

Climatic Variation and Trend Analysis in Pakistan Using GIS Technique

Nadia SHAHZADA¹, Asma Khan KAKAR^{1*}, Zakaria SHAH¹, Nadeem AHMED¹

¹ Department of Geography and Regional Planning, University of Balochistan, Quetta, Pakistan.

*Correspondence: asmahakeem12@gmail.com

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Abstract: Background: The fluctuations in temperature and precipitation caused by climate change have a substantial impact on many regions worldwide. Pakistan and other agricultural nations face serious concerns due to climate variability. **Objective:** The main objectives of this study were to use GIS techniques to determine trend deduction in the analysis of climatic variation in Pakistan and to explore the variability of the country's climate. **Method:** This study analyzed data from 50 areas in Pakistan, to assess the degree of climatic sensitivity. The metrological data, which was collected from 1991 to 2022 from 50 stations, is used in this analysis. Using GIS, the long-term fluctuations as well as the mean annual, average temperatures as well as precipitation, were studied. Software for Geographic Information Systems (GIS), such as ArcMap, uses a spatial interpolation technique termed Inverse Distance Weighting (IDW). IDW uses the values observed at measured places to estimate values at unmeasured locations, giving closer points more weight than faraway points. **Result:** The past shows that the climate is changing. All aspects of our lives will be affected, but over time and across the country, the rate of change and the nature of the resulting consequences will vary. From the turn of the 20th century, Pakistan's average surface temperature has increased; the highest average temperature ever recorded in Larkana was 28.62 degrees in 1992. The highest recorded average temperature in Jacobabad was 27.64 degrees in 2022. In 2012, Abbottabad and Khurram Agency experienced the highest amount of rainfall. The rainfall from the previous year is not at all comparable to this year's. The locations with the highest rainfall in 2022 were Jacobabad, Khairpur, Abbottabad, Bhimbir, Noshera, Sawat, Dadu, and Larkana. This year's rainfall is significantly different than the previous thirty years. Since the precipitation on that day caused flooding across the country, 2022 was a rainy year. **Conclusion:** Research conducted on the variability of Pakistan's climate suggests that climatic shifts impacting the nation's diverse ecosystems and socio-economic framework interact in a complex way. Temperature data analysis showed seasonal patterns of fluctuation and a trend for average temperatures to increase in a number of areas.

1. Introduction

Globally, many locations are significantly impacted by the variations in temperature and precipitation brought on by climate change. (Trenberth, 2011b). Scholars have focused a great deal of attention on it over the last few decades. Climate change has become an issue in some places in recent years (Sharifi et al., 2021). Numerous studies provided evidence, that anthropogenic actions as well as natural processes are to blame for the observed variations in precipitation, temperature, and relative humidity in the modern age (Trenberth, 2011a). There was an increase of around 0.72°C in the global mean surface temperature (GMST) from 1951 to 2013 (Hu et al., 2021). Pakistan's agricultural and water supplies have ultimately been impacted by variations in precipitation patterns. (Fahad & Wang, 2020) As a result, the fraction of global land precipitation increased by 2%. Changes in the patterns of precipitation have eventually affected Pakistan's agricultural and water resources (Mahmood et al., 2016). Additionally, precipitation, relative humidity, and temperature all show homogeneous

variations in time with the natural world (Willett et al., 2014). Climate variability, for example, is the subject of many computations; nonetheless, precipitation, rainfall, temperature, as well as relative humidity are important indicators (Box et al., 2019). Their seasonal and yearly variations can be used to research climate change (Konapala et al., 2020).

Worldwide precipitation and droughts are closely correlated with climate indicators via atmospheric coupling, or teleconnection. Droughts are becoming more frequent due to changes in climatic trends (Kakar & Qurat-ul-ain; Naumann et al., 2018). Reports on drought vulnerability and its numerical evaluation, however, are uncommon, separating the relative influences of various climate variables is therefore essential to increasing the rationale of impact assessments (Vogt et al., 2018). Large-scale atmospheric, oceanic, and heat flux circulations are among the primary causes of climate fluctuation. They also transport moisture. Under the effect of teleconnections, large-scale ocean circulations are researched. It is essential to comprehend the connections between anthropogenic activities and climate variability to foresee future changes and comprehend the intricate processes and variations in climate systems (Moss et al., 2010). Along with human interference, altered natural occurrences have accelerated the climate system and produced protracted winter droughts (Wehner et al., 2017). These include fewer monsoons, longer and stronger rain cycles, sea level rise, cyclones, and even tropical storms (Lau et al., 2022).

Pakistan is an agrarian country, with the majority of its people employed in this industry (Rehman et al., 2015). Several natural and socioeconomic systems rely on precipitation as one of their most important components, including water resource management, forestry, agriculture, and food production (Misra, 2014). Unpredictable rainfall and a pattern of unusually high or low precipitation are important concerns for the country's economy and agriculture (Simelton et al., 2013). Global warming is widely acknowledged to be the cause of variations in rainfall, both globally and regionally (Papalexioiu and Montanari, 2019). Various research have indicated that climate change may have an adverse effect on the availability of environmental resources, resulting in an imbalance in sustainability (Azher Hameed Qamar, 2023). Certain species, for example, are in danger of becoming extinct due to global warming because of the increasing pressure from climate changes in the tropical forest area (Jitariu et al., 2017). The decline in water accessibility is causing natural water supplies to run dry. The aforementioned changes are the result of changing climate variables (Azher Hameed Qamar, 2022).

Urbanization and industrialization are the biggest threats to the natural climate in developing nations like Pakistan (M. Hussain et al., 2020; M. Hussain et al., 2018). The main economic activity in these countries is agriculture, which is extremely sensitive to climate change and has few resources to adapt to changing conditions (Kurukulasuriya & Rosenthal, 2013). In that regard, in nations like Pakistan where the agriculture sector serves as the backbone of the economy, identifying historical shifts in climate factors is crucial (Mumtaz, 2019). One of the areas where temperatures are suddenly rising is Pakistan. Climate variability analysis has identified certain environmental system occurrences that represent serious risks to human welfare and sustainability (Bernai,

2013). Previous research has delineated temperature variations across various regions of Pakistan, including the Indus basin, where temperature indices have demonstrated a noteworthy upward tendency (Ali et al., 2023).

On the other the same direction, reports of declining precipitation and increasing temperatures in several Pakistan regions began to surface in the late 1990s. (Syed et al., 2021). Thus far, no thorough investigation has been carried out about the spatiotemporal patterns of temperature, precipitation, Pakistan's Climatic Variation, and Trend deduction in different areas of Pakistan a crucial area for agriculture (Kaur et al., 2022). This study's main objectives were to use GIS techniques to determine trend deduction in the research of climate variation in Pakistan and to examine into the country's variability in terms of climate.

2. Materials and Methods

2.1 Data Sources

To determine the degree of climate vulnerability, this study analyzed data from 50 locations in Pakistan (Fig. 1). This investigation uses the Pakistan metrological data and NASA, 50 stations' daily data from 1991 to 2022 were gathered. The long-term variations as well as the yearly mean, minimum, and maximum temperatures, and precipitation, were examined using GIS. These fifty stations were picked due to their popularity, extensive use, history, regularity, and the completeness of recordings based on their spatiotemporal coverage. The Pakistan Meteorological Department (PMD) provided temperature and precipitation data from 1982 to 2022. In order to evaluate regional climate variability, the data was gathered at the provincial level. To find long-term trends and anomalies, annual averages were computed. Because they directly affect agricultural and environmental systems, these factors were chosen.

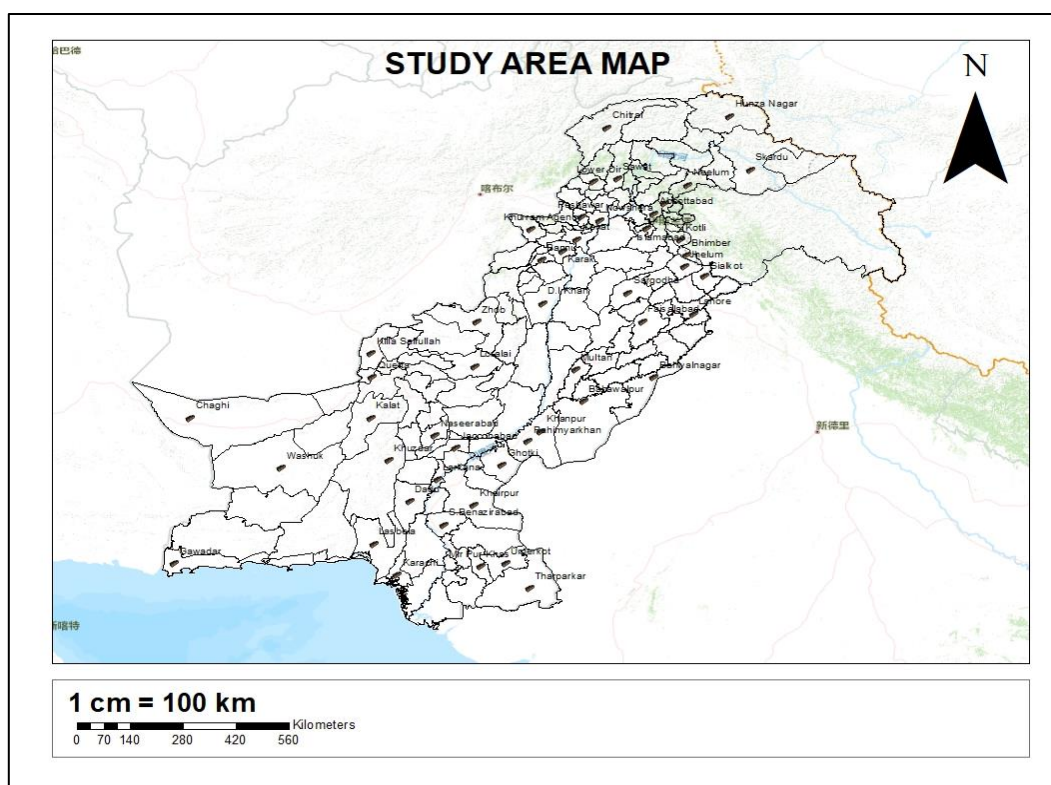


Figure 1 Study Area Map

2.2 Setting

The country of Pakistan is located in South Asia, usually between latitudes 24°N and 37°N and longitudes 61°E and 76°E. Westward borders are shared by Iran, Afghanistan, China, India, and the Arabian Sea; north and northeast borders are shared by China; east and southeast borders are shared by India; and southward borders are shared by Afghanistan. A total of 796,095 square kilometers, or 307,375 square miles, make up the country, excluding the territory of Kashmir. North West Frontier Province (NWFP), Punjab, Sindh, and Balochistan provinces make up its republic. However, the federal government has direct control over other areas, including high-altitude Northern Areas (NA), the tribal areas close to Afghanistan's border, and Azad Jammu & Kashmir (AJK). In terms of geography, it is the large basin formed by the powerful Indus River and its tributaries, which flow through the entire nation like bloodlines. Pakistan's north is endowed with one of the world's highest regions. The arid regions also include some places below 30°N. Through Arabian Desert, which borders the Sahara, towards the Thar Desert of India and Pakistan, there is a comparatively continuous chain of deserts in the subtropics.

2.3 Used Techniques

Inverse Distance Weighting (IDW) is a spatial interpolation technique used in Geographic Information System (GIS) software, including ArcMap. IDW estimates values in unmeasured places as a function of the values found at measured places, with closer points given more influence than those farther away.

ArcMap

Open ArcMap on your PC, add the point dataset to the load data that contains the map's measured values. The variable we wish to interpolate should be included in this dataset. Set Up Environment Before running IDW, set the analysis environment by clicking on the "Geoprocessing" menu, and then selecting "Environments." Set the extent, cell size, and any other relevant parameters.

2.3.2 Geostatistical Analyst

Build a Layer for geostatistics to access the geostatistical Wizard, click the "geostatistical Analyst" toolbar icon and then choose "geostatistical Wizard." Select the "Interpolation" option and press "Next." Select the Input Dataset. As your input dataset, use the point dataset. Choose the interpolation method "Inverse Distance Weighting (IDW)". Adjust the power parameter to regulate the rate at which influence diminishes with increasing distance. Closer points have greater effect from a higher power. After checking your configuration, click "Finish" to start the geostatistical layer. Map will now include the geostatistical layer. For an effective visualization of the interpolated results, modify the geostatistical layer's symbology. Other symbology alternatives, such as a color ramp, are available. Examine and evaluate the findings. The estimated values for the entire research area can be shown by using the geostatistical layer.

3. Results

An indication of the long-term unpredictability in precipitation is the shift in ocean patterns, which is less influenced by human activities. Nevertheless, atmospheric circulation still has the primary effect. Actual temperature trends for each year are studied using about 50 climatological stations. The regional distribution of precipitation patterns is linked to its varying temporal behavior. The daily variable data used in this study is from fifty distinct sites between 1991 and 2022. Pakistan is extremely sensitive to climate change, and the possibility of floods poses a threat to its low-lying, heavily populated deltas. Of the climatic factors, temperature as an independent variable. Changes in temperature lead to proportional adjustments in the pressure distribution, which in turn affects the direction and strength of the wind. These adjustments in turn regulate atmospheric humidity, cloud formation, condensation processes, and other related factors. In this way, temperature influences every other aspect of the weather, either directly or indirectly. The distribution of rainfall and the water it produces are essential for a nation's success, especially for Pakistan, which is mostly an agrarian nation. The Arabian Sea or the Bay of Bengal are the entry points for the monsoonal systems into the nation. Occasionally reaching the Indus Plains, the monsoonal currents originate by way of tropical depressions into the Bay of Bengal and travel west and northwest through the Gangetic Plains in India. Their intensity drops significantly by the moment they get there. Yet occasionally, depending on the synoptic conditions, these depressions coincide with powerful western disturbances or become amplified by southwesterly currents off the Arabian Sea, resulting in severe rainfall within the sub montane regions as well as other portions of the nation. The significant pressure gradient from the sea and the surrounding continental lands also makes it easier for monsoon systems and depressions to continue flowing to sub montane regions. Winter rains

typically fall in regions above 30°N because to passing western disturbances. These disruptions along with additional circulation systems, which are primarily active in the winter and during the pre-monsoon transition, be situated the primary causes of rainfall across western regions.

The mean surface temperature in Pakistan has been steadily increasing since the start of the 20th century. The mean temperature conditions of 1992 are examined using data from about 50 climatological stations. Thus, utilizing the standard data for the 1992-time period, a map of 50 stations has been generated for each station (Figure 2). 28.62 degrees was the highest temperature ever recorded in 1992 in Larkana (altitude 147 meters); the next highest temperatures were recorded in Khairpur (28.54), and Gotki (altitude 72 meters) (28.44). With an annual temperature of -5.32 degrees, Hunza Nagar (altitude 3438 meters) set the lowest record. In contrast to the Bay of Bengal, where the monsoon season typically begins on July 1, the Arabian Sea has its monsoon rains earlier in June. Heatwaves and dry spells are common from April to May, and occasionally even into early June. Throughout these months, the semi-permanent heat low forms in excess of portions of the area of Balochistan, as well as adjacent areas of Sindh as well as Southern Punjab. This low is crucial in enabling the uninterrupted movement of maritime air masses to the Arabian Sea towards the sub-montane regions and other parts of the country, contingent on the prevailing weather conditions, during the monsoon season. The maximum rainfall recorded in 1992 was in Abottoabad and Bhimbir.

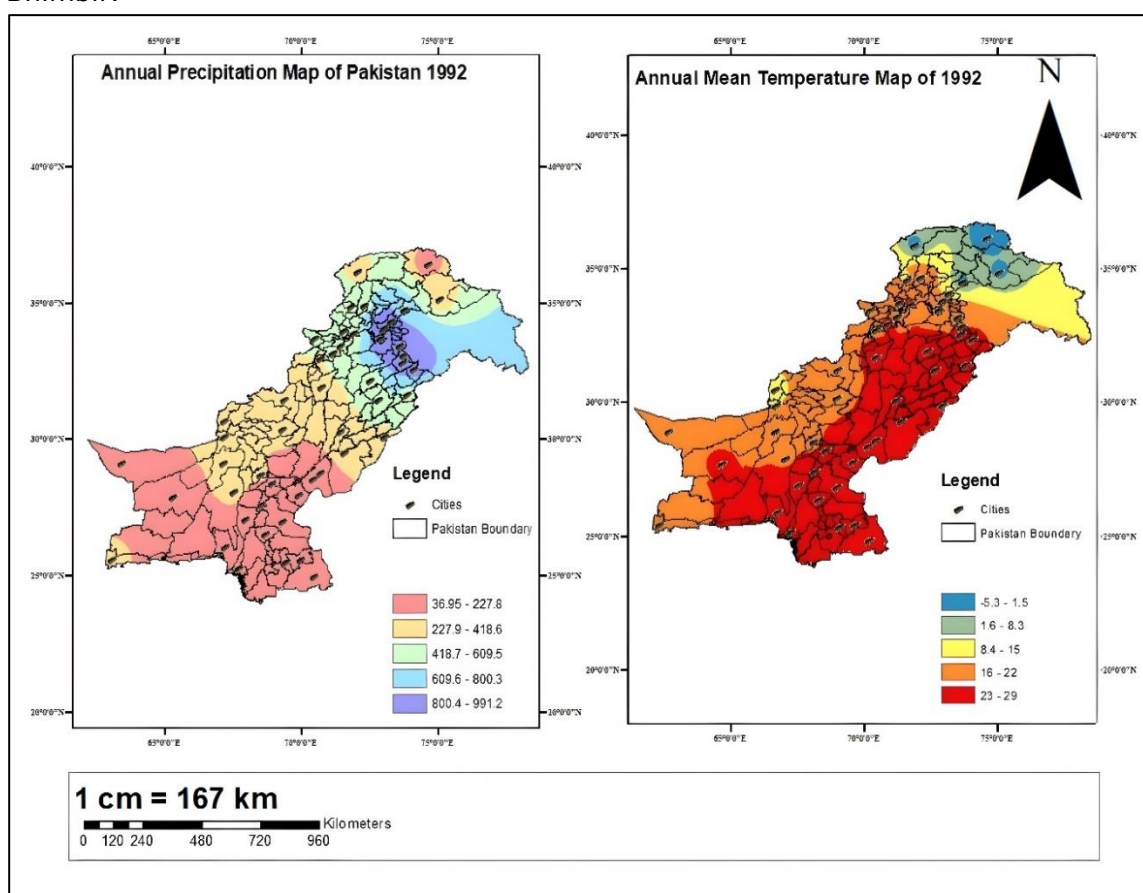


Figure 2 Annual mean temperature and Precipitation Map of 1992

One of the meteorological factors that varies independently is temperature. Temperature variations result in equivalent changes to the pressure distribution, which in turn affects the direction and intensity of the wind. Consequently, a map of fifty stations has been made for each station using the standard data for the 2002 period of time. In 2002, the highest temperature recorded was Larkana (altitude 147 meters) 29.62 degrees, followed by 29.58 degrees Jacobabad (altitude 62 meters) and, 29.38 degrees Gotki (altitude 72 meters). Hunza Nagar (altitude 3438 meters) recorded the lowest annual temperature, -5.35 degrees (Figure 3). Throughout the pre-monsoon season, Pakistan experiences a significant amount of precipitation. In Pakistan, the southwest monsoon typically withdraws by mid-September. In Arabian Sea in addition the Bay of Bengal, powerful tropical cyclones are forming concurrently. The highest recorded rainfall in 2002 was in Jhehlum and Bhimbir.

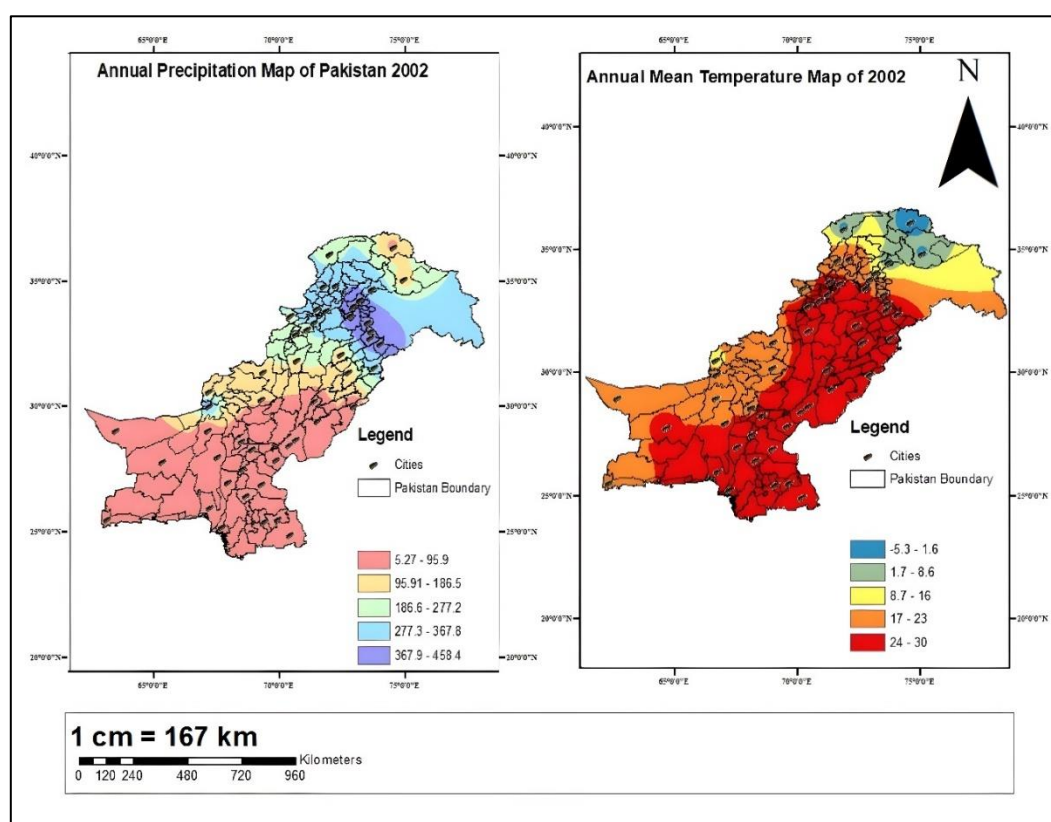


Figure 3 Annual mean temperature and Precipitation Map of 2002

As a result, a map with 50 stations for each station has been developed with the standard data for the year 2012 (Figure 4). Larkana (altitude 147 meters) recorded the highest temperature (28.3) in 2012, which was followed by Jacobabad (altitude 62 meters) at 28.19 degrees, Khairpur at 28.08 degrees, and Jacobabad at 27.96 degrees. With a yearly temperature of -6.29 degrees, Hunza Nagar (altitude 3438 meters) has the lowest. However, sometimes, due to synoptic factors, these storms coincide with strong western disturbances or are exacerbated by southwesterly currents over the Arabian Sea, which leads to intense rainfall across sub montane regions along with further parts of the country. The significant pressure gradient from the ocean and the surrounding continental lands also makes it easier for monsoon systems and depressions to continue

flowing to sub montane regions. The maximum rainfall in 2012 was recorded in Abottoabad and Khurram Agency. This year's rainfall is much different from last year's.

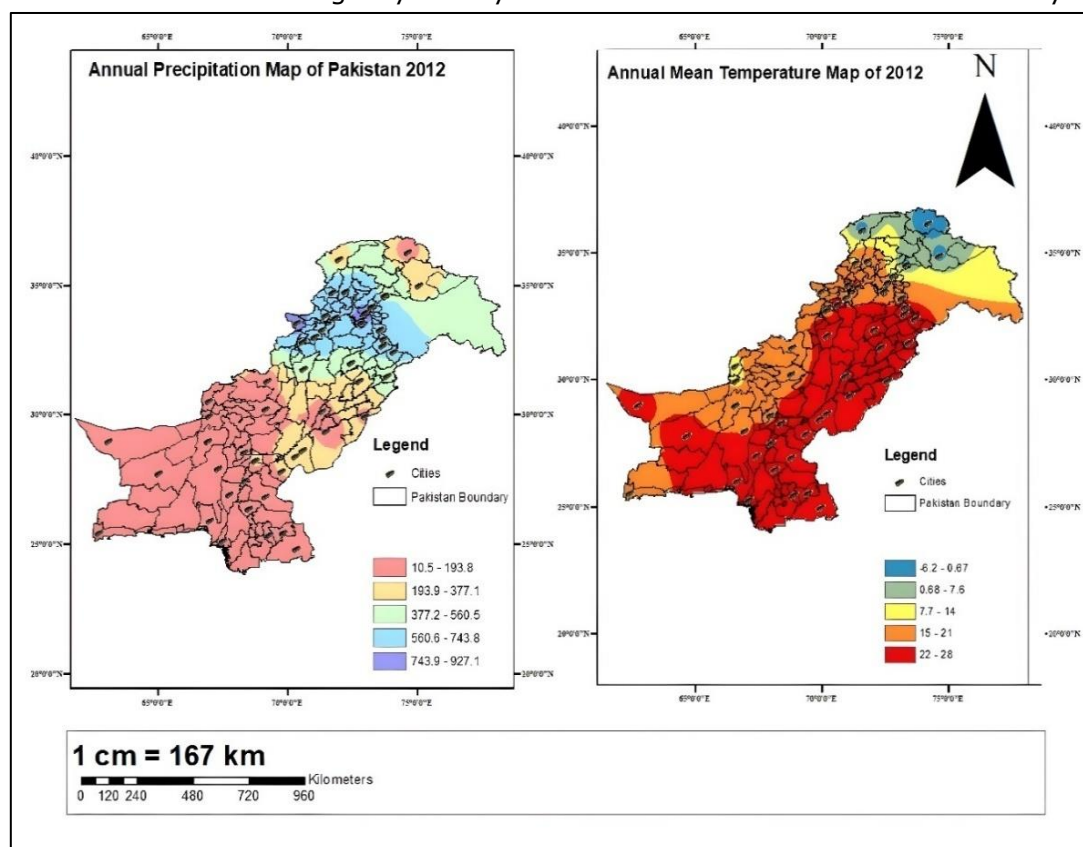


Figure 4 Annual mean temperature and Precipitation Map of 2012

As a result, a map has been developed with 50 stations for each station using the standard data for the year 2022 (Figure 5). In 2022, Larkana (altitude 147 meters) reached 27.69 degrees, while Jacobabad (altitude 62 meters) had the highest temperature of 27.64 degrees. Hunza Nagar (altitude 3438 meters) recorded the lowest annual temperature, at -4.56 degrees. In certain areas of Balochistan, Sindh, and southern Punjab, a semi-permanent thermal low form over the summer (April–June) and supplies the pressure gradient force required to separate the Arabian Sea from these adjacent land masses. The winter rains originate from western disturbances, which carry moisture to the upper regions of the country as main waves or disturbances. Sometimes, they develop their secondaries, travel far into lower latitudes, and are enhanced by the moisture of the Arabian Sea, which results in rain in most of the nation. The places with the most rainfall in 2022 were Abbottabad, Bhimbir, Noshera, Sawat, Dadu, Jacobabad, Khairpur, and Larkana. In comparison to the 1992–2022 prior, this year's rainfall has changed significantly. Rainfall that day caused the entire country to flood, making 2022 a rainy year.

Punjab has scorching summers, mild winters, plus monsoon season precipitation that makes up most of the region's climate, which is semi-arid. Regional and worldwide climatic patterns, however, can cause specific variances in rainfall and temperature to vary from year to year (Figure 6). Temperatures can reach highs of 40–45°C (104–113°F) during the peak summer months, especially in May and June, due to changes in

precipitation and temperature. The amount of rainfall has varied more recently. The monsoon season is when Punjab receives almost all with its yearly rainfall. In certain places, excessive and irregular rainfall can cause floods. Wintertime precipitation might include light drizzle or rain, which adds to the annual total of precipitation.

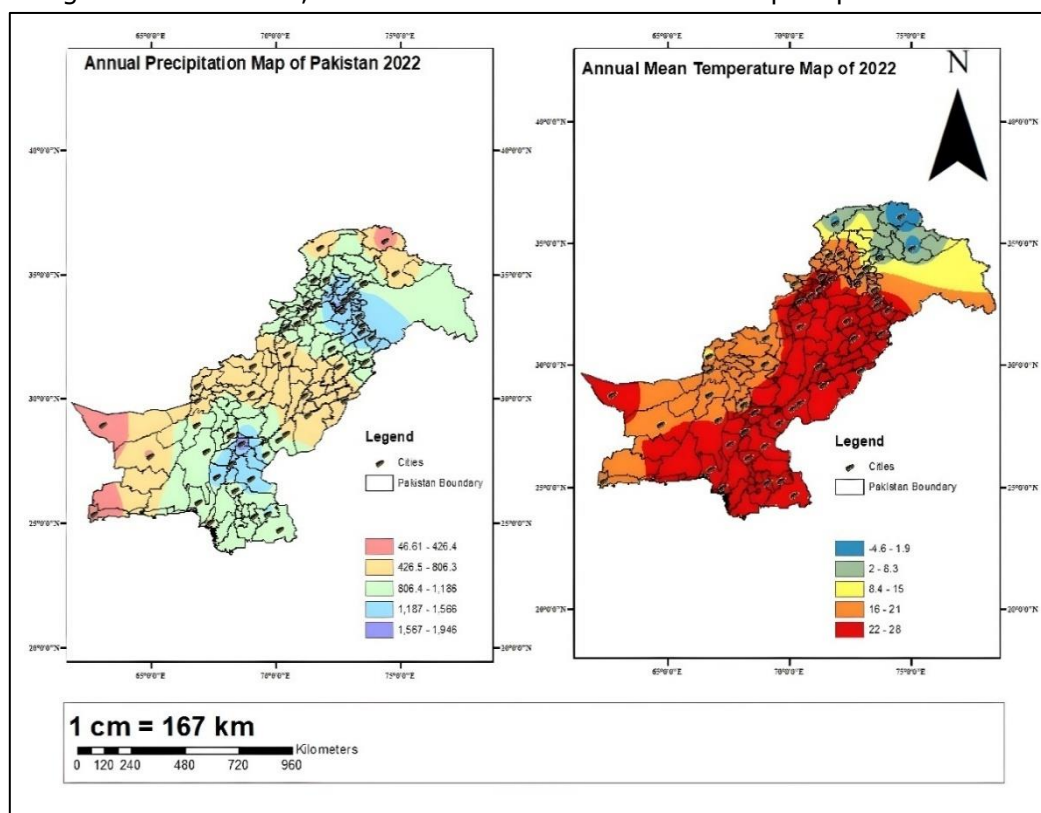


Figure 5 Annual mean temperature and Precipitation Map of 2022

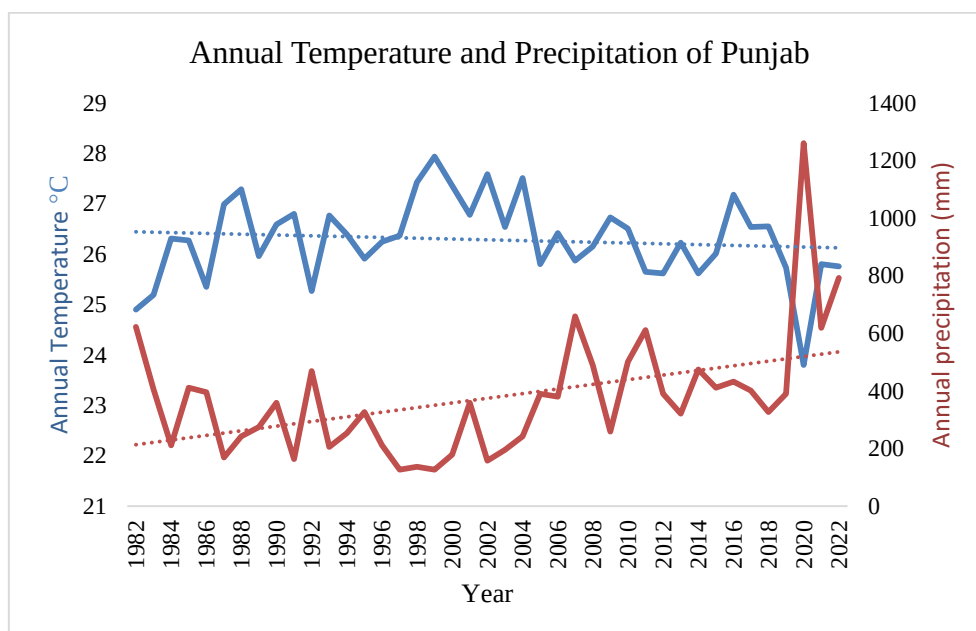


Figure 6 Annual average Temperature and Precipitation of Punjab

The climate of Balochistan is primarily arid to semi-arid, with high temperatures, little rainfall, and notable temperature fluctuations. Due to its large size, Balochistan, Pakistan, has a varied climate, but it typically experiences fluctuations in temperature

and precipitation (Figure 7). Balochistan experiences very hot and dry summers. In lowland regions like Sibi and Jacobabad, temperatures can frequently rise above 45°C (113°F). Winters may be quite chilly, particularly in higher altitudes like Quetta where lows can fall below freezing. Snowfall occurs in certain regions of Balochistan throughout the winter, particularly in Quetta and the adjacent areas. There is not much rainfall in Balochistan, which is typically desert. But throughout these months, there's a chance that some areas will see volatile, erratic rain.

The climate of Khyber Pakhtunkhwa (Figure 8) ranges from subtropical through temperate, with notable variations in precipitation and temperature among its highland and lowland regions. The region's yearly climate fluctuations are mostly caused by the winter precipitation and the monsoon season, which both have an impact on weather patterns. The climatic conditions of Khyber Pakhtunkhwa (KP) within the country are varied because of its uneven topography. Higher elevations, such as Swat and Abbottabad, experience more moderate summertime temperatures, although lower-lying locations typically experience scorching summertime temperatures. The monsoon season is when KPK receives a large amount of its annual rainfall. There might be a lot of rain, particularly in the northern areas like Chitral, Dir, especially Swat Valley. In certain regions of KPK, especially those at higher altitudes including Malakand Division, Swat, along with Hazara Division, winter precipitation takes the form of rain or snow.

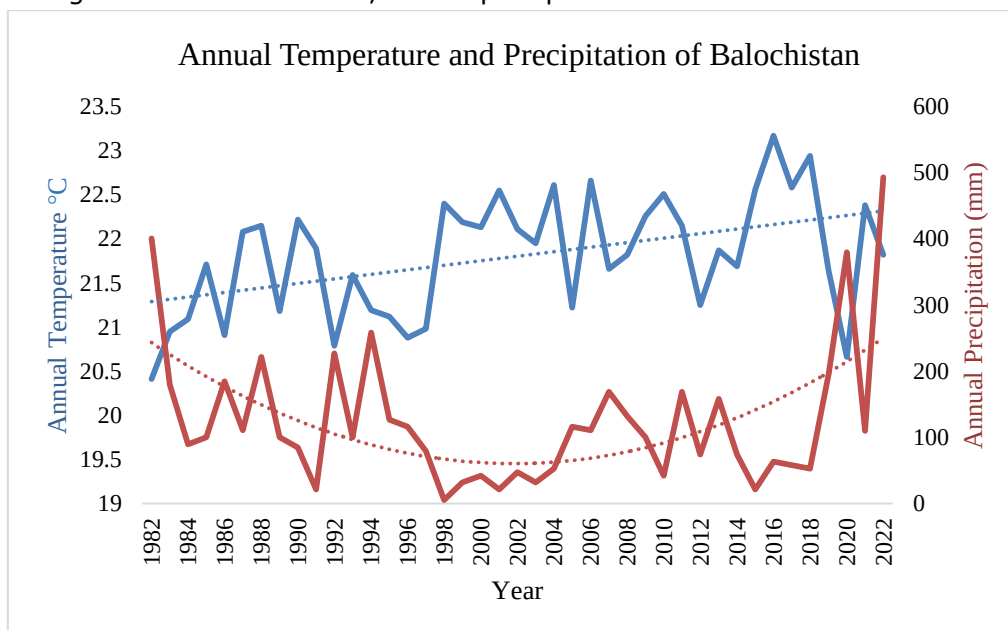


Figure 7 Annual average Temperature and Precipitation of Balochistan

The climate in Sindh (Figure 9) is hot in the summer and warm in the winter, with little precipitation for most all the year. Because of its proximity of the Arabian Sea, coastal regions may experience slightly distinct weather patterns, with higher humidity and milder temperatures. Sindh has a hot, dry climate with variable annual temperatures and precipitation patterns. The state's summers are very hot, especially in southern parts like Karachi. In contrast, winters in coastal areas are often warmer than those in inland areas. In instance, the southeastern regions of Sindh receive most of its yearly rainfall throughout the monsoon season. Nonetheless, as compared to neighboring areas like

Punjab and Khyber Pakhtunkhwa, Sindh experiences significantly less rainfall overall throughout the monsoon season. The months of winter are primarily dry, though some places may get some light snowfall.

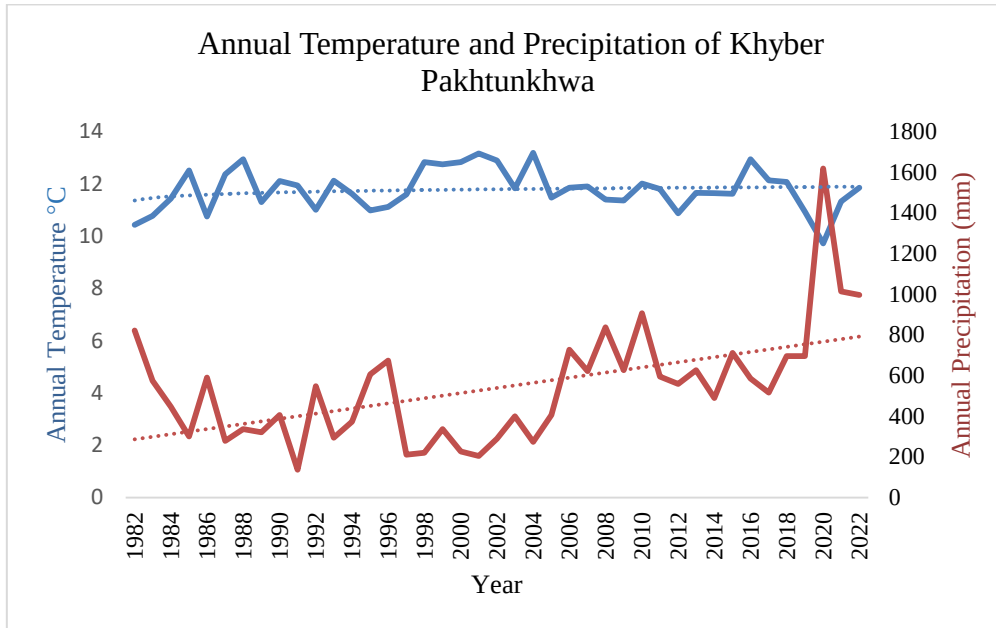


Figure 8 Annual average Temperature and Precipitation of Khyber Pakhtunkhwa

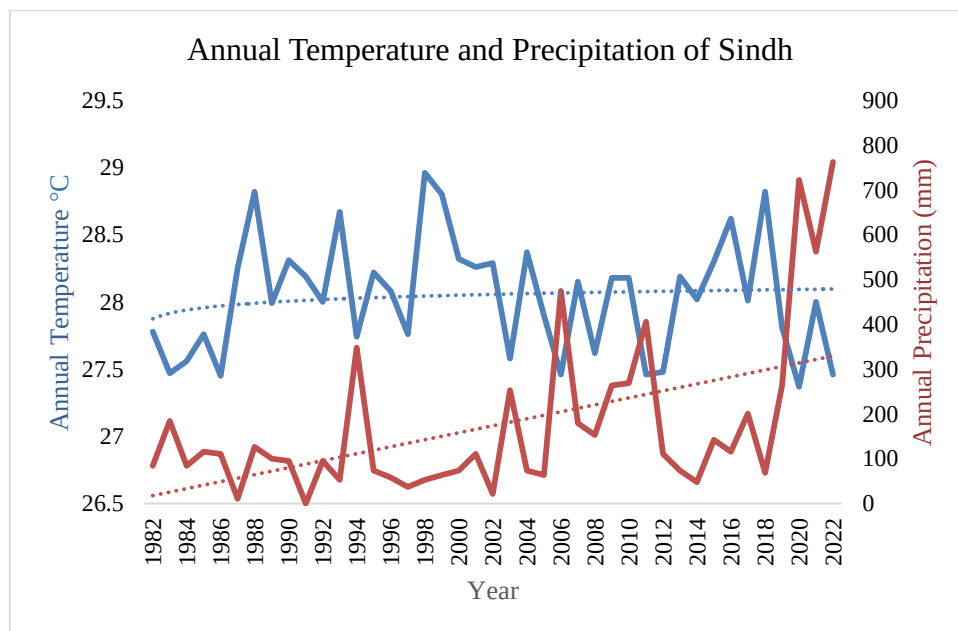


Figure 9 Annual average Temperature and Precipitation of Sindh

4. Discussion

Extreme weather patterns pose a serious risk to both humans and ecosystems, especially at this time of year. Thus, these events are receiving more attention and are being given careful thought since data suggests that the intensity of severe climatic patterns has grown during the 1990s. Finding a monotonic trend is crucial when conducting a time series analysis. About 50 climatological stations were used to study the definite temperature patterns for each year. The different temporal behavior of precipitation patterns is related to their spatial dispersion. The daily variable data from 10

different sites between 1991 and 2020 were used in this study. Pakistan's low-lying, densely inhabited deltas are in danger from potential flooding, as the country is very vulnerable to climate change. Particularly for Pakistan, which is mostly an agrarian nation, the distribution of rainfall and the water it generates are crucial for a country's success (ULLAH, 2019; Wells et al., 2023). Sub montane locations are also more easily reached by monsoon systems and depressions because to the substantial pressure gradient resulting from the sea and the adjacent continental lands.

Since the turn of the 20th century, Pakistan's average surface temperature has been increasing (Tariq et al., 2020). The real temperature conditions of 1992 are examined using data from about fifty climatological stations. For each station, a map of 50 stations has been created using the standard data for the 1992-time period. The majority of the semi-arid climate in Punjab is characterized by sweltering summers, moderate winters, and precipitation during the monsoon season ([Figure 2](#)). However, certain variations in rainfall and temperature might differ from year to year due to global and regional climate patterns ([Figure 6](#)). Balochistan has a mostly dry to semi-arid environment with high temperatures, minimal rainfall, and noticeable temperature swings. In 1992, the hottest temperature ever recorded in Larkana was 28.62 degrees. Temperature changes cause corresponding shifts in the pressure distribution, which modify the wind's direction and strength. As a result, using the standard data for the year 2002, a map with fifty stations for each station has been created ([Figure 3](#)).

The monsoon from the Bay of Bengal along with the western disturbances across the Mediterranean Sea both provide precipitation to Pakistan. When compared to winter rainfall, the monsoon contributes significantly to annual precipitation. As such, the yearly precipitation's regional distribution is found to be nearly identical to that of the monsoon (A. Hussain et al., 2022). More lately, the amount of rainfall has changed. The majority of Punjab's annual rainfall falls during the monsoon season. Floods can be caused by high and erratic rainfall in some locations. Balochistan during the winter, especially in Quetta and the surrounding regions. Normally a dry region, Balochistan receives little rainfall. However, there's a potential that some places may get irregular, volatile rain during these months. While summer temperatures are normally scorching in lower-lying regions, they are relatively temperate at higher elevations like Swat and Abbottabad ([Figure 5,7,9](#)).

A significant portion of KPK's yearly rainfall falls during the monsoon season. Winter precipitation and the monsoon season both affect weather patterns, which is what mostly causes the region's annual climate changes. Because to the region's irregular geography, Khyber Pakhtunkhwa (KP) experiences a variety of climates ([Figure 8](#)). The southwest monsoon usually reaches Pakistan by mid-September. Above mean sea level elevation, precipitation patterns were impacted (Zia et al., 2023). Because to its northern location, subhumid environment, high temperatures, and little precipitation, Robust tropical cyclones are simultaneously building in the Arabian Sea and the Bay of Bengal. The areas of Jhehlum and Bhimbir saw the most rainfall in 2002. In 2022, Abbottabad, Bhimbir, Noshera, Sawat, Dadu, Jacobabad, Khairpur, and Larkana saw the highest rainfall. This

year's rainfall has changed significantly from the previous 30 years. 2022 was a wet year because of the widespread flooding produced by the day's precipitation.

5. Conclusions

Pakistan is one of the most vulnerable countries to climatic variability and climate change in the world. Because of its geographical location. Being an agricultural region, it poses a challenge for the country's economy. Similarly, research on Pakistan's climate variability indicates a multifaceted interaction between environmental changes affecting the country's varied ecosystems and socio-economic structure. Ecosystems are subject to perturbations that affect biodiversity and ecosystem services that are essential for maintaining livelihoods. A study of temperature trends showed changes in seasonal variability along with a tendency to increase average temperatures in several places. This increase in temperature melts glaciers, as Pakistan is the home of glaciers. Furthermore, there were variations in the patterns of precipitation, having different consequences in different regions. Pakistan has several different kinds of issues as a result of these climate fluctuations. A shifting water supply, crop cycles that are disrupted, and growing strain on arable land are all signs of uncertainty in the agricultural landscape. The rapid rise in the amount of rainfall in the year 2022 triggered a flood that was highly responsible for huge economic losses for the country. It also resulted in catastrophic damage to infrastructure, and millions of people were displaced and killed. All in all, bleak consequences have become common in Pakistan. If timely measures are not adopted, the country will have to face the music in future. Though governments had taken a step ahead by introducing the 10 billion tsunami project. Likewise, urgently, more steps are needed to mitigate the hazardous effects of climate variability.

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References

1. Ali, S.; Khorrami, B.; Jehanzaib, M.; Tariq, A.; Ajmal, M.; Arshad, A.; Zhang, L. (2023) Spatial downscaling of GRACE data based on XGBoost model for improved understanding of hydrological droughts in the Indus Basin Irrigation System (IBIS). *J Remote Sensing*, 15(4), 873. <https://doi.org/10.3390/rs15040873>
2. Bernai, R.R. (2013) Managing the risks of extreme events and disasters to advance climate change adaptation. *J Economics of Energy Environmental Policy* 2(1), 101-113.
3. Box, J.E.; Colgan, W.T.; Christensen, T.R.; Schmidt, N.M.; Lund, M.; Parmentier, F.-J.W.; Romanovsky, V.E. (2019) Key indicators of Arctic climate change: 1971–2017. *J Environmental Research Letters*, 14(4), 045010.
4. Fahad, S.; Wang, J. (2020) Climate change, vulnerability, and its impacts in rural Pakistan: a review. *J Environmental Science Pollution Research* 27, 1334-1338.
5. Hu, X.-M.; Ma, J.-R.; Ying, J.; Cai, M.; Kong, Y.-Q. (2021) Inferring future warming in the Arctic from the observed global warming trend and CMIP6 simulations. *J Advances in Climate Change Research*, 12(4), 499-507.

6. Hussain, A.; Cao, J.; Ali, S.; Muhammad, S.; Ullah, W.; Hussain, I.; Zhou, J. (2022) Observed trends and variability of seasonal and annual precipitation in Pakistan during 1960–2016. *J International Journal of Climatology*, 42(16), 8313–8332.
7. Hussain, M.; Butt, A.R.; Uzma, F.; Ahmed, R.; Irshad, S.; Rehman, A.; Yousaf, B. (2020) A comprehensive review of climate change impacts, adaptation, and mitigation on environmental and natural calamities in Pakistan. *J Environmental monitoring assessment* 192, 1–20.
8. Hussain, M.; Liu, G.; Yousaf, B.; Ahmed, R.; Uzma, F.; Ali, M.U.; Butt, A.R. (2018) Regional and sectoral assessment on climate-change in Pakistan: social norms and indigenous perceptions on climate-change adaptation and mitigation in relation to global context. 200, 791–808.
9. Jitariu, V.; Rosca, B.; Rusu, C. (2017). Pedo-climatic risks over Fălticeni city related orchards. *J Present Environment Sustainable Development* 11, (2), 151–162. <https://doi.org/10.1515/pesd-2017-0033>
10. Kakar, A.K.; Qurat-ul-ain, M.H. Wildlife under climate change, a systematic review of impacts, *International Journal of Contemporary Issues in Social Sciences*, 3(1), 1294–1310. <https://ijciss.org/index.php/ijciss/article/view/550>
11. Kaur, L.; Rishi, M.S.; Chaudhary, B.S. (2022) Assessment of meteorological and agricultural droughts using remote sensing and their impact on groundwater in an agriculturally productive part of Northwest India. *J Agricultural Water Management* 274, 107956. <https://doi.org/10.1016/j.agwat.2022.107956>
12. Konapala, G.; Mishra, A.K.; Wada, Y.; Mann, M. E. (2020) Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. *J Nature communications*, 11(1), 3044. <https://doi.org/10.1038/s41467-020-16757-w>
13. Kurukulasuriya, P., & Rosenthal, S. (2013) Climate change and agriculture: A review of impacts and adaptations. Environment department papers;no. 91. Climate change series. © World Bank. <http://hdl.handle.net/10986/16616> License: [CC BY 3.0 IGO.](https://creativecommons.org/licenses/by/3.0/)
14. Lau, Y.-Y.; Yip, T.-L.; Dulebenets, M.A.; Tang, Y.-M.; Kawasaki, T. (2022) A review of historical changes of tropical and extra-tropical cyclones: a comparative analysis of the United States, Europe, and Asia. *International journal of Environmental Research Public Health* 19(8), 4499. <https://doi.org/10.3390/ijerph19084499>
15. Mahmood, R.; Jia, S.; Babel, M.S. (2016) Potential impacts of climate change on water resources in the Kunhar River Basin, Pakistan. *Water*, 8(1), 23. <https://doi.org/10.3390/w8010023>
16. Misra, A.K. (2014) Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment*, 3(1), 153–165. <https://doi.org/10.1016/j.ijsbe.2014.04.006>
17. Moss, R.H.; Edmonds, J.A.; Hibbard, K.A.; Manning, M.R.; Rose, S.K.; Van Vuuren, D.P.; Kram, T. (2010) The next generation of scenarios for climate change research and assessment. *J Nature*, 463(7282), 747–756. <https://doi.org/10.1038/nature08823>
18. Mumtaz, M. (2019) *Climate change adaptation in the agriculture sector: an analysis of governance challenges in two Pakistani provinces*. (Doctoral dissertation).
19. Naumann, G.; Alfieri, L.; Wyser, K.; Mentaschi, L.; Betts, R.A.; Carrao, H., et al. (2018). Global changes in drought conditions under different levels of warming. *Geophysical Research Letters*, 45(7), 3285–3296. <https://doi.org/10.1002/2017GL076521>
20. Papalexiou, S.M.; Montanari, A. (2019) Global and regional increase of precipitation extremes under global warming. *Water Resources Research*, 55(6), 4901–4914. <https://doi.org/10.1029/2018WR024067>

21. Qamar, A.H. (2022) *Social Dimensions of Resilience and Climate Change: A Rapid Review*. Paper presented at the Innovative Approaches; Climate Change Resilience in Urban Environments.
22. Qamar, A. H. (2023). Social dimensions of resilience and climate change: a rapid review of theoretical approaches. *Present Environment and Sustainable Development*, 17(1). <https://doi.org/10.47743/pesd2023171010>
23. Rehman, A.; Jingdong, L.; Shahzad, B.; Chandio, A.A.; Hussain, I.; Nabi, G.; Iqbal, M.S. (2015) Economic perspectives of major field crops of Pakistan: An empirical study. *J Pacific science review b: humanities social sciences* 1(3), 145-158.
24. Sharifi, A.; Simangan, D.; Kaneko, S. (2021) Three decades of research on climate change and peace: A bibliometrics analysis. *Sustainability Science*, 16, 1079-1095. <https://doi.org/10.1007/s11625-020-00853-3>
25. Simelton, E.; Quinn, C.H.; Batisani, N.; Dougill, A.J.; Dyer, J.C., Fraser, E.D.; et al. (2013) Is rainfall really changing? Farmers' perceptions, meteorological data, and policy implications. *Climate Development*, 5(2), 123-138. <https://doi.org/10.1080/17565529.2012.751893>
26. Syed, A.; Liu, X.; Moniruzzaman, M.; Rousta, I.; Syed, W.; Zhang, J.; Olafsson, H. (2021) Assessment of climate variability among seasonal trends using in situ measurements: A case study of Punjab, Pakistan. *Atmosphere*, 12(8), 939. <https://doi.org/10.3390/atmos12080939>
27. Tariq, A.; Riaz, I.; Ahmad, Z.; Yang, B.; Amin, M.; Kausar, R.; et al. (2020) Land surface temperature relation with normalized satellite indices for the estimation of spatio-temporal trends in temperature among various land use land cover classes of an arid Potohar region using Landsat data. *Environmental Earth Sciences*, 79, 1-15. <https://doi.org/10.1007/s12665-019-8766-2>
28. Trenberth, K.E. (2011a) Attribution of climate variations and trends to human influences and natural variability. *Wiley Interdisciplinary Reviews: Climate Change*, 2(6), 925-930.
29. Trenberth, K.E. (2011b). Changes in precipitation with climate change. *J Climate research*, 47(1-2), 123-138. <https://doi.org/10.3354/cr00953>
30. Ullah, W. (2019) *A geographical study of farmers' adaptations to climate change in Khyber Pakhtunkhwa, Pakistan*. 北海道大学,
31. Vogt, J.V.; Naumann, G.; Masante, D.; Spinoni, J.; Cammalleri, C.; Erian, W., et al. (2018) Drought risk assessment and management: A conceptual framework. In EUR 29464 EN, Publications Office of the European Union (Vol. 2018, Issue August). <https://doi.org/10.2760/057223>
32. Wehner, M.F.; Arnold, J.R.; Knutson, T.; Kunkel, K.E.; LeGrande, A.N. (2017) Droughts, floods, and wildfires. *Climate science special report: fourth national climate assessment*, 1(GSFC-E-DAA-TN49033).
33. Wells, C.; Saggiaro, E.; Petty, C.; Cornforth, R. (2023) Pakistan climate change impact storylines based on existing literature. *Zenodo*, 19, 1-117.
34. Willett, K.; Dunn, R.; Thorne, P.; Bell, S.; De Podesta, M.; Parker, D.; et al. (2014). HadISDH land surface multi-variable humidity and temperature record for climate monitoring. *J Climate of the Past*, 10(6), 1983-2006. <https://doi.org/10.5194/cp-10-1983-2014>, 2014.
35. Zia, A.; Rana, I.A.; Arshad, H.S.H.; Khalid, Z.; Nawaz, A. (2023) Monsoon flood risks in urban areas of Pakistan: A way forward for risk reduction and adaptation planning. *Journal of Environmental Management*, 336, 117652. <https://doi.org/10.1016/j.jenvman.2023.117652>



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