IJASD ISSN:2618-1193

Impact of Urbanization on Agriculture and Ambient Air Temperature

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Citation | Shehzadi. A, Mahmood. S. A, Ahmad. H. H, Younas. F, "Impact of Urbanization on Ambient Air Temperature in Punjab, Pakistan", IJASD, vol. 4, no. 4, pp. 146-163, 2022

Received | Sep 14, 2022; **Revised |** Sep 28, 2022; **Accepted |** Oct 20, 2022; **Published |** Oct 24, 2022.

Mean monthly temperature, maximum temperature, and minimum temperature data over the previous 40 years are used to examine the seasonal and annual mean trends and their respective spatial distribution due to urban development in Provincial Punjab, Pakistan. Using population data, 45 weather and climatic stations were divided into three groups, and reference (rural) stations were selected. Several types of urban stations, as well as all stations, have their urban-rural temperature gap, as well as their trend, assessed. It also examines the impact of urbanization on the climate of major cities in Punjab. According to the data, urban warming is strongly correlated with population density. Extreme urban heat island (UHI) effects of 0.67 K annually over major metropolitan station pairs are found, leading to large urban-rural disparities in maximum temperature. Since Pakistan's technological advancement and opening in 2005, the impact of urbanization on air temperature has shifted substantially. Cities in the northeastern part of Punjab showed a greater UHI effect than those in the southern part of the province, indicating that urban areas with strong UHI effects tend to be located in regions with rapid industrial growth.

Keywords: Air temperatures, Urbanization, UHI, Punjab, Pakistan

Introduction

Affluence rises as a result of urbanization, which occurs when a large population migrates to a relatively small number of cities. The term "developed" is used to describe a city that has expanded in terms of the number of its urban centers, the size of its metropolitan rate, and the percentage of its population that lives in urban regions. It's fair to say that the rapid growth of the urban population has been at the expense of public, economic, and ecological accumulation, as seen by the rising need for government services at the expense of urban residents. The climatological, meteorological, and thermal features of certain ecosystem services are predicted to shift as a result of climate change and urban sprawl, which may have a negative impact on these services [1].

The term "urban sprawl" became commonplace in the 1950s, when U.S. metropolitan regions began to sprawl even further outside. Rapid population growth has reshaped forested and farmland areas, and this trend has the additional effect of diverting agricultural resources away from forests and towards urbanization. Each new district built outside a city or town was able to support itself. The depletion of natural resources is just one negative impact of today's industrialization on the planet. The term "urbanization" describes the overall trend of cities sprouting up in unexpected places [2].

There is no denying that suburbanization has played a significant role in the expansion of major cities in the developing countries. The term "suburban sprawl" refers to the outward growth of suburbs past the limits of their original cities. Being part of the greater metropolitan area's commuting suburbia, the quaint little hamlet is also somewhat of a commuter outpost. The settlement is far removed from the rest of the metropolitan area, while being part of the commuter belt. Federal legislation in the 1940s triggered it, and in the 1950s, a massive road-building program and cheaper builder and consumer loans made it simpler to avoid communities, jobs, and activities.

There has been a progressive transformation of suburban life into a desirable way of life for the vast majority of Americans. This has resulted in a phenomenon known as "sub-urbanization," or the movement of people from urban centers to their surrounding suburbs. Urbanization is a form of spatial distribution that arose in the Industrialized World as a result of sub-urbanization [3]. So, the fundamental drivers of urban sprawl in newer cities might be quite different from one another. There have been a lot of investigations into what prompts urban sprawl in already-established global cities [4].

The Urban Revolution's Important Role

Natural population growth and rural-to-urban migration are the two primary reasons for urbanization. Megacities, defined here as cities with tens of millions of residents or more, are the result of urbanization, but it has an impact on all types of communities, from rural villages to major metropolitan areas. Due to economic, social, and political factors, as well as industrialization, people are leaving the countryside for the cities [5]. What follows are some contributions made possible by urbanization:

The advent of industrialization and manufacturing firms in a particular metropolitan region results in the creation of more employment opportunities and significantly contributes to urban development. The agricultural industry provides a large portion of the workforce in rural areas. As cities and economies grow, more people will be able to take advantage of higher-paying work options that require less physical labor.

Because of social factors, many cities provide a greater standard of living than their rural counterparts. Migration from less economically secure and successful ethnic groups to quickly expanding urban centers is a developing economic trend. To put it simply, new technologies are being used to upgrade urban infrastructure. Better organization, medical centers, and cultural centers can all entice people from the rural to move into the city. Urban sprawl is a multifaceted phenomenon caused by a number of interrelated causes and variables. Policy elements that attract more people are likely to flourish once a rural city reaches a critical mass of residents [6].

Growth in industry often coincides with an increase in available jobs. When an economy undergoes industrialization, it often follows a period of transition from an agricultural economy, and thus paves the way for a wider range of jobs to be created. Mine work and farming are two examples of labor-intensive rural industries. Contrarily, urban industries like healthcare, business, and education require a big pool of applicants with varied skill sets to fill a variety of open positions [7].

The city's amenities have been improved with cutting-edge technology. Industrialization has allowed cities to accommodate diverse cultural norms and build in future-proof infrastructure [8]. Furthermore, upgrading can result in more environmentally friendly urban designs, infrastructure, market hubs, and public transit networks. Large businesses can benefit from mobile technology in advanced vehicle mobility hubs, which can drastically reduce traffic levels in expanding cities for progressives in advanced cities [9].

With the use of the Internet and AI advancements, we could theoretically connect people from all over the world, manage the city's utilities, and control the city's lighting.

These are only a handful of the ways that progress and modernity have improved people's quality of life and made previously intractable problems easier to solve [10].

Impacts of Climate Change

The implications of climate change are multifaceted, and they may have repercussions not just in Europe but around the world. The research identified and ranked the most significant consequences of climate change. The following factors should be taken into account:

• The necessity of coastal defence in the face of rising sea levels, flooding, and the loss of land and coastal wetland.

Consequences for energy use (including heating and cooling).

• The consequences for human health as a result of shifts in the severity of relevant cold and heat effects.

Effects of disease prevalence on public health (and other secondary effects).

• The influence disease load has on public health.

• Affects on the quantity and quality of available water supplies.

• Continual, dramatic shifts in the attractiveness and accessibility of tourist locations.

Repercussions on ecosystems (loss of productivity and biodiversity).

Natural catastrophes' effects

Effects of flooding.

The monetary benefits of climate change were also analysed as part of this effort. The full and incremental global cost of GHG emissions has been estimated using a variety of approaches. We can use these forecasts to evaluate the benefits of various climate change methods against the expenses associated with doing so. A lot of places around the globe faced the wrath of climate change this year.

A severe monsoon season has caused catastrophic floods in Pakistan, displacing 20 million people and destroying their homes and livelihoods. China has experienced its worst drought in 60 years, leaving millions of people facing water shortages. Many other countries have also experienced record heatwaves and excess rainfall this summer [11].

Scientists and world leaders have increasingly focused their attention on climate change in recent decades. It is also of great interest and worry to think about how climate change will affect the entire world and the ways in which different regions are susceptible to its impacts [12].

In Pakistan, 2019 has already seen a number of tragic events. In the Peshawar Valley of Khyber Pakhtunkhwa on April 27, 2015, a hurricane with winds of 110 km/h and a record precipitation of 60 mm wreaked havoc. More than 1,500 deaths are projected in Karachi due to the inclement weather that hit the Sindh province from June 18th to the 26th, 2015. On July 15, 16, 19, 24, and 28, 2018, heavy rains originated from Meltwater Lake and flooded areas of the Chitral district in the province of KPK. On October 24, 2015, the Kaghan Valley had its first snowfall in half a century, with some areas receiving as much as 5 feet in less than 24 hours [13].

The frequency with which these kinds of catastrophic weather events occur implies that Pakistan is already feeling the effects of climate change brought on by soil degradation and urbanization. In addition, several studies find that Pakistan is one of the extremely vulnerable countries to warm environments due to its hot summers and geographic area in the rapid urbanization temperature zone. Anthropogenic climate studies show that Pakistan is experiencing a spike in average high temperatures [14].

According to the Global Climate Risk Index, Pakistan is among the most at-risk nations due to climate change (1995-2020) [15]. Pakistan, the eighth most populous region in the world, places special emphasis on water toxins caused by pollution. The Hindu-Kush Karakoram is quickly disappearing as a result of climate change; this mountain range is significantly important for supplying water to Pakistan's rivers and Himalayan glaciers. Since agriculture is the backbone of Pakistan's economy, it is particularly at risk from climate change [16]. With these numbers, it is critical to evaluate environmental issues affecting forestry, water sources, the economy, and food security by knowing the future climate [17].

Considered an essential resource for calculating and understanding climate and the impact of greenhouse gas emissions on ecosystems worldwide and locally. These models utilise mathematical analysis to depict the interrelationships of landscapes, coasts, soil, and snow, and to make realistic forecasts of potential extreme weather events [18].

Methodology

Punjab is the second largest province in Pakistan in terms of land size, at 205,344 square kilometres. It's used in every quarter of a roof in Pakistan every day. The provinces of Sindh and Balochistan lie to the south, Khyber Pakhtunkhwa and the capital of Islamabad Territory to the west, and Azad Kashmir and the Islamabad Territory to the north form Punjab's borders. Punjab is bounded by Jammu and Kashmir to the north and by Jammu and Kashmir and Rajasthan to the east in India. Punjab's capital and largest city is ancient Lahore. Other major urban centres include Faisalabad, Rawalpindi, Gujranwala, Sargodha, Multan, Sialkot, Bahawalpur, Gujrat, Sheikhupura, Jhelum, and Sahiwal. The Jhelum, Chenab, Ravi, and Sutlej Rivers, which flow north to south through Punjab, are the four major waterways in Pakistan; the Beas River, the fifth of the Punjab River's "five bodies of water," flows entirely within the Indian state of Punjab. Canals can be found all across the province, and the environment is one of the most highly irrigated on the planet.

The Suleiman Mountains, located in the southwest of Punjab, are just one of the province's several mountain ranges. The Margalla Hills, located north of Islamabad and the Salt Range, cut off the Pothohar Plateau, the northernmost portion of Punjab, from the rest of the province. You'll find scant deserts in southern Punjab, close to the Rajasthan border, and in the Suleiman range. The Punjab region also includes a portion of the Thal and Cholistan deserts. In the Dera Ghazi Khan hill station of Fort Munro, the southernmost point of Punjab reaches an elevation of 2,327 metres (7,635 feet) [19].

The majority of Punjab is subjected to severe weather, with foggy winters being the norm. The average annual temperature ranges from 50 to 10 degrees Celsius in the Punjab region, with summer highs of 122 degrees Fahrenheit. Punjab experiences three different seasons, with summertime seeing highs of 110 °F (43 °C). In the sub-mountain region, annual precipitation is 96 cm, whereas in the lowlands it is just 46 cm. Under mildly chilly conditions, temperatures can dip to 40 degrees Fahrenheit (around 4 degrees Celsius) (October to March). The hot and dry south and the cold hills of the north both contribute to the region's extreme climate. Extreme weather still occurs in the Himalayan foothills, and the climate is significantly colder and wetter, with massive amounts of snow normal at higher elevations [20].

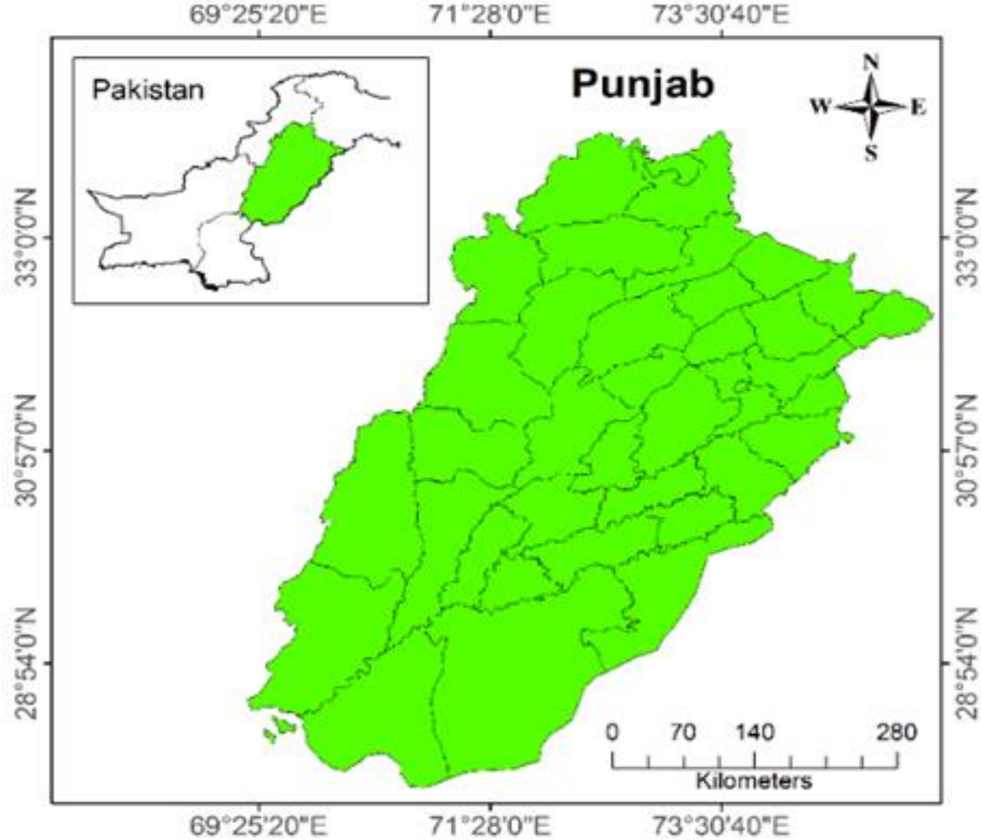

Figure 1. Map of the study area, Punjab province, Pakistan

The economy of Punjab, Pakistan's most populous province, is the backbone of the country's overall economy. It was responsible for 54.7% of Pakistan's GDP in 2000 and for 59.2% in 2018. Providing between 52.1 and 64.5 percent of economic activity in the service sector and between 56.1 and 61.5 percent in agriculture (Kousar, Rehman et al. 2018). Punjab is the most developed province in Pakistan despite the country's total lack of a coastline. Manufacturing in this country produces a wide variety of goods, including textiles, sporting goods, heavy machinery, electrical instruments, surgical devices, engines, car components, metals, sugar mills, aircraft, cement, agricultural machinery, bicycles and rickshaws, floor coverings, and processed food. The province produced 90% of Pakistan's paper and paperboard, 71% of Pakistan's fertilizers, 69% of Pakistan's sugar, and 40% of Pakistan's cement in 2016 [21].

More than half of Pakistan's people live in this province, making it not only the most populated in the country but also the most populous sub-national body in the world outside of China and India. Punjab boasts Pakistan's lowest poverty rate, yet the state's northern and southern halves are very different [22].

the Punjabi climate

The Punjab region of the "five rivers country," located in the northern part of the Indo-Gangatic plain, experiences a subtropical climate characterized by a mild and moderately rainy winter, a scorching period from mid-April to June during which temperatures can reach 46/47 °C (115/117 °F), and a trembling summer with some rain brought by the monsoon from July to September. In the spring, especially in March, tornadoes can erupt when opposing air masses collide. In May and June, just before the monsoon, there was a very hot wind, the Loo, that may bring dust storms, severe degradation of animals and humans, and the decomposition of plants. There will most certainly be some quite intense rains, and the temperature will rise by an unknown amount.

Between the latter week of June and the first week of July, we experience the rainy season, which is marked by bouts of terrible weather mixed with extended periods of high temperatures and drought. But, when it does rain, it can deluge an area in a couple of hours or minutes and cause rivers to overflow if it continues to do so for several days.

Acquiring and Analyzing Information

The information used in this analysis comes from two different fields:

Earth's Climate Research Facility

Meteorological Service

This analysis made use of each station's monthly average, monthly maximum, and monthly lowest air temperatures in Punjab, Pakistan. Station categorization is a critical topic in urban heat island (UHI) and urbanization studies. Taking into account the specifics of urbanization in Punjab, we'll divide the stations into four categories based on their populations: large city (LC) stations with populations over 500,000; medium city (MC) stations with populations between 300,000 and 500,000; small city (SC) stations with populations between 100,000 and 300,000; and country (CS) stations with populations below 100,000. Given the urban development pattern seen in some rural territories in Punjab over the past decades, the pair-station approach faces challenges in locating 'unmitigated' country stations close to every city. However, a station in a neighbourhood with fewer than 100,000 inhabitants can be used to describe a rustic area in this investigation because Pakistan's population base is much lower. More than 70% of country stations chosen were in areas with fewer than 50,000 inhabitants in the year 2000 (one of the most recent year of the period considered), indicating extremely slow population development around these station zones. This is because urban areas grow at a much faster rate than rural areas [23].

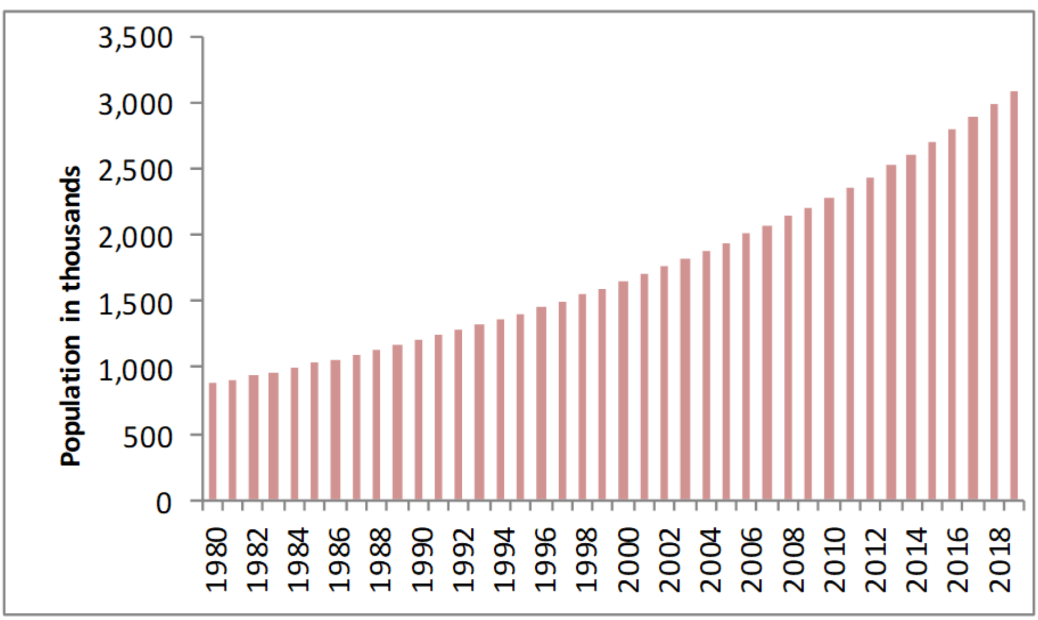

Figure 2. Mean population trend of ten large cities of Punjab, Pakistan from 1980-2019.

Selection of Urbanization Indicator

The percentage of urban land use area surrounding the observation-based sites will be assessed in several buffer circular central locations to analyse the effects of varying levels of urban growth on the temperature at different spatial scales from the scale (40-100 km) (Figure 3). Stations in rural areas with populations under 30,000 were prioritised, and station pairs were then chosen in order to ensure that as many large, medium, and small stations as possible were located in close proximity to each rural area [24].

After that, we looked at how the population was affected by the temperature fluctuations near these stations. As city populations grow, so does the average temperature. This is made simple by the visual representation of various buffer circles around the observational locations, making it easy to determine what proportion of the surrounding area is covered by urban development. It would also be found that within a certain radius of the observing locations, the impact on SAT records would increase in proportion to the percentage of built-up regions nearby.

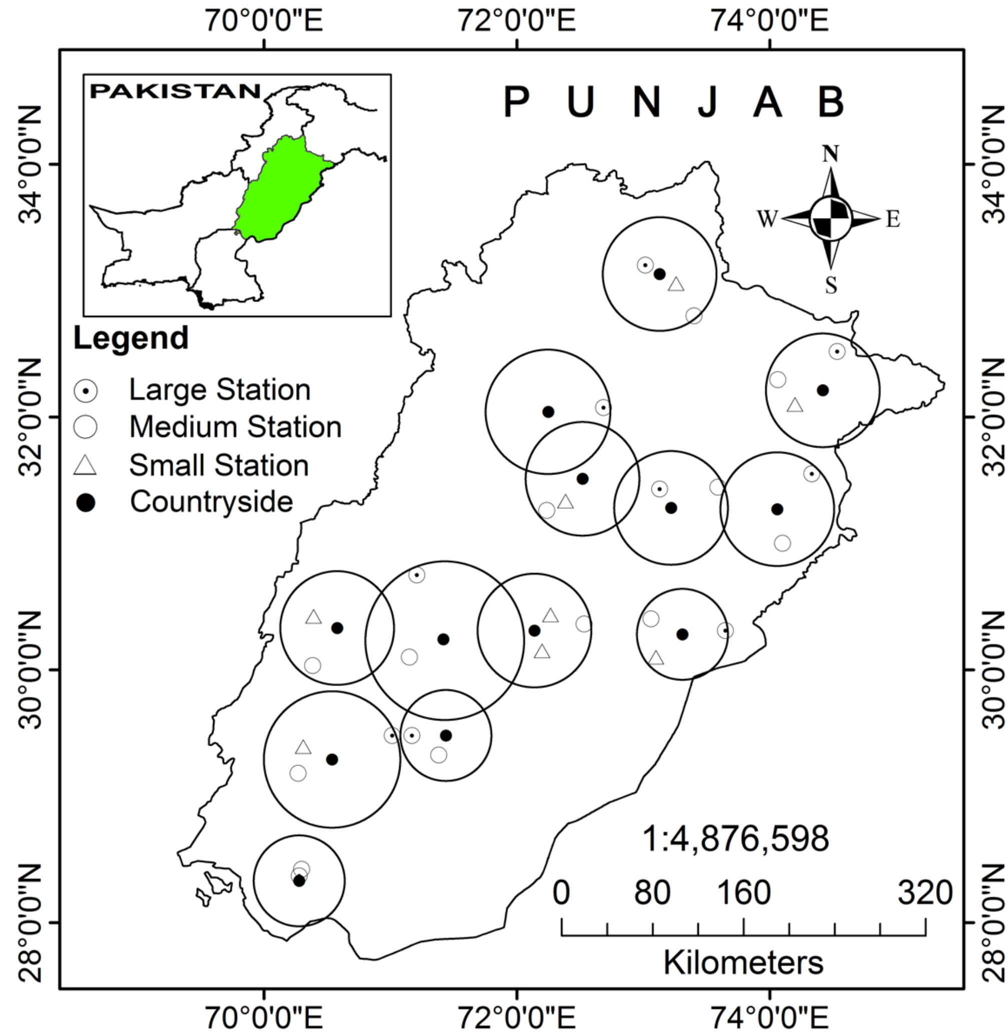

Figure 3. Percentage of urban land-use area around the observation-based sites shown in different buffer circles

Statistical Methods

In this analysis, annual means are calculated by averaging 12 monthly means, whereas seasonal means are calculated by averaging three months from any given season. At least one station is selected for both the grid reference series and the "urban station" series over the whole study region, which is partitioned into grid boxes with a spatial resolution of 2°*2°. This is what we mean when we talk about the urbanization effect:

$$\Delta T_{U\text{-}R}=T_U-T_R$$

Where; T_U is the linear trend of any temperatures forthe metropolitan station within the grid, and T_R is the linear trend of any temperatures of the reference stations within the grid.

It is necessary to compute the geometric mean for each reference and target station, as well as the mean temperature anomalous series for the grid box. Anomalies in temperature are determined by comparing the current year with the average for 1965-2019. The mean temperature differential series between the urban station and the grid reference station has increased dramatically due to urbanization. If the population growth effect is statistically significant on the grid, the urbanization contribution, defined as a percentage of the urbanization effect to the overall trend, will be calculated. The urbanization contribution (C_U) is calculated as follows:

$$C_U = \left| \Delta T_{U\text{-}R} / T_U \right| \times 100\%$$

Where; T_U is the linear trend of any temperatures of an urban/town station, and T_R is the linear trend of any temperatures of reference stations within the grid.

Ordinary least squares is used to determine the linear trend of the temperature anomaly series. Due to its expected negligible effect on trend estimation, the serial correlation of monthly mean temperatures will be held off until trend estimation is finalised. (Von Storch and Navarra, 2013). The statistical significance of the linear trend in the sequence of temperature anomalies is determined using the Normal distribution. A temperature trend (temperature difference) series is deemed statistically significant when the level of confidence in the series is equal to or greater than 99 percent.

Periodic seasonal breaks

Pakistan has a tropical climate, however its climate varies widely. The climate varies greatly from region to region, with the highlands experiencing perpetual snow and the plains a monsoon-tropical climate, while the north and the mountains get more rain and chill.

Pakistan's Springtime

The first days of March usher in mild, gentle spring weather, while those living in higher altitudes have to wait until May to experience the same. Yet, the mild spring season is over all too fast, making way for the scorching summer months. Daylight hours continue to increase, and so does the average temperature. The average high temperature in March is around +20 °C, and by the middle of April it has risen to approximately +30 °C. There has been a dramatic shortage of rain during this time period.

Pakistani summer

The hottest and longest season, it often begins in the plains regions around the first of May and lasts until the middle of July. During this time, the weather is consistently warm; in fact, the nights may get quite toasty. Temperatures average around +29 °C in coastal locations, whereas in the desert they might reach +35 °C. Ending in June with the first showers, summer finally lets up and gentle, warm days return. These downpours often include thunderstorms, but they last only a few minutes at most.

Pakistn w okn

Early October sees the onset of autumn on the plains, whereas early September sees it on the mountains. Up in the mountains, you can only expect cold winter weather. The greatest time to travel across the country is during the mild and beautiful fall season. Day by day, the temperature climbs to a high of +27 °C in October and +20 °C in November.

Pakistani winter

The plains have never experienced a true winter with snow. Warm weather is always guaranteed. There may not be any snow or even any significant wind, but it is still rather chilly. In the winter, it is not uncommon for Pakistan to see intense downpours that last only a short while. But desert regions are an outlier, with year-round temperatures that never dip below freezing. The months of January and February in Pakistan are typically the coldest.

Discussion and Results

Regular Tendency

So, while population can serve as a proxy for a city's size, we have nonetheless made an effort to use the appropriate approach in order to identify any potential correlation between UHI and urbanization. Annual urban-rural disparities in Tmean, Tmax, and Tmin for the three station types are shown in Figure 4. (SPs). If we look at the table below, we can see that the mean differences between urban and rural areas are positive for all three categories (Figure 4a). Of the three types of SPs, LC SPs show the largest mean annual variations in Tmean (0.30 K). K/decade is the unit of measure for the average temperature. However, between 2000 and 2005, the disparity in urban and rural areas in terms of Tmean in LC SPs has been growing, with a particularly dramatic shift occurring in the middle of the decade. The diagram depicted in (Figure 4a).

Increases in urbanization in Pakistan have been particularly dramatic since the early stages of the country's technological growth and introduction. The values of LC SPs diverge significantly around 2005. The values of LC SPs changed significantly between 2000 and 2005, while those of MC SPs and ST SPs followed similar patterns.

Figure 4b shows that there are fluctuations in the annual gap between urban and rural Tmax values, especially when compared to (Figure 4a). The three different kinds of SPs show a clear progression. On the other hand, a difference of just about 0.34 K was observed between the three types of ST SPs. Notably, between 1980 and 2019, there was less fluctuation between the ST SPs compared to the LS SPs. From the turn of the millennium to the turn of the millennium, LC SPs showed an increasing trend of urbanization effect, coinciding with the first decade of Pakistan's rapid development, and the disparity between LC SPs grew dramatically in 1995.

Due to the mild climate of the 1990s, there was only a slight difference in maximum temperature (Tmax) between urban and rural areas. During this warm period, environmental imbalance was likely easier to develop. Heat transfer between urban areas has decreased because of extensive vertical heat diffusion. Nonetheless, both MC and ST SPs showed a substantial Tmax difference between urban and rural areas.

Also, our research indicated that the regional average urban-rural difference in Tmax values might not be reliable when used to evaluate the regional UHI potential of reaching major cities in Pakistan. The regional average Tmax appears to be meaningless for LC SPs. The warming effect of urbanization alone cannot account for this.

Due to population, transportation, and industrialization, maximum temperatures in urban regions and countryside stations are high, making Tmean significantly higher for the three types of SPs in all the examined series (Table 1), compared to urban variations in Tmin and Tmax. The similar 0.67 K difference between urban and rural LC SPs was discovered. This suggests that the UHI forms more rapidly after dark than it does during the day.

This means that the daytime UHI is soaked up by increased radiative behaviour. moderate heat When compared to rural areas, city temperatures, especially at night, might be up to 10 degrees Celsius higher. The urban heat island effect (UHI) describes the increased temperatures. This heat is then transmitted downstream by a layer of air about 1 km thick. Cities tend to have greater average surface temperatures than their surrounding rural areas, with the exception of those in desert regions. Throughout the day, a city's surface temperature can rise above that of the air just above it, creating what's known as a Surface Urban Heat Island (SUHI).

The UHI is substantially weaker during the day than the SUHI due to the structure of the atmosphere and the vigorous mixing of the air by turbulence. When released into the air at night, the stored heat prevents the air from chilling. This is why, after sundown and continuing through the night (and occasionally into the morning), urban areas tend to be significantly warmer than their rural environs.

Cities and towns have similar daytime air temperatures, but urban areas cool off more gradually in the evening because of the greater sensitivity to heat influx from the absorbed radiant radiation at the urban base and the more consistent circular motion.

As a result of this phenomenon, the temperature gap between urban and rural areas is greatest late at night, when temperatures in both urban and rural areas have dropped to roughly 0.01K. Each of the three categories of prefrontal SPs has a distinct change in Tmax, and each exhibits a distinct temporal trend across time (Figure 4c). Moreover, population data has demonstrated the significance of the Tmax differential between urban and rural areas. Studies and observations have also been made on the major shifts that took place in 2005.

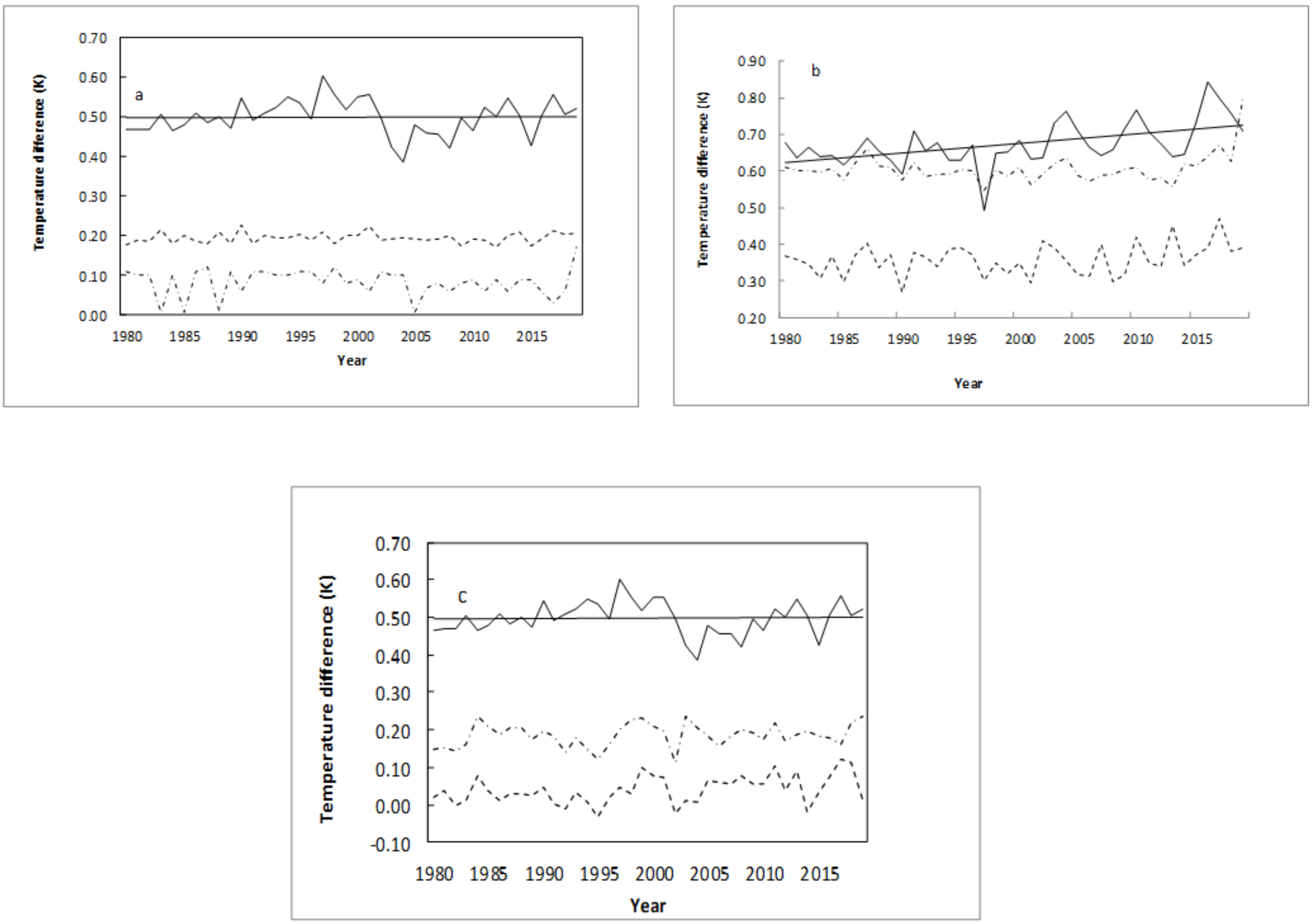

Figure 4. Annual trends of the urban-rural differences from 1980 to 2019 for (a) Tmean, (b) Tmax, and (c) Tmin. Solid lines represent LC SPs' trend, dashed lines represent MC SPs, and dotted-dashed lines represent ST and SPs.

As shown in the graph, the variation in trend observed from 1980 to 2019 and the total temperature variation observed is between the ranges 0.45K to 0.55K for the T_{mean} (Figure 4a). In contrast, the T_{max} from 1980 to 2000 shows a rapid decrease in temperature difference values, with the minimum value reaching 0.50K. Aside from that, the T_{min} in 2005 has the lowest value of 0.42K.

Table 1. Average values for annual and seasonal urban-rural differences 1980-2019 (Unit: K/decade)

ANNUAL			WINTER			SPRING			SUMMER			AUTUMN		
LC	MC	ST	LC	MC	ST	LC	MC	ST	LC	MC	ST	LC	MC	ST

T_{mean}	0.30	0.27	0.11	0.35	0.23	0.09	0.50	0.20	0.04	0.30	0.20	0.20	0.38	0.32	0.11
T_{max}	0.67	0.61	0.34	0.44	0.31	0.19	0.90	0.28	0.02	0.41	0.31	0.10	0.40	0.35	0.15
T_{min}	0.50	0.19	0.04	0.26	0.15	0.12	0.23	0.18	0.01	0.29	0.15	0.04	0.34	0.29	0.24

These urban-rural temperature differences comprising the time periods (1980-2019) have a major impact on seasonal variation. The winter season has a total T_{mean} value in the range (0.35K to 0.09K) for LC, MC, and ST, whereas the spring season has a significant variation for LC, MC, and ST in the range (0.50K to 0.04K), showinga decrease in value from high to low Furthermore, the summer season considers T_{mean} values ranging from (0.30K to 0.20K) with a total difference of 0.10, while the early fall season considers a difference of 0.27K with T_{mean} values ranging from (0.38K to 0.11K) for LC, MC, and ST, as shown in Table 1.

Seasonal Trend

The seasonal characteristics of urban-rural differences in T_{mean} for the three types of SPs values are depicted in (Figure 5). The seasonal trend, particularly the LC SPs, had a relationship similar to the annual trend shown in (Figure 4a). Furthermore, the LC SPs had greater average UHI impacts than the other two SP types, particularly in the spring, when the average UHI value was 0.50 K (Table 1).

These analyzed results show that LC SPs are beginning to experience a rapid change in temperature difference (K) values, especially during the spring, summer, autumn, and winter seasons, mainly between the beginning of 2000 and the end of 2005. Another notable difference is that the UHI impact was greater in LC SPs than in MC SPs during spring and autumn, and the exact opposite was observed in summer and winter (Figure 5). As a result, the resulting seasonal trend exhibits an opposite relation during the spring-autumn and summer-winter seasons.

Three different types of SPs values characterise the yearly shifts in mean Tmean between urban and rural regions. Predictability of climate, and in particular temperature change over time, has received considerable attention in many parts of the world. The amount to which temperature differentials vary with spring, summer, fall, and winter seasons changes with time, as depicted in (Figure 5). The spatial-temporal analysis of weather data revealed that the mean temperature (Tmean) rose sharply beginning in the spring of 1980 and holding steady until 2004.

Then, from 2005 to 2019, there is a notable climate-induced change and a practical adaption approach is recommended throughout the spring months, with the largest temperature differences occurring between 0.2K and 0.3K. The current research looks at the long-term temporal shifts from 1980 to 2019, as well as variations in the summer season's temperature differential value. The data for the entire period from 1980 to 2019 were analyzed, and the sharp increase in temperatures seen between 2005 and the present, with a huge discrepancy of 0.2K, was made clear. According to data from 2005, the minimum July temperature was 0.2K, while the maximum was 0.4K. Also, using data from 2005 as a reference, spring and summer are related, as there is a significant change in temperature values after 2005.

In order to assess and explore the variability in temperature differential curve values, a statistical pattern research of fall and winter temperatures from 1980 to 2019 was conducted. Figure 5c, a breakdown of autumnal values, reveals a sinusoidal pattern of temperature differential values for 2005, rising to a peak of 0.35K before rapidly falling to a minimum of 0.2K. During 2005-2019, there has been a 0.3K increase in average yearly high and low temperatures and a 0.5K increase in average fall high temperatures.

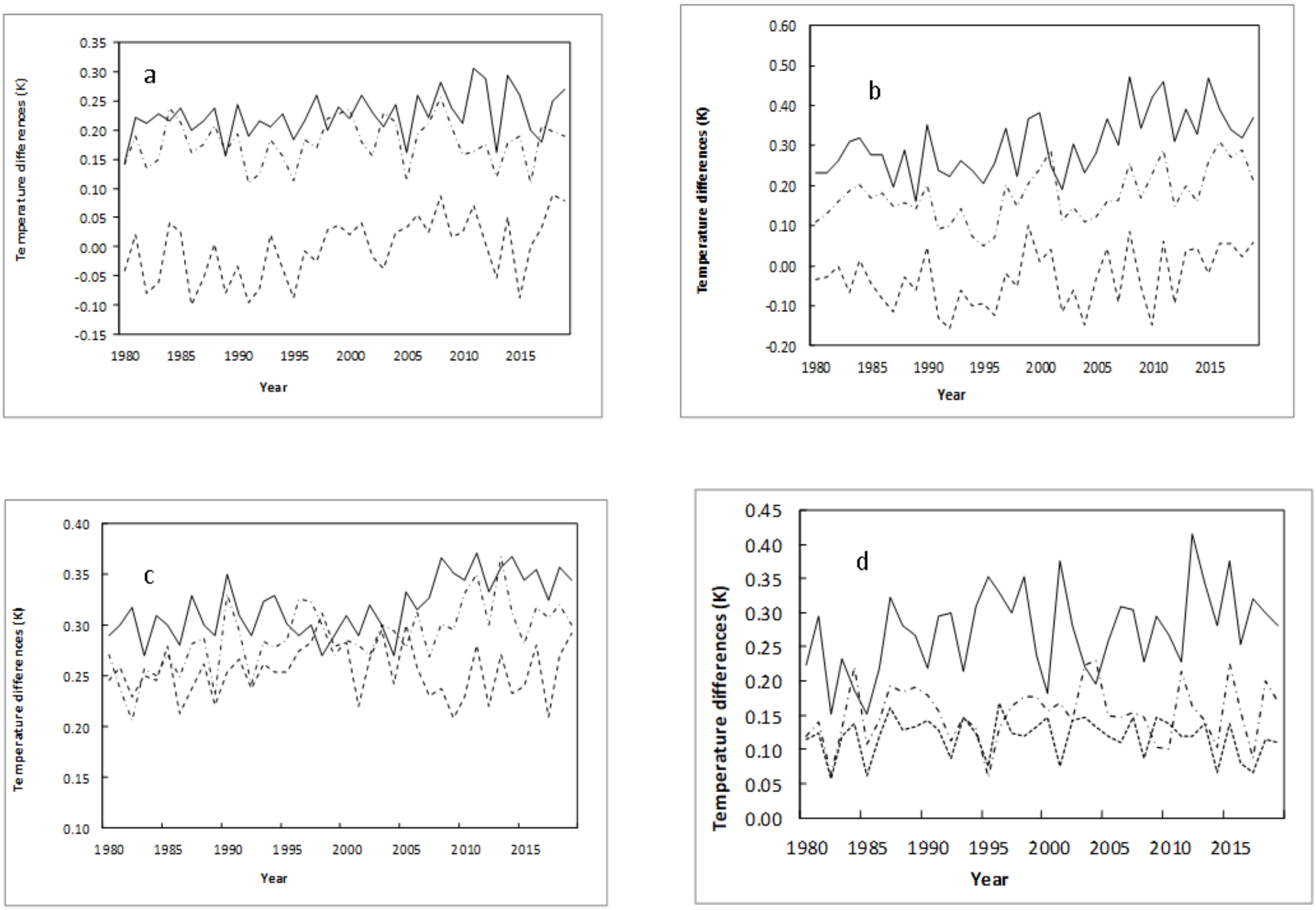

Figure 5. Seasonal trends of urban-rural differences for T_{mean} from 1980-2019 for (a) spring, (b) summer, (c) autumn, and (d) winter. Solid lines represent LC SPs' trend, dashed lines represent MC SPs, and dotted-dashed lines represent ST and SPs.

In addition, significant trends in the winter season's temperature differential values from 1980 to 2019 are uncovered. Temperatures have dropped significantly from 1985 to 1985, as shown in (Figure 5d). After that, the year 1996 was identified as having the highest temperature increase. The lowest annual temperature differences were recorded in 1983, 1985, 2000, and 2005 during the winter season. The temperature differential value has risen sharply since 2015, reaching 0.42K at its highest point relative to the previous seasons. The resulting graphs reveal the severe seasonal fluctuations in temperature, with a total high peak in winter of 0.4K temperature difference and a minimum peak of 0.15K temperature difference even throughout the winter (Figure 5d).

When Tmax was used to represent the seasonal aspects of UHI, the urban-rural disparities indicated weak UHI patterns as an annual variable (Figure 6). The mean UHI effect was likewise highly connected with the population, with greatest spring values in LC, and the seasonal mean values of urban-rural disparities for Tmax have showed a rising tendency over the four seasons (Figure 6).

We have found seasonal shifts in the areas of Punjab over the past few decades, and the delayed urban-rural airflow that has resulted from heavy stabilizing has led to rising city temperatures. Anthropogenic factors have contributed to an increase in temperature, which has led to global warming, which in turn has caused a reversal of the rainy and summer seasons, a shift in the time cycle, and the discovery that the summer season overlaps with the spring season. Seasons in Pakistan are getting longer in the summer and shorter in the winter. Due to climate change, not only are temperatures rising, but rain patterns are also changing. The increased humidity that affects nearly all of Pakistan throughout the summer is a direct result of the monsoon rains that fall throughout the country at that time.

Moreover, the spring boundary is primarily described as poor because of high air turbulence in Punjab and because of heavy flow of transport; use of air conditioning in the summer is also a reason for this; now, even the countryside station areas in Punjab are using air conditioning; and atmospheric heat in the spring should be regarded as another significant aspect when investigating the causes of UHI. According to the data, the average UHI effects for LC SPs throughout all four seasons were larger than 0.50 K. (Table 1). In the spring, LC SPs had a bigger effect on UHI than MC SPs, as shown by the 2005 time series. In my opinion, this is a fascinating area that needs more investigation.

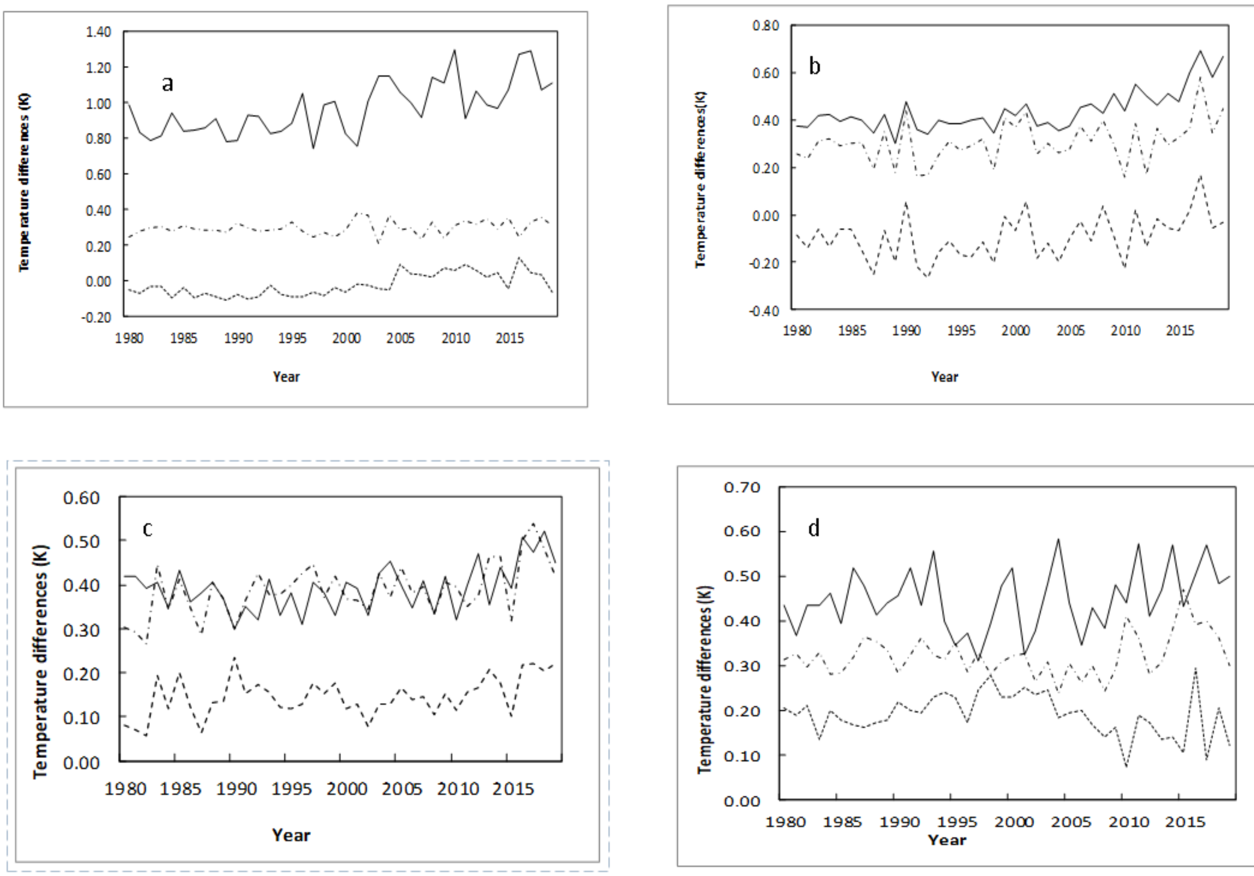

Figure 6. Seasonal trends of urban-rural differences for T_{max} from 1980-2019 for (a) spring, (b) summer, (c) autumn, and (d) winter. Solid lines represent LC SPs' trend, dashed lines represent MC SPs, and dotted-dashed lines represent ST and SPs.

Extending seasonal trends in urban-rural areas from 1980 to 2019 for Tmax is also done, and the findings are shown in (Figure 6). Results for the spring season are shown in (Figure 6a), suggesting a steady-state trend to the year 2000, and the results for the LC SPs, MC SPs, and ST and SPs are all measured using the difference in temperature values to determine the upward or downward trend of the variable through time. Thereafter, a sharp upward trend in LC SPs was identified, but the pattern of MC SPs, ST, and SPs was stable across the time period studied, exhibiting just a slight deviation beginning in 2005. Statistics for the summer months (Figure 6b) reveal an exponential growth pattern from 1980 to 2019 across all examined rates (LC SPs', MC SPs', ST and SPs').

There is, however, a steady-state scenario for all of the assessed rates throughout the autumn season, followed by a strong upward trend for the LC SPs' discovered after 2010, while the patterns for both the LC SPs and the MC SPs remain consistent across the timeframe with a little change beginning in 2005. In addition, the 1995 winter season LC SPs pattern exhibits a significant downward shift. Two troughs in decreasing temperature values are seen before 1997 and after 2003 throughout the 1980-2017 time period, but this pattern is least connected with the LC SPs'.

In addition, the Tmin has been applied to characterize UHI's seasonal features (Figure 7). With average values of 0.29 and 0.34 K, respectively, for LS SPs in the summer and fall, the urban-rural disparities showed that the pattern was higher for LS SPs during those seasons (Table 1). Average UHI effect was highly associated with population and peaked in the fall when LS SPs values were highest.

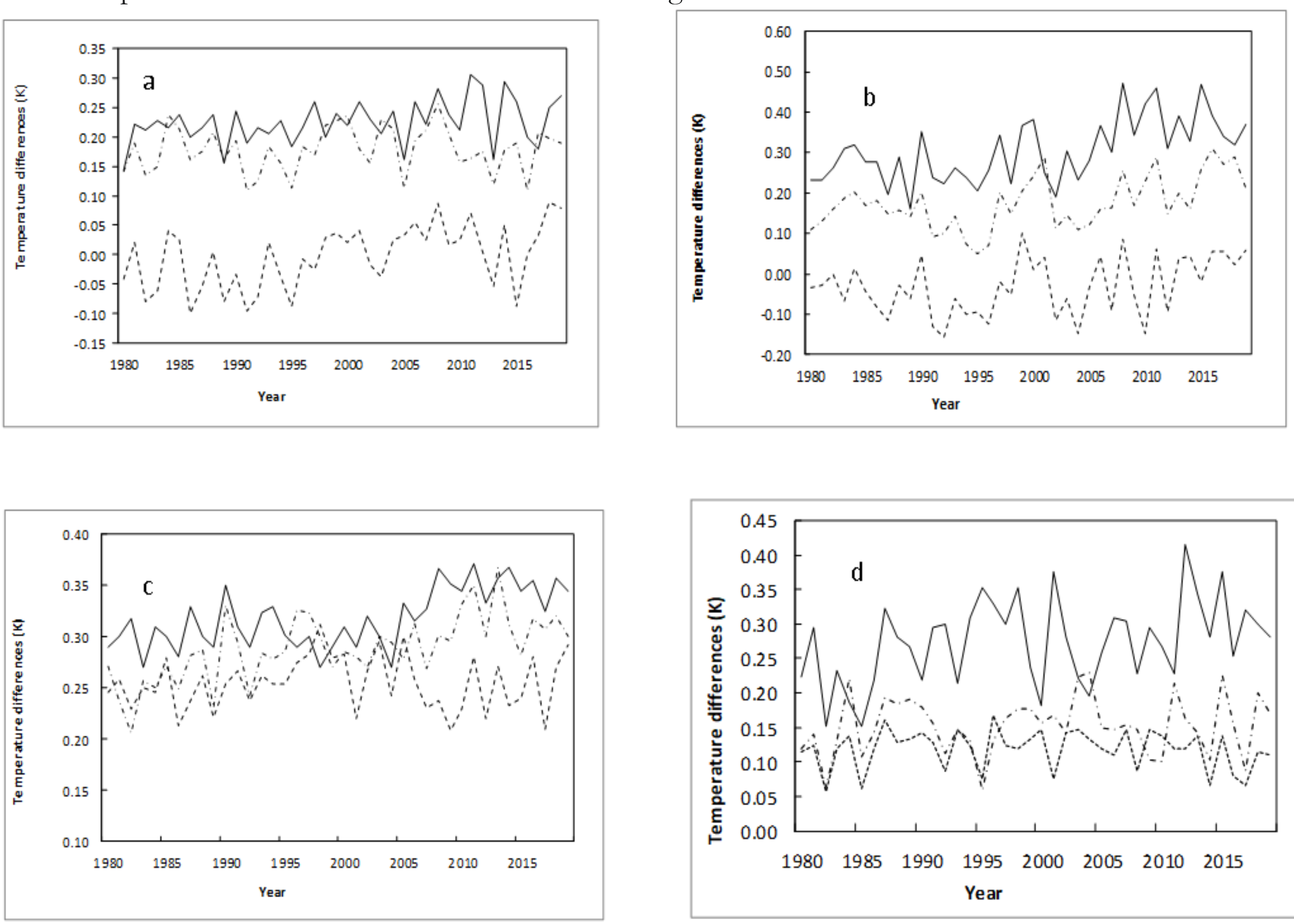

Figure 7.Seasonal trends of urban-rural differences for T_{min} from 1980-2019 for (a) spring, (b) summer, (c) autumn, and (d) winter. Solid lines represent LC SPs' trend, dashed lines represent MC SPs, and dotted-dashed lines represent ST and SPs.Lines represent ST and SPs.

Spatial Distribution

As previously stated, the above analysis concentrated on the average temporal aspects of urban warming (UW) across Pakistan's major cities and Punjab district. It is also interesting to investigate the spatial patterns of UW because each city has its own distinct characteristics. As a result, there is a significant difference in UW between southern and northern Punjab. The spatial distribution of annual average urban-rural differences for T_{mean}, T_{max}, and T_{min} SPs with UW is depicted in (Figure 8).

As shown in (Figure 8a), the majority of the stations with weakening urban warming had mean temperature values (T_{mean}). Nonetheless, urban warming has influenced more stations in Punjab's eastern regions. Furthermore, the North-East had more urban warming stations than the North-West and Southern Punjab combined. During a 40-year study, the average urban warming indicated by T_{min} was 0.04 K, and T_{max} was 0.50 K. The rising effect of urban warming had been observed in major cities of Punjab, such as Lahore and Faisalabad, as a result of increased industrial development and urban growth dissipation. Furthermore, there is more development and opportunities, maximum rise in population can be found, and strong urban warming can be witnessed in urban cities.

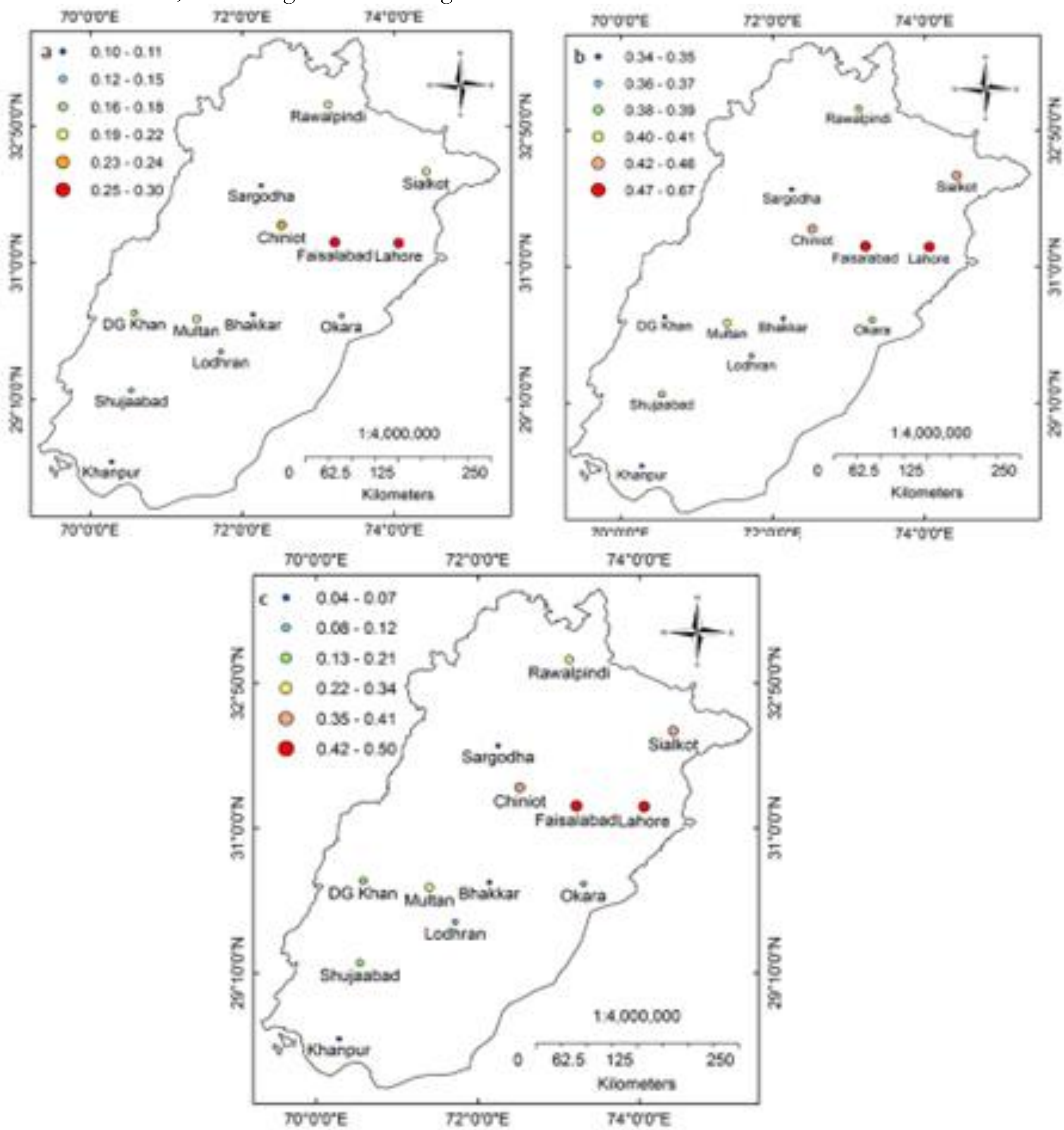

Figure 8. Spatial distributions of the trends of annual average urban-rural differences of the SPs with UW from 1980 to 2019 for (a) T_{mean}, (b) T_{max}, and (c) T_{min}.

There are many applications for the distribution of population data from 1980-2019, broken down into metropolitan city regions according to their urban rural-difference of SPs per year. Its use is widespread in calculating temperature dispersion across regions. One of the most prominent characteristics of climate, temperature difference is subject to dynamic, time- and space-varying change as a result of a wide range of exogenous influences. Figure 8b shows that significant temperature shifts have occurred in the country's two largest cities, Lahore and Faisalabad. These climatic temperature shifts encompass both short- and long-term macro- and micro-scale climate shifts (1980-2019). Furthermore, one of the most crucial aspects of calculating climate change is determining temperature fluctuations on a regional scale.

What's more, annual Tmin (minimum temperature) and Tmean (mean temperature) values in different cities of Punjab Province, Pakistan showed a substantial variance tendency, as shown in Figure 8. In terms of Tmax (highest temperature) values, there was a marked shift to the northeast (Lahore and Faisalabad). Tmin has been rising at a pace of 0.42K to 0.50K for the same cities, resulting in a minimum temperature difference. Overall, based on seasonal variations in temperature values reaching extremist values (Tmax and Tmin) predominantly at lower elevation areas, we can estimate and act as evidence of the district-level climate change aspects, which may have a significant impact on the vegetation and water resources at both the district and station level in the major cities of Punjab.

Even though urban heat islands (UHI) can be mitigated by increasing concrete surfaces, transportation, high-density buildings, and anthropogenic temperature, increasing vegetation in urban areas reduces the total radiative energy of the metropolitan boundary layer, which in turn reduces the effectiveness of surface heat storage. In contrast to the heavily industrialized, more populous, and better connected northern half of the province, the southern part of Punjab is not wholly desert. The impact of UHI in southern Punjab is smaller than in cities since UHI is more prevalent in densely populated areas. The cumulative result of this energy equilibrium is a lessening of the urban/rural energy gap.

Hence, due to urbanization and the region's unique climate, Southern Punjab has far less urban warming than other parts of India. Moreover, we inferred the average trend of urban-rural temperature differences from the chart above. Tmax, which exhibited a similar pattern to Tmean, but with stronger urban warming stations appearing in the northeast of Punjab, had the highest rising and dropping trends, while Tmean, which showed a similar pattern to Tmax, had the most notable increasing trends.

Conclusion

The population of major metropolitan cities in Pakistan's Punjab area was analyzed, together with the features of maximum, minimum, and mean temperatures. Using the population as a criterion, the cities in Punjab are divided into three groups: those with populations exceeding 500,000, those with populations between 300,000 and 500,000, and those with populations between 50,000 and 100,000. In major cities, where the urban warming effect is most pronounced, population growth appears to be intrinsically tied to urbanization. Mean and maximum temperatures are useful in defining the impact of urbanization on climate. Among the three factors considered, the highest recorded temperature was the most telling of the UHI effect. The year 2005 marked the beginning of Pakistan's time of innovation and opening up, and it also saw the spread of urban areas. After that, there were major shifts across the board for SPs, especially LC SPs. Both the Tmean and Tmax time series exhibited noticeable shifts, with Tmax reaching a maximum of 0.67 K.

Significant UHI was discovered in Northeast Punjab in the spring due to urbanization, a high flux of people migrating, and human movement patterns. Many UHIs are more valuable because people are more likely to live in and work in them; this is because both employment possibilities and mobility patterns are more concentrated in and around large cities.

The northeastern region of Punjab, Pakistan has experienced extreme weather and other climate change occurrences. It is conceivable and beneficial to use population as an index to classify metropolitan stations into three types and evaluate urban growth, despite the fact that every city has its own unique geographical qualities and economic position.

The exact mathematical formula connecting urban population to UHI impacts is uncertain, though. Further analysis for different regions in Punjab, Pakistan should take into consideration other elements including heating costs during the Pakistani winter. The mechanisms that underlie the ideas discussed here warrant additional research in the future.

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