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A HISTORICAL ANALYSIS OF TEMPERATURE AND RAINFALL PATTERNS OF PUNJAB, PAKISTAN

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ABSTRACT

Rising annual mean temperature and unstable rainfall (especially from monsoons) have badly affected socioeconomic and environmental situations in Pakistan, especially that in the Punjab province which is the largest food provider and most populous unit of the country. An analysis of historical record (2009–2019) of average monthly temperature and average monthly rainfall for all 36 districts of Punjab, Pakistan, was carried out to evaluate spatial and temporal patterns. Observed pattern during the period of study suggested an overall warming in the region started from 2013 onwards till 2019 except for 2014. Analysis revealed that the central part of the province affected the most by warming (4.1-5 degree Celsius) during the study period and western portion of this central part (DG Khan, Multan and Khanewal districts) have shown the highest warming level (more than 5 degree Celsius) while the least affected part was confined to only two north-eastern districts (Sialkot, 1.9 degree Celsius and Narowal, 1.8 degree Celsius increase).The noteworthy phenomenon was that the 27 degree Celsius isotherm kept shifting (started through 2013) towards north of the province (except for 2014) till 2019 and even those districts of upper (northern) Punjab came under its influence (and got included in hot group in this study) which were once used to experience less than 25 degree Celsius average annual temperature (and were placed in cool group in this study from 2009 till 2017). The lowest TAR among the eleven years of period of study fell in 2009 when only three northern districts experienced semi-arid condition and rest of the districts of the province faced aridity. The TAR kept increasing from 2009 onwards (except for 2016 and 2017) till 2019 which proved the wettest year when 9 northern districts experienced supper-Humid condition and further 5 southward neighboring districts had humid level TAR while no part of the province included in arid club.

KEYWORDS: Temperature, Rainfall, Patterns, the Punjab, Variability

INTRODUCTION

The global average surface temperature has increased by 0.074° ± 0.018°C per decade over the past 20th century; however, since 1981, a greater rate of warming corresponding to 0.177° ± 0.052°C per decade was calculated (Cess & Udelhofen, 2003)(Seidel & Lanzante, 2004). Climate of the 21st century will be branded by a modest warming, mainly in the high latitude areas in winter, with reduced seasonal and diurnal temperature fluctuations (Balling Jrlr & Michaels, 1998).

A visible variability in temperature has been observed in Pakistan, during the recent past, resulting into lengthy droughts and irregular monsoon periods (mostly causing torrential rain, leading to severe flooding) (Rasul et al., 2008). Warming temperature trend was reported for the Faisalabad

region (Punjab, Pakistan) with an overall increase in temperature by 0.22°C for the analysis period of 1945-2004 (Farooq & Munir, 2006).

Experts believe that the changing pattern of monsoon is the result of regional warming in South Asia and that the similar happenings will adversely affect the ecosystems in Pakistan in the current century. Society and infrastructure will become more vulnerable to severe and intense weather (Dey et al., 2013).

According to a recent study of past five decades (for the period 1961-2014), a rising trend of maximum temperature was noted in spring season (0.028°C /year) and a declining trend was observed in summer (-0.013°C /year) (caused by more rainfall in summer than past) in Punjab. While the minimum temperature was increasing in all seasons except for summer season. (Shahzad Khattak & Khalil, 2015).

Increased surface temperature affects seed germination and evapotranspiration (Huang et al., 2003)(Kazmi & Rasul, 2012). Irrigated lands can change the surface energy balance and its associated temperature, humidity, and climate features (Roy et al., 2007). For better management of resources to mitigate the effects of climate change, a good understanding of temperature extremes is necessary (Cairns et al., 2012). Agronomic management practices (predominantly changes in selection of crop type and seeding dates) and Crop production are significantly influenced by the duration of growing season, which is imprinted by prevailing environmental conditions, chiefly by the temperature (G. Abbas et al., 2017).

Many parts around the globe are experiencing precipitation extremes since the past few decades. That is why, this phenomenon has attracted the attention of analysts (along with temperature extremes) to predict the degree of climate change (Easterling et al., 2000).

Qian et al., (2011) found that northern China has witnessed persistent and prolonged wet and dry periods during the last millennium. (Annamalai et al., 2013) found that the monsoon rainfall had decreasing trend during the last five to six decades over South Asia.

MATERIAL AND METHODS

This study is based on secondary data (monthly average) acquired from World Weather Online website. Tabular dataset was regenerated. Microsoft Excel 2013 used for the arrangement and analysis of climatic data, historical record (2009-2019) of all 36 districts of Punjab Pakistan. Annual averages were calculated using monthly averages. Line-graph and histogram, data visualization techniques were used to determine the pattern of climatic data. Spatial pattern of the climatic data was analyzed using Software ArcGIS 10.4.1. Spline (Tension Variogram) interpolation

method was used to show temperature and rainfall data in the form of thematic maps.

STUDY AREA (PUNJAB, PAKISTAN)

Punjab, Pakistan is located between 27.70° N to 34.01° N and 69.31° E to 75.38° E. To the North of the Punjab is the Khyber Pakhtunkhwa Province and the Federal Capital Territory of Islamabad, to the North-East is Kashmir, to its South-East is India (Indian Punjab & Rajasthan), to the South-West is the province of Sindh while to the West are Baluchistan and the Federally Administered Tribal Areas (FATA). The lands of five rivers are also known as the granary of the East. Punjab is the lifeline of Pakistan. It is Pakistan's most populous province, with an estimated population of 110.012,442 as of 2017. Punjab is Pakistan's second largest province by area after Baluchistan with an area of 205,344 square kilometers (79,284 square miles). It occupies 25.8% of the total landmass of Pakistan(Government of Punjab, 2018). The province of Punjab accommodates over 60 % of Pakistan's total population and produces more than 50 % of the country's agricultural commodities (A. Abbas et al., 2013).

The province is predominantly on plain level; however, there are some hilly areas in the North-West and extreme South-West. There is also a plateau adjacent to the mountains known as the Potohar plateau and a desert belt in the South Eastern part known as Cholistan. All the major rivers of the country namely Indus, Jhelum, Chenab, Ravi, &Sutlej flow through this province. They originate from the Himalayas and pass from North-West to South-West. They are primeval in nature and the volume of water increases in the summer after the monsoon rains, resulting sometimes in floods.

Punjab Province administratively divided into 9 divisions and 36 districts. Rawalpindi, Sargodha, Gujranwala, Lahore, Faisalabad, Sahiwal, Multan, Bahawalpur and Dera Ghazi Khan are nine divisions in Punjab. The provincial capital and largest city is Lahore (Government of Punjab, 2018).

CLIMATE OF PUNJAB, PAKISTAN

Most of the Punjab province lie in the lowland zone (semi-arid to arid) and some parts, north of Salt Ranges are included in highland zone (cool and humid). It has extreme climate with hot summer and cool to cold winter. It is positioned at the western tale end of tropical monsoon (summer rain bearing winds coming from Bay of Bengal) and at the eastern tale end of western depressions (winter cyclone system originating over Mediterranean Sea).

Temperature ranges from -2°C to 45°C, but at times can reach 50°C (122°F) in summer and can touch down to -10°C in winter. Punjab has four major

seasons; First is hot-dry weather, pre-monsoon (April to June) when temperature rises as high as 110°F and very less rain falls. Second is slightly less hot but humid monsoon season (July to September). Third is Cooler / mild and mostly dry weather (October to November). Fourth is cool to cold weather with light showers of rain from western disturbances (December to March) when temperature goes down as low as 40°F. Average rainfall annual ranges between 96cm sub-mountain region and 46cm in the plains. Most of the rain falls from summer monsoon system which enters in Punjab from north-east, so, north-eastern and northern parts receive more rain as the foothills of Himalayas and Potohar Plateau are much wetter. These areas got rainfall from western depressions and convectional currents too. Thunderstorms are common in north and north-west. Some northern mountainous parts also receive relief rainfall.

The amount of precipitation keeps decreasing southwards where the extreme southern tip is the driest part of the province; the Cholistan Desert (a part of the great Thar Desert). This area receives much less rain and spells of high temperature. Extreme heat, dryness, dust storms and loo (hot and dry wind) are the main features of the southern arid parts of the province.

Four main factors affect the temperature in Punjab spatially, first; the Latitudinal Effect: the areas closer to the equator (the southern districts of the province) receive relatively direct sun rays while the areas further northward receive a bit slanting rays, so, the former witness more temperature than the latter group. Second; the Continental Effect: No part of Punjab is near to the sea, so, none of the areas has maritime influence that can moderate the temperature rather the whole of the province is under continental effect and faces temperature extremes not only in summer but in winter also. Third; the Altitudinal Effect: Height above sea level keep increasing as we move from south to north of the province and we know that the increasing altitude lowers the temperature, that is why the northern elevated parts remain much cooler as compared to the low laying southern parts. Fourth; Angle of Sun Rays: Punjab is positioned in a north-south stretching rectangular slab shape and located in northern hemisphere where sun rays start shifting northward of the equator from the month of March onwards, so, the southern parts encountered earlier and remain under high angle sun rays for more period of the year than the northern districts, that is why the summer season is more prolonged in southern region, resulting in high temperature (Khan, 1991)(Sethi, 20014).

RESULTS AND DISCUSSION

Temperature Patterns

Position of the 27°C isotherm was in our especial focus while determining the spatial pattern of temperature from 2009 to 2019 in all the 36 districts of Punjab, Pakistan. From 2009 to 2012 the situation remained almost the same with minor changes but the said isotherm kept shifting and encroaching more districts under its influence northwards started through 2013 till 2019 (except for 2014) and even those districts of upper (northern) Punjab came under its effect in 2018 and 2019 (and got included in hot group in this study) which were once used to experience less than 25 degree Celsius average annual temperature (and were placed in cool group in this study from 2009 till 2017).

In 2009: AAT ranged 19.6-28.8°C in the province of Punjab, Pakistan where the minimum side of the temperature range prevailed over northern region and maximum values were noted for the southern parts. The highest AAT ranged 27.1-28.8 and prevailed over 10 extreme southern hot group districts extending from Pakpattan (in the north-east of this cluster) to Rahim Yar Khan (in the south west of this cluster). The cool group comprised of three extreme northern (Rawalpindi, Attock and Chakwal) and one north-eastern (Narowal) district which experienced the lowest AAT range 19.6-25°C.The medium group (AAT 25.1-27°C) included 22 northern and central districts extending from Mianwali, Khushab and Jhelum in the north to Sahiwal, Khanewal and Muzaffargarh in the south. (See figure 3).

In 2010: Ten southern and one western district (hot group) experienced 27.1-29.3°C AAT and it was noted that the maximum limit of the temperature range remained a bit high (29.3°C) as compared to the previous year (28.8°C in 2009). Ten northern districts (cool group) experienced AAT 19.2-25°C, and the minimum limit of the range decreased a little from 19.6 in 2009 to 19.2 in 2010.

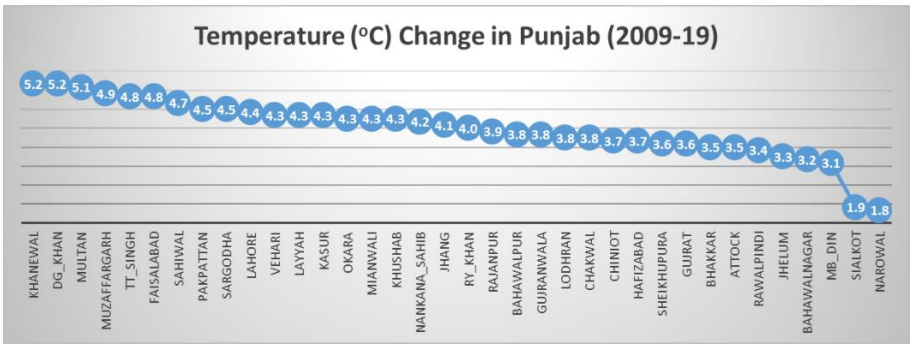

Figure 1: Temperature (°C) change in Punjab (2009-2019)
Source: Made by Author

Fifteen central districts (medium group) experienced AAT range 25.1-27°C. 27°C isotherm expanded towards north as compared to the previous year. (See figure 3).

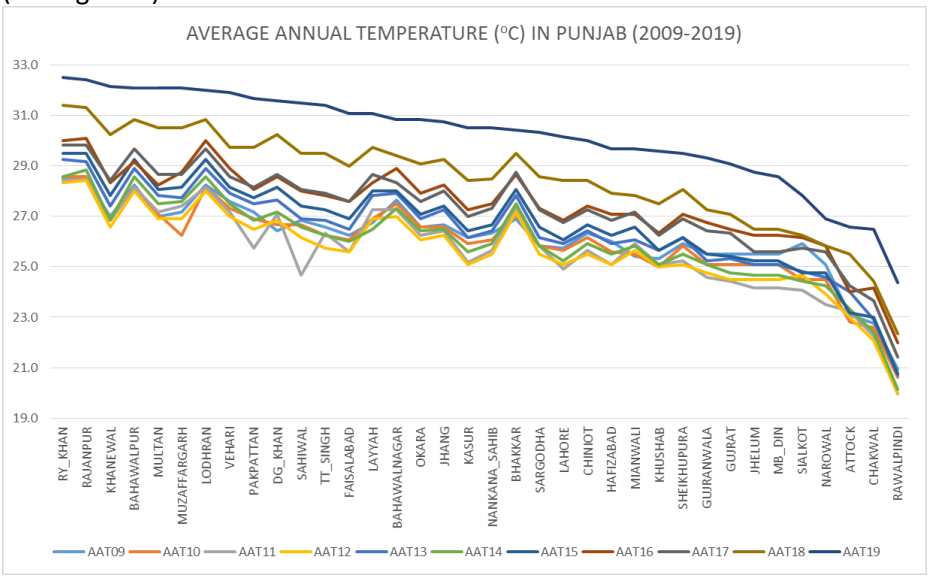

Figure 2: Average annual temperature (°C) in Punjab (2009-2019)
Source: Made by Author

In 2011: Eleven southern districts remained in hot group (27.1-28.7°C), the upper limit of range dropped from 29.3 of previous year to 28.7 this year. Ten northern districts fall in cool group (18.8-25°C), the lower limit of the class dropped from 19.2°C of the previous year to 18.8°C in 2011. Fifteen central districts (as was the case in the previous year) placed in medium group experienced AAT range 25.1-27°C. 27°C isotherm shifted a bit more towards north as compared to the previous year. (See figure 3).

In 2012: Four southern and one western district fall under hot group; the AAT class 27.1-28.8°C. Six districts slipped (which remained the member of this cluster formerly) into medium group. Cool group (18.7-25°C) contained as usual 10 northern districts and the lower limit of the class matches to that of the previous year. Medium group expanded to include 21 districts this year (six districts increased which were formerly members of cool group). The 27°C isotherm retreated towards south for the first time during the total course of study. (See figure 3).

In 2013: Came with more heat. 14 southern districts clustered in hot group; the AAT class 27.1-28.8°C. The upper limit also elevated to 29.6°C this year from 28.8°C of 2012. Cool group (19.5-25°C) contained only five northern districts. The lower-class limit also elevated to 19.5°C from 18.7°C of the previous year. Medium group slipped northwards and comprised of 17 central as well as northern districts. The 27°C isotherm stretched

towards north, covering more than half of the province under its influence. (See figure 3).

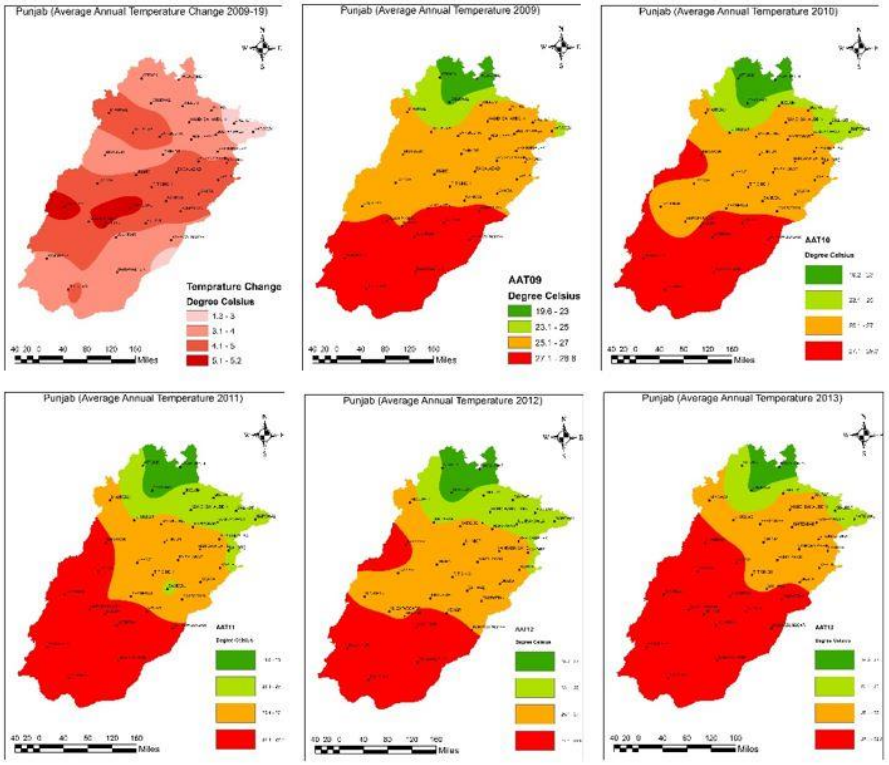

Figure 1: Punjab Average Annual Temperature Maps (2009-2013)
Source: Made by Author

In 2014: 10 southern districts included in hot group (27.1-28.9°C), the upper limit lower to 28.9°C as compared to 29.6°C of the preceding year. Cool group (18.7-25°C) expanded southward to include 8 northern districts as compared to 5 of the previous year. The lower limit of the class dropped to 18.7°C from 19.5°C of previous year. Medium group slipped southward, covering 18 districts. The 27°C isotherm retreated towards south for the second time (first retreat was in 2012) and 4 districts got excluded from the hot group. (See figure 4)

In 2015: Lowering of temperature averages during the previous year proved only a temporary phenomenon and 2015 brought continuation of the warming process started through 2013. 17 southern districts fall in hot group; the AAT class 27.1-29.8°C. The upper limit also elevated to 29.8°C this year from 28.9°C of 2014. Cool group (19.4-25°C) remained limited to only five northern districts. The lower-class limit also elevated to 19.4°C from 18.7°C of the previous year. Medium group slipped northwards and comprised of 14 central as well as northern districts, excluding the former

southern members and including more northern districts, once the part of cool group. The 27°C isotherm was approaching Faisalabad, far more northward as compared to the preceding years. (See figure 4).

In 2016: The hot group extended northwards, covering almost 80% of central districts along with southern. 25 southern and central districts got included in hot group; the AAT class 27.1-30.4°C. The upper limit jumped to 30.4°C from 29.8°C of 2015. Cool group (19.4-25°C) shrank to only three extreme northern districts. The lower-class limit also elevated to 20.6°C from 19.4°C of the previous year. Medium group slipped northwards and comprised of only 8 northern districts. The 27°C isotherm crossed Mianwali, Sargodha, Hafizabad and Sheikhupura, and seems approaching upper Punjab. (See figure 4).

In 2017: Replicated almost exactly the situation of previous year of 2016 with minor increments. (See figure 4).

In 2018: The hot group extended further northwards, covering 27 southern and central districts; the AAT class 27.1-31.7°C. The upper limit further rose to 31.7°C from 30.1°C of 2017. Cool group (21.2-25°C) further contracted to only 2 extreme northern districts. The lower-class limit also elevated to 21.2°C from 20.3°C of the previous year. Medium group contained only 5 northern districts. The 27°C isotherm touched Gujrat in the North-East. (See figure 4).

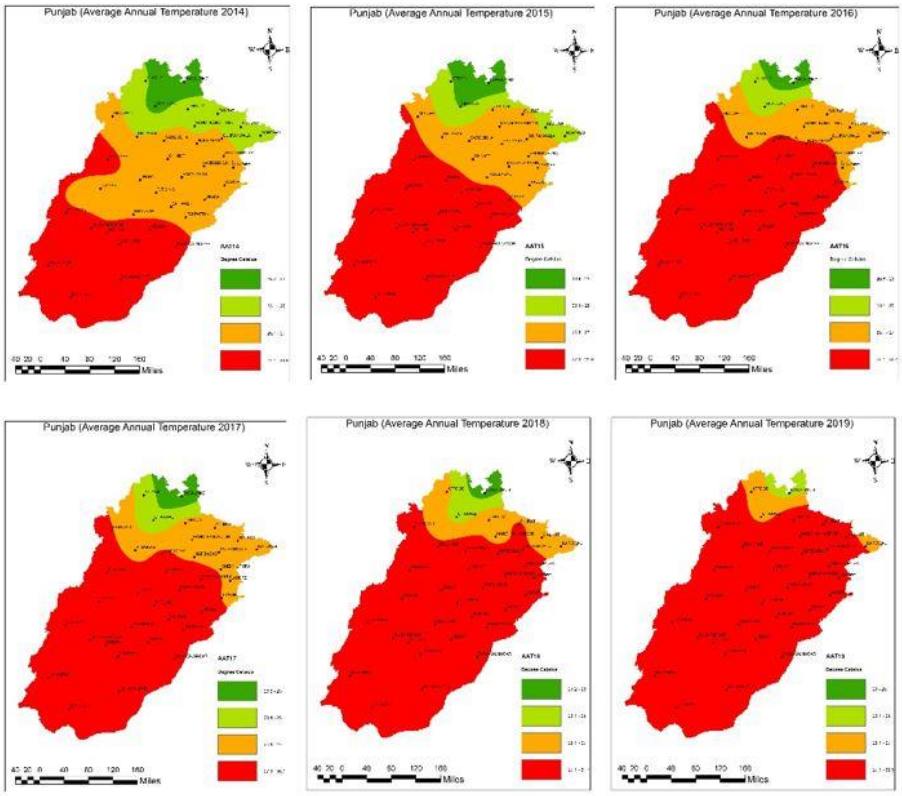

Figure 4: Punjab Average Annual Temperature Maps (2014-2019).
Source: Made by Author

In 2019: The 27°C isotherm shifted further northward and the hot group swallowed the medium group completely. Almost the entire province experienced AAT more than 27°C except for Rawalpindi, Attack and Chakwal in the north and Narowal in the north-east. Rawalpindi was the only representative of cool group and Attack, Chakwal and Narowal represented the medium group. Maximum AAT was 32.6°C and minimum was 23°C. (See figure 4).

Rainfall Patterns

The amount of Total Annual Rainfall kept increasing every year till 2019 which remained the wettest year except for 2016 and 2017 when aridity prevailed over most parts of the province, 27 and 25 districts respectively faced drought conditions and TAR remained less than 125 mm in this cluster.

The highest rain fell during 2019 when no part of the province fall under less than 125 mm TAR category. Minimum amount was 180.9 mm and only four southern districts got 180.9-250 mm TAR. Larger central part of the province received 250-500 mm TAR while the northern districts received

more than 500 mm, even a wide strip stretching from Narowal in the north-east to Attock in the north-west and covering 9 districts, received 750-1914 mm TAR.

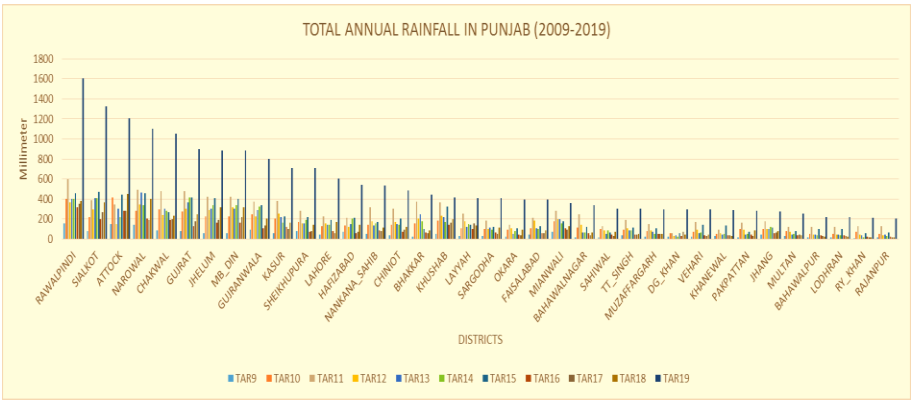

Figure 5: Total rainfall in Punjab (2009-2019)
Source: Made by Author

The lowest rainfall among the eleven years period of study fell in 2009 when only three districts (Rawalpindi, Attock and Narowal) received more than 125-millimeter TAR but less than 250 mm. The rest of the province got less than 125 mm TAR. The southern districts received as low as 10.4 mm TAR. (See figure 6).

2010: The drought conditions somewhat relieved in the northern portion of the central region of the province. 5 northern districts experienced semi-humid condition ranging 250.1-500 mm TAR. 13 more districts, south of the semi-humid region experienced semi-arid level TAR (125.1-250 mm). 18 central and southern districts still faced aridity, receiving less than 125 mm TAR. However, the minimum amount of TAR enhanced to 48.7 mm in southern most districts as compared to 10.4 mm in the previous year. (See figure 6).

2011: Drought condition further lessened this year when two districts (Rawalpindi in the North and Narowal in the North-East) slipped from semi-humid to humid condition, receiving 500.1-750 mm TAR. 15 districts to the south of humid region got semi-arid conditions. 6 districts further southward witnessed semi-arid while only six southern most districts faced the conventional arid situations. (See figure 6).

2012: TAR fluctuated this year once again to the lower margins and 7 districts experienced semi-humid situation; one district (Kasur) was in the east and other 6 were clustered in the north and north-east. 13 central districts came under semi-arid conditions while 16 falls in arid category. An interesting fact may be noteworthy here that all the districts facing aridity were located to the south of the province except for Sargodha and

Hafizabad; the two outliers positioned in the northern region whose surrounding districts received more rain. The southernmost parts received less than 10 mm TAR. (See figure 6).

2013: Narowal was the only district falling in humid circumstances. 8 northern districts remained under semi-humid while 9 districts to the south of semi-humid region experienced semi-arid situations. Arid region expanded northwards, covering the remaining 17 districts. (See figure 6).

2014: 8 northern districts were included into the semi-humid region but this time Attock was excluded from this club and Narowal was included. It seems that may be the western depression rain system got weaker this year because the Attock receives most of its rain from this system. 11 districts to the south of semi-humid region got semi-arid rain scheme and surprisingly, Sargodha remained an outlier once again which received less than 125 mm TAR and fell into arid club. The remaining 17 districts remained under drought. The southernmost parts once again got less than 10 mm TAR after 2009 and 2012 for the third time during the course of study. (See figure 6).

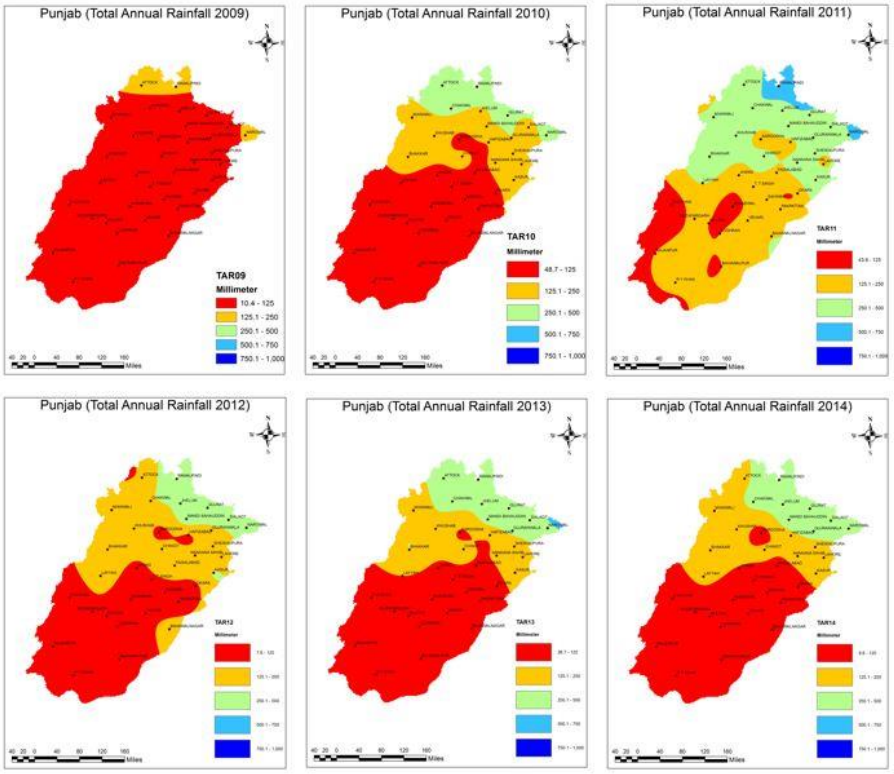

Figure 2: Punjab Total Annual Rainfall Maps (2009 -2014)
Source: Made by Author

2015: Parts of four districts; Rawalpindi, Attock, Sialkot and Narowal received humid level TAR. And 10 districts were included in semi-humid region. Semi-arid region split apart into two clusters; the northern cluster included 9 while the southern cluster included three districts (Layyah, Khanewal and Vehari) in a diagonal strip from north-west to south-east. Arid region also contained two clusters; both of them included 7 districts in each. (See figure 7).

2016: This year proved the second dry spell after 2009, during the whole course of study. Only Rawalpindi and Attock got semi-humid level rain. It seems that the monsoon system remained inactive that year, which was why the north-eastern districts (Sialkot and Narowal) got less rain that usually receive much more than the amount fell in 2016. 7 districts adjacent to semi-humid region southwards witnessed semi-arid level TAR. Most of the parts of the province (27 districts) faced aridity and drought conditions. (See figure 7).

2017: A similar situation prevailed in 2017 to that of the preceding year (2016). 3 northern districts got semi-humid level TAR. 8 districts got semi-arid level while the remaining larger part (25 districts) faced aridity. (See figure 7).

2018: Only parts of district Attock got humid level TAR. 6 northern districts received semi-humid and 10 southern neighbors got semi-arid level TAR. 20 remaining districts faced aridity and this cluster covered almost 2/3rd of the province. The southernmost districts received almost no rain at all. (See figure 7).

2019: The wettest year came when no part of the province remained in arid club. 9 northern districts got supper-humid level TAR while their 5 southern neighbors got humid level. Central and southern 18 districts included in semi-humid while the southernmost 4 districts received semi-arid level TAR. (See figure 7).

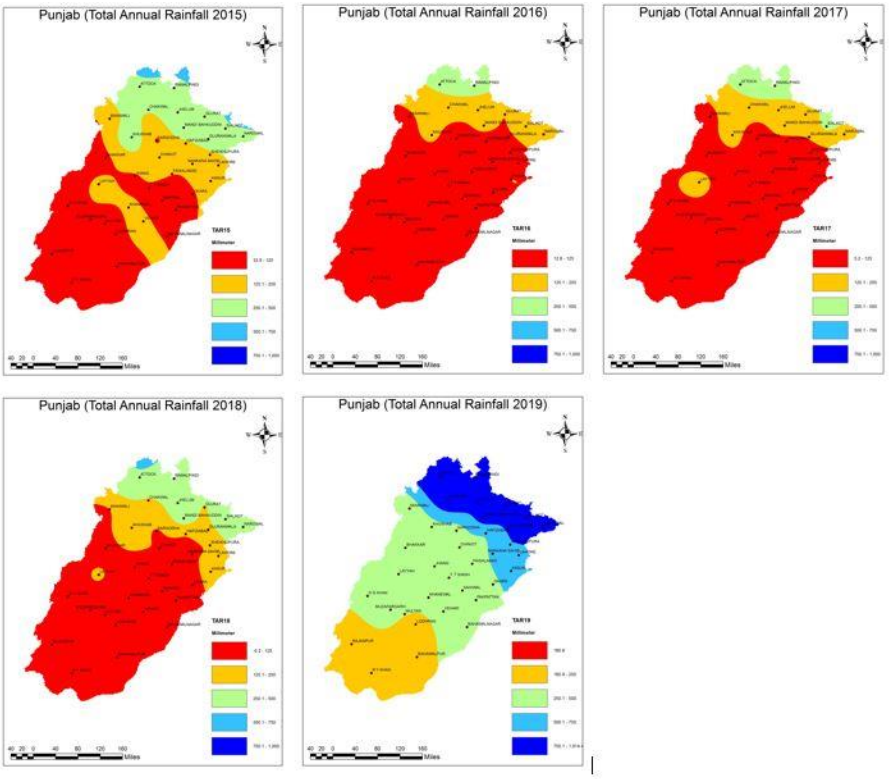

Figure 3: Punjab Total Annual Rainfall Maps (2015-2019)
Source: Made by Author

CONCLUSION

Data analysis shown that the central part of the province adversely affected by warming (4.1-5 degree Celsius) and fluctuations in total annual rainfall during the study period and western portion of this central part (DG Khan, Multan and Khanewal districts) have shown the highest warming level (more than 5 degree Celsius) while the least affected part comprised of only two north-eastern districts (Sialkot, 1.9 degree Celsius and Narowal, 1.8 degree Celsius increase). The noteworthy phenomenon was that the 27 degree Celsius isotherm kept shifting (started through 2013) towards north of the province (except for 2014) till 2019 and even those districts of upper (northern) Punjab came under its influence in 2018 and 2019 (then got included in hot group) which were once used to experience less than 25 degree Celsius average annual temperature (and were used to be placed in cool group in this study from 2009 till 2017). The lowest TAR among the eleven years of period of study fell in 2009 when only three northern districts experienced semi-arid condition and rest of the districts of the province faced aridity. The TAR kept increasing from 2009 onwards (except for 2016 and 2017) till 2019 which was the wettest

year when 9 northern districts experienced supper-Humid condition and further 5 southward neighboring districts had humid level TAR while no part of the province received arid level TAR.

Abbreviations and Key Terms Used

AAT; Average Annual Temperature, **TAR;** Total Annual Rainfall, **Cool Group;** having less than 25 degree Celsius AAT, **Medium Group;** having AAT ranged 25.1-27 degree Celsius, **Hot Group;** having more than 27 degree Celsius AAT, **Arid Condition;** receiving less than 125 millimeter TAR, **Semi-Arid Condition;** receiving 125.1-250 millimeter TAR, **Semi-Humid Condition;** receiving 250.1-500 millimeter TAR, **Humid Condition;** receiving 500.1-750 millimeter TAR, **Supper-Humid Condition;** receiving more than 750.1 millimeter TAR

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