Climate vulnerability index of the coastal subdistricts of Badin, Sindh, Pakistan

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Abstract

The frequent occurrence of climate related events and changes in average temperature, are predicted to increase the vulnerability of the coastal population of Sindh. A climate vulnerability index (CVI) was established and applied to the coastal subdistricts of Badin, Sindh, Pakistan. This study aimed to recognize the vulnerabilities of the coastal population of Sindh exposed to climate change. According to the study, the subdistricts of Badin have been exposed to high temperatures and significant climatic tragedies during the last two decades. The highest vulnerability to climate variability was found in Tando Bago (0.72) and Badin (0.70). Matli is better off in adaptive capacity through socio-demographic (0.29). The vulnerability to resource dependency and knowledge and skill was low in the sub-district of Talhar. In terms of sensitivity, Tando Bago is the most sensitive subdistrict in terms of health (0.55) and resource variability (0.80). The study raises concerns related to coastal communities and their aptitude to address present and upcoming challenges connected with climate change and increased insecurity. The CVI calculated (0.59) can be utilized to improve adaptive capacity, minimize sensitivity, and mitigate exposure to climatic extremes in adaptation planning.

Keywords: Badin; climate change; coastal districts; Sindh; vulnerability index.

1. Introduction

The prolonged consequences of climate change on the socio-economic system have become a major concern, prompting an array of vulnerability assessments to be started in various locations in order to protect vulnerable communities facing climatological extremes (Reed *et al.,* 2013). Climate vulnerability is the result of the combination of climate exposure, sensitivity and the adaptive capacity of the communities (Fatima *et al.*, 2021). Exposure to climate disasters (droughts, floods, and heavy rains) are regarded to pose the biggest harm to agriculture-based communities (Rehman *et al.,* 2015, Fatima *et al.,* 2021). Climate change and fluctuations in average temperature have already had a severe impact on community vulnerability and livelihood, particularly in the coastal areas (IPCC, 2014). Like in Pakistan, the coastal areas of Sindh are highly susceptible to these changes and frequently experience extreme events. Major climate variability concerns in the coastal areas of Sindh are the alteration in temperature (Rehman *et al.,* 2015), precipitation (Gajbhiye *et al*., 2016), and other meteorological parameters (Fatima *et al.,* 2021). These long-term and drastic changes in climatological parameters across multiple geographical areas have caused heat waves (Chaudhry *et al*., 2009), flash floods (Kazi, 2014), droughts (Khan *et al.,* 2013), cyclones (NDMA, 2019), food insecurity (Gelan & Atkinson, 2021), as well as damage to water and land resources on which livelihood of the coastal communities are largely dependent. For instance, damage to agricultural crops (Fatima *et al.*, 2021), livestock and water resources is widely reported (reference missing). A climate change scenario changed the outlook of the environmental factors in the coastal areas of Sindh, thus affecting the livelihood, natural resources, and other sectors of life (Alamgir *et al.,* 2017). Climate variability in the coastal areas of Sindh has been widely studied in association with its impacts (e.g., floods, cyclone, drought). However, few of the studies in Pakistan have assessed livelihood vulnerability at the community level (Salik *et al.,* 2015; Sattar *et al.,* 2017; Qaisrani *et al.,* 2018). A simple human vulnerability index (HVI) for 103 districts in Pakistan was developed by (Khan & Salman, 2012) to study the spatial analysis of vulnerability to climate change hazards in the country. Similarly, the Pakistan Institute of Development Economics (PIDE) in 2013 estimated a district level vulnerability to climate change index for 22 districts in Pakistan.

Multiple indicators of community vulnerability are used in vulnerability assessments to quantify multifaceted challenges that cannot be characterized by a single metric. The models are also increasingly used in the identification and mapping of vulnerable hotspots (Hinkel, 2011). The top priorities are given to the communities experiencing vulnerability, increasing awareness of where adaptation measures should be placed and identifying mechanisms for monitoring adaptation policies.

This study developed a climate vulnerability index (CVI) for the coastal subdistricts of Badin, Sindh Pakistan. The region has been exposed to the consequences of climate change in the last two decades (Alamgir *et al.,* 2017). The objective of the study was to identify and compare the vulnerabilities in the light of coastal communities expose to climate change. It investigates how vulnerability in the context of climate change may alert measures to reduce vulnerability in climate-vulnerable region(s). This research focused on assessing household vulnerability in coastal subdistricts, which enhances the application of vulnerability assessment literature based on indicators.

2. Methodology

2.1 Study area and sample size

The coastal district of Badin was selected for this study and identified as vulnerable hotspot. According to Pakistan NHDR 2017, the human development index (HDI) of Badin is 0.4, placing it in the low development category. The substantial populations in subdistricts of Badin living in poverty, have low adaptive capacity and their socio-economic activities are heavily influenced by climate change issues. These subdistricts are located in Pakistan's southern area, between 23°43' and 25°26' N, and 67°05' and 68°45'E. The coastal district of Badin was stratified into five sub-districts (Badin, Golarchi, Matli, Talhar and Tando Bago) and a total of 235 households were surveyed.

2.2 Index computation

2.2.1 Selection of Indicators

Based on IPCC tripartite typology of vulnerability (Hahn *et al.*, 2009), 10 indicators baskets (Figure 1) were categorized in terms of adaptive capacity: (1) socio-demographic (SD), (2) socio-political networks (SP), (3) livelihood strategies (LS), (4) infrastructure (IS), (5) resource dependency (RD), (6) knowledge and skills (KS); sensitivity: (7) health (HE), (8) natural asset (NA), (9) resource variability (RV); and exposure: (10) climate variability (CV). Definition and explanation of major indicator basket and its subcomponent are given in Appendix A.

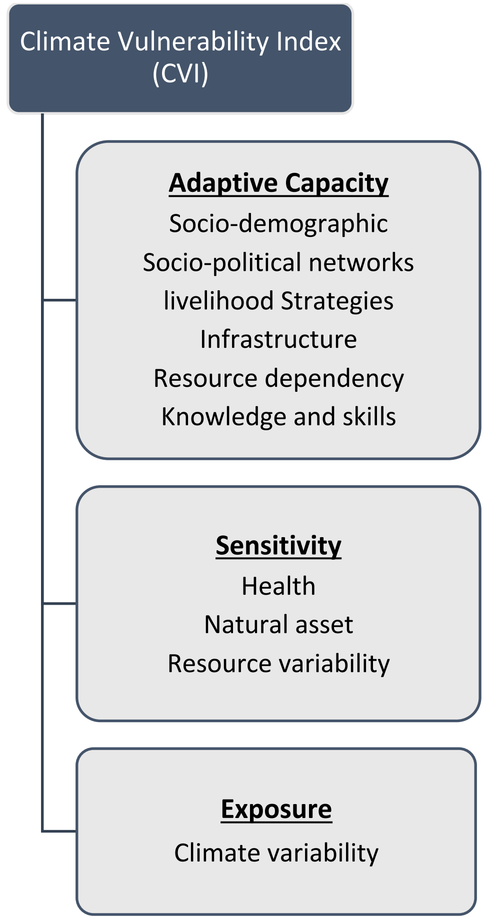

Fig. 1. Major Indicator Baskets used for CVI

2.2.2 Data collection

A field survey was conducted to identify the practicality of gathering the required data through questionnaires. Appendix-B outlines the mechanism through which each indicator was quantified and standardized. Also, secondary data were added on climate change variables such as average maximum monthly temperature (^{0}C) and average monthly precipitation (mm) over the period 2001–2020 from Badin station of the Pakistan Metrological Department (PMD).

2.2.3 Standardization

Primary household survey data were transformed into suitable measurement units (percentages, ratio and indices) to quantify the indicators. The CVI uses indicators that were scaled differently and standardized to make the indicators to a uniform, equivalent scale and aggregate into a single index by using the following equation (Hahn *et al*., 2009):

$$\text{Index } S_i = \frac{S - S_{min}}{S_{max} - S_{min}} \quad (1)$$

Where Si is a sub-indicator of Indicator Basket i, and S_{max} and S_{min} are maximum and minimum values, reflecting high and low vulnerability, respectively.

2.2.4 Weighting Indicator Basket

Assuming an equal contribution of each indicator basket to overall vulnerability, equal weights were applied (Hahn *et al.*, 2009). The weighting approach is an important aspect for indexing (Hinkel, 2011) based on different settings. In this regard, it is appropriate for climate-prone settings where comparisons between groups that were similarly exposed can be made.

2.2.5 Composite Index Calculation

The value for the indicator baskets was computed by taking the average scores of the standardized subcomponent in each basket using Eq. 2:

$$Ib = \frac{\sum_i^n indexSi}{n} \tag{2}$$

Where Ib represent each of the 10 major indicator baskets, indexSi is the sub-indicator for the i making up each indicator basket and n represents the number of indicators for a specific basket. The values of the indicating baskets were calculated to obtain the CVI score for each coastal subdistrict (Eq. 3).

$$\mathrm{CVI} = \frac{\sum_{i=1}^{10} \mathrm{WiIbi}}{\sum_{i=1}^{10} \mathrm{Wi}} \tag{3}$$

Where CVI is the computed climate vulnerability index, equivalent to the average weight of all 10 indicator baskets, and Wi is the weight of each major indicator basket (Ibi), which is calculated from the sum of all sub-indicators present in each indicator basket which contributes equally to the overall climate vulnerability index. The vulnerability score was computed for each subdistrict. The CVI is scaled from 0 (least vulnerable) to 1 (most vulnerable). Based on indicator baskets defined in section 2.2.1, the equation 3 for CVI can be expressed as:

$$\mathrm{CVI} = \frac{[W_{SD}SD + W_{SP}SP + W_{LS}LS + W_{IS}IS + W_{RD}RD + W_{KS}KS + W_{HE}HE + W_{NA}NA + W_{RV}RV + W_{CV}CV]}{W_{SD} + W_{SP} + W_{LS} + W_{IS}IS + W_{RD} + W_{KS} + W_{HE} + W_{NA} + W_{RV} + W_{CV}} \tag{4}$$

A comprehensive example for CVI estimation of major Indicator basket resource variability (RV) for sub-district Badin is given in Appendix B.

3. Results

The values for CVI and each indicator basket of subdistricts of Badin are presented in Table 1, and Figure 2. The results of each sub-indicator in the indicator basket are given in Appendix C. Starting with the socio-demographic (SD) indicator basket of the district Badin, the greater vulnerability was shown by subdistricts Golarchi (0.36), followed by Talhar (0.34), Badin (0.32), Tando Bago (0.32) and Matli (0.29). The age dependency ratio (SD1) in Golarchi (0.37) was higher than in other sub-districts, indicating that it has a higher ratio of economically dependent population to productive population. The vulnerability score for education (SD2) is higher in Talhar (0.70), where the majority of the household heads did not have primary school education. Similarly, more than half of the household heads in Badin, Golarchi and Tandgo Bago, and half of the household heads in Matli were also uneducated, with index values of 0.52, 0.65, 0.64 and 0.50, respectively. The majority of the household heads have more than two years' experience in their respective fields (farming/fishing/herding). This showed a low vulnerability score for experience (SD3) in Badin, Golarchi and Matli and zero for other subdistricts.

Table 1. Climate Vulnerability Index (CVI) of coastal subdistricts of Badin, Sindh, Pakistan.

Vulnerability	Indicator Basket	Index Value					
		Badin	Golarchi	Matli	Talhar	Tando Bago	District Badin
Adaptive Capacity	Socio Demographic	0.32	0.36	0.29	0.34	0.32	0.32
	Socio-Political Networks	0.60	0.64	0.57	0.59	0.64	0.61
	Livelihood Strategies	0.70	0.77	0.67	0.73	0.72	0.71
	Infrastructure	0.54	0.62	0.59	0.63	0.61	0.59
	Resource Dependency	0.35	0.38	0.35	0.23	0.35	0.34
	Knowledge and Skills	0.35	0.48	0.42	0.30	0.41	0.40
Sensitivity	Health	0.46	0.47	0.43	0.49	0.55	0.48
	Natural Assets	0.76	0.78	0.74	0.74	0.77	0.76
	Resource Variability	0.80	0.80	0.80	0.80	0.80	0.80
Exposure	Climate Variability	0.70	0.68	0.69	0.69	0.72	0.70

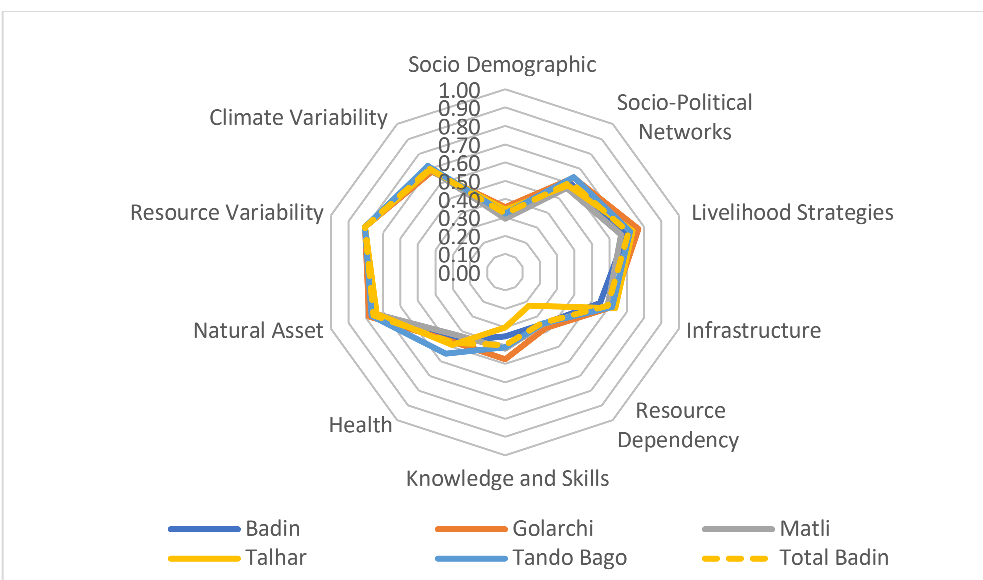

Fig. 2. The CVI values for Subdistricts of Badin

The vulnerability score for socio-political (SP) support during hard times is similar and higher in Golarchi (0.64) and Tando Bago (0.64). Except for a few, the majority of respondents were not members of any official local organization or group (SP1). More than 70% of households in each sub-district did not approach local government and NGOs in the last five years for any kind of assistance or external support (SP2). The majority of them had no access to information regarding climate, security, aid support programs (SP3) and had no contact with local government (SP4). Moreover, households borrowed money and received assistance from their landlords (Zamindars) in hard times (SP5). Cooperation was also observed among villagers of all subdistricts during periods of harsh weather conditions and scarcity (SP6). About 54-65% of households in each subdistrict had access to social media/information through TV, radio, telephone/mobile phone (SP7), Overall, Golarchi and Tando Bago were more vulnerable than other subdistricts in the social-political network basket (SP8).

Subdistrict Golarchi showed more vulnerability in the livelihood strategy (LS) basket than the other subdistricts (Table 1). The majority of households in all subdistricts did not receive remittances (LS1) in the last two years in the form of cash or in-kind assistance from family members or friends living in urban regions. Some of the households that are active in socio-political networks find assistance from other sources like landlords, NGOs or any funding agencies. Moreover, they have low annual net income to cover major domestic expenditures (LS2) and Golarchi showed a higher vulnerability score (0.85) as compared to other subdistricts.

In terms of savings (LS3), households in all sub-districts had no savings to cope with natural disasters, showing high vulnerability index values (Appendix C) for Tando Bago (0.91) followed by Golarchi (0.90), Talhar (0.90), Badin (0.87) and Matli (0.82). Further, more than half of the households stated that they did not have access to any financial institution for credit/loans (LS4) to support their activities. In terms of livelihood dependency (LS5), a major proportion of households in Talhar were dependent on farming and fishing as a primary source of income, making them more vulnerable (0.95) to the consequences of climate change. On the other hand, recent floods also forced landless farmers into debit/loans (35-47%), which they usually borrow from landlords and private money lenders.

The infrastructure of all coastal subdistricts is inadequate and they are vulnerable to future climate induced disasters. Infrastructure that is unable to withstand a severe climatic event (e.g., heavy rains or flood, cyclone and storms) has low adaptive capacity and therefore is more vulnerable. More than 50% of households reported in all sub-districts that they travel a long distance to reach the nearest vehicle station (IS1) and it takes more than 30 mins (Appendix A). More than 70% households in Talhar and Tando Bago reported that the village roads were not properly paved (IS2). The houses owned by respondents have wood and bamboo-based roofs, and walls were mainly composed of mud bricks (IS3). Basic government facilities were present but generally disseminated, inactive and poorly equipped.

In terms of resource dependency (RS), Matli showed the highest vulnerability score (0.6) where most of the households were dependent on electricity (RS1). However, subdistrict Golarchi was more vulnerable (0.93) and dependent on natural gas (RS2) for its domestic. The results of knowledge and skills (KS) also showed that a majority of households were satisfied with recent efforts made by local government and NGOs to share knowledge (KS1) about climate change, while 50% of households in Badin and 45% in Golarchi have not received any type of vocational training to improve their skills (KS2), making them more adaptable to sudden livelihood changes.

The vulnerability index in terms of health was high in Golarchi, where half of the households with members reported chronic diseases (HE1). On the other hand, households in all sub-districts except in Badin did not use healthcare facilities at all or once in a while due to access constraints (too far away, too costly, unsuitable, lack of tools or staff, not enough facilities) (HE2).

The vulnerability score for the natural asset (NA) was similar for Matli and Talhar (0.74) and higher in Golarchi (0.78). It was found that more than half of the households in Talhar and Tando Bago did not have access to backup private wells or piped water (NA1). In terms of land ownership (NA2), more than half of the households in all subdistricts did not own the land where they currently live, farm, or graze animals (or are unable to access/rent land legally). House ownership (NA3) was high in Talhar, resulting in low vulnerability scores (0.35) and similarly for other subdistricts like Tando Bago (0.40), Matli (0.43), Golarchi (0.45), and Badin (0.48). Livestock ownership was high in the households for the animals they were using for grazing (NA4). Around 50% of households reported that they saved grain crops like wheat, rice, and barley and had no food shortages in the last 30 days (NA5).

The influence of resource variability (RV) on the coastal communities and their livelihoods has also been studied with reference to water resources. As shown in Table 1, the vulnerability score for all sub-district was similar (0.80), indicating that more than 80% household were experiencing nearly the same issues related to the water system (RV1), resource scarcity (RV2), distance to water resources (RV3), and income-based changes (RV4). The vulnerability score for the public water system was high in Badin (0.88), followed by Golarchi, Matli (0.85), Matli (0.82), Tando Baggo (0.73), and Talhar (0.70), and more than 35% of households reported a long distance to the water point (RV3). Moreover, around 95% of households considered resource scarcity a big problem, showing a high vulnerability score (0.90-0.95) in all subdistricts (RV2). Consequently, around 32% of farmers in Badin district reported that they have experienced income-based changes resulting from the decreasing fresh water resources used for agriculture activities. The vulnerability score for livelihood changes was high and similar in Tando Bago (0.90) and Matli (0.90), showing a large dependency on water (RV4).

Shifts in temperature and rainfall indices were generally similar for all subdistricts of Badin. However, Tando Bago showed the greatest vulnerability (0.72) in the climate variability (CV) basket than other subdistricts because of the reported higher climate-related losses to crops and livestock. Most of the households noticed long-term shifts or changes (≤ 20 years) in temperature (CV1) and precipitation (CV2), indicating high vulnerability scores (0.95-0.98) (Appendix C). On the basis of the mean standard deviation of monthly average maximum daily temperature (CV3) and monthly average precipitation (CV4), the index value was the same for all subdistricts and was calculated as 0.46 and 0.24, respectively. However, the vulnerability score for the number of hot months with an average monthly temperature above 30 °C (2001–2020) was 0.80 for all sub-districts. The results also showed a high vulnerability score for climate related losses to crop damage (CV7) and livestock (CV8) in all subdistricts. More than 80% of households reported ground water salinity due to sea water intrusion in the last 20 years (CV9). Some households (20%) reported villagers migrating due to climate change and natural disasters, but their vulnerability index was low (CV8).

4. Discussion

This study assessed an integrated vulnerability analysis with multiple indicators of climate variability and social system vulnerability at the household level. The results in (Figure 3) showed that the exposure to climatological events and their losses were high in subdistricts of Badin. The subdistricts were better off in adaptive capacity through socio-demographic, adequate infrastructure and resource dependency, but highly sensitive in terms of health, natural assets and resource variability. The households showed high access constraints to healthcare facilities, less land ownership, and high-water scarcity in Badin.

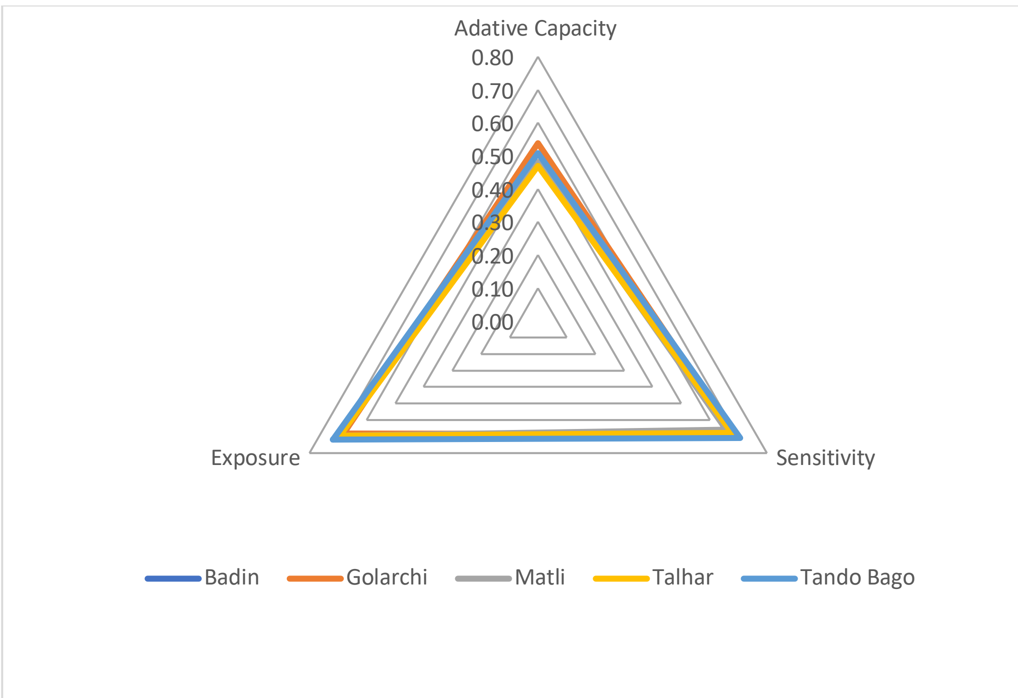

Fig.3. The vulnerability triangle of Adaptive Capacity, Exposure and Sensitivity

The livelihood strategy and resource variability are two of the major contributors to the vulnerability index of Badin. Livelihood vulnerability occurs due to income diversification being lower. The results specify that households involved in more than one livelihood activity, especially those dynamic in socio-political networks, are relatively less likely to be vulnerable. Vulnerable households have less access to local organizations, external support, and NGOs than those less vulnerable (Agrawal, 2008). This condition is applicable to the subdistricts of Golarchi, where households had low annual income, less savings, livelihood dependency, and low remittance opportunities, as well as limited involvement in political participation, all of which contributed to their low adaptive capacities. Moreover, the villagers have less access to information regarding climate, security, and aid support programs due to the high influence of the landlords in the region. At the regional level, the federal government has a weak role, and most of the information dissemination is under the control of the landlords. Thus, households active in socio-political networks with landlords have more access.

Furthermore, one of the factors also contributing to livelihood vulnerability was a credit or loan that farmers had taken for crop inputs with a huge profit margin. Moreover, due to any constraint, if the quality of the crop is reduced and they have not paid the credit on time, the credit goes to the next crop season or year with an even larger interest. The land lord (Zamindar) frequently provides these loans to farmer households and also binds them to deliver further labor services (Oxfam & ADPC, 2014). Due to these loans the farmers and Zamindar are locked into a long-term contractual relationship. As a result, poor households remain to be poor due to indebtedness, and their adaptive capacity remains low, making them more vulnerable and less resilient (Fatima *et al.,* 2021). The vulnerability score for the credit/loan was found to be higher in all subdistricts of Badin.

Resource variability and natural assets (houses, land, livestock, etc.) could be easily converted into other assets and play a crucial role in determining the sensitivity of communities (Lemos *et al.,* 2013). Households in the subdistrict of Tando Bago were the most sensitive in terms of resource variability and natural assets. The coastal districts showed higher vulnerability to the public water supply, water-related income changes, and community perspective on water scarcity. The local government has publicized a number of water supply schemes, but none of them has been executed due to unavailability of funds. Land ownership was rare in the region, which would increase their adaptive capacity by enhancing diverse crop productivity (Fischer *et al.,* 2007). Another important indicator of vulnerability is health (Lemos *et al.,* 2013) in terms of chronic diseases and access to healthcare centers. Tando Bago is the most sensitive subdistrict in terms of the health index. During a field survey, it was observed that an increasing temperature has made most of the regions suitable for a number of vectors and extended their season. In addition, seawater intrusion into freshwater is also responsible for increasing waterborne diseases, which include vomiting, diarrhea, gastroenteritis, skin and kidney problems reported in these regions (Memon *et al.,* 2011).

Climatological events also contributed to major vulnerability in the coastal districts of Sindh. The sub-district of Tando Bago showed higher vulnerability to climate exposure (Figure 3), as evidenced by high losses of land, crops and livestock. Based on statistical evidence, it has been found that the hot days frequency index in coastal areas of Sindh has significantly increased (0.15) during a 36-year time period (Abbas *et al.,* 2018). Since rising temperatures have already affected the natural resources in the area, particularly the agriculture sector, the livelihood opportunities in the area have become limited (Fatima *et al.,* 2021). The decline of the Indus deltaic region is mostly due to diminished downstream flow, which has resulted in seawater encroaching over 1,700 km^2 of the delta over the last five decades (Alamgir *et al.,* 2017). The groundwater and soils in coastal areas are becoming salinized, rendering them useless for agriculture, resulting in an involuntary migration of the local population. If the Indus River's flow continues to dwindle, the scenario will become even more dangerous due to seawater intrusion into freshwater, groundwater, and land resources.

5. Conclusion

This study has evaluated the usefulness of the climate vulnerability index for understanding the numerous dimensions of vulnerability to climate change and factors connected with the socio-economic and human development of communities. The CVI can be used as a valuable tool for exploring climatic interactions as well as contrasting coastal community vulnerability and climate change adaption. The tool is designed in response to livelihood perceptions and takes a prescriptive approach that is consistent with the unique social context and spatiotemporal character of vulnerability. The coastal district of Badin is more vulnerable in terms of sensitivity due to high resource variability (0.8) and low natural assets (0.76), which make them more vulnerable to the climatological exposure (0.7). Golarchi is more vulnerable in terms of adaptive capacity (0.54), while Tando Bago showed high vulnerability to climatic exposure (0.72) and sensitivity (0.71). The CVI computed in this study can be used in adaptation planning to improve adaptive capacity, reduce sensitivity, and mitigate exposure to climate extremes.

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