Pakistan Geographical Review, Vol.78, No. 1, June. 2023, PP 94-105

INVESTIGATING THE RELATIONSHIP OF SOIL MOSITURE CONTENT, PRECIPITATION AND AEROSOLS WITH ENHANCED VEGETATION INDEX IN PAKISTAN

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ABSTRACT

Soil moisture content is a key element of various hydro-ecological processes at spatiotemporal scales. The soil moisture content is greatly influenced by the amount of precipitation and vegetation. Therefore, this study examined the relationship between Soil Moisture Content (SMC), Precipitation and Aerosol Optical Depth (AOD) on Enhanced Vegetation Index (EVI) in Pakistan from 2002 to 2022. Enhanced Vegetation Index (EVI) uses the NIR, red and blue channels to measure healthy vegetation, pixel by pixel with a simple algorithm. Enhanced Vegetation Index (EVI) showed a rising trend from 2002 to 2022. The range of values for the EVI is -1 to 1, where healthy vegetation generally falls between values of 0.20 to 0.80.Therefore; a high EVI is observed in northern and eastern Pakistan while low EVI towards the southwestern direction of Pakistan. A positive correlation (0.6 to 1) of EVI with SMC in eastern Pakistan indicates high precipitation and more vegetation. In southwestern Pakistan, a negative correlation (-0.2 to -0.4) was observed because of EVI and AOD. A positive correlation is found between EVI and precipitation in eastern Pakistan and a negative correlation in northern and western Pakistan.

KEYWORDS: Soil Moisture Content, Enhanced Vegetation Index, Precipitation, Pakistan, Aerosol Optical Depth

1. INTRODUCTION

Soil moisture content (SMC), is one of the key hydro- ecological variables in the soil-plant atmosphere range (Wang et al., 2019; Zhang, 2020; Oleszczuk et al.,2022). SMC is inevitable for plant growth, biodiversity and ecosystem services (Lin et al., 2018). SMC is amid a fundamental nexus in the exchange of energy, water, and carbon between the earth's surface and its lower atmosphere (Seneviratne et al., 2010; Goa et al 2014; Oleszczuk et al,2022; Zhang et al., 2023). The amount of water content in surface and sub-surface soil regulates the segregate of precipitation into surface runoff and infiltration, the insolation partitioning into heat fluxes(sensible and latent) , and carbon dioxide uptake by plants via transpiration (Oleszczuk et al.,2022) Being an environmental variable soil moisture is gaining vital importance in various ecological and hydrological processes (Qiu et al., 2019) .It is widely acknowledged that SMC could be affected by number of meteorological parameters like rainfall, soil permeability, vegetation types, and anthropogenic activities (Tariq et al 2021).

Remote Sensing Satellite data set has been used extensively across the globe to measure the trend in vegetation cover and its phenology (Sarmah et al., 2018). The enhanced vegetation index (EVI) is a vegetation index normally utilized to evaluate the healthiness and productivity of the vegetation cover. To calculate the biomass sensitivity, soil condition and atmospheric background the EVI is a widely used technique and it is the modified version of Normalized difference vegetation index (NDVI) (Udelhoven et al., 2015). Jin and Wang (2018) have studied that increase in the amount of rainfall, vegetation and soil moisture content leads to the significant decrease in the dust aerosols in the northwest of the Indian sub-continent. Furthermore, they found an increase in rainfall leads to an increase in vegetation and a decline in AOD. Chakraborty and Lee (2019) identified that during 1980-2018 tropical regions including Northern Pakistan experienced intensified local climate for a longer period indicating the role the vegetation covers in regulating the interaction of aerosols-climate interaction. Furthermore, on the basis of ground evidence, a positive impact of aerosols has been reported on growth of vegetation during growing seasons (Wang et al., 2018). In an area of thick vegetative cover wind speed reduces due to friction and consequently it stops the transformation of long distance air aerosols from ground surface (Chi et al., 2022). Zeydan et al (2022) investigated a strong correlation of aerosols optical depth (AOD) and EVI in Turkey in area of Mediterranean and Black sea whereas a week correlation between AOD and EVI is found in regions of less vegetation cover e.g. eastern, central and south eastern regions of Turkey. Tariq et al., (2021) also have found a negative correlation of AOD with EVI in the eastern side of Pakistan.

High AOD was reported in the south eastern part of Pakistan by using MODIS –AOD data set from 2001-2013 (Sharif et al., 2015). Sarmah et al., 2018 reported that seasonal and regional variation in vegetation cover results in differences in vegetation phenology in a number of satellite data sets. Sarmah et al., 2018 reported that seasonal and regional variation in vegetation cover results in differences in vegetation phenology in a number of satellite data sets. The increase in rainfall leads towards more soil moisture content and vegetation cover and because of that considerable reduction in dust is reported on the northwestern part of the Indian sub-continent (Jin and Wang, 2018). Previous studies have examined the spatio-temporal distribution and human induced activities impact on aerosols distribution and AOD response to EVI in Pakistan e.g.

Kumar et al.,2018; Tewari et al.,.2018; Tariq et al., 2021,2022; Khan et al, 2023. Previously, no research was conducted to investigate the relationship of SMC, precipitation and AOD with EVI in Pakistan.

The objective of this study is to investigate the relationships of SMC, precipitation, and AOD with EVI from the satellite based datasets of MODIS (AOD & EVI) MERRA-2 from July 2002 to December 2022 in Pakistan. Since the source of moisture over Pakistan is largely Monsoon (July onwards) and Winter Depressions (December onwards) therefore the aforementioned period was taken due to rainy seasons in the vast areas throughout Pakistan-the study area.

1.1. Study Area

Pakistan is located at 23.5° N-37° N latitude to 61-77° E longitude in South Asia and covers an area of 796,096 square kilometers. Pakistan shares its northern side with China and southwest side with Iran, Afghanistan on Western side and the Eastern side with India. The physiography of Pakistan is mainly classified into three main regions: Northern highlands, the Indus River plains and the Balochistan plateau. Pakistan lies in a sub-tropical region with diverse climatic conditions ranging from arid to semi-arid with four seasons. Pakistan receives the maximum rainfall from the south western- monsoon from late July to mid-September in the eastern and southern half while western winds precipitation in the western half. The northern areas of Pakistan receive rainfall more than 2000 mm while the 3/4 part of the country receives less than 250 mm rainfall annually (GoP, 2000).

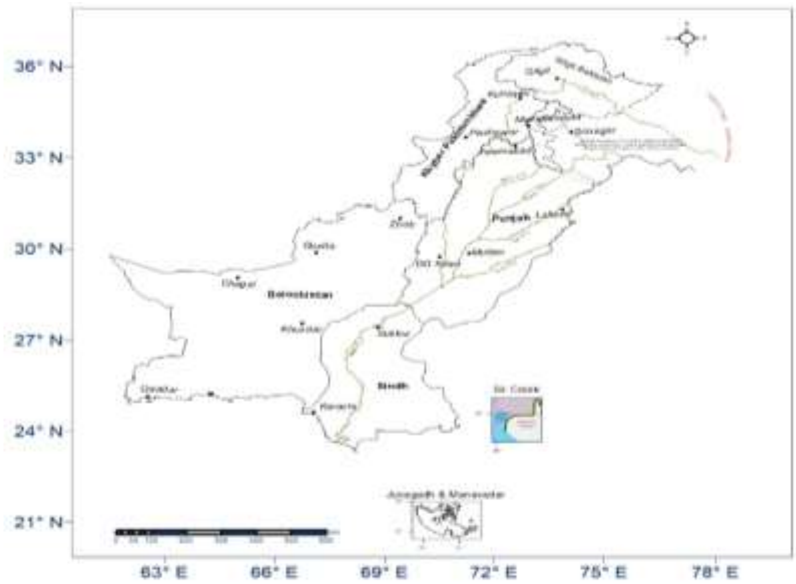

Figure 1. Map of study area-Pakistan

2. MATERIAL AND MEATHODS

The following datasets have been used to investigate the study and to achieve the aforementioned objectives.

2.1. MODIS

For this study all data sets were obtained from (https://giovanni.gsfc.nasa.gov/giovanni/)from July 2002 to December 2022. The Moderate Resolution Imaging and Spectroradiometer (MODIS) sensor was launched in 1999/2002.This near polar and sun-synchronous orbiting satellite consisted primarily of Terra and Aqua. The spectral band range for MODIS is from 1 to 36.The MODIS has a spectral range from 1 to 36 with spatial resolution of 250,500 and 1000 m resolution and temporal resolution is 1 to 2 days (Kahn et al., 2010; Jackson et al.,2013; levy et al.,2013) Terra crosses the equator in descending path at 10.30 am being the morning satellite whereas, the Aqua follows ascending orbit and cross the equator at 13.30 the local sun-time as it is well-known afternoon satellite (Lee, 2020; Hsu et al., 2013; Zeydan, et al., 2022). MODIS (Aqua/Terra) are observing every point on earth within 1-2 days depending on the latitude with its 2330 km wide band. The temporal resolution of MODIS is one to two days. MOIDS (Aqua and Terra) provides diurnal aerosols data sets across the globe.

The MODIS AOD retrieval consists of two algorithms namely Dark Target (DT) and Deep blue (DB) (Tanré et al., 1997; Kaufman et al., 1997; Tariq et al, 2022). MODIS AOD product the projected uncertainty is found ± 0.05 _ ±0.15 (AOD) and ±0.03 _ ±0.05 respectively over land and ocean (Chu et al., 2003; Remer et al., 2005 Bilal et al. 2021; Hsu et al., 2013 Wei et al. 2019)For this study AOD deep blue for land product with wavelength of 550mm (MODIS –Aqua MYD08_M3 v6.1) was used. The spatial resolution of the AOD product was 1° × 1° and the temporal coverage of the AOD product was from July 2002 to December 2022. Enhanced vegetation index (MODIS-Aqua MYD 13c2 v006) EVI monthly product with spatial resolution 0.5°and Temporal 0.5° was used for this study.

2.2. MERRA-2

MEERA -2 product is launched by National Aeronautics and Space Administration (NASA) and can be obtained from Giovanni. The extent of original MERRA was replaced by the reanalysis Model by MERRA -2. MERRA-2 changed the extent of MERRA-land that was previously used. The precipitation correction algorithm is a product of MERRA -2 and an advanced version of MERRA-Land. The spatial resolution of MERRA-2 is about 70km with 0.625°, 0.50° longitude and latitude respectively. MERRA-2 temporal resolution is 60 minutes while horizontal resolution is ~50 km (Gelaro, et al., 2017). For this study total surface precipitation monthly product (MERRA-2 M2TNFXFLX V5.12.4) kgm-2 for the period July 2002-December 2022 was used.

3. RESULTS AND DISCUSSION

To investigate the relationship of SMC, Precipitation, AOD with EVI index in Pakistan The time averaged maps of EVI, and correlation maps of EVI with SMC, (AOD) and precipitation were prepared for the time period of July 2002 to December 2022.

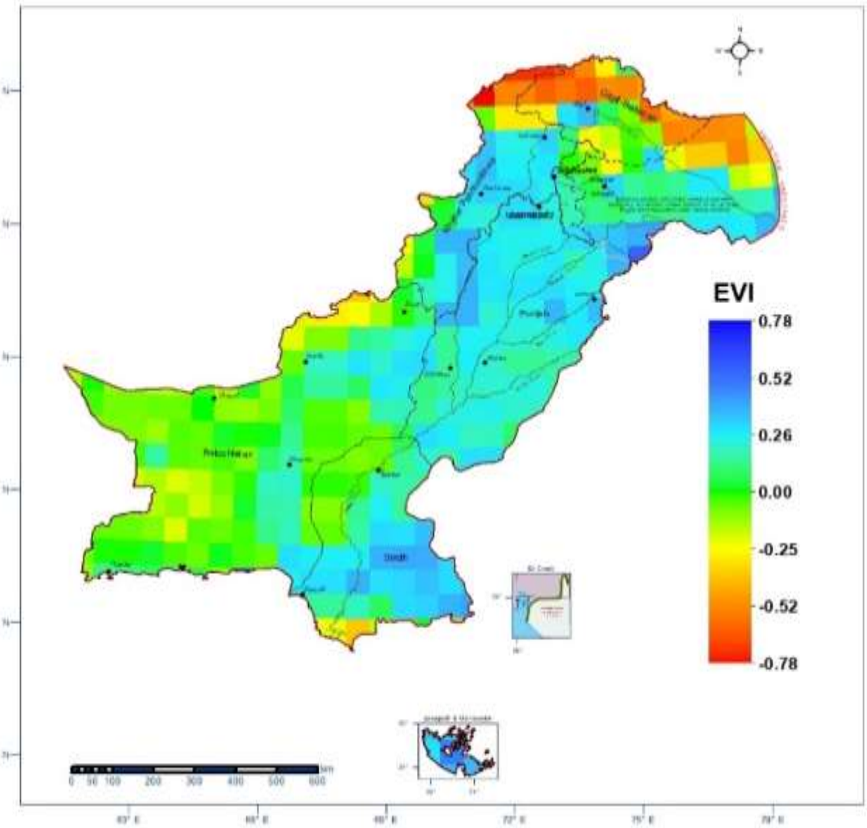

Figure 2. Monthly averaged EVI

Figure 2 demonstrate the MODIS retrieved EVI in Pakistan from July 2002 to December 2022.The EVI averaged map is indicating positive value in eastern side of Pakistan, while negative value of EVI values on Northern side of Pakistan.

Figure 3 indicates a positive correlation of 0.6 to 1 between EVI & SMC is observed in eastern Pakistan indicating high precipitation and vegetation. While negative correlation is found on south-western side of Pakistan because of less rainfall.

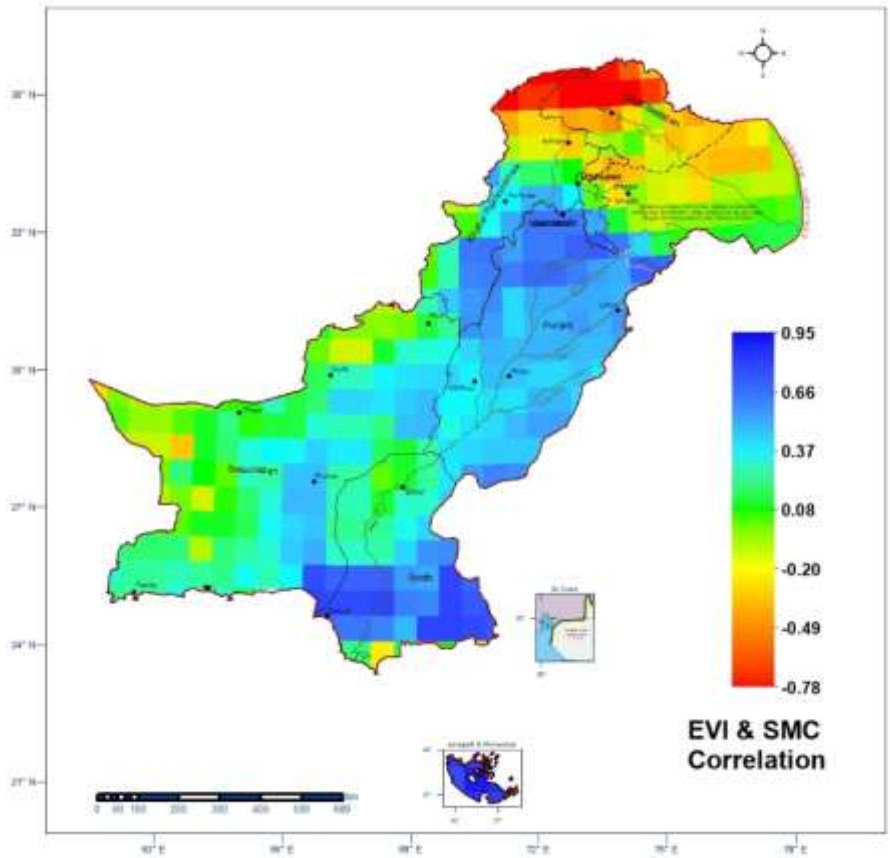

Figure 3. EVI correlation with SMC

In Pakistan, the relationship between EVI and soil moisture content varies depending on the season and the type of vegetation cover. During the monsoon season (July to September), when most of the vegetation in Pakistan is irrigated by the rain water, EVI shows a strong positive correlation with soil moisture content. This is because the increased soil moisture content during the monsoon season results in higher plant growth and photosynthetic activity, which is reflected in the EVI (figure 2). However, during the winter season (November to February), when most of the vegetation in Pakistan is irrigated by surface and groundwater, the relationship between EVI and vegetation cover. Variations in amount of soil moisture are main factor that controls the sensitivity and types vegetation cover. Farrar et al., (1994) and Wang et al. (2007) also found vegetation cover's sensitivity response to soil moisture varies mainly dependent on type of vegetation cover and soil type and prevailing meteorological factors.

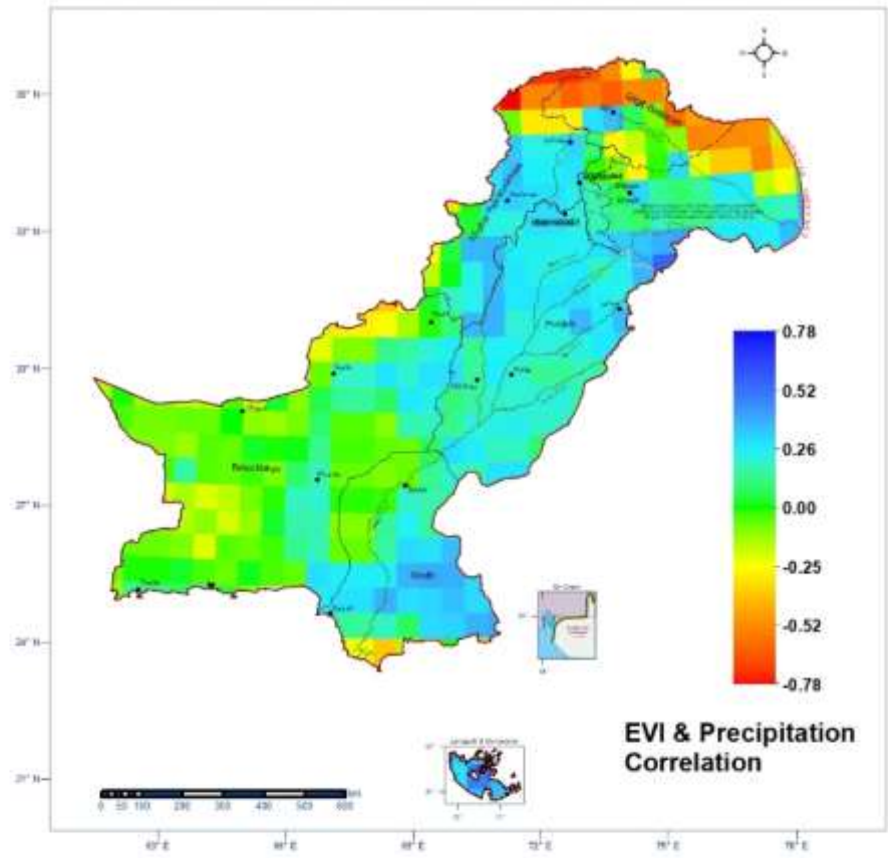

Figure 4. EVI and precipitation correlation

Figure 4 shows EVI and Precipitation exhibits the positive correlation between EVI and precipitation. The value range lies 0.78 to 0.2. A positive correlation in northeastern to south eastern direction has been seen while a negative correlation is found in western Pakistan. The reason for positive correlation towards eastern Pakistan is because of precipitation patterns over Pakistan; As Pakistan receives maximum rainfall from the Monsoon wind system in summer season so EVI is more.Whereas, the amount of precipitation is decreasing towards south-western direction due to lesser penetration of western winds in the region. He et al., (2021) also found that precipitation was a key factor in growth of vegetation cover in the region of Loess Plateau, North-Central China. Peng et al., (2017) also examined the regional and seasonal variation in temperature and precipitation as the main factor in variation of vegetative cover, over Tibetan Plateau, (China).

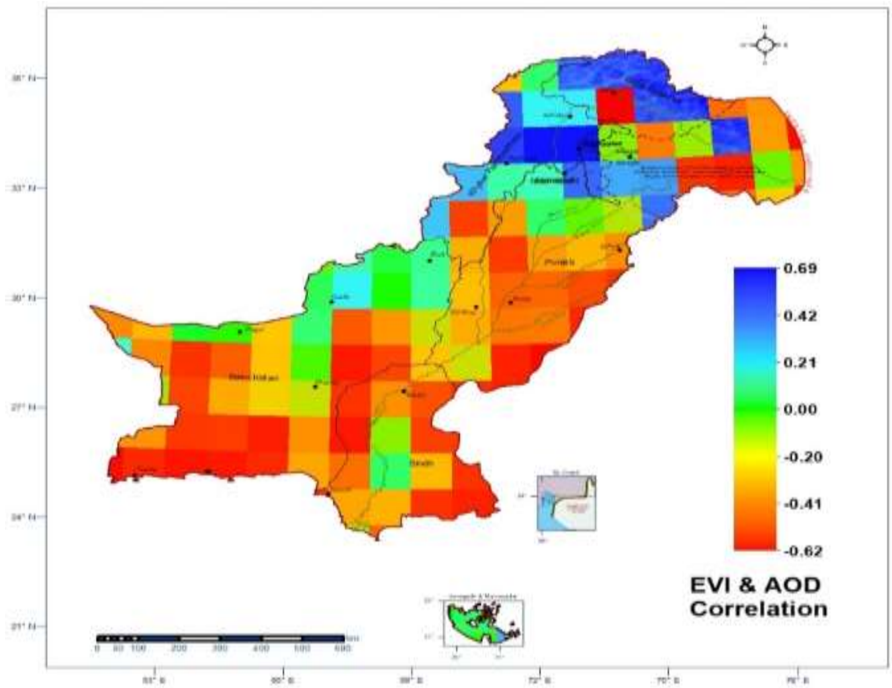

Figure 5. EVI and AOD Correlation

Fig 5 Illustrates spatial correlation of MODIS retrieved EVI with AOD in Pakistan from July 2002 to December 2022. The EVI value of 0.69 is observed in the northern side, while eastern Pakistan exhibits correlation coefficient (R) value -0.62 in western Pakistan. In the southwestern Pakistan there is a negative correlation of -0.2 to -0.4 because of low EVI and high AOD. The negative correlation indicates a decrease in EVI and increase in aerosols over the southwest of Pakistan. Tariq and Ali (2015) also found that higher temperature and wind are the major contributing factors of higher AOD in southern Pakistan. Tariq et al., (2021) stated a weak correlation is reported in south western (Quetta and Zohab (Pakistan) and Sistan region in Iran) While a value of ~ 0.6 indicates the positive correlation of AOD and EVI over Northern Pakistan. Tariq et al., (2022) examined that high negative correlation in AOD and EVI observed in the southern side (Pakistan) and western side (India) because low EVI due variation in vegetation cover.

4. CONCLUSION

This study investigated the relationship between soil moisture content, precipitation and aerosols with enhanced vegetation index in Pakistan.

MODIS and MERRA -2 retrieved datasets were used from July 2002 to December 2022. The EVI averaged map indicates positive value in the eastern side of Pakistan, while negative value of EVI on the northern side of Pakistan. A positive correlation of 0.6 to 1 between EVI & SMC is observed in eastern Pakistan indicating high precipitation and more vegetation. While negative correlation is found on southwestern side of Pakistan because of less rainfall. As Pakistan received maximum rainfall from Monsoon wind because of that precipitation exhibits the positive correlation between EVI and precipitation. The value range lies 0.78 to 0.2, therefore a positive correlation in northeastern to south eastern direction while, negative correlation is found western Pakistan. The EVI value of 0.69 is observed in the northern side, while eastern Pakistan exhibits correlation coefficient (R) value -0.62 in western Pakistan. In the southwestern Pakistan there is a negative correlation of -0.2 to -0.4 because of low EVI and high AOD.

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