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Research Article

Response of Rangeland Vegetation to Recent Trends in Seasonal Climate in Mansehra, Pakistan

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Abstract: The deterioration of rangeland resources as a result of environmental changes is a serious concern in the Himalayan mountainous region of Pakistan. The present study is aimed to evaluate the response of vegetation cover of rangeland to recent trends in climate parameters, such as the seasonal temperature and rainfall in the Mansehra district of Khyber Pakhtunkhwa province, Pakistan. Correlation analysis was performed between the MODIS data products, i.e., NDVI (Normalized difference vegetation index) and LST (Land surface temperature), and TRMM rainfall datasets of the 2000-2018 period. NDVI indicated a negative correlation with LST of winter (R= -0.56), spring (R= -0.7), summer (R= -0.24), and autumn (R= -0.23) significant ($p<0.05$) for winter and spring seasons only. In contrast, the correlation of NDVI was observed positive with seasonal rainfall exhibiting coefficient of correlation values of 0.41, 0.79, 0.64, 0.7 for winter, spring, summer, and autumn significant ($p<0.05$) for the last two seasons only. The low correlation observed between NDVI and LST of summer and autumn seasons is likely because of the prevailing stress condition of chlorophyll contents of the vegetation cover under warming conditions. However, this situation appears to be compensated by the rainfall as indicative of the moderate to strong correlation between the NDVI and rainfall of these two seasons. The least NDVI values observed during the winter season indicate limited vegetation cover for grazing opportunities in the lower valleys. However, an in-depth investigation of production patterns would further facilitate analyzing the grazing potential to support decision-making for long-term grazing management.

Keywords: Climate change, Rangeland, Vegetation, Remote sensing, NDVI

1. INTRODUCTION

The vegetation cover of Himalayan rangelands forms a major source of feed for livestock and is closely linked to the socio-economic systems of the region [1]. Assessment of climate change impacts on vegetation cover is an important subject to livestock management. Vegetation cover is a commonly used indicator to assess terrestrial environmental and rangeland conditions and any change in the cover pattern will alter the structures and functions of the environment. According to FAOSTAT [2], the world's total grassland has been reduced nearly by 1% during the 1994-2012 period. Climate change is believed to be one of the reasons impacting rangeland ecosystem processes [3, 4]. However, evaluating rangeland's capacity and productivity in a spatially and temporally dynamic way concerning climate change effects is still a great challenge. There are many techniques and or/ indices that can be used to monitor and assess vegetation cover using the remote sensing data (e.g., Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), and Fractional of Photosynthetically Active Radiation (FPAR) [5-9]. The normalized difference vegetation index (NDVI) driven by remote-sensing tools is used as a substitution for field-based vegetation monitoring studies which are usually time and cost-consuming. Moderate-Resolution Imaging Spectro-radiometer (MODIS) land products like LST (Land Surface Temperature) and NDVI are freely available and have been widely

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applied for monitoring rangeland production [7, 10-12]. Similarly, the microwave instruments onboard the Tropical Rainfall Measuring Mission (TRMM) satellite have contributed significantly to various environmental applications worldwide [13, 14].

In Pakistan, rangelands constitute nearly 65 % area up to 4000 m elevation and over 60 % of small ruminants' food and 5 % supply of large ruminants' food are reliant on this resource [15]. The sustainability of rangelands is one of the fundamental problems in the perspective of environmental challenges in the Mansehra district of Khyber Pakhtunkhwa province of the country. Currently, no study exists about the impacts of recent trends of seasonal climate on the vegetation cover of mountain rangeland in the Mansehra district. It was hypothesized that long-term changes in seasonal climate would have a great impact on the vegetation cover of the rangelands in this mountainous region. The primary focus of this study is to assess the impact of climate parameters, such as seasonal temperature and rainfall on the vegetation cover of Mansehra district, Khyber Pakhtunkhwa province of Pakistan using MODIS data products such as NDVI, LST, and TRMM rainfall data of 2000-2018 period. Time-series analysis of the Normalized Difference Vegetation Index was performed to understand the projected status of the rangeland vegetation and its relationship with the influential climatic parameters (i.e., temperature and rainfall). This study can help in understanding the effects of changes in temperature and rainfall on the vegetation cover and evaluating the season in which these effects will become critical in this Himalayan region.

2. MATERIALS AND METHODS

2.1 Study Area

Mansehra district stretches over an area of about 4579 km^2 within longitudes 72.81°E–74.13°E and latitudes 34.18°N–35.18°N in the Khyber Pakhtunkhwa province of Pakistan (Figure 1). The elevation ranges from 200 m in the south to over 4500 m above sea level towards the north. The climate is humid with annual rainfall exceeding 1200 mm. Heavy snowfall occurs during the winter season. The mean temperature at the nearest meteorological station (Balakot) is about 16° C in the winter and 32° C in the summer season. The district is significant for its biological resources. The rangeland of the district belongs mainly to the Subtropical Lower foothills; Subtropical Chirpine

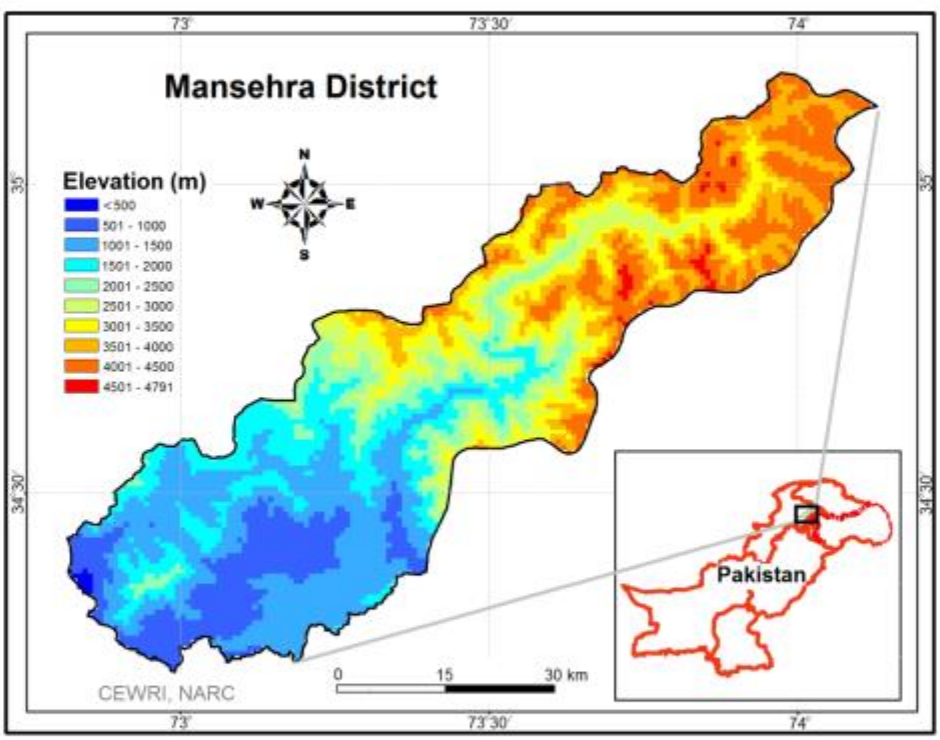

Fig.1. Location of the study area in Pakistan

zone; Moist temperate zone, and Sub-alpine and alpine area. The subtropical Lower foothill zone below 1000 m elevations is usually utilized by nomads during the winter season when the higher reaches are normally snow-covered [16]. They utilized grasses and forbs along with green leaves of species like *Olea ferrugenia, Grewia optiva, Acacia modesta*, and *Prosopis sp*. for livestock rearing. In the subtropical Chirpine zone above 1000 m, the understory of the Pinus is managed by the community for producing grasses and the moist temperate zone above 1700 m elevation is used for livestock grazing during autumn. Above 3000 m, the sub-alpine zone consists of vegetation species like Abies pindrow, Juniperus sp. accompanied by Artemisia as understory at lower reaches and in the alpine zone, the dominant species are *Kobersia sp*. turf. *Sibbaldia cuneata, Trifolium* sp. and *Poa pratensis* [17].

2.2 Data and Methodology

The climate data is mostly available from the valley-based meteorological stations in this region which do not represent the climatic conditions of higher altitudes, so we used RS-based products for monitoring the response of vegetation cover to climatic factors in this study. The processed data products of MODIS, i.e., NDVI and LST were acquired from the United States Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) for the 2000-2018 period. The NDVI product (MOD13Q1, Level 3) with a spatial resolution of 250 m received at 16 days interval [18] was used in this study. NDVI is considered a qualitative and quantitative measure of vegetation cover and is measured by deducting the red band value from the near-infrared (NIR) value and then divided by the sum of the values of NIR and red bands.

$$NDVI = \frac{NIR-R}{NIR+R} \quad (1)$$

The NDVI values range from –1 to +1, with high values (closer to one) being associated with a greater level of photosynthetic activities. Healthy vegetation reflects more near-infrared energy than stress vegetation. The methods involved in preprocessing of time series of MODIS vegetation indices are described in detail in several previous studies [19, 20]. The MODIS 8-day LST products (MOD11A2/MYD11A2) are the averaged LSTs of the daily MOD11A1/MYD11A1 products over 8 days [21]. Therefore, the MODIS/Terra 8-day LST product (MOD11A2) Level-3 with a spatial resolution of 1 km and temporal resolution of 8 days was used in this study. The LST or the emissivity-corrected land surface temperature Ts is computed as follows [22]:

$$T_s = \frac{\mathrm{BT}}{\{1+[(\lambda BT/\rho)]\mathrm{In}\ \varepsilon_\lambda]\}} \quad (2)$$

where Ts is the LST in Celsius (oC), BT is at-sensor BT (°C), λ is the wavelength of emitted radiance (for which the peak response and the average of the limiting wavelength (λ =10.895), $\varepsilon\lambda$ is the emissivity as calculated in Barsi et al. [23].

$$\rho = h\frac{c}{\sigma} = 1.438 \times 10^{-2}\ m\ K \quad (3)$$

where σ is the Boltzmann constant (1.38 × 10−23 J/K), h is Planck's constant (6.626 × 10−34 J s), and c is the velocity of light (2.998 × 108 m/s) [24]. The LST data was validated using the mean temperature data of the nearby station and found a mean drift of 2oC in the seasonal LST data from the observed data. According to Srivastava et al. [25], the accuracy of LST at places may indicate a difference of ±2°C with actual ground temperature measurements. This difference is obvious as LST represents the ground surface temperature while the latter exhibits air temperature above the ground surface.

The TRMM Multi-satellite Precipitation Analysis (TMPA) product Ver.7 consists of three products at different temporal resolutions: 3-hourly (3B42), daily (3B42 derived), and monthly (3B43). We used monthly 3B43 products with a spatial resolution of 25 km to evaluate the rainfall in the study area. Many studies on this region have proven the effectiveness of TRMM monthly precipitation products when compared with meteorological station data [26, 27]. According to these studies, a strong correlation exists between 12 hourly TRMM and field data in this region as the correlation coefficient comes out to be 0.9 for monthly, seasonal, and annual TRMM data values. We relied on this correlation analysis as validation of the seasonal TRMM data in this study.

The natural vegetation of rangeland serving as grazing land for the livestock was selected to study the influence of seasonal temperature and rainfall. Global Landcover dataset [GlobeLand30, 2010] downloaded from http://www.globallandcover.com/ was used to analyze land cover (Figure 2) and delineate rangeland boundaries which served as a sample area for vegetation cover analysis in our study. The sample boundary of rangeland was used to extract mean values from the three time-series remote sensing products (2000-2018 period) using the zonal statistics tool of the spatial analyst function of ArcMap GIS software. This tool helped in determining the mean values of raster datasets of variant-scale parameters (e.g. NDVI data of 250 m, LST of 1 km, TRMM data of 25 km) within the defined zone or boundary.

We performed trend analysis using time-series data of seasonal NDVI, LST, and TRMM of the study area. Four seasons were defined, i.e. winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep) and Autumn (Oct-Dec) to execute statistical analysis in this study. The time-series data of each parameter was plotted using line graph type and a linear trend-line was added to exhibit the direction of the parametric trend in Microsoft Excel software. The relationship of NDVI was studied with LST as well as with rainfall over 19 years. Among several types of the correlation coefficient, the most popular one – Pearson's correlation (also called Pearson's R) was used to measure the relationship between the two variables in the Excel software. This correlation coefficient is commonly used in linear regression to obtain the strength and direction of the relationship between two variables. The correlation value varies between -1 and 1, where, 1 indicates a strong positive relationship, -1 is a strong negative relationship, and zero no relationship at all.

3. RESULTS

3.1 Seasonal NDVI, LST and Rainfall Analysis

INDVI values were observed within the range of 0.18–0.32 during autumn and within 0.15–0.27 during the summer season of the 2000-2018 period in the rangeland of the Mansehra district. During autumn, maximum NDVI was observed in the year 2011 and minimum in the year 2000, while during summer, maximum NDVI was found in the year 2015 and minimum in the year 2002 (Figure 3). The NDVI values of winter and spring seasons were observed within the range of 0.15–0.26. The

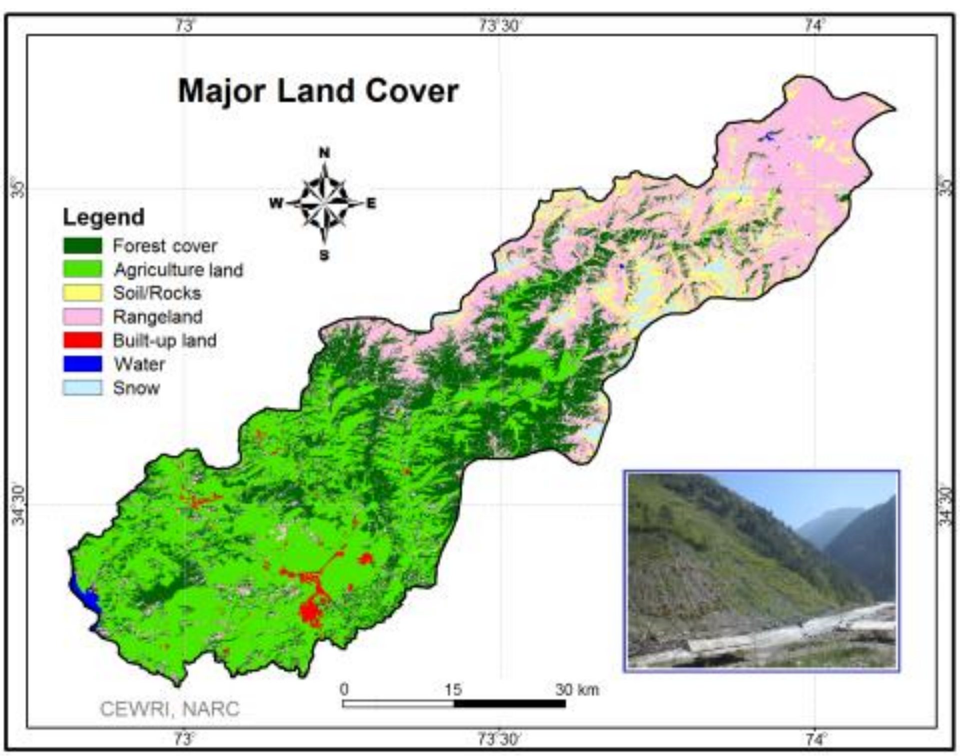

Fig. 2. Major land cover distribution in the study area

maximum NDVI during winter was in the year 2016 and the minimum in the year 2000, while the maximum NDVI during the spring season was in the year 2014 and the minimum in the year 2001. High LST values were observed during summer (i.e., within the range of 31° C–37.1° C), followed by the spring season (within the range of 30.9° C–36.8° C) during the 2000-2018 period. During summer, maximum LST was observed in the year 2009 and minimum in 2015, while during the spring season, maximum LST was found in the year 2010 and minimum in the year 2014 (Figure 4). The LST of winter was found least, i.e., ranging from 17oC to 24.4° C, highest in the year 2000 and lowest in the year 2005. The LST of autumn ranged between 29° C and 33.4° C, lowest in the year 2010 and highest in year 2013. The LSTs of winter, summer, and autumn appear to be more or less stable, while the LST of spring seems to be on the lower side across the 19 years. Variable patterns of seasonal rainfall were observed during the 2000-2018 period in the study area (Figure 5). Higher rainfall was observed during the summer (i.e., within the range of 111–339 mm), followed by the spring season (within the range of 7–265 mm). The rainfall of winter ranged between 22 mm and 127 mm, and of autumn between 22 mm and 167 mm. Overall, the seasonal rainfall indicated rising trends across the 2000-2018 period (Figure 5).

3.2 Correlation of NDVI with LST & Rainfall

We compared seasonal NDVI with corresponding LST and rainfall patterns of the 2000-2018 period in the study area. The upland areas in the northern parts of Mansehra showed low NDVI values likely due to a decline in temperature and rainfall in the upper reaches, whereas the lowlands exhibited increased NDVI values because of higher temperature and rainfall conditions (Figure 6). NDVI values were observed within ranges of -0.16 to 0.82, 0.15 to 0.78, -0.15 – 0.8, and -0.13 – 0.86 during the years 2000, 2006, 2012, and 2018 respectively. LST had shown positive change during each season mostly in the lower parts of the study area during the 2000-2018 period. However, it exhibited a negative change in the uplands of the study area during the spring and autumn seasons.

NDVI indicated a moderately negative correlation with the LST of winter (R= -0.56) and spring (R= -0.7) significant at $p<0.05$ (Figure 7). The correlation of NDVI was low and negative with the LST of summer (R= -0.24) and autumn seasons (R= -0.23). In contrast, the correlation of NDVI with rainfall was observed positive for all seasons,

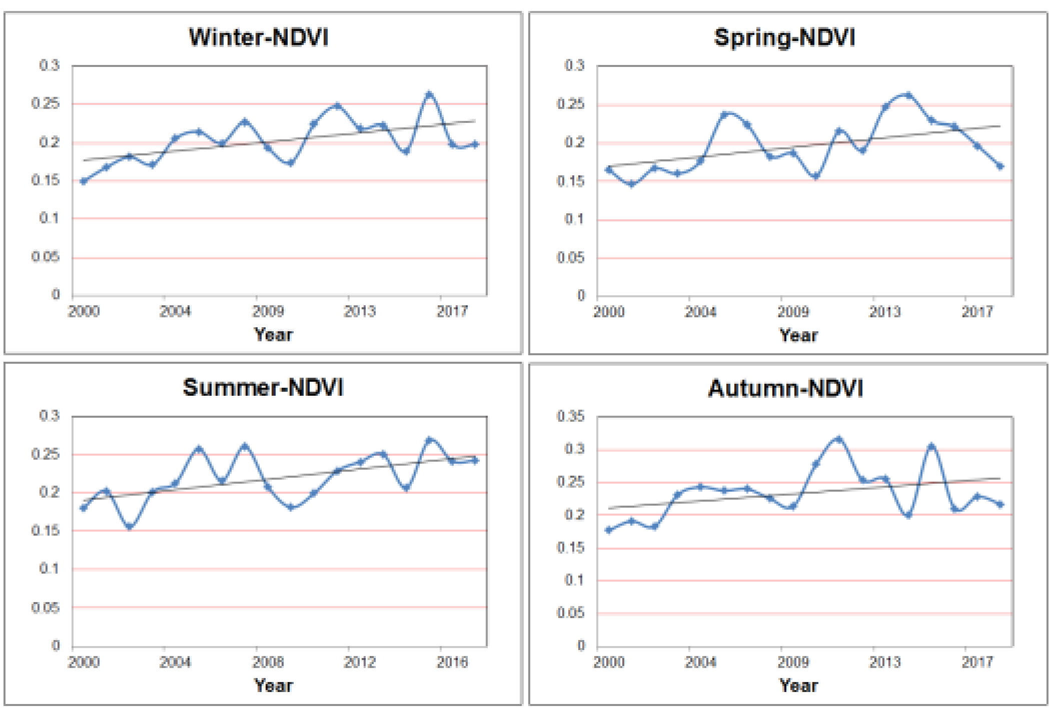

Fig. 3. Seasonal trends in NDVI during 2000-2018 period

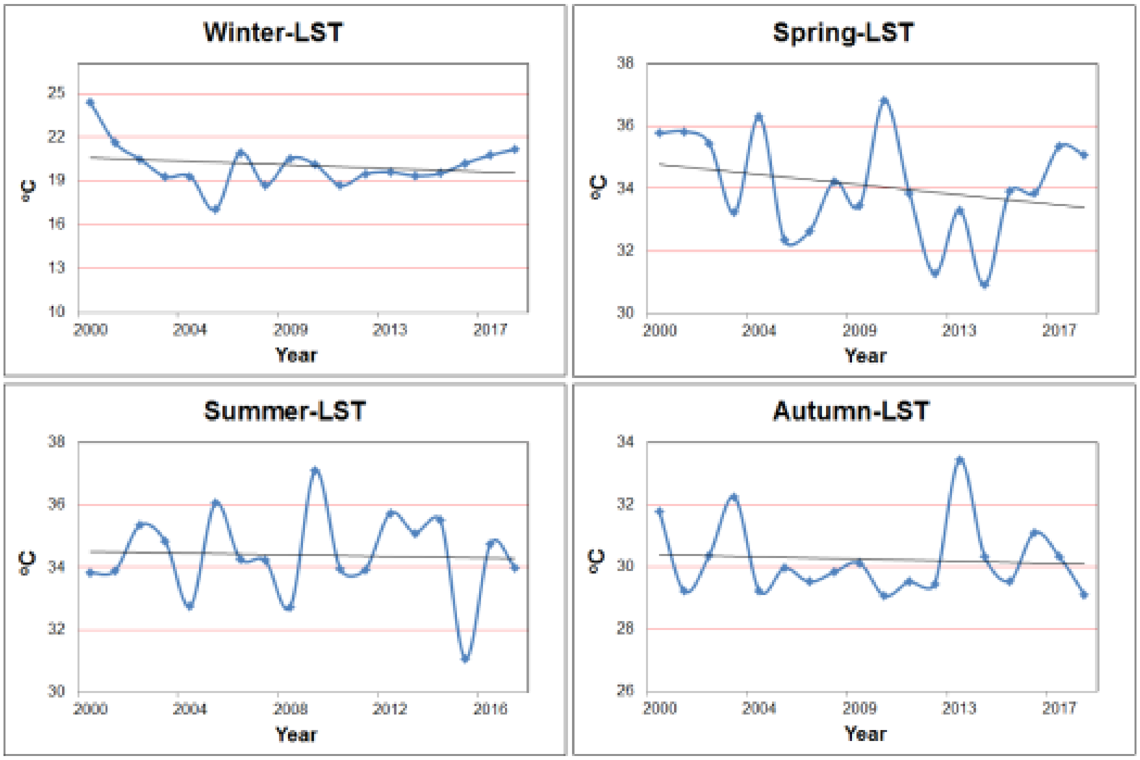

Fig. 4. Seasonal trends in LST during 2000-2018 period

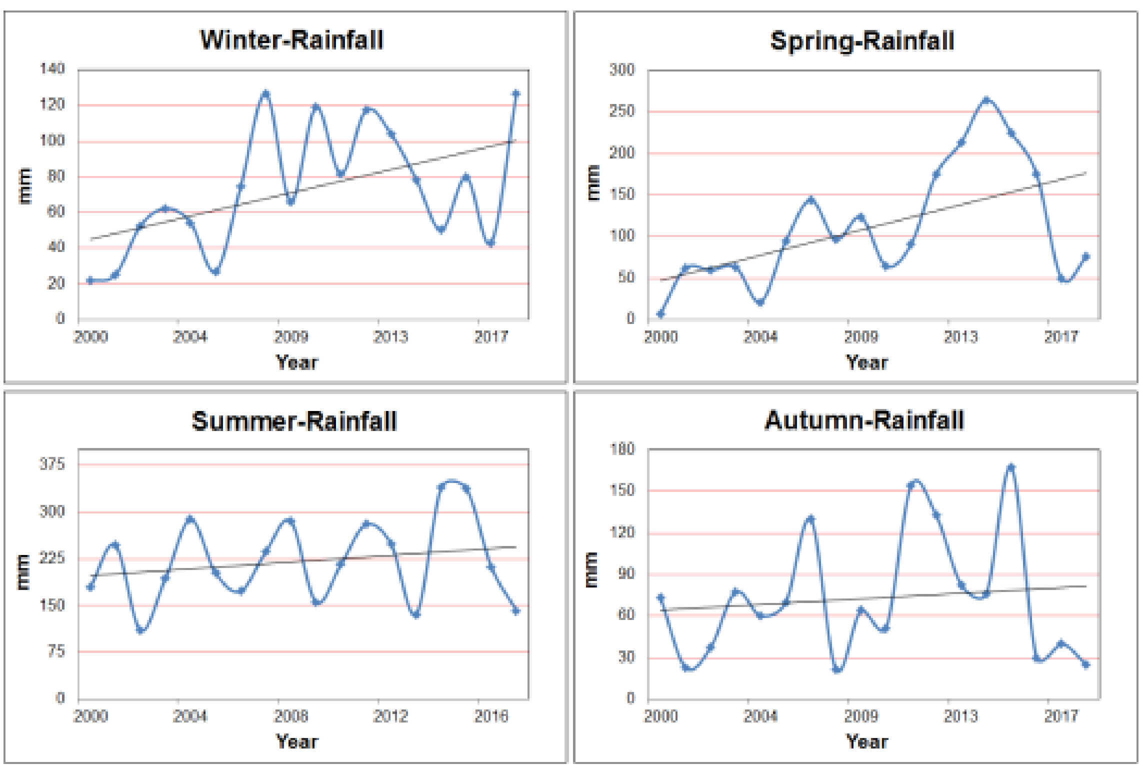

Fig. 5. Seasonal rainfall trends in the study area during 2000-2018 period

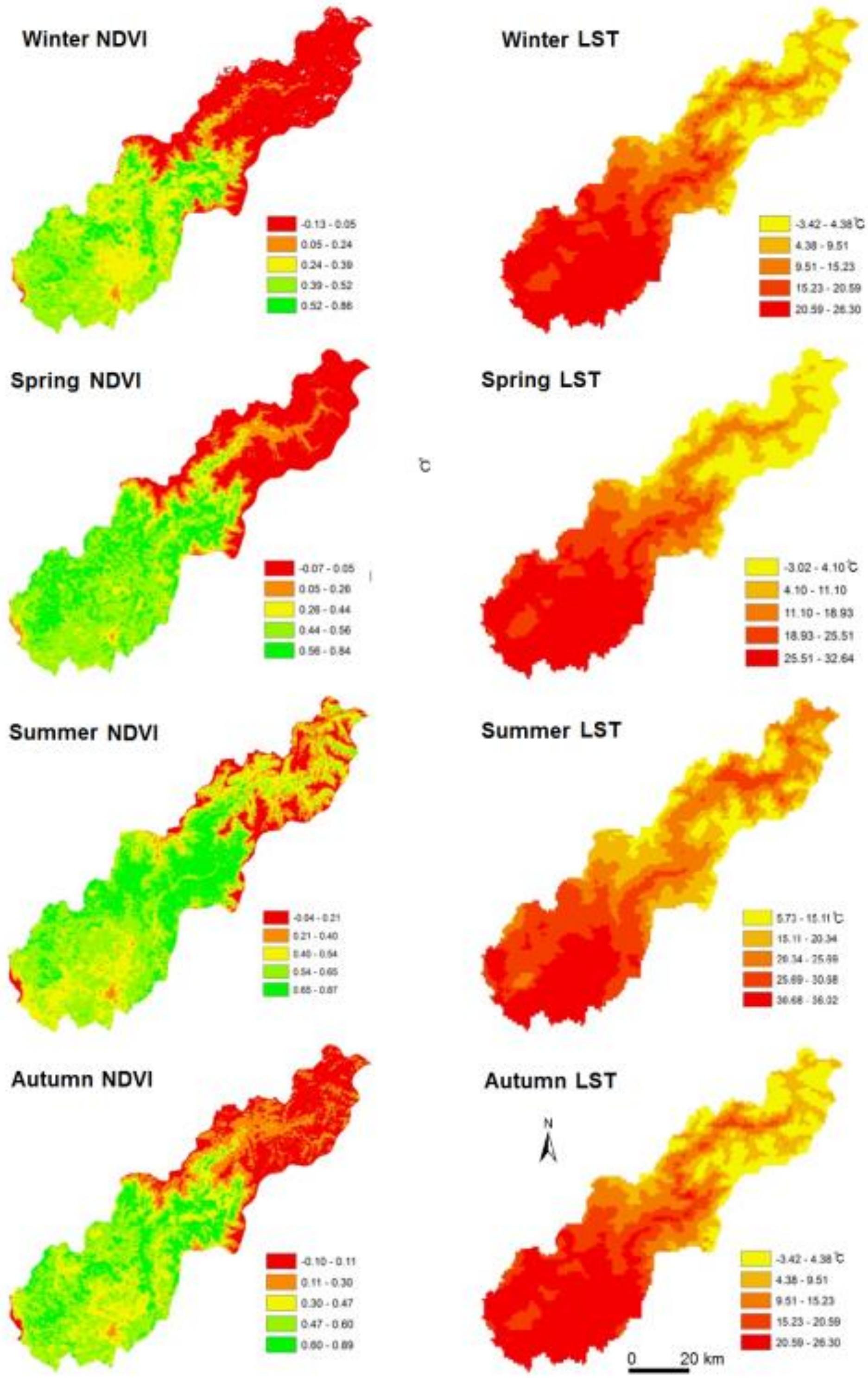

Fig. 6. Seasonal NDVI and LST in the study area (2018)

moderate for summer (R= 0.64) and autumn season (R= 0.7) significant at p<0.05 (Figure 7). The correlation of NDVI was strong with rainfall of spring (R= 0.79) and low with rainfall of winter season (R= 0.41).

4. DISCUSSION

The rising trend observed in seasonal rainfall in the study area during 2000-2018 (Figure 5) is also depicted in the findings of Hasson *et al.* [28] and Latif *et al.* [29] according to which precipitation had shown an increasing trend in the Upper Indus Basin (UIB) during 1995–2012 period. Chaudhry [30] reported a 25 % increase in average annual rainfall and 18 % – 32 % in summer rainfall over the monsoon region of Pakistan during the last century. The situation of higher rainfall trends appears to be favorable for rangeland vegetation which depends mainly on moisture availability

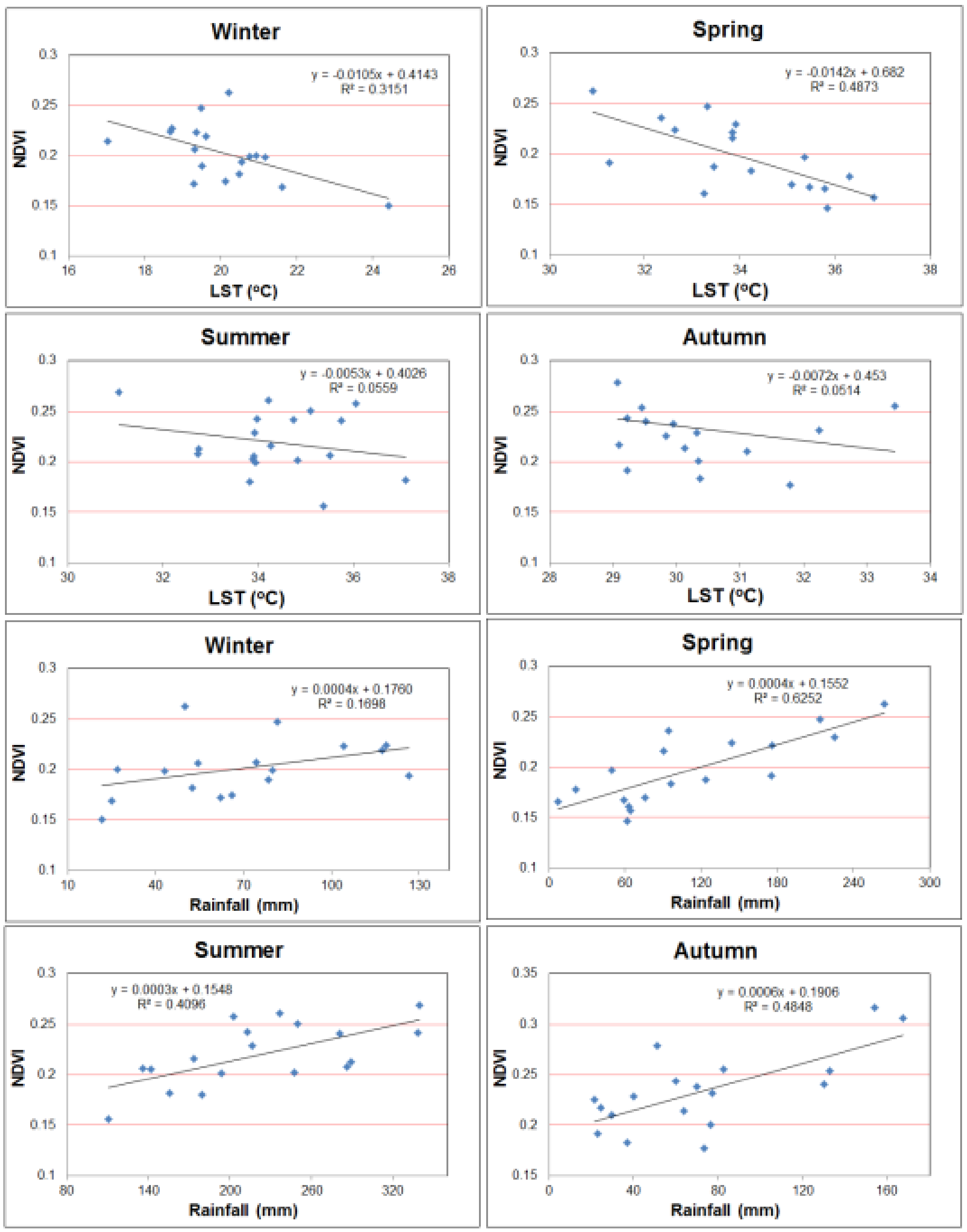

Fig. 7. Relationship of NDVI with seasonal LST and rainfall (2000-2018)

and so indicated a positive correlation with rainfall in different seasons (Figure 7). The stable and in some cases declining trends in LST observed in different seasons indicate the influential effect of the vegetative cover of various types in the study area, as Chaudhry et al. [31] observed 1.5°C rises in temperature during the last 40 years in the northern mountainous region of Pakistan. The NDVI had shown relatively higher variability during spring, autumn, and summer seasons than in winter (Figure 6), however, positive trends in NDVI were observed during all four seasons. According to a study by Liu and Lei [32], the autumn and spring seasons indicated high variations in NDVI, while the summer NDVI showed lesser variability in a part of China. The lowest NDVI values were observed during the winter months from December to March, which may be attributed to heavy snowfall occurrence during this season. Generally increasing trends in seasonal NDVI were observed in the lowlands, however, the trends were on the negative side in the uplands, especially during the spring and autumn seasons. Besides the decrease in warm conditions, high grazing pressure during pre- and post-snowfall conditions might contribute to reducing NDVI in the upper reaches of the district. The increased NDVI values observed during autumn followed by the summer season during the 2000-2018 period are likely due to increasing trends in rainfall in the area. The least NDVI values noticed in different seasons of 2000-2002 were likely due to prevailing drought conditions during that period [33], which influenced the vegetation resource of this region. However, not only drought conditions, but the overuse of rangeland coupled with intense monsoon rainfall leads to massive erosion and landslides [34] which may cause a lowering of NDVI values. The study by Rehman *et al.* [35] indicated that the NDVI in Ketibunder Sindh Pakistan had a moderately negative correlation with LST between 2000 and 2010 and a strongly negative correlation with LST during 2014.

The correlation of NDVI was observed low with LST of the summer season ($R= -0.24$) likely because of the contribution of warm conditions in reducing chlorophyll contents of the vegetation cover. In a study by Yang et al. [12], a negative correlation between NDVI of grasslands and temperature was found in Mongolia during the autumn and summer seasons of the 1982-2011 period. Several studies conducted in various parts of the world also concluded that NDVI is strongly affected by temperature as compared to precipitation [36-39]. The positive correlation observed between NDVI and rainfall for all seasons (significant for summer and autumn seasons at $p<0.05$) is likely because of the favorable influence of increasing wet conditions on the rangeland vegetation. According to a study by Wang *et al.* [38], NDVI is strongly influenced by the precipitation pattern during the growing and proceeding winter.

5. CONCLUSION

In the present study, time-series data of MODIS products, i.e., NDVI & LST, and TRMM rainfall were used to analyze seasonal trends and examine the relationship between NDVI with climatic parameters in the lesser Himalayas of Pakistan during the 2000-2018 period. Higher NDVI values were observed during the summer and autumn seasons due to the positive effect of wet conditions on the vegetation during the 19 years. The low correlation observed between NDVI and LST during the summer season is likely because of the prevailing stress condition of chlorophyll contents of the vegetation cover under warm conditions. However, this situation appears to be compensated by the rainfall of the summer and autumn seasons as indicative of the moderate to strong correlation between the NDVI and the rainfall of these seasons. Overall least NDVI values were observed during the winter season, which may be attributed to the prevalence of snow cover over higher altitudes, i.e., above 2300 m, and the availability of limited vegetation cover and grazing opportunities in the lower valleys of the district. The dynamics and snow cover change and its impacts on the vegetation of high reaches need in-depth research for better understanding and getting scientific evidence. The large swath and resolution of the satellite images provided rapid observations of bioclimate conditions over a large part of the area in a synoptic view thus facilitating spatial variability and change analysis. NDVI data product was found effective in monitoring the status, distribution, and trends of rangeland vegetation and biomass variability in this mountainous region. In the absence of high-altitude observational data on climate, validation of the gridded climate data is challenging and can be improved through the provision of a network of high-altitude climate observatories. Regular monitoring of land use, plant phenology, and socioeconomic conditions is needed for effective rangeland management and to develop viable resource conservation strategies for this fragile mountain ecosystem in the future.

6. ACKNOWLEDGEMENTS

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7. CONFLICT OF INTEREST

There is no conflict of interest among authors

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