TOPIC- ASSESSING THE IMPACT OF CLIMATIC VARIABLES ON MIZORAM VEGETATION USING REMOTE SENSING

ABSTRACT

This study aims to evaluate the impact of climatic variables on vegetation in the state of Mizoram, India, using remote sensing data. Remote sensing imagery, specifically satellite data, offers a valuable tool for monitoring and analysing vegetation dynamics over large areas. The research focuses on investigating the relationship between climatic variables and vegetation health to gain insights into the response of Mizoram's vegetation to environmental changes. Data from 1982 to 2019 was utilized, encompassing variables such as Precipitation, Temperature, Vapor Pressure, ENSO, IOD, etc. The study period was divided into four segments for temporal analysis. Missing data gaps were addressed through Cubic Spline Interpolation. Results indicate that average temperatures had a minimal impact on vegetation throughout the study period, while rainfall exhibited a profound influence. ENSO displayed significant effects on vegetation from 1982 to 2002 but diminished thereafter, whereas the impact of IOD became more pronounced in later years. Furthermore, certain relationships demonstrated temporal shifts. Additionally, we explored the correlation between Aizawl's population and the NDVI of Aizawl to assess the impact of an increasing population on vegetation. These findings contribute to the understanding of Mizoram's vegetation dynamics in response to abiotic variables. It is important to acknowledge potential errors in satellite data collection, such as cloud cover and technical issues, as well as interpolation errors in the NDVI data. This study provides a foundation for further investigations into Mizoram's vegetation and the influence of abiotic factors.

Keywords: Mizoram, vegetation dynamics, climatic variables, remote sensing, satellite data, NDVI, precipitation, temperature, Vapor Pressure, ENSO, IOD, temporal analysis, population, abiotic variables, cloud cover, technical issues, interpolation errors

INTRODUCTION

According to the definition given by the Food and Agriculture Organization (FAO), forest is land spanning more than 0.5 hectares with trees higher than 5 meters and canopy cover of more than 10 percent. The world's total forest area, as given in FAO's global assessment report, is over 4 billion hectares, or 31 percent of total available land. Forest ecosystems provide a wide range of beneficial ecosystem services, such as climate regulation, the production of essential materials for nourishment, and a reduction in the effects of natural hazards. They also play significant roles in the protection of the world's biodiversity (Estoque et al., 2022). Globally, forests store large amounts of carbon sequestered from the atmosphere and retained in living and dead biomass and soil. Biodiversity is incredibly abundant in forests. Two-thirds of all land-based organisms are thought to reside in forests or rely on them for existence. Approximately 1.75 million species of plants, animals, and fungi are known at this time. There may, however, be up to 100 million species altogether, the majority of which are found in tropical rainforests.*(*INTERNATIONAL DAY FOR BIOLOGICAL DIVERSITY FOREST BIODIVERSITY Earth's Living Treasure*, 2011)*

It has become increasingly obvious that the climate is changing globally over the past 20 years. This point was made clear in the 1990 publication of the first assessment report of the Intergovernmental Panel on Climate Change (IPCC). Since then, its follow-up studies have continued to offer more and more convincing evidence that human-induced climate change has had a significant impact on human societies and ecosystems. It is evident that Climate change has had a significant impact on the Forest. Ecological predictions of the impact that climate change might have on forests are generally based on the outputs of General Circulation Models (GCMs). As a result of warming, almost all GCMs predict a rise in global precipitation, but the pattern of regional increases and declines in precipitation is more complicated (for instance, midcontinental regions could become much drier). Furthermore, the degree of temperature change is probably going to be less toward the equator and increase toward the poles.(*FOREST IMPACT ON CLIMATE CHANGE*, n.d.).

India, one of the seven biodiversity hotspots of the world, accounts for 2 percent of the total forest area in the world. They cover around 21 percent of the country's total land area. It has been observed that changes in climatic variables such as rainfall, temperature, etc. have a significant impact on the forest vegetation, especially at high and moderate altitudes in India.(Al Balasmeh & Karmaker, 2020) . In recent years, According to IMD, there has been a significant reduction in Indian Summer Monsoon Rainfall in North-East India. It can have a significant impact on the vegetation of northeast India (Saikia, 2009). India's average temperature has risen by around 0.7 degrees Celsius between 1901 and 2018. This rise in temperature is largely due to GHG-induced warming, with forcing from anthropogenic aerosols and changes in Land use and land cover slightly offsetting it(Krishnan et al., n.d.). These changes are causing a significant rise in drought and flood situations in India. It is also seen that during ENSO warm events, vegetation in some tropical regions, like India, has been degraded (Yan et al., 2021). Due to climate change, ENSO processes and feedbacks are impacted, which in turn leads to changes in the characteristic amplitude or frequency of ENSO events (Collins et al., n.d.). Due to these changes in ENSO, vegetation is also affected, especially in tropical regions like India and Malaysia. In recent years, there has been an increase in the intensity and frequency of forest fire events, which is believed to be due to climate change. There has been a significant loss of Vegetation due to the forest fire (*CliMAtE ChAnGE's RolE in WorsEninG ForEst FirEs*, n.d.).

It is also observed that ENSO (NINO3, NINO3.4, and NINO4), IOD, and PDO have a significant impact on Indian Summer Monsoon Rainfall. In Positive El-NINO years, it has been observed that there has been a decrease in ISMR, whereas in Negative ENSO (La-NINA) years, there has been an increase in ISMR.(Pothapakula et al., 2020). The Indian Ocean Dipole had a strong correlation with the ISMR until around 1967. After 1967, the correlation drops abruptly. In contrast, NINO3 has a strong negative correlation with the ISMR from the 1967s to the 1977s. After the 1977s, ENSO and ISMR have a weak correlation, whereas with IOD, it has increased very rapidly. It was also seen that the IOD-ISMR relationship rises, whereas the ENSO-ISMR relationship weakens. (Ashok et al., 2001).

The ISMR for Northeast India (NEI) is quite different from rest of India. It has experienced a declining trend in summer rainfall during the last 4–5 decades. It was observed that IOD and ENSO had a high correlation with the ISMR of NEI. Positive IOD has a negative correlation with summer monsoon rainfall over the region, whereas with El Nino, the correlation was found to be positive(Saha et al., 2021).

It was also observed that PDO also has a significant impact on Summer Monsoon Rainfall over Northeast India. It shows a strong correlation with Indian Summer Monsoon Rainfall on an inter-annual timescale but a weak corelation when observed on a decadal timescale.(Singh et al., 2020). It was also observed that Sea surface Temperatures have a significant correlation with Indian Summer Monsoon Rainfall at seasonal, monthly, and daily time scales. (Goswami et al., 2022). It can also explain the rainfall deficit with an increase in sea temperatures due to Global warming.

There has also been a significant increase in annual and seasonal maximum temperatures in Northeast India. There is also a significant increase in the annual mean temperature in the region. The minimum temperature was also found t····o have increased throughout the time period 1901–2003.(Deka et al., 2009). These changes can have an impact on the vegetation in the region. Land use changes and institutional frameworks are also reasons for changes in vegetation in the region.

METHODOLOGY

1. STUDY AREA

Mizoram is a hilly state in Northeast India surrounded by Manipur (northeast), Assam (north), and Tripura (west) on the domestic front and Myanmar (east to southeast) and Bangladesh (west to southwest) internationally. The total geographical area of Mizoram is around 21,087 sq. km. It lies in the latitude range of 21°58' N to 24°35' N and the longitude range of 92°15' E to 93°29' E. It comprises several hills with altitudes ranging from 21m (Tlabung) to 2157m (Phawngpui). The Tropic of Cancer passes divide the state in 2 parts.

The state falls within a region (tropical to subtropical) that receives heavy rainfall with an average of 2500 mm to 3000 mm every year. The climate is pleasant, with an average of 11 to 21°C during the winter and 20 to 30°C during the summer (Lallianthanga, n.d.). Due to the topographic conditions, the state is inclined to suffer heavily if there are abnormal changes in climate variability as well as the long-term climate pattern.

According to Indian State of Forest Report 2021, of the total geographical area, forest cover 84.53% of which very dense forest account for 157 sq. kms and rest are moderately dense and open forests. These Forests are classified into 6 types (Singh et al. (2002))

1. Tropical Wet Evergreen Forest
2. Montane sub-tropical Forest
3. Temperate Forests
4. Bamboo Forests
5. Quercus Forests
6. Jhumland

The tropical wet evergreen forest and semi evergreen forest are one of the major types of forests found in state with very rich flora and fauna. These forests are very vulnerable to the ongoing

Global Climate Change. Shifting Cultivation is most prominent here and most of the families are dependent on it.

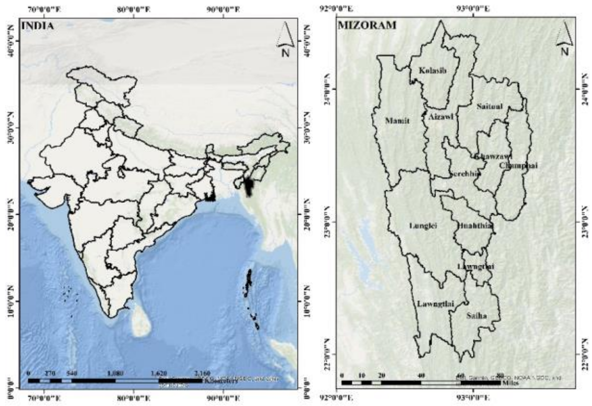

Figure 1-MIZORAM- The STUDY AREA

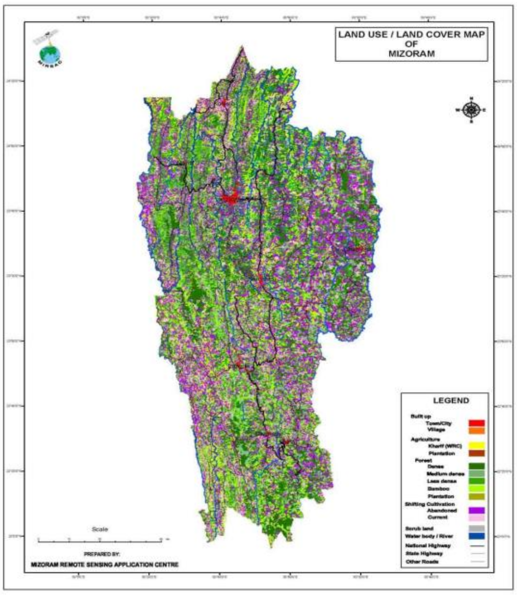

Fig2- land use and land cover change map of

2. MATERIALS AND METHODS

- NDVI

NDVI stands for Normalised Difference Vegetation Index. It is used for measuring the density and health of the vegetation. It can be measured from satellite data. It is based on experimental result of typical spectral signature of leaves. The leaves will absorb more visible ray compared to infrared and hence the intensity of reflected visible would be less compared to infrared which leaves not absorb. The contrast between red and near infrared is a sensitive measure of vegetation amount where the maximum contrast will occur over full canopy and minimal contrast when there is no vegetation. Vegetation indexes are measures of this contrast, which integrate canopy structural (%cover, LAI, LAD) and physiological (pigments, photosynthesis) factors.

We calculate NDVI by,

$$NDVI = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

where NIR is the Near Infrared Reflectance and RED is the Red reflectance. From using Ratio, it will minimise certain type of band correlated noise and influences due to irradiance variation, clouds and cloud shadows, topography and atmospheric attenuation. The main disadvantage of using the ratio is they can't correct non-linear asymptotic behaviour which can cause insensitivity in certain land cover conditions.

The NDVI data used for this study is collected from KNMI climate explorer which uses NOAA-7 Advanced Very High-Resolution Radiometer (AVHRR) GAC data from NOAA-07 for 1982, days 175 to 175, processed by the Long-Term Land Data Record (LTDR) project (v3.5.45) into normalized difference vegetation index (NDVI) and quality-control flags at resolution of 0.1° over region of (92.200°E,22.000°N) to (93.500°E,24.600°N).

The data were then processed out with KNMI processing which mask out all cloud pixels and take monthly mean demanding at least one valid pixel and take average throughout the whole region with minimal valid fraction of 30. The monthly mean average NDVI data was collected from 1982 to 2019 for this study. Its values are between -1 to 1 where negative values indicates Clouds and water whereas 0.6 to 1 vindicates a dense green vegetation and 0 to 0.4 indicates bare soil.

After obtaining the data, there were certain gaps in data which represent missing NDVI values due to satellite not able to collect data for months. To fill the missing gaps, we have used Cubic Spline Interpolation, one of the interpolation techniques used for gap-filling of NDVI values (Wolberg & Alfy, 1999).The interpolation was done in MATLAB using Spline function where we find the polynomial curves which have degree less than or equal to 3 but also are continuous and smooth and also have continuity for first and second derivatives when they join also known as piecewise continuous curves.

- EL-NINO SOUTHERN OSCILLATION(ENSO)

The ENSO phenomenon is the term used to describe changes in the climate that result from variations in the tropical Pacific Ocean's air pressure and sea surface temperatures. El Nino, or the ocean component, and the Southern Oscillation, or the atmospheric component, are the two main parts of ENSO that reflect its complex interrelated nature. El Niño and La Niña are part of the ENSO cycle that lasts from 12–18 months, over periods of 2–7 years, associated with alterations of the SO; although some El Niño and La Niña events can last beyond 24 months. The ENSO cycle describes the change in climate fields linked to the Sea surface temperature anomalies' emergence, apex, and decay in the eastern and central Pacific, as well as changes to the atmosphere's circulation and global weather patterns. Around July, positive (negative) sea surface temperature (SST) anomalies in the central and eastern Pacific first show signs of El Nino (La Nina) or warm (cold) event conditions. These continue to grow as the ENSO cycle goes on, peaking in the Northern Hemisphere (McGregor & Ebi, 2018). Southern Oscillation is change in pressure measured between Tahiti and Darwin that is related to Trade winds strength. For measuring its strength, South Oscillation Index is used which measure the pressure which in turn give pacific wind direction and power over the pacific basin.

There are several indices used to monitor the tropical Pacific, all of which are based on SST anomalies averaged across a given region. They are classified into 4 parts based on the region-

NINO1+2, NINO3, NINO4 of which NINO3.4 is one of the most commonly used to define used indices to define El Nino and La Nina events.

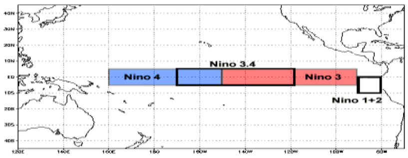

Figure 2- NINO REGIONS

The numbers of the Niño 1,2,3, and 4 regions correspond with the labels assigned to ship tracks that crossed these regions.

Nio 1+2 (0-10S, 90W-80W): The Nio 1+2 zone is the smallest and most eastern of the Nio SST regions, and it correlates with the area of coastal South America where local residents first became aware of El Nio. Of the Nino SST indicators, this one has the tendency to have the most variance.

Nino 3 (5N-5S, 150W-90W): Initially, this area was the main focus for observing and forecasting El Nio, but further studies revealed that the critical area for coupled ocean-atmosphere interactions for ENSO is located further west (Trenberth, 1997). As a result, the Nio 3.4 and ONI were increasingly used to categorize El Nio and La Nia events.

Niño 3.4 (5N-5S, 170W-120W): The Niño 3.4 anomalies may be thought of as representing the average equatorial SSTs across the Pacific from about the dateline to the South American coast. The Niño 3.4 index typically uses a 5-month running mean, and El Niño or La Niña events are defined when the Niño 3.4 SSTs exceed +/- 0.4C for a period of six months or more.

The Nio 4 index captures SST anomalies in the centre equatorial Pacific (5N-5S, 160E-150W). Compared to other Nio regions, this region often exhibits less variation.

The ENSO data collected for the study from OISST V2.1(https://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices) and high-resolution dataset with 0.25° resolution from 1982 to 2019 monthly values.

- <u>Indian Ocean Dipole (IOD)</u>

  It was observed that there is difference in sea surface temperature between eastern pole in eastern Indian Ocean and western pole of Arabian Sea of Indian Ocean. This phenomenon is known as Indian Ocean Dipole. It significantly affects the climate of India and other countries surrounded by Indian Ocean Basin and also contributor to rainfall variability in the region. It is modification over the local Hadley cycles. Warm SSTA boosts atmospheric convection in the west whereas cold SSTA suppresses convection in the east.

Winds originate in the southwest off the coast of Sumatra and blow westward over the equatorial Indian Ocean, with the latter being favourable for coastal upwelling. Weakened equatorial jets result in less warm water being transported eastward, causing the thermocline in the east to be shallower than usual. In the eastern equatorial Indian Ocean, sea level falls, while it increases in the centre. The equatorial Indian Ocean's middle and western regions are where the thermocline deepens and rises in the east (Pavanathara et al., 2010).

The IOD data for the study is collected from KNMI climate explorer which uses data of KNMI climate explorer and Met Office Hadley Centre. The HadISST 1.1 monthly Sea Surface Temperature which is between Difference between hadisst1_wtio.dat and hadisst1_seio.dat is used for data for 39 years monthly data.

- <u>Pacific Decadal Oscillation (PDO)</u>

The PDO is a long-term fluctuation of the Pacific Ocean and is characterised by fluctuations sea surface temperatures and atmospheric pressure over North pacific region. It primarily affects the Northern Pacific Ocean but also can have implications for global climate patterns. It is known for its long-lasting positive (warm) or negative (cool) phases that can persist for 20 to 30 years (Mantua & Hare, 2002).

The 1982 to 2019 monthly PDO data used for the study is collected from KNMI climate explorer and Southwest Fisheries Science Centre which uses KMO Historical SST data set for 1900-81, Reynold's Optimally Interpolated SST (V1) for January 1982-Dec 2001, OI SST Version 2 (V2) beginning January 2002.

- The data for monthly Temperature (mean, max, min) used in the study is collected from KNMI climate explorer and British Atmospheric Data Centre from (92.000°E, 22.000°N) to (93.500°E, 24.500°N) with resolution of 0.5° from CRU TS version 4.06.
- The data for average monthly rainfall used in the study is collected from KNMI climate explorer and British Atmospheric Data Centre from (92.000°E, 22.000°N) to (93.500°E, 24.500°N) with resolution of 0.5° from CRU TS version 4.06.
- The data for SST of Bay of Bengal used in the study is collected from KNMI climate explorer and Met Office Hadley Centre which uses resolution of 1

degree on HadISST monthly average sea surface temperature on Bay OF Bengal region with longitude and latitude range from (87.250°E, 13.000°N) to (87.500°E, 13.250°N).

- Vapor pressure is a measure of the tendency of a material to change into a gaseous or vaporous state. It increases with an increase in temperature. The data for Vapor Pressure used in the study is collected from KNMI Climate Explorer and the British Atmospheric Data Centre with a resolution of 0.5 degree over the Mizoram with a longitude and latitude range from (92.00°E, 22.000°N) to (93.500°E, 24.500°N).
- All Data used in this study was Obtained with a minimum valid Fraction of 30.
- <u>Regression Analysis</u>

Regression Analysis is the study of a statistical method that shows relationships between two or more variables. It usually tests a dependent variable against an independent variable. In simple regression, we linearly relate the independent variable to the dependent variable.

$$Y = aX + b + u$$

Where Y = Independent Variable
X = Dependent Variable
a = Slope of explanatory variable
b = The y-intercept
u = Regression residual or error term

For this study, the datasets are divided into 4 parts: 1982 to 1992, 1992 to 2002, 2002 to 2012, and 2012 to 2019 for better examining the correlation. NDVI is correlated with parameters like NINO3, NINO4, NINO3.4, IOD, PDO, SOI, mean rainfall, Mean Temperature, Minimum Temperature, and maximum temperature using the correlation function in MATLAB to determine if the correlation is statistically significant or not. A higher value indicates that NDVI is dependent on the parameter, whereas a lower value indicates that NDVI is not dependent on the parameter.

RESULTS

After obtaining the data and correlating the interpolated NDVI data of Mizoram with variables such as NINO3.4, NINO3, NINO4, IOD, Temperature, rainfall, etc., which gives the correlation coefficient, which in turn gives how much NDVI is interrelated to the variables, the calculated correlation coefficient for four parts from 1982 to 2019 is given in the table.

Table- Correlation Coefficient of NDVI with different Variables

Parameter	1982-1992	1992-2002	2002-2012	2012-2019
NINO4	0.2821	-0.4867	0.35401	-0.3478
NINO3	0.3491	-0.2122	-0.04	0.0468
NINO3.4	0.3526	-0.4017	0.1655	-0.0767
SOI	-0.08	0.137	-0.1463	-0.0027
IOD	-0.1541	0.0244	0.2498	-0.332
PDO	-0.05	-0.2769	-0.08	-0.05
SST_BAY	-0.7109	0.1608	0.6219	-0.1276
MAX_TEMPERATURE	-0.78	-0.0172	0.7537	0.1626
MIN_TEMPERATURE	-0.9488	0.9645	0.9676	-0.1496
Average Temperature	-0.03	0.1727	0.0666	0.0475
Rainfall	-0.766	0.122	0.8173	-0.0386
Vapor Pressure	-0.9336	0.3407	0.9644	-0.1679

Significant at 0.05 p value.

Red indicates a high negative correlation coefficient value, whereas green indicates a high positive correlation coefficient value, and Black indicates a low correlation coefficient value (both positive and negative).

It can be clearly seen that some of these variables have a high correlation coefficient with NDVI, which suggests their strength of impact on the vegetation. Overall, NINO4, NINO3.4, Vapor Pressure, Minimum and Maximum Temperatures, and rainfall have a significant impact on the vegetation, whereas Average Temperature, South Oscillation Index (SOI), and Pacific Dipole Oscillation (PDO) have little to no impact on the Vegetation of Mizoram. The IOD, NINO3, and SST OF Bay OF Bengal correlations change very significantly with time.

From 1982-1992,

- Minimum Temperature, Vapor Pressure, Rainfall, Maximum Temperature, and SST of the Bay of Bengal have significant negative correlation coefficients, which suggest an inverse relationship with the vegetation of Mizoram.
- NINO4, NINO3, and NINO3.4 have significant positive correlation values, which suggest a linear relationship with the vegetation of Mizoram.
- SOI, PDO, IOD, and average temperature have very low correlations, which suggests a weak correlation with the vegetation of Mizoram.

From 1992-2002

- NINO4, NINO3.4, NINO3, and PDO have significant negative correlation coefficient values, which suggest an inverse relationship with the vegetation of Mizoram.
- Vapor Pressure and Minimum Temperature have significant positive correlation values, which suggest a linear relationship with the vegetation of Mizoram.
- SOI, IOD, Maximum Temperature, Average Temperature, Rainfall, and SST of the Bay of Bengal have very low correlations, which suggests a weak correlation with the vegetation of Mizoram.

From 2002-2012

- NINO4, IOD, SST of the Bay of Bengal, Maximum Temperature, Minimum Temperature, rainfall, and Vapor pressure have significant positive correlation values, which suggest a linear relationship with the vegetation of Mizoram.
- NINO3, NINO3.4, SOI, PDO, and Average Temperature have very low correlations, which suggests a weak correlation with the vegetation of Mizoram.

From 2012-2019

- NINO4 and IOD have significant negative correlation coefficient values, which suggest an inverse relationship with the vegetation of Mizoram.

- NINO3, NINO3.4, SOI, PDO, SST of the Bay of Bengal, Maximum Temperature, Minimum Temperature, Average Temperature, rainfall, and Vapor Pressure have very low correlations, which suggests a weak correlation with the vegetation of Mizoram.

From this data, it can also be seen that some variables like Minimum Temperature, NINO4, rainfall, etc. that are showing positive correlations with vegetation will show an inverse relationship in the next decade. These changes can be seen in almost every other variable.

As Indian Summer Monsoon Rainfall generally occurs from May to July, which is also known as the growing season, the NDVI for these months is also correlated with parameters that affect ISMR like ENSO, PDO, IOD, and rainfall, which can affect the NDVI. It will give a better explanation for how these variables are affecting the vegetation of Mizoram.

Table- Correlation coefficient of different variables with NDVI om vegetation for growing season

Parameter	1982-1992	1992-2002	2002-2012	2012-2019
NINO4	0.4494	-0.5135	-0.206	-0.4557
NINO3	0.3966	-0.1692	-0.0085	0.1044
NINO3.4	0.3985	-0.3601	-0.1212	0.0067
IOD	0.0349	0.1863	0.1378	0.2088
PDO	-0.1136	-0.2512	0.0034	0.0824
Rainfall	-0.7726	0.0827	0.8282	-0.0355

Significance at 0.05 confidence level

Commented [MS1]:

In the growing season, Overall NINO4, NINO3.4, and rainfall have significant correlation values, which suggest they are affecting the vegetation significantly, whereas others have a significant effect but only for some years.

- NINO4 had a significant positive correlation coefficient with NDVI from 1982–1992, but afterwards it had a negative correlation coefficient.
- NINO3 had a significant positive correlation coefficient with NDVI from 1982–1992, but afterwards there was no significant correlation with NDVI. IOD

- 4 has a significant positive correlation coefficient with NDVI from 1982–1992, but it shows a significant negative correlation value, which suggests an inverse relationship from 1992–2002. The positive correlation coefficient with NDVI from 1982–1992 onwards has no significant correlation.
- IOD had no significant correlation value with NDVI until 2012, but afterwards it showed a significant positive correlation value.
- PDO has shown a significant correlation value (negative) during 1992–2002; otherwise, it has no significant correlation.
- Rainfall has a strong negative correlation with NDVI during 1982–1992, but shows no significant correlation during 1992–2002, and again shows a significant correlation value but is positive during 2002–2012, after which it shows no significant correlation value.

DISCUSSION AND CONCLUSION

The Results obtained tells that NDVI is strongly correlated with some climatic factors whereas for others they are not and this relation varies with decade. Due to good vegetation in Mizoram, we can see that