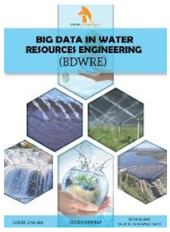
ZIBELINE INTERNATIONAL™ PUBLISHING
ISSN: 2716-5655 (Online)
CODEN: BDWRAP

Big Data in Water Resources Engineering (BDWRE)

DOI: http://doi.org/10.26480/bdwre.01.2021.18.23



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RESEARCH ARTICLE

REGIONAL CLIMATIC RESPONSE TO GLOBAL WARMING AND AGRICULTURE IN PAKISTAN

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ARTICLE DETAILS

Article History:

Received 20 April 2021
Accepted 28 May 2021
Available online 10 June 2021

ABSTRACT

Human-induced anthropogenic variations cause a significant change in the local climate, which in turn lead to variations in different climatic regions. The effects of global warming have wide spatial variability, feedback of climate change, like, surface temperature towards precipitation, surface, and subsurface runoff are critical. As the climate, variability is critically important for nature and society, especially if it increases in amplitude and fluctuations become more persistent. However, the issues of weather surface temperature is changing, and if so, whether this has a positive or negative impact on precipitation, surface and ground runoff, and theirs distinguish response to different climate classes, are subjects of ongoing debate. The current research is mainly concerned with distinguishing the response of surface temperature on the precipitation, storm surface run off, and subsurface runoff on different climate classes over the mainland of Pakistan, for a time duration of 71 years, from 1948–2018. Here, we used monthly based two sets of GLDAS (Global Data Assimilation System) datasets i.e. GLDAS-2.0 (1948-2010) and GLDAS-2.1 (2011-2018) having the spatial resolution of 0.25°×0.25° for surface temperature, precipitation, and runoff. While, for regional based climatic classification, Köppen Grignard climate classification map was used. The spatial-temporal trend of all the involving parameters has been estimated using Mann-Kendall's trend. Spatial-temporal variation in the precipitation, surface temperature, and runoff fluctuations have been detected in different climatic regions. We showed that annually based variability of surface temperature has positive feedback over the surface runoff over the entire region as well as different climate regions of Pakistan. Despite the declining precipitation trend, the temperature seems to be a major cause of the melting of glaciers leading to an increase in the runoff. Based on our findings of established trends and corresponding mechanistic 'feedback' we hypothesize that increasing temperature might risk severe water shortage and cause disastrous floods in the future. Furthermore, different climatic zoning's surface temperature variability contributed to observed variation in the precipitation, surface, and subsurface runoff variability, which in turn contributed to the persistent droughts. Changes in surface temperature and their impact on precipitation and runoff deliver valued evidence for understanding the region's sensitivity over the entire region in Pakistan.

KEYWORDS

GLDAS-2.0; GLDAS 2.1; Temperature; Precipitation; Runoff; Climate; Mann-Kendall; Pakistan

1. INTRODUCTION

The over the last 60 years, a rise in duration, intensity, and frequency of surface temperature and heat waves have been observed globally (Perkins-Kirkpatrick and Gibson, 2017). It is widely recognized that some acutely affected regions with increasing surface temperature may soon become uninhabitable (Pal and Eltahir, 2016). While global warming is estimated to increase surface temperatures by 1.5 °C to 2 °C in most regions, surface temperatures in Southern Africa and Asia are exceptionally projected to increase by over 2.5 °C. In Asia, increasing surface temperatures, persistent droughts, frequent and intensive floods have become among the leading causes of nature-related human and economic losses. In Pakistan, in 2010, nearly 20 million people were affected by floods, 14 million temporarily displaced, and over a billion US dollars lost in livelihoods affected (Mueller and Seneviratne, 2014).

Consequently, many global and regional conventions such as Paris Agreement (December 2015), have been conducted to draw frameworks for cooperation on limiting anthropogenic activities leading to climate change. For instance, Paris Agreement targets to limit global warming to below than rising below 2 °C by the year 2100. However, cascading of such global targets to respond to specific diverse regional vulnerabilities remains to be the challenge (Perkins-Kirkpatrick and Gibson, 2017). Despite advancement in technologies, specific investigation of the strong correlation between climate factors remains largely general with numerous exemptions.

Solar radiation affects sea-land surface temperatures which influence precipitation patterns. Coupled by the seasonal inclination of the earth, the precipitation variations follow an annual seasonal pattern called monsoon (Pal and Eltahir, 2016). In the southeast Asian region, distinctively four

Quick Response Code	Access this article online	
	Website: www.bdwre.com.my	**DOI:** 10.26480/bdwre.01.2021.18.23

Cite The Article: Muhammad Mazhar Iqbal, Malik Muhammad Akram, Maqsood Ahmad, Saddam Hussain, Ghulam Usman (2021). Regional Climatic Response to Global Warming and Agriculture in Pakistan. *Big Data in Water Resources Engineering, 2(1): 18-23.*

seasons of monsoon precipitation are observed in summer between the western North Pacific and South China Sea (Kripalani and Kulkarni, 1997; Iqbal, 2018). Previously, the seasonal variation in precipitation patterns in Asia has been positively correlated to variations in regional surface temperatures (Loo et al., 2015). It is therefore expected that increasing surface temperatures in the regions such as Pakistan will positively influence precipitation. Pakistan Meteorological Department has reported most areas of Pakistan are experiencing droughts. The severely affected areas include Sindh, Balochistan, Punjab, and parts of Northern Areas which are nowadays receiving less than the mean 250 mm of precipitation (Abid, 2016; Dilawar, 2021).

The precipitation variability in Pakistan and neighboring countries has led to water shortage and stress. The contribution of Glaciers in the high mountain region to stabilize the surface water run-off especially during the dry periods has not been well monitored (Pritchard, 2017). Indirectly, the melting glaciers, however, play a significant role to stabilize surface runoff during the droughts (Iqbal, 2018; Iqbal, 2019; Immerzeel et al., 2010; Hussain, 2020; Shoaib, 2019). Unlike the seasonal snow regimes, glaciers provide the delayed hydrological drag by storing precipitation for several years to as ice-caps above the mountain. During the high summer surface temperatures, they melt and flow as surface and sub-surface run-offs slowly to downstream areas. This process provides a momentary buffer to the downstream population against droughts. However, declining glacier coverage due to increased surface temperature can upset the hydrological balance and intensify regional water insecurity (Iqbal et al., 2019; Iqbal, 2018; Iqbal et al., 2019; Kayiranga, 2021). Spatial variability of the groundwater levels, declining water table, seawater intrusion have exerted pressure on the availability of groundwater as strategic terrestrial storage. Overall, the decline in aquifer recharge has been generally observed in some climatic zones across Pakistan (Macdonald, 2016; Rizvi, 2021; Aslam, 2021; Iqbal, 2018).

Due to the cumulative and composite impacts of climate change in Pakistan, livelihoods have been adversely affected. The predominantly agricultural communities are usually sensitive to the impacts of climatic changes. High poverty incidence, inadequate infrastructure coupled with lack of financial resources, pre-disposes communities in Pakistan to high vulnerability to climate change impacts (Abid, 2016; Waqas, 2018). The sustainability of agriculture to support the high population growth in Pakistan cannot be guaranteed. This study mainly investigated the long-term changes of surface temperature on precipitation, surface and subsurface runoff over the entire region of Pakistan as a dominant climate change indicator. Furthermore, for deep analysis, we also investigated the effect of temperature on precipitation and runoff over different arid sub-climatic zones of Pakistan. The study explains why despite declining precipitation surface and subsurface runoff increase.

2. MATERIALS AND METHODS

2.1 Study Area

Pakistan is situated approximately on the prodigious mainland (62-75 °E longitudes and 25-36 °N latitudes) in the western south Asian landmass. Its climate is the type of continental considered to a great risk variation of temperature, precipitation, both daily, seasonally, and annually. Higher altitude regions change the temperature in the winter, northern ice and snow roofed mountainous region, the hot arid region in the Balochistan Plateau. Around the coastline strip, the climate is changed by the increasing temperature at an alarming level. In another part of the country, temperatures range higher in the summer, warm breezes named Loo blow across the arid plain regions during the daytime. The arid, desert warm temperature is shattered infrequently by thunderstorms and heavy dusty winds that briefly lesser the warmth. Sunsets are pleasant; the daytime changes in temperature can go up to 10C to 15C. Winters are cold, with the minimum average daily temperature in the province Punjab around 4.5 °C in January, and freezing minus temperature in the northern regions. The distribution of precipitation fluctuates on extensive assortments, mostly linked with the winds of monsoon and the winds comings by western turbulences, but the precipitation does not occur thoroughly entire year (Salma et al., 2012).

Likewise, the northern mountainous region obtained the maximum amount of precipitation in the winter season in the form of rain and snowfall, while in the southern and central part of Pakistan 50- 75% of precipitation occurs during the late summer season (Salma et al., 2012; Luo and Lin, 1999). The total amount of precipitation in all of it's from rainfall and snow cover occurred over entire Pakistan can be separated into the two main seasons, winter and monsoon precipitation. The monsoon precipitations enter the country from the east and the northeast during mid-July to mid-September. During this period northeastern areas of Pakistan also receive a good amount of precipitation. This water comes from the northern region due to snowmelt and monsoon precipitation play a vital role to cover up the needs of agriculture production. Agriculture is primarily weather and climate-dependent, and every zone and season has its cropping system and types according to its eco-friendly environment. The region's most vital fruits and crops are grownups in wintertime in different climatic zones according to its climatic requirement. If there is any irregularity in the normal environmental and climatic condition the region will suffer in the future more severely and there will be also a huge loss to the economy (Iqbal, 2018; Iqbal, 2020; Aslam, 2017).

2.2 Datasets

GLDAS stands for Global Land Data Assimilation System. It's freely available on http://ldas.gsfc.nasa.gov/gldas/. It combines data from satellite and ground observations to provide datasets in spatial resolution (0.25° and 1°). GLDAS is obtained as an extension of the North American region land data management and assimilation systems project (Zhang et al., 2008; Rodell, 2004; Gottschalck, 2005). Ideally, it's a collection of terrestrial energy and water fluxes that systematically combines satellite-based with ground-based data sets. The integrated data sets are then used to parameterize, force, and constrain a set of offline terrestrial surface models, in the directive to produce optimum spectra fields of land surface fluxes. Presently, GLDAS has been applied to developed four LSMs: Mosaic Noah community terrestrial model together with variable infiltration capacity assimilation model. In this category, the GLDAS version NOAH model product characteristics (GLDAS_Noah025) include a monthly based 0.250 × 0.250 resolution capacity, making it suitable for basin-wide applications. Applications and Evaluations of the GLDAS/Noah data systems have been mostly limited to the regions with sufficient data. Exceptionally, few studies have been conducted out to assess influences of different climatic conditions while applying GLDAS/Noah outside North American (Zhou, 2013). This study assesses whether GLDAS/Noah can be a viable data system for the assimilation of temporal and spatial distributions of energy and water fluxes. Therefore, it is important to extensively apply GLDAS/Noah water and energy fluxes to understand the temporal-climatological dynamics. In our study, we used GLDAS/Noah product having a 0.25 ° X 0.25° spatial resolution with the temporal resolution of a month (Rodell, 2004; Gottschalck, 2005).

2.3 Mann Kendall Trend Test

For a long time, time series have been used as a tool to investigate hydro-metrological trends and fluxes. Consequently, several statistical tests have been developed to analyze the significance levels and variances of the trend in a space-time-based study. One of the widely applied nonparametric methods for trends test is the Mann-Kendall trends test method. Mann-Kendall's null hypothesis in the test presumes that input information applied is not only independent but also randomly obtained and ordered. Mann-Kendall's assumption is significant because any positive correlation of the data enhances the occurrence of distinguishing trends even where none existed and conversely. Despite this fact being well known, many types of research seldom address the issue of auto-correlation-ship of data leading to potential bias in the outcome which is not declared. Assuming that two sets of statistical observations are represented as x and y, the rank correlation test are formulated as x = x1, x2... xn and y = y1, y2... yn (Kendall, 1955). The statistic, represented as S is obtained using Eq. (1) as below:

$$S = \sum_{i<j} a_{ij} b_{ij} \tag{1}$$

Whereby

$$a_{ij} = \operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & x_i < x_j \\ 0 & x_i = x_j \\ -1 & x_i > x_j \end{cases} \tag{2}$$

And also, b_{ij} is equally defined for the corresponding observations in the Y values. If applied to the null hypothesis that Y and X are independent and are randomly ordered, then statistic S should normalize for large values of n, with a statistic mean and variance represented by equations (3) and (4):

$$E(S) = 0 \tag{3}$$

$$var(S) = n(n-1)(2n+5)/18 \tag{4}$$

If Y values are replaced with the time sequence of the series- X, that is; 1, 2, 3,… n, then the test can be applied normally as a trend test. Z_c, (variance statistic), is represented as a standard normal distribution. A positive (greater zero) value of Z implies an upward trend and vice-versa. Similarly, α (significance level) is used to test an upward or downward monotonic trend and a two-tailed test. If Z_c is found to be greater than $Z_{\alpha/2}$, then the trend is interpreted to be significant (Eq. 5).

$$Z_C = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad (5)$$

3. RESULTS

3.1 Long-term behavior of climate change over the entire area of Pakistan

This preliminary analysis for this study included computing the man Kandel trend test for visual-spatial map description for the year of 71-years (1948–2017). The mean annual times series anomalies further conclusively address the behavior of surface temperature toward precipitation and runoff over entire Pakistan and its different sub-arid climatic zones Figure 1(a-e). Results show that long-term feedback of increasing temperature tends to enhance surface and subsurface by melting glaciers, despite the continuous decline in precipitation trend. impacts on other climatic factors are more obvious at the regional scale. It should also be noted that the extreme surface runoff to the development of hazardous floods. Hence, carefulness should be taken when understanding the results although it was controlled by temperature increment measurements. To evaluates and identify the uncertainty bases from both decreasing trend of precipitation and increasing runoff requires further efforts. In this study, our main focus was to conclusively address long-term climatic changes in Pakistan. Therefore, the ability of our findings will reproduce observed runoff and these findings should provide vital directions for our following analysis behavior of temperature its impacts on climate in the past and future periods.

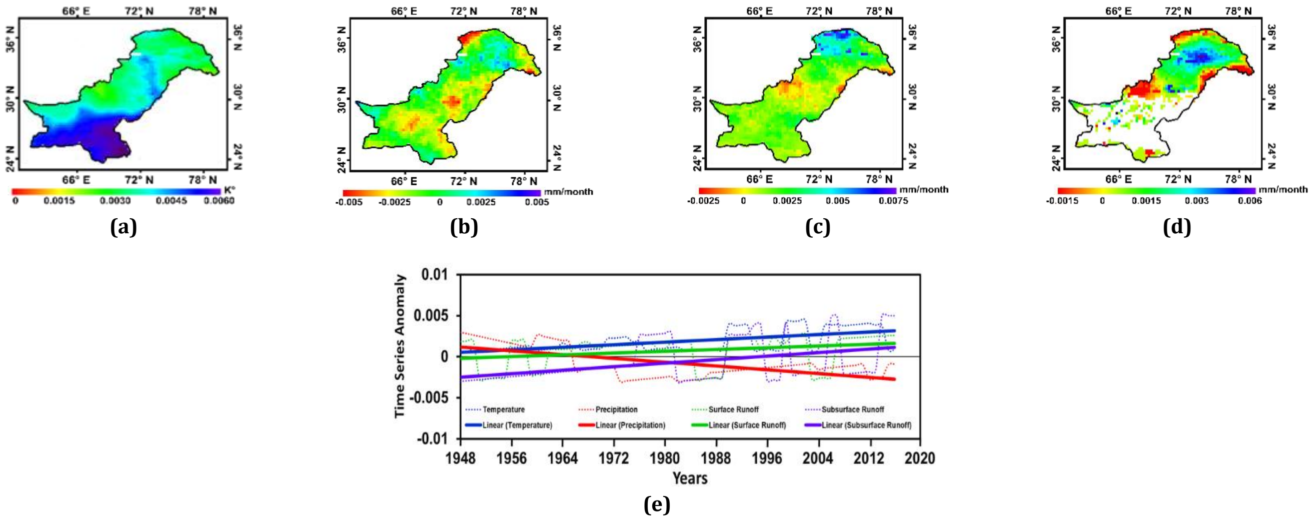

Figure 1: Spatial maps of Mann Kendall trend, (**a**) Temperature, (**b**) Precipitation, (**c**) Surface Runoff, (**d**) Subsurface Runoff, and (**e**) Time series anomalies for the period of 1948-2018 over the entire region of Pakistan.

3.2 Long-term impact of climate change on different climatic zones of Pakistan

3.2.1 Feedback of temperature on precipitation, surface, and subsurface over Arid/Desert/Hot climate

Figure 2(a-e) shows long-term trend and time series anomaly of temperature, precipitation surface, and subsurface runoff over sub climatic zone of arid climate named (arid desert hot climatic zones). Very high increasing temperature trends have positive feedback over the surface and subsurface runoff in hot arid climatic zones, while still declining trends are observed for the case of precipitation over the entire study period. The highest warming was observed in this climatic zone from 1988 through 2018. The highest runoff was also observed in the same period corresponding to the temperature.

3.2.2 *Feedback of temperature on precipitation, surface, and subsurface over Arid/Desert/Cold climate*

Figure 3(a-e) shows long-term trend and time series anomaly of temperature, precipitation surface, and subsurface runoff over sub climatic zone of arid climate named (arid desert cold climatic zones). Increasing temperature trends have positive feedback over the surface and subsurface runoff in cold arid climatic zones, while still declining are observed for precipitation over the entire study period. The highest warming was observed in this climatic zone for the period 1996–2014. The highest runoff trend was also observed in the same period corresponding to the temperature.

3.2.3 Feedback of temperature on precipitation, surface, and subsurface over Arid/Steppe/Hot climate

Figure 4(a-e) shows long-term trend and time series anomaly of temperature, precipitation surface, and subsurface runoff over sub climatic zone of arid climate named (arid desert cold climatic zones). Increasing temperature trends show positive feedback over the surface and subsurface runoff in hot steppe arid climatic zones, while still declining are observed for precipitation over the entire study period. The highest warming was also observed for a similar period as for arid/desert/cold climatic zone for the period 1996–2014. The highest subsurface runoff trend was also observed in the same period corresponding to the temperature.

3.2.4 Feedback of temperature on precipitation, surface, and subsurface over Arid/Steppe/Cold climate

Figure 4(a-e) shows long-term trend maps and time series anomalies of temperature, precipitation surface, and subsurface runoff over sub climatic zone of arid climate named (arid steppe cold climatic zones). Increasing temperature trends show positive feedback over the surface in cold steppe arid climatic zones, while only this climatic zone showed a declining trend for both precipitation and subsurface runoff over the entire study period. The highest warming trend was observed for the period 2000–2002. The highest subsurface runoff trend was also observed in the same period corresponding to the temperature.

4. DISCUSSION

The climate-change historical long-term trend indicated the effect of temperature-increasing surface and subsurface runoff over an entire region of Pakistan. As precipitation shows a decreasing trend which cannot be causes of runoff enhancement. From these finding, we can deduce that the only temperature is the main factor which tends to melt glaciers leading to enhancement of surface and subsurface runoff. Decreasing precipitation trends hint toward severe future water security. Our finding of precipitation trend is very similar to the previous study of who have concluded decline in precipitation trend with increasing temperature trend (Kumar and Jain, 2010). Other findings of some old study using a high-resolution model, had concluded reduced precipitation over the northern area of in the historic and future events (Rajendran and Kitoh, 2008). Another study using a regional climate modeling system concluded the states of growing sulfate aerosols and greenhouse gas concentrations showed a noticeable growth in both precipitation and temperature toward the last decade of this century over the northern area of this region (Kumar et al., 2005; Kumar, 2006).

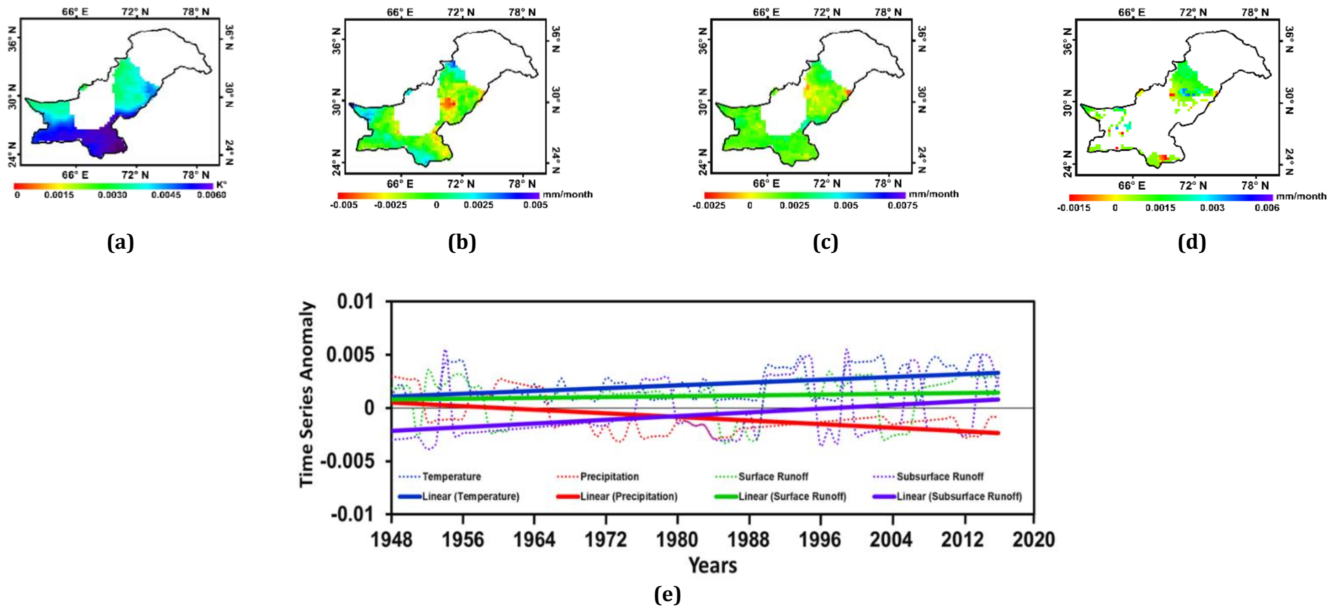

Figure 2: Spatial maps of Mann Kendall trend (**a**) Temperature, (**b**) Precipitation, (**c**) Surface Runoff, (**d**) Subsurface Runoff, and (**e**) Time series anomalies for the period of 1948-2018 over arid/desert/hot climatic zone.

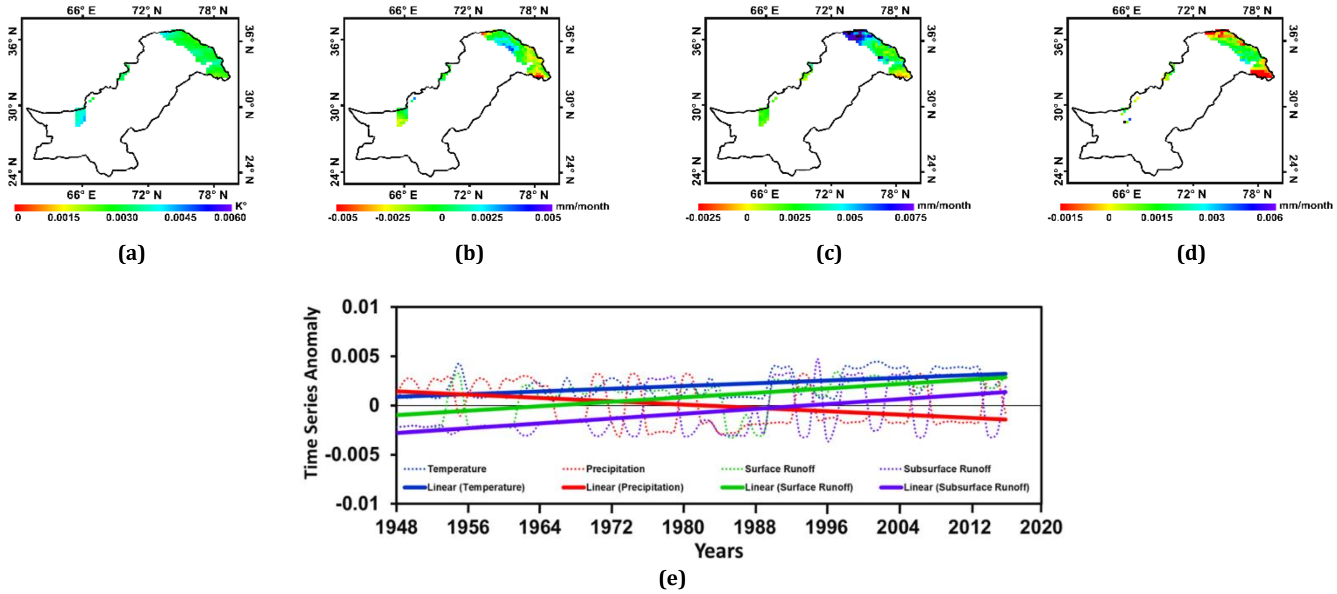

Figure 3: Spatial maps of Mann Kendall trend, (**a**) Temperature, (**b**) Precipitation, (**c**) Surface Runoff, (**d**) Subsurface Runoff, and (**e**) Time series anomalies for the period of 1948-2018 over arid/desert/cold climatic zone.

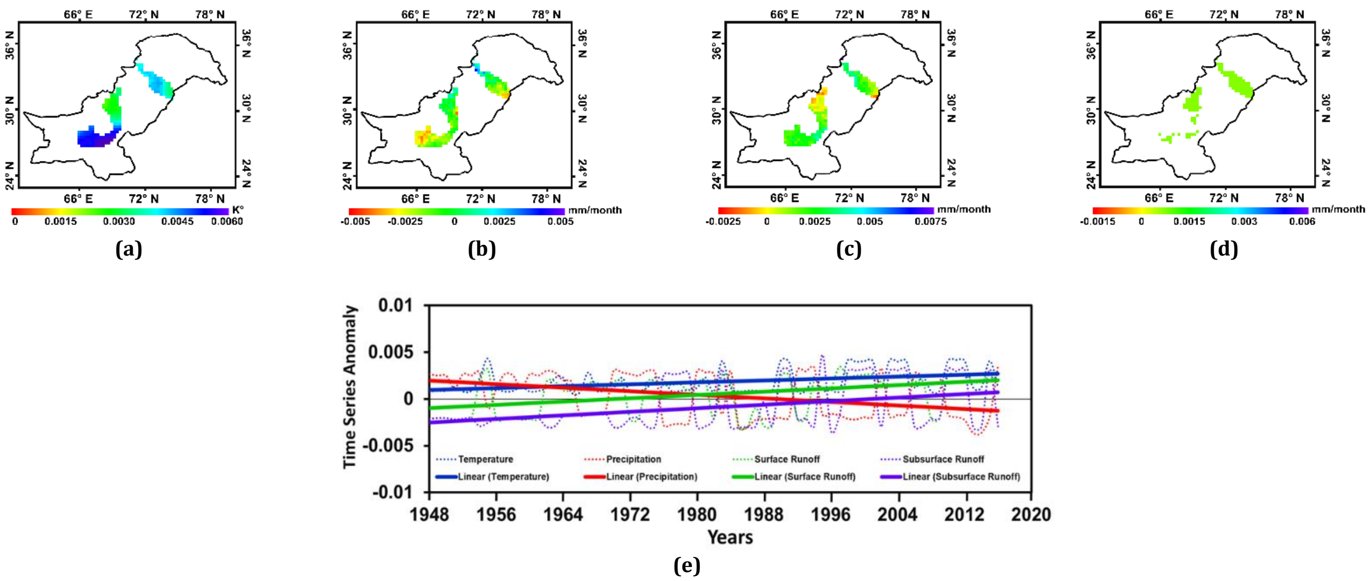

Figure 4: Spatial maps of Mann Kendall trend, (**a**) Temperature, (**b**) Precipitation, (**c**) Surface Runoff, (**d**) Subsurface Runoff, and (**e**) Time series anomalies for the period of 1948-2018 over arid/steppe/hot climatic zone.

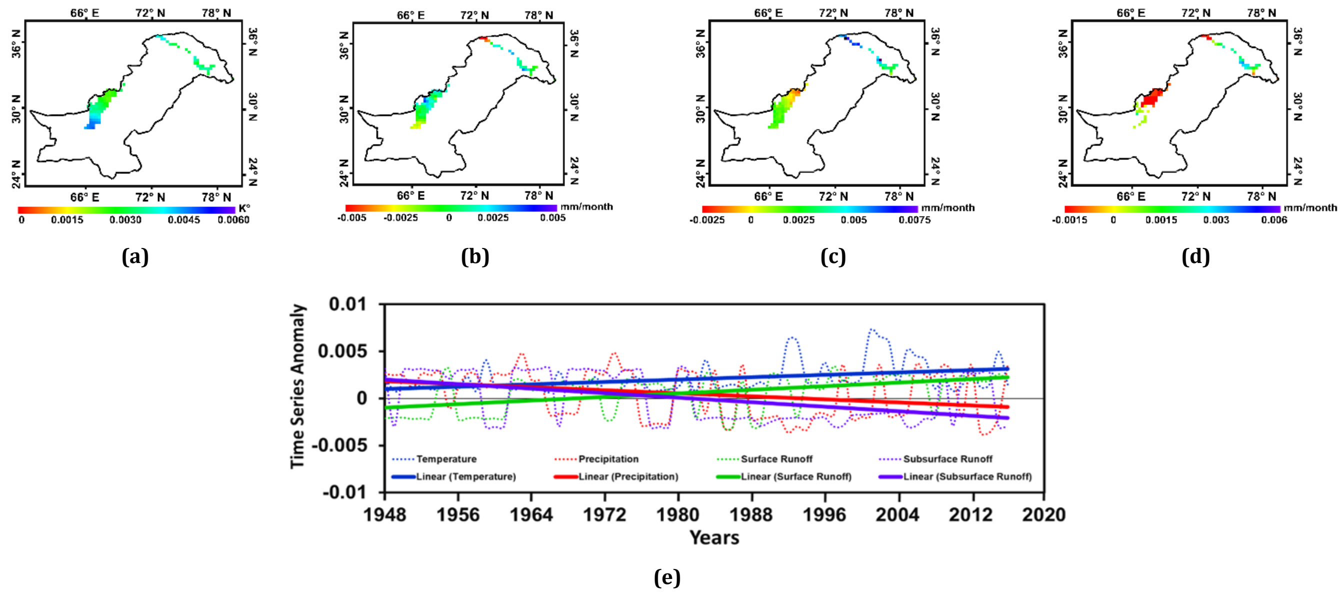

Figure 5: Spatial maps of Mann Kendall trend, (**a**) Temperature, (**b**) Precipitation, (**c**) Surface Runoff, (**d**) Subsurface Runoff, and (**e**) Time series anomalies for the period of 1948-2018 over arid/steppe/cold climatic zone.

From the findings of the above studies, this runoff enhancement is associated with the enhancement of temperature scenarios. A group researchers suggested that, in the northern area, the consequence of variations in surface temperature inclined a linear rise in melting of snow cause increment in surface and subsurface runoff, while runoff due to the melting of the glacier seemed to be contrary wise interrelated to variations in the rainfall (Singh and Kumar, 1997). Another study had also determined that the feedback of surface temperature change is mainly impacted on surface and subsurface runoff in snow-covered regions (Sinha and De, 2003). Despite the questions related to declining precipitation and increasing runoff about the detailed magnitude of future trends of climate-changing and its possible effects, actions must be carried to antedate, avoid or minimalize the causes of climate change and alleviate its worse calamities (Mall, 2006; Waqas, 2021).

4.1 Climate Change Impact on Agriculture

The long-term change in weather portrays the regions in Global climate change worldwide. The weather of a region may define as the daily short-period changes in temperature, wind, and precipitation. The change in weather over a long duration can affect the agriculture of any region in many ways like impact on water productivity of the crop by reducing/increasing the quality and quantity of the crop. The crop growth rates, photosynthesis, and transpiration rates may also change. This leads to a direct impact on food production in that region or globally. The increasing temperature can alter the crop production period resulting decrease in yield. In some areas where the temperature is not suitable to physiological maxima of crops will immediately reduce the yield. Plant physiology can influence by the change in atmospheric Drivers of climate change. The negative impact of climate change on agriculture and food production has been projected as a threat to world food security and hence, requires special agricultural strategies to mitigate the negative impact.

Global warming is the outcome of climate change, the world is facing the impact of climate change in sense of increasing temperature. The globally preliminary factor of climate is causing more difficulties in the agriculture sector and food production. The climatic variable venture the type of crops to be grown and the pattern of vegetation in a country/region. The culturing of insects and pests is directly related to the climate, optimum limits of atmospheric temperature, and humidity which can outbreak the different types of crop diseases bring about by global warming especially change in perspiration patterns ultimately maximizing the food security of a country. The overall impact on food security will be relating to the adaptation of climatic measures and capacity to crumble the consequences without disturbing the global environment. To minimize the impact of climate hazardous in agriculture required biodiversity and smart management for water and land resources.

The different scenarios of climate change foremost centered on the presence of a higher concentration of CO_2 in the atmosphere, temperature, and change in precipitation arrays. Global warming is affecting the environment of the plant, soil, and irrigation methods resulting in an effect on yield and water use efficiency. The frequency of agricultural inputs like the use of herbicides, insecticides, and fertilizer is changing. The soil erosion, drainage leaching of nitrogen is also changing and leading to alteration the food production and agriculture productivity.

4.2 Global Warming Impact on Irrigation methods

The innovative irrigation technologies in agriculture can root a credible positive effect on food security and also save water resources of an area, country abut also at the global level. Adaption of smart irrigation methods hastily affects the climate. The unnecessary evaporation and absorption of solar radiation in the atmosphere combined with the greenhouse effect are the basic agricultural indicators of global warming. The irrigating field causes the humidity in the atmosphere by increasing water vapors from the surface which results in decreasing the temperature near to surface which transmits impact to the higher temperature in the atmosphere. The presence of water vapor may affect convection, formation of clouds, and occurring of precipitation. Similarly, the atmospheric temperature can affect the mixing ratio of water vapor, convection, cloud formation, and precipitation, etc.

Moreover, globally it can change the precipitation pattern and duration of seasons of a region or area. This concluded that by the advection process of water vapors climate variables of the remote area can also be altered. The soil moisture flux is directly affected by irrigation. The studies showed that the frequency of irrigation applications reduces temperature, increases cooling via latent heat flux and sensible heat flux, increases humidity and precipitation. Climate change will distress the irrigation water demand of cops via changes in crop physiology and phenology, soil water balances, evapotranspiration, and operative precipitation. As agriculture is the core sector of water use in Pakistan, assessment of the irrigation water demand in the varying environment is indispensable for long-term water resources development and planning.

5. Conclusions

This research is mainly focused on the distinctive behavior of surface temperature on the precipitation, storm surface, and sub-surface runoff on different climate classes over the mainland of Pakistan, for a period of 71 years, from 1948–2018. Here, we used monthly based two sets of GLDAS (Global Data Assimilation System) datasets i.e. GLDAS-2.0 (1948-2010) and GLDAS-2.1(2011-2018) having a spatial resolution of 0.25°×0.25° for surface temperature, precipitation, surface, and subsurface runoff. While, for regional-based climatic classification, the Koppen Grignard climate classification map was used. Most of the area of Pakistan is located in the main arid climatic zone according to Koppen Grignard climate classifications. We divided the main arid climatic zone into further sub arid climatic zones arid/desert/hot climate, arid/desert/cold climate, arid/steppe/hot climate and arid/steppe/cold climate. The spatial-temporal trend of all the involving parameters has been estimated using Mann-Kendall's trend test. Long-term variation in precipitation, surface temperature, and runoff fluctuations have been detected in entire and sub-arid climatic regions using average annual time series anomalies.

Our study provides an investigates of long-term historical trends of surface temperature, precipitation, surface, and subsurface runoff. Our outcomes conclude that temperature is the main climatic variable affecting the surface and subsurface runoff in Pakistan because of its direct impact on the melting glacier. However, the temperature impact on the subsurface runoff growth/decline is negligible in some areas of Pakistan. Our results also indicated the strongest positive correlations between temperature and surface runoff, while significant negative correlation among surface temperature and precipitation. So, our conclusions deduced only through the relationship between the surface temperature and runoff should be examined with a more detailed analysis considering the other climate factors from different historic simulated and ground-based data sources in future studies.

ACKNOWLEDGMENTS

The Director-General Agriculture (Water Management), Punjab, Lahore, and Director, Water Management Training Institute, Punjab Lahore have regularly supervised the implementation of this research and provided valuable guidance advice for smooth implementation of the research activities. Their contribution is gratefully acknowledged.

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