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Evaluating Vegetation Response to Climate Variability over Japan

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Vegetation plays a significant role in the exchange of energy, water and carbon between the atmosphere and land surface, understanding its response to climate variability is of great importance for climate adaptation studies. This study examined Seasonal June-July- August, and December-January-February(JJA and DJF) vegetation response to Temperature(T) and Rainfall(R) variability. Vegetation response to climate dynamics over Japan are still poorly understood, in other to quantify these response spatio-temporal distribution of T and R were investigated, vegetations changes was also accessed utilizing MODIS Normalized Difference Vegetation Index (NDVI) data from 2007-2016(10 years) along with T and R datasets from 1987-2017 (31 years), The NDVI patterns show a checked heterogeneity relating to seasonal variations in climates, our findings further reveals Northern region record an increasing trend in T and R, standard deviation of 0.48, 9.66, with CV of 6.63%, 9.25% respectively were recorded. Also, an increasing trend in T and R was equally observed in the southern region with standard deviation of 0.43, 28.5, by a CV of 2.47% and 15.05. Further analysis revealed critical patterns in the NDVI during DJF months and then afterward NDVI was seen with critical expanding values during the JJA month and diminishing NDVI patterns were seen over similar districts. The result further made it clear that NDVI changes were highly connected to different T and R patterns over the region while seasonal mean NDVI showed a critical increment for JJA in the North and DJA in the south.

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1. INTRODUCTION

The impact of climate on vegetation efficiency has been concentrated in numerous studies as global circulation models project an increase in inter-annual temperature and rainfall, through an escalated precipitation system with bigger individual precipitation occasions coupled with longer interceding dry periods. Scientific consensus shows that atmospheric CO_2 concentration has increased from a pre-industrial level of 280 parts per million (ppm) to 379 ppm in 2005 [1] and mean yearly temperatures have increased by around 0.74°C. The power of precipitation occasions is required to increment, particularly in wet areas which results shows diminishes in mean precipitation in most mid-scope and bone-dry regions add to drying throughout the late spring, showing an extraordinary danger of dry season around, surface air temperature is projected to rise due to an increase in the concentration of greenhouse gases in the atmosphere. Therefore, more evaporation is expected to happen at Earth's surface due to warming and, subsequently more water vapour presence in the atmosphere. Thus, an increase in the precipitation intensity as more frequency of extreme precipitation events is expected [2,3] (O'Groisman et al. 2005; Gorman and Schneider 2009; IPCC 2012) [4,3]. As per estimates, dryland areas will become hotter and drier, and wet locales will get hotter [5].

Understanding and predicting vegetation feedback for climate change is a critical question in adaptation study [6] and there has been developing research to distinguish early indications of climate change impacts and detect vulnerable regions. The response of vegetation to climate change relies upon the magnitude of change, the connections between the factors (i.e. rainfall, temperature and CO2) the historical and environmental conditions (land-use change). The main driving components for vegetation growth in different regions remain vague and poorly understood. Albeit incredible endeavors have been made to explain the different responses of vegetation changes to climatic fluctuation. Neglecting the influences impacts of human exercises on vegetation can result in limited assessment of land conditions. Also, past investigations were restricted to surveying vegetation changes and reactions to change and did not consider the eccentricities of various vegetation types (de Beurs et al., 2015)

Vulnerability on how climate is probably going to change combined with uncertainty in the mechanisms driving the change is presently restricting the capacity to project future vegetation change [7], Response of vegetation to climate drivers depends on the distribution of precipitation and temperature during the different seasons, , it can also be linked to vegetation types, depending on geographical region, topography, and soil water retention capacities, Improved long-term observation on regional spatial scales of changes in vegetation design and structure joined with further developed models of vegetation work is needed to give exact appraisals of current vegetation states and capacities just as future projections of progress (Hill et al. 2011). The need of such evaluation has expanded not exclusively to help dynamic yet in addition for further developing environment models at different scales. Altered precipitation patterns effectively affect vegetation communities, particularly as far as vegetation development and improvement, despite the fact that impacts fluctuate among various biological systems and species. The relationship between precipitation and the Normalized Difference Vegetation Index (NDVI; Sellers 1985) as an indicator of plant growth [8] has been thoroughly investigated in arid and semiarid regions (Jobbagy et al. 2002; Chu et al. 2007; Iwasaki 2009). Response of NDVI to rainfall depends on rainfall distribution throughout the growing season and the intensity of individual precipitation events [9].

Understanding the connections between climatic factors and vegetation growth is still a major challenge [10]. Studies that investigate the linkages between vegetation elements and climate variability are still restricted (Buermann et al., 2014) and have given conflicting outcomes to Northern Europe [11,12] (Bjerke et al., 2014). It is hence as yet unclear whether the adverse consequences of a worldwide temperature alteration on vegetation will surpass the positive ones and regardless of whether such impacts are consistently appropriated around here, the goal of this study is to understand the component and degree of the impact of climate on vegetation change and ascertain its feedback. To address this research gap, we utilized gridded rainfall, temperature and satellite NDVI dataset which are usefulness to investigate how vegetation respond to climatic drivers.

2. STUDY AREA

Japan's climate ranges from subarctic in the north to subtropical in the south, distinctive seasonal conditions exist between the Pacific side and the Sea side. Japan has a total land area of about 378,000 square kilometers, the region lies approximately between longitude 30.07 °N to 45.09 °N latitude, and 129.1° W to 147.1°W longitude, The land area is made up of dense forest and mountainous territory covering 70% of the country. A distinguishing feature associated with the climate of Japan is the obvious temperature changes between four seasons. It covers a range of latitude of some 25 degrees from north to south and is mostly influenced by winds blowing from Siberia in the winter with a seasonal wind blowing from the Pacific Ocean in the summer. With its rather small area, Japan is characterized by four different climatic patterns, spring, summer, autumn, and winter.(https://www.data.jma.go.jp/).

2.1 Dataset and Methodology

2.1.1 MODIS data

NDVI dataset as produced by MODIS has a resolution of 250m X 250m which were made available by NASA. The product has a 16-day composition of Normalized Difference Vegetation Index (NDVI) Enhanced Vegetation Index (EVI), blue, red, near infrared (NIR), mid-infrared (MIR) and pixel reliability (Huete et al.,2002. To reduce or avoid the presence of cloud cover in helping match field survey capture time for vegetation coverage, the MODIS downloaded data of 16 day composition were converted to 32-day composite using the Maximum Value Composition as basis. This MODIS data was obtained through the online archive at the NASA Land Processes Distributed Active Archive center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/get_data)" using the United States Geological Survey (USGS) Earth Explorer (EE) web based tool (http://earthexplorer.usgs.gov/).

Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). NDVI ranges from -1 to +1. NDVI is computed using a normalized ratio of the near infrared and visible red bands:

$$NDVI = (\rho NIR - \rho RED) / (\rho NIR + \rho RED)$$

where NIR and RED are the near infrared and red spectral reflectance values, respectively, measured by the MODIS sensor.

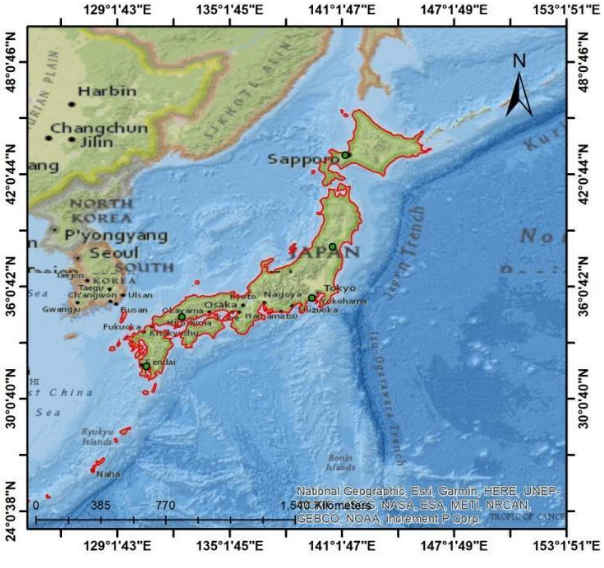

Fig. 1. Study area map

Negative values likely reflect water and NDVI values close to +1 possibly represent dense green leaves. Overall, high NDVI values indicate healthier vegetation and low NDVI values indicate unhealthy vegetation. In evaluating changes in vegetation greenness over the study area, we characterized wet seasons under June, July, August, and Dry seasons as December, January, February as the average monthly composite Normalized Differential Vegetation Index (NDVI). The satellite measured NDVI dataset from the NASA Global Inventory Monitoring and modeling system (GIMMS) over a period of 10 years ranging between 2007 – 2016. The reliability of this dataset quality for time series analysis has been confirmed in some studies [13,14,15].

2.1.2 Meteorological data

This research work adopt monthly temperature and rainfall data over Japan the dataset utilized for this study the data were obtained from the Climatic Research Unit (CRU), dataset contains two different products, the gridded time-series (TS) data and Year-by-Year Variation for the period 31 years(1987–2017) over Japan, Data are gridded and available at 0.5° x 0.5.

Coefficient of Variation (CV), also known as Relative Standard Deviation (RSD), was used to compare the degree of variation of climatic factors over the study period, as shown in equation below

$$CV = \frac{\sigma}{\mu} * 100$$

Where;

σ = Standard Deviation of the data
μ = Mean of the grouped data

Standard Deviation (σ) reveals how much the members of a group differ from value for the group. It is expressed in equation ;

$$\sigma = \frac{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}}{n - 1}$$

n = the number of data points
x = the mean of xi
xi = each of the values of data

Mann-Kendall test analyses were conducted to estimate linear time trends of climate variables accessed rainfall and temperature over the study region climate variability was measured as linear regression slope and the ratio of slope to the initial values, we determined Pearson connection coefficients of variation between the variables, accepted that interannual variability was identified in rainfall, NDVI and temperature The Mann Kendall z-statistic is given as

$$Z = \frac{|S|}{\square^{1/2}}$$

A positive value of Z demonstrates an increasing trend while a negative value indicates a decreasing trend and the other way around. The basic test statistic values for various significance levels for observations are 1.645, 1.97 and 2.57 at 90, 95 and 99% probability levels. These tests were applied to temperature and precipitation datasets to detect the trends/patterns and to quantify the change both spatially and temporally.

3. RESULTS AND DISCUSSION

We studied the observed changes in rainfall and temperature, over the study region which shows the observed Annual mean temperature and rainfall variation the highest variation was observed in kagoshima region and also these region recorded the highest rainfall and temperature amount while annual precipitation and annual rainfall values for Sapporo, Kagoshima, Tokyo, were analysed individually to ascertain individual climate variability in this region respectively.

Fig. 2. depicts the seasonal spatial distributions of temperature Between 1987 and 2017 which shows an increasing trend, the highest temperature value was observed during the JJA months with temperature values reaching 30 degree celsius the lowest value was observed during the DJF months as shown in Figure 2 above, spatial distribution reveals southern region such kagoshima during JJA months, recorded temperature values up to 30 degree celsius while northern region such as sapporo recorded very low temperature values as low as 10 degree celsius, during the DJF months observed temperature value for kagoshima ranges from 10 degree celsius while sapporo recorded a lower value reaching -10 degree celsius. Northern regions experience values and uncover critical patterns in the NDVI prior and

then afterward the of JJA temperature patterns, NDVI was seen with critical expanding temperature during the JJA month and diminishing NDVI patterns were seen over similar districts, during the DJF month when low temperature values were also recorded, contrary to the southern region related to diminishing temperature a steady pattern was observed during both seasons DJF and JJA Essentially, over expanded NDVI pattern is related to the expanded temperature, and the diminished NDVI pattern is related to the decreased temperature value, however the hotter temperature and greener vegetation happened after the MAM season, we noticed temperature and vegetation development patterns are steady with past discoveries over southern region with a decrease pattern during JJA.

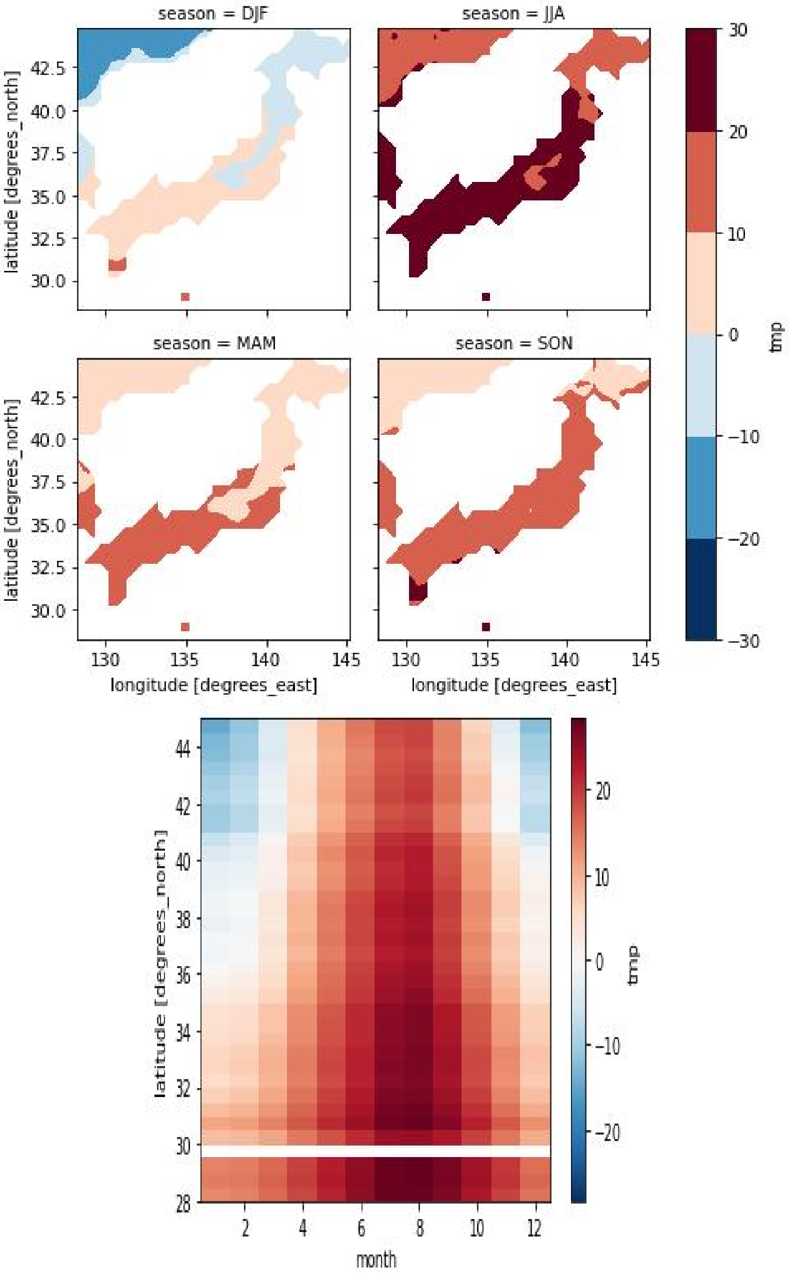

Fig. 2. Seasonal Temperature distribution over Japan from 1987-2012 (DJF, JJA,MAM,SON)

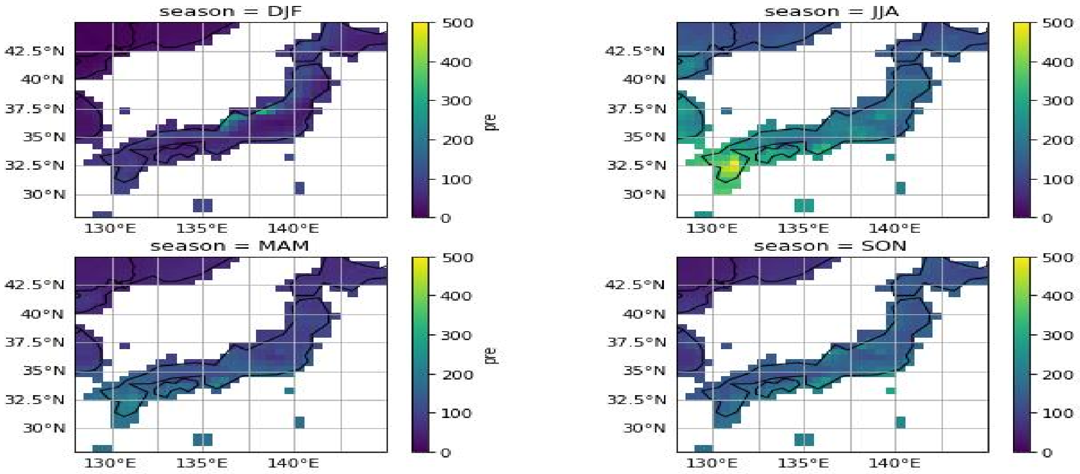

Fig. 3. Seasonal Rainfall distribution over Japan from 1987-2012 (DJF, JJA,MAM,SON)

Fig. 3. depicts the seasonal spatial distributions of rainfall Between 1987 and 2017 which shows an increasing trend increasing trend, the highest rainfall amount was observed during the JJA months with mean rainfall value above 500mm while lowest rainfall amount was recorded in northern Japan during DJF months, spatial distribution of rainfall reveals region from central japan (i.e Tokyo to kagoshima received high rainfall amount during this periods as the rainfall amount decreases northward during the period of 1987-2017, northern regions experience values and uncover critical patterns in the NDVI during DJF months and then afterward the of JJA rainfall patterns, NDVI was seen with critical expanding rainfall during the JJA month and diminishing NDVI patterns were seen over similar districts, during the DJF month when low rainfall values were also recorded, Fig. 3 contrary to the southern region related to diminishing rainfall a steady pattern was observed during both seasons DJF and JJA Essentially, over expanded NDVI pattern is related to elongation in rainfall, and the diminished NDVI pattern is related to high variability pattern observed in rainfall in the south, increased rainfalls amount leads to greener vegetation.

3.1 Coefficient of Variation in Rainfall and Temperature

Fig. 4.1. - 4.3. depicts the behaviours and degree of variation of climatic variables and how it changes over Sapporo, Kagoshima, Tokyo respectively in the past thirty years over the study area. Temperature over sapporo has a mean value of 7.34, standard deviation of 0.48 was observed, temperature was following an increasing order from 1987-2017 and has a coefficient of variation of 6.63%, while rainfall has a mean value of 104.42mm during the same period, it is observed that Rainfall was following increasing trend from the years 1987 – 2017 by a coefficient of variation of 9.25% although a slight decrease was observed in 2009 followed by an increasing order from 2010 – 2017 as shown in Fig. 3.1, This shows that there is high variation in Temperature over sapporo compared to the other two regions.

Fig. 4.2. shows Temperate over tokyo which has a standard deviation of 0.40, the mean value of temperature recorded was 14.7, an increasing order was observed from 1997 - 2017 by coefficient of variation of 2.76%, rainfall on the other hand has a mean value of 155.42mm during the same period of time, continuous increasing order was observed from in rainfall from the period of 1995 - 2017 by a coefficient of variation of 12.9% and a standard deviation of 20.21.

Fig. 4..3 Temperature over kagoshima southern location has a mean value of 17.69, temperature was following an increasing trend in this region by a coefficient of variation 2.47, standard deviation of 0.43 was recorded, the region recorded the highest temperature amount. Rainfall over kagoshima has a mean value of 189.46mm during the same period of time, it is observed that Rainfall was following increasing trend from the years 1987 – 1995, a continuous increasing order was observed from 1995-2017 by a coefficient of variation of 15.05%, rainfall in

this area exhibits high variability factor over the study period this ascertain high temperature and rainfall connection to vegetation dynamics over the region.

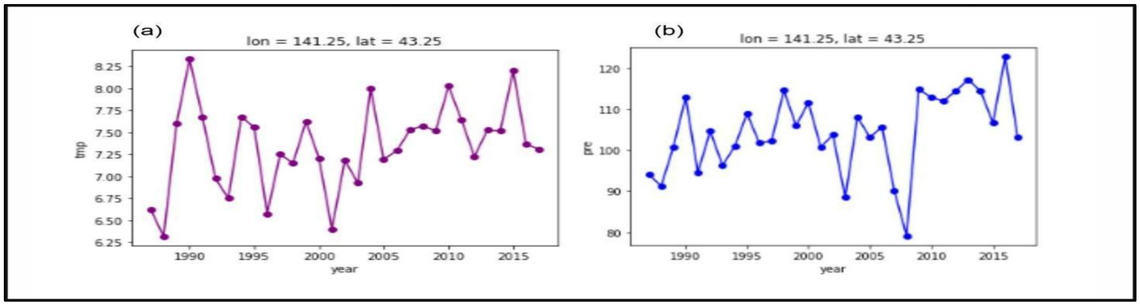

Fig. 4.1. Coefficient of Variation in (a) temperature (b) rainfall over Sapporo 1987 – 2017

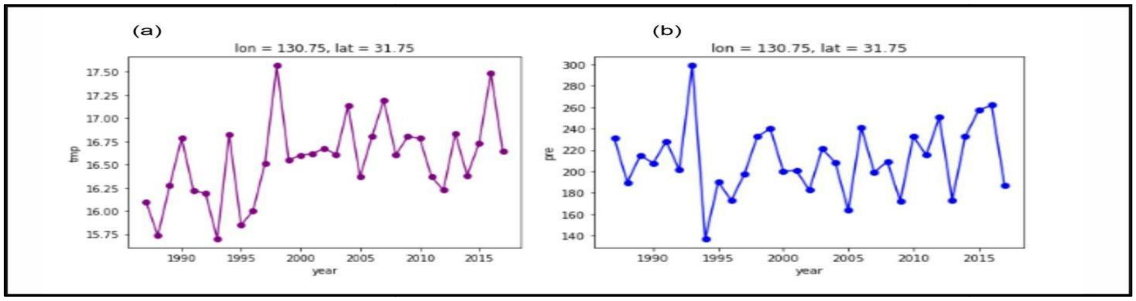

Fig. 4.2. Coefficient of Variation in (a) temperature (b) rainfall over kagoshima 1987 - 2017

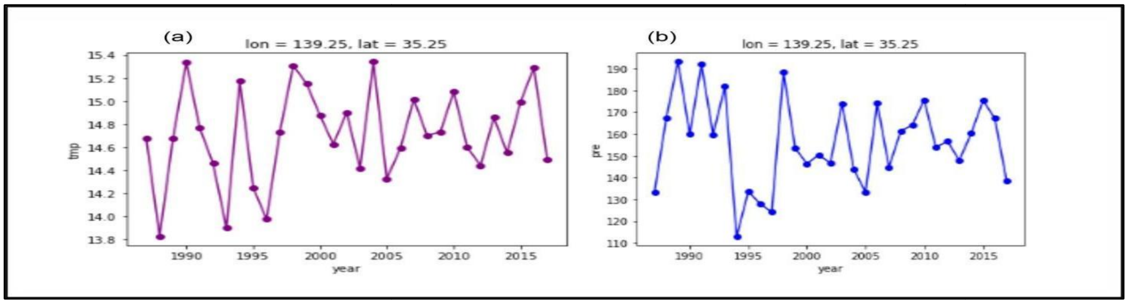

Fig. 4.3. Coefficient of Variation in (a) temperature (b) rainfall over Tokyo 1987 - 2017

Table 1. Linear trend in annual variation of Rainfall

	P-value	R^2	Slope	Mean	STDEV	CV%
Sapporo	0.005	0.43	0.52	104.42	9.66	9.25
Tokyo	0.86	0.78	0.075	155.42	20.21	12.9
Kagoshima	0.30	0.46	0.75	189.46	28.52	15.05

Table 2. Linear trend in annual variation of Temperature

	P-value	R^2	Slope	Mean	STDEV	CV%
Sapporo	0.148	0.10	0.018	7.34	0.48	6.63
Tokyo	0.49	0.042	0.007	14.7	0.40	2.76
Kagoshima	0.007	0.19	0.002	17.69	0.43	2.47

3.2 Seasonal change in NDVI

Normalized Difference Vegetation Index (NDVI) is a proportion of the vegetation thickness over an area. Over the years in most places, this tends to reduce with increasing human activities which replaces the vegetal covers into bare soil of closely compacted impervious surface. Theoretically, NDVI values are represented as a ratio ranging in value from -1 to 1. Extreme negative values of NDVI represent water, very low values (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values denote shrub and grassland fields (0.2 to 0.3), while high values show temperate and tropical rainforests (0.6 to 0.8).

For example, due to the limits of the geographical extent and some ecological conditions, the study couldn't conduct an adequate ground truth process to detect or provide robust characterization of error in the data used for correlation purposes. Nonetheless, this study could be used as a premise for other future researchers in this region in order to both address some of the weaknesses as stated above and also meet the needs of scientist who may be interested in achieving a better result and also for policy making.

Moreover, the study result had shown a true correlation between MODIS NDVI product with natural vegetal cover in the regions studied. As observed, the mean value from the annual NDVI during 2007 - 2017 as shown in figure 5 shows a clear spatial differentiation for the northern region Sapporo. The Vegetation trend shows the yearly distributed NDVI values in the northern region, with mean value of (0.6 - 0.7). Tokyo area maintain a moderate NDVI which was constant during two steps both DJF and JJA season respectively values of 0.5 was observed over these region, the southern area a clear difference in pattern was totally observed, low NDVI values were distributed towards the southern area of Japan i.e the kagoshima area, values lesser than 0.3 was observe over these region.

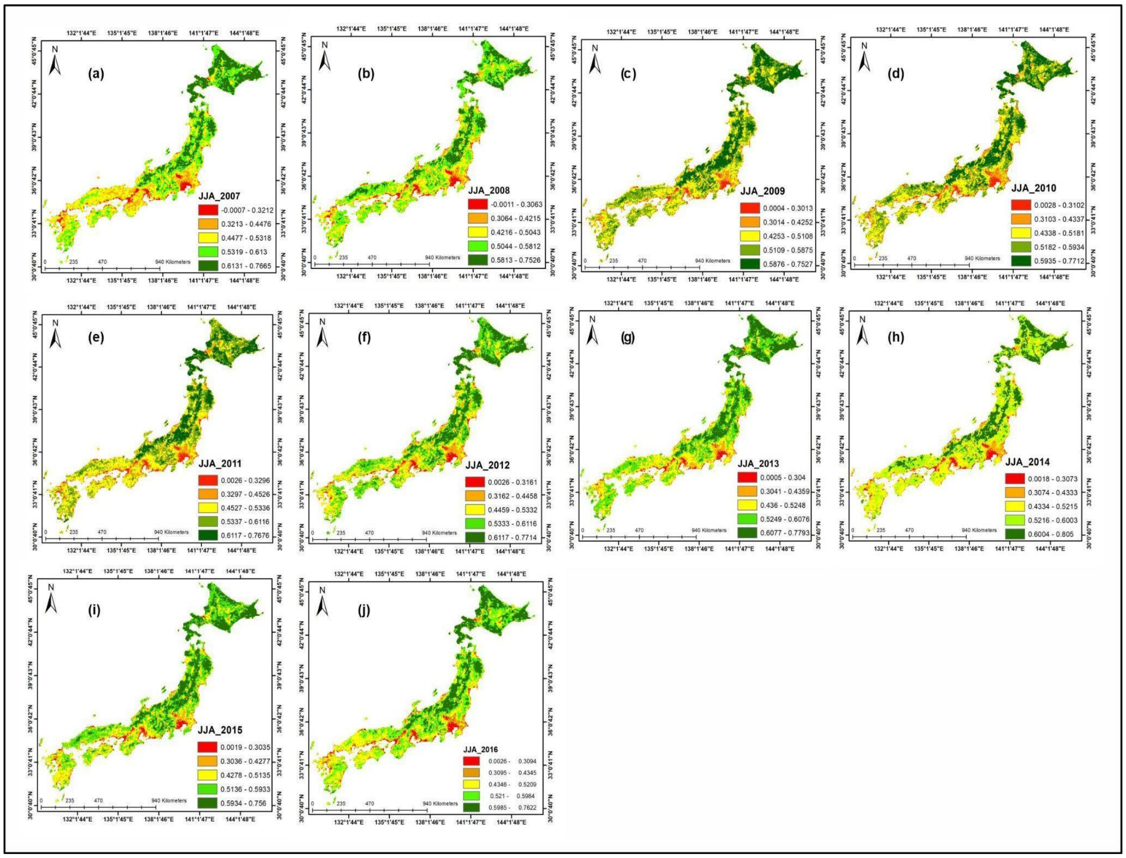

Fig. 5. Spatial distribution of vegetation during JJA (2007-2017)

The relationship between precipitation and the Normalized Difference Vegetation Index (NDVI; Sellers 1985) regarded an indicator of plant growth [8] has been thoroughly examined in arid and semiarid regions (i.e. Jobbagy et al. 2002; Chu et al. 2007; Iwasaki 2009). response of vegetation to precipitation relies upon the distribution of precipitation all through the developing season and the intensity of individual precipitation occasions [9]. as shown in Fig. 5(a - i) It also depends on vegetation types, e.g. with different water storage capacities [8,16], and varies depending on the geographical region and topography such as valleys, slopes or hillsides [17].

As shown in Fig. 6(a - i), the NDVI analyses provided an overview of the character relationship between vegetation health and precipitation in Japan. As observed, the high rainfall amount of about 500mm during summer (JJA) helped in vegetation growth over the observed years which is responsible for the high NDVI values of 0.805. This likewise upholds a new perspective on the warm-dry to warm-wet change around here [18,19]. Past examinations of satellite-estimated vegetation growth suggested a greening pattern of vegetation in the Sahel [20,14] and also in the central United States [21,22], as a result of increasing precipitation at seasonal and annual time scales, Coupled with increasing variability in precipitation, region with generally high qualities could be concluded up to be ecologically delicate and inclined to dry spells because of their dependence on precipitation [23] (Zhang et al. 2017). the mean value from the annual NDVI during 2007 - 2017 as shown in figure shows a clear spatial differentiation compared to the JJA season for the northern region Sapporo. The Vegetation trend shows a very low distributed NDVI value, with mean value of lesser than 0.05. Tokyo area maintain also observed a low values which shows vegetation reduction over the area in DJF seasons contrary to JJA, the southern region shows a clear different pattern high NDVI values were distributed towards the southern area of Japan i.e the kagoshima area recorded NDVI values as high as 0.3 and above.

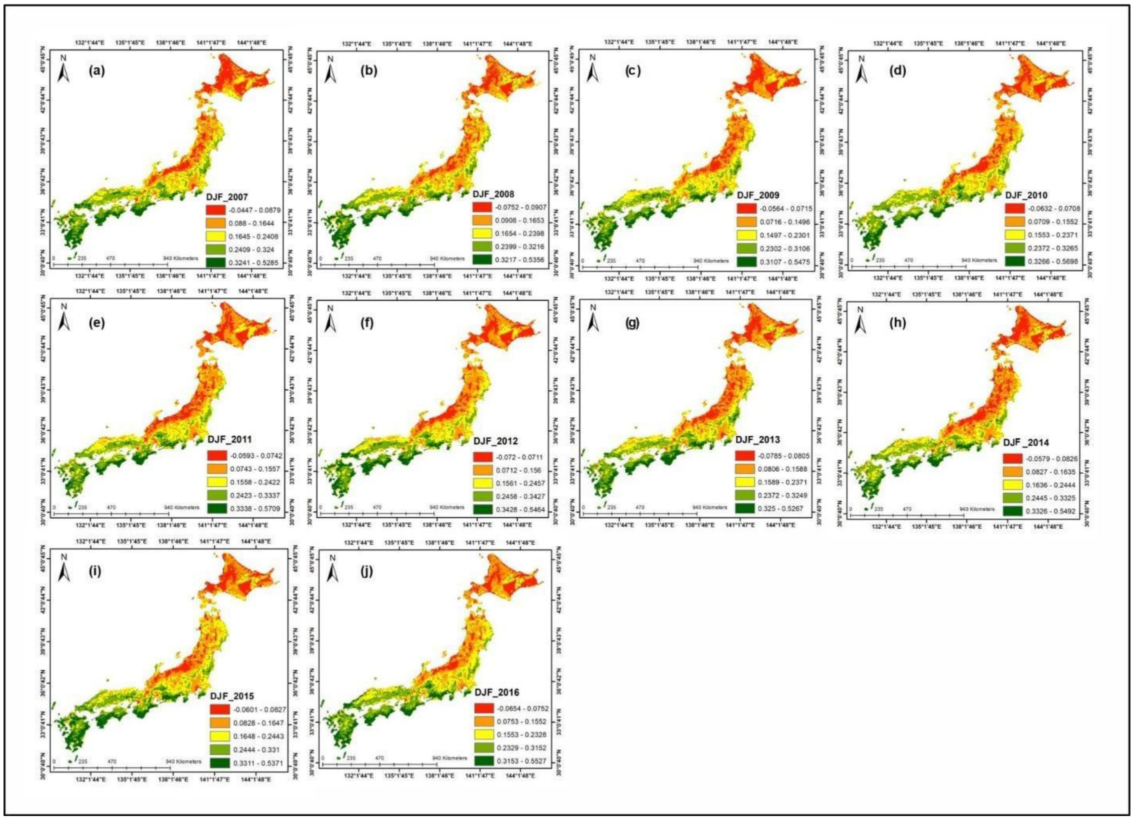

Fig. 6. Spatial distribution of vegetation during DJF(2007-2017)

While precipitation changes over the whole of Japan appear not to be clear, studies have proved that extreme precipitation events have gotten more variable.This in return caused a shi In particular, the IPCC [1] states that by and large there have been no significant increasing or decreasing trends/patterns in precipitation during the twentieth Century. Recently, [24,3] observed that the observed increase are much higher than found in studies of precipitation intensity alone and that the complete changes in extreme precipitation events are an aftereffect of consolidated changes in both frequency and intensity Nonetheless, the fluctuation (i.e., timing, irregularity, amount, and so forth) has expanded for Japan. This kind of progress could convert into a more unusual precipitation pattern, which would make anticipating farming and water assets the executives more troublesome. In certain regions of Japan, critical diminishing patterns in yearly mean precipitation have been noticed [25].

Extreme weather occasions in Japan have expanded in recurrence and power. During the previous 100 years, there has been an increment in the recurrence of outrageous downpour occasions and these have been ascribed to an increment in the quantity of front facing climate frameworks. however there has been an increase in the measure of precipitation during the period 1961 to 2000 [26,27].

In winter (DJF), the Siberian High develops over the Eurasian Continent and the Aleutian Low develops over the northern North Pacific. Prevailing northwesterly wind triggers the advection of cold air from Siberia to Japan and carry hefty snowfall to Japan's Sea of Japan side (upstream of mountainous land) while a sunny weather is experienced at the pacific side (downstream of mountainous land). This is responsible for the interseasonal changes between the observed wet seasons(JJA) and dry season(DJF) in the produced images in Fig. 5 above. Temperatures as low as -20°C are frequently observed in inland regions of Hokkaido, while Amam and Okinawa have mild winters(DJF) as a result of their subtropical location (http://web-japan.org/).

4. CONCLUSION

Seasonal NDVI patterns showed an enormous spatial heterogeneity, compared to climate and its seasonal variability. increased temperature and precipitation could prompt an expansion in NDVI in many regions, as seen in figure 5, increased temperatures could likewise cause occasional dry spell in dry areas, for example northern Japan (Sapporo), increased rainfall could prompt a decline in plant photosynthesis because of diminished sun oriented radiation The rate and degree of NDVI increment shifted occasionally, Seasonal mean NDVI showed a critical increment for JJA in the North and DJA in the south. A few enormous fluctuations in the temperature patterns were reasonable because of large fluctuations in precipitation. These outcomes recommended that both temperature and precipitation are basic to interannually inconstancy of NDVI, climate variability is the essential driving factor of increased vegetation growth during the JJA month over most pieces of the investigation regions both previously,

Hotter temperatures appears useful in southernmost region and wetter areas, while their effects appear negative in the southern and drier region, These various reactions can in part clarify the clashing discoveries detailed so far in regards with the impacts of increasing temperatures, the circumstance of precipitation has a higher illustrative force for vegetation efficiency than precipitation sums, as a result of its part on the event of climate drivers variation, These variation suggested the principal drivers of vegetation efficiency in Japan as they provide essential and innovative information about the general response both in Northern and Southern region and also during two seasons (JJA, DJF).

The effect of precipitation and temperature on vegetation relies on transient succession wherein precipitation happens. We demonstrate that NDVI can be clarified by the fluctuation in precipitation and temperature between seasons. Subsequently, the clarified change depends on a particular time period (June–August) of precipitation and temperature, in general higher than the clarified change over the whole season, NDVI can be clarified by the fluctuation in precipitation and temperature between the start of March and the center of May. Results from the analysis in figure 5 and 6 show the best clarified fluctuation in mean NDVI by the difference in precipitation between the start of June and end of August. This is the most minimally clarified huge fluctuation in mean NDVI, The result infer that the fluctuation in precipitation and temperature during JJA and DJF particularly form the basis for mean NDVI. Lower positioning yet additionally of high impact is the fluctuation in precipitation and rainfall. A reduction in precipitation power at higher temperatures can be identified with water fume accessibility. Deficient water fume supply for immersion at higher temperatures can cause less development of mists and outrageous precipitation Reactions, for example, a lessening in precipitation at higher temperatures can be reliant upon the time-size of precipitation, seasons, and areas.

We might want to additionally explore seasonal to subseasonal precipitation in various seasons and sub-districts over Japan, specifically to take overall significance of dynamic and thermodynamic accessible impacts on outrageous precipitation related to an expansion in temperature. This recommends that the dampness source in every one of the periods impacts the vegetation elements over Japan. For NDVI on the upside of the complete vegetated space of Northern Japan The diminishing values of vegetation as demonstrated by NDVI in figure 6 over Northern Japan during the DJF month and also in Southern Japan during the JJA is an indication of climate variability. The aftereffects of our evaluation shows that NDVI relies upon the time and measure of precipitation and temperature, vegetation distribution was observed to be higher in northern Japan.

The consequences of this investigation revealed the seasonal changes in vegetation and emphasized the significance of seasonal precipitation and temperature in controlling vegetation dynamics. To better preserve the fragile delicate climate in Japan, we should focus harder on the effects of climate change and climate variability under the condition of global warming for climate adaptation studies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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