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Oceanity and continentality climate indices in Pakistan

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Abstract

Conceptually, the influence of oceans and continents plays key roles in the climate of any region. This study considers continentality and oceanity thermal climate index and focuses on the synoptic classification of Pakistan. The country has a diversified geographic relief which has profound influence on its climate from region to region. While its more than 990 km long coastal belt has wetter maritime condition, its interior belt is under the influence of arid and semi arid conditions and its higher altitude region has a hyper-arid climate. Marsz, also called Kerner Oceanity and Conrad Continentality Indices were calculated for Pakistan using the country's temperature annual range data of the past fifty years (1961-2010) at 51 climate stations. When correlations between the two continental indices are compared, it indicates that a large area of Pakistan has continental climate. This comparison may be beneficial for Pakistan's energy reforms and agricultural sectors.

Keywords: climate, climate indices, continentality, oceanity, synoptic classification, variation of temperature

Introduction

Seasonal and diurnal variations of temperature over oceans is far less than over land. This divergence is due to the high heat absorbing capacity and lesser power of radiation and absorption of oceans, therefore, diurnal variations in temperature are small. Land masses absorb and radiate more, as a result of which diurnal range of temperature is considerably large. Thus, although being located on the same latitude, a station in the middle of the continent experiences greater variation in temperature while stations having mid-oceanic locations have least variation. Variation of temperature at stations with coastal location depends on wind direction. Oceanic wind currents essentially transfer oceanic characteristic of slight variability of temperature considerable distances inland, while wind currents from the continent carry its essential feature of variability of temperature considerable distances out at sea. Thus, stations along the shore reveal marked *continentality* or *oceanity* of climate, accordingly as the prevailing wind is from land or from sea, and it may be oceanic during one season of the year, and continental during another. In other words continentality is the degree to which a climate is affected by continental influences; the inverse being oceanity. Both are synoptic phenomenon. Nota bene: Sea and land breezes are the winds formed (during the course of solar day) due to temperature differences between land and sea at the coastal belt within an average 32-48 km (minimum few hundred meter of the shoreline to maximum 160 km). It is a mesoscale phenomenon.

Oceanity and continentality are significant notions in climate study (Deniz, 2011; Rajabi & Shabanlou, 2012). Climate is influenced by large expanses of lands or oceans. Many scholars (Barry & Chorley, 1972; Conrad, 1946; Johansson, 1926; Brunt ,1924; Laaksonen, 1977; Gorczynski, 1920; Prohaska, 1976; Ratisbona, 1976) put forward some indices to measure these effects. Annual temperature range is a factor which affects climate (Conrad, 1950). Supan (1884) used annual range of temperature in the computation of continentality index. Latitude is also a factor influencing climate. The ratio between annual temperature range and geographic latitude define index of continentality (Johanson, 1926; Raunio 1948; Gorczynski, 1920). Some researchers incorporated temperature and/or precipitation into climate studies (Bagnouls & Gausen, 1957; Gausen, 1956; Walter, 1955; Charles-Edwards, 1984; Rosenberg et al., 1983).

The twofold purpose of this paper is to examine the spatial variation of climate indices and henceforth the climate structure of Pakistan using the Mersz/Kerner Oceanity Index (OI) and Conrad Continentality Indices (CCI) , and analyse the climate indices using the mean monthly range of temperature (°C) .

Data and methodology

Being key factors in influencing regional climate, oceanity and continentality both moisture and thermal contents influence and are affected by temperature and precipitation. The total monthly precipitation (mm) and monthly maximum and minimum temperature (°C) data from 51 meteorological stations spread over the whole country were utilised. The data have been collected from Pakistan Meteorological Department, CDPC, Karachi for the study period 1960-2010. The annual range of temperature for these stations was computed and the CCI and OI calculated. GIS software was used in preparing the spatial distribution maps which were then examined and analyzed.

Continentality Index

Continentality quantifies the effect of remoteness on climate of an area from the oceans and oceanic air. Due to lower specific heat capacity of land, landmasses experience more thermal variation than water. Oceanic climates tend to be wetter with the increase of moisture input to the atmosphere from evaporation while continental climates tend to be drier due to lesser evaporation induced in the atmosphere. The difference between the mean temperatures prevailing during the warmest and coldest months, often quoted as indicators as suggested by Supan (1884) is as follows:

$$CI = (T_{mx} - T_{mn}) \qquad \dots 1$$

Where CI = Continental Index

$T_{.max}$ = mean temperature (°C) of warmest month

$T_{.min}$ = mean temperature (°C) of coldest month

Conrad and Pollak (1950) reveal a correlation between annual range of temperature and geographical latitude. Receipt of solar radiation does not increase equally in accordance to latitude with increasing distance from the equator but reaches a maximum at about 55° N (Driscoll & Yee Fong, 1992). Consequently, its distribution, however, is not equal to the distribution of sine of latitude. In many continental indices, the physical correlation between annual range of temperature and geographical latitude is incorporated in ratio form. Gorczynski (1920; 1922) proposed continentality index (CI) in percent as:

$$CI = \frac{1.7(T_{AR} - 12\sin\theta)}{\sin\theta} = \frac{1.7\,T_{AR}}{\sin\theta} - 20.4 \qquad \dots 2$$

Where

T_{AR} = annual range of temperature (°C) and

θ = Geographic latitude in degree

Later on many scholars (Flocas, 1994; Chronopoulou-Sereli, 1996; Sjögersten, 2004; Filatov et al., 2005) used the formula for calculating continentality and climate classification. Johansson (1926) also put forward the following Continentality Index:

$$CI = \frac{1.6\ T_{AR}}{\sin\theta} - 14.0 \quad \ldots\ldots 3$$

Raunio (1948) suggested another form of Continentality Index:

$$CI = \frac{1.57\ T_{AR}}{\sin\theta} - 11.7 \quad \ldots\ldots 4$$

The annual amplitude of air temperature is employed to assess continentality of climate. The above mentioned formula is the most often exercised in many studies (Filatov et al., 2005; Sjögersten, 2004; Baltas, 2008). The climate is characterized as maritime when CI is between 0 and 33, as continental when CI is between 34 and 66, and as exceptionally/extreme continental climate when CI is between 67 and 100. Chronnopoulou-Sereli, Flocas and Baltas (1996; 1994; 2007) used this formula to compute Continentality Index.

Johansson (1926) considered irregularity of the seasonal thermal wave, thermal amplitude and geographic latitude to differentiate climate classification between oceanic and continental. Johansson's (1926) approach is recommended for climatic classification differentiation between oceanic and continental climates. Conrad pointed out the weakness of the formula: CI tends to be infinity when sinθ tends to be zero. Therefore, Conrad and Pollak (1950) suggested the following modification:

$$CCI = \frac{17\ T_{AR}}{\sin(\theta+10)} - 14.0 \quad \ldots\ldots 5$$

Where

CCI = Conrad Continentality Index
T_{AR} = annual range of temperature (°C) and
θ = Geographic latitude in degree

The CCI should acquire a value of 100 for a fully continental and 0 for a fully maritime climate. The climate is typified as Hyper-oceanic when CCI in between -20 to 20, oceanic/ maritime when CCI in between 20 and 50; sub-continental when CCI in between 50 and 60; continental when CCI in between 60 to 80 and as extreme/hyper-continental climate when CCI in between 80 and 120.

Oceanity Index

Seas and oceans have their own weather pattern. Winds and currents range in character, depending on the ocean. Landmasses approximating the sea share its patterns, whereas further away they tend to develop their own weather patterns. Oceanity is the degree of influence of the sea on the climate of a region. Retuerto and Carballeira (1992), Gavilan (2005) and Baltas (2007) having stated that spring months are colder than autumn months in cases of maritime climate, formed the thermoisodynamic fraction and defined Kerner Oceanity Index as:

$$OI = \frac{100\ (T_{OCT} - T_{APR})}{T_{AR}} \quad \ldots\ldots 6$$

Where

T_{OCT} = Mean monthly air temperature for (°C) October
T_{APR} = Mean monthly air temperature (°C) for April
T_{AR} = annual range of temperature (°C), respectively

Small or negative values of OI denoted continental climate, while larger values imply oceanity (Zambakas, 1992). In this study, OI higher than 10 is characterized as an oceanic climate. Kejna (1999) studied air temperature on King George Island, South Shetland Islands, Antarctica and incorporated Marsz Oceanity Index (Marsz, 1995)

$$OI = \frac{(0.731\theta + 1.767)}{T_{AR}} \quad \ldots \ldots \ldots \; 7$$

Where

T_{AR} = annual range of temperature (°C), respectively
θ = Geographic latitude in degree

Kejna (1999) discussed and found strong oceanity effect in his studied area which was also found in the paper of Styszyńska (1988; 1995). The effects of latitude and annual range of temperature have been justified in a better way in equations 5 and 7, hence, have been considered in the present study. The term Marsz Oceanity Index and Kerner Oceanity Index is interchangeable and hereinafter referred as OI. Similarly, Conrad Continentality Index (CCI) is referred as CI in this study.

Results and discussion

Pakistan is spread over a great landmass composed of several geographic areas, having the world's second highest point K2 (Godwin-Austen) in addition to being 8611 meter amsl in the northern mountainous highlands (Figure1). The Indus river plain, Balochistan and Potohar Plateaus, Thar and Cholistan Desert, 990 km long coastal belt, stretched over from the Iranian border in the west to the Indian border in the east (Rabbani et.al., 2005) about Sindh (270 km) and Makran coast range of Balochistan (720 km); and Sistan Basin, all being part of the Pakistan landmass. The catchment area of Indus river plain is estimated to be about one million km. Continental shelf of Balochistan measures 15-40 km whereas that of Sindh extends to 150 km. The Makran coast range is composed of steep mountains rising to 1500 m elevation along with desert beaches. Oceanic currents prevail clockwise during the summer monsoons while they are reversed in winter during the western disturbances season (also known as northwest monsoon).

Geographically, Pakistan is located above the tropic of cancer in the temperate climatic zone. The sub-tropical high pressure belt extends horizontally through the middle of Pakistan plain. Total annual mean precipitation of the country varies from 200 mm to over 1700 mm per annum (Figure 2). The total annual mean precipitation and mean annual total rainy days were 632.8 and 60.7 in GB/AJK, 170.1, 14.8 in Balochistan, 869.4 and 81.0 in KPK/FATA, 649.8 and 56.5 in Punjab, 155.8 and 8.5 in Sindh. Abundant precipitation occurs in Punjab during the monsoons. Dry, lesser and adequate precipitation is received in the coastal south where conditions are arid. June through September are monsoon months, while December to February are chief westerly disturbance months.

The eastern belt experiences monsoons while the western and northern regions witness westerly disturbances. May and June are the warmest months. The coastal belt along the Arabian sea is usually warm, whereas the northern snow-covered ridges of mountainous Karakoram, Hindukush and Himalaya are frozen and cold (Figure 3). The mean annual maximum temperatures were 23.2, 29.8, 24.8, 30.0, and 34.2. Minimum were 10.0, 15.3, 11.7, 16.4, and 19.3 in GB/AJK, Balochistan, KPK/FATA, Punjab and Sindh respectively. Sindh is the warmest and GB/FATA the coldest province of the country. Temperature gradually increases from north (higher latitude) to south (lower latitude). Instrumental records available with PMD reveal that Asia's warmest temperature 53.7°C was registered at Moenjodaro, Sindh on May 26, 2010. Only Al 'Aziziyah, in Libya (57.8°C in 1922), Death Valley in California (56.7 in 1913) and Tirat Zvi in Israel (53.9 in 1942) are thought to have been hotter. Hot winds (*loo*) blow across the plains during the daytime in summer. No precipitation is received when periods of continental air prevail.

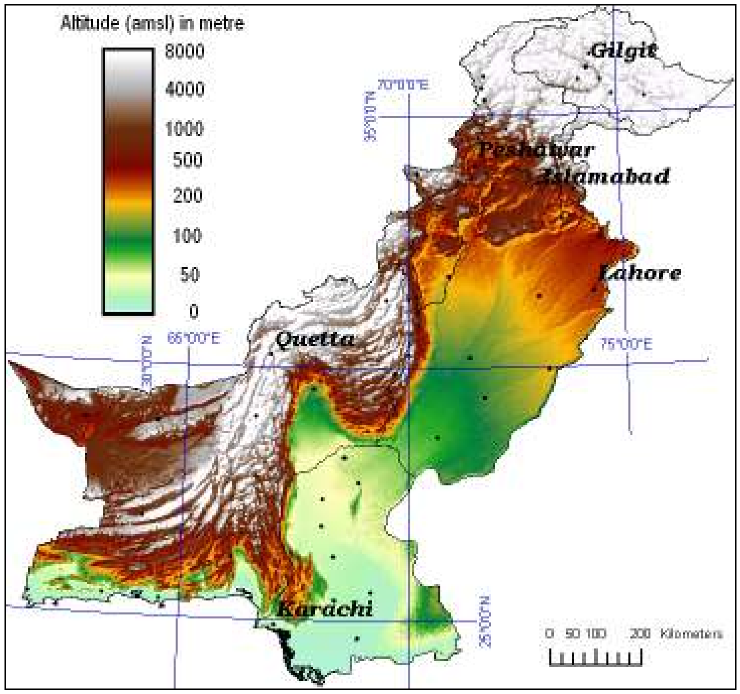

Figure 1. *Topographic map of Pakistan (altitude amsl in meter)*

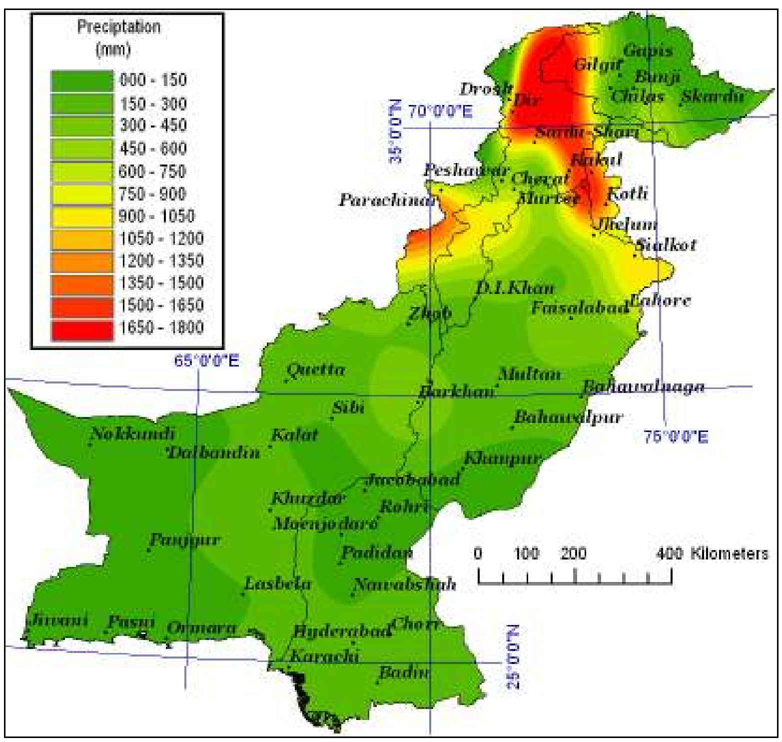

Figure 2. *Mean annual total precipitation (mm) for half century period (1961-2010)*

The CCI and OI analysis reveal that sub-continental climate prevails in GB/AJK region, while maritime climate is observed at coastal stations of Sindh and Baochistan. Influences of Arabian sea are identified at almost all the stations of Sindh and two stations (Lasbela and Khuzdar) have been graded as

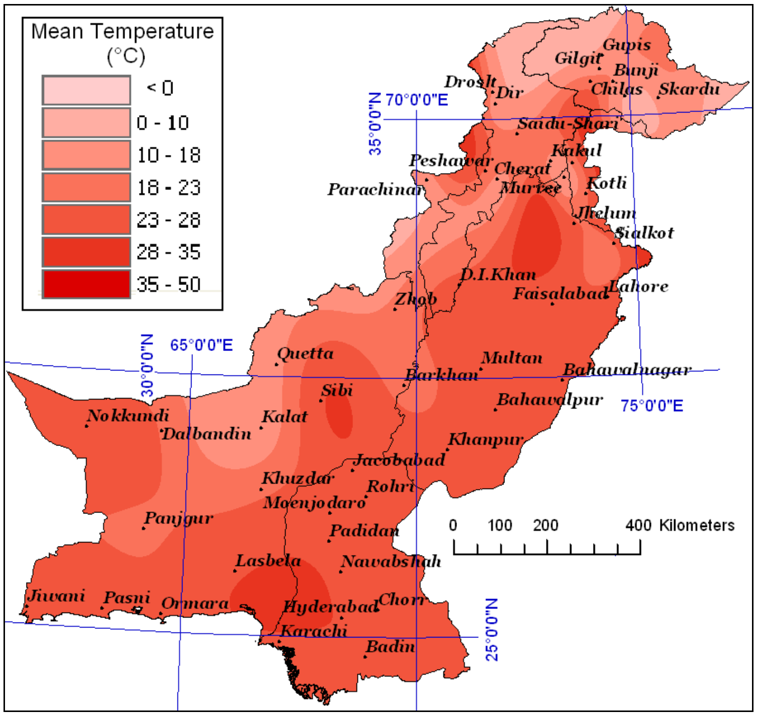

Figure 3. *Mean annual temperature (°C) of half century period (1961-2010)*

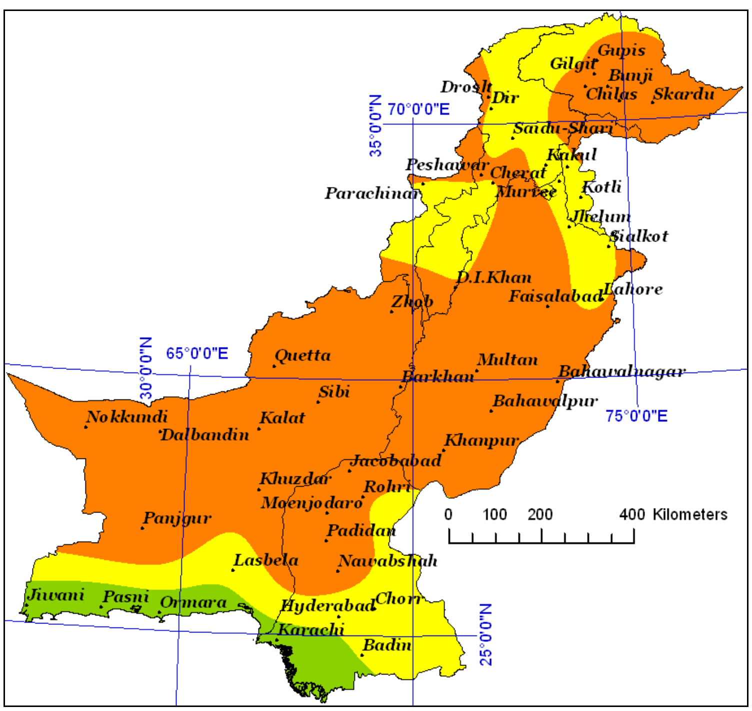

Figure 4. *Spatial distribution based on Conrad Continentality Index (CI)*

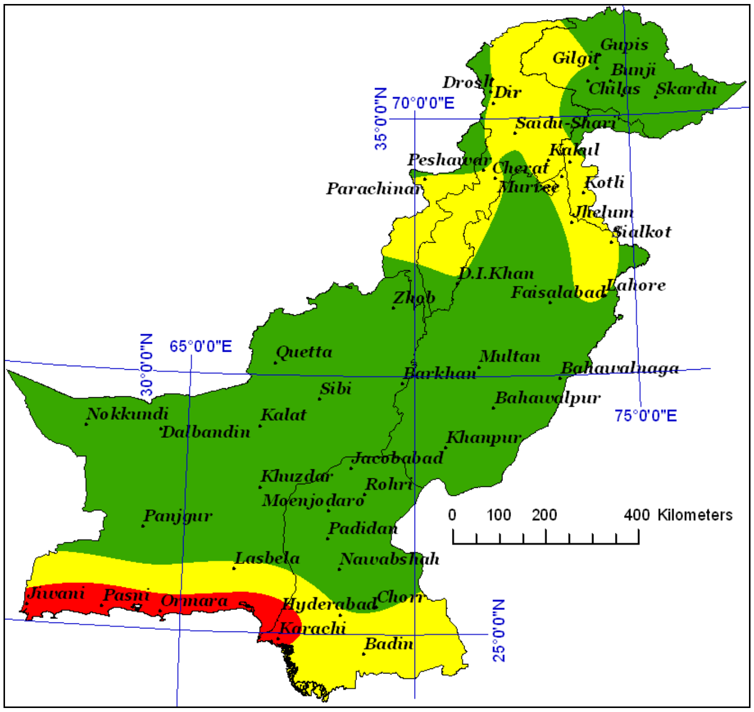

Figure 5. *Spatial distribution based on Mersz/Kerner Oceanity Index (OI)*

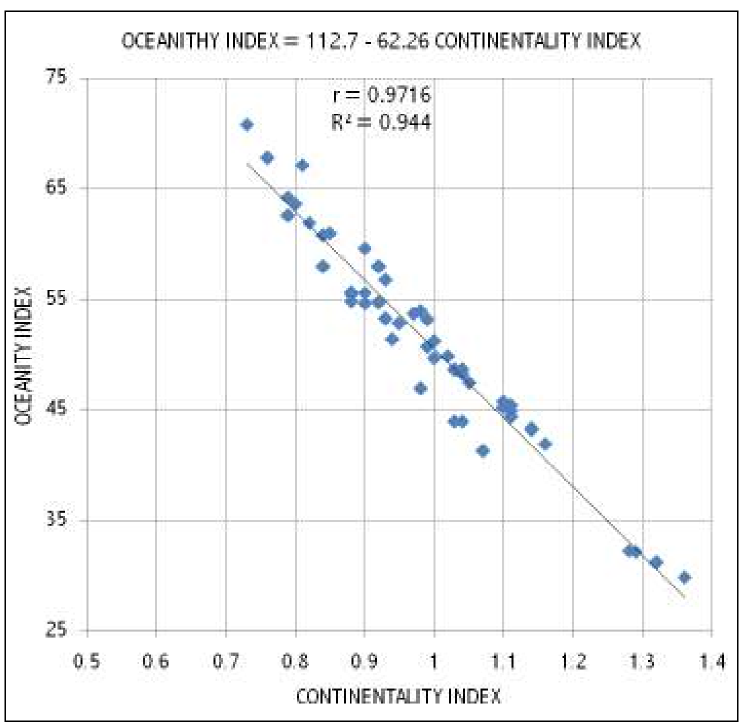

Figure 6. *Correlation between Continental Index (CCI) and Oceanity Index (OI)*

areas of sub-continental climates (Figure 4 and Figure 5). Rest of Balochistan is categorized as area of Continental climate. According to Continentality Index, Padidan had sub-continental climate while according to Oceanity Index it is designated as having continental climate. KPK/FATA and Punjab have been classified as sub-continental climate.

The classification at fifty out of fifty-one stations was identical according to both indices, indicating an affinity between both methods. The high correlation coefficient (Fig.6) proves the affinity between the computations. Evaluating the definition and classification of continental and oceanic is preferable in CCI as it contains specifically distinct values. Whereas, the oceanic and continentality values categorized in OI were determined during the study and statistical analysis.

Conclusion

The study highlights the fact that the direction of the Himalaya mountain range constitutes a crucial factor in the spatial distribution of precipitation. Standing as barrier to the eastern air masses, the lofty mountain ranges of Hindukush, Himalaya and Karakoram divide the country into north eastern high and south-western low precipitation areas. Most of the world's deserts lie within the horse latitudes. The influence of this sub-tropical high pressure belt is witnessed in the forms of the great Thar and Cholistan deserts and is also a cause of the permanent arid feature of the country.

The CCI results for Pakistan reveal that index values lower than 50 are found over the coastal areas while it is 50 to 80 over the entire inner landmass region. According to this index, the lowest and highest continentality effects have been found at Pasni with 29.89 and at Dalbandin with 70.83. Continentality effects are magnified away from coastal areas. Maximal Continentality effect is found in Balochistan Plateau areas, while along the coastal belts of Sindh and Balochistan, the effect was found to be much lower.

The Continentality Climate Classification Analysis of fifty-one stations based on CCI was in consonance with the Oceanity Classification based on OCI. In addition, the correlation analysis between the two indices revealed a high correlation along with similar spatial distributions. The CCI is preferable to OCI owing to its diverse and clear differentiation of oceanity from continentality. The temperature-precipitation diagrams visually defined the differences between obviously diverse climates but do not describe climate gradients.

CCI does not exhibit the seasonal continentality and/or oceanity effect due to the lower seasonal extreme temperatures compared to annual differences. The continentality effect was found in maximum number of stations. The oceanity effect as seen along the coast line of Arabian sea was greater in the coastal belt of Sindh. This may be attributed to the general synoptic patterns over Pakistan. There is a significant correlation between OCI and CCI. Furthermore, due to the annual data used indices do not support the seasonal patterns in spite of an acceptable difference between the distribution of the precipitation and the temperature patterns with indices variations.

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