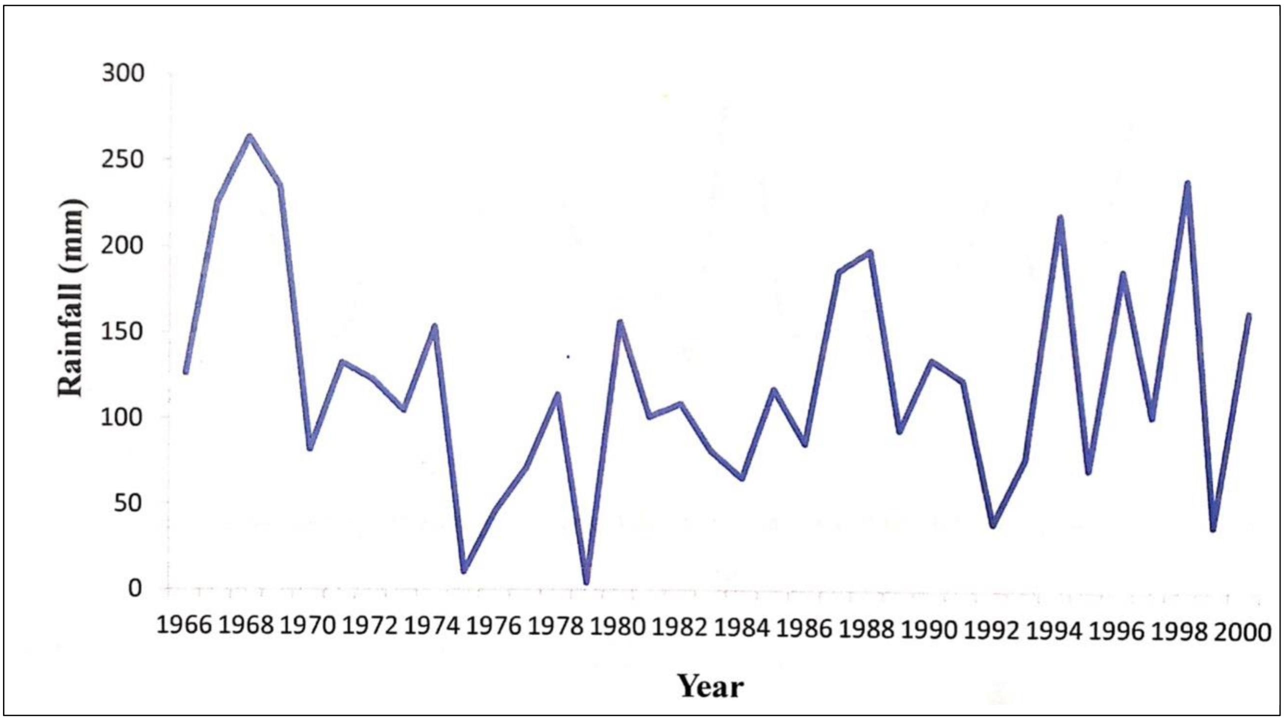


**Figure 5.11.16 Rainfall Variation Graph of MAR from 1966-2000**

The minimum rainfall was observed in 1979 as 4.3mm, while the maximum value of rainfall was observed in 1968 as 263.9mm and the average rainfall was 122.1mm during this time.

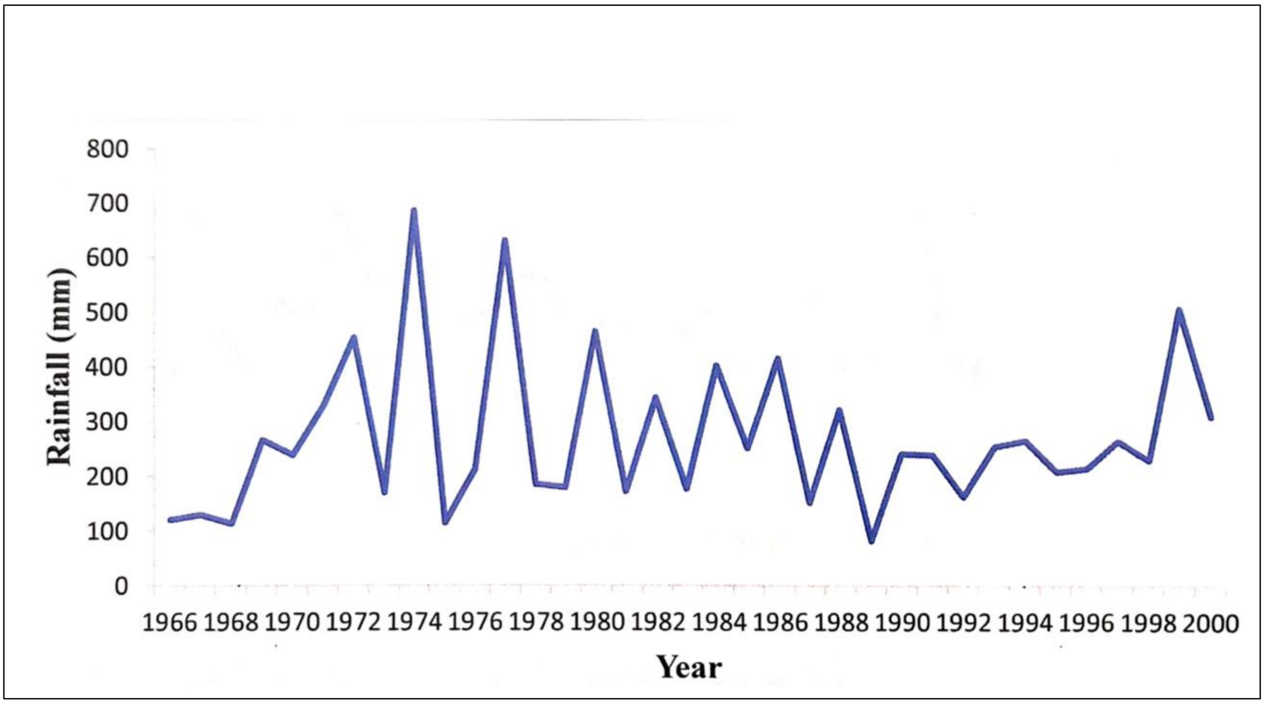


Figure 5.11.17 Rainfall Variation Graph of APRIL from 1966-2000

The minimum rainfall was observed in 1989 as 81.5mm, while the maximum value of rainfall was observed in 1999 as 504.8mm and the average rainfall was 270.9mm during this time.

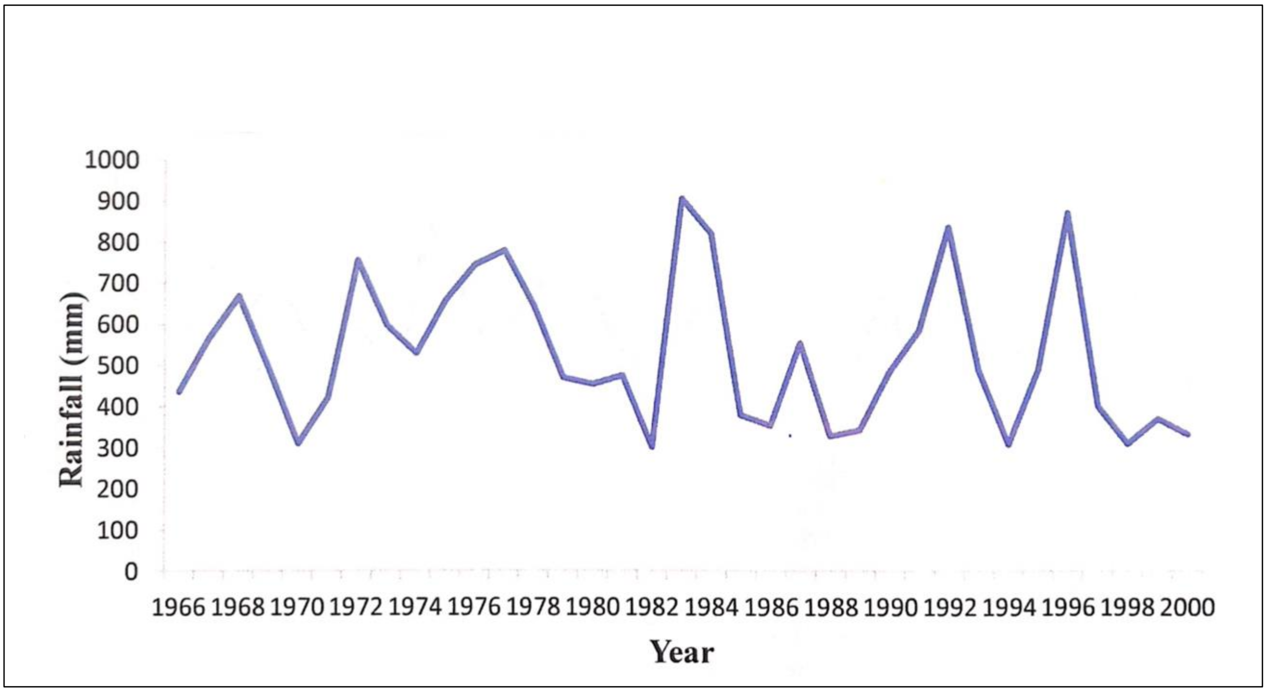


Figure 5.11.18 Rainfall Variation Graph of MAY from 1966-2000

The minimum rainfall was observed in 1970 as 309.6mm, while the maximum value of rainfall was observed in 1983 as 906.7mm and the average rainfall was 527.6mm during this time.

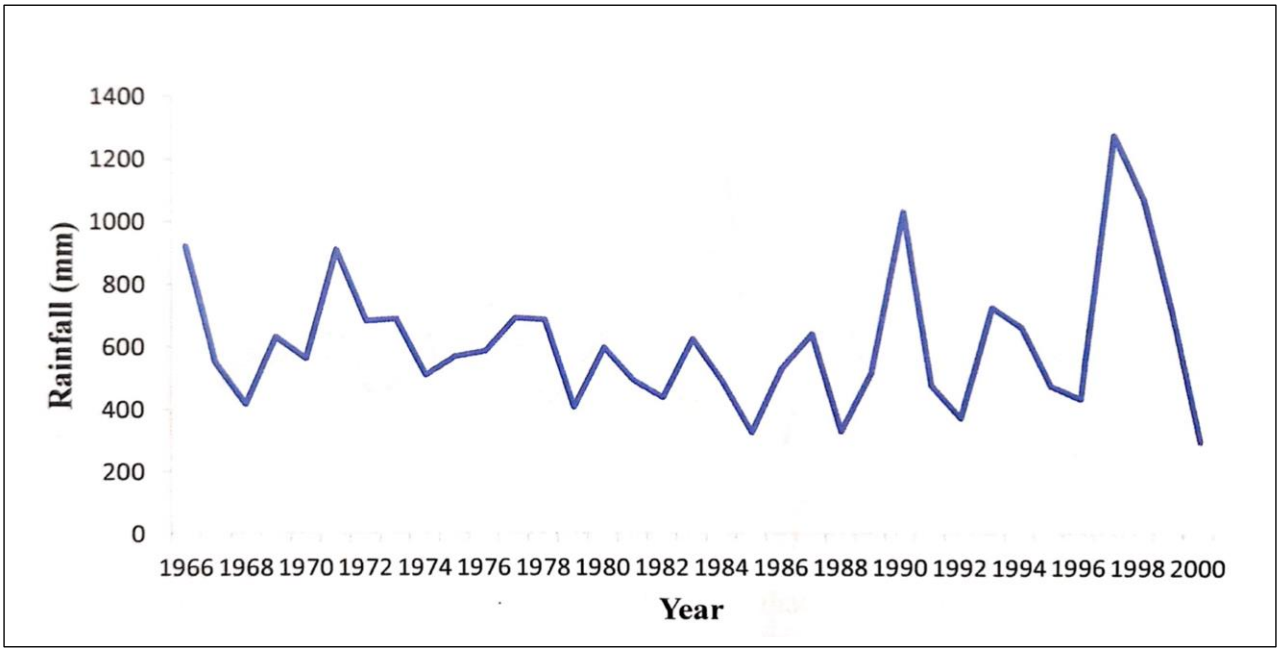


**Figure 5.11.19 Rainfall Variation Graph of JUNE from 1966-2000**

The minimum rainfall was observed in 2000 as 299.3mm, while the maximum value of rainfall was observed in 1997 as 1281.2mm and the average rainfall was 611.3mm during this time.

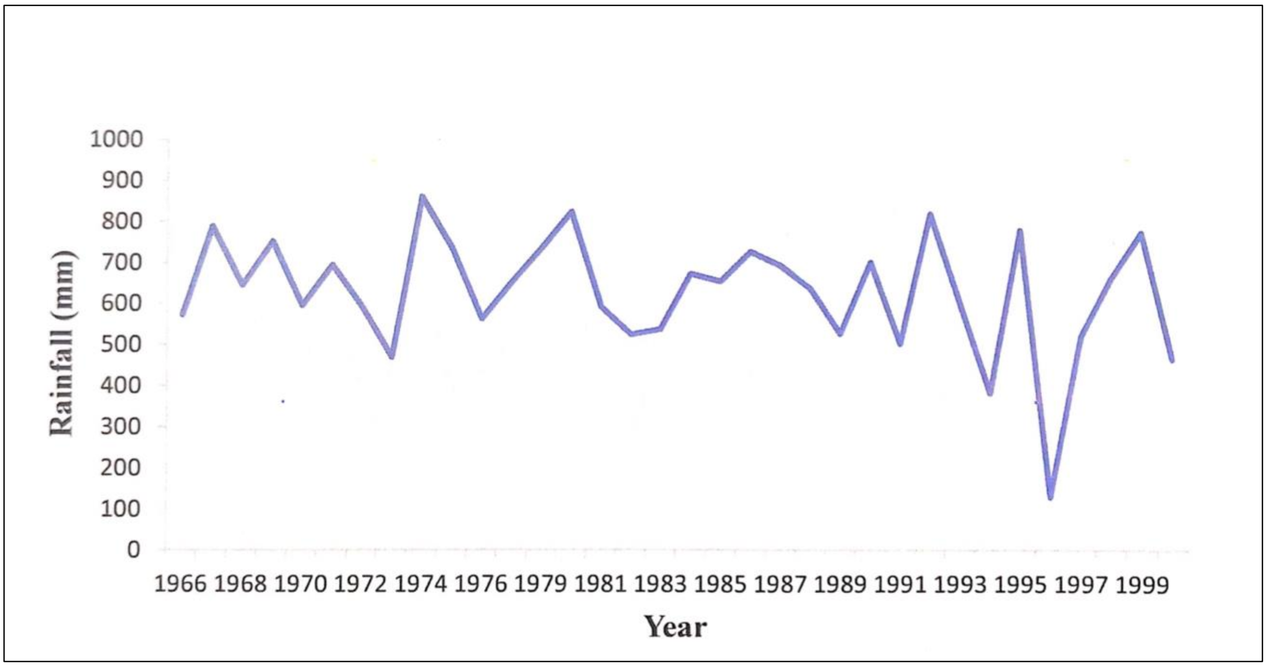


**Figure 5.11.20 Rainfall Variation Graph of JULY from 1966-2000**

The minimum rainfall was observed in 1984 as 3809mm, while the maximum value of rainfall was observed in 1967 as 788.5mm and the average rainfall was 628.5mm during this time.

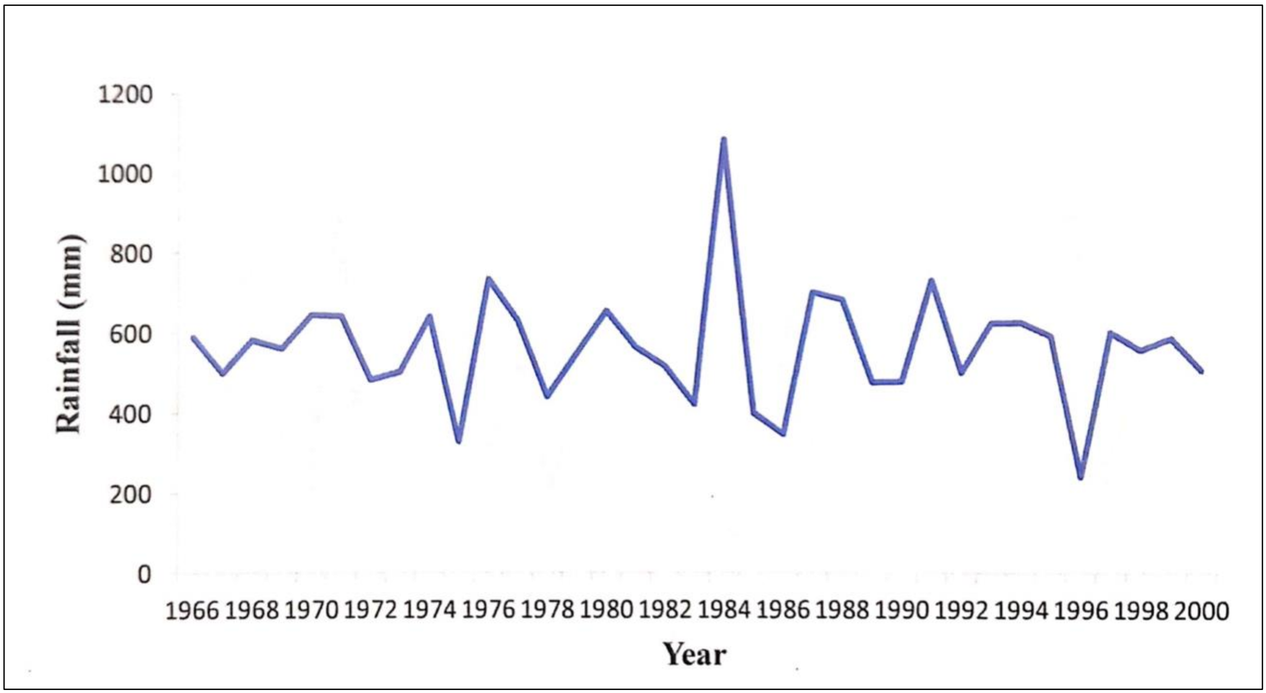


**Figure 5.11.21 Rainfall Variation Graph of AUG from 1966-2000**

The minimum rainfall was observed in 1996 as 239.7mm, while the maximum value of rainfall was observed in 1984 as 1088.2mm and the average rainfall was 563.21mm during this time.

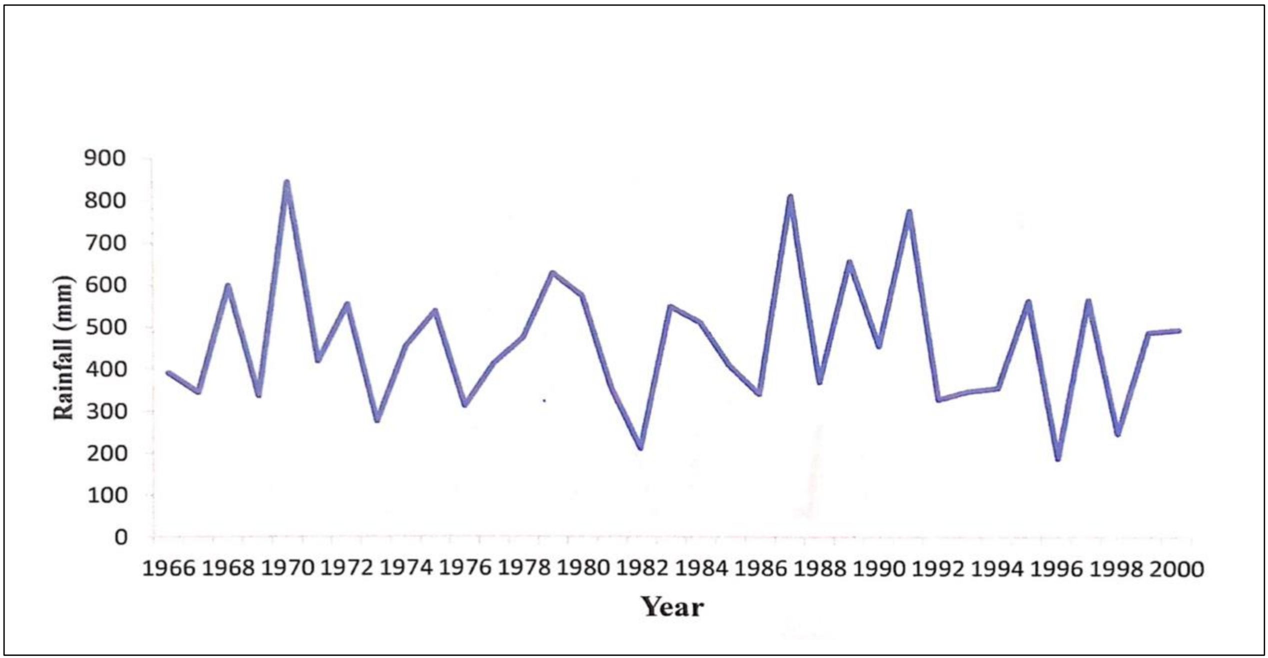


**Figure 5.11.22 Rainfall Variation Graph of SEP from 1966-2000**

The minimum rainfall was observed in 1996 as 188mm, while the maximum value of rainfall was observed in 1970 as 848.3mm and the average rainfall was 463.3mm during this time.

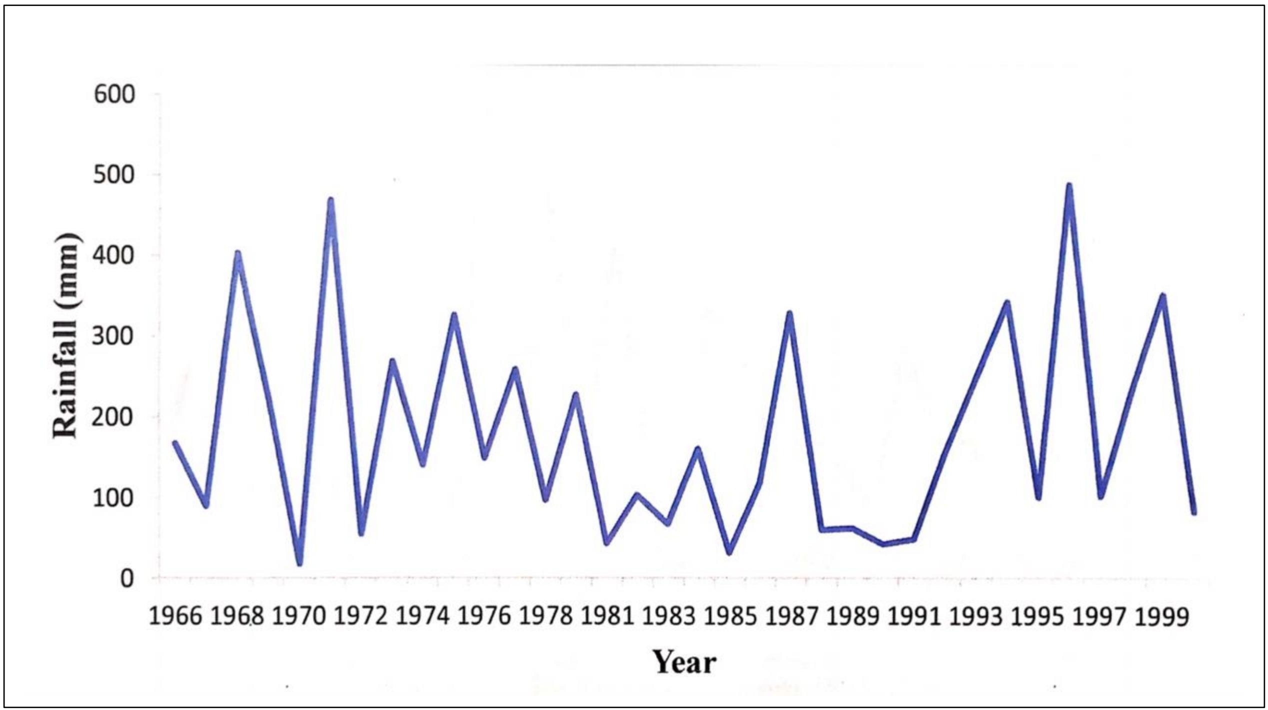


**Figure 5.11.23 Rainfall Variation Graph of OCT from 1966-2000**

The minimum rainfall was observed in 1970 as 17.3mm, while the maximum value of rainfall was observed in 1996 as 488mm and the average rainfall was 177.8mm during this time.

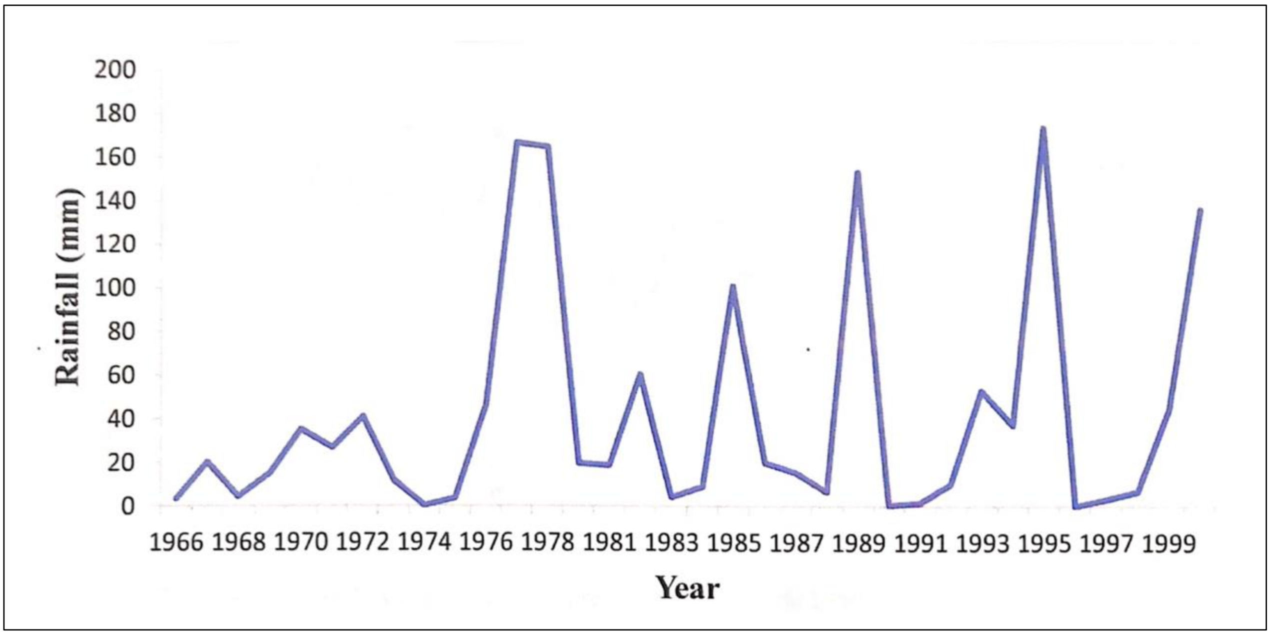


**Figure 5.11.24 Rainfall Variation Graph of NOV from 1966-2000**

The minimum rainfall was observed in 1996 as 0.2mm, while the maximum value of rainfall was observed in 1995 as 173.5mm and the average rainfall was 41.6mm during this time.

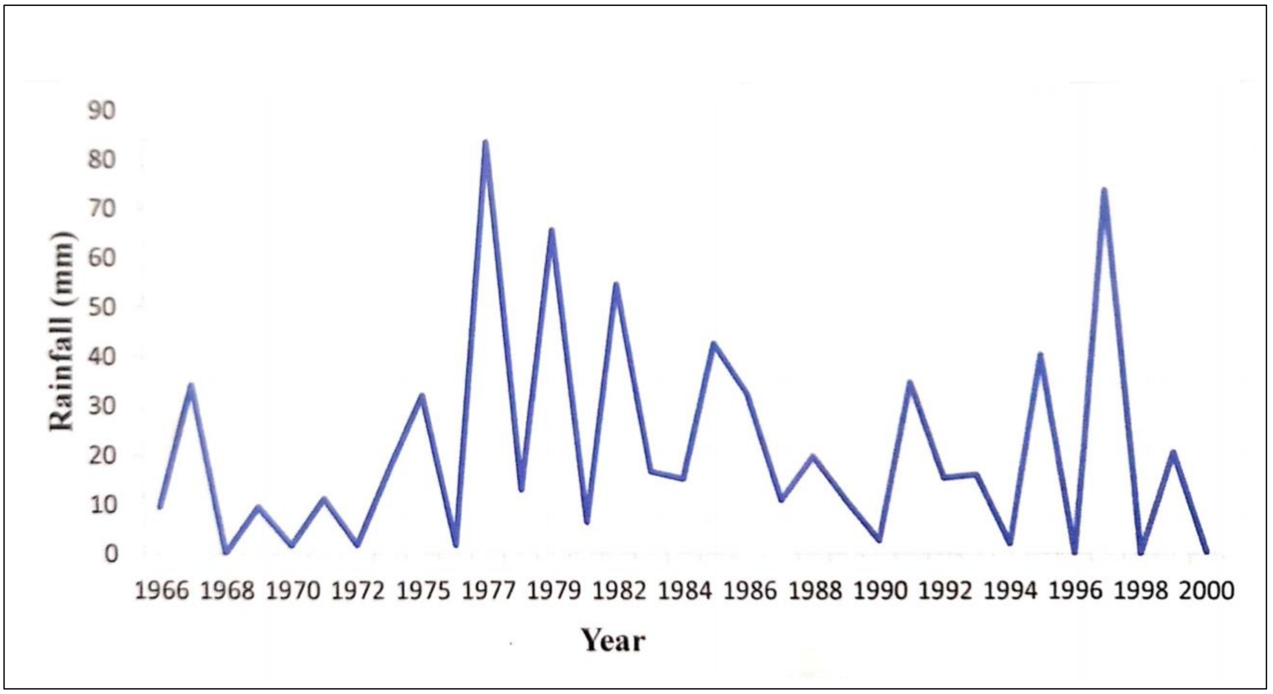


**Figure 5.11.25 Rainfall Variation Graph of DEC from 1966-2000**

The minimum rainfall was observed in 1968 as 0mm, while the maximum value of rainfall was observed in 1977 as 83.8mm and the average rainfall was 21.1mm during this time.

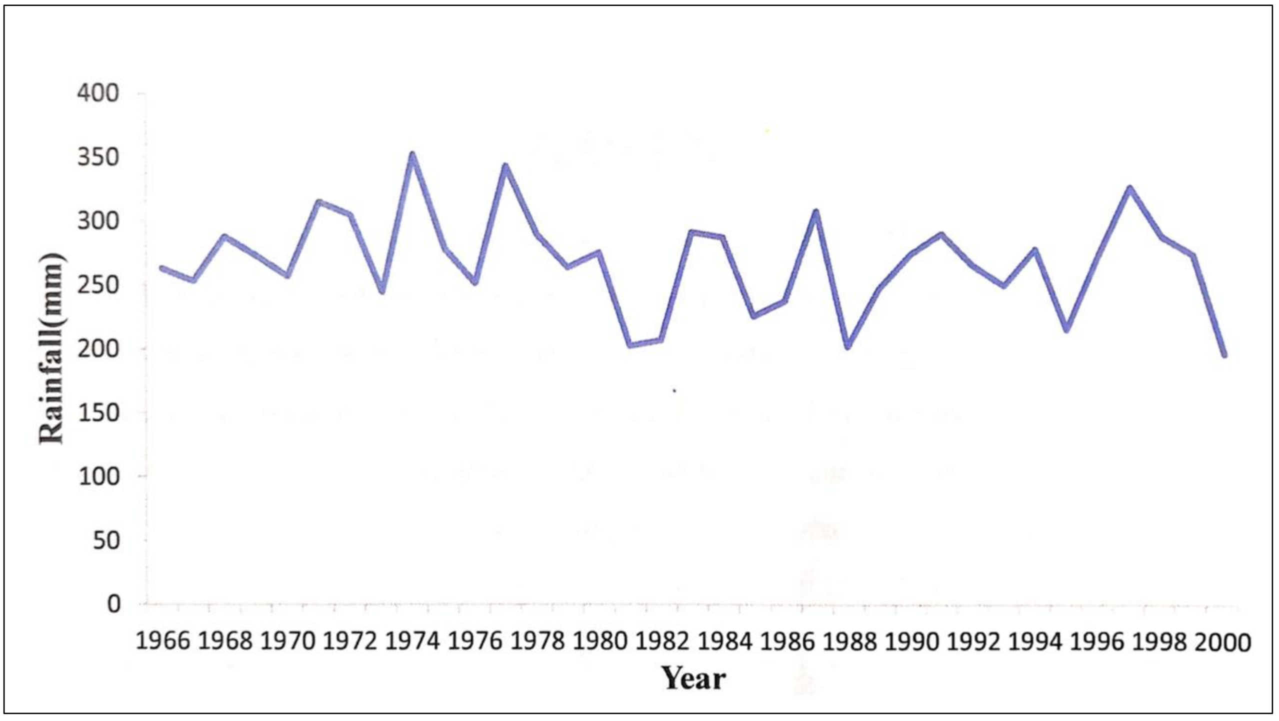


**Figure 5.11.26 Annual Average Rainfall Variation Graph from 1966-2000**

The minimum rainfall was observed in 2000 as 197mm, while the maximum value of rainfall was observed in 1974 as 353.6mm and the average rainfall was 269.2mm during this time.

# CHAPTER 6

# RESULTS & DISCUSSIONS

This study highlights the assessment of lakes present in the Sikkim Himalayan region for possible inferences of global climate change impacts in high mountains like the Himalaya. The study has been done with the help of remote sensing data obtained from Landsat Thematic Mapper and Indian Remote Sensing (IRS) satellite images. Data has been obtained from USGS (United States Geological Survey) system named Earth explorer for the year 2000, 2005, 2010, 2012, 2016, 2017 and 2018. Area for all the years has been calculated by performing various tasks in ArcGIS.

The total glacial lakes area was observed as 8.49 $Km^2$ in 2000, 8.91 $Km^2$ in 2005, 9.95 $Km^2$ in 2010, 12.78 $Km^2$ in 2012, 17.2 $Km^2$ in 2016, 18.9 $km^2$ in 2017 and 19.6 $Km^2$ in 2018. With the area calculated for all the years it is observed that with the passage of time area of glacial lakes in the Sikkim Himalayan region is continuously increasing. The area coverage of glacial lakes increased during the period of 2000 to 2018. The overall area of glacial lakes in the Sikkim region was 31.24 ±2.36 $km^2$ as reported by Aparna et.al. till 2017. The percentage change in the area of glacial lakes is 3.77% during 2017 to 2018 whereas the overall change in the area of glacial lakes from 2000 to 2018 is 130.8%( i.e 11.11 $Km^2$). Glacial lakes area is increasing in size year by year because the falling snow is not able to replace the melting of ice. Since glacial lakes are one of the most reliable climate indicators which indicated the change in the climate could be due to anthropogenic activities.

### Table 6.1 Glacial Lakes Area

| YEAR | AREA ($Km^2$) |
|---|---|
| 1965 | 5.627 (Kulkarni et al. 2010) |
| 1976 | 6.073 (Kulkarni et al. 2010) |
| 1989 | 7.874 (Kulkarni et al. 2010) |
| 1997 | 8.37 (Kulkarni et al. 2010) |
| 2000 | 8.49 (this study) |
| 2005 | 8.91 (this study) |
| 2010 | 9.95 (this study) |
| 2012 | 12.78 (this study) |
| 2016 | 17.2 (this study) |
| 2017 | 18.9 (this study) |
| 2018 | 19.6 (this study) |

Glaciers are the coolers of the planet earth and as the study shows that glacial lakes area are increasing which means glaciers area are decreasing and that is not good for our natural environment and for the human race as it also hinders the environment and brings many natural disaster with them. The number and area of glacial lakes are shown in the table above.

# CHAPTER 7

# CONCLUSION

Area of glacial lakes in the Sikkim Himalayan region was calculated for years 2000, 2005, 2010, 2012, 2016, 2017 and 2018. Landsat data was used to carry out the study. Automatic delineation methods were used to derive the results. As per the results of the study, the region has shown to have gain 130.8% of area from 2000 till 2018. Results calculated might vary with actual situation of depletion of area. The variation might occur as per resolution problem in data, presence of debris presents in the glacial lakes, the shadows of the mountains and cloud cover (which could not be classified very efficiently).

Since temperature and rainfall plays a very significant role in changing in climatic conditions and these climatic changes are responsible for increase in area of glacial lakes. So, temperature and rainfall data taken from IMD website was analysed for years 1966-2000. The average value of temperature from 1966-2000 was found to be 15.1 whereas the average value of rainfall from 1966-2000 was found to be 269.22 mm. The observed value of temperature was found to be very less as compared to temperature values now a days, 'Industrial revolution' is mentioned as the main cause of this rise in average temperature in many researches done earlier.

According to the results given out by World Glacier Monitoring Service, the UN Environment programme declared that around the world glaciers are melting rapidly which in turn cause in increase in the size of glacial lakes. Mainly recent research had revealed that the average rate of formation in the area of glacial lakes had increased and it is definitely a major cause of concern for whole world. It had been observed in the research that glacial lakes area have increased over the past centuries. The prime reason for this increase in area of glacial lakes is rapid industrialisation which in turn has caused global warming is the prime culprit of formation of these glacial lakes.

Formation of these glacial lakes and increase in the area of these glacial lakes can cause the stream and rivers to overflow and also a huge deposition of the melted water is getting accumulated in the mountainous region, which will outburst when this melted water will cross its certain limit. These GLOFs are very dangerous and can occur at any time in future.

This thesis is a kind of warning for all of us to anyhow control the cause of global warming, so as to preserve the nature and control the adverse climatic changes in the atmosphere. Government as well as individual should work at their levels to control pollution which is directly or indirectly responsible for global warming.

# CHAPTER 8

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