INT. J. BIOL. BIOTECH., 18 (3): 485-497, 2021.

VARIATION IN CLIMATOLOGICAL REGIMES IN COASTAL-RURAL DISTRICTS OF SINDH, PAKISTAN

Syeda Urooj Fatima[1], Moazzam Ali Khan[1*], Mariam Khan[1], Nadeem Mahmood[2] and Nasir Sulman[3]

[1]*Institute of Environmental Studies, University of Karachi, Karachi-75270, Pakistan*
[2] *Department of Computer Science, University of Karachi, Karachi-75270, Pakistan*
[3] *Dean Faculty of Education, University of Karachi, Karachi-75270, Pakistan*
**Corresponding author:*moazzam@uok.edu.pk

Emails: uroojfatima987@yahoo.com;moazzam@uok.edu.pk;mariam.kkhan@outlook.com;nmahmood@uok.edu.pk and nsalman@uok.edu.pk

ABSTRACT

Sindh Coastal and Rural Districts(CRDs) including Thatta, Sujawal and Badin arehighly vulnerable due to multifaceted impacts of climate change which has become a major challenge. This study deals with the statistical time series analysis of mean annual maximum temperature (T_{MAMax}), minimum temperature (T_{MAMin}) and precipitation (P_{MA}) during 1961 to 2017 (57 years), and relative humidity (RH_{MA}) and wind speed (WS_{MA}) during 1961 to 2008 (48 years) using Mann-Kendall's Trend Model (MKTM) and Sen's Slope Estimator (SSE). The resultsshowed that T_{MAMax} and T_{MAMin} are significantly increased across all the CRDs; whereas, P_{MA} is significantly declined. RH_{MA} and WS_{MA} are significantly decreased in Thatta and Sujawaland increased in Badin, while only increase in RH_{MA} remained significant in Badin. The major finding of this study is that the gap between the T_{MAMax} and T_{MAMin} is narrowing since the annual increase in $T_{MAMin}$is greater than annual increase in T_{MAMax}. Therefore, it can be concluded that the T_{MAMin} may replace the T_{MAMax} in the region in coming years, while T_{MAMax} is expected to be further escalated than its upper limit. The analysis further reveals that variation inclimatological regimes is at extreme in the region.

Keywords: Climate change, Precipitation, Relative humidity, Temperature, Time series analysis, Wind speed

INTRODUCTION

Over centuries and particularly after the Industrial Revolution, Earth's climate has changed (Kitoh, 2020).Currently, the indicators and impacts of climate change on human lives are being widely studiedgloballyas an emerging research discipline (Fleming, 2020).The Earth's temperature due to human activities has reached approximately 1°C greater than pre-industrial levels andit is further rising at a rate of 0.2°C/decade (IPCC, 2018). IPCC (2018) alsopredicted that the global surface temperature is projected to increase by 1.4°C to 5.8°C from 1990 to 2100. In terms of precipitation, the trend has also changed globally. Dry areas have become drier and wet areas are now getting more precipitation (Trenberth, 2011). Specifically, to South Asia, the surface air temperature has been risen up to 2.9°C; and in Pakistan, the annual temperature rise is 3°C (Farooqi*et al.*, 2005; Zahid and Rasul, 2010). Similarly, as a result of asymmetrical precipitation patterns, spatially varied monsoon seasons and abrupt floods have resulted in South Asia and Pakistan, particularly in Sindh (Abbas *et al*,. 2017).

Climate is a major controlling factor for all socioeconomic activities in any region. Comprising versatile topographic features and vast geographical area, climatological regimes in Pakistan highly fluctuate from the Northern to Southern extremes. Besides this, the agriculture-based economy makes it more vulnerable to these climatological changes (Rasul*et al.*, 2012). Pakistan has been ranked as 5th atGlobal Climate Risk Index since 1999 to 2018 (Eckstein *et al.*, 2019). This increasing trend of climate vulnerability is a significant threat for the population of Coastal-Rural Districts (CRDs) ofSindhwhich has been stricken by poverty and is totally dependent on inadequately available natural resources for their livelihood. Consequent to the changes in the temperature (Zahid*et al.*, 2017; Khan *et al.*, 2019a) and precipitation trends (Salma *et al.*, 2012; Ahmed *et al.*, 2017; Iqbal *et al.*, 2019; Gadiwala and Bruke, 2019), the floods (Mirza, 2011; Houze*et al.*, 2011; Lau and Kim, 2012; Martius*et al.*, 2013; Sayed and González, 2014; Nie*et al.*, 2016; van der Schrier*et al.*, 2018; Mahessar*et al.*, 2019),droughts (Ahmed *et al.*, 2018; Siddiqui and Safi, 2019) and heatwaves (Rauf*et al.*, 2017; Saeed *et al.*, 2017; Nasim*et al.*, 2018; Khan *et al.*, 2019b) have been extensively reported in the CRDsof Pakistan. Currently, the frequency of these extreme events has been increased than before (Malik *et al.*, 2012). Asian Development Bank (ADB, 2010) reported that a single flood incident in the CRDs ofSindh caused severe economic constraintsof about US$10 billion, particularly in the agriculture sector.

Since Thatta, Sujawal and Badin are highly climate change vulnerable CRDs, temperature and precipitation patterns have been generally altered in these areas (Alamgir*et al.*, 2015;Salik*et al.*, 2015; Alamgir*et al.*, 2016). Time series analysis of temperature and precipitation using Mann-Kendall'sTrend Model (MKTM) and Sen's Slope Estimator (SSE) has been widely carried out across Pakistan (Table 1) including entire Indus River Basin (Hartmann and Buchanan, 2014; Krakauer *et al.*, 2019), Upper Indus River Basin (Archer and Fowler, 2004; Khattak *et al.*, 2011; Ahmad *et al.*, 2015; Rahman and Dawood, 2017; Latif*et al.*, 2018; Iqbal *et al.*, 2019; Latif *et al.*, 2019), Middle Indus River Basin (Ahmad *et al.*, 2014), Lower Indus River Basin (Ahmad *et al.*, 2014; Abbas *et al.*, 2017) and specifically to Sindh (Samo *et al.*, 2017) and Punjab (Abbas, 2013; Abbas *et al.*, 2013; Hussain *et al.*, 2015; Khattakand Ali, 2015; Jahangir *et al.*, 2016). However, studies reporting the trends of relative humidity and wind speed in CRDs of Sindh are not available.Therefore, the objective of this study includes the time series analysis of past and recent changes in the climatological regimes in the CRDs of Sindh, Pakistan. For this purpose, MKTM and SSE are applied in this study for an elongated period of timeseriesinorderto interpret Man-Kendall's Trend (MKT) and Sen's Slope Magnitude (SSM) for major climatological parameters.

METHODOLOGY

The Study Area

The study area comprises three CRDsof Sindh; Thatta, Sujawal and Badin,locatedat theLowerIndus River Basin (Fig. 1). General climatological and physiographical conditions of the study area are represented in Table 2.District Thatta comprises 4 sub-districts (Ghorabari, KetiBunder, MirpurSakro and Thatta), Sujawal comprises 5 sub-districts (Jati, MirpurBathoro, Shah Bunder, Kharochan, and Sujawal), and Badin comprises 5 sub-districts (Golarchi, Badin, Matli, Talhar and TandoBago) according to the recent administrative boundary divisions.The population of Thatta, Sujawal and Badin is 979, 817, 781, 967 and 1, 804, 516, respectively (PBS, 2017). In terms of socioeconomic conditions, all three CRDs are well known as *poverty-stricken* areas (OPHI 2015, 2019). Since more than 50% of the population lives in rural areas (DSS 2017), the major source for their livelihood is agriculture.

Data Sets and Meteorological Stations

The data for five climatological parameters;mean annual maximum temperature (T_{MAMax}), mean annual minimum temperature (T_{MAMin}),mean annual precipitation (P_{MA}), mean annual relative humidity (RH_{MA}) and mean annual wind speed(WS_{MA}) were obtained from two meteorological stations of Pakistan Meteorological Department (PMD). For T_{MAMax}, T_{MAMin} and P_{MA}, the data collected for 57 years (1961-2017); and for RH_{MA} and WS_{MA}, the data was only available for 48 years (1961-2008). For Badin, the dataweretaken from PMD's M eteorologicalObser-vatory (MO) located in the district; however, there is no MO present in Thatta and Sujawal (Alamgir *et al.*, 2015). Therefore, the data taken from the nearest PMD's MO, located in Karachi. This MO is selected on the basis of similar climatological conditions and proximity. Moreover, although separated after the census of 2017, Thatta and Sujawal are considered as a single district in this study since there is no separate data available for the selected time intervals.

Trend Analysis

The obtained data for T_{MAMax}, T_{MAMin}, P_{MA}, RH_{MA} and WS_{MA} from the selected stations were considered for the evaluation of two different time series statistical analysis, using MKTM and SSE. The analysis was done using Add-in-soft XLSTAT software (2018v.5) to calculate MKT and SSM.

Mann-Kendall'sTrendModel (MKTM)

MKTM is a non-parametric test which is used to calculate time series trendand is subjected to have a monotonic trend. This model was basically designed by Mann (1945) and Kendall (1975). MKTM represents the continuously increasing or decreasing trends in mathematical terms. To calculate the Mann-Kendall's Trend (MKT) for the climatological parametersof the CRDs of Sindh, following hypothesis were set prior to the trend analysis: (i) *Null Hypothesis (H_o):* There is no increasing or decreasing trend in the climatological regimes of the CRDs over 57 years (1961-2017) or 48 years (1961-2008), and (ii) *Alternative Hypothesis (H_1):* There is a significant increasing or decreasing trend in the climatological regimes of the CRDs over 57 years (1961-2017)or 48 years (1961-2008). During the course of the two-tailed hypothesis testing, confidence interval of 95% ($\alpha = 0.05$) is used. Using MKTM, two types of statistics can be applied for MKT analysis; S-Stats and Z-Stats.

- S-Stats:

S-stats is done when number of observations is less than 10. The following equation represents theMKTM S-Stats:

$$\mathbf{S} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathbf{Sign}\ (\mathbf{x_j} - \mathbf{x_i})$$

where, x_i and x_j = annual values in *i* and *j* years, *j* is greater than *i*; and *n*= total data points

$\boldsymbol{Sign}\ (\boldsymbol{x_j} - \boldsymbol{x_i})$ can be calculated as follows:

$$\mathbf{Sign}\left(\mathbf{x_j} - \mathbf{x_i}\right) = \begin{cases} \mathbf{1} & \text{if } \mathbf{x_j} - \mathbf{x_i} > \mathbf{0} \\ \mathbf{0} & \text{if } \mathbf{x_j} - \mathbf{x_i} = \mathbf{0} \\ \mathbf{-1} & \text{if } \mathbf{x_j} - \mathbf{x_i} < \mathbf{0} \end{cases}$$

Negative and positive value of S indicates the increasing or decreasing trend. S can be asymptomatically normally distributed asVar (S):

$$\boldsymbol{E(s) = 0}$$

$$\mathbf{Var(S)} = \left\{\mathbf{n(n-1)(2n+5)} - \sum_{i=1}^{n} \mathbf{t_i(t_i-1)(2t_i+5)}\right\}\frac{\mathbf{1}}{\mathbf{18}}$$

where, n = number of groups; and t_i= total points in the group

- *Z-Stats*

However, when the number of observations is greater than 10, a standard normal random variable, Z-Stats, is used using following equation:

$$\mathbf{Z} = \begin{cases} \dfrac{\mathbf{S-1}}{\sqrt{\mathbf{Var(S)}}} & \text{if } \mathbf{S} > 0 \\ \mathbf{0} & \text{if } \mathbf{S} = 0 \\ \dfrac{\mathbf{S+1}}{\sqrt{\mathbf{Var(S)}}} & \text{if } \mathbf{S} < 0 \end{cases}$$

Sen's Slope Estimator (SSE)

- *Q-Stats*

SSE is used to calculate the Sen's Slope Magnitude (SSM), i.e., change per unit time (Sen 1968). The following equation is used for SSM estimation and represented as Q-Stats (Q):

$$\mathbf{Q} = \frac{\mathbf{x_j - x_k}}{\mathbf{j - k}}$$

fori = 1, 2, 3, ...n

where, x_j and x_k data values at time *j* and *k*, *j*>*k*

Using this equation, interpretation can be done as the trend is increasing (upward) when SSM (Q)is positiveand the trend is decreasing (downward) if thevalue of SSM (Q) is negative.

RESULTS AND DISCUSSION

Mann-Kendall's Trend Model (MKTM) and Sen's Slope Estimator (SSE) were used to detect the changes in the climatological regimes (T_{MAMax}, T_{MAMin}, P_{MA}, RH_{MA} and WS_{MA}) in the CRDs of Sindh, Pakistan, over periods of 57 years (1990-2017) and 48 years (1961-2008). The statistics of MKTM and SSM are illustrated in Table 3. For each CRD, trends of SSM for the climatological regimes of CRDs are displayed in Fig. 3. The graphical representation of Z-stats and Q-stats is given in Fig. 4 and 5, respectively. The results are interpreted on the basis that if the *p*-value is less than the significance level (α = 0.05),then the null hypothesis (H_o) is accepted. This indicates that there is no significant increasing or decreasing trend exists. On the other hand, greater *p*-values than the significance level (α = 0.05) indicates that the null hypothesis (H_o) is rejected and alternate hypothesis (H_1) is accepted and results are statistically significant.

Temperature

Maximum Temperature (T_{MAMax})

Statistical results for MKT analysis (Table 3) show that among CRDs, T_{MAMax} has significantly increased in Thattaand Sujawalduring 1961-2017 (57 years); however, non-significant increasing trend is observed in

Badin.Overall, the SSM shows that all selected CRDs have positive increasing trends of T_{MAMax} (Fig. 3a,b). Positive values of Z-Stats and Q-stats by graphical representation further shows that the trend of T_{MAMax} is significant in CRDs and are increasing upward (Fig. 4a,b and 5a,b). In contrast to this, no significant increasing or decreasing trendwas observed in Badin during relatively shorter time period of 40 years, from 1971 to 2010 (Ahmad *et al.*, 2014); while among the other districts located in the Lower Indus River Basin, including Hyderabad, Jacobabad and Kanpur, significant increasing trends of T_{MAMax} were observedduringthe same 40 years' time interval (Ahmad *et al.*, 2014).Interestingly, the trend of hot days and their frequency index has linearly increased in Badin during 1980 - 2015, and it is statistically significant. It is also predicted that the frequency of hot days and nightsin Badin are also expected to rise at a rate of 1.20 daysand 1.12 nights per decade, respectively (Abbas *et al.*, 2017).

Table 1. A review of the studies conducted to assess climatological regimes in Pakistan using MKTM and SSE.

Author	**Meteorological Variables**	**Time Period**	**Study Area**	**No. of Meteorological Stations**
Krakauer *et al.*, 2019	Precipitation	35 years (1980 - 2014)	Entire Indus River Basin	35
Hartmann and Buchanan 2014	Precipitation	30 years (1979 - 2011)	Entire Indus River Basin	-
Ahmad *et el.*, 2015	Precipitation	51 years (1961 - 2011)	Swat River Basin, KPK (Upper Indus River Basin)	15
Archer and Fowler 2004	Precipitation	varies from station to station	Upper Indus River Basin	17
Iqbal *et al.*, 2019	Precipitation	57 years (1951 - 2007)	Sub-Himalayan region (Upper Indus River Basin)	4
Khattak*et al.*, 2011	Temperature and Precipitation	39 years (1967 - 2005)	Upper Indus River Basin	20
Latif *et al.*, 2018	Precipitation	53 years (1961 - 2013)	Hindu Kush Himalaya, KPK (Upper Indus River Basin)	15
Latif *et al.*, 2019	Temperature	53 years (1961 - 2013)	Hindu Kush Himalaya, KPK (Upper Indus River Basin)	20
Rahman and Dawood, 2017	Temperature	varies from station to station	Hindu Kush Himalaya, KPK (Upper Indus River Basin)	7
Ahmad *et al.*, 2014	Temperature and Precipitation	40 years (1971 - 2010)	Middle and Lower Indus River Basin	12
Abbas *et al.*, 2017	Temperature and Precipitation	36 years (1980 - 2015)	Indus Delta (Lower Indus River Basin)	4
Samo*et al.*, 2017	Temperature and Precipitation	19 years (1996 - 2014)	ShaheedBenazirabad, Sindh	1
Abbas, 2013	Temperature	30 years (1981 - 2010)	Across Punjab	5
Abbas *et al.*, 2013	Precipitation	30 years (1981 - 2010)	Across Punjab	5
Hussain *et al.*, 2015	Precipitation	37 years (1977 - 2013)	Chakwal, Punjab	1
Jahangir *et al.*, 2016	Temperature	35 years (1979 - 2013)	Across Punjab	8
Khattak *et al.*, 2015	Temperature and Precipitation	54 years (1961 - 2014)	Across Punjab	8

Table 2. Physiographical and Climatological Conditions of CRDs.

Parameters	**Thatta-Sujawal**[c]	**Badin**
Elevation from sea level (m)	11.27-17	9.7
Geographical area (km^2)	17,355	6,726
Latitude (N, DMS)	24°44'50" to 24°36'23"	24°39'20"
Longitude (E, DMS)	67°55'24" to 68°04'19"	68°50'14"
Mean Precipitation[a] (mm)	0.0-713.0 (169)	0.0-913.9 (183.74)
Maximum Temperature[a] (°C)	30.9-34.8 (32.23)	32.3-37.5 (33.84)
Minimum Temperature[a] (°C)	19.6-28.0 (21.70)	18.8-27.8 (21.05)
Mean Relative Humidity[b] (%)	45.5-58.3 (50.61)	33.6-45.7 (39.86)
Mean Wind Speed[b] (knots)	5.7-9.1 (7.59)	1.9-10.1 (6.62)
General Climate	Moderate climate (arid to semi-arid)	Mild climate (moist and humid)

[a]Mean annual precipitation and temperature during 1961-2017, based on the average of processed data collected from PMD
[b]Mean annual relative humidity and wind speed during 1961-2008, based on the average of processed data collected from PMD
[c]Thatta-Sujawal are recognized as separate districts after 2017 census, therefore the available data for the selected time period are same.

Table 3. Results of MKT and SSM of T_{MAMax}, T_{MAMin}, P_{MA}, RH_{MA} and WS_{MA} inThatta-Sujawaland Badin.

Variable	Time Series	District	MKT	S	Var(S)	p-value (Two-tailed)	SSM	Interpretation	Results
T_{MAMax}	1961-2017	Thatta-Sujawal	0.584	913	20986.3	< **0.0001**	0.030	H_1 accepted	Increased, Significant
	1961-2017	Badin	0.098	157	21101.6	0.280	0.016	H_o accepted	Increased, Not Significant
T_{MAMin}	1961-2017	Thatta-Sujawal	0.621	975	21025.6	< **0.0001**	0.063	H_1 accepted	Increased,Significant
	1961-2017	Badin	0.622	972	20994.0	< **0.0001**	0.048	H_1 accepted	Increased,Significant
P_{MA}	1961-2017	Thatta-Sujawal	-0.318	-508	21102.6	**0.000**	-3.624	H_1 accepted	Decreased,Significant
	1961-2017	Badin	-0.200	-319	21101.6	**0.028**	-2.577	H_1 accepted	Decreased,Significant
RH_{MA}	1961-2008	Thatta-Sujawal	-0.521	-585	12649.0	< **0.0001**	-0.188	H_1 accepted	Decreased,Significant
	1961-2008	Badin	0.199	224	12652.7	**0.046**	0.077	H_1 accepted	Increased,Significant
WS_{MA}	1961-2008	Thatta-Sujawal	-0.219	-244	12626.0	**0.030**	-0.021	H_1 accepted	Decreased,Significant
	1961-2008	Badin	0.038	43	12640.0	0.702	0.007	H_o accepted	Increased,Not Significant

Bold face figures: Significant at $p < 0.05$, confidence interval of 95% ($\alpha = 0.05$)

Minimum Temperature (T_{MAMin})

Alarming results for the MKT are observed for T_{MAMin}in all the selected CRDs of Sindh (Table 3). The results show that in all years, the T_{MAMin}has increased at highly significant values in Thatta-Sujawal and Badin during 1961-2017 (57 years). The SSM shows that strongly positive increasing trends are observed in T_{MAMin}across the CRDs of Sindh (Fig. 3 c,d). Positive values of Z-Stats and Q-stats further confirm that the trend of $T_{MAMin}$is significant in CRDs and the temperature is increasing upward (Fig. 4 c,d and 5 c,d).

The Narrowing Gap between T_{MAMax} and T_{MAMin}

Pakistan is geographically located in a fast temperature rising zone (Khan *et al.*, 2019a), which contributes to increase its temperature relatively greater than the world's average (Rasul *et al.*, 2012). The repercussions of increasing temperature have been recorded all over the country (Krakauer *et al.*, 2019). This study has analyzed one of the major anomalies of the increasing temperature "*the narrowing gap between T_{MAMax} and T_{MAMin}*", which have observed in the CRDs of Sindh. The overall trend of $T_{MAMax}$and$T_{MAMin}$of Thatta-Sujawal and Badin during 57 years' time period (1961-2017) shows that the gap between the maximum and minimumextremes of the temperature, is getting closer (Fig. 2). Due to this, the summers are getting hotter and the frequency of hot days is also increasing rapidly (Abbas *et al.*, 2017). Such trends also indicate that an increase in the rate of T_{MAMin}/year is greater than the increase in T_{MAMax}/year. Thus, the CRDs of Pakistan, being located in a warmer country than the global average, are likely to get more warming with elongated summers. This abrupt upward shift in the T_{MAMin}has potential to replace the T_{MAMax}. Furthermore, T_{MAMax} may dramatically rise to an additional increase in the upper limit of it. Heatwaves and hot spells in the CRDs in the recent past decade (Rauf *et al.*, 2017; Saeed *et al.*, 2017; Nasim *et al.*, 2018; Khan *et al.*, 2019b) are true evidences for such changes in T_{MAMax} and T_{MAMin} trend.

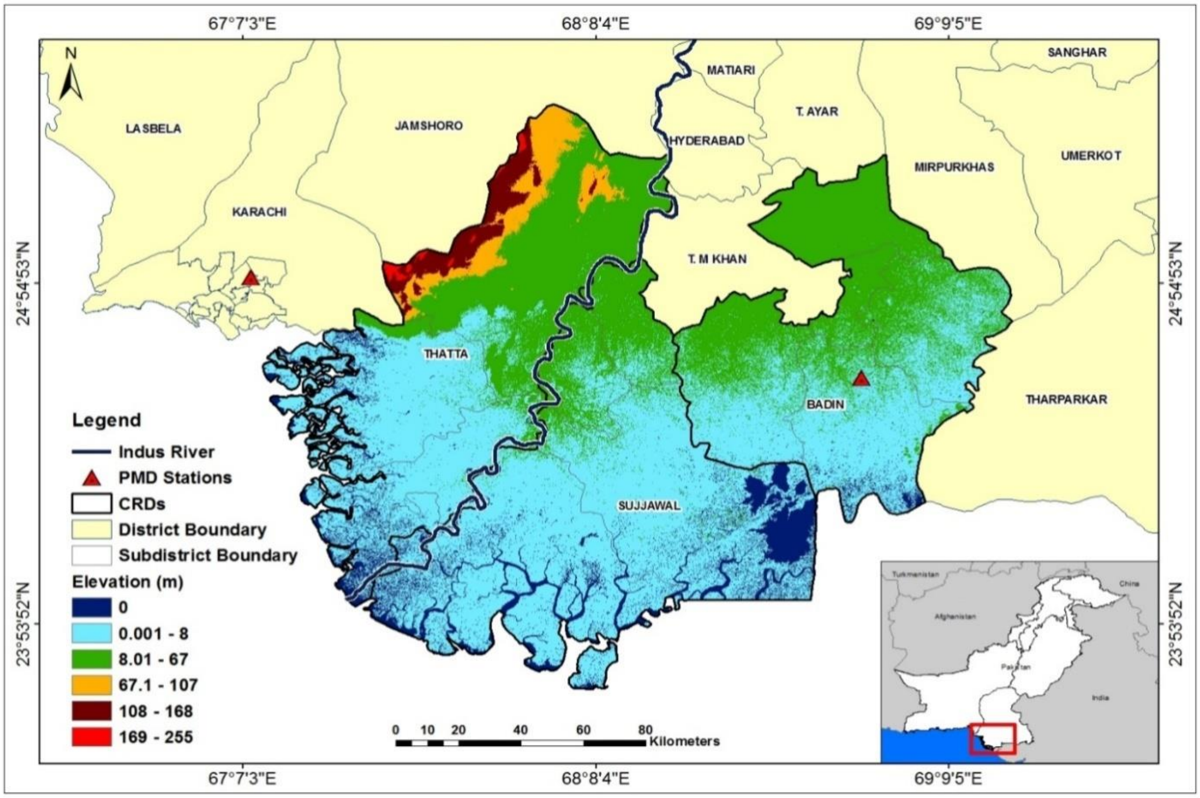

Fig. 1.Location of the study area.

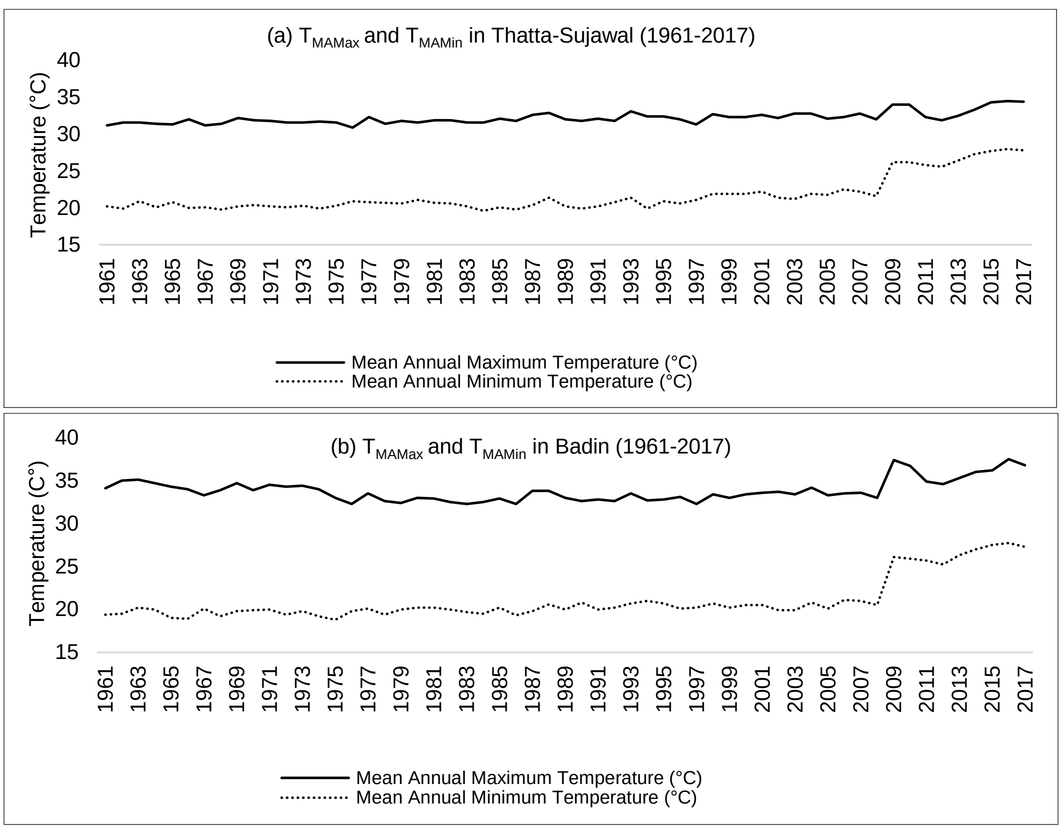

Fig.2. The Narrowing Gap between T_{MAMax}andT_{MAMin}in (a) Thatta-Sujawal and (b) Badin.

Precipitation (P_{MA})

Mean annual precipitation(P_{MA}) showed significant decreasing trends across the CRDs of Sindhduring 1961-2017 (57 years). The results of MKT (Table 3) depict that, the trend is highly significant and an overall decline in the annual precipitation amount can be clearly observed in the region.Although the overall pattern of P_{MA} is highly irregular throughout the analyzed study period i.e., 1961-2017 (57 years), the SSM has shown a sharp negative decrease in the P_{MA} across CRDs of Sindh (Fig. 3 e,f).Negative values of Z-Stats and Q-stats also show that the trend of P_{MA} is significant in CRDs and the precipitation is decreasing at an alarming rate (Fig.4 e,f and 5 e,f). Moreover, Badin has been facing severe droughts and dry spells due to uneven rainfall distribution across the region. Due to irregular precipitation patterns, only 5 years during 1980 to 1990, 3 years during 1991 to 1999 and 2 years during 2000 to 2008 had observed with having precipitation more than 200mm; while during 1996 to 2003, severe drought prevailed across the CRDs of Sindh (Alamgir *et al.*, 2015).Since CRDs are largely dependent on agriculture for their livelihood, their crops production has severely affected due to less rainfall and drought spells. Being a swampy place, Badin is a major producer of rice. Due to the limited amount of precipitation, the yield of rice is declined in the district which has affected the economic status for the poor farmers of CRDs (Abbas *et al.*, 2017).

Relative Humidity (RH_{MA})

Statistical results of MKT for RH_{MA} for Thatta-Sujawal and Badin during 1961-2008 (48 years) shows that the trend is statistically significant (Table 3) and the negative and positive trend of SSM shows that RH_{MA} has decreased in Thatta-Sujawal and increased in Badin(Fig. 3 g,h). Negative values of Z-Stats and Q-stats are observed in Thatta-Sujawal which show that the trend of RH_{MA} is significantly decreasing in the area. However, opposite trends, i.e., positive values of Z-Stats and Q-stats, are observed in Badin depicts that RH_{MA} is significantly increased (Fig. 4 g,h and 5 g,h).

Wind Speed (WS_{MA})

During 1961-2008 (48 years), a significant MKT for $WS_{MA}$is observed in Thatta-Sujawal, while the MKT for Badin is not significant(Table 3). Further, the SSM indicates that in Thatta-Sujawal, WS_{MA} has significantly declined in the area. In contrast to this, opposite results are observed in Badin, i.e., WS_{MA} is increased in the area but the results are not significant (Fig. 3 i,j). Except February, overall negative values of Z-Stats and Q-stats are observed in Thatta-Sujawal which show that the trend of WS_{MA} is significant in CRDs and the WS_{MA} is decreasing in the area. However, opposite trends, i.e., positive values of Z-Stats and Q-stats, are observed in Badin depicts that WS_{MA} is overall significantly increased with the exception of March and November (Fig. 4 i,j and 5 i,j).

Socioeconmic impacts of climate change

Climate change unpredictability austerely affecting not only the natural environment but also social environments of the entire Sindh province while the study area has no exception. The local population particularly the coastal communities endure the dispossession of natural resources owing to persistant climate change variations. Climate change has prime affect on agriculture and water resources that limits the livelihhod options. Furthermore, the alterations in the ecosystem services and landscape are also evident in the study area. The crop yield is sharply declined due to high temperature and rainfall changes. High temperature and severe drought is also affecting the natural vegetation of the study area. The small farmers are the worst suffer of climate change events. They are the most porrer segment of the society and have very limited technical capability to cope with climate exterems. Such poor segment of the society either directly suffer from econmic losses or facing food security problems. The climate changes also responsible for the increase in the prices of agricultural commodities that further exacerbate poverty.

The pregannat women and the children are on the verge of risk malnutrition and hunger. Women of the study area are highly insecured with regards to climate change. The main role of the women even today is limted toacquire food, water and energy for daily spending. During the drought periods, women have no option but to to travel long distances to fetchwater. Moroever, in rural setup they are having a low status in the society.

Climate change is putting tremendous pressure on the physical asset base of the area with increased impoverishment of resources that exacerbate poverty and other socieconmic problems. Increasing health issues in the local population is also one of the drirect evidence of climate change. This challenge is emerging with an alarming threat. It has been noticed that the children below 5 years of age are suffering from malnutrition and stunted growth. The study area has very limited health care facilties and those which are available are in deplorable condition. Most of the diseases that predominanatlyoocurs includes gastrointestinal tract and skin diseases whichimmedtaely evident after the wet spell following prolonged dry period. Cardiopulmonry diseases are also evident due to extreme temperatures.

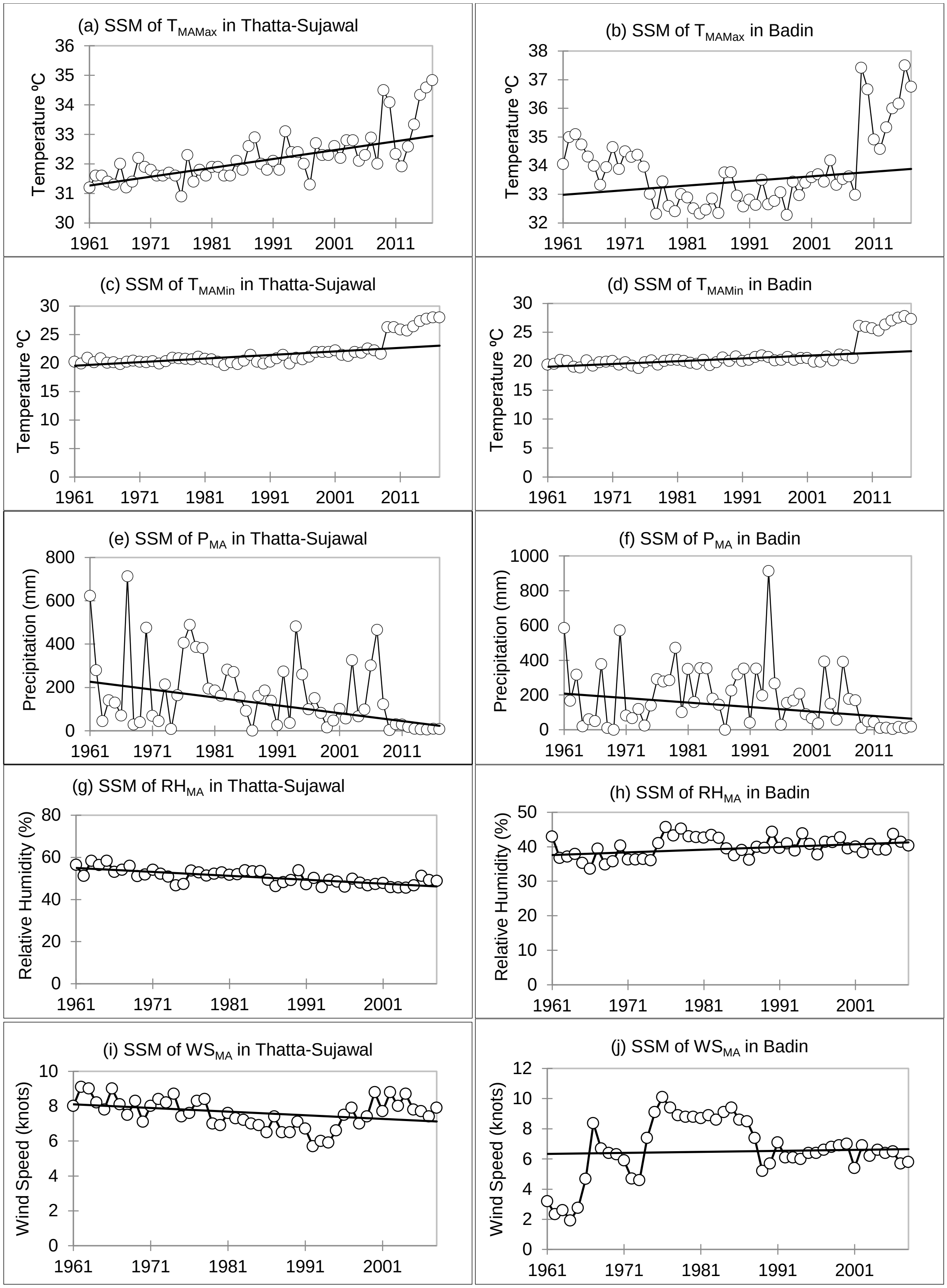

Fig. 3. Sen's Slope Magnitude (SSM) in CRDs of Sindh: (a) T_{MAMax} in Thatta-Sujawal; (b) T_{MAMax} in Badin; (c) T_{MAMin} in Thatta-Sujawal; (d) T_{MAMin} in Badin; (e) P_{MA} in Thatta-Sujawal; (f) P_{MA} in Badin; (g) RH_{MA} in Thatta-Sujawal; (h) RH_{MA} in Badin; (i) WS_{MA} in Thatta-Sujawal and (j) WS_{MA} in Badin.

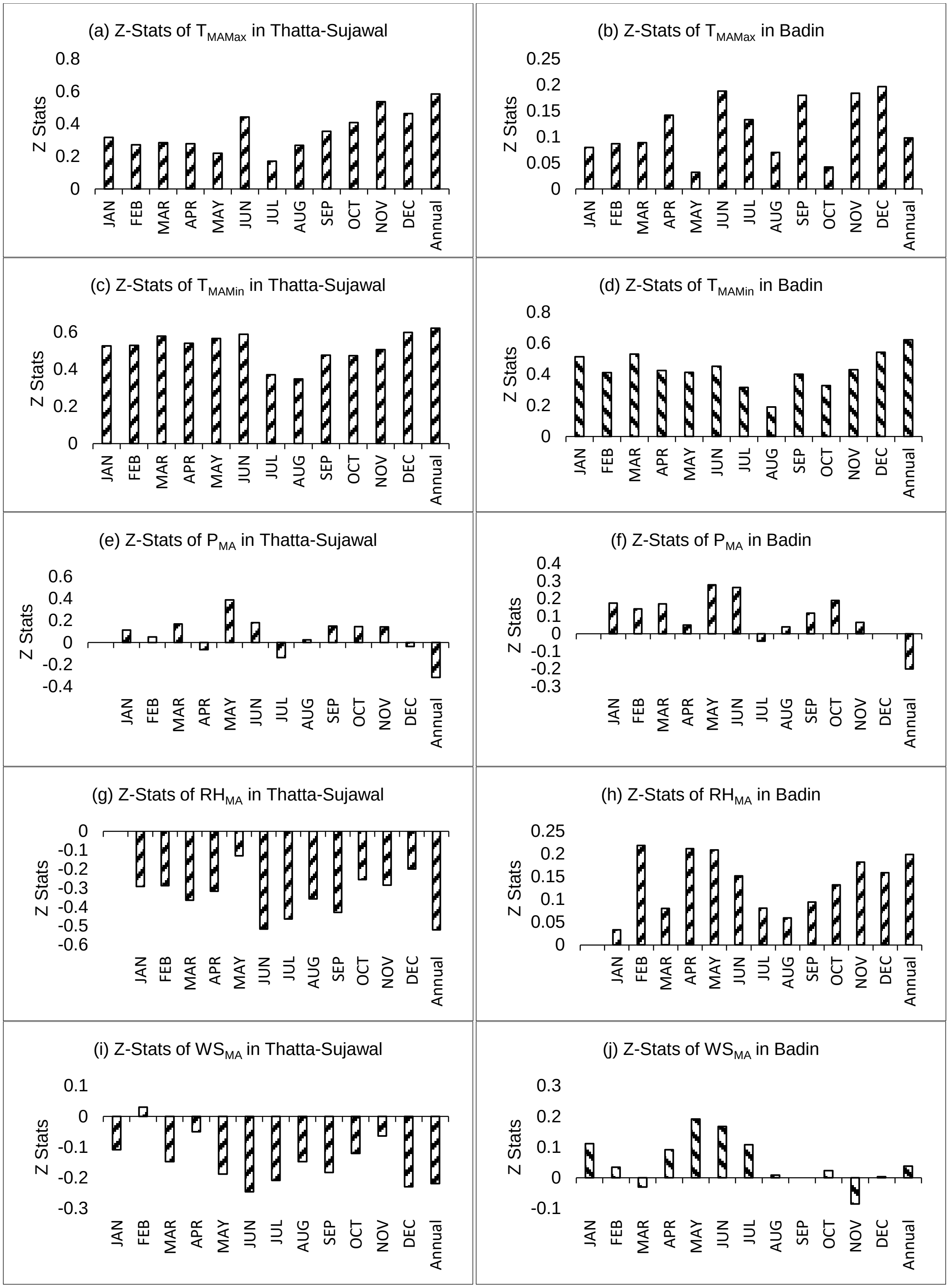

Fig. 4. Z-Stats of (a) T_{MAMax} in Thatta-Sujawal; (b) T_{MAMax} in Badin; (c) T_{MAMin} in Thatta-Sujawal; (d) T_{MAMin} in Badin; (e) P_{MA} in Thatta-Sujawal; (f) P_{MA} in Badin; (g) RH_{MA} in Thatta-Sujawal; (h) RH_{MA} in Badin; (i) WS_{MA} in Thatta-Sujawal; and (j) WS_{MA} in Badin.

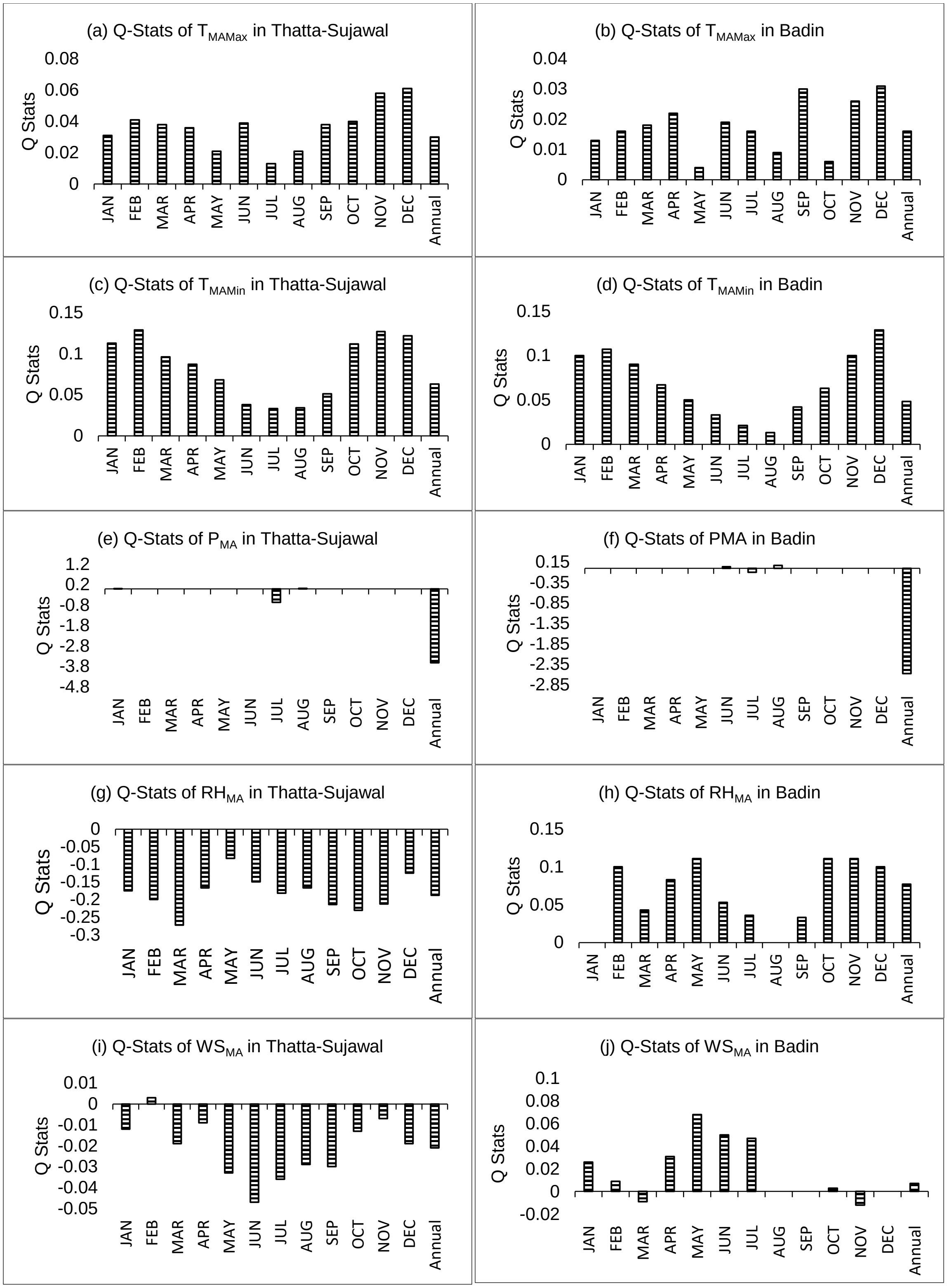

Fig. 5. Q-Stats of (a) T_{MAMax} in Thatta-Sujawal; (b) T_{MAMax} in Badin; (c) T_{MAMin} in Thatta-Sujawal; (d) T_{MAMin} in Badin; (e) P_{MA} in Thatta-Sujawal; (f) P_{MA} in Badin; (g) RH_{MA} in Thatta-Sujawal; (h) RH_{MA} in Badin; (i) WS_{MA} in Thatta-Sujawal; and (j) WS_{MA} in Badin.

In poverty stricken area the diertry habits of the people are changed. Instead of having three mels per days most of the families are now having two meals. Children drop out ratio from the schools is all time higher. The people have changed their professional affiliations. The unskilled people are mostly engaged as cheap labour force in the study area. Since the livelihood options are limted therefore, migration is all time high in the study area. The wooryingisuue is that the coping mechanism and adapatation to climate change is very limited this may be due to the fact that the general polutaion hardly anticipate the worse effects of climate change. The dwindling resources are overwhelmingly vanished due to climate change events.

The economic infrastructure of the study area is already decrepit mainly because of pitiable governance and political instability where the ruling elite capture most if not all resources. In the current weak governance system the ownership of land weaken the community resilience as the land is mostly occupied by bigger landlords and the poor people cannot move against the will and consent of the landlord.

As described above that the research area is resource scarce area where a very limited minority in the name of elite ruling over the masses. This make a state of affairs where only inadequate resources are available for poor and marginalized people. The factors, which are disgustingly affecting the community resilience, are on hand governance system, politicization of technical roles, undefined and uncleared responsibilities of the stakeholders and capturing of resources by ruling elite. These explanation call for a paradigm shift and separate the case of study area with rest of the country. There are strong evidences which can show how conflict sensitive resources are mismanaged.

CONCLUSIONS

The attempted study concludes that the trends of climatological regimes in the CRDs are quite alarming. The statistical analysis using MKTMand SSE revealed that the data collected for T_{MAMax}, T_{MAMin} and P_{MA} shows significant variationduring 57 years (1961-2017). The temperature patterns have shown rising trends; whereas, precipitation seems to be declined across the CRDs. RH_{MA} and WS_{MA} are decreased in Thatta and Sujawal while both are increased in Badin during 48 years (1961-2008). This study concludes that the margin between the mean annual maximum and minimum temperaturecontinues to get narrower which is a highly alarming situation in terms of further temperature rise in the CRDs of Sindh, Pakistan.

The case findings clearly delinates that the community of the study area are suffering badly due to extreme climate change events. The livlihhod options are getting limited while resources are diminishing with an alarming trends. This situation may leads to climate change induced conflicts in the study area. A key possibility to build up community harmony and creating peace opportunities could be through climate change resilience policies such as adaptation policies that prioritize government's development agendas, which spotlight more on the broader governance issue and building capacity of the governance at the grass root level .

ACKNOWLEDGMETS

The author is thankful to Higher Education Commission (HEC) for providing financial support, and also to Pakistan Meteorological Department (PMD) for providing climatological data.

REFERENCES

Abbas, F. (2013). Analysis of a historical (1981–2010) temperature record of the Punjab province of Pakistan. *Earth Interactions*, 17(15): 1-23.

Abbas, F., A. Ahmad, M. Safeeq, S. Ali, F. Saleem, H. Hammad and W. Farhad (2013). Changes in precipitation extremes over arid to semiarid and subhumid Punjab, Pakistan. *Theor Appl Climatol.*, 116(3): 671–680.

Abbas, F., I. Rehman, M. Adrees, M. Ibrahim, F. Saleem, S. Ali and M. Salik (2017). Prevailing trends of climatic extremes across Indus-Delta of Sindh-Pakistan. *Theor Appl Climatol.*, 131(3): 1101-1117.

ADB. (2010). *Pakistan Floods 2010 Damage and Needs Assessment*. Asian Development Bank. Retrieved from https://www.adb.org/projects/documents/pakistan-floods-2010-damage-and-needs-assessment.

Ahmad, I., D. Tang, T. Wang, M. Wang and B. Wagan (2015). Precipitation trends over time using Mann-Kendall and Spearman's Rho tests in Swat River Basin, Pakistan. *Advances in Meteorology, 2015*.

Ahmad, W., A. Fatima, U.K. Awan and A. Anwar (2014). Analysis of long term meteorological trends in the middle and lower Indus Basin of Pakistan—A non-parametric statistical approach. *Global and Planetary Change*, 122: 282-291.

Ahmed, K., S. Shahid, E. -S. Chung, T. Ismail and X. J. Wang (2017). Spatial distribution of secular trends in annual and seasonal precipitation over Pakistan. *Climate Research*, 74(2): 95-107.

Ahmed, K., S. Shahid and N. Nawaz (2018). Impacts of climate variability and change on seasonal drought characteristics of Pakistan. *Atmospheric research,* 214: 364-374.

Alamgir, A., M. A. Khan, I. Manino, S.S. Shaukat and S. Shahab (2016). Vulnerability to climate change of surface water resources of coastal areas of Sindh, Pakistan. *Desalination and Water Treatment,* 57(40): 18668-18678.

Alamgir, A., M.A. Khan, S. S. Shaukat, S. J. Kazmi, S. Qureshi and F. Khanum (2015). Appraisal of Climate Change Impacts on the Coastal Areas of Sindh Using Remote Sensing Techniques. *American-Eurasian J. Agric. and Environ. Sci.,* 16(6): 1102-1112.

Archer, D. R. and H. J. Fowler (2004). Spatial and temporal variations in precipitation in the Upper Indus Basin, global teleconnections and hydrological implications. *Hydrology and Earth System Sciences,* 8(1): 47-61.

DSS. (2017). *Development Statistics of Sindh.*: Sindh Bureau of Statistics, Government of Sindh.

Eckstein, D., V. Künzel, L. Schäfer and M. Winges (2019). *Global Climate Risk Index 2020*. In: Bonn, Germanwatch: GERMANWATCH.

Farooqi, A. B., A.H. Khan and H. Mir (2005). Climate change perspective in Pakistan. *Pakistan Journal of Meteorology,* 2(3): 11-21.

Fleming, R. J. (2020). Future Research on Climate and Energy Issues. In:*The Rise and Fall of the Carbon Dioxide Theory of Climate Change* (pp. 109-125). Cham: Springer.

Gadiwala, M. S. and F. Burke (2019). Climate change and precipitation in Pakistan-A meteorological prospect. *International Journal of Economic and Environmental Geology,* 4(2): 10-15.

Hartmann, H. and H. Buchanan (2014). Trends in extreme precipitation events in the Indus River Basin and flooding in Pakistan. *Atmosphere-Ocean,* 52(1): 77-91.

Houze, R. J., K. Rasmussen, S. Medina, S. Brodzik and U. Romatschke (2011). Anomalous atmospheric events leading to the summer 2010 floods in Pakistan. *Bulletin of the American Meteorological Society,* 92(3): 291-298.

Hussain, F., G. Nabi and M.W. Boota (2015). Rainfall trend analysis by using the Mann-Kendall Test and Sen's Slope Estimates: A case study of district Chakwal rain gauge, Barani Area, Northern Punjab province, Pakistan. *Science International,* 27(4): 3159-3165.

IPCC. (2018). Summary for Policymakers. In: *Global Warming of 1.5°C*. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

Iqbal, Z., S. Shahid, K. Ahmed, T. Ismail and N. Nawaz (2019). Spatial distribution of the trends in precipitation and precipitation extremes in the sub-Himalayan region of Pakistan. *Theoretical and applied climatology,* 137(3): 2755–2769.

Jahangir, M., S.M. AliandB. Khalid(2016). Annual minimum temperature variations in early 21st century in Punjab, Pakistan. *Journal of Atmospheric and Solar-Terrestrial Physics,* 137: 1-9.

Kendall, M. (1975). *Rank Correlation Methods.*: Oxford University Press, USA, London.

Khan, N., S. Shahid, T.Bin-Ismail and X.-J. Wang (2019a). Spatial distribution of unidirectional trends in temperature and temperature extremes in Pakistan. *Theoretical and applied climatology,* 136(3-4): 899-913.

Khan, N., S. Shahid, T Ismail, K. Ahmed and N. Nawaz (2019b). Trends in heat wave related indices in Pakistan. *Stochastic environmental research and risk assessment,* 33(1): 287-302.

Khattak, M. S. and S. Ali (2015). Assessment of temperature and rainfall trends in Punjab province of Pakistan for the period 1961-2014. *Journal of Himalayan Earth Science,* 48(2): 42-61.

Khattak, M. S., M. Babel and M. Sharif (2011). Hydro-meteorological trends in the upper Indus River basin in Pakistan. *Climate Research,* 46(2): 103-119.

Kitoh, A. (2020). Climate Change We Human Are Responsible for. In:*Human Geoscience* (pp. 283-293): Springer.

Krakauer, N. Y., T. Lakhankarand G. H. Dars (2019). Precipitation Trends over the Indus Basin. *Climate,* 7(10): 116.

Latif, Y., M. Yaoming and M. Yaseen (2018). Spatial analysis of precipitation time series over the Upper Indus Basin. *Theoretical and applied climatology,* 131(1-2): 761-775.

Latif, Y., M. Yaoming, M. Yaseen, S, Muhammad and M.A. Wazir (2019). Spatial analysis of temperature time series over the Upper Indus Basin (UIB) Pakistan. *Theoretical and applied climatology,* 139(1): 741-758.

Lau, W. K. and K.. Kim (2012). The 2010 Pakistan flood and Russian heat wave: Teleconnection of hydrometeorological extremes. *Journal of Hydrometeorology,* 13(1): 392-403.

Mahessar, A. A., A.L. Qureshi, I. A. Siming, S. M. Kori, G. H. Dars, M. Channa and A.N. Laghari (2019). Flash flood climatology in the lower region of Southern Sindh. *Engineering, Technology and Applied Science Research,* 9(4): 4474-4479.

Malik, S. M., H. Awan and N. Khan (2012). Mapping vulnerability to climate change and its repercussions on human health in Pakistan. *Globalization and health,* 8(1): 31.
Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the Econometric Society,* 13(3): 245-259.
Martius,O., H. Sodemann, H. Joos, S. Pfahl,A . Winschall, M. Croci-Maspoli, M. Graf, E. Madonna, B. Mueller, S. Schemm, J. Sedl´a cek, M. Sprenger and H. Wernli (2013). The role of upper-level dynamics and surface processes for the Pakistan flood of July 2010. *Quarterly Journal of the Royal Meteorological Society,* 139(676): 1780-1797.
Mirza, M. M. Q. (2011). Climate change, flooding in South Asia and implications. *Regional environmental change,* 11(1): 95-107.
Nasim, W., A. Amin, S. Fahad, M. Awais, N. Khan, M. Mubeen, A. Wahid, V. Turan, M.H. Ihsan, S. Ahmad, S. Hussain, I.A. Mian, B. Khan and Y. Jamal (2018). Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan. *Atmospheric research,* 205: 118-133.
Nie, J., D.A. Shaevitz and A.H. Sobel (2016). Forcings and feedbacks on convection in the 2010 Pakistan flood: Modeling extreme precipitation with interactive large-scale ascent. *Journal of Advances in Modeling Earth Systems,* 8(3): 1055-1072.
OPHI. (2015). *Multidimensional Poverty in Pakistan. Oxford Poverty and Human Development Initiative.* Retrieved from https://www.ophi.org.uk/wp-content/uploads/Multidimensional-Poverty-in-Pakistan.pdf
OPHI. (2019). *Global MPI Country Briefing 2019: Pakistan (South Asia). Oxford Poverty and Human Development Initiative*.
PBS. (2017). *Province Wise Provincial Results of Census, 2017.* Pakistan Bureau of Statistics, Government of Pakistan.
Rahman, A.andM. Dawood (2017). Spatio-statistical analysis of temperature fluctuation using Mann–Kendall and Sen’s slope approach. *Climate dynamics,* 48(3-4): 783-797.
Rasul, G., A. Mahmood, A. Sadiq and S. Khan (2012). Vulnerability of the Indus delta to climate change in Pakistan. *Pakistan Journal of Meteorology,* 8(16): 89-107.
Rauf, S., K. Bakhsh, A. Abbas, S. Hassan, A. Ali and H. Kächele (2017). How hard they hit? Perception, adaptation and public health implications of heat waves in urban and peri-urban Pakistan. *Environmental Science and Pollution Research,* 24(11): 10630-10639.
Saeed, F., M. Almazroui, N. Islam and M.S. Khan (2017). Intensification of future heat waves in Pakistan: a study using CORDEX regional climate models ensemble. *Natural Hazards,* 87(3): 1635-1647.
Salik, K. M., S. Jahangir, W.Z. Zahdi and S. Hasson (2015). Climate change vulnerability and adaptation options for the coastal communities of Pakistan. *Ocean and Coastal Management,* 112: 61-73.
Salma, S., S. Rehman and M. Shah (2012). Rainfall trends in different climate zones of Pakistan. *Pakistan Journal of Meteorology,* 9(17): 37-47.
Samo, S. R., N. Bhatti, A. Saand, M. A. Keerio and D.K. Bangwar (2017). Temporal analysis of temperature and precipitation trends in Shaheed Benazir Abad Sindh, Pakistan. *Engineering, Technology and Applied Science Research,* 7(6): 2171-2176.
Sayed, S. A. and P.A. González (2014). Flood disaster profile of Pakistan: A review. *Science Journal of Public Health,* 2(3): 144-149.
Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's Tau. *Journal of the American statistical association,* 63(324): 1379-1389.
Siddiqui, S. and M. W. A. Safi (2019). Assessing the Socio-Economic and Environmental Impacts of 2014 Drought in District Tharparkar, Sindh-Pakistan. *International Journal of Economic and Environmental Geology,* 8(4): 8-15.
Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate Research,* 47(1): 123-138.
van der Schrier, G., L. Rasmijn, J. Barkmeijer, A. SterlandW. Hazeleger(2018). The 2010 Pakistan floods in a future climate. *Climatic change,* 148(1): 205-218.
Zahid, M., R. Blender, V. Lucarini and M.C. Bramati (2017). Return levels of temperature extremes in southern Pakistan. *Earth System Dynamics,* 8(4): 1263-1278.
Zahid, M. and G. Rasul (2010). Rise in summer heat index over Pakistan. *Pakistan Journal of Meteorology,* 6(12): 85-96.

(*Accepted for publication June 2021*)