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AN EMPIRICAL INVESTIGATION OF SPATIO-TEMPORAL CHANGES IN ARIDITY DURING RABI AND KHARIF SEASONS, IN SINDH, PAKISTAN

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ABSTRACT

The changing features of aridity over the spatio-temporal scale have gained much interest in recent decades due to climate change. Pakistan lies in an arid to semi-arid climate zone, where water is the most scarce resource and is critical for food security. Sindh Province is the second largest agricultural producer after Punjab in Pakistan. This study evaluates the Spatio-temporal changes in aridity during two major crop growing seasons (*Rabi* and *Kharif*) in Sindh province from 1991-2020. Ernic aridity index, was used to forecast aridity for *Rabi* and *Kharif* seasons for six districts (Karachi, Umerkot, Hyderabad, Sukkar, Jacoabad, and Nawabshah). The analysis shows that Umerkot, Nawabshah, and Hyderabad experienced dry to semi-dry conditions during the *Rabi* season in the studied period, while Jacobabad experienced wet and semi-wet conditions. For the *Kharif* season, extremely wet conditions were identified in all the investigated districts. The forecast result also shows that the decreasing trends of the Erinc index were identified for Jacobabad (Rabi), followed by Karachi (Kharif), Umerkot (Kharif), and Nawabshah (Rabi) seasons. While the remaining stations also showed a steady increase in the Erinc index for both seasons. Wheat is a Rabi crop and requires irrigation backup provided through governmental policies. This study also identifies aridity intensifying in Umerkot, Nawabshah, and Hyderabad. The outcomes of this study serve as a guide to policymakers to plan proper policies to deal with extremely wet and arid conditions, faced by the crops of the area under study.

KEYWORDS: Ernic index, Changes in Rabi and Kharif season aridity, Sindh,

1. INTRODUCTION

Aridity is a major risk threatening the majority of the world's regions (Şarlak and Agha 2018). Especially in the regions where agriculture forms the backbone of the economy, the monitoring and assessment of aridity become essential. World's arid lands are home to over 20% of the global population. This 20% witness the most severe impacts of changing climate, especially increased hydrological extremes (Alazard, Leduc et al. 2015). In contrast to droughts, aridity is a permanent feature of climate and is dependent on long-term climatic conditions (Araghi, Martinez et al. 2018).

The world's arid and semiarid regions are extremely vulnerable to human-induced climate change or land transformation (Evans, 2004). Evaluating changing aridity patterns is a serious concern in the context of global climate change. Nearly 40% of the world's land area is covered by arid and semiarid regions. Dry regions may become drier as a result of global warming, while wet regions may become wetter (Chou, Chiang et al. 2013).

Additionally, the area covered by arid and semi-arid climates is projected to increase by 11%–23% in the future, increasing the likelihood of aridification and putting more strain on fragile dry land ecosystems (Huang, Yu et al. 2016). The Intergovernmental Panel on Climate Change classified Pakistan's climate as arid and semi-arid (IPCC 2019). The country remains a frequent victim of droughts as predominantly the climate is arid. Droughts occur two to three times every ten years in Pakistan (Mazhar and Nawaz 2014). Pakistan is also afflicted by extreme aridity in the regions of Punjab (Mazhar et al., 2018) and Sindh. In Pakistan, decreasing precipitation is the main contributor to aridity. Aridity has been activated in Pakistan as a result of agricultural land loss and climate change (Haider and Adnan 2014). The water shortage limit in Pakistan is gradually declining, and climate change may exacerbate the problem. Wheat is widely used as a food crop around the world, and it is also Pakistan's primary staple crop, ranked eighth in the world (Memon, Sheikh et al. 2021). Punjab and Sindh are the most important wheat-growing provinces, with wheat mostly grown during the Rabi season (Pakistan Bureau of Statistics, 2014). Sindh accounts for 38 percent and 12 percent of the country's rice (approximately 2 mha) and wheat (approximately 8 mha) fields, respectively. Sindh's rice and wheat production account for 50% and 13% of the country's total rice (3 million tons) and wheat (16 million tons) respectively (Aslam and Prathapar 2001).

Changing climate, coupled with unsustainable land use practices in the recent past, have resulted in increased frequency of droughts which is the amongst the most devastating climatic hazards. Drought has impacts on land which may prolong from even months to years (Ain, Latif et al. 2020). Changes in precipitation are strongly affected by the spatial patterns of aridity trends. Studies have shown that the southwestern Pakistan witnesses an increasing trend in aridity (drier) as precipitation is low in this region, especially during the Kharif season. On the contrary, a decreasing trend in aridity (wetter) has been reported for the Rabi season, as in this region, high precipitation is caused in winter months due to western disturbances (Ahmed, Shahid et al. 2019).

Millions of hectares of rice and wheat are produced by irrigation in Pakistan. Due to high water tables, rice predominates on the Indus River's Right Bank. Rice-wheat rotations are the most common in Upper Sindh. Lower Sindh accounts for 32 percent of the rice area, while Upper Sindh accounts for 68 percent (Aslam and Prathapar 2001). Water scarcity is one of the world's most pressing issues, especially for agriculture, which is the primary user of freshwater. Pakistan is located in the arid to semi-arid climatic region, where water is the most limited resource and is critical for food security, and Sindh also suffers from it. (Memon, Sheikh et al. 2021).

Climatologists across globe, rate climatic indices as reliable tools for investigating climate types in the world and they have proposed various indices to classify climate based on different set of parameters. Similarly, there are indices that are used to investigate the humidity and aridity in any region. Numerous aridity indices exist for the classification of aridity, including the de Martonne aridity index (1926), the Thornthwaite aridity index (1931), the Erinç aridity index (1965), and the UNESCO aridity index (UNESCO, 1979). Similarly, spatiotemporal variations of aridity in Iran was examined during the last six decades, using climate indices (Araghi, Martinez et al. 2018) and in a study by Zhou and Ismaeel (2021), the authors concluded that during the water-stressed crop season, there is a strong linkage of enhanced vegetation index (EVI) with the evaporative stress index (ESI). Response of EVI had a negative correlation with temperature and solar radiation. On the contrary, there is a positive correlation between rainfall with EVI. Keeping in view the link between aridity and stressed crops, this study aims to assess the spatio-temporal change in aridity over 30 years in Sindh province during two distinct cropping seasons (Rabi and Kharif), using the aridity index.

2. MATERIAL AND METHODS

2.1. Study Area

Sindh province, after Baluchistan, has a high aridity level. Sindh province lies in the southern part of Pakistan. Administratively, it is the third largest province of the country, stretching over an area of 140,915 km². The climate of Sindh is subtropical with hot summer and cold winter. The highest Temperature of 46° C was recorded in July, and the least temperature of 2° C was recorded in January.

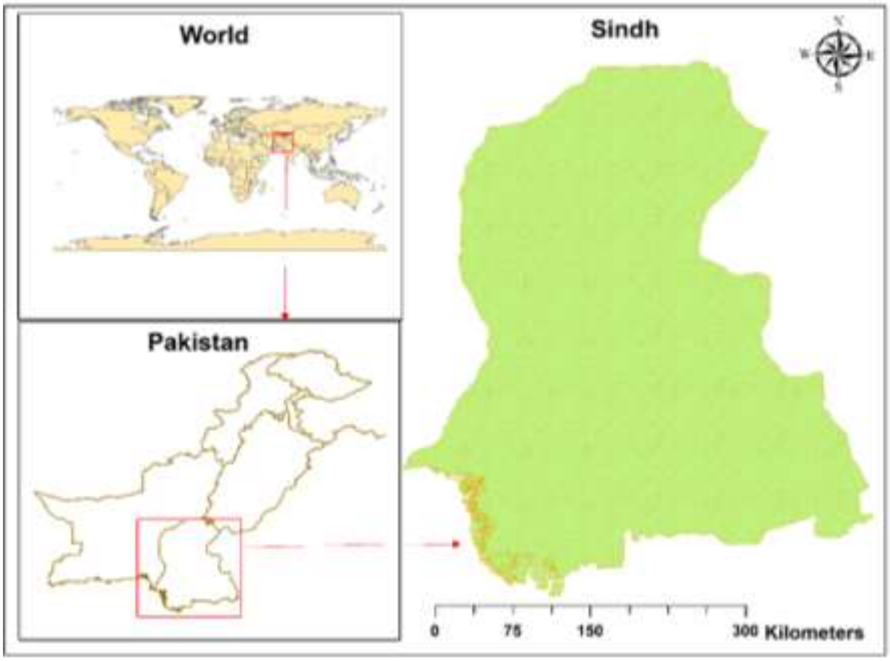

Figure 1. Locational map of Study Area

2.2. Meteorological dataset

In the present study meteorological data was acquired from Pakistan Metrological Department (PMD) from 1991-2020 for the following variables. Further, data was collected from six different stations located in Sindh i.e.: Karachi, Umer Kot, Hyderabad, Sukkar, Jacobabad, Nawab Shah.

a) Mean Monthly Maximum Temperature
b) Mean Monthly Minimum Temperature
c) Monthly Total Rainfall
d) Mean Monthly Relative Humidity

2.3. Data Analysis

Meteorological dataset was used to analyze the aridity trend in Sindh province. The analysis was performed using following technique.

2.4. Erinç aridity index (EAI)

This study has used Erinc aridity index for demarcating and mapping the arid zones of Sindh, as it is one of the most widely used index for aridity mapping across the globe (Ullah et al., 2022; Andrade et al., 2021; Sarlak and Agha, 2017; Haider and Adnan; 2014, Sahin, 2012). The main benefit of this index lies in the fact that it helps demarcating regions based on aridity differences, and thus makes comparison on global level, between drylands, having similar characteristics, possible.

Erinc is calculated aridity index by taking the ratio of total annual rainfall (P) to the annual mean maximum temperature (Tmax) as shown:

$$Im = \frac{P}{Tmax} \quad \text{(Eq.8)}$$

Where, Im is the aridity index, P is the annual total precipitation (mm), Tmax is the mean annual

maximum temperature (°C) (Haider and Adnan 2014). Erinc aridity index further classified into six climatic zones is described in Table1.

2.5. Forecast of Aridity of Sindh for the next 10 years

Classification of Six climatic zones namely, hyper-arid, arid, semi-arid, dry sub-humid, humid and very humid are proposed by Erinc Aridity index as shown in the table below.

Table 1: **Classification of the climatic region based on Erinc Index**

Sr. no	**The classifications of the climate region based on Erinc Aridity Index**	
	Class	**Index value**
1	Completely dry	<8
2	Dry	8 to 15
3	Semi-dry	15 to 23
4	Semi-wet	23 to 40
5	Wet	40 to 55
6	Extremely wet	55<

Source: (Haider and Adnan 2014)

3. RESULTS AND DISCUSSION

Umer Kot

Erinç Index of Umer Kot is calculated in figure 2 using the 30-year data for Rabi and kKarif season, and also the relationship of EAI with humidity, was analyzed. Erinc index is classified on the base of table 1.

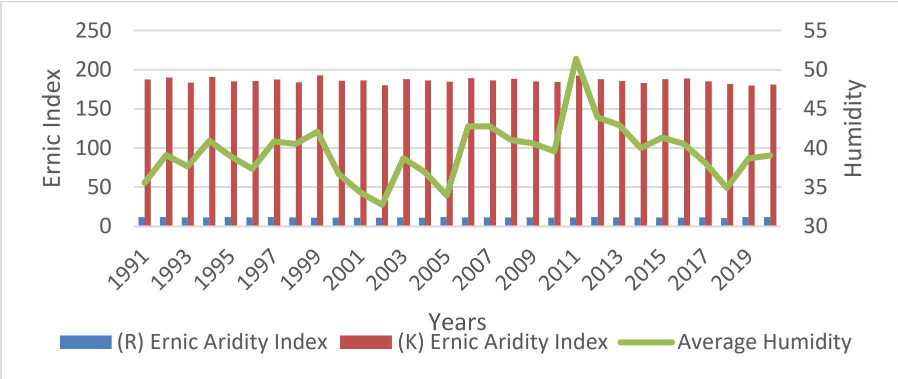

Fig. 2. Umer Kot Erinc Index

Figure 2 shows the result obtained from EAI which is (Ratio of maximum temperature and sum of precipitation) for the Rabi and Kharif seasons and the humidity of Umer Kot is also presented for 30 years. The Rabi season EAI approximately ranges between 0 to 15, while in Kharif Season range is from 0 to 200. Lowest Humidity occurred in 2002 and highest humidity was recorded in 2011.

Hyderabad

EAI of Hyderabad is calculated using the 30-year data for Rabi and Kharif season, and also the relationship of EAI with humidity was analyzed, as shown in figure 3. The analysis revealed that Rabi season EAI approximately ranges between 0 to 15 and in Kharif Season its range varied from 0 to 200. The lowest Humidity occurred in 2002 and the highest humidity was recorded in 1994.

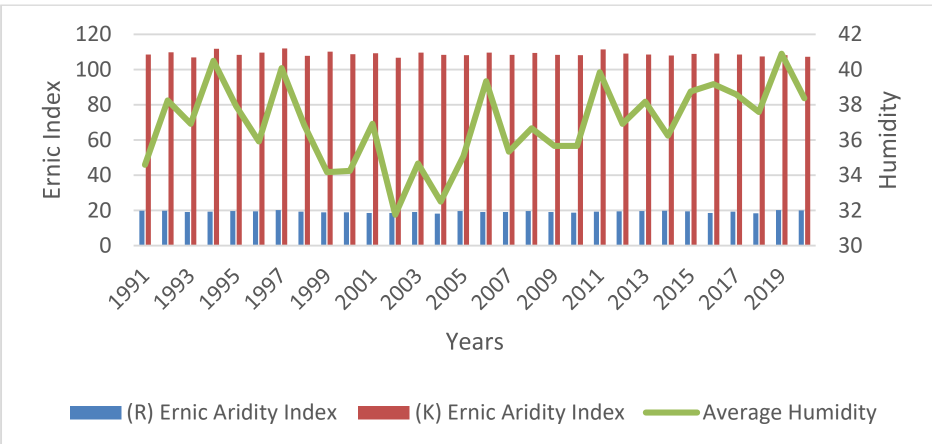

Fig. 3. Hyderabad Erinc Index

Jacobabad

Figure 4shows that during Rabi season EAI approximately ranges between 0 to 45 and in Kharif Season it ranges from 0 to 90. The lowest Humidity occurred in the year 2001 and the highest humidity occurred in 2012.

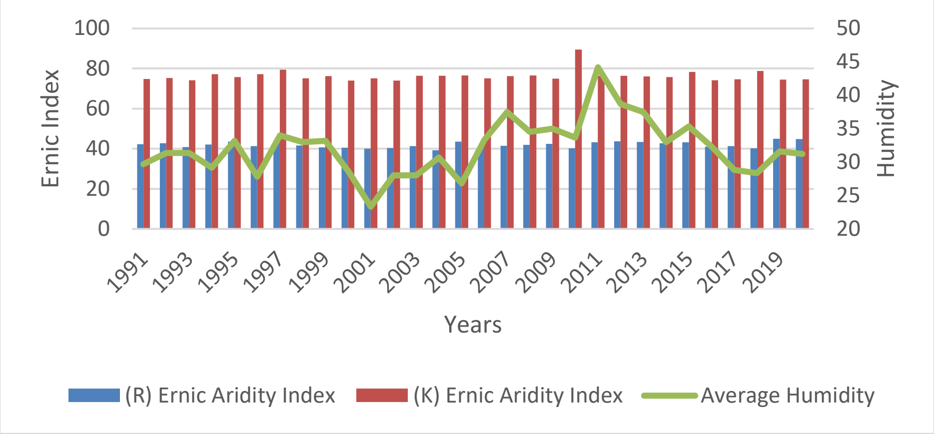

Fig. 4 Jacobabad Erinc Index

Karachi

The index in figure 5 shows that the Rabi season EAI ranges from 0 to 30, while in Kharif Season it ranges from 0 to 140. The lowest Humidity was reported in 2004 and the highest humidity was found in 2006 as shown in figure 5.

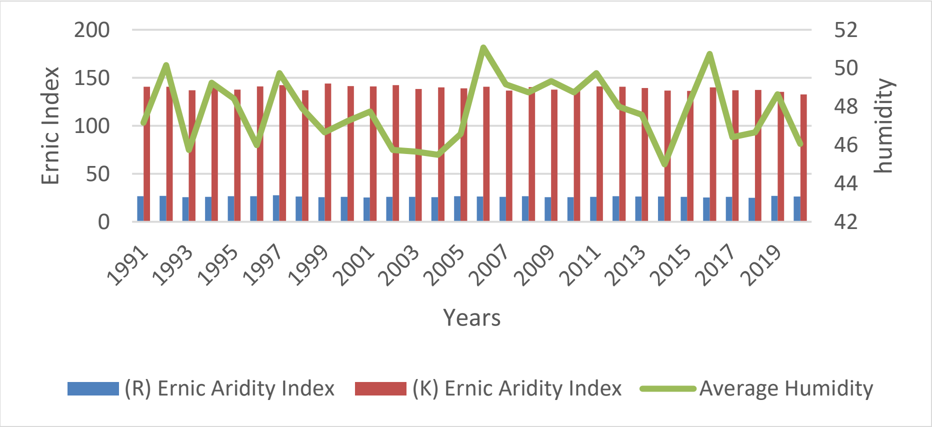

Fig. 5. Karachi Erinc Index

Nawabshah

Figure 6 revealed that the Rabi season EAI ranges from 0 to 20 and in Kharif Season it ranges from 0 to 140. The lowest Humidity was indicated in 1999 and the highest humidity was found in 1997.

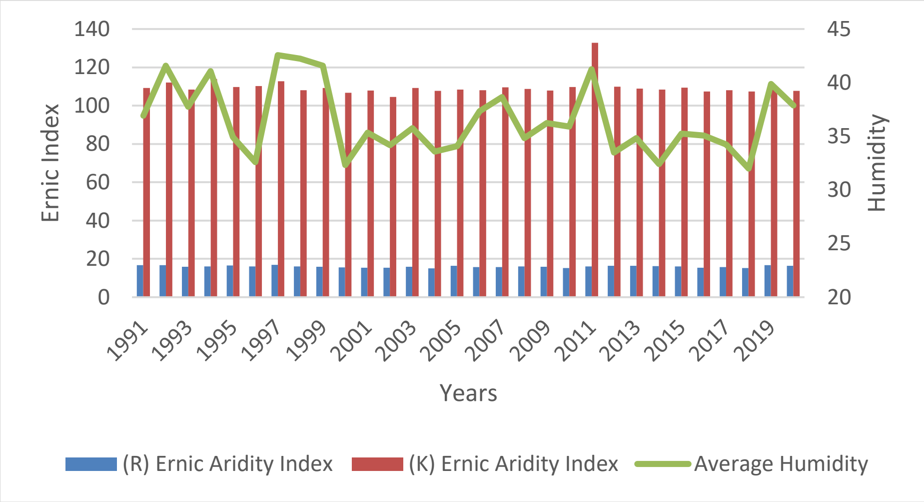

Fig. 6. Nawab Shah Erinc Index

Sukkar

The result showed that the Rabi season EAI ranges from 0 to 35 and in Kharif Season it ranges from 0 to 180. The lowest Humidity was found in 2001 and the highest humidity was indicated in 2019 as shown in figure 7.

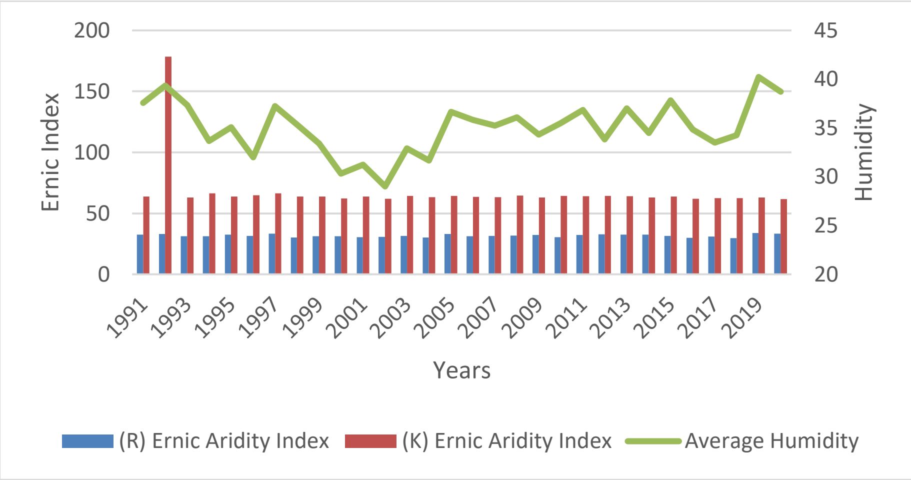

Fig. 7. Sukkar Erinc Index

Forecasting trends

Forecasts are presented for the districts that were chosen for the study, along with notable forecast trends for the Rabi and Kharif seasons.

Umerkot Rabi Season

The Forecast of the Rabi season based on the Erinc index is shown below.

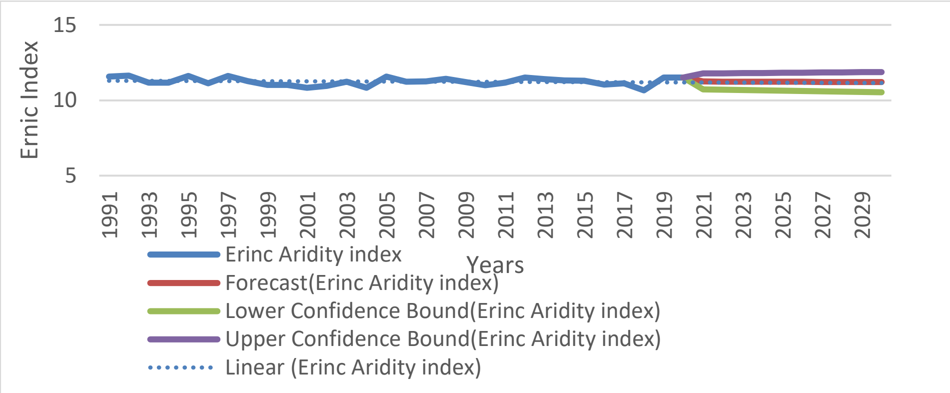

Fig. 8. Umer Kot Rabi season Forecast

According to figure 8 the linear trend in forecast is showing a decreasing trend, which shows a steady decrease in the Erinc index value, and this hints toward a drier area to increase in the Rabi season of Umerkot. The upper confidence bound represents a humid season, and the lower confidence bound indicates a dry season.

Umerkot Kharif Season

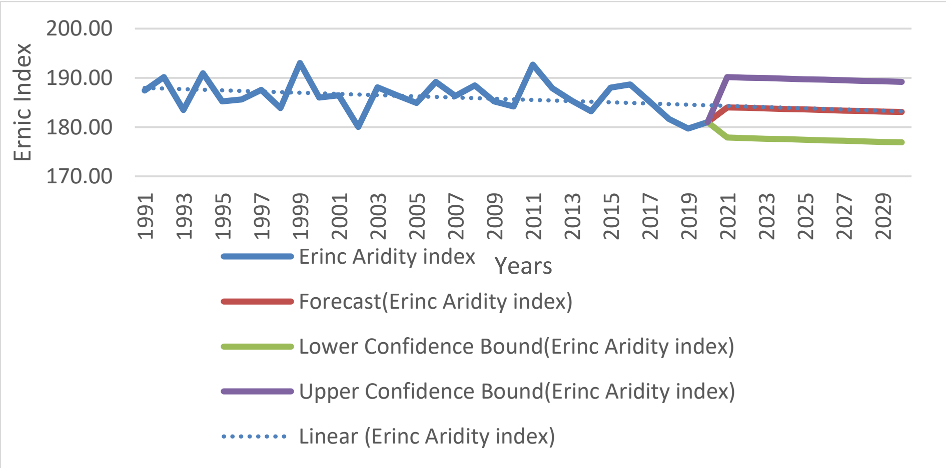

Fig. 9. Umerkot Kharif Forecast

According to figure 9, the forecast shows a steadyy decrease in the Erinc index value, and this decrease hints toward a dry area to increase in the Kharif season of Umerkot. Upper confidence value shows more humid condition and the lower confidence show dry condition.

Hyderabad Rabi Season

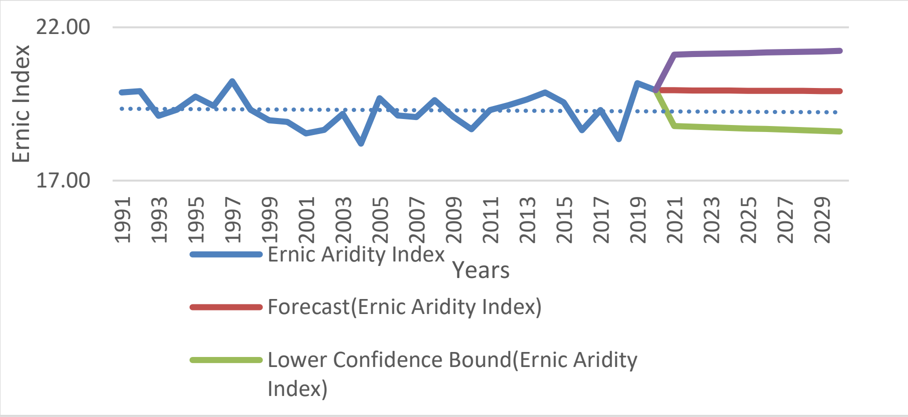

Fig. 10. Hyderabad Rabi Forecast

According to figure 10, the Erinc Index values of the Hyderabad Rabi season fluctuated over the years. The figure is also providing us with the forecast for 2021 to 2030. The highest Erinc index values, which are equivalent to the Semi-Dry according to table 3 (Haider and Adnan 2014), can be seen in 1992, 1997, 2014, 2019 and to some extent in 1995, 2005 and 2008. According to figure 10, the forecast shows the steady decrease in the Erinc index value, and this decrease hints toward a drier area to increase in the Rabi season of Hyderabad.

Hyderabad Kharif Season

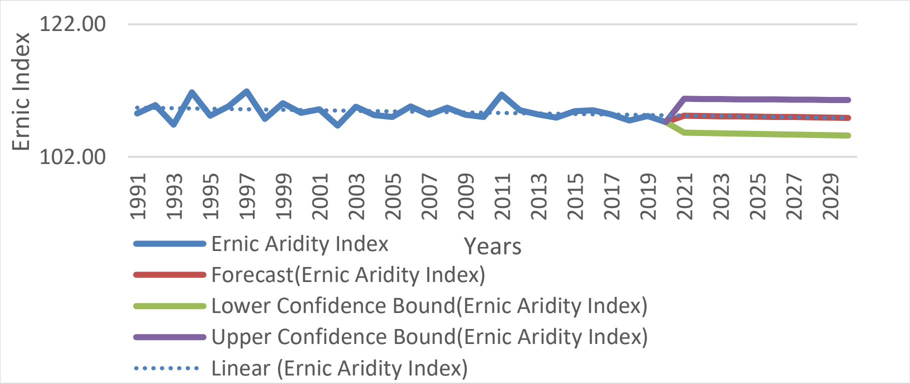

Fig. 11. Hyderabad Kharif Forecast

According to figure 11, the Erinc Index values fluctuated over the years. The figure is also providing us with the forecast for 2021 to 2030. The highest Erinc index value, which is equivalent to the extremely wet Erinc Index values in table 1 (Haider and Adnan 2014), can be seen in 1993, 2002 and to some extent in 1995, 1998, 2005, and 20019. According to figure 11, the linear line decrease toward the forecast shows that the Erinc index value remains constant.

Karachi Rabi Season

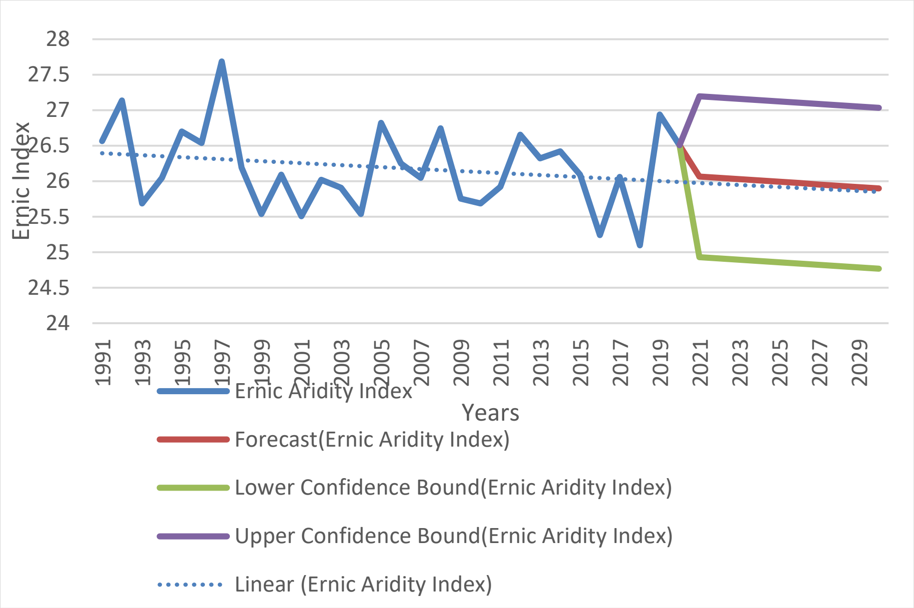

Fig. 12. Karachi Rabi Forecast

According to figure 12, the linear trend is gradually decreasing which shows that the forecast value is decreasing in the next 10 years, and its Erinc index might move toward dry condition. The upper confidence bound represents the wet season, and the lower confidence bound indicates the dry season.

Karachi Kharif Season

According to figure 13, the linear trend is gradually decreasing which shows that forecast value will sightly increase in next 10 years and its Erinc index will move toward more Wet condition. The upper confidence bound represents wet season, and the lower confidence bound indicates the dry season. Aridity is the term associated with 'drylands' mostly, and this word brings o mind images containing scanty and stunted vegetation, sand dunes, water scarcity in surface water bodies, meagre rainfall and rising temperatures. Actually, aridity is a climatic phenomenon principally characterized by a shortage of water. However, aridity is a complex phenomenon, requiring a comprehensive assessment of related climatological variables in order to understand their role in aggravating this phenomenon. Ernic Aridity Index is used to forecast the cropping season in vegetative countries. In this study Ernic Aridity Index is used to forecast the Rabi and Kharif forecast.

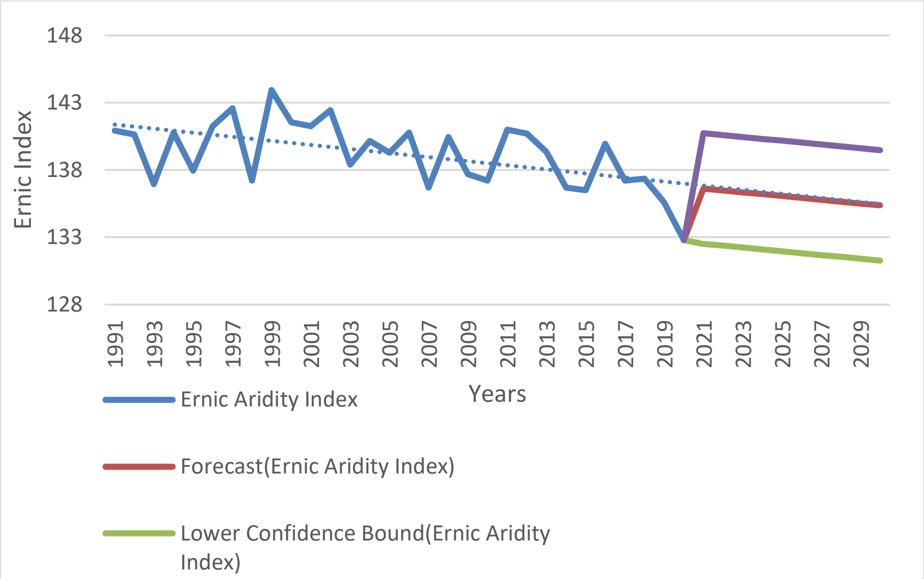

Fig. 13. Karachi Kharif Forecast

The Erinc index analysis explains the arid and semi-arid zones covering most of Sindh's metrological stations. The forecast result of six districts for both the Rabi and Kharif seasons shows that the trend in the Rabi season is decreasing toward dry areas, while the trend in the Kharif season is progressively increasing, indicating humid places. Similar water-stressed crops, due to increasing aridity, as identified using the Erinc aridity index, have been reported by Haider and Adnan, (2014) for arid regions of Pakistan. Not only in Pakistan, this index helped in identifying the areas experiencing an increase in arid areas, in the Iberian Peninsula region (Andrade et al., 2021).

4. CONCLUSION

Spatiotemporal changes in aridity were analyzed in Sindh province for Rabi and Kharif seasons during 1991-2020. The spatiotemporal scale is a widespread tool to evaluate the magnitude of aridity. The first study of its kind was conducted in Sindh, Pakistan, to estimate the extent of aridity.

Due to its contribution to the country's economy, Sindh ranks second after Punjab in the agriculture sector. Thus, the aridity index and forecast were used for 30 years, from 1991 to 2020, to evaluate the changes and patterns of aridity in Sindh. The availability of water in Sindh may increase or decrease as a result of climate change in the Upper Indus Basin and local climate change. Dam reservoir sedimentation is expected to result in decreased water availability during the Rabi season due to less storage to meet Rabi crop demands, and increased availability during the Kharif season due to less storage to capture large Kharif river flows. Erinc index analysis depicts that arid and semi-arid regions cover the majority of Sindh's metrological stations. The forecast result shows that the trend is decreasing toward dry areas in the Rabi season and gradually increasing in the Kharif season. This indicates shifting arid areas to humid areas. The findings of the study help to suggest that policies must be formulated to manage water supply, especially for the Rabi crops in the Sindh province, to sustain food security and the provincial economy. The findings of the study might help the areas that need sustainable water management strategies to be developed, at the local level, e.g. kareez that can be integrated into micro-level watershed management of an area. This could promote in-site moisture management strategies to be promoted. Secondly, area and climate-specific drought-prone varieties of Rabi crops should be suggested by the relevant Agricultural departments.

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