

## Assessing Precipitation Impact on Vegetation Using Satellite Data and Remote Sensing Techniques: A Case Study of Yakawalang-Afghanistan

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### ABSTRACT

Water is essential for all living creatures, including humans. Precipitation directly impacts plant growth; adequate water supply promotes sufficient growth, while drought conditions lead to inadequate growth and plant desiccation. This research investigates the effects of precipitation on vegetation in the Yakawalang District. The study utilizes NDVI vegetation data from the MODIS Terra satellite and precipitation data from the Global Precipitation Measurement (GPM) system. This study employed the non-parametric Mann-Kendall test to identify changes in the obtained data. The research covers the period from 2010 to 2020. Our findings indicate an increasing trend in precipitation and vegetation in the Yakawalang District during the study period. Interestingly, 2010 recorded the lowest precipitation (277 mm) but the highest vegetation index (0.100). Conversely, 2015 saw high precipitation (510 mm) but the lowest vegetation index (0.079). Further analysis of temperature data for 2015 suggests that low temperatures may have inhibited vegetation growth despite increased precipitation. This research concludes that precipitation alone does not guarantee increased vegetation. Other factors, such as appropriate temperature, are crucial in vegetation growth. These findings underscore the complex interplay of environmental factors in plant development and highlight the need for comprehensive approaches to understanding and managing vegetation dynamics.

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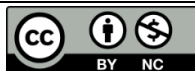
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## INTRODUCTION

Climate change is widely recognized as one of the most critical issues in scientific discourse across global platforms. Its effects are far-reaching, with the Earth's ecosystem experiencing significant impacts (Rezaei & Gurbanpour, 2017). In recent years, the rapidity of changes in climate parameters, particularly those resulting from the continuous increase in greenhouse gases such as carbon dioxide, methane, and nitrogen oxide, has become a cause for concern.

These changes are primarily attributed to intensive industrial activities, deforestation, and exponential population growth, which have elevated greenhouse gas levels to alarming proportions. Scientific consensus suggests that anthropogenic intervention in the composition of greenhouse gases, primarily through fossil fuel consumption, has increased the average temperature of the Earth's atmosphere (Torabi-Pode et al., 2017).

This temperature increase has the potential to alter various components of the hydrological cycle, including precipitation patterns and effective precipitation in different regions globally. Consequently, recent decades have witnessed a surge in studies examining trends in various meteorological and hydrological variables. Atmospheric and hydrological researchers have predominantly focused on understanding climate change processes, particularly precipitation variations. Irrespective of a location's climatic classification (wet or dry), comprehending precipitation changes can significantly aid managers and water-related practitioners in making informed decisions regarding the implementation of long-term projects (Mohammadi, 2018).

Climate change can be effectively studied by tracking characteristics such as climatic elements' quantity and spatiotemporal patterns. Among these, the study of precipitation is particularly prevalent. As a fundamental climatic element, precipitation has shown a 0.1% increase during the 20th century, especially in the middle and upper latitudes of the Northern Hemisphere. Conversely, tropical drylands (latitudes 10-30 degrees north) have experienced a precipitation decline of approximately 0.3%, while tropical areas have seen a relative increase of 0.2 to 0.3%. The Mediterranean Basin has exhibited a negative precipitation trend since the 1950s, whereas the Southern Hemisphere has not shown significant changes. Due to these spatial disparities and to gain a more accurate understanding of precipitation changes, numerous studies have been conducted on its characteristics and variations. These studies can be broadly categorized into trend analyses and fluctuation studies (Asakere & Razmi, 2017).

The present research utilizes satellite data to analyze the effects of precipitation on vegetation in the Yakawalang District. To achieve this, precipitation data from the Global Precipitation Measurement (GPM) satellite was collected over 11 years from 2010 to 2020 and prepared as monthly datasets. Additionally, Normalized Difference Vegetation Index (NDVI) data for the Yakawalang District was obtained from the MODIS Terra satellite for the same period. The Mann-Kendall method was employed to determine the statistical significance of the acquired data.

Karl and Knight (1998) examined the United States' precipitation trends, amounts, frequencies, and intensities. Their findings indicate that from 1910 to the end of the 20th century, US precipitation increased by approximately 10 percent, primarily reflected in daily heavy precipitation events. Notably, over 53% of the rise in precipitation was attributed to a positive trend observed in the top 10% of the precipitation distribution. They further posit a significant trend in high amounts of daily and monthly precipitation across most of the United States, although no consistent national trend in precipitation amounts was observed.

Khalili and Bazarafshan (2012) analyzed changes in monthly, seasonal, and annual precipitation in Iran over 116 years (1877-2001) using autocorrelation methods and supplementing monthly values through a combined approach. Their results did not confirm any significant trend in the annual precipitation series across five studied stations. However, seasonal precipitation changes revealed both increasing and decreasing trends.

Asakere (2004) investigated the precipitation trend in Isfahan Province by combining time series analysis and geostatistical methods, applying a technique of temporal-spatial changes. This research demonstrated that the annual precipitation trend in all obtained data was proportional, with more than 24 mm of precipitation change observed during the last three decades.

Hajam et al. (2007) conducted a study on the trend of changes in seasonal and annual precipitation at selected stations in the central basin of Iran, utilizing non-parametric methods such as the Mann-Kendall test and Sen's Estimator Slope. This research did not confirm a significant increase in the use of either test.

The accumulation of greenhouse gases (GHGs) in the atmosphere is causing changes in extreme weather patterns and consequent climate variations, substantially affecting crop and animal production. Climate change is altering meadows and pastures that serve as primary feed sources for animal husbandry, leading to production losses and threatening the sustainability of this sector. Safi et al. (2024) propose a holistic approach to mitigate the adverse effects of heat stress on animal production. This involves identifying gene regions resistant to heat stress through breeding studies, improving the physical environment by modifying diets, and enhancing the genetic resilience of animals to climate change.

This research's primary objective is to investigate precipitation's effects on vegetation using Geographic Information Systems (GIS) and remote sensing techniques. This study aims to determine whether precipitation is the sole factor influencing vegetation growth. The central research question guiding this investigation is: Can the effects of precipitation on vegetation be comprehensively examined through the application of GIS and remote sensing methodologies?

## **METHODS AND MATERIALS**

This study utilized spatial precipitation data from the Global Precipitation Measurement (GPM) satellite and vegetation data from the MODIS Terra satellite, collected every 16 days, to analyze vegetation in the Yakawalang District. Precipitation data were processed and analyzed using ArcGIS software, and the results were compiled into tables and graphs using Microsoft Excel. Vegetation data were similarly analyzed in ArcGIS and mapped accordingly. The temporal scope of the study spans eleven years, from the beginning of 2010 to the end of 2020, as illustrated in the flowchart presented in Figure 2.

Precipitation and vegetation data were collected from the GPM and MODIS satellites for analysis. Initially, the Mann-Kendall test was applied to the precipitation data to assess the

significance level of the observed trends. Subsequently, the MODIS satellite data, comprising land surface temperature and vegetation data, were analyzed using GIS software, and the results were presented as maps. These data were employed to evaluate the effects of precipitation on vegetation.

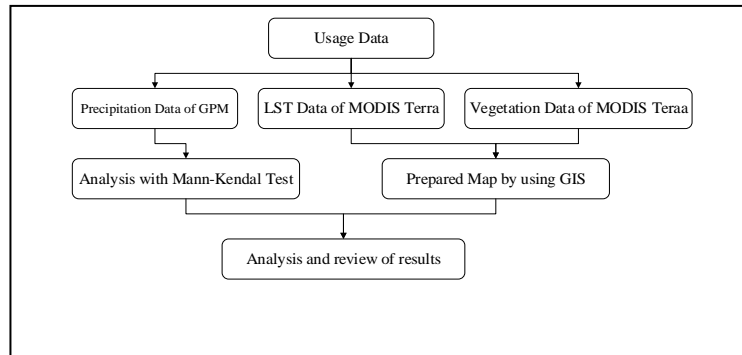


Figure 1. Methodology Flowchart

The Mann-Kendall test assessed the parameter trends across varying significance levels. This non-parametric test is widely used for analyzing hydro-climatic series due to its robust handling of non-normally distributed data. The test's null hypothesis assumes no trend in the data series, whereas rejecting the null hypothesis indicates the presence of a trend. In the Mann-Kendall method, a time series, denoted as  $x_1, x_2, \dots, x_n$ , is analyzed, and the test statistic is calculated according to Equation 1. In this formula,  $j$  and  $k$  represent the order of observations, and the sign function,  $\text{sgn}(x)$ , is defined by Equation 2.

$$(1) S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k)$$

$$(2) \text{Sgn}(x) = \begin{cases} +1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

No trend is detected if the test statistic  $S$  is not significantly different from zero. Otherwise, the trend is determined to be either upward or downward. The standard normal  $Z$  variable is calculated using Equation 3 to assess the statistical significance of the trend. In this context, the null hypothesis ( $H_0$ ) posits the absence of a trend, while the alternative hypothesis ( $H_1$ ) suggests the presence of a trend (Salmi et al., 2002).

$$(3) \begin{cases} Z = \frac{S-1}{(\text{var}(S))^{\frac{1}{2}}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S-1}{(\text{var}(S))^{\frac{1}{2}}} & \text{if } S < 0 \end{cases}$$

$$(4) \text{Var}(S) = \{n(n-1)(2n+5)\}$$

### Study area

Yakawalang District, situated at  $34^{\circ}58'48''\text{N}$  and  $66^{\circ}57'00''\text{E}$ , shares borders with Bamiyan's central region to the east, Dar-e-Suf District in Samangan Province to the north, Punjab District in Bamiyan Province to the south, and Balkhab District in Sarpul Province to the west.

Annually, thousands of people, including foreign tourists, visit Amir Dam, which boasts seven natural dams and serves as a major source of income for the local population and the government (Azimi, 2012). The district's population is 68,821, covering an area of 6,917 square kilometers with an average elevation of 2,714 meters above sea level. Yakawalang District is one of the most populous and culturally significant regions in Bamiyan Province. It is known for its scenic landscapes and rich historical significance, making it a key tourist destination in Afghanistan.

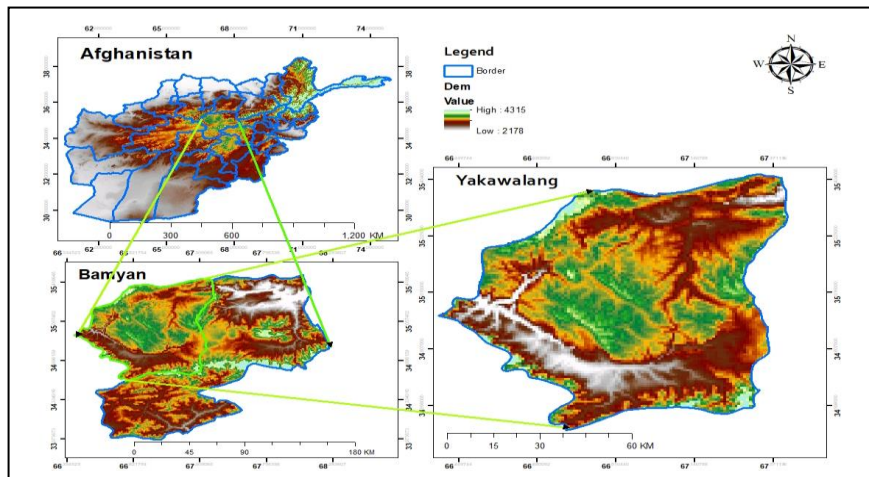


Figure 2. Map of the study area

### Data used

To investigate the effects of precipitation on vegetation in the Yakawalang District, the following datasets were utilized, all sourced from NASA's public archives:

**Precipitation Data from GPM Satellite (2010–2020):** The GPM satellite is a collaborative international mission led by NASA and JAXA (Japan Aerospace Exploration Agency). It is designed to provide precise global precipitation measurements, including rain and snow, essential for climate and meteorological studies.

GPM Satellite Features:

- Global Coverage: Measures precipitation across the Earth's entire surface, including remote regions and oceans
- High Accuracy: Equipped with advanced radar and microwave sensors for accurate precipitation intensity and type measurements
- Rapid Update Cycle: Provides updated data every three hours, enabling near-real-time monitoring
- Data Integration: GPM data can be integrated with other satellite observations and ground-based stations to view weather and climate comprehensively

Importance of GPM satellite

- Weather Forecasting: Enhances the accuracy of precipitation forecasts.

- Water Resource Management: Supports efficient water management and usage planning.
- Climate Research: Offers critical data for climate change studies and atmospheric phenomena like hurricanes and tornadoes.
- Disaster Prediction and Mitigation: Assists in forecasting natural disasters like floods and landslides, helping reduce their impacts.

#### GPM Satellite Operations

- Space-Based Measurement: Utilizes radar and sensors from orbit to measure precipitation.
- Data Transmission and Analysis: Data are transmitted to Earth, analyzed, and made available to users.
- Continuous Updates: Provides regular updates for real-time atmospheric monitoring.

#### Usage of data

1. Researchers and scientists can access GPM data through different platforms and use it in their research.
2. Governments and organizations: they can use this data to plan and manage resources and respond to natural disasters (<https://gpm.nasa.gov/>).
3. Vegetation data from MODIS Terra satellite from 2010 to 2020

The MODIS-Terra satellite is part of NASA's larger Earth Observing System mission, which is used to study Earth systems. Terra satellite is equipped with MODIS (Moderate Resolution Imaging Spectroradiometer). This tool collects critical data in various fields, including climate, vegetation, water quality, and wildfires. The following will examine the MODIS-Terra satellite's features, importance, and applications.

#### MODIS-Terra satellite Features:

- Global Coverage: Provides comprehensive data on land surfaces, the atmosphere, and oceans.
- High Precision: MODIS captures data in 36 spectral bands with spatial resolutions ranging from 250 meters to 1 kilometer.
- Frequent Data Collection: Offers full global coverage every 1-2 days.
- Diverse Applications: Monitors various environmental phenomena, including climate change, wildfires, air pollution, and vegetation dynamics.

#### Significance of MODIS-Terra satellite

- Environmental Monitoring: Tracks long-term ecological changes such as deforestation, glacial melt, and temperature shifts

- Climate Research: Facilitates the identification of climate trends and the development of accurate climate models.
- Natural Resource Management: Provides data for managing forests, lakes, and agricultural resources.
- Disaster Management: Assists in forecasting and managing natural disasters like wildfires, droughts, and floods.

#### Applications of MODIS-Terra satellite:

- Vegetation Analysis: Monitors seasonal and long-term vegetation changes, offering detailed information on vegetation distribution.
- Water Quality Monitoring: Tracks water quality in lakes and oceans by measuring clarity and color parameters.
- Surface Temperature Measurement: Collects land surface temperature data, essential for studying climate change and predicting weather patterns.
- Wildfire Monitoring: Identifies hotspots to provide timely information on the location and intensity of wildfires.
- Air Quality Monitoring: Measures atmospheric pollutants like particulate matter and ozone, which are crucial for assessing air quality and its impacts on health and the environment.

#### Advantages of MODIS data

- Public Accessibility: Data are freely available for researchers and the general public.
- Data Variety: Offers a broad range of datasets, including land surface, atmosphere, and oceanic data.
- Analytical Utility: Supports advanced analysis for various scientific and practical applications (<https://modis.gsfc.nasa.gov/>).
- Land surface temperature data from MODIS Terra satellite for 2010 and 2020.

## **FINDINGS AND DISCUSSION**

The following results were obtained using the data and calculations made to analyze the effects of precipitation on the vegetation of Yakawalang District. First, the precipitation data from the GPM satellite was analyzed. Over the 11 years, the precipitation in Yakawalang District shows an increasing trend, as confirmed by the Mann-Kendall test. Next, the NDVI (Normalized Difference Vegetation Index) data, sourced from the MODIS satellite, was analyzed using the same Mann-Kendall test for the same period. The results are as follows:

Table 1 below illustrates the monthly average precipitation during the days when precipitation occurred each month. The average annual precipitation for each year was

calculated based on these monthly averages. During this period, the lowest precipitation was recorded in 2010, and the highest was in 2018. Table 1, along with the accompanying graph, displays the fluctuations in annual precipitation for 2010-2020, showing a general upward trend.

Table 1. Average monthly Precipitation data of Yakawalang District during 2010-2020

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Weighted Average
2010	18.23	85.23	35.50	25.47	28.90	27.76	16.39	24.61	3.98	3.03	4.97	3.79	277.85
2011	22.61	77.50	45.92	58.26	37.44	6.23	3.76	3.31	27.23	19.06	87.94	8.56	397.81
2012	78.58	105.42	79.31	96.60	27.58	4.29	3.47	28.21	6.35	7.32	20.53	69.42	527.08
2013	45.73	71.73	74.87	100.39	14.05	23.97	0.47	26.45	0.00	44.60	19.47	32.31	454.02
2014	15.23	69.98	116.05	43.85	41.21	15.42	1.37	4.26	14.58	37.94	19.90	19.50	399.29
2015	68.24	117.02	75.77	45.53	47.85	4.68	15.06	10.18	21.48	8.18	69.27	27.08	510.35
2016	56.76	33.95	68.53	78.02	55.37	53.29	3.68	2.63	0.11	0.52	8.18	8.74	369.77
2017	96.44	112.35	34.39	37.92	14.82	0.21	1.48	0.00	0.08	0.00	7.03	20.65	325.37
2018	11.02	54.15	173.90	109.68	225.84	0.27	0.16	0.00	0.00	20.82	25.29	14.23	635.35
2019	198.73	209.27	46.58	43.37	27.68	7.10	0.06	1.11	0.02	10.00	29.39	7.32	580.63
2020	67.77	23.79	39.03	76.58	63.19	0.81	1.90	0.00	0.16	0.32	60.19	67.39	401.15

Figure 3 shows the average precipitation over the time range of 2010-2020, with the lowest precipitation recorded in 2010 at 277 mm and the highest in 2018 at 635 mm.

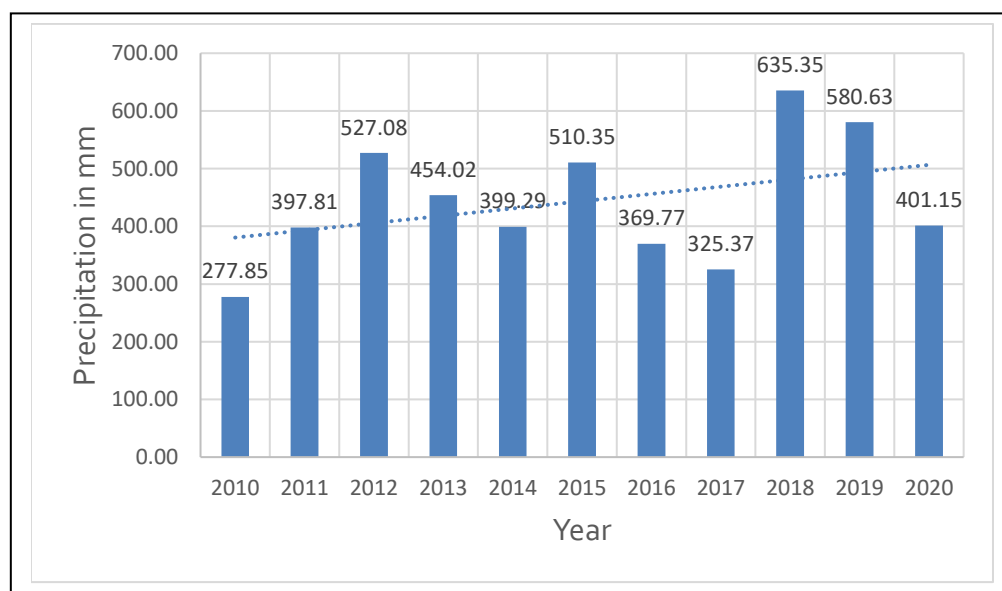


Figure 3. Average annual Precipitation graph of Yakawalang District during 2010-2020

Table 2 below shows the final result of the Mann-Kendall test on the precipitation data obtained from the GPM satellite, examining data from 11 years.

Table 2 Man-Kendall test of Precipitation data of Yakawalang District from 2010 to 2020

Man-Kendall test of Precipitation data of Yakawalang District			
Month	Test Z	Definition level	Trend
JAN	1.09		Increases
FEB	-0.6		Decreases
MAR	0.00		
APR	0.31		Increases
MAY	1.40		Increases
JUN	-1.25		Decreases
JUL	-1.80	+	Decreases
AUG	-2.60	**	Decreases
SEP	-1.33		Decreases
OCT	-0.78		Decreases
NOV	0.62		Increases
DEC	0.16		Increases
Yearly	0.93		Increases
+Definition level $\alpha=0.1$		*Definition level $\alpha=0.05$	Definition level $\alpha=0.01$
		** $\alpha=0.01$	Definition level $\alpha=0.001$
			***

The results indicate that while there is an incremental trend in annual precipitation, this trend is not statistically significant. However, in July and August, a significant decreasing trend was observed.

Figure 4 below provides a detailed view of monthly precipitation patterns for a specific year, with the highest precipitation recorded in February (85.23 mm) and the lowest in October (3.03 mm).

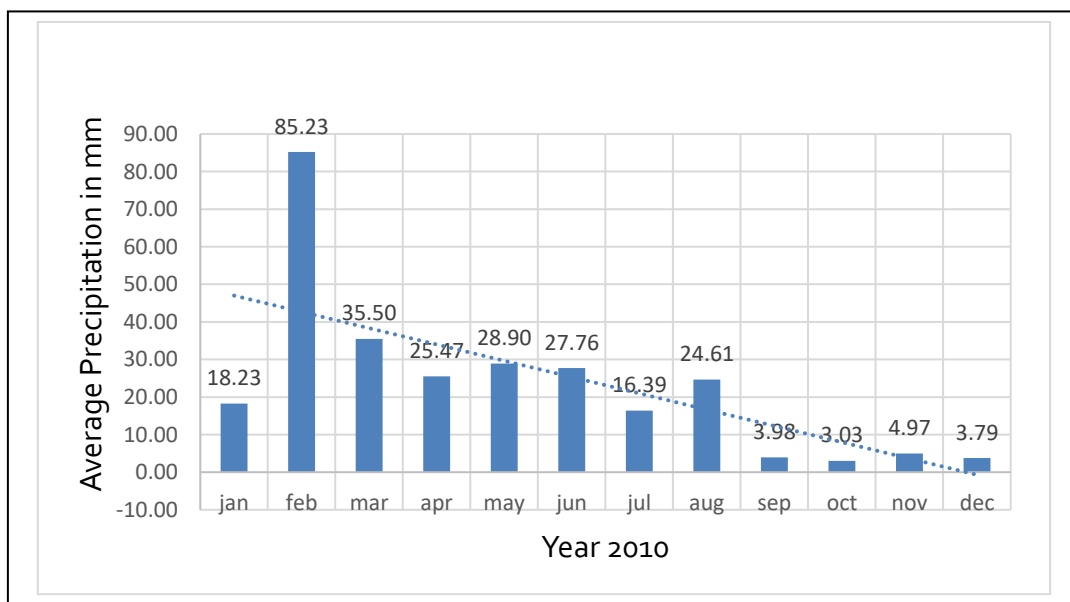


Figure 4. The average Precipitation graph of 2010 in Yakawalang district

The total precipitation for this year amounted to 277.85 mm. The average monthly precipitation exceeded 30 mm only in February and March, with the other months receiving less than 30 mm of rainfall.

In Figure 5, the highest monthly average precipitation was recorded in May (225.84 mm), while the lowest was in August and September (0.00 mm), bringing the annual average precipitation for this year to 635.35 mm.

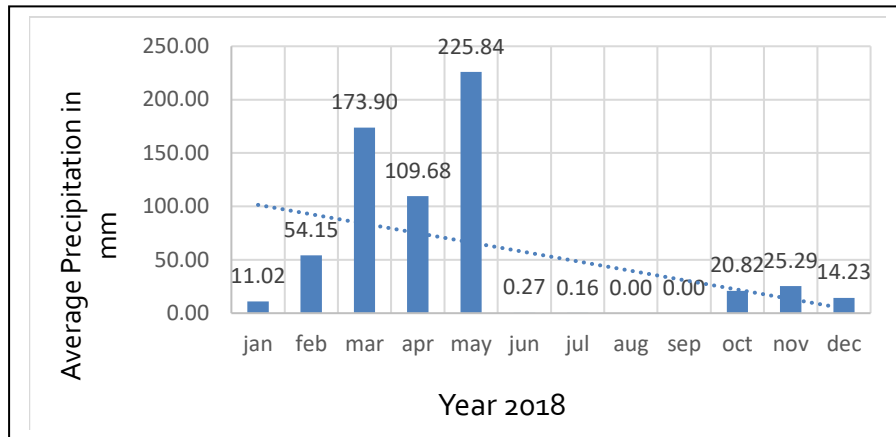


Figure 5. The graph of average Precipitation in 2018 of Yakawalang District

For clarity, precipitation maps for each year were produced to illustrate the spatial distribution of rainfall over time.

Next, the vegetation analysis in Yakawalang District was conducted using NDVI data from the MODIS-Terra satellite. The analysis shows that the vegetation cover in Yakawalang District has generally increased over the 11 years, as confirmed by the Mann-Kendall test. The NDVI data is normalized, with values ranging between -1 and +1, reflecting the extent of vegetation cover.

Table 3. Average of NDVI data of Yakawalang District from 2010 to 2020

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
2010	-0.008	-0.029	-0.002	0.098	0.170	0.185	0.170	0.145	0.132	0.129	0.123	0.103	0.100
2011	0.023	-0.021	0.003	0.071	0.160	0.166	0.147	0.134	0.130	0.124	0.032	0.010	0.080
2012	-0.013	-0.026	0.014	0.095	0.155	0.179	0.174	0.153	0.138	0.119	0.046	0.003	0.088
2013	-0.019	-0.022	-0.003	0.067	0.149	0.180	0.163	0.144	0.130	0.128	0.060	0.009	0.080
2014	0.000	-0.016	-0.015	0.029	0.147	0.181	0.166	0.147	0.135	0.134	0.054	0.033	0.081
2015	-0.006	-0.014	-0.013	0.049	0.160	0.183	0.170	0.148	0.133	0.129	0.032	-0.002	0.079
2016	-0.023	-0.018	0.002	0.062	0.174	0.189	0.163	0.145	0.135	0.134	0.132	0.040	0.093
2017	-0.011	-0.023	-0.008	0.063	0.170	0.183	0.161	0.142	0.136	0.131	0.068	0.022	0.084
2018	0.017	-0.006	0.023	0.104	0.165	0.193	0.171	0.150	0.139	0.134	0.066	0.014	0.096
2019	-0.016	-0.027	-0.019	0.077	0.163	0.199	0.176	0.154	0.143	0.139	0.049	0.013	0.085
2020	-0.022	-0.015	0.007	0.054	0.155	0.186	0.173	0.152	0.139	0.133	-0.006	-0.019	0.082

Table 3 presents the NDVI vegetation data, showing that the highest vegetation cover was recorded in 2010 (0.100), while the lowest was in 2015 (0.079).

Table 4 shows the final results of the Mann-Kendall test on the NDVI data from the MODIS-Terra satellite. The analysis indicates an incremental trend in vegetation cover over the 11 years, though this trend is not statistically significant. Significant increases in vegetation cover were observed only in June, September, and October.

Table 4. Man-Kendal test of NDVI data of Yakawalang District from 2010 to 2020

Man-Kendall test of NDVI data of Yakawalang District			
Month	Test Z	Definition level	Trend
JAN	-1.09		Decreases
FEB	1.25		Increases
MAR	-0.16		Decreases
APR	-0.62		Decreases
MAY	0.00		
JUN	2.49	*	Increases
JUL	1.10		Increases
AUG	1.40		Increases
SEP	2.66	**	Increases
OCT	2.19	*	Increases
NOV	-0.39		Decreases
DEC	-0.93		Decreases
Yearly	0.16		Increases
+Definition level $\alpha=0.1$		*Definition level $\alpha=0.05$	Definition level $\alpha=0.01$
		** $\alpha=0.01$	***

The analysis indicates an incremental trend in vegetation cover over the 11 years, though this trend is not statistically significant. Significant increases in vegetation cover were observed only in June, September, and October.

In addition, the land surface temperature (LST) for Yakawalang District was analyzed using data from the MODIS-Terra satellite. The analysis reveals that the LST has decreased over the 11 years, as shown by the Mann-Kendall test.

Table 5 Average of land surface temperature LST data of Yakawalang District from 2010 to 2020

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	average
2010	-6.41	-8.97	6.02	15.70	21.08	29.74	33.24	31.54	26.84	20.74	10.51	0.16	15.88
2011	-8.50	-10.23	4.00	15.84	27.27	32.60	35.40	34.31	28.95	14.88	1.23	-5.75	14.12
2012	-12.47	-12.77	0.69	15.90	21.99	28.51	33.17	33.08	27.19	15.93	2.53	-8.40	12.11
2013	-11.59	-6.44	3.84	10.80	22.77	32.97	35.91	32.32	30.58	20.95	4.10	-9.06	13.84
2014	-8.56	-9.42	0.66	9.86	20.35	30.65	35.46	33.99	29.92	17.13	1.67	-4.60	12.96
2015	-9.04	-5.25	0.90	11.46	22.11	32.28	34.24	32.51	26.86	17.26	1.11	-7.01	11.06
2016	-9.46	-5.12	2.78	13.59	24.71	31.43	34.90	32.79	30.02	19.29	7.22	0.27	14.17
2017	-11.90	-8.32	0.36	13.08	24.39	33.45	35.42	33.92	28.01	20.66	6.64	-4.93	14.12

2018	-4.93	-5.89	8.16	15.17	20.41	32.73	36.04	34.08	28.64	17.13	2.66	-4.09	14.96
2019	12.44	-9.05	0.45	12.26	22.64	29.86	36.10	33.96	29.41	18.57	0.14	-5.45	12.86
2020	13.31	-5.18	2.04	12.58	22.80	32.67	32.86	34.73	28.14	18.46	0.25	11.64	12.89

Table 5 shows the LST data, calculated based on monthly and annual averages. The highest recorded LST was in 2010 (15.88°C), and the lowest in 2015 (11.06°C). The non-parametric Mann-Kendall test was used to analyze the trend in surface temperature changes using the LST data.

Table 6 Man-Kendal test of LST data of Yakawalang District from 2010 to 2020

Man-Kendall test of LST data of Yakawalang District			
Month	Test Z	Definition level	Trend
JAN	-1.56		Increases
FEB	1.56		Decreases
MAR	-0.93		
APR	-0.62		Increases
MAY	0.31		Increases
JUN	0.93		Decreases
JUL	0.93		Decreases
AUG	1.71	+	Decreases
SEP	0.47		Decreases
OCT	0.47		Decreases
NOV	-1.40		Increases
DEC	-0.31		Increases
Yearly	-0.31		Increases

+Definition level  $\alpha=0.1$    \*Definition level  $\alpha=0.05$    Definition level  $\alpha=0.01$    Definition level  $\alpha=0.001$

\*\* $\alpha=0.01$    \*\*\*

In Table 6, the LST data from the MODIS-Terra satellite shows a decreasing trend in surface temperatures over the analyzed period. Figure 6 presents the NDVI vegetation cover data alongside average precipitation and LST trends for Yakawalang District.

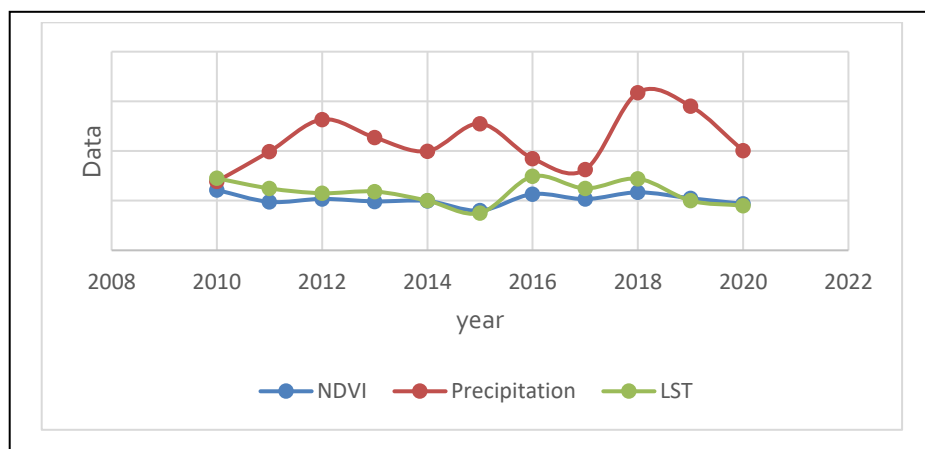
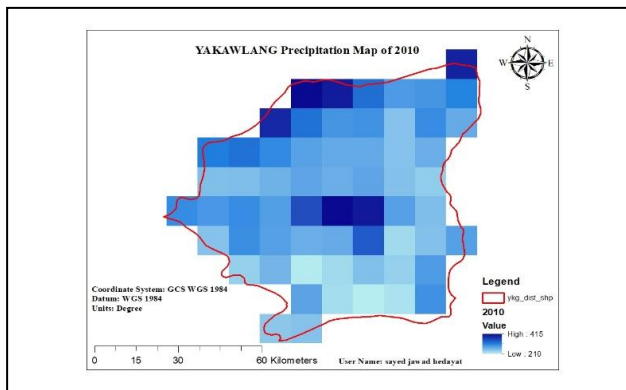


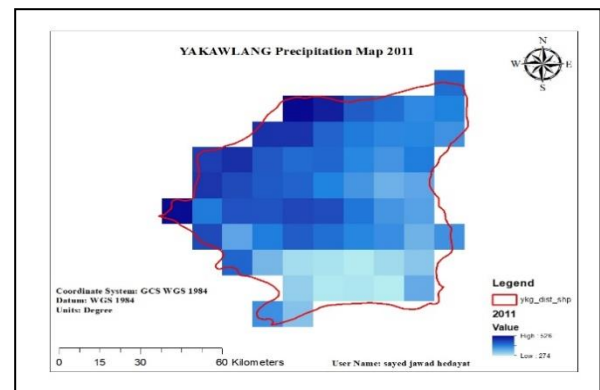
Figure 6. Graph of NDVI and Precipitation of Yakawalang 2010 to 2020

Figure 6 above illustrates the relationship between NDVI, rainfall, and LST. For example, in 2010, vegetation cover was at its highest despite the lowest recorded rainfall, while the highest surface temperatures were also recorded. Conversely, in 2011, rainfall increased, but both vegetation cover and surface temperature showed a declining trend. In 2015, while rainfall increased, vegetation cover and LST recorded their lowest values. In contrast, in 2016, despite a decrease in rainfall, vegetation cover and surface temperatures showed an upward trend. In subsequent years, vegetation cover and precipitation generally followed expected trends: an increase in rainfall typically led to an increase in vegetation cover, and vice versa.

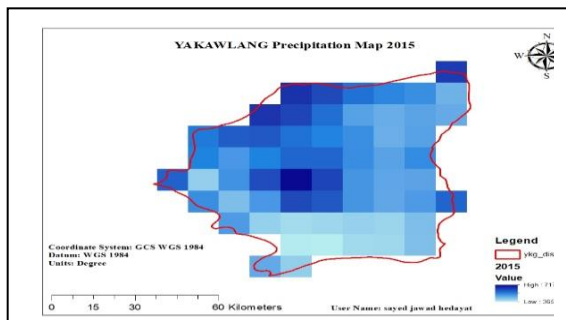
Figures 7 to 10 below show the annual precipitation maps of Yakawalang District, with each year displayed separately. On these maps, pixels in bold blue indicate areas with high precipitation levels. According to data from the GPM satellite, 2018 had the highest precipitation between 2010 and 2020, while 2010 experienced the lowest.



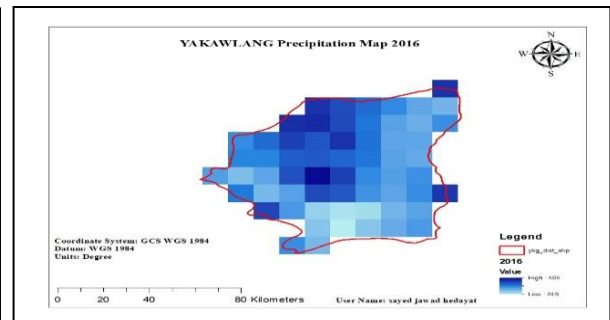
*Figure 7 Precipitation Map of 2010*



*Figure 8 Precipitation Map of 2011*



*Figure 9. Precipitation Map of 2015*



*Figure 10. Precipitation Map of 2016*

Using data from the MODIS Terra satellite, the vegetation cover map of Yakawalang District was generated. This map clearly illustrates the fluctuations in vegetation cover over the years. In some years, vegetation cover expanded significantly; in others, it was limited. The lowest vegetation cover was recorded in 2015 and the highest in 2010.

Figures 11 to 14 below show the vegetation maps of Yakawalang District from 2010 to 2020, represented by the green color indicating vegetation cover. These maps were created using MODIS Terra satellite data. As shown, 2010 had the highest vegetation cover, while 2015 had the lowest.

Despite higher precipitation in 2015 compared to 2011 and 2017, vegetation cover was much lower in 2015. This raises the question: Why was vegetation cover so limited despite more significant precipitation in 2015? The answer lies in other factors, such as climatic changes, surface temperature, topography, and air fronts in the study area, all of which will be explored further.

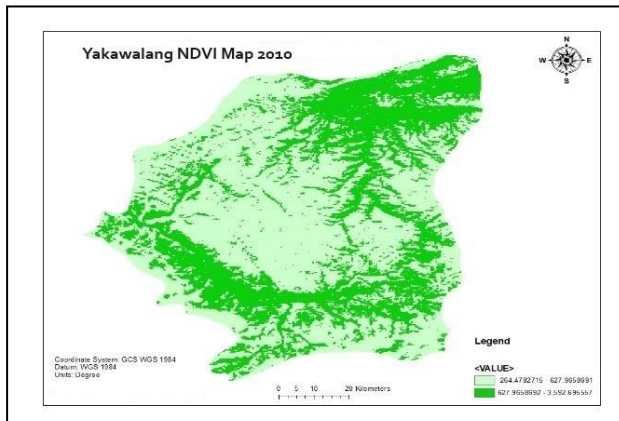


Figure 11. Vegetation Map of 2010

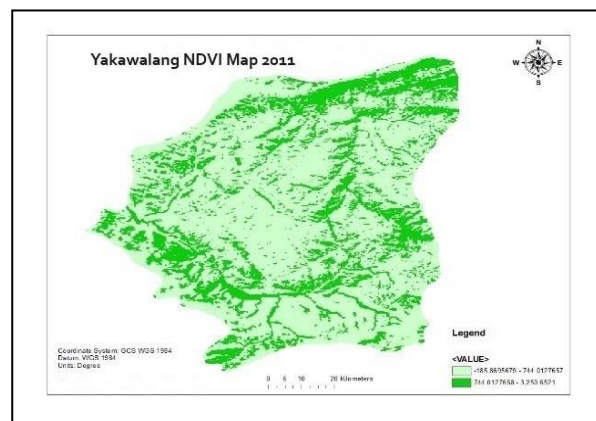


Figure 12. Vegetation Map of 2011

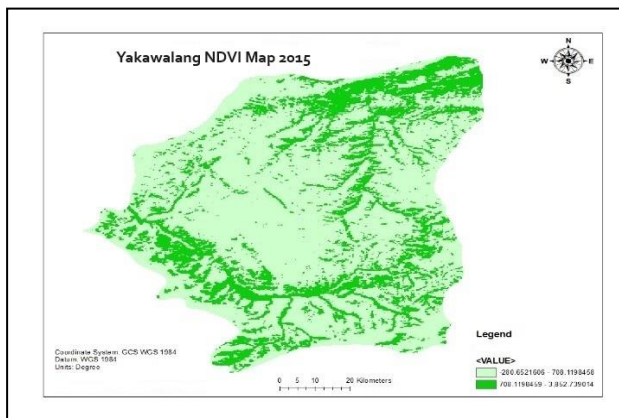


Figure 13. Vegetation Map of 2015

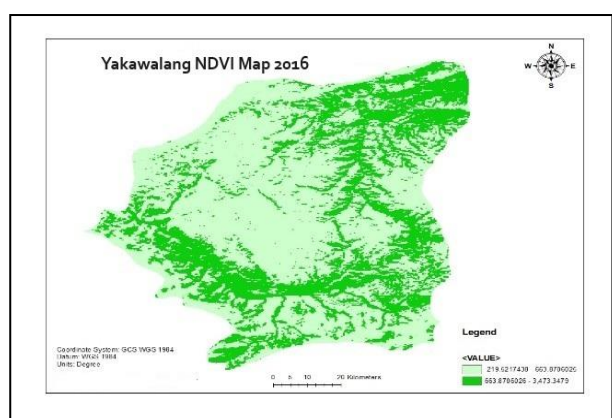


Figure 14. Vegetation Map of 2016

## CONCLUSION

Yakawalang District, with its mountainous climate, has an average elevation of 2714 meters above sea level (Azimi, 2012). Between 2010 and 2020, the region experienced an increasing trend in precipitation. However, despite this increase, vegetation growth remained limited in most years. Therefore, examining additional factors contributing to reduced vegetation growth, including surface temperature, is crucial.

In 2010, although precipitation was lower than in 2011, vegetation growth was highest between 2010 and 2020. This is due to favorable surface temperatures and the absence of cold air fronts during the growing season. In contrast, in 2015, despite receiving 510 mm of precipitation, vegetation growth was minimal. This was mainly due to low surface temperatures during the growing season and cold air fronts.

Figure 15 below shows that in 2014, surface temperatures during the plant growing season were optimal, resulting in the highest rate of vegetation growth. However, in Figure 16 below, despite the highest annual precipitation recorded between 2010 and 2020, vegetation growth was significantly lower due to several critical factors:

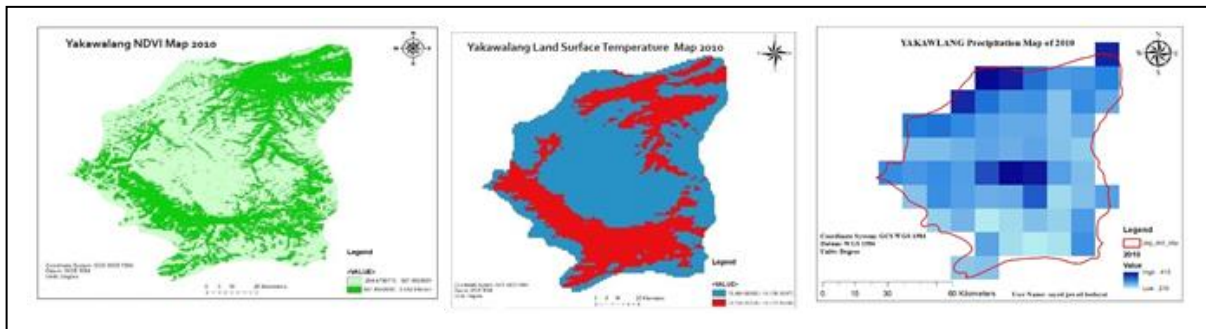


Figure 15. Map of Precipitation, Vegetation, and Land Surface Temperature of 2014

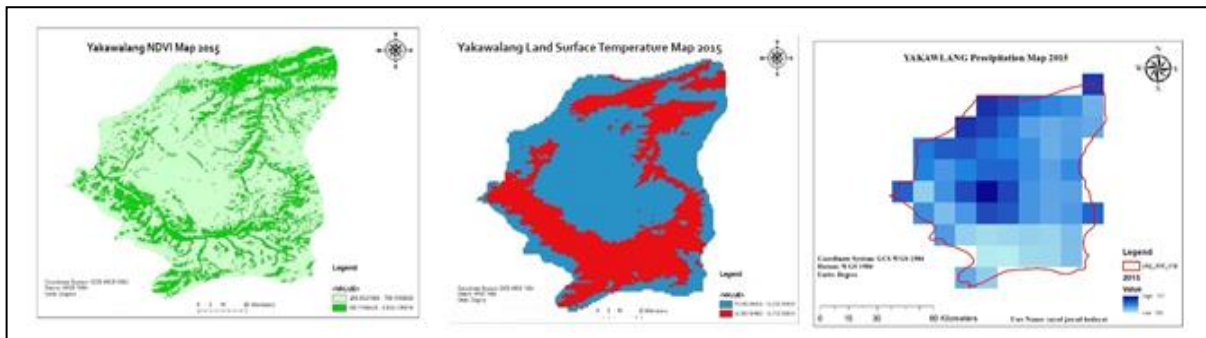


Figure 16. Map of Precipitation, Vegetation, and Land Surface Temperature of 2018

1. The mountainous nature of the region and its high altitude contributed to cooler temperatures, with excessive precipitation causing further temperature drops, negatively impacting plant growth.
2. On May 5, 2015, a cold air front entered the region, resulting in approximately 4 centimeters of snow (Water and Meteorology Department of Bamiyan Province, 2015). According to the Bamiyan Water and Meteorology Department, this cold front caused severe frost, damaging orchards, vegetables, potatoes, wheat, barley, and other crops.

Based on these findings, we conclude that precipitation alone does not determine vegetation growth. Several other factors significantly affect vegetation development, including surface temperature and climatic fronts. High precipitation was recorded in some years, but vegetation cover remained limited due to decreased surface temperatures or unfavorable climatic conditions.

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**Conflict of Interests:** The authors declare no conflict of interest.

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