Journal of Natural Science Review

Vol. 3, No. 4, 2025
https://kujnsr.com
e-ISSN: 3006-7804

The Investigation of Factors Affecting Surface Water Change Using Satellite Data and Remote Sensing Techniques: A Case of Study BAND-E-AMIR National Park, Afghanistan

Sayed Jawad Hedayat✉[1], Mohammad Kazem Yosufi[2], Mohammad Israfeel Azadmanish Azadzoi[3]

[1] Department of Geography, Faculty of Social Sciences, Parwan University, Parwan, Afghanistan.
[2] Department of Geography, Faculty of Geoscience, Kabul University, Kabul, Afghanistan.
[3] Department of Geography, Faculty of Social Sciences, Parwan University, Parwan, Afghanistan.
✉E-mail: sayedjawadhedayat32@gmail.com (corresponding author)

ABSTRACT

This study employs multi-sensor remote sensing technology to analyze the spatiotemporal dynamics of surface water area in Band-e-Amir National Park, Afghanistan. In a context of global water scarcity and a critical lack of in-situ hydrological data, satellite imagery from Sentinel-2, JRC, and Global Surface Water datasets was processed using GIS and the Automated Water Extraction Index (AWEI) to quantify surface water extent. The Mann-Kendall statistical test was applied to determine significant trends. Contrary to declining water trajectories observed in other Afghan regions, the analysis reveals a significant increase in surface water area within the park from 2000 to 2020. Interannual variability is evident, with the surface water area measured at 708.7 hectares in 2016 and 636.6 hectares in 2023. Correlation with climatic drivers indicates that this positive trend is primarily attributable to a significant increase in precipitation, as derived from GPM satellite data.In contrast, land surface temperature data from MODIS-Terra showed no statistically significant trend, ruling it out as a major contributing factor. The findings demonstrate the critical utility of remote sensing for environmental monitoring in data-scarce regions and highlight localized hydrological resilience to climate change in Band-e-Amir, driven predominantly by precipitation patterns. This research provides a foundational assessment essential for the park's future conservation and water resource management strategies.

ARTICLE INFO

Article history:

Received: August 5, 2025
Revised: November 2, 2025
Accepted: December 2, 2025
Published: December 31, 2025

Keywords:

Band-E-Amir national park; Lakes; land surface temperature; Global surface water.Man-Kendal;

To cite this article: Hedayat, S. J., Yosufi, M. K., Azadzoi, M. I. A, (2025). Article title. *Journal of Natural Science Review, 3* (4), 174-190. *https://doi.org/10.62810/jnsr.v3i4.282*
Link to this article: https://kujnsr.com/JNSR/article/view/282

INTRODUCTION

The water crisis, especially freshwater, is one of the most controversial issues in the world today, as the whole world faces this major problem (Hedayat & Yosufi, 2025). The lack of water and poor management of water resources create a water crisis that exacerbates droughts and has various environmental, social, and economic dimensions (Ebrahimi-Khusfi, 2023). The Band-e-Amir river is also the source of the Band-e-Amir Sea, which begins in Band-e-Amir and flows through the Balkh district of Balkh province, supplying water to a large number of residents of the villages. Due to financial constraints and the lack of ground monitoring and evaluation networks for supervising surface water in Afghanistan, this will cause serious problems in the future. Remote sensing and satellite imagery enable the consistent evaluation and monitoring of surface water resources over time (Wang & Xie, 2018). In addition, the presence of satellite archives since the 197s enables the identification of factors affecting the quantitative and qualitative changes in water resources and the recommendation of solutions to future changes (Yang et al., 2011). Unfortunately, there has been no survey on the surface water area of Band-e-Amir National Park. There is no land data on the surface water area of the Amir National Park; only a 2025 topic on Band-e-Amir surface water. In this topic, only monitoring and detection of two large lakes in Band-e-Amir national park (Akyuz et al., 2025); therefore, satellite data will be suitable for calculating the surface water area of Band-e-Amir national park. Since climatic monitoring shows that global warming of the Earth's climate results in less but more severe Precipitation (the Precipitation period decreases, but the amount of Precipitation is high), and this causes more surface water changes(Hedayat & Yosufi, 2024). Global climate change has modified the regional climate of Band-e-Amir National Park, leading to a significant decrease in precipitation. This climatic variable is a key factor influencing the variability and changes observed in the park's surface water resources. Today, with the advancement of science and technology, and especially Remote Sensing (RS) technology, it is widely used worldwide in many areas such as natural resources, climatic, soil science, agriculture, surface water and underground, etc (Hedayat et al., 2024). In this study, using remote sensing technology, the surface water area of Band-e-Amir national park has been calculated. Band-e-Amir national park has made many changes to its natural face after the announcement of the first national park in Afghanistan. For example, with the increase in the population of tourists and the lack of basic amenities such as roads, release houses, garbage, etc., the area's pollution increased year by year, and this increased pollution caused climate change. Climate change has reduced precipitation and had a direct impact on the surface water of Band-e-Amir national park.

Akyuz et al. (2025) conducted their research on analyzing and mapping changes in water surface area using remote sensing data: a case study of Band-e-Amir National Park, Afghanistan. In this study, the Landsat 8 satellite data were used. This research focuses on monitoring and detecting surface water in Band-e-Amir National Park. Surface water monitoring and detection in this study used the NDWI and AWEI indices. The results of this study show only the Zulfiqar and Haibat lakes because they are the largest lakes in Band-e-Amir National Park.

Hedayat and Yosufi (2024) conducted a study analyzing factors affecting changes in surface and groundwater resources in Kabul province using satellite images and remote sensing techniques. The results showed that the groundwater resources of Kabul province, obtained from the Grace satellite and calculated by the Maan-Kandal test, have a significant decline. The results obtained from NDVI and EVI vegetation data from the MODIS-Tara sensor, calculated by the Maan-Kandal test showed that the amount of vegetation in the province increased and has a significant increase in trend; The area obtained for EVI vegetation was obtained in 2002 (283 km 2), 2016 (313.020 km 2) and 2022 (436 km 2) and for NDVI vegetation in 2002 (316 km 2), 2016 (363 km 2) Kilometers) calculated; It should be noted that the area of the classified vegetation is the image of Sentinel 2 in 2022 (519 km2). The area of surface water resources in Kabul province has also changed. Data from the JRC Landsat Satellite 5, 7, and 8 products show that the province's surface water area has decreased significantly. The area obtained for surface water in Kabul province was calculated in 2000 (1616 hectares), 2005 (2902 hectares) and in 2020 (1706 hectares). The area obtained by the surface water of Kabul province was calculated using a monitoring class (1128 hectares) in 2022.

Azadmanish (2024) conducted his research on the effects of climate change on underground water in Kabul at Parwan University. He has concluded that the city of Kabul, the capital of Afghanistan, has been affected by serious climate change, including reduced groundwater levels. On the one hand, climate change; on the other hand, reduced water demand has led to groundwater depletion in Kabul. In this research, a mixed-method approach combining a review of the library's articles and resources, field research with the Environmental Department of Environment, and climatic information was used to collect and analyze data. The data have been analyzed using GIS software. In order to analyze the factors affecting the reduction of groundwater in Kabul, compare the impact of climate change on water recovery and extraction, and conclude that due to the lack of Precipitation and sustained droughts on the one hand, and the increase in demand for water on the other, the sub-land of Kabul will be severely reduced in the near future.

Ehsani (2024) has defended his master's dissertation on the impact of temperature and Precipitation parameters on the surface and underground coating of the Hirmand Basin at Yazd University. He has concluded that climatic parameters, especially temperature and Precipitation, have a direct impact on surface and groundwater in the Hirmand Basin. Of course, temperature and precipitation alone do not cause surface and groundwater changes in the Hirmand Basin, but they are among the most important factors. Other factors, such as population growth, recent droughts, increased vegetation, and increased evapotranspiration, have also reduced surface and groundwater resources in the Hirmand Basin.

Karl & Knight (1998) conducted research on underground water in the Kabul Basin. They said about the underground water in Kabul: Kabul is located in the southern part of the Kabul Basin. The city has been growing since 2001, and its population is increasing day by day. In 2015, after 15 years, the city's population reached 4.8 million, accounting for approximately 15% of Afghanistan's population. The rapid population growth in the city, along with the effects of climate change, has raised concerns about declining groundwater levels. The entire city's population supplies its own drinking water from groundwater sources. They believe that natural factors, such as climate change, and human factors, such as rapid population growth and unnecessary groundwater extraction, have reduced the city's underground water, which has so far lowered the groundwater level in Kabul to 1.5 meters.

The purpose of this study is to analyze the factors affecting surface water changes in Band-e-Amir National Park, using satellite data. Because there has been no survey on the water of the Band-e-Amir national park, it is still important to investigate the surface water area of Band-e-Amir national park. Due to the lack of ground data in this study, satellite data has been used as a substitute.

METHODS AND MATERIALS

This section details the study area, the data collected, and the methods of data analysis. A specific methodology was employed to ensure the research objectives were met, and the approach was designed to be replicable.

For data analysis in this research, a mixed (analytical-scientific and statistical) method has been used. First, the desired data is collected from the satellites and prepared using GIS and Excel Software. The servant used the prepared data for a special purpose, for example, to apply the AWEI index, satellite images were used, JRC data was used to change the surface water area, use GPM satellite data for the effect of Precipitation on surface water, and for monitoring of Band-e-Amir surface water using global surface water data. Some of the data used in this study is a series of times when Excel calculates the trend of increasing or decreasing changes. The area of the other data will also be calculated first in GIS and then displayed in Excel as tables and graphs.

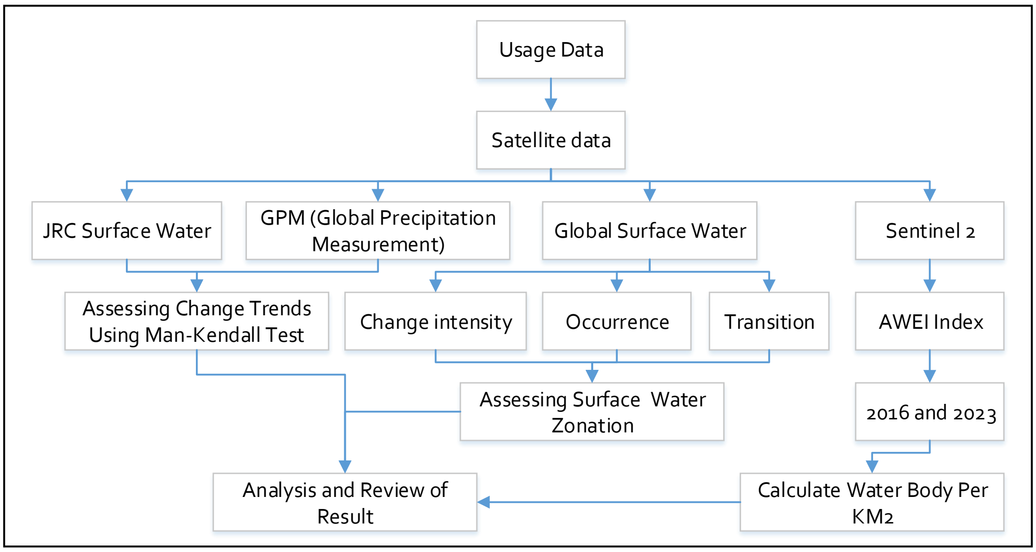

Figure 1.*methodology flowchart*

The Flowchart is shown in the method. The satellite data used consists of four sections: Sentinel 2, Global Surface Water, GPM, and JRC Surface Water. Sentinel 2 images for extracting surface water of Band-e-Amir national park using the AWEI index in 2016 and 2024 are calculated, and the surface water area has been calculated in both years. Global Surface Water data were used to capture surface water changes, three of which were used to adjust water intensity, water occurrence, and water state changes. The GPM satellite time series data were used to obtain precipitation, and the JRC time series data were used to obtain surface water area. These data were calculated using my unprecedented test, and the process of change was calculated. For surface water zoning, Sentinel 2 and three Global Surface Water products are used, processed in GIS software, and displayed as maps. Finally, using the products and calculations made, the surface water zoning of the Band-e-Amir national park has been analyzed.

In this research, the trend of changes in all parameters at different levels of significance has been investigated using the Mann-Kendall test. As a nonparametric method, this test has advantages that have led to its widespread use in analyzing the trend of hydroclimatic series (Giardino et al., 2010). In this test, the null hypothesis indicates randomness and the absence of a trend in the data series, and accepting the null hypothesis (rejecting it) suggests the existence of a trend in the data series (Gilabert et al., 2002). In the Mann-Kendall method, it is assumed that the time series is x1, x2,..., xn. The Mann-Kendall test statistic is calculated using equation 1. In this relation, j and k are the order of observations, and the sign function sgn(x) is defined as equation 2(Tenreiro et al., 2021).

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

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

According to this test, if S is not significantly different from zero, there is no trend. Otherwise, the trend will be upward or downward. To test the significance of the trend, the standard normal Z variable is used according to equation 3. The null hypothesis (Ho) in the Mann-Kendall test is the absence of a trend, and the hypothesis H1 is the presence of a trend (Salmi et al., 2002).

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

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

Equation 5 shows the AWEI (Automatic Water Extraction Index). This index is used for water body extraction from satellite images. The formula of this equation is:

$$(5)\quad AWEI= G*(GREEN-SWIR2)-(L*NIR+C*SWIR1)$$

In this equation, G = 4, L = 0.25, and C = 2.75 are fixed numbers. I use Sentinel 2 satellite images in this research; in these images, GREEN equals band 3, SWIR1 equals band 11, and AWIR2 equals band 12 (Kundzewicz, 1997).

Study Area

Band-e-Amir National Park is located in Bamyan province, Yakawalang number 1 district. Band-e-Amir National Park has 7 natural lakes: Zulfiqar Lake, Pudina Lake, Panir Lake, Haibat

Lake, Ghulaman Lake, Qambar Lake, and Espinaab Lake. The largest lake in Band-e-Amir National Park is Zulfiqar Lake, and the smallest is Qambar Lake. The water resources of these lakes are snow and natural glaciers. At the bottom of these lakes, some mineral springs exist. Band-e-Amir National Park is a popular tourist destination that attracts many domestic and international visitors each year. Band-e-Amir National Park is the first national park in Afghanistan and was designated in 2009 (Smallwood et al., 2011). Band-e-Amir national park includes 14 villages, and the people there are Sadat and Hazara. Band-e-Amir National Park is located 215 kilometers from Kabul, the capital of Afghanistan, 75 kilometers west of Bamyan province, and 17 kilometers northeast of Yakawalang number 1 district, and lies among the eastern Hindu Kush and Baba mountains in the center of the country (Akyuz et al., 2025).

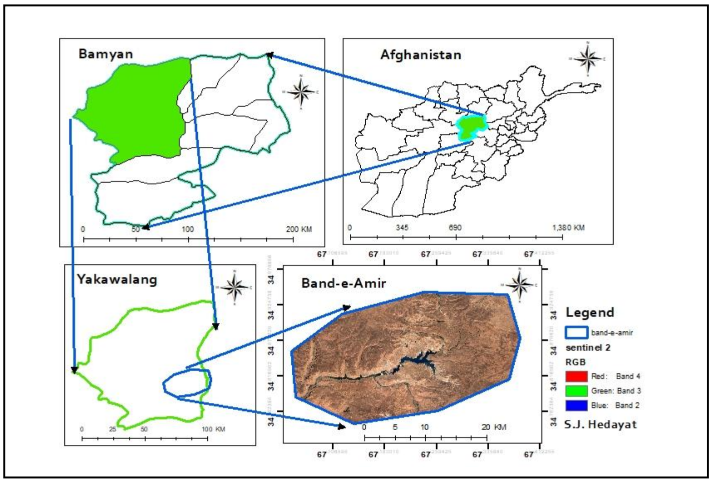

Figure 2. *Map of the study area*

Data Usage

Due to the lack of ground data and a careful survey of the surface water area of Band-e-Amir national park, in this study, satellite data is used, which includes the following:

For surface water zoning in Amir National Park, Sentinel 2 images from 2016 and 2023 are used. For the surface water in Band-e-Amir National Park, the AWEI index has been applied to the images, and the surface water delineated. Then, using GIS software, the surface water area of Band-e-Amir National Park is calculated.

Global Surface Water images have been used to map the surface water of Band-e-Amir National Park. These images are made from a series of Landsat satellites that are destroyed for seasonal water, freshly formed water, and the maximum probability of data available. Using these data, seasonal water and surface water can be eliminated, and newly formed surface water can be identified.

The JRC data have been used to study changes in surface water area. This data is from the Landsat Satellite series taken from Google Earth Engine. Using this data, the process of changes in the surface water area of the Band-e-Amir national park will be determined. This data is numeric and was calculated using the Maan-Kandal test and the process of change; its meaningful level will be determined.

GPM Data has been used to assess the impact of Precipitation on the surface water area of the Band-e-Amir National Park. Using this data, the changes in precipitation will be calculated first. Then, the effects of precipitation on changes in surface water area in Band-e-Amir National Park will be determined. This data is also numerical and is calculated using the Mann-Whitney test, and the change and its significance level will be determined.

FINDINGS

In this section, the results of the analyzed data are displayed in tables, maps, and graphs. The numeric data will first be examined in tables, then in graphs, and finally in maps.
The table below shows the area of surface water of the Band-e-Amir national park.

Table 1. *Surface water area per hectare*

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Area per hectare
2000	0.0	28.0	195.0	7847.0	7664.0	7261.0	7128.0	7437.0	7168.0	0.0	7699.0	0.0	749.0
2001	0.0	0.0	72.0	6305.0	0.0	7318.0	0.0	0.0	7323.0	0.0	7811.0	0.0	720.7
2002	0.0	29.0	0.0	5598.0	7619.0	0.0	7350.0	7157.0	7222.0	7535.0	7810.0	0.0	740.0
2003	0.0	35.0	228.0	0.0	6223.0	0.0	0.0	6407.0	6879.0	7163.0	7315.0	0.0	713.5
2004	0.0	0.0	41.0	0.0	7744.0	7203.0	7469.0	7326.0	7414.0	7771.0	0.0	0.0	749.5
2005	0.0	0.0	61.0	8098.0	6597.0	7674.0	7378.0	7363.0	7468.0	7706.0	7360.0	0.0	746.3
2006	0.0	0.0	244.0	7819.0	7785.0	7525.0	7470.0	7399.0	6708.0	7714.0	7377.0	0.0	750.5
2007	0.0	13.0	0.0	7850.0	7673.0	7555.0	7121.0	7436.0	7472.0	7815.0	7612.0	0.0	756.8
2008	0.0	6.0	224.0	7336.0	7539.0	7475.0	7488.0	7344.0	7625.0	7723.0	7729.0	0.0	756.1
2009	0.0	44.0	47.0	4869.0	7985.0	7704.0	7647.0	7561.0	7528.0	7890.0	8041.0	0.0	741.5
2010	0.0	0.0	112.0	7777.0	7312.0	7701.0	7394.0	6778.0	7375.0	7796.0	7566.0	0.0	747.6
2011	0.0	15.0	230.0	8176.0	7578.0	7448.0	7457.0	0.0	7598.0	7650.0	0.0	0.0	769.2
2012	0.0	2.0	10.0	7374.0	7224.0	7606.0	7372.0	7324.0	7198.0	7649.0	8010.0	0.0	747.1
2013	0.0	5.0	258.0	7903.0	7962.0	7621.0	7548.0	7443.0	7600.0	7901.0	7996.0	0.0	778.0
2014	0.0	5.0	155.0	6464.0	7682.0	7865.0	7607.0	7536.0	7695.0	7715.0	8010.0	0.0	759.2
2015	0.0	1.0	146.0	8094.0	7736.0	7768.0	7638.0	7568.0	7605.0	8065.0	6297.0	0.0	761.5
2016	0.0	65.0	1544.0	7972.0	8155.0	7785.0	7581.0	7661.0	7862.0	8009.0	7438.0	0.0	800.9
2017	0.0	44.0	1085.0	8224.0	8118.0	7876.0	7702.0	7658.0	7781.0	8070.0	7707.0	0.0	803.3
2018	0.0	309.0	1361.0	8206.0	7997.0	7810.0	7635.0	7570.0	7573.0	7958.0	7896.0	0.0	803.9

2019	0.0	27.0	114.0	8522.0	8169.0	7482.0	7773.0	7675.0	7778.0	8036.0	7207.0	0.0	784.8
2020	0.0	32.0	678.0	8481.0	8315.0	7941.0	7729.0	7741.0	7756.0	8305.0	0.0	0.0	814.0

The above table calculates the surface water area of Band-e-Amir National Park from 2000 to 2020. This data was obtained from the JRC site, which is available by 2020. In the table above, the monthly area of surface water is calculated as square meters, but the intermediate area of the annual area is calculated as hectares.

The bottom graph shows the trend of surface water area of the Band-e-Amir national park from 2000 to 2020.

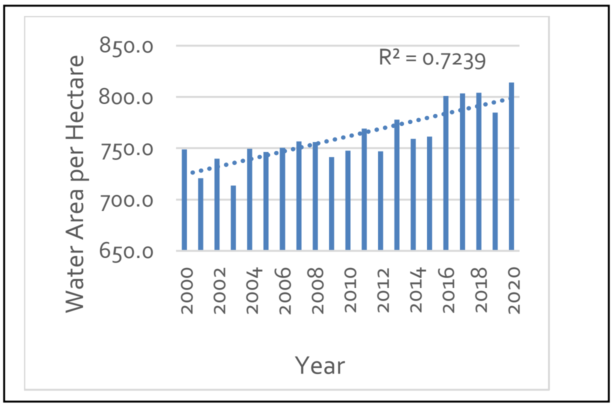

Figure 3. *water average per hectare*

In the above graph, changes in surface water area per hectare in Band-e-Amir National Park are shown, with an increasing trend (R2 = 0.7239).

At the bottom of the applied index, surface water extraction is applied to satellite images of the 2016 and 2023 surface water.

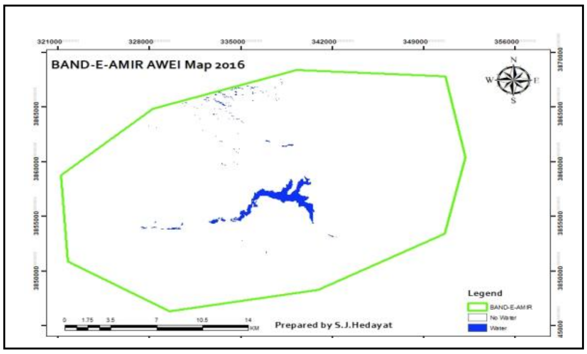

Figure 4. *AWEI map of Band-e-Amir 2016*

The figure above shows the water extraction index on an image from the Sentinel 2 satellite in 2016. The area of surface water is 708.7 hectares using this index.

At the bottom of the applied index, surface water extraction is applied to the 2023 satellite image and surface water zones.

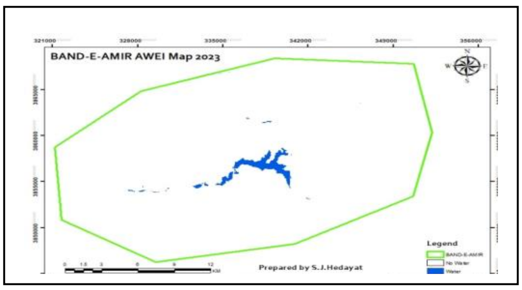

Figure 5. *AWEI map of Band-e-Amir 2023*

The figure above shows the water extraction index on an image from the Sentinel 2 satellite in 2016. The area of surface water is 636.6 hectares using this index.

The bottom table shows the surface water area obtained using the automatic water extraction index in Band-e-Amir National Park from Sentinel-2 satellite imagery in 2016 and 2023.

Table 2. *AWEI area on 2016 and 2023*

Year	Parameter	Total Pixel	Pixel Area Per m²	Total Area per m²	Total Area per Hectare
2016	Water	83433	84.9	7087024.7	708.7
	Non-Water	5977794	84.9	507769995.0	50777.0
2023	Water	74939	84.9	6365521.4	636.6
	Non-Water	5986288	84.9	508491498.3	50849.1

In the table above, the surface water area of Band-e-Amir National Park is calculated in hectares. It should be noted that due to the lack of access to the file-studied area, the area obtained from the water-free areas is not equal to the total area of Band-e-Amir national park.

Global Surface Water data has been used to detect changes in surface water. These data consist of six different products, with only three products used in this study:

The bottom of the map shows the surface water intensity of the Band-e-Amir national park. This map shows areas where water levels are reduced or increased as a percentage.

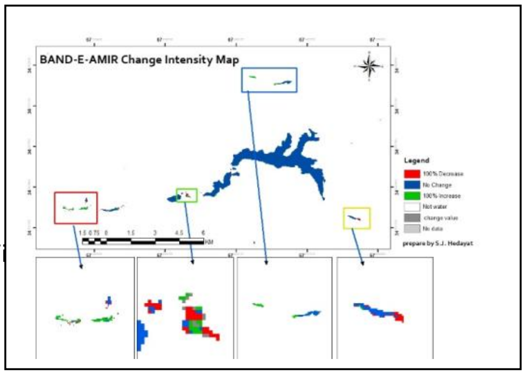

Figure 7*. change intensity map of Band-e-Amir*

In the map above, the red areas indicate where surface water has been reduced by 100%, meaning the water has already dried up and been destroyed. Green-colored areas indicate a 100% increase in surface water, meaning that water has not previously formed in these areas. Areas displayed in water include areas where surface water has no changes. It should be noted that the data span the period from 1984 to 2021. The bottom of the map shows the water percentage.

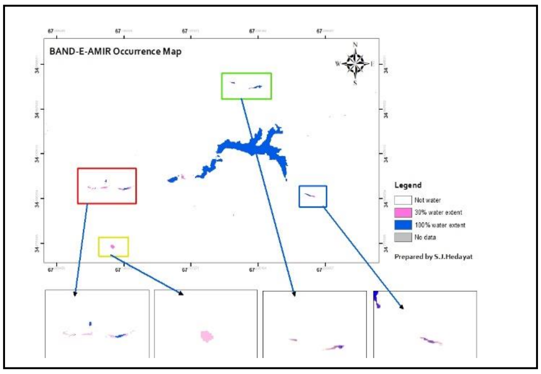

Figure 8: occurrence map of Band-e-Amir

The above map shows the surface water of Band-e-Amir National Park as a percentage. This data covers the period from 1984 to 2021. That is, all surface water data between the above years are compared and displayed in different colors. Purple -shown areas include areas where 30% of water is available during this period, and areas displayed in blue include areas where water was completely unavailable during this period, and no changes have occurred. The bottom of the map shows the surface water modification of the Band-e-Amir national park. The period covered by these data is 1984 to 2021.

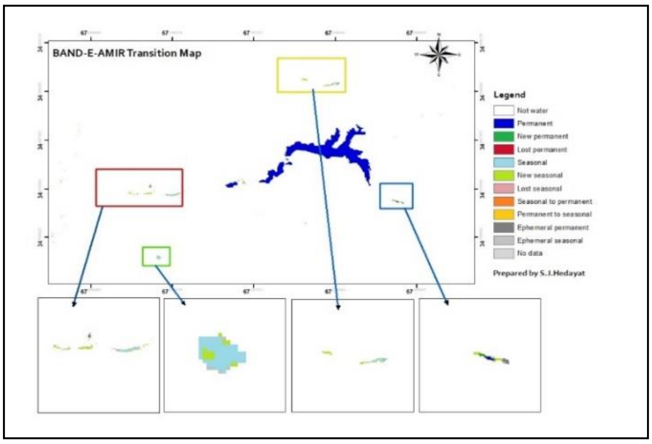

Figure 9. *transition map of Band-e-Amir*

The above map shows the surface water change of the Band-e-Amir national park between 1984 and 2021. On this map, permanent, seasonal, new permanent, permanent, and seasoned water are displayed. This means in which areas of this period there was permanent water, and for whatever reason, there was no permanent water, but newly formed as well as seasonal water. The table below shows the process of surface water change in Band-e-Amir National Park between 2000 and 2020, calculated using the Mann-Kendall test.

Table 3. *Maan-Kendal test of Band-e-Amir surface water*

	Man-Kendall test of Band-E-Amir surface water		
Month	Test Z	Definition level	Trend
JAN			
FEB	1.68	+	Increases
MAR	2.24	*	Increases
APR	3.20	**	Increases
MAY	3.41	***	Increases
JUN	3.87	***	Increases
JUL	4.23	***	Increases
AUG	3.75	***	Increases
SEP	3.77	***	Increases
OCT	4.23	***	Increases
NOV	-0.21		Decreases
DEC			
Yearly	3.59	***	Increases
+Definition level ∝=0.1	*Definition level ∝=0.05	Definition level **∝=0.01	Definition level ∝=0.001 ***

The table above shows my test results for the surface water of Band-e-Amir National Park. The process of surface water change in Band-e-Amir National Park is increasing and showing significant changes. GPM satellite data and surface temperature from the MODIS-Terra satellite have been used to identify factors affecting surface water changes. The period covered by these data is 2000 to 2021. The table below shows the Precipitation of Band-e-Amir National Park between 2000 and 2021.

Table 4. *Band-e-Amir precipitation table*

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2000	0.0	0.0	0.0	0.0	0.0	4.3	2.2	0.0	0.7	14.9	7.9	33.5	63.6
2001	38.7	39.0	19.3	10.8	6.7	5.0	2.2	0.0	0.0	3.0	8.6	20.1	153.5
2002	84.8	57.1	29.8	20.9	17.1	2.9	0.0	0.7	0.7	0.7	20.2	50.6	285.5
2003	20.8	51.1	75.9	31.7	11.2	0.7	0.0	1.5	3.6	0.7	23.0	93.0	313.2
2004	41.7	18.8	9.7	22.3	8.2	2.9	6.0	4.5	0.0	3.7	12.2	70.7	200.6
2005	72.2	83.3	32.0	14.4	43.9	4.3	0.7	0.7	0.0	0.7	14.4	15.6	282.4
2006	203.9	36.3	28.3	14.4	6.0	2.9	1.5	6.7	2.9	3.0	42.5	158.5	506.6
2007	29.0	67.9	72.9	23.0	7.4	13.7	5.2	6.7	0.0	0.7	4.3	64.0	294.9
2008	103.4	107.2	19.3	46.8	8.2	2.9	0.7	3.7	2.2	1.5	2.9	25.3	324.1
2009	161.4	85.3	48.4	63.4	22.3	10.1	0.7	0.0	14.4	2.2	15.8	85.6	509.7
2010	20.8	90.7	28.3	19.4	24.6	28.8	8.2	20.8	2.9	3.0	2.9	5.2	255.6
2011	31.2	65.2	43.2	51.8	21.6	7.9	3.7	3.7	29.5	13.4	80.6	10.4	362.3
2012	87.8	131.5	76.6	83.5	18.6	2.2	2.2	9.7	6.5	9.7	26.6	107.9	562.8
2013	65.5	86.7	70.7	92.2	4.5	12.2	0.0	10.4	0.0	48.4	26.6	33.5	450.6
2014	15.6	75.9	129.5	33.8	42.4	15.8	1.5	2.2	14.4	46.9	15.1	19.3	412.6
2015	62.5	112.2	67.7	51.1	32.7	3.6	9.7	9.7	20.2	9.7	63.4	37.2	479.6
2016	59.5	50.1	63.2	71.3	32.7	44.6	4.5	2.2	0.0	1.5	10.1	5.2	345.0
2017	107.9	116.9	44.6	34.6	7.4	0.0	0.0	0.0	0.0	0.0	4.3	7.4	323.2
2018	9.7	57.8	183.8	63.4	204.6	0.7	0.0	0.0	0.0	10.4	22.3	16.4	569.0
2019	232.9	232.5	45.4	40.3	20.1	4.3	0.0	0.0	0.7	5.2	36.7	8.2	626.3
2020	69.9	25.1	35.7	71.3	34.2	0.7	1.5	0.0	0.7	0.7	58.3	80.4	378.6
2021	30.5	9.4	49.1	13.0	27.5	0.0	3.0	0.0	0.7	0.0	0.0	0.0	133.2

The table above shows the amount of Precipitation in Band-e-Amir National Park between 2000 and 2021. These data are obtained from the GPM satellite and are calculated monthly to the national level. The bottom graph shows the process of Precipitation changes in Band-e-Amir National Park.

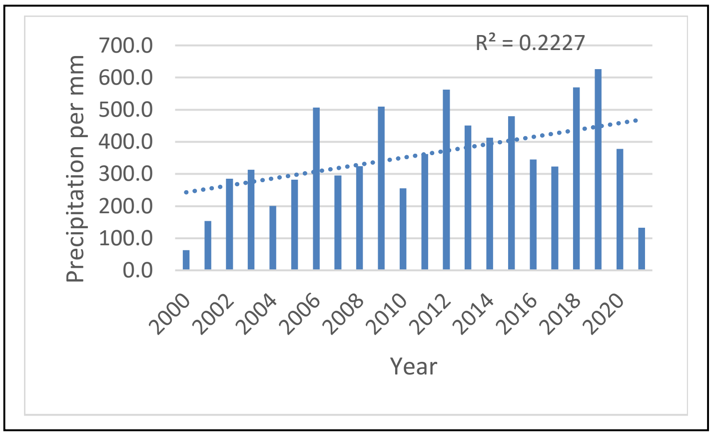

Figure 10. *precipitation graph of Band-e-Amir*

The above graph shows the precipitation process in Band-e-Amir National Park. The trend in Precipitation in the national park increased between 2000 and 2021, and the R2 value for Precipitation is 0.227. The table below shows the results of the Mann-Kendall test for Band-e-Amir National Park.

Table 5. *Man-Kendall test of Band-e-Amir precipitation*

Man-Kendall test of Band-E-Amir Precipitation			
Month	Test Z	Definition level	Trend

JAN	0.54		Increases
FEB	1.52		Increases
MAR	2.26	*	Increases
APR	2.74	**	Increases
MAY	2.46	*	Increases
JUN	-0.60		Decreases
JUL	-0.17		Decreases
AUG	-0.44		Decreases
SEP	0.35		Increases
OCT	0.00		Increases
NOV	0.76		Increases
DEC	-1.86	+	Decreases
Yearly	2.54	*	Increases
+Definition level ∝=0.1	*Definition level ∝=0.05	Definition level **∝=0.01	Definition level ∝=0.001 ***

In the table above, the precipitation process in Band-e-Amir National Park is analyzed using a nonparametric test, and the trend of its changes is significantly detected. The table below shows the surface temperature of Band-e-Amir National Park over the period 2000 to 2022. These data are obtained from the MODIS-Terra satellite.

Table 6. *Band-e-Amir LST table*

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE
2000		-6.82	2.10	23.80	36.17	36.82	38.44	38.45	31.29	22.72	-2.53	-10.21	21.22
2001	-11.99	-7.14	5.80	21.73	32.05	37.08	37.96	36.11	30.65	23.10	8.27	-7.42	16.04
2002	-11.73	-7.91	3.70	14.73	28.04	35.48	36.98	37.25	30.63	22.84	4.53	-10.46	15.19
2003	-10.10	-10.06	-1.94	15.31	25.66	34.49	37.88	34.98	30.06	23.72	3.83	-12.09	14.08
2004	-11.67	-7.46	8.10	18.48	30.50	34.53	34.89	35.72	30.78	18.32	7.02	-9.68	15.67
2005	-15.04	-10.13	-1.86	10.96	19.72	27.62	35.04	35.27	31.42	21.53	0.42	-4.87	12.34
2006	-12.17	-5.48	1.63	15.01	31.40	34.62	36.36	35.52	30.64	22.67	2.75	-12.27	14.89
2007	-13.32	-8.61	-2.99	15.23	26.95	34.04	35.73	35.35	29.18	22.51	15.27	-10.75	14.71
2008	-16.17	-9.03	10.76	15.26	29.88	36.17	37.34	34.70	31.14	20.26	9.72	-2.16	16.35
2009	-12.80	-10.02	-0.86	6.87	23.08	28.17	35.94	35.58	29.89	19.13	4.54	-11.30	12.32
2010	-9.31	-9.78	3.83	17.94	21.88	31.78	34.89	32.75	29.22	23.39	13.39	1.36	15.74
2011	-7.35	-10.94	3.88	19.36	31.05	34.91	37.68	36.78	31.49	17.52	3.98	-3.44	16.15
2012	-12.43	-13.11	1.04	18.28	25.11	30.31	34.98	35.40	29.80	18.13	2.75	-8.74	13.44
2013	-12.70	-7.00	1.94	10.59	24.92	34.39	36.87	33.92	33.07	23.55	4.42	-10.02	14.38
2014	-8.99	-10.83	-1.90	8.93	20.98	32.08	37.07	36.05	32.42	19.16	3.03	-2.84	13.75
2015	-10.02	-5.02	0.41	12.25	24.98	34.60	35.88	35.18	29.54	19.04	0.88	-7.98	14.08
2016	-9.89	-6.14	2.13	15.36	26.11	33.61	36.81	34.78	32.58	22.11	9.81	2.72	16.61
2017	-12.60	-9.29	-0.98	14.16	26.78	35.46	37.26	36.17	31.04	23.11	9.63	-2.74	15.54
2018	-4.27	-4.91	10.31	18.56	22.60	35.37	38.46	36.15	31.57	20.35	4.44	-5.36	16.83
2019	-13.85	-9.96	-1.73	13.79	25.47	32.44	37.71	36.04	31.99	21.02	-0.09	-7.12	13.65
2020	-14.01	-6.23	0.12	13.38	25.37	35.35	34.57	37.03	30.60	21.02	0.34	-12.79	13.77
2021	-11.83	-4.15	3.83	20.06	27.15	35.24	36.32	36.42	33.44	21.17	7.67	-0.50	16.92
2022	-11.73	-7.74	11.76	25.84	30.85	36.00	37.20	34.65	31.41	23.02	4.41		20.05

In the table above, the precipitation of Band-e-Amir National Park is calculated based on the temperature in Celsius between 2000 and 2022. These data are obtained from the MODIS-Terra satellite. The bottom figure shows the process of surface temperature changes in Band-e-Amir National Park over the period 2000 to 2022.

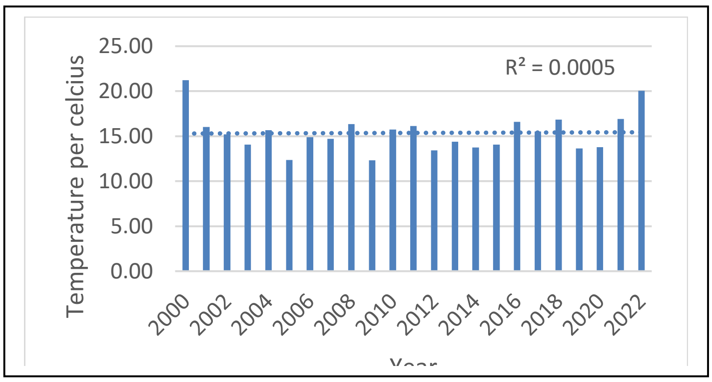

Figure 11. *Band-e-Amir LST graph*

In the above graph, the surface temperature of the Band-e-Amir National Park is shown for the years 2000-2022 in Celsius. The process of temperature changes in Band-e-Amir national park has been normal during this period, with neither rising nor falling. The calculated R2 value for the surface temperature of Band-e-Amir National Park is 0.0005. The following table shows the results of the Mann-Kendall test for the temperature of Band-e-Amir National Park between 2000 and 2022.

Table 7. *Man-Kendall test of Band-E-Amir LST*

Man-Kendall test of Band-E-Amir Temperature			
Month	Test Z	Definition level	Trend
JAN	0.34		Increases
FEB	0.63		Increases
MAR	0.21		Increases
APR	-0.16		Decreases
MAY	-1.27		Decreases
JUN	-0.05		Decreases
JUL	-0.32		Decreases
AUG	-0.26		Decreases
SEP	1.53		Increases
OCT	-0.69		Decreases
NOV	-0.32		Decreases
DEC	1.64		Increases
Yearly	0.32		Increases
+Definition level ∝=0.1	*Definition level ∝=0.05	Definition level **∝=0.01	Definition level ∝=0.001 ***

The table above shows the results of the Mann-Kendall test for the surface temperature of Band-e-Amir National Park. Using this test, the results show that the process of surface temperature changes in Band-e-Amir National Park is increased but not significantly meaningful.

DISCUSSION

This study provides a comprehensive spatiotemporal analysis of surface water dynamics in Band-e-Amir National Park from 2000 to 2020, leveraging multi-sensor remote sensing data to overcome the critical challenge of in-situ data scarcity in Afghanistan. The central finding a statistically significant increasing trend in surface water area, contrary to the declining trajectories observed in many other regions of the country (Hedayat et al., 2024; Karl & Knight, 1998; Akyuz et al., 2025), warrants detailed interpretation and situates Band-e-Amir as a potential anomaly of hydrological resilience.

Our analysis unequivocally identifies precipitation, derived from GPM satellite data, as the principal driver of the observed expansion in surface water extent. The Mann-Kendall test revealed a significant positive trend in annual precipitation, which correlates strongly with increasing surface water area (R^2 = 0.72 for the water-area trend). This direct relationship underscores the high sensitivity of the park's closed or semi-closed basin lakes to climatic forcing, notably precipitation inputs. The lakes, primarily fed by snowmelt and mineral springs, appear to be highly efficient at capturing and retaining increased rainfall, leading to a net gain in water storage over the two-decade period. This finding aligns with the broader understanding that precipitation is a key determinant of surface water variability (Yang et al., 2011), yet it challenges the narrative of uniform hydrological decline across Afghanistan (Hedayat et al., 2024; Azadmanish, 2024) and highlights the critical role of localized climatic patterns and geological settings.

Contrary to global patterns in which rising temperatures exacerbate water loss through evaporation (Giardino et al., 2010; Ehsani, 2024), our analysis of MODIS-Terra Land Surface Temperature (LST) data found no statistically significant trend. The Mann-Kendall test results for LST were non-significant across all months and annually, with a near-zero R^2 value (0.0005) for the trendline. This suggests that, during this study period, evaporative demand has not been a dominant opposing force on the water budget of Band-e-Amir. The stability of LST, coupled with increasing precipitation, creates a unique hydrological regime in which rainfall gains outweigh potential losses, leading to the observed positive water balance. This stands in contrast to the findings of Ehsani (2024) in the Hirmand Basin, where temperature was identified as a direct factor alongside precipitation in reducing water resources.

The increasing trend in Band-e-Amir stands in stark contrast to studies conducted in other parts of Afghanistan. For instance, research in Kabul province documented a significant decrease in both surface and groundwater, attributed to a combination of declining precipitation, population pressure, and unsustainable extraction (Hedayat et al., 2024; Azadmanish, 2024). Similarly, Ebrahimi-Khusfi (2023) reported severe desiccation in the Hamoon wetlands, driven by prolonged drought and upstream water management. This divergence underscores the danger of extrapolating national-scale hydrological trends to specific, geographically unique ecosystems (Smallwood et al., 2011). Band-e-Amir's high-altitude location, geological structure (travertine dams), and its status as a protected area likely buffer it from the direct anthropogenic stressors (e.g., uncontrolled groundwater pumping, extensive agriculture) that severely impact water resources in urban and agricultural centers like Kabul (Karl & Knight, 1998; Azadmanish, 2024). Therefore, our study emphasizes the necessity of regional and ecosystem-specific assessments for effective water resource management.

The use of multiple, complementary satellite datasets (Sentinel-2, JRC GSW, GPM) and robust indices such as AWEI enhances the credibility of our findings and demonstrates the power of remote sensing for environmental monitoring in data-scarce regions (Wang & Xie, 2018). The inter-annual variability captured in the data, such as the difference between the surface water area in 2016 (708.7 ha) and 2023 (636.6 ha), is a crucial aspect of the hydrological system. These fluctuations are likely linked to short-term climatic oscillations and annual precipitation variability, a phenomenon also noted in other hydrological studies (Kundzewicz, 1997). The long-term trend, however, remains positive and significant. The maps derived from the Global Surface Water datasets (Change Intensity, Occurrence, Transition) provide valuable spatial context, identifying specific zones within the park that have experienced permanent gains, losses, or seasonal transformations, thereby offering actionable insights for targeted conservation.

Despite the robust methodology, this study is not without limitations. The reliance on satellite data, while necessary, introduces uncertainties related to sensor accuracy, cloud cover, and algorithmic classification of water bodies. The unavailability of post-2020 data for the JRC and GPM datasets prevents analysis of the most recent trends, a significant gap given accelerating global climate change. Furthermore, the study focuses on surface water area but does not quantify water volume or depth, which are critical for a complete hydrological assessment.

Future research should prioritize:

- Integrating altimetry data (e.g., from ICESat-2) to estimate lake water volume changes.
- Investigating the role of groundwater interactions with surface lakes, which could serve as a stabilizing factor.
- Extending the temporal analysis as new satellite data becomes available to monitor if the increasing trend persists.
- Conducting more granular analyses on the impact of tourism and local land-use changes within the park on micro-hydrology.

In conclusion, this research demonstrates that Band-e-Amir national park has exhibited a significant increasing trend in surface water area from 2000 to 2020, primarily driven by a concomitant increase in precipitation, while land surface temperature has played a negligible role. This presents a compelling case of localized hydrological resilience within a nation facing widespread water scarcity. The findings underscore the indispensable value of remote sensing for environmental monitoring in data-scarce regions and provide a critical baseline for the conservation and sustainable management of Afghanistan's first national park. Policymakers and conservationists should note this positive trend but remain vigilant, as Band-e-Amir's unique water balance remains vulnerable to long-term shifts in climate patterns and potential future anthropogenic pressures.

CONCLUSION

Band-e-Amir National Park in Bamyan Province, Yakawalang Number 1 District. Seven natural lakes in the area attract many tourists annually. Satellite data has been used for zoning and calculating surface water changes. In the absence of ground data, satellite data is a good substitute. In this study, satellite data were used to zone the surface water of Band-e-Amir National Park. Satellite data includes Sentinel-2 images from 2016 and 2023, Global Surface Water data, JRC surface water area data, GPM satellite data, and Earth's surface temperature data from the MODIS-Terra satellite. The AWEI Index was first used for surface water zoning and applied to Sentinel 2 images in 2016 and 2023. After extracting surface water zones, the area was calculated: in 2016, the surface water area of the Band-e-Amir national park was 708.7 hectares, and in 2023, 636.6 hectares. Global Surface Water and JRC data were used to obtain the process of surface water change. Using three products of Global Surface Water data, including Change Intensity, Occurrence, and Transition, surface water changes such as decreasing or incremental changes, permanent and temporary water, and water changes have been shown and have been identified in some areas where these changes have occurred. Using JRC data, the surface water area of Band-e-Amir National Park was evaluated and calculated using the Mann-Kendall nonparametric test. The results showed that the surface water area of Band-e-Amir National Park increased significantly. Using the above data, the processes of zoning and surface water change in Band-e-Amir national park were carried out, and effective factors for surface water supply, Including Precipitation data and surface temperature, were used. Precipitation data from the GPM satellite covers the period from 2000 to 2021. These data are calculated using the Mann-Kendall test and show a significant trend of increasing changes. Precipitation has a direct impact on surface water, and this increase in Precipitation in Band-e-Amir National Park has directly affected the area. Another factor affecting surface water change is the Earth's surface temperature. Earth's surface temperature data from Band-e-Amir National Park from 2000 to 2022 were analyzed using the Mann-Kendall test, and the results indicate that the data exhibit a trend. If the process of change is normal, it does not make sense or decrease because the process is on the zero line. Also, the process of normal change has little impact on the parameter's nature. Hence, the surface temperature of Band-e-Amir National Park, which undergoes normal changes, has no effect on the surface water changes there. Finally, using the above data and calculations, it was concluded that the water of Band-e-Amir National Park showed an increasing trend and was significantly different.

AUTHORS CONTRIBUTIONS

This research has been conducted by three people: Seyed Jawad Hedayat, Mohammad Kazem Yosufi, and Mohammad Israfeel Azadmanish. In this research, data preparation was performed by Mohammad Israfeel Azadmanish; Seyed Jawad Hedayat performed calculations, map design, and report writing; and the overall review was conducted by Mohammad Kazem Yosufi.

ACKNOWLEDGEMENTS

I would like to sincerely thank all the people and organizations who have helped in the successful completion of this study, titled "Investigating Factors Affecting Surface Water Change Using Satellite Data and Remote Sensing Techniques (A Case Study: BAND-E-AMIR National Park, Afghanistan)." First, I am deeply indebted to my academic advisor, Abdul Ghias Safi, for his guidance, encouragement, and insightful feedback throughout the research process. I am also grateful to the faculty and staff of the Faculty of Earth Sciences, especially the Department of Geography, for providing the necessary resources and a favorable environment for research. Special thanks to Seyed Jawad Hedayat for his technical assistance in the field of GIS and remote sensing tools. This research would not have been possible without data from various sources. I want to thank NASA and USGS for providing precipitation and vegetation data used in this study.

FUNDING INFORMATION

All data and software used in this research have been free, and no agency or organization has provided financial support for this research.

CONFLICT OF INTEREST STATEMENT

All material and spiritual benefits of this research are equally distributed to all members participating in this research.

DATA AVAILABILITY STATEMENT

All data used in this research has been free and can be obtained from satellite websites; however, some data from recent years (after 2023) has not been uploaded to these websites and is therefore unavailable.

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