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№ 6593

Land Surface Temperature Variability over Various Land Covers in Punjab (Pakistan) from MODIS Data

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September 13, 2021

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Keywords- LST; DTR; MODIS; Pakistan

***ABSTRACT*—Land Surface Temperature (LST) is the core biophysical parameter of the surface thermal energy budget. In this study, daily maximum, daily minimum, and daily average LST, as well as diurnal temperature range (DTR), are analyzed using satellite remote sensing data. These parameters are studied over five land covers, including the cropland, barren land, grassland, shrubs, and urban areas in Punjab-Pakistan. Long-term temporal analyses from 2004 to 2018 showed that minimum LST increased over all land covers, while maximum LST showed a mixed trend over various land covers. Average LST increased over all land covers except grasslands. DTR showed a significantly decreasing trend over the majority of land covers except over barren lands. Croplands showed the most dominant effects on the temporal trends over the whole Punjab. Our results of temporally reduced DTR are in line with the previous studies. It indicates the imbalance of LST, which is a potential cause of climate change.**

1. INTRODUCTION

LST is the radiative skin temperature of the land surface and measures the thermal radiance emitted from the land surface. LST is an important parameter for biomes, ecosystem, and climate change studies [1], [2]. Studies showed that global changes in LST contributed to global warming [3]. LST is one of the most widely observed climate parameters, yet the ground observations are unable to cover the whole surface as the ground stations are sparse and unevenly distributed. Thus observing LST through remote sensing satellites is an effective source of information [4], [5]. Measured spectral radiance is used to derive LST by applying inverse Planck's law [6].

To analyze LST, maximum temperature (T_{max}), minimum temperature (T_{min}), average temperature (T_{avg}), and diurnal temperature range (DTR) are the key parameters. Though all LST parameters have their significance, DTR is considered a suitable measure to analyze and evaluate diurnal LST variations. DTR variations are considered as an index of climate change [7]. Another important application of DTR is the urban heat island. It was reported that reduced DTR contributed to an increased urban heat island effect [8]. The importance of DTR is not only confined to climate change, energy budget, and urban heat island studies but also extends to human health and even mortality rate [9], [10]. Effects of DTR variations are also reported on crop yields [11].

Anthropogenic activities, such as the clearing of forests have a significant effect on LST [12]. The impact of land covers on LST is widely studied and scholarly proved [1], [13]. It is observed that land cover changes especially loss of vegetation have a significant impact on LST in Pakistan [14], [15]. Along with other land cover changes, urbanization is an important trigger to alter LST especially DTR [16]. Recent literature observed the narrowing of global DTR [3], [17] but on a regional scale, these trends may differ with different geographical locations.

In this study, satellite remote sensing data was used to observe daily maximum, daily minimum, daily average LST, and DTR, over the northeastern province of Pakistan, vis. Punjab. These parameters were analyzed on five different land covers, cropland, barren land, grassland, shrubs, and urban or built-up area. Long-term temporal trend analyses were performed on mean annual data from 2004 to 2018, over the whole Punjab and the aforementioned land cover classes.

2. STUDY AREA

Punjab is located in the Northeast of Pakistan. The total area of Punjab is 205,344 square kilometers (79,284 square miles) and the total population is approximately 11 million, which makes it the most populated province of Pakistan. The soil of Punjab is considered one of the richest soils in the world for crop production. A variety of land covers exists in Punjab from southern deserted barren areas to the northern mountainous ranges. The majority of its area is covered with croplands Average annual air temperature of Punjab varies between 0 to 52 ^{o}C. Being a densely populated geographical

area with vast potential climate change activities, it is much important to analyze LST and its relation with different land covers.

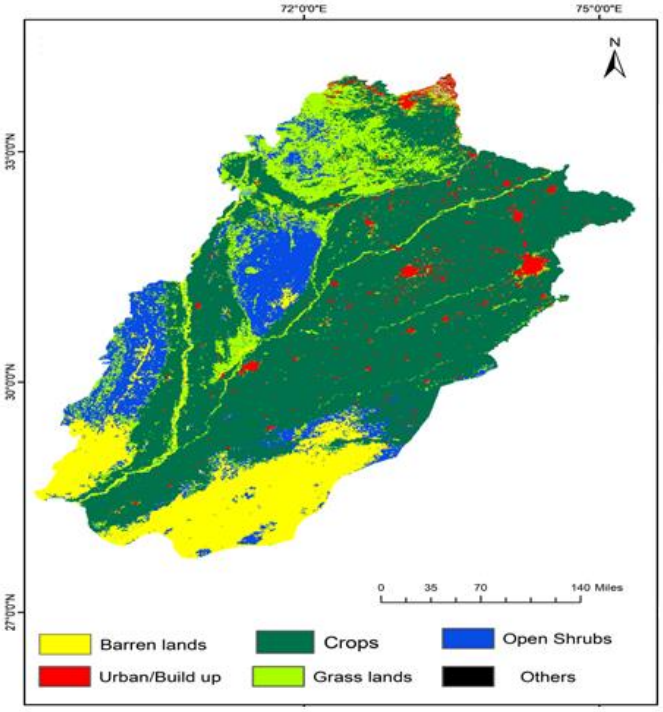

Figure 1: Punjab land cover map is created using 15 years spatial images of MODIS land cover product

3. MATERIALS AND METHODS

Moderate Resolution Imaging Spectroradiometer (MODIS) sensors mounted on Terra and Aqua satellites provide a wide range of surface products including LST. MODIS Terra passes over local zenith at 10:30 and 22:30 local time while for Aqua it passes at 01:30 and 13:30 local time. In this study, MOD11A2 and MYD11A2 LST products are used from Terra and Aqua MODIS, respectively. The accuracy of the MODIS LST product was reported up to 1K [18]. MODIS Aqua passes local zenith at such time which is meteorologically considered to be maximum (mid-noon) and minimum (midnight) temperature observational time. These observations were taken as temperature extremes i.e., T_{max} and T_{min} while T_{max} refers to maximum LST observed at 13:30 and T_{min} is minimum LST observed at 01:30 local time. DTR is calculated by subtracting T_{min} from T_{max}, while for daily average temperature T_{avg}, all four available MODIS observations of LST were averaged to avoid the chance of any biasness in LST which may appear due to a short time occurrence of extreme temperature over the daily cycle.

For land cover classification, combined MODIS product MCD12Q1 was used which contains five different land cover classes from which the International Geosphere-Biosphere Program (IGBP) was selected for the current study. This land cover scheme classifies land into 17 classes from which croplands, barren lands, grasslands, shrubs, and urban or built-up areas were considered. These are the most abundant classes with respect to the area in Punjab. For the final analysis, only those pixels from each class were selected which remained associated with the same class throughout the study period. LST values were averaged for the spatial window of 5 × 5 (25) pixels and out of which at least 20 pixels must have valid observations.

We perform temporal analyses for T_{max}, T_{min}, T_{avg}, and DTR on the whole Punjab and targeted land covers for 15 years (2004 to 2018). Temporal trends of these parameters were analyzed using linear regression slope. In the end, a relationship was established between T_{max}, T_{min}, and DTR.

4. RESULTS AND DISCUSSIONS

Temporal analyses of LST parameters over the whole Punjab are shown in Figure 2. Mixed trends were observed for T_{max}, T_{min}, T_{avg}, and DTR from 2004 to 2018. T_{max} exhibited a decreasing trend (slope = -0.03) while T_{min} showed an increasing trend with a 0.03 slope value, which ultimately accumulated for DTR and resulted in a decreasing trend with a slope of -0.06. Daily T_{avg} is not largely affected during the study period and slightly increased by 0.006.

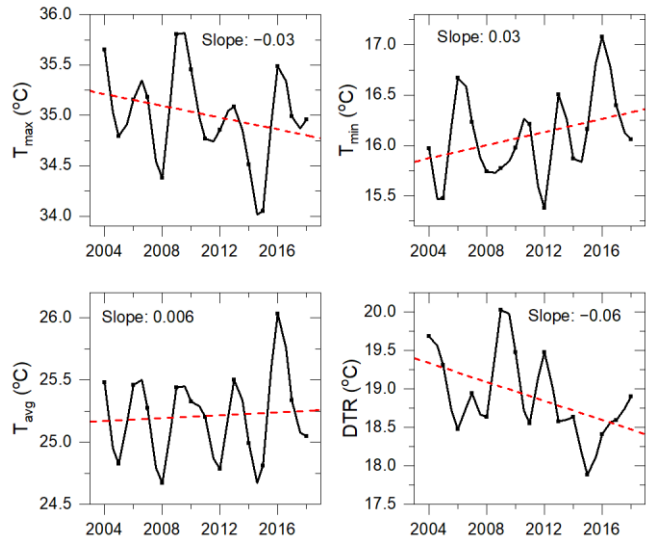

Figure 2: Temporal trends of T_{max}, T_{min}, T_{avg} and DTR over Punjab. Each value represents the mean annual LST of the corresponding parameter.

For different land covers, miscellaneous trends were observed. Figure 3 presents the temporal trends of T_{max}, T_{min}, T_{avg}, and DTR over all observed land covers. T_{max} showed an increasing

trend over all other land cover types except over croplands where a decreasing trend was observed. T_{min} kept on increasing over all land covers. T_{avg} also showed an increasing trend over all land covers except grasslands. Barren lands were the only land cover on which DTR exhibited a minor increasing trend, while other land covers showed a decreasing trend.

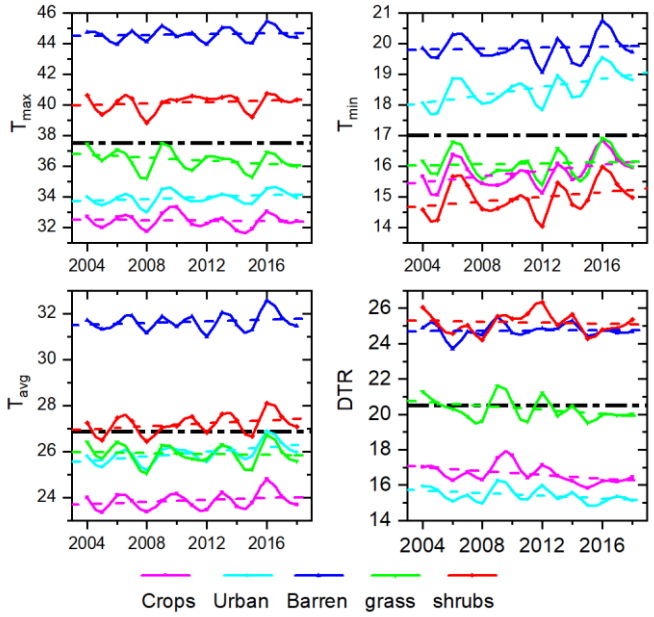

Figure 3: Temporal trends of T_{max}, T_{min}, T_{avg} and DTR over various land covers. Each value represents the mean annual LST of the corresponding parameter.

Our results suggest that although there were significant changes in T_{max} and T_{min} and eventually these variations contributed to DTR variations. Over the entire study period and whole study area, T_{min} increased significantly, consequently, the difference between T_{max} and T_{min} reduced except over barren lands. For air temperature, this pattern is supported by previous literature over major cities of Punjab [19]. The same trend is observed globally that increased T_{min} while unaltered or minor changed T_{max} resulted in a reduction in DTR [3], [17]. These trends are summarized in table 2, in which long-term trends of T_{max}, T_{min}, $T_{avg,}$ and DTR are analyzed using the slope of their temporal pattern.

From different land covers, it was observed that trend of cropland is dominated over the whole Punjab as it is the most abundant land cover in the province. Rapid urbanization had the most severe effects on LST with a maximum increase in T_{max}, $T_{min,}$ and T_{avg}. The negative impact of urbanization on DTR has its roots in recent literature [16]. For barren land, although the increasing slope is observed in all four parameters, yet none of them showed any prominent change. Barren land is the only land cover where DTR showed a minor increasing trend.

Table 1: Trend of LST parameters over Punjab and various land covers.

	Crops	Urban	Barren	Grass	Shrubs
T_{max}	-0.007	0.0284	0.0128	-0.0495	0.0234
T_{min}	0.0467	0.0658	0.0079	0.0082	0.0379
T_{avg}	0.0211	0.0493	0.0178	-0.0106	0.0325
DTR	-0.0542	-0.0374	0.0049	-0.0577	-0.0145

DTR exhibited approximately the same relation with T_{max} and T_{min} but with opposite signs. Figure 4 showed the Pearson's correlation coefficient between T_{max} and T_{min} with DTR. With the increasing slope and positive correlation coefficient, DTR and T_{max} were positively correlated with each other, and the same was reversed in the case of T_{min}. Thus, increasing minimum LST was eventually resulted in decreasing DTR.

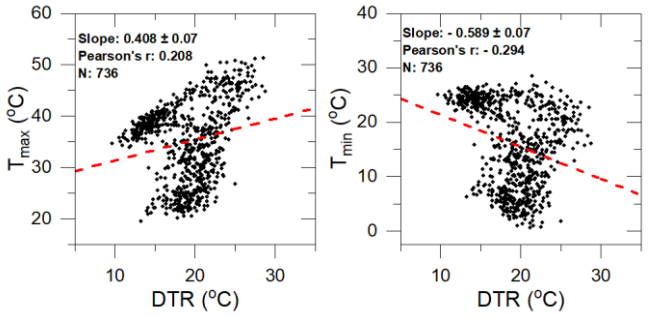

Figure 4: the relation between DTR, T_{max} and T_{min}

5. CONCLUSION

Land surface temperature (LST) variability is analyzed and evaluated over various land covers in Punjab (Pakistan) from MODIS data. For daily average LST, arithmetic mean for all four available observations were averaged from Terra and Aqua MODIS. On these observations 15 years (from 2004 to 2018) temporal trends were estimated of daily maximum, minim, average LST, and DTR. These trends were analyzed on cropland, barren land, grasslands shrubs, and urban areas. Our key findings are:

Over the whole Punjab, T_{max}, decreased while T_{min} increased in the approximately same amount, resulting in a slight increase, but these changes accumulated for DTR, and a strong decreasing trend was observed. This trend is in line with trends over croplands. Being a major land cover area of Punjab, it is concluded that croplands are the main influencing land body on temporal trends of LST over Punjab. Urbanization influenced minimum and average LST in maximum capacity than any other land cover type showed

increasing trends for maximum, minimum, and average LST. DTR also showed a decreasing trend in urban areas, although less severe than croplands. Barren lands showed maximum LST values amongst all land covers, but temporal change over barren lands was not significant. Thus, LST remained consistent over barren lands for longer periods.

Diurnal Temperature Range (DTR) is an important phenomenon to understand the net thermal radiation balance. Analyses of DTR over different land covers helps to understand its mechanism. Narrowing down the DTR strip can serve as an important cause of climate change. In the near future, densely populated areas like the one in our study must be analyzed and interpreted for DTR to predict any potential climate change.

6. REFERENCES

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