Changing Pattern of Agroclimate in Pakistan and Measures for Agriculture Sustainability

Ashraf, A.[1,2], A. Ahmed[2], A. Mukhtar[2], M. B. Iqbal[2]

Abstract

Climate change impacts are aggravated with increase in population and shrinking of land and water resources which may consequently affect agriculture productivity and planning process. In the present study, country-wide changes in agroclimate were identified using climate data of two normals (i.e., 1960-1989 & 1990-2019) for adopting viable measures for sustainable agriculture in the country. The arid and hyper-arid zones were observed collectively over 80% area of the country during 1960-1989, which indicated a decrease to about 68% during 1990-2019 period. The humid zone exhibited an increase from 4.2% to 7.3% and sub-humid from 4.5% to 5.8% during the two periods. The situation necessitates adoption of appropriate water harvesting and conservation techniques to enhance agriculture productivity and improve livelihoods of the major dry-land farming communities

Keywords: Arid region, climate change, sustainable agriculture; drought, Indus basin

Introduction

Increasing water use under growing developments in agriculture, industrial and urban sectors places demands and constraints on the natural environment as water resource depleted (Li et al., 2010), especially in the arid regions where rainfall is a primary water source (Markhi et al., 2019). The climate change impacts vary in various regions and ecosystems. The agriculture sector in the arid region receiving insufficient rains for vegetation growth (Haider and Adnan, 2014; Adnan et al., 2017; Qaiser et al., 2021) is highly vulnerable to changing climate (Ahmed and Schmitz, 2011; Safdar et al., 2014). The agriculture sector of Pakistan is facing challenges of rapid urbanization and reduced surface water availability owing to changes in climate and land use (World Bank, 2017). The growing food requirements of the country under a projected increase of 213 million in population till 2025 are exerting tremendous pressure on the agriculture sector and the two natural resources, land and water, which are the medium of food production (Farooq et al., 2020). According to Chaudhry et al. (2009), Pakistan experienced 0.76°C rise in temperature during the last 40 years and the increase in temperature in the mountain environment hosting thousands of glaciers was even higher, i.e., 1.5°C during the same period. According to a study by Bukhari and Sayal (2011), 0.6–1.0°C rise in mean temperature and 10–15% decrease in both winter and summer rainfall were observed in arid coastal areas, arid mountains and hyper-arid plains of Pakistan during 1980-2007 period. Furthermore, 18–32% increase in rainfall in the monsoon zone and a significant increase in the number of heat wave days per year with a rate of 11 days per decade were observed in the country. The increase in rainfall intensity in the northern half of the country resulted in occurrence of extreme flood events, e.g. in 1992, 2003, 2005, 2010-2014 (Rahman, 2010; Rahman et al., 2011; Zeba and Khan, 2019). Knowledge of the broad-scale changes in agroclimate can provide information on shifts in the suitability and potential for crop production in a region or country under climate change (Carterand Saarikko, 1996; Challinor, 2011). Agroclimatic indicator approaches are sometimes applied to provide a more comprehensive picture of the agroclimate for larger areas and its shifts under climate change (Harrison and Butterfield, 1996; Trnka et al., 2011). It is hypothesized that the changes in climate and land use during the last several decades have influential impact on the agroclimate of this region. Although previous studies used gridded climate data (Mitchell, 2004; Parry, 2004; Meehl, 2007; Osborne, 2013; Rötter et al., 2013), but it is usually of short durations and cannot depict long-term changes in agroclimate. The present study is aimed at identifying

[1] mashr22@yahoo.com
[2] Climate, Energy and Water Research Institute (CEWRI), NARC, Islamabad

changes in agroclimate of Pakistan using climate data of two normals (i.e., 1960-1989 & 1990-2019) for sustainable agriculture development in the country.

Materials and methods

Geographical setup

Pakistan lies in sub-tropical to tropical monsoon region where main rainfall generating weather systems are the monsoons and winter rains caused by western disturbances (Khan et al., 2019). Major amount of monsoon rainfall occurs in the northern half of the country comprising parts of the eastern Khyber Pakhtunkhwa (KP), Azad Jammu and Kashmir (AJK) and the adjoining mountainous areas of the Punjab province (Zeba and Khan, 2019). Some of the monsoon effects are also felt in the southeastern parts of the country, whereas western parts of the Balochistan province remain dry and unaffected. The western disturbances system generates a secondary rainfall peak during winter (January to March) mostly in the northern and western parts of the southern half of the country (Zeba and Khan, 2019). The landform is generally mountainous with patchy soil cover containing numerous dry nullahs, intermittent and perennial streams. The soils are mostly brown/dark brown, moderately to strongly calcareous and silty to clayey (Mohammad, 1984). In the east, major part comprises of alluvium derived from the northern Himalayan mountains and in the west, gravel fans form distinct Piedmont zones consisting of finer sediments (sand and silt) and gravels. The arid areas in the west contain less fertile sandy soils where the sparse vegetation is mostly used for grazing. At places, karezes and perennial streams exist to sustain scanty vegetation of drought resistant trees and some agriculture land in patches (Khan et al., 2019). In the irrigated area of Indus plain, shrubs, grasses and medium size trees are common. The main crops grown here are wheat, rice, maize, sugarcane, cotton, fodder, vegetables and fruits (FAO, 2017). In the mountainous regions, vegetables and fruits like apple, peach, apricot, citrus, loquat and pears are grown where irrigation water from dams, dug wells/tube wells and springs are available (Ashraf, 2019). Livestock holds the central position in livelihood of the farming communities in major mountain areas of the country.

Data used

The climate data (rainfall and temperature) of 58 meteorological stations (period 1960-2019) was collected from Pakistan Meteorological Department (PMD) for mapping rainfall and evapotranspiration for agroclimate analysis. A CHIRPS precipitation product was used for trend analysis of precipitation at provincial and country level. CHIRPS dataset is a new quasi global gridded precipitation product with high temporal and spatial resolution of 0.05° available at daily, monthly, pentad, and annul timescales since 1981 (Funk et al., 2014, 2015a). The dataset was developed based on Inverse Distance Weightage (IDW) interpolation techniques and recorded precipitation based on IR Cold Cloud Duration (CCD) observations. TMPA 3B42 V7 was used for the calibration of CCD precipitation estimation (Funk et al., 2014, 2015a, 2015b). The newly emerged precipitation product was validated by Nawaz et al. (2020) over diverse topography of Pakistan which shows reliable results for this region.

European Reanalysis 5 (ERA5) is the updated version of the ERA interim reanalysis and is the fifth generation European Center for Medium Weather Forecast (ECMWF) atmospheric reanalysis of the global climate. It is the output of the model data and the observed data collected from across the globe. ERA5 dataset has a spatial resolution of 0.25° (approximately equal to 27.5 km) and is available from 1979 to near present time.

Methodology

The monthly rainfall data was checked qualitatively and databases were developed on annual and normal basis, i.e., 1960-1989 and 1990-2019. The point data of annual rainfall of all stations was interpolated in GIS to prepare rainfall maps of the two climate normals. Later, temporal analysis was performed using the rainfall maps of the two climatic periods. The mean monthly temperature data (minimum & maximum) of two climatic periods were used in ETo calculator, software of the Land and Water division of FAO, to determine reference evapotranspiration (ETo) at each station. The ETo calculator uses Penman-Montheith method as the standard method. The ETo data was interpolated following Inverse distance weighting (IDW) interpolation technique in ArcGIS software and evapotranspiration maps of two climatic periods were developed for change analysis. There exists several approaches for climatic zonation in the literature (Chaudhry and Rasul, 2004) but we selected the one adopted by Roohi et al. (2002) in the present study. The aridity index (Ia) was estimated using mean annual rainfall and reference crop evapotranspiration (UNESCO, 1976). The Ia can be computed using the following relationship:

$$I_a = \frac{R}{ETo} \quad (1)$$

Where, *R*= sum of the monthly rainfall; and *ETo* = sum of the monthly reference evapotranspiration.

Table 1: Percentage change in extent of different Rainfall classes in Pakistan during 1960-1989 and 1990-2019 periods

S.No.	Rainfall (mm)	Evapotranspiration	Zone
1	>1500	2501-2830	Very High
2	1001-1500	2001-2500	High
3	751-1000	1751-2000	Moderate
4	501-750	1501-1750	Medium
5	251-500	1251-1500	Average
6	101-250	1001-1250	Low
7	0-100	921-1000	Very low

The index values were used for defining various agroclimate zones following Roohi et al. (2002) as given in Table 2.

Table 2: Aridity index based on mean annual rainfall and reference evapotranspiration in the country

S.No.	Aridity Index	Zone
1	<0.05	Hyper-arid
2	0.05-0.25	Arid
3	0.251-0.5	Semi-arid
4	0.51-0.75	Sub-humid
5	>0.75	Humid

Google Earth Engine (GEE) platform was used for analysis of time-series precipitation data of CHIRPS and mean temperature data of ERA5 for 1981-2020 period. GEE is an online platform based on Java scripting where CHIRPS precipitation and ERA5 temperature datasets are available in its repository. These datasets were imported and analyzed in the code editor of the GEE.

Results

Climate variability analysis

Overall rainfall trending was linear and positive exhibiting Pearson correlation R value of 0.5 at country level (Figure 1). Initially the trend appears to be negative up to year 2002 when the last extreme drought prevailed in the country. Thereafter the rainfall trend rise continuously with several ups and downs during 2003-2020. Over 38% data indicated rainfall values below 300 mm, 57% within 300–400 mm, while 5% data only exhibited rainfall values higher than 400 mm during 1981-2020 period. Generally, August receives the maximum rainfall and November the minimum rainfall. The rainfall trends were found prominent for Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB) and Punjab province indicative from Pearson R values of 0.65, 0.57 and 0.54 respectively. Mean annual temperature indicated linear and positive trending (R=0.44) at country level (Figure 2). Over 41% data indicated temperature values below 16°C, 56% within 16–18°C, while 3% data only exhibited rainfall values higher than 18°C during 1981-2020 period. The mean temperature trends were found prominent for KP and Balochistan province exhibiting R value of 0.52.

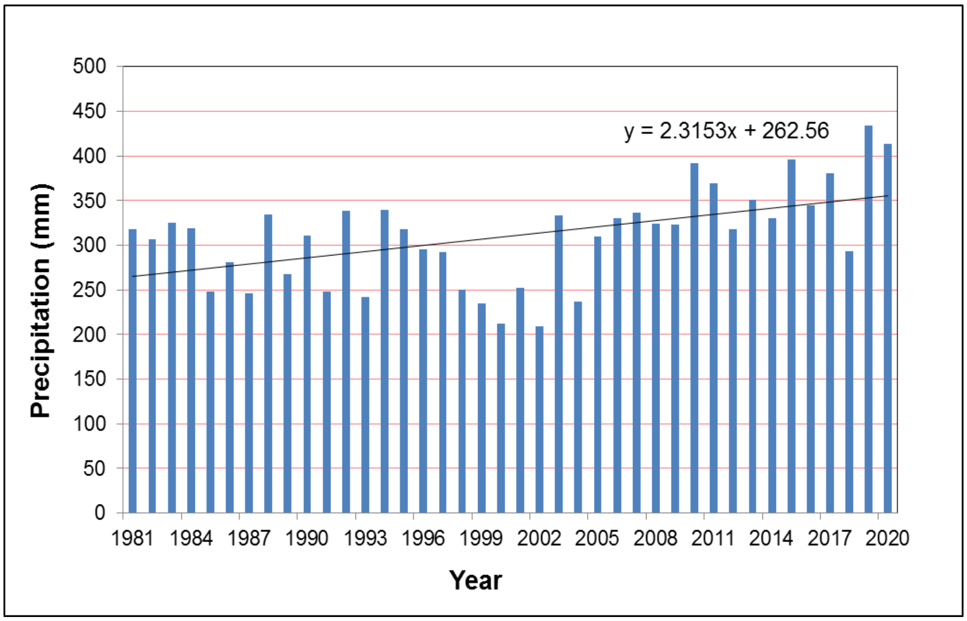

Figure 1: Variability and trending in mean annual rainfall of Pakistan

3.2 Rainfall change analysis

There is an explicit change in the rainfall pattern of Pakistan between 1960-1989 and 1990-2019 periods. The rainfall zone >1500 mm indicated a reduction from 0.8% to 0.2% during the two climatic periods (Table 3). In the first period 1960-1989, >1500 mm rainfall zone covered parts of lower Neelum, Muzaffarabad and Hattian Bala and western parts of Poonch and Sudhnoti districts of Azad Jammu and Kashmir (Figure 3). In Punjab, the zone covered Northern part of Rawalpindi District (Murree and Kotli Sattian), and eastern parts of Abbottabad, central part of Mansehra and eastern part of Batagram in KP. In the second climatic period 1990-2019, this zone appeared in Northern part of Rawalpindi in Punjab, south eastern part of Abbottabad in KP, and western parts of Bagh, Poonch and Sudhnoti districts in AJK.

The rainfall zone 1001–1500 mm indicated an increase from 2.9% to 5.4% during the two periods (Table 3). In the first climatic period, it covered districts of KP (Dir, Swat, Shangla, Kohistan, Tor Kher, Buner, Batagram, Mansehra, Abbotabad, Haripur), some districts of AJK (Neelum, Haveli, Poonch, Sudhnoti, Kotli and northern part of Mirpur) and only western part of Rawalpindi in Punjab (Figure 3). In the second climatic period (1990-2019) this zone expanded towards south and covered whole Islamabad and Rawalpindi district, eastern part of Attock, Northern part of Chakwal, and north western part of Jhelum districts. This zone also stretched towards east covering north of Bhimber in AJK, east of Gujrat, north of Gujranwala and more than half of Sialkot district in Punjab. The Kurram district of KP is also found under high rainfall zone in the second climatic period. In Kashmir, 1000–1500 mm zone increased from 41% to 71%, e.g. Muzaffarabad, Haitian and Bagh have come under this zone during the recent normal.

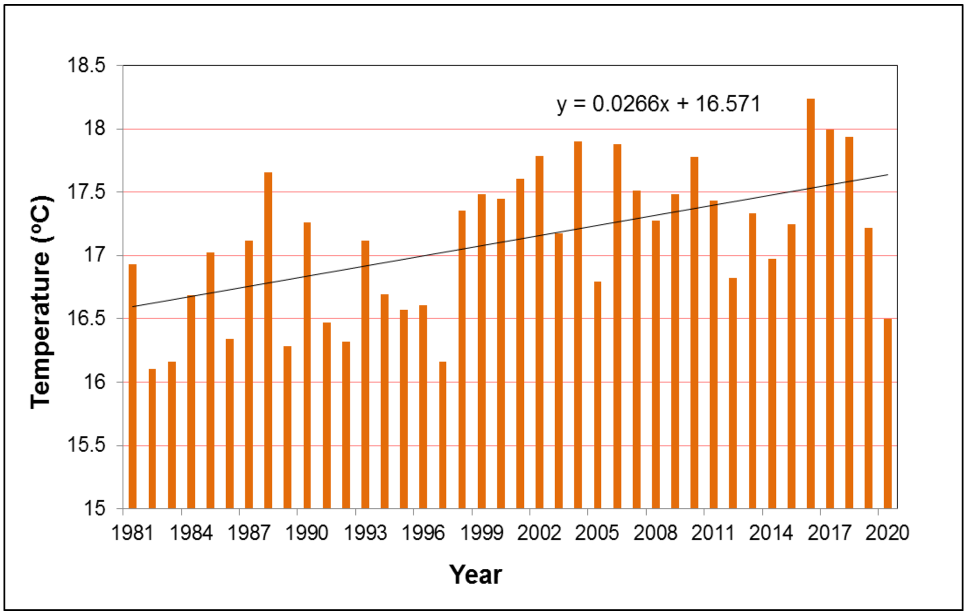

Figure 2: Variability and trending in mean annual temperature of Pakistan

The rainfall zone 751–1000 mm decreased from 3.7% to 3.5% during the two periods (Table 3). In the second period, most of the area of this zone has been replaced by high rainfall zone. For example, rainfall range 1000–1500 mm has dominated 750–1000 mm range in Sialkot and several other places. The rainfall zone 501–750 mm has increased by 1.6%, i.e., from 6.2% to 7.8% area during the two periods. In the second climatic period it has expanded towards south covering half of Karak district of KP, whole Mianwali and more than half of the Khushab district in Punjab province. It has also expanded towards the eastern part of Lakki Marwat, and northern parts of D.I.Khan, Bhakkar and Okara districts. In GB, this rainfall zone appears in Astore and Skardu districts. Average rainfall zone 251–500 mm indicated an expansion from 22.2% to 24.3% during the two periods. Vehari, Bahawalnagar, Pakpattan and Sahiwal now fall under this rainfall zone. It covers most of the Gilgit Baltistan, parts of Chitral, Karak to D.I.Khan districts in KP, central and south western parts of Punjab, and northern parts of Balochistan province. It indicated a shift towards south in Punjab covering Vehari, Bahawalnagar and Pakpattan districts, in some parts of Khuzdar district of Balochistan and GB during the second climatic period. The rainfall zone 101–250 mm decreased from 53.8% to 46.0% during the two periods (Table 3). Major area of the country appears to fall within this rainfall zone (Figure 3). Most of this rainfall zone exists in the south eastern parts of Punjab and almost 90% of Sindh and Balochistan provinces. This zone indicated an expansion in GB districts (e.g. Ganche, Ghizer, Hunza Nagar), while it exhibited a decrease in the Balochistan districts like Washuk, Panjgur, Gwadar, and Punjab districts like Pakpattan, Bahawalnagar and Vehari. The rainfall zone 0-100 mm exhibited an increase from 10.5% to 12.3% during the two periods. In climatic period 1960-1989, this zone prevailed over some parts of Sindh (Sukkur, Ghotki, Shikarpur, Kashmore) and Balochistan province. In 1990-2019, it appeared mainly in the south-western part of Balochistan comprising of Chaghi, Washuk, Panjgur, Awaran, Kech, Gwadar districts (Figure 3).

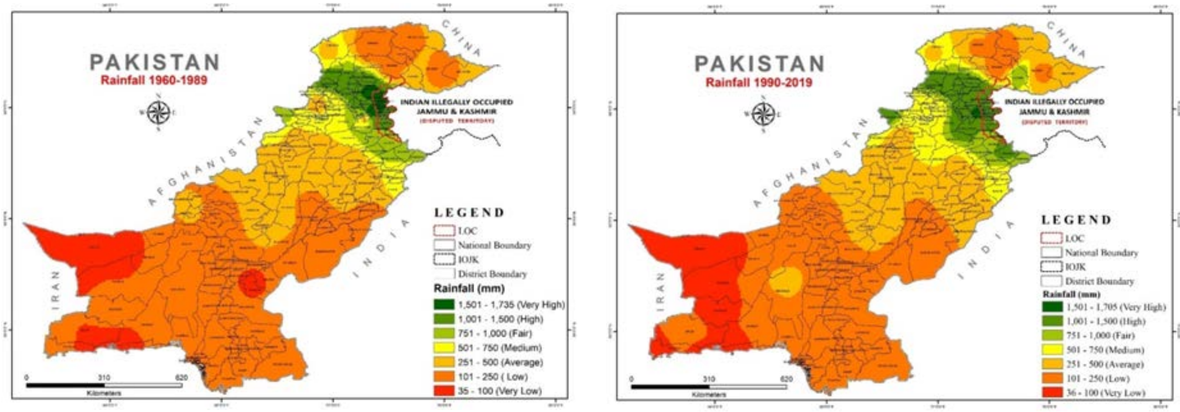

Figure 3: Distribution of mean annual rainfall (mm) in Pakistan during 1960-1989 (Left) and during 1990-2019 (Right)

Table 3: Percentage change in extent of different Rainfall classes in Pakistan during 1960-1989 and 1990-2019 periods

Rainfall (mm)	1960-1989 (%)	1990-2019 (%)	Difference (%)	Status
0–100	10.5	12.8	2.3	Increase
101–250	53.7	46.0	-7.7	Decrease
251–500	22.2	24.3	2.1	Increase
501–750	6.2	7.8	1.6	Increase
751–1000	3.7	3.5	-0.2	Decrease
1001–1500	2.9	5.4	2.5	Increase
>1500	0.8	0.2	-0.6	Decrease

3.3 Evapotranspiration change analysis

During 1990-2019, more than half of the country was found under ET range of 1500–2000 mm. Punjab has more than 90% of its area and Balochistan >75% area in this range. Lasbella has the highest value of evapotranspiration where it lies in the range of 2500–2800 mm. KPK has half of its area in the range of 1000–1250 mm and around 30% in the range of 1500–1750 mm (Figure 4). Sindh has 100% of its area in evapotranspiration range of 1750–2500 mm, whereas Gilgit-Baltistan and Azad Kashmir have more than 80% of their area in the range of 1000–1250 mm.

The ET zone 1501–1750 mm increased from 28.2% to 31.7% during the two periods (Table 4). In the first period, it prevailed over northern, north-eastern and western Punjab, central and southern KP and northern, north-western and central Baluchistan (Figure 4). In the second period, this zone was found over T.T.Singh, Sahiwal, Jhang, Khanewal, Vehari, Lodhran, Bahawalpur districts of Punjab province. The ET zone 1251–1500 mm increased from 2.7% to 3.5% over Lahore, Sheikhupura and northern part Kasur district, which were previously covered by the 1501–1750 mm zone. The ET zone 1001–1250 mm increased from 13.7% to 14.6% during the two climate periods (Table 4). During 1960-1989, it prevailed over whole GB except Astore and Ghizar districts, 80% of the AJK (from Kotli to Neelum), and the northern districts of KP (from Chitral, Dir, Swat, Abbotabad to north), Peshawar valley, Kurram and parts of the North Waziristan district. During 1990-2019 period, this zone prevailed over Ghizar district and expanded towards south. The ET zone <1000 mm indicated a decrease from 1.7% to 0.5% during the two climate periods (Table 4). In the first period, it covered Ghizar and Astore districts of GB, and in the second period, it appeared over Astore and southern parts of Skardu district (Figure 4).

The ET zone 1751–2000 mm indicated a decrease from 36% to 29.9% during the two periods. In the first period, this zone included central and eastern districts of Punjab (Jhang, T.T. Singh, Sahiwal, Okara districts), northern parts of Sindh down to Khairpur, Larkana and Shahdad Kot districts and in the Balochistan, Kohlu, Harnai, Sibi, Kachhi, Jhal Magsi, Kharan, Chaghi, Washuk, Panjgur, Kech, Gwadar districts (Figure 4). In the second period, parts of D.I.Khan and Bhakkar, and several districts in Punjab, Sindh and Balohistan provinces. The ET zone 2001–2500 mm has increased from 15.3% to 17.4% during the two periods (Table 4). In both climatic periods, this zone appeared in the southern parts of Sindh and Balochistan provinces, but in the second period, it expanded towards the west over whole Kech district and partially over Gwadar and Awaran districts of Balochistan province (Figure 4). The ET zone 2501–2830 mm decreased slightly, i.e., from 2.6% to 2.4% in the south of the country covering parts of Khuzdar, Awaran and Lasbela districts.

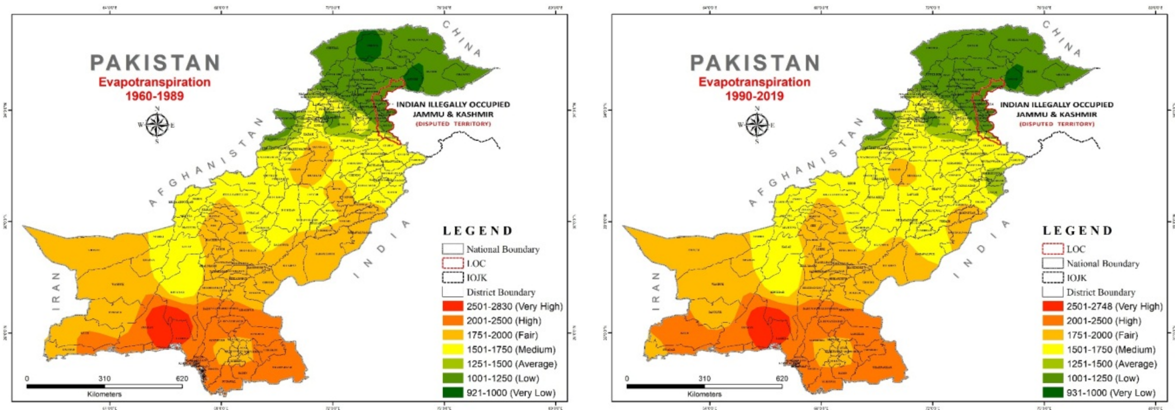

Figure 4: Distribution of Evapotranspiration (mm) in Pakistan during 1960-1989 (Left) and during 1990-2019 period (Right)

Table 4: Percentage change in extent of different Evapotranspiration classes of the country between 1960-1989 and 1990-2019 periods

ET mm	1960-1989 (%)	1990-2019 (%)	Difference (%)	Status
921-1000	1.7	0.5	-1.2	Decrease
1001-1250	13.7	14.6	1.0	Increase
1251-1500	2.7	3.5	0.8	Increase
1501-1750	28.2	31.7	3.5	Increase
1751-2000	36.0	29.9	-6.1	Decrease
2001-2500	15.3	17.4	2.2	Increase
2501-2830	2.6	2.4	-0.2	Decrease

3.4 Change analysis of Agroclimatic zones

During 1990-2019, the agroclimate zones indicated arid zone over 55.6% area, semi-arid over 14.9% area and hyper-arid over 12% area, whereas sub-humid and humid zones exhibited 5.8% and 3.1% extents respectively, in the country (Table 5 and Figure 5). The agroclimate during 1960-1989 indicated maximum area of about 71.7% in arid zone followed by 10.9% area in semi-arid and 8.7% in hyper-arid zone (Figure 5). The sub-humid and humid zones exhibited 4.5% and 4.2% coverages in the northern half of the country respectively (Table 5). The arid zone indicated a decrease from 71.7% to 55.6%, because some arid area in the past has converted into hyper-arid region in the Balochistan and semi-arid region in the northern half of the country. The hyper-arid zone had shown an increase from 8.7% to 12% during 1960-1989 and 1990-2019 periods (Table 5). This zone was only found in Balochistan province. In the first climatic period, only Chaghi, north western part of Washuk and southern parts of Kech and Gwadar districts were under hyper-arid region, while in the second period, these parts and some other regions like more than half of Panjgur and western half of Awaran district are completely fall under hyper-arid (Figure 5). The semi-arid zone exhibited an increase from 10.9% to 14.9% during the two periods. Half of the area of Hunza, Ghizar and Skardu districts has changed into this zone. The sub-humid zone indicated an increase from 4.5% to 5.8% in parts of Astore, Gujranwala, Narowal, Chakwal, Kohat and Attock districts between 1960-1989 and 1990-2019 periods. The humid zone exhibited an increase from 4.2% to 7.3% during the two periods (Table 5). The parts of the sub-humid zone comprising districts of Rawalpindi, Islamabad, Attock, Swabi and Chakwal in the past has transformed into the humid zone during the 1990-2019 period.

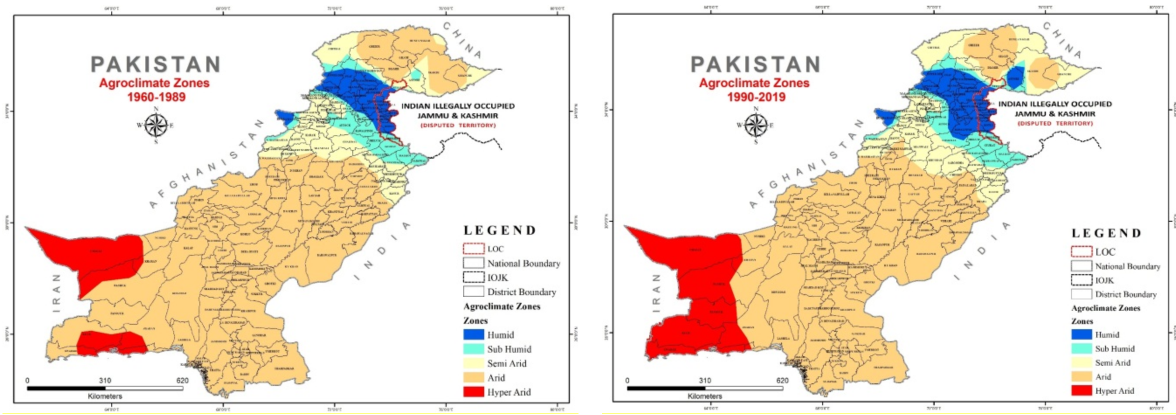

Figure 5: Distribution of Agroclimate zones during 1960-1989 (Left) and during 1990-2019 (Right) in the country

Table 5: Changes in extent of Agroclimate zones between 1960-1989 and 1990-2019 periods in the country

Zone	Area (1960-1989)		Area (1990-2019)		Difference	Status
	(km^2)	%	(km^2)	%	%	
Humid	37128.5	4.2	64556.0	7.3	3.1	Increase
Sub-humid	39421.5	4.5	90131.5	10.2	5.8	Increase
Semi-arid	96128.5	10.9	131669.6	14.9	4.0	Increase
Arid	632243.4	71.7	490167.2	55.6	-16.1	Decrease
Hyper-arid	76991.0	8.7	105476.8	12.0	3.2	Increase
Total	881913.0	100	881913.0	100	0	

Discussion

The fact of rise in rainfall and temperature trends in the country is reported in several previous studies (e.g. Farooqi et al., 2005; Hussain et al., 2005; Chaudhry et al., 2009; Yu et al., 2013; Ashraf and Rehman, 2019). The shift in the sub-humid and humid zones is evident from the analysis by PMD according to which the monsoon in the mid-hills has shifted 100 km towards the west in the country (FAO, 2020). The fact of increase in rainfall is also evident from the analysis of snow depth data, which indicated a significant declining trend during 2007-2018 period (Zeba and Khan, 2019). In the irrigated areas, most of the deficiency in canal water supply compared with the irrigation requirements is met by the groundwater abstractions through tubewells. Groundwater's share has gone above 50% in fulfilling the irrigation requirements (Qureshi, 2011). The groundwater use has been increased many folds because of rapid growth in urbanization, extension in agriculture activities and frequent drought conditions in the Indus basin (Qureshi, 2011; Laghari et al., 2012; Nasir et al., 2018; Sadaf et al., 2019). The increase in rainfall intensity may also affect soil and agricultural productivity through exaggerating rate of land degradation at places

(Alam et al., 2007; Ahmad, 2013; Ashraf, 2019). Also waterlogging and salinity are the major problems arising from intense rainfall, over irrigation and seepage from earthen channels. Such land degradation problems needs to be controlled through proper landuse planning and effective water resource management. There is a need to integrate irrigation and drainage, because efficient irrigation supplements drainage. As an innovative system, introduction of ponds in low-lying areas of watercourse command can help in raising high delta forest plants and crops for profitability. Also, broad beds and furrow irrigation is an effective system to manage waterlogging for crops other than rice in this area.

Likewise, the rise in temperature subsequently led to harsh and severe climate conditions like heat waves during 2003, 2015 and 2020, and severe drought prevailed during 1998-2002 mostly in parts of the Sindh and Balochistan provinces (Qureshi, 2010; Ganguli and Reddy, 2014). These water-stressed and heat-stressed conditions in this region have relatively strong spatial impact on the arid regions (Miyan, 2015; Ward and Makhija, 2018) leading to reduced agricultural productivity and forest biomes. In the arid, economic agriculture is only possible through appropriate irrigation techniques (Laghari et al., 2012). Although, there exists an extensive network of irrigation infrastructure in the Indus plain lying mostly in the eastern arid region of the country, but it is still under stress due to factors like climatic change and growing demand of water use for improving agriculture productivity. It is important to build capacity of the local communities, scientists and managers engaged in agriculture, environment and water sectors for better risk mitigation and adaptation to natural hazards like droughts, heat waves and flash floods.

The changing pattern of sub-humid and humid regions is also contributed by deforestation occurring at the rate of 2 to 2.5 percent per annum which calls for implementation of National Environment Policy and emphasis on the significance of communities' involvement (FAO, 2020). The formulation of policy standard at the federal level is very beneficial particularly for the conservation of natural resources like forests and rangelands for sustaining biodiversity and assisting in implementation of international conventions and agreements linked to forestry, wetlands, biodiversity and climate change.

In the western hyper-arid to arid areas, annual rainfall is low and uncertain but brings large amount of water with each rainfall event (NESPAK, 1995). Unfortunately, major part of the flood/runoff water is lost here due to unavailability of any kind of storage and modernized engineering structure. Rainwater harvesting systems may be adopted to enhance agricultural productivity as well as to reduce risk of extreme climate change events like droughts/floods in these areas (Bakir et al. 2008; Saher et al., 2014). At places deepening of groundwater levels due to overexploitation is a major problem. The farmers are of the opinion that if the runoff water is stored in small earthen ponds/dams, it can be used for agriculture as well as for groundwater recharge in the area. Most of the mountainous terrain in this region is barren that generate soil erosion owing to rangeland degradation and extreme flood/drought conditions. Therefore, restoration of vegetation cover is emphasized on the mountain slopes and to log the water at different places using water harvesting techniques. The situation demands engaging of farmers in the decision making process of water use and natural resource conservation at various levels.

Conclusion

The present study is focused on identification of country-wide changes in agroclimate of Pakistan using geospatial techniques for sustainable agriculture development in the country. An explicit change in the climate is observed during the last several decades in the country. The arid and hyper-arid zones were observed collectively over 80% area of the country during 1960-1989, which indicated a decrease to about 68% during 1990-2019 period. The major area under arid and water stressed conditions necessitates adoption of appropriate interventions like rainwater harvesting, water smart technologies (drip, sprinkler, raingun) and surface storages for sustainable agriculture. There is a need to raise awareness and build skills of the communities in efficient water use, adoption of modern water conservation techniques and climate smart agriculture. Policy measures are required to address important areas like; enhancing adaptive capacity; research; reforms in governance; conserving biodiversity and managing risks of extreme climate change impacts in this region in future.

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