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A Study of Decadal December Temperature Variability in Pakistan

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Abstract

The spatial distribution of December temperature in Pakistan has been assessed by statistical method based on mean monthly data from 51 ground stations. The analysis is performed at decadal scale over the period of 1950-2000. December is one of the representative months of winter season in Pakistan, the country with subtropical location and complex rugged terrains, plateaus and plains. The results support a slight rising temperature trend in December. However, this change in temperature varies from region to region as well as from decade to decade and reflects a complicated spatial-temporal structure of temperature anomalies. The assessment shows that the temperature anomalies in different national territories at local scale do not follow the assumption that winter months are warming in northern hemisphere. Both the isothermal shift and temperature anomalies confirm that the mountainous areas of Pakistan face more temperature variability than plains.

Keywords

Temperature Anomaly, December, Pakistan, Decadal Scale, Spatial Distribution

1. Introduction

The true essence of climate change is hard to be understood without the temperature analysis at different temporal and spatial scales. Pakistan faces extreme weather events like drought, floods and heat waves [1]-[4]. The variability of temperature over complex rugged terrains remains great attraction for searchers in climate change sciences e.g. [5] [6] and surface air temperature is the most important climate element that helps understanding

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of climate variability [7]. In the current national scenario, economic development is not sustainable in the agro-based developing society of Pakistan without understanding of climate change and its impacts on agriculture [8]-[10] where the faster growing population already has faced meteorological hazards [11] [12]. The monthly diagnostic of temperature variability is instrumental in future climate policy [13]-[16]. More than half of the total area of Pakistan is dominated by rugged mountains including Hindukush Karakoram Himalayas (HKH). The Himalayas were already declared sensitive area in term of high glacial ablation by Working Group II in the Asian Chapter of IPCC [17].

This paper is focused on the analysis of December temperature variability with emphasis on spatial distribution and its regional detail in Pakistan. Most of climatic studies are supported by "time series figures of temperature", while rarer studies map the anomalies and also neglect the spatial distribution of the observations. In this paper, we mapped the isotherms through which we learned about the shifts of average temperature at regional scale and recognized their anomalies by simulating temperature coefficient at decadal scale.

2. Data and Methods

The monthly temperature data of surface air temperature were obtained from Pakistan Meteorological Department (PMD). The 51 stations (**Figure 1**, **Table 1**) were selected from all over the country. The mean monthly data of December temperature were analyzed separately for each decade from 1950s to 2000s.

The isothermal maps (**Figure 2**) for each decade were prepared to check the shift of average temperatures. The distribution of spatial anomalies is shown with the help of maps (**Figure 3**) that configure the spatial distribution of temperature coefficient. This simulation is instrumental in understanding the temperature variability in different parts of the country.

The following technique was adopted to calculate the temperature coefficient trend,
$\hat{x}_i = a + bt_i \quad (i = 1, 2, \cdots, n)$.

The above relation establishes linear regression between, the time series t_i and variable x_i (temperature) for the specified period.

By taking into account t_i as independent and x_i dependent variable, regression coefficient "b" and the regression constant "a" of least-squares estimation have been calculated, respectively by using the following principle.

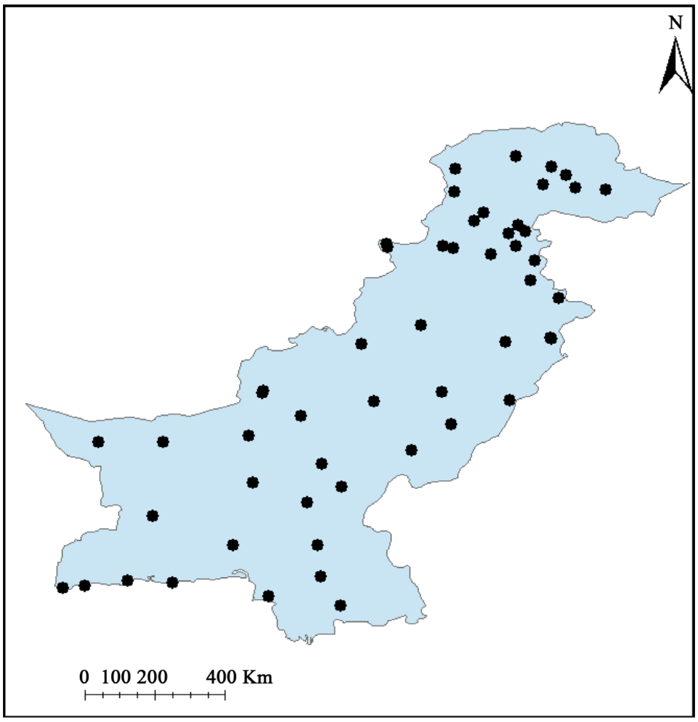

Figure 1. The geographical distribution of the meteorological stations utilized in the study.

Table 1. The 51 stations data were utilized in the analysis that almost covers the whole national territories.

Serial No.	Stations	Latitude	Longitude	Region
1	Astor	35°20'	74°54'	Gilgit-Baltistan
2	Badin	24°38'	68°54'	Sindh
3	Bahawal Nagar	29°57'	73°51'	Punjab
4	Bahawal Pur	29°24'	71°47'	Punjab
5	Balakot	34°23'	73°21'	KPK
6	Bar Khan	29°53'	69°43'	Balcohistan
7	Bunji	35°67'	74°63'	Gilgit-Baltistan
8	Cherat	33°49'	71°53'	KPK
9	Chhor	25°31'	69°47'	Sindh
10	Chilas	35°25'	74°06'	Gilgit-Baltistan
11	Chitral	35°51'	71°50'	KPK
12	Dalbandin	28°53'	64°24'	Balochistan
13	Dera Ismail Khan	31°55'	70°52'	KPK
14	Dir	35°12'	71°51'	KPK
15	Drosh	35°34'	71°47'	KPK
16	Faisalabad	31°26'	73°08'	Punjab
17	Garhi Dupatta	34°13'	73°37	AJK
18	Gilgit	35°55'	74°20'	Gilgit-Baltistan
19	Hyderabad	25°23'	68°25'	Sindh
20	Islamabad	33°43'	73°05'	Punjab
21	Jacobabad	28°18'	68°28'	Sindh
22	Jhang	31°27'	73°32'	Punjab
23	Jiwani	25°04'	61°48'	Balochistan
24	Kakul	34°11'	73°15'	KPK
25	Kalat	29°02'	66°35'	Balochistan
26	Karachi	24°54'	66°56	Sindh
27	Khanpur	28°39'	70°41'	Punjab
28	Kohat	33°57'	71°43'	KPK
29	Kotli	33°31'	73°54'	Sindh
30	Lahore	31°35'	74°24'	Punjab
31	Larkana	27°32'	68°14'	Sindh
32	Mianwali	32°55'	71°52'	Punjab
33	Multan	30°12'	71°26'	Punjab
34	Murree	33°55'	73°23'	Punjab
35	Muzaffarabad	34°22'	73°29'	AJK
36	Nawabshah	26°15'	68°22'	Sindh
37	Ormara	25°12'	64°40'	Balochistan
38	Padidan	26°51'	68°08'	Sindh
39	Panjgur	26°58'	64°06'	Balochistan

Continued

40	Parachinar	33˚52'	70˚05'	FATA
41	Pasni	25˚16'	63˚29'	Balochistan
42	Peshawar	34˚01	71˚35	KPK
43	Quetta	30˚05'	66˚57'	Balochistan
44	Risalpur	71˚98'	34˚07'	KPK
45	Rohri	27˚40'	68˚54'	Sindh
46	Saidu Sharif	34˚44'	72˚33'	KPK
47	Sarghoda	32˚05'	72˚67'	Punjab
48	Sialkot	32˚31'	74˚32'	Punjab
49	Sibbi	29˚33'	67˚53'	Balochistan
50	Skardu	35˚18'	75˚41'	Gilgit-Baltistan
51	Zhob	31˚21'	69˚28'	Balochistan

$$\begin{cases} b = \dfrac{\sum_{i=1}^{n} x_i t_i - \dfrac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} t_i\right)}{\sum_{i=1}^{n} t_i^2 - \dfrac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2} \\ a = \dfrac{1}{n}\sum_{i=1}^{n} x_i - \dfrac{b}{n}\sum_{i=1}^{n} t_i \end{cases}$$

3. Results and Discussion

Based on results **Figure 2** and **Figure 3** show the geography of average temperature marked by isotherms and observed decadal temperature anomalies marked by temperature coefficient respectively. The comparison of various decades configures that the isotherms were shifted from decade to decade. It means spatial temperature changes were there in the study area. Therefore, the temperature anomalies (ΔT) mark these changes by statistical significance.

Pakistan have variety of temperatures from south (north) to north (south) and east (west) to west (east) in December. The reason for this obvious difference in temperature in the same month is latitudinal extent and landforms. Obviously, the temperature divides Pakistan into parts of high and low temperatures in Indus Plains and north/western rugged parts respectively. The said reasons are (were) only true for the distribution of average temperatures in normal atmospheric condition but the distribution of spatial anomalies was quite complex and varied from area to area. The comparison of various decades is evident of the isothermal shift for a selected temperature (e.g. 15˚C or 12˚C or any other isotherm), it means temperature change occurs at local scale in the study period. It has been observed that where the isotherms were closely spaced the temperature anomalies were more obvious and vice versa. This mostly happened in mountains and confirmed that rugged lofty portions of the country were more susceptible to temperature variability.

3.1. The Decade of 1950s

Reference to **Figure 2(a)** the temperature above 18˚C prevailed over southern coastal area, while the northern most areas showed the average temperature below 0˚C. The comparison of 1950s (**Figure 2(a)**) and 1960s (**Figure 2(b)**) shows that the 12˚C isotherms has been moved down towards east in Federally Administered Tribal Areas (FATA) and the belt of temperature which was over the mountains in 1950s was shifted to the piedmonts in 1960s. The shift of isotherms is clear indication that there was change in average temperature in Pakistan at local scale in various decades.

Reference to **Figure 3(a)** most of Balochistan shows temperature in the ranges below average ($\Delta T \le -1.5$ & −2) except Kalat and Khuzdar region where the temperature is above average with the temperature coefficient range of $0.0 \le \Delta T \le 0.5$ & 1 (above average), ΔT represents temperature change. In most parts of the Indus

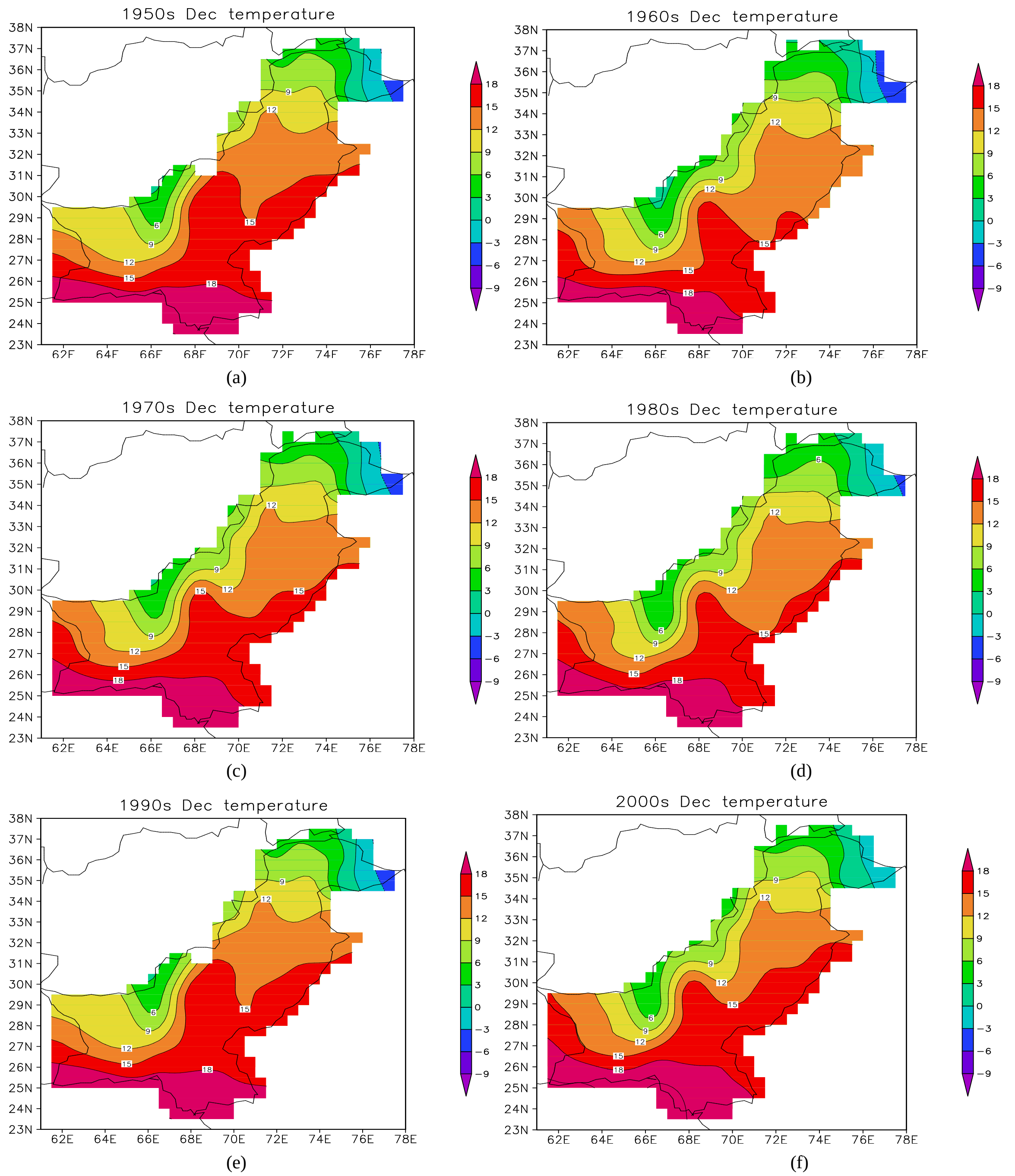

Figure 2. (a)-(f): The spatial distribution of average temperatures of December their shift in various decades in Pakistan over the decades of 1950s to 2000s.

plains (in both Punjab and Sindh) and Khyber-Pakhtoonkhwa (KPK), the observed anomalies were $0.0 \le \Delta T < 0.5$. Nevertheless, Bahawalpur region, FATA, southeastern parts of Sindh falls with in the anomalous temperature coefficient of $0.5 < \Delta T \le 1.0$. The Potwar Plateau reflects slight cooling tendency acknowledged by $-0.5 \le \Delta T < 0.0$.

3.2. The Decade of 1960s

The area in Indus plains between the isotherms of 15˚C and 12˚C is wider (**Figure 2(b)**) than in case of 1950s

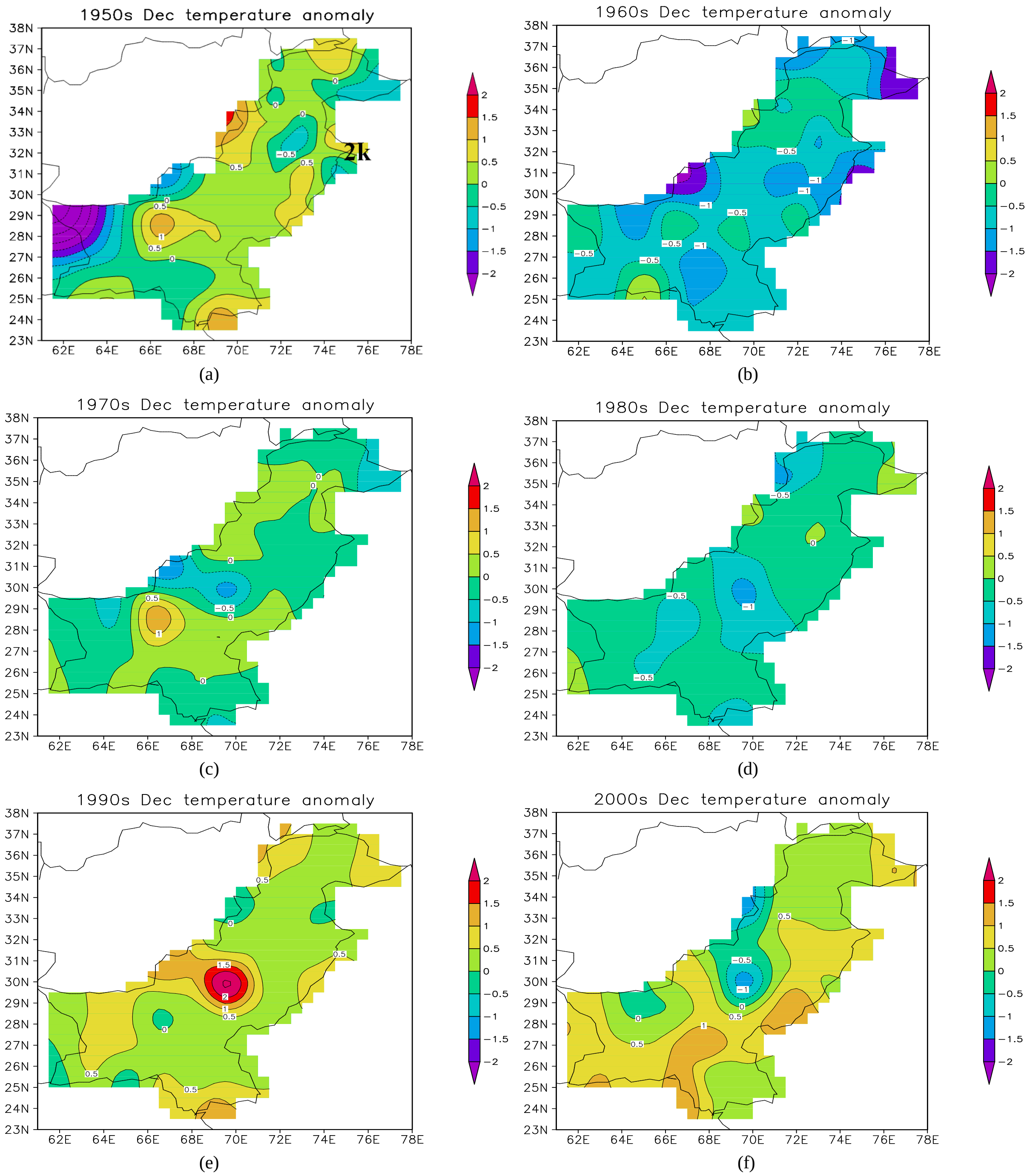

Figure 3. (a)-(f): The spatial distribution of December temperature coefficient in the decades of 1950s to 2000s, the figure depicts the temperature variability at local scale in Pakistan.

(**Figure 2(a)**) the same is true for Balochistan also while the area between 18˚C and 15˚C is wider in Sindh in 1950s than in case of 1960s, this confirms the changes in average temperatures at local levels.

Now consider the temperature anomalies (**Figure 3(b)**) most of Pakistan was under cooling temperatures $(-1.0 \le \Delta T < -0.5)$ including most of Sindh, Punjab, Azad Kashmir and Balochistan except the Gawadar area. Most of KPK and FATA were characterized by slight negative coefficient signatures $(-0.5 \le \Delta T < 0.0)$ except its upper parts in Hindukush Mountains. In the extreme northeast of the country in HKH mountains temperature was found below average $(-1.0 \le \Delta T < -0.5)$. The Quetta valley and surroundings experienced temperature

$(-2 \le \Delta T < -1.0)$ well below reference point in 1960s, that belt of temperature change extends up to Noshki region close to Pak-Afghan border.

3.3. The Decade of 1970s

The comparison between 1960s and 1970s acknowledged that in 1970s (**Figure 2(c)**), the isotherm of 18˚C has been pushed northward and the same is true for 15˚C isotherm also. The 12˚C, 9˚C, 6˚C, 3˚C and 0˚C isotherms also recorded up slope shift in the mountains. It confers the warming condition especially in rugged parts during the decade of 1970s.

In the decade of 1970s (**Figure 3(c)**), many parts of the country like KPK, FATA, Jammu & Azad Kashmir (AJK), lower Indus Plains in southern Punjab and upper Sindh experienced temperature change above average acknowledged by $0.0 \le \Delta T < 0.5$. The highest warming $(0.5 \le \Delta T < 1.0)$ of the decade in December was found in Kalat and Surroundings. The KKH, upper Indus Plains, southwestern Balochistan and southern Sindh were dominated by temperature change below average with confidence level of $-0.5 \le \Delta T < 0.0$. The Quetta Valley and surrounding were found with $-1.5 \le \Delta T < -0.5$ anomalous temperatures and noticed to be the coolest area of the decade.

3.4. The Decade of 1980s

The coastal areas reflected variation of temperature averages almost in all decades, here one thing can not be ignored that is the impact of changes in sea surface temperature (SST) of Arabian Sea [18]. The 12˚C isotherm has climbed slightly up slopes in piedmonts areas (**Figure 2(d)**). However, the spacing of isothermal lines is more or less analogous in 1970s and 1980s.

The 1980s (**Figure 3(d)**) registered no obvious warming surface temperatures and most of the country was dominated by $-0.5 \le \Delta T < 0.0$ that shows temperature slightly below average. The Chitral in KPK and an elongated patch from Mastung-Kalat area to Makran Hills in Balochistan experienced temperature decrease $(-1.0 \le \Delta T < -0.5)$ and the temperature was obviously low than their surrounding territories. The only temperature change of the decade with coefficient value below −1 was registered in Sulaiman Ranges.

3.5. The Decade of 1990s

The comparison of 1980s (**Figure 2(d)**) and 1990s (**Figure 2(e)**) supports that a northward as well as northwestward shift of isotherms has occurred in 1990s. The northward shift was not only true for mountains but also obvious in plains and piedmonts which is clear indication of warming. Both the isothermal shift and temperature anomalies confirmed that the mountainous areas of Pakistan face more temperature changes (warming) than plains.

The temperature anomaly in 1990s (**Figure 3(e)**) was not as uniform over the country as in the decade of 1980s. Abrupt temperature changes were noticed in 1990s where almost all Pakistan was dominated by warming condition. The Sulaiman Ranges and surrounding was below average in 1980s but in 1990s opposite situation persisted with obvious warming tendency $(2 \le \Delta T < 0.5)$. Maximum portion of the national territory configures the change of $0.0 \le \Delta T < 0.5$. The Hindukush Mountains in Chitral, parts of Himalayas, parts of eastern Punjab along the Pak-Indian border southern most Sindh, central and northern Balochistan were subjected to warming and have shown changes in temperature within the range of $0.5 \le \Delta T < 1.0$.

3.6. The Decade of 2000s

The shift of isothermal lines in 2000s (**Figure 2(f)**) towards north and northwest was even more than the case of 1990s. The shift of high temperature averages towards north is devastating for the big valley glaciers in HKH and will badly affect the agriculture-based economy of the country based on the Indus Rivers System.

Reference to the decade of 2000s (**Figure 3(f)**), except FATA, southern KPK, Sulaiman Ranges and Noshki with surroundings the rest of Pakistan is under warming condition. The amount of warming observed was significant as $0.0 \le \Delta T < 0.5$ in HKH, KPK, area surrounding Sulaiman Ranges lobe, eastern parts of Sindh, Kharan region in Balochistan and upper Indus plains while temperature changes of $1.0 \le \Delta T < 1.5$ was observed in southeastern Punjab and Kirthar Ranges. The upper Indus plains, parts of lower Indus plains, most of Balochistan especially its piedmonts and plains exhibits the change of temperature in December with the range of $0.5 \le \Delta T < 1.0$. Generally, based on results, as one proceeds down from mountainous territories to the plains, the temperature coefficient values are increasing. Therefore, in 2000s warming was much obvious in the plains than mountainous regions while in 1990s the mountains regions have shown more warming than the plains.

4. Conclusions

In Pakistan, the temperature anomalies in December vary from decade to decade and region to region within the same decade. It was noticed that after 1980s, the warming tendency was obvious in most of the national territories. Nevertheless, the regional detail of temperature anomalies at local scale were complex and did not comply with the assumption totally that winter months were warming. Generally, by shift from mountainous territories to the plains, the temperature coefficient values are generally increasing. Therefore, in the 2000 decade warming was much obvious in the plains than that in mountainous regions while in 1990s the mountains regions showed more warming than the plains. This sort of study could be useful for local agriculture especially in various enclosed valleys in rugged parts of the country.

It has been observed that wherever the isotherms were closely spaced, the temperature anomalies found were with high statistical significance on the contrary where the isotherms were widely spaced and the temperature change per unit area was less. Generally, it is clear that the shift of isotherm was obvious in the northern and western parts of the study domain acknowledged by high level of statistical significance pertaining to temperature anomalies there. Both the isothermal shift and temperature anomalies confirm that the mountainous areas of Pakistan face more temperature variability (warming) than plains.

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