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Climate change vulnerability and adaptation options for the coastal communities of Pakistan

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ABSTRACT

This study aims to explore climate change induced socio-economic vulnerability of mangrove-dependent communities in the Indus Delta. We evaluate the linkages between vulnerability indicators by relating a community perceptions with observed and projected climate change scenarios. In evaluating these linkages, some key questions are considered such as: what are the likely socio-economic drivers contributing to community's sensitivity? Are these drivers impacting the community and how much is the community's coping potential to climate change? What are the key adaptation options necessary for increasing the community's resilience? This study is carried out in a coastal town (Keti Bandar), which is located in the Indus delta. This region is highly sensitive to declining fresh water flows, changing climate and meager socio-economic resources of local population. We have used the Composite Vulnerability Index (CVI) approach in order to draw a general picture of the community's vulnerability under a changing climate in Keti Bandar. The data for three CVI components (exposure, sensitivity and adaptive capacity) are collected at household level through questionnaire-based survey in six villages, however for exposure, secondary data is also acquired. Our assessment shows that these coastal communities, either engaged with the fishery or agriculture sector, are not only exposed, but are also highly sensitive to climate change driven threats. Moreover, lack of access to basic facilities, inadequate income diversification, and low education levels are negatively affecting the adaptive capacity of the entire local population. However, the communities' nature of dwelling, their strong family networks, and their ability to migrate contribute positively to their adaptive capacity.

1. Introduction

Mangrove forests are the vital component of coastal ecosystems that support a diversity of economically and ecologically important fauna and flora (Walters et al., 2008; Valiela et al., 2009) providing livelihoods for dependent communities. Khan (2011) estimate that one hectare of a well-protected and healthy mangrove ecosystem can produce from 15 kg of crabs to 400 kg of fish, mollusks, and shrimp that mature in off-shore areas.

In Pakistan, the Indus Delta hosts 97% of total mangrove forests with an area of around 98,128 ha (Abbas et al., 2013). Besides providing multiple livelihood opportunities, mangrove ecosystems of the Indus Delta significantly contribute to the economy mainly through marine fish export. For example, in fiscal year 2012–13, the fishery sector in Pakistan generated a revenue of US $ 270.3 million from the export of fish and fish products (GoP, 2013). Further, the Indus Delta mangroves are reported to have high potential for carbon dioxide (CO_2) sequestration: about 320–1120 million tonnes (Mt) Carbon and 1160–2110 Mt CO_2 in plants and soil collectively (Crooks et al., 2011).

Mangrove forests are under the serious threat of degradation and extinction in Pakistan, as they are highly sensitive to both climatic and non-climatic factors (Amjad et al., 2007; Khatoon and Akbar, 2008). The climatic factors range from increased variability of air temperature, precipitation and sea surface temperature to intensification of extreme weather events and sea level rise (Gilman et al., 2008; Adger et al., 2005). There is a strong concern that this situation can further be aggravated by decrease in fresh water flows to the Indus Delta region, which in the past had resulted in less sediment deposition and increased soil erosion and salinity (Diop, 2003; FAO and SUPARCO, 2011).

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Climate models project changes in climate patterns that further intensify impacts on mangroves. The CMIP3 (Coupled Model Intercomparison Project Phase 3) general circulation models under SRES- A1B scenario suggest a decrease in freshwater budget of the Indus basin by the end of 21st and 22nd centuries (Hasson et al., 2013, 2014a). The persistent drought period in the Indus delta from 1998 to 2003, (Levinson and Waple, 2004; Baig and Rasul, 2009) and the floods of 2010 have severely impacted the mangrove cover and productivity, affecting over 2106 ha of the area (Gill et al., 2012). If climate projections as depicted in the CMIP3 models, occurrence of such extreme weather events become multifold in the future and stability of mangrove ecosystems will be certainly affected. The deterioration of the ecosystem will equally disturb the productivity of local biota and the ecosystem services upon which the local population depends on (Badjeck et al., 2010).

The socio-economic conditions of coastal communities also define the health of mangrove that is directly dependent on such forests for their livelihood (McLeod and Salm, 2006). Most of the communities are marginalized, dwelling in small and scattered settlements built around fringes of creeks that are highly vulnerable to the natural calamities in the Indus Delta (Zaheer et al., 2012). In general, the communities are characterized by very low education, lack of health care facilities, low income diversification, high dependency ratio, and absence of water and sanitation conditions (Agrawal, 2008). The studies conducted on the socio-economic status of Pakistani coastal communities find similar patterns. In southern province of Sindh, the coastal district of Thatta stands low in terms of economic development and access to basic services; despite being closest to the mega city of Karachi (Dehlavi and Adil, 2012). The concurrent extreme climatic events have also shown to directly impact the livelihood of people. The four major floods from 2010 to 2013 and six historical cyclones during the past two decades caused innumerable damage to life and property of communities in Thatta, and Badin coast areas (GoS, 2012). The rising sea level in these areas has contributed to a high rate of soil erosion of about 20 m per year, which have caused the town to shift westwards three times since 1952 (WWF, 2008a,b).

Under these circumstances, it is more crucial to look into the issues of climate risk and socio-economic vulnerability in more integrated manner to understand linkages. Evidence-based adaptation strategies and instruments have a potential to improve livelihoods and well-being of the coastal communities by making them an essential part of the strategies planning and development policy. Therefore, in present study, we try to answer some key research questions by relating community's perceptions with observed and projected climate change scenarios. For example, what are the possible drivers of sensitivity to climate, how these drivers are impacting socio-economic conditions of communities, what is the resiliency thresh hold level of these communities to changing climate and what adaptation options would enhance the community's resilience?

A few studies in the past were carried out on socio-economic vulnerabilities of the coastal communities in Pakistan. But these studies narrowly focus either on socioeconomic baseline assessment (WWF, 2007; Zaheer et al., 2012), ecosystem components and services (WWF, 2008a,b; Gowdy et al., 2011), or environment and climatic change (Pettengell, 2010). However, an integrated approach is more productive that will consider indicators of exposure (E), sensitivity (S) and adaptive capacity (A), and hence will provide comprehensive vulnerability assessment of the study area. The subsequent recommendations can be applicable for inclusion into the ongoing national efforts for developing localized action plans such as *National Climate Change Policy in 2013* and *Framework for Implementation of Climate Change Policy* for the period of 2014–2030.

2. Study area

The study site is located to the southeast of Sindh Province in Thatta district (Fig. 1). The district spans over an area of 17,355 square kilometers which is around 13% of the total geographical area of Sindh (GoS, 2008). The Indus River flows downstream in to the Arabian Sea through this area and develops a fan-shaped Indus Delta. The Delta extends up to 150 km along the Arabian Sea, and is a landmark of Pakistan's coastline (WWF, 2007). It occupies almost 600,000 ha area located mainly in Thatta and Badin districts of Sindh province. The Delta comprises 17 major and numerous minor creeks, an extensive area of mud flats and 97% of the total mangrove forests of Pakistan, which is around 98,128 ha (Abbas et al., 2013; Gowdy et al., 2011).

Thatta district comprise 9 sub-districts (*tehsils* or *tallukas*) including the study site Keti Bandar. According to last population census in 1998 the total population of Thatta District was 1.113 million compared to 0.761 million in 1981. Though current population growth rate is 2.26 percent per annum, majority (about 89%) lives in rural areas. Education status in the district is very poor and ranked 133 out of 146 districts in Pakistan (Memon et al., 2014). Most of the housing units are self-owned, contracted with wood and bamboo and 78 percent contain only one room in rural areas (GoS, 2008). The piped water is available in urban areas and that is only 14 percent of the housing units (WWF-P and SG, 2007). The incidence of poverty is very high as district Thatta ranked 5th and 34th among 20 districts of Sindh and 110 districts all over Pakistan respectively (Naveed and Ali, 2012). The district Thatta is also highly vulnerable to natural disasters including frequent cyclones, floods, and droughts (Table 1). These disaster brought devastating impacts in terms of economic and human life in District Thatta, e.g., the cyclone A2 in 1999 had taken 118 human lives, destroyed 3758 villages and 38,509 houses, eroded 5667 cattle and damaged 11,5789 ha of agriculture crops (GoS, 2008).

Our study site is Keti Bandar, a sub-district (Taluka) of coastal district Thatta located in the Indus Delta (Fig. 1). It extends from 67° 45′ to 67° 17′ longitude and from 24° 46′ to 24° 20′ latitudes. The entire area is characterized by mangroves, mudflats, creeks and versatile flora and fauna. Currently, it constitutes 42 Dehs (cluster of villages) with the total population of 12,000 and comprises of total area of 60,969 ha (WWF, 2008a; Khatoon and Akbar, 2008).

The study area experiences mild winters from the months of November to February, while summer season extends from the months of March to October. Mean annual rainfall is about 220 mm, which is quite erratic in its distribution. Most of the rainfall is received during the monsoon season (July–September). January is the coldest month with a minimum temperature of 9.5 °C, while the maximum temperature of 36 °C is observed from June–July. The area is prone to natural disasters such as floods, storms, and sea intrusions that engulfed some of the villages and settlements causing displacement of local communities. Fishing and agriculture make up the major source of livelihood for the people in Keti Bander, where 77% of households are solely dependent on fishing (Dehlavi and Adil, 2012).

3. Data collection

Research data was collected for exposure (E), sensitivity (S), and adaptive capacity (A) during the field visit in April 2013. The cross-sectional data for the sub-indices S and A were collected from six selected villages: three islands near the creeks and three inlands-using random sampling technique. In order to ensure unbiased sampling, equal number of villages associated with agriculture and fishery sectors were identified and surveyed. The total household sample size was sixty. It comprised of 456 household members

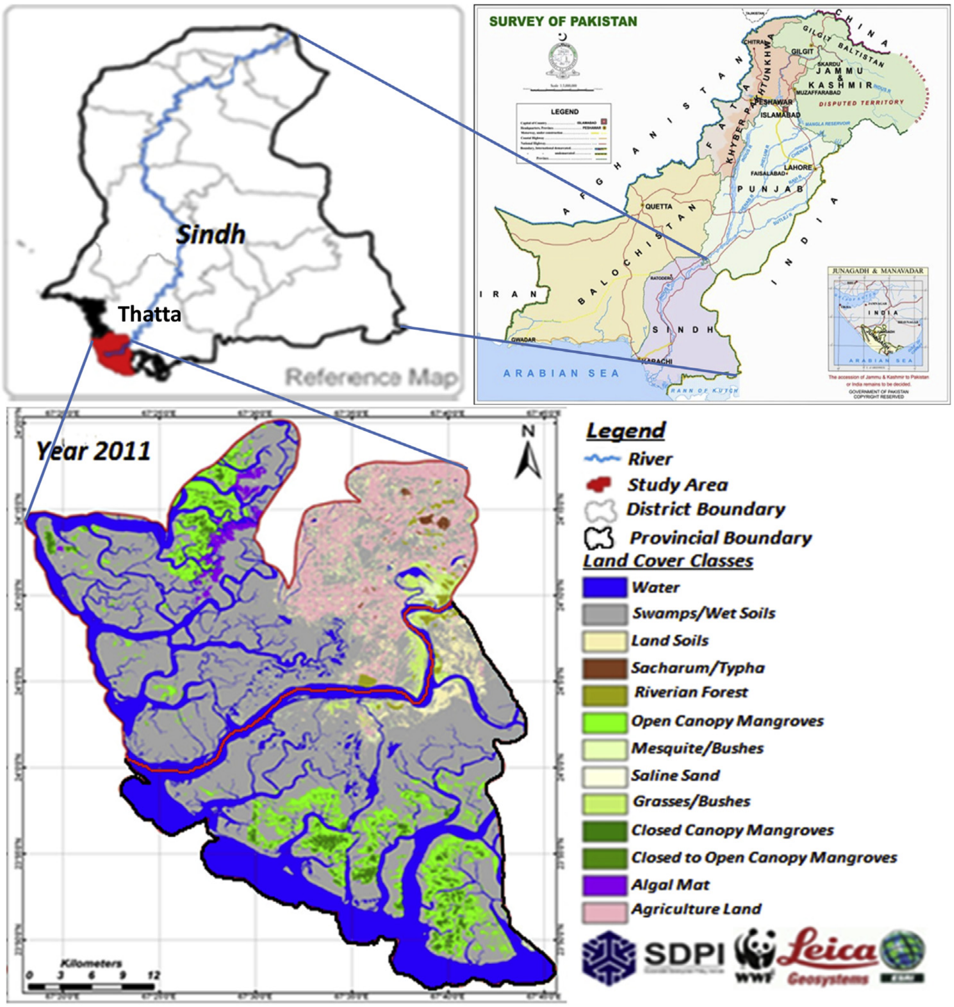

Fig. 1. The study area — Keti Bandar, district Thatta, Pakistan.

Table 1
History of disaster in district Thatta.

Sr. No	Type of disaster	Year	Severity	Area most affected (*Tehsil*)
1	Cyclone A2	1999	High	Keti Bandar, Shah Bandar, Kharochan, Jati
2	Drought	1998–2002	High	Whole district
3	Flood	2003	Medium	Whole District
4	Tsunami	2005	High	Keti Bandar, Shah Bandar, Kharochan, Jati
5	Drought	2005	Low	Thatta
6	Cyclone-Yemyin	2007	High	Whole District
7	Flood	2010	Very High	Whole District
8	Flood	2011	Very High	Whole District

Source: GoS (2008).

among whom 255 and 201 were male and female respectively. The sample household was randomly selected from different livelihood groups as mentioned in Table 2.

A well-structured mixed type questionnaire (both open and close-ended questions) was used related to exposure, sensitivity and adaptive capacity indicators. The questionnaire comprised of seven sections: (1) General information of the area, (2) Socio-economic conditions of the respondents, (3) Environment and Climate, (4) Fisheries, (5) Agriculture, (6) Mangroves forest services, and (7) Freshwater flow and sea intrusion. The survey was conducted with a team of six members, among whom two were recruited locally for better understanding of local customs, language and issues.

Table 2
Distribution of the households according to their main occupation/source of income.

Main source of income	Percentage distribution of household	Major livelihood activities
Farmer	44	Agriculture, Livestock, Horticulture, Poultry
Fisherman	39	Fishing
Wage labor	11	Fishing and agriculture daily labor
Service	6	Boat building, Net stitching and Weaving, Watchman, shop-keeping, Hotel owners, Technicians

Source: Based on structured interview of 60 respondent (Out of total 456 household member 228 were earning household) in the Keti Bandar of Indus Delta conducted during April, 2013.

The data for the sub-index E was obtained from the Pakistan Meteorological Department (PMD) for the period of 1951–2010. Since the network of meteorological stations in the Indus Basin is not concentrated (Hasson et al., 2014b), there was no station available within the study area. Therefore, the observed meteorological data from a nearby meteorological station i.e. Karachi-AP was used. Additionally, the mean monthly climatology of temperature and precipitation was obtained from the Climate Research Unit (CRU) global gridded observational dataset, which is available at 0.5° resolution (CRU 2012). For future climate change scenario, output of the PRECIS regional climate model forced with ECHAM4 General Circulation Model (GCM) for the IPCC SRES A2 (Business-as-usual) scenario was used. The data was dynamically downscaled for the South Asian domain (5°–50° North and 55°–100° East) at the horizontal resolution of 0.44° (~50 km) for the period of 1961–1990 (Base period) and for three future time slices of 2010–39 (F1), 2040–69 (F2) and 2070–2099 (F3).

4. Methodology

The literature on vulnerability and resilience assessments mainly combines input variables of sensitivity, exposure and adaptive capacity that would leads to potential impacts (Adger, 2001; Adger et al., 2004; Bowen et al., 2012; Pelling, 2011). This approach can provide better understanding of system's physical exposure to climate stressors; economic sensitivity to climate extremes or other environmental pressures; and, adaptive capacity to avoid adverse impacts of climate change (Pelling, 2011).

Different researchers have used different vulnerability assessment approaches in the context of adaptation to climate change: For example, Hossain et al. (2007) and Omo-Irabor et al. (2011) used index-based *GIS-based multi-criteria evaluation* approaches to understand socio-economic mangroves vulnerability with climatic and environmental indicators such as precipitation, temperature, water, soil quality, infrastructure, etc., in Bangladesh and Nigeria. In another study, Bunce et al., 2010, have used *Mental models* using participatory approach to develop linkages of climate change impacts on livelihoods of coastal communities in Africa. More recently, *Fuzzy Cognitive Mapping (FCM) Approach* and *Risk Hazard (RH) mapping* used for combining qualitative and quantitative information related to identified hazards to future scenarios (Murungweni et al., 2011; Hammaili et al., 2013). Some other widely used approaches include *Driver-Pressure-State-Impact-Response (DPSIR)* developed by OECD in 1993 and *System Approach Framework (SAF)* for coastal zones to understand complex systems (Human-Ecology-Climate-Development) interactions (Newton, 2012).

However, we have used the Composite Vulnerability Index (CVI) to provide an indicator-based estimation of socio-economic factors of the coastal area in relation to the environmental and climatic parameters (Gornitz et al., 1993; Cooper and McLaughlin, 1998; Heltberg and Osmolovskiy, 2011). The CVI approach employs IPCC definition of vulnerability (as a function of exposure, sensitivity and adaptive capacity) and allows to incorporate social, economic, and environmental indicators to current climate variability and integrate *adaptive capacity* as a component of vulnerability assessment (Pelling, 2011). Thus avoiding the more complex and data intensive techniques, CVI provides useful insight to community's need for adaptation as well as a proxy for understanding resilience to ongoing and future climate change impacts. Following Heltberg and Osmolovskiy (2011), we did not weigh the considered variables in the present study. The data of all the considered variables for sub-index *S*, *E* and *A* were normalized using the Eqn. (1) (Briguglio et al., 2008; Hasson et al., 2014a):

$$\boldsymbol{X}' = \frac{(\boldsymbol{X} - \boldsymbol{X_{min}})}{(\boldsymbol{X_{max}} - \boldsymbol{X_{min}})} \tag{1}$$

where X is any considered variable, X_{max} is the maximum value of the variable, and X_{min} is the minimum value of the variable among its investigated sample. The normalized variables were used to calculate the respective sub-indices (Exposure, $\overline{E}$, Sensitivity, $\overline{S}$, and Adaptive Capacity, $\overline{A}$) using the Eqns. (2)–(4) respectively. The index values were analyzed through composite analysis after categorizing the normalized indices at different levels to ensure consistency in the results (Comer et al., 2012; Hammill et al., 2013). Consequently, four categories of vulnerability levels were developed to categorize the impact of three sub-indices i.e., exposure, sensitivity, and adaptive capacity against vulnerability (Table 3). Finally, the CVI was calculated by using Eqn. (5).

$$\overline{\boldsymbol{E}} = \frac{1}{6}\left[\sum_{x=1}^{x=4}\frac{1}{12}\left[\sum_{m=1}^{m=12}\boldsymbol{E}'_{x,m}\right] + \frac{1}{2}\left(\boldsymbol{E}'_5 + \boldsymbol{E}'_6\right) + \boldsymbol{E}'_7\right] \tag{2}$$

$$\overline{\boldsymbol{S}} = \frac{1}{4}\left[\frac{1}{3}\left\{\sum_{x=1}^{x=3}\boldsymbol{S}'_x\right\} + \frac{1}{2}\left\{\sum_{x=4}^{x=5}\boldsymbol{S}'_x\right\} + \frac{1}{4}\left\{\sum_{x=6}^{x=9}\boldsymbol{S}'_x\right\} + \frac{1}{4}\left\{\sum_{x=10}^{x=13}\boldsymbol{S}'_x\right\}\right] \tag{3}$$

$$\overline{\boldsymbol{A}} = \frac{1}{8}\left[\sum_{x=1}^{x=4}\boldsymbol{A}'_x + \frac{1}{2}\left(\boldsymbol{A}'_5 + \boldsymbol{A}'_6\right) + \frac{1}{2}\left(\boldsymbol{A}'_7 + \boldsymbol{A}'_8\right) + \frac{1}{2}\left(\boldsymbol{A}'_9 + \boldsymbol{A}'_{10}\right) + \frac{1}{2}\left(\boldsymbol{A}'_{11} + \boldsymbol{A}'_{12}\right)\right] \tag{4}$$

$$\boldsymbol{CVI} = \frac{1}{3}\left[\overline{\boldsymbol{E}} + \overline{\boldsymbol{S}} + \left(1 - \overline{A}\right)\right] \tag{5}$$

where $\boldsymbol{E}'_x, \boldsymbol{S}'_x, \boldsymbol{A}'_x$ are all the normalized variables belonging to Exposure, Sensitivity and Adaptive Capacity sub-indices respectively (See Table 3), m is month of the calendar year, $\overline{\boldsymbol{E}}, \overline{\boldsymbol{S}}, \overline{\boldsymbol{A}}$ are the composite values for Exposure, Sensitivity and Adaptive Capacity sub-indices respectively and *CVI* is the composite vulnerability index.

5. Selection of indicators and their criteria for justification

5.1. Exposure indicators

5.1.1. Air temperature

Mangrove forests are dependent on optimal temperatures, which impact their biophysical processes such as photosynthesis, leaf formation, root development, flowering and fruiting etc. (Nicholls et al., 2008; Belkin, 2009; Bardach, 1989). Salinity is also directly related to increase in temperature that can trigger changes in the composition and distribution of the mangroves species, favoring only high salt tolerant species (Lovelock et al., 2010; Cohen et al., 2009). Further, fish distribution and size is altered by changing temperature coupled with precipitation patterns (Ayub, 2010).

5.1.2. Precipitation

The mangroves growth and extent in arid climate are highly dependent on precipitation patterns within and outside the ecosystem (McLeod and Salim, 2006). Low precipitation level increases salinity in seawater leading to anaerobic conditions which in turn adversely impact the mangroves growth and reproduction

Table 3
Categorization of vulnerability Levels (Adopted and transformed from Comer et al., 2012; Hammill et al., 2013).

Index value scale	Exposure/vulnerability	Sensitivity/vulnerability	Adaptive capacity/vulnerability	CVI
$0.0 \leq CVI \leq 0.3$	Low/Low	Low/Low	Low/Very high	Low
$0.31 \leq CVI \leq 0.5$	Medium/Medium	Medium/Medium	Medium/High	Medium
$0.51 \leq CVI \leq 0.7$	High/High	High/High	High/Medium	High
$0.71 \leq CVI \leq 1.0$	Very High/Very High	Very High/Very High	Very High/Low	Very High

cycles of the existing fauna (Rogers et al., 2005; Brander, 2007). The erratic patterns of rain and flooding are likely to reduce ecosystem productivity due to soil erosion, phytoplankton displacement, less sedimentation deposit and reduction in agricultural yields (Keller et al., 2009).

5.1.3. Sea surface temperature (SST)

An average warming of 0.3 ± 0.1 °C per decade was observed in the coastal areas of Pakistan; while projected increase in the global mean SST under IPCC SERS A2 scenario is around 2.6 °C by the end of 21st century (Singh and Sarker, 2002; Khan et al., 2004, 2008; Belkin, 2009; IPCC, 2007). This would significantly impact the intensity of cyclone, evolution of monsoons, sea level rise, and sea water intrusion; thus changing the salinity levels and land use patterns (Krishna and Roa, 2010; Khan et al., 2008; Chowdhury et al., 2010). Similarly, fish diversity, distribution, abundance, phenology and its spawning season all are closely related to SST variability (William et al., 2013).

5.2. Sensitivity indicators

5.2.1. Mangrove degradation

The overexploitation of mangrove forests led to its degradation making it one of the highly sensitive ecosystems in Pakistan. Almost 70% reduction in mangrove forest cover was witnessed in the past three decades; which is mainly associated with the cutting for fuel wood and clearing land for agriculture, housing and industrial purposes (Zaheer et al., 2012).

5.2.2. Water and sanitation

It was reported by the World Water Assessment Program (2009) that unavailability of safe drinking water and sanitation facility causes three million pre-mature deaths in rural areas of developing countries. The floods and droughts damage water and sanitation infrastructure and make the dependent population more prone to diseases, pathogens, agriculture runoff like pesticides and industrial effluents (Bates et al., 2008).

5.2.3. Fresh water flows

The fresh water availability is an important factor, not only for growth of mangrove forests but also for agricultural and fish production (Amjad et al., 2007). The decrease in freshwater availability causes a decrease in soil productivity and change in land use pattern consequently affecting the economic activities in the area (Dehlavi and Adil, 2012).

5.2.4. Cost of climatic disasters

The climate or weather induced disasters caused 80% more damages than the non-climatic one (Costello et al., 2009). Frequencies of climate disaster possess more cost to vulnerable communities of coastal areas (FAO and SUPARCO, 2011). For example, agriculture sector received a major setback during 2011 flood costing to US$ 1840 million, where the total reconstruction cost was estimated to be US$ 2747 million followed by housing and education infrastructure that were badly demolished (World Bank and ADB, 2010).

5.3. Adaptive capacity indicators

5.3.1. Consumption patterns

Consumption pattern become less diversified with the increased deterioration rate of natural resources, such as fish. Therefore, communities have to improve their coping capacity and to adapt to some resilience mechanisms. During emergency situation or a disaster, food production and access is the first thing being compromised in coastal areas (World Bank, 2005).

5.3.2. Income diversification

The major income sources in the coastal areas are fishing and agriculture; where the latter is under severe threat with decreasing fresh water flows in the coastal areas. Livestock is considered as the most valuable commodity as well as an addition for consumptive needs (WWF, 2005). If income is diversified, especially in case of off-farm income, 20–35% of additional income can be augmented to primary income (Azhar, 1995).

5.3.3. Dependency ratio

The dependency is negatively related to the adaptive capacity, as higher the dependency ratio, low is the adaptive capacity (World Bank, 2007). The adaptive capacity increases when communities have access to vocational trainings, as it not only decreases the dependency ratio but also the dependence on the natural sources of income. The linkage between adaptive capacity and dependency ratio is reported to be getting worse at the times of shocks or disasters (Piya et al., 2012).

5.3.4. Schooling or education level

Factors that contribute to low coping capacity due to climate change include low literacy rate and education level, weak institutions, low skill sets, and limited infrastructure (UNDP, 2006). There are no updated and authentic estimates of literacy level in this study area so far, but a general agreement is on a much lower level than the recorded ones (Dehlavi and Adil, 2012).

5.3.5. Infrastructure

Infrastructure status is a crucial variable in determining the adaptive capacity of any vulnerable population (Satterthwaite et al., 2007). It includes all kinds of basic human needs including transportation, coastal defense work, access to clean water and sanitation. General civic facilities in both rural and urban areas are crucial in order to reduce the vulnerability (Assaf, 2009).

5.3.6. Household assets holdings

For enhanced adaptive capacity, ownership of diversified, surplus and interchangeable assets plays a critical role (Ospina and Heek, 2010; Daze et al., 2009). Among physical assets, nature of houses (already considered under infrastructure), number and size of boats, and livestock are important, while for human and natural assets, qualification (and trainings) and land owned by households are considered of vital importance for assessing the adaptive capacity (Piya et al., 2012).

5.3.7. Family networks

The coping capacity of a community dealing with the climate change associated risks is highly dependent upon social factors like, social values, networks, customs as well as the social capital. Social networks either within a family or community are very effective tool for ascertaining the adaptive capacity (Sutherland et al., 2005). Particularly, during time of stress, kinship or good relationships between family members and members of the communities and networks can help to better cope with sudden environmental changes (Adger, 1999).

5.3.8. Migration

Migration is a socially embedded process, which is mostly perceived for bringing low adaptive capacity to the individuals or the communities coping with stressful changes in the environment (Adger, 1999; Brooks et al., 2005). However, considering the broader perspective of migration, it can be established that migrations enhance adaptive capacity of any community to cope with climate change (Barnett and Webber, 2009).

6. Results and discussion

6.1. Exposure index trends

The analysis of observed temperature record from Karachi-AP station suggests a consistent increase of mean annual air temperature by 1.47 °C during 1951–2010 period (Fig. 2a and b). The CRU data suggests a mean annual air temperature trend change of 1.441 °C over the study area for the period of 1901–2011. Similarly, the index values for 'monthly variability of temperature' and 'monthly average diurnal temperature range' rank high, showing increased incidence of abrupt changes in the temperatures (Table 4). These changes in temperature range can trigger many bio-physical processes in coastal areas such as its impact (mostly negative due to abrupt decline in temperature) on mangroves vegetative and reproductive growth, habitat loss that may force many species of fish, shrimp and crab to migrate, increase in salinity, reduction in agricultural yields, and fish catch and stock.

Annual total precipitation trend change is estimated as −78.4 mm over the period 1951–2010 from a nearby meteorological observatory (Karachi-AP) and −13.42 mm from CRU TS 3.2 dataset over the study area for the period 1901–2011 (Fig. 3a and b). As mentioned in results (Table 4), the frequency of extreme dry months in summer and spring seasons is high. The sensitivity of mangroves to precipitation exposure can therefore be categorized as moderate to highly sensitive and vulnerable.

The rise in sea surface temperature signifies an increase in vulnerability and exposure to climate change, rendering negative impact on fish biodiversity. Therefore, the local livelihood that is directly dependent on ecosystem services would likely to become more vulnerable.

6.1.1. Future climate change scenarios and likely impacts

While considering the index approach applied on observed climate parameters in Section 5.1, we develop climate change scenarios for looking into possible future vulnerabilities. This provides us the best-available means of exploring how human activities and the observed environmental changes may change the future composition of the atmosphere. The mean projected changes in temperature and precipitation are calculated over the study area for three future climate time periods that are F1 (2010–39), F2 (2040–2069) and F3 (2070–2099) with respect to the base climate time period (1961–1990). The analysis shows that the annual temperature will rise to 1.15, 2.4 and 4.19 °C by the F1, F2 and F3 time slices respectively (Fig. 4, column 2–4). In case of precipitation, it is found that it will increase twice the times of the base in F1 time period, 1.5 times of the base in F2 and 1.8 times of the base in F3 time periods. Such a large increase is attributed to very dry nature of the study area with precipitation rate of around 0.5 mm/day. The observed climatology for base period (1961–1999) for temperature and precipitation from the gridded CRU dataset is also given (Fig. 4, column 1).

The increasing temperature and decreasing precipitation throughout 21st century, consistent with people's perception on climate change (Fig. 5a and b), may further increase the value of CVI index in the study area, particularly, given the same management or governance level as well as socio-economic conditions.

6.2. Sensitivity index trends

The statistical results for exposure indicators and criteria mentioned in section 4 show direct linkages with the sensitivity indicators. Scores of all sensitivity indicators for the Keti Bandar fall into the category of extremely sensitive/vulnerable, except for two variables i.e. 'mangroves used per month as a fuel' and 'estimated per capita economic cost of disasters'. The low values for these variables are mainly due to consistently shrinking mangrove cover; rendering low accessibility to mangroves for the local communities and high rate of migration during disasters as shown in Table 4.

Moreover, inadequate and non-regulated release of fresh water flows from the Indus River below Kotri barrage allows sea water

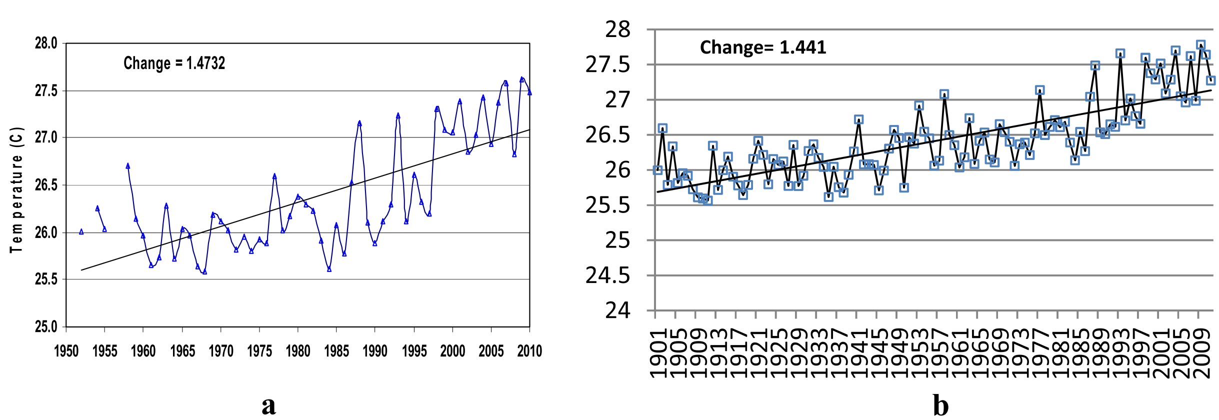

Fig. 2. a: Annual temperature trend of nearby meteorological station (Karachi-AP) for the period 1951–2010. b: Mean annual temperature trend over the study area between 1901 and 2011 taken from CRU TS gridded observational dataset.

Table 4
Sub-indices of CVI assessment, their indicators, related variables and their computed values. Based on structured interview of 60 respondents in the Keti Bandar of Indus delta conducted during April, 2013.

Sub-Indices and their Indicators	Variable	Variable Description	Index overall	Index for Agriculture	Index for Fisheries
Exposure (E)			**0.521**	**0.521**	**0.521**
Air Temperature	E1	Monthly Variability of Temperatures during 1951–2010	0.677	0.677	0.677
	E2	Monthly Average Diurnal Temperature Range	0.549	0.549	0.549
	E5	Frequency of extreme hot months (above 30 °C)	0.41	0.41	0.41
	E6	Frequency of extreme cold months (below −10 °C) months			
Precipitation (P)	E7	No of extreme dry days: Spring (P < 5 mm) Summer (P = 0 mm)	0.555	0.555	0.555
	E3	Monthly Variability of total precipitation	0.394	0.394	0.394
Sea Surface Temp.	E4	Monthly variability of Sea Surface Temp. during (1951–2010)	0.542	0.542	0.542
Sensitivity (S)			**0.652**	**0.638**	**0.669**
Mangrove Forests	S1	Sensitivity of mangroves in Keti Bandar	0.808	0.845	0.769
	S2	Accessibility to Mangroves	0.371	0.269	0.444
	S3	Mangroves used per month as fuel	0.024	0.001	0.050
Water and sanitation	S4	Share of households relying on unprotected water sources	0.908	0.787	0.758
	S5	Population deprived of sanitation Facility	0.967	0.938	1
Fresh Water Flows	S6	Change in Fresh Water flows	0.815	0.742	0.913
	S7	Effect of unavailability of Fresh water on Agriculture	0.804	0.935	–
	S8	Effect of unavailability of Fresh Water on Fish	0.848	–	1
	S9	Frequency of sea intrusion or inundation	0.649	0.610	0.692
Climatic Disasters	S10	Frequency of Natural Climatic Disasters	0.959	0.924	1
	S11	Intensity of Natural Climatic Disasters	0.881	0.903	0.857
	S12	Estimated per capita economic costs of these disasters	0.062	0.066	0.058
	S13	Percentage of population financially aided by different agencies	0.817	0.781	0.857
Lack of Adaptive Capacity (1-A)			**0.564**	**0.581**	**0.546**
Consumption Patterns	A1	Household Consumption per Capita	0.081	0.057	0.105
Income Diversification	A2	Herfindahl index of income diversification (higher value, more diversification)	0.141	0.161	0.122
Dependency Ratio	A3	Ratio of total number of people and number of people earning in a family	0.214	0.236	0.189
Education Level	A4	People educated above secondary level	0.017	0.031	0
	A5	Percentage Share of Literate People	0.195	0.307	0.067
Infrastructure	A6	Access to Basic Services	0.196	0.234	0.152
Assets	A7	Nature of Dwellings	0.85	0.875	0.821
	A8	Number of the Assets owned by the community members	0.65	0.453	0.875
Family Networks	A9	Level of cooperation within the family network within the village	0.983	0.969	1
	A10	Level of cooperation within the family network outside the village	0.883	0.844	0.929
Migrations	A11	Extent of Migration due to natural Disasters	0.8	0.844	0.75
	A12	Extent of Migration because of material reasons	0.783	0.719	0.857
CVI			**0.580**	**0.579**	**0.580**

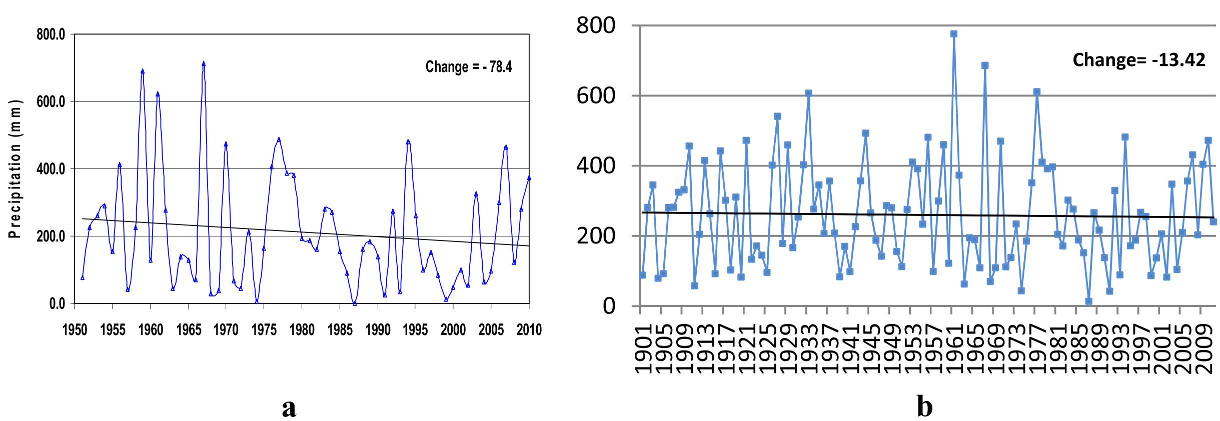

Fig. 3. a: Annual total precipitation trend taken from the nearby meteorological station (Karachi-AP) for the period 1951–2010. b: Annual total precipitation trend over the study area between 1901 and 2011 taken from CRU TS gridded observational dataset.

intrusion (Ali et al., 2009); impacting agriculture and fisheries production in Keti Bandar; rendering them highly sensitive/vulnerable. Frequency of sea water intrusion or inundation is recorded as high. If an individual variable of 'effects of unavailability of fresh water for fish' is considered for fishing community, the index value is 1. This value reflects a very high impact on the economy of community that depends entirely on fisheries.

Furthermore, considering the relationship between the exposure and cost of climatic disasters, the respective variables showed a high index values; referring to the fact that climatic disasters are quite frequent in Keti Bandar (Fig. 6a and b; Table 1), and the area was hit worst by the floods of 2010 and 2011. The climatic disasters faced by Keti Bandar were both frequent and intense (Ali et al., 2009). The communities were not financially supported during and after the disasters that made them highly sensitive/vulnerable, ending up in a high rate of poverty in the area. The situation of drinking water and sanitation in the study area is also worse. Almost none of the households in fishing community have access to

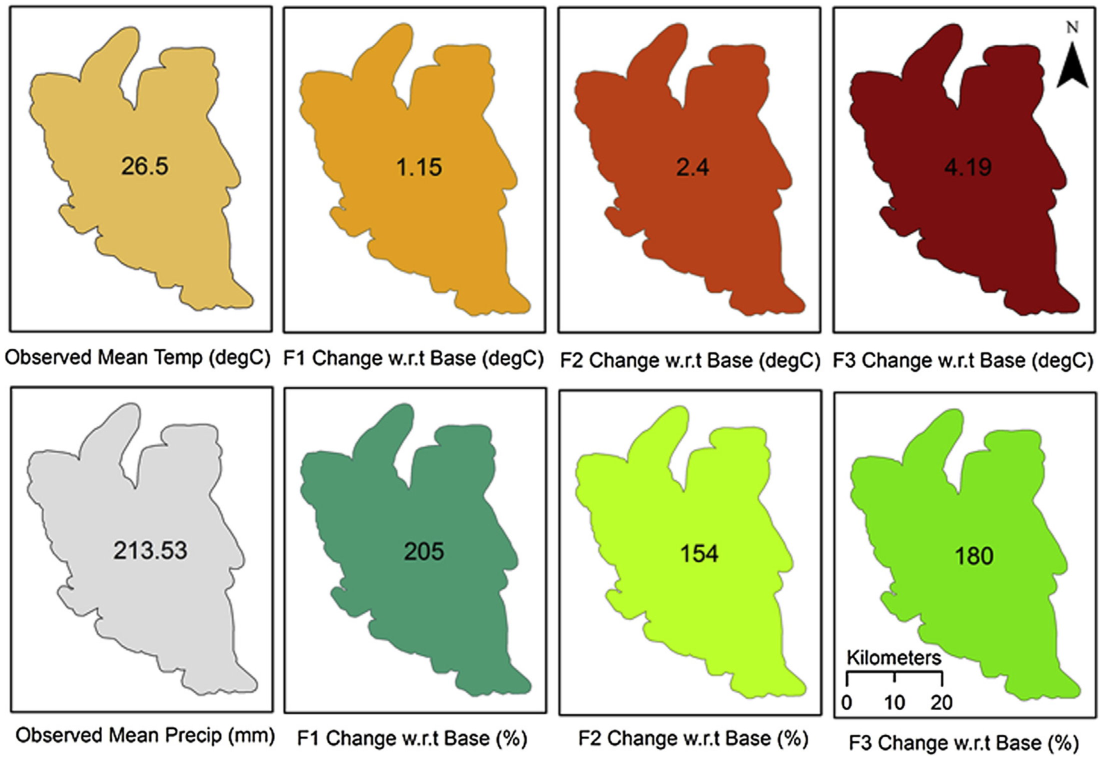

Fig. 4. Observed Temperature (°C) and Precipitation (mm) Climatology along with the absolute projected changes in Temperature (°C) and relatively change in Precipitation (%) for the three future climates (F1, F2, F3) with respect to base for the study area.

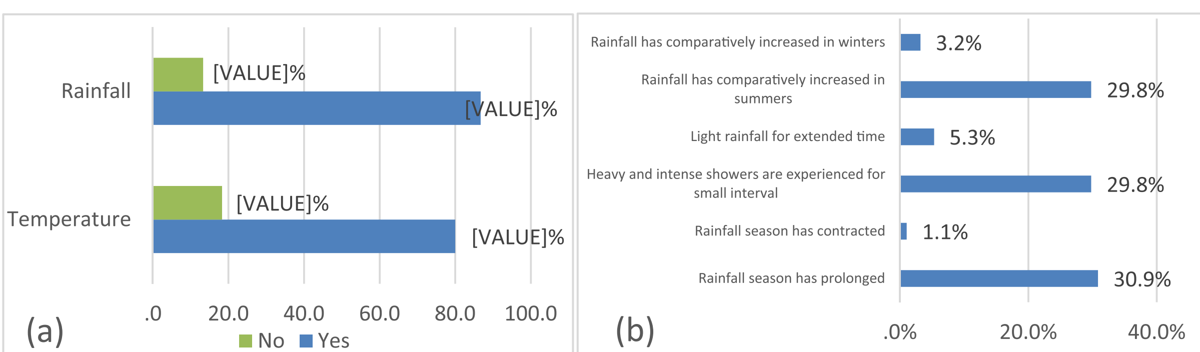

Fig. 5. People perception (%) on increase in temperature and rainfall (a) and shift of seasonal patterns (b) over last 30 years. Based on structured interview of 60 respondents in the Keti Bandar Indus delta conducted during April, 2013.

the sanitation facility and nearly the same situation was recorded in case of access to clean drinking water.

6.3. Potential impacts and adaptive capacity

The potential impacts that resulted from exposure and sensitivity indicators include devastation of mangroves, unavailability and low access to fuel wood, extinction of mangroves species due to increased salinity level, degradation of agricultural lands due to sea water intrusion, decrease in fresh water flows, decreased access to clean drinking water and almost absence of sanitation facilities, and increased frequency, intensity of climatic disasters and rising socio-economic costs associated with them.

Migrations in the Keti Bandar were recorded as high, depicting high adaptive capacity of the community, owing to the reasons that people were capable enough to migrate at the times of natural disasters to seek shelter and job opportunities away from their villages. According to the perception survey (Fig. 7a and b), decreasing trend of livelihood, unavailability of civic facilities, and seeking better job opportunities are the typical non-climatic factors triggering migration; however, among the climatic factors, the floods and heavy rainfalls are the main causes of migration (Fig. 8a and b).

It can be ascertained that the consumption patterns, income diversification, dependency ratio, schooling or education level and infrastructure (access to basic facilities) are the indicators reflecting low adaptive capacity/very high vulnerability in the community of Keti Bandar (Table 4). There are many reasons for these circumstances but low or nearly insignificant literacy rate (worst among the fishing community with an index value of 0) and low diversified and intervallic sources of income are the most significant reasons behind low adaptive capacity.

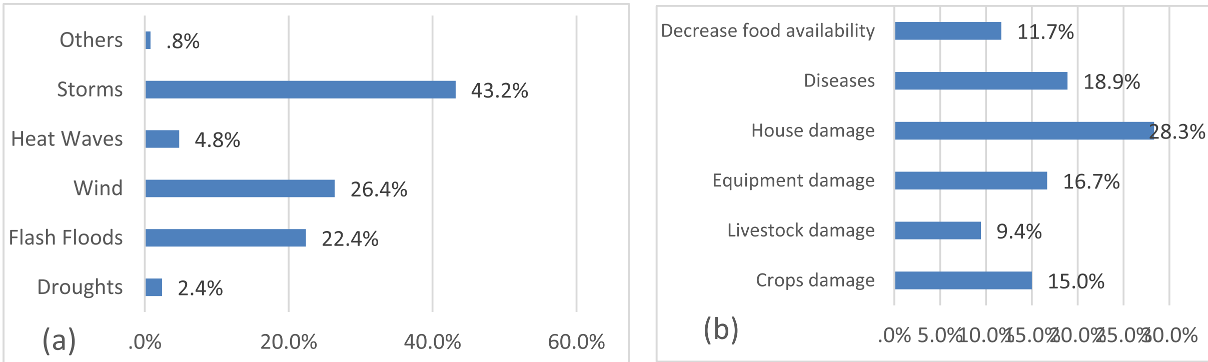

Fig. 6. People perception (in %) on type of natural disaster experienced (a) and type of damages/vulnerabilities (b) over last 30 years. Based on structured interview of 60 respondents in the Keti Bandar Indus delta conducted during April, 2013.

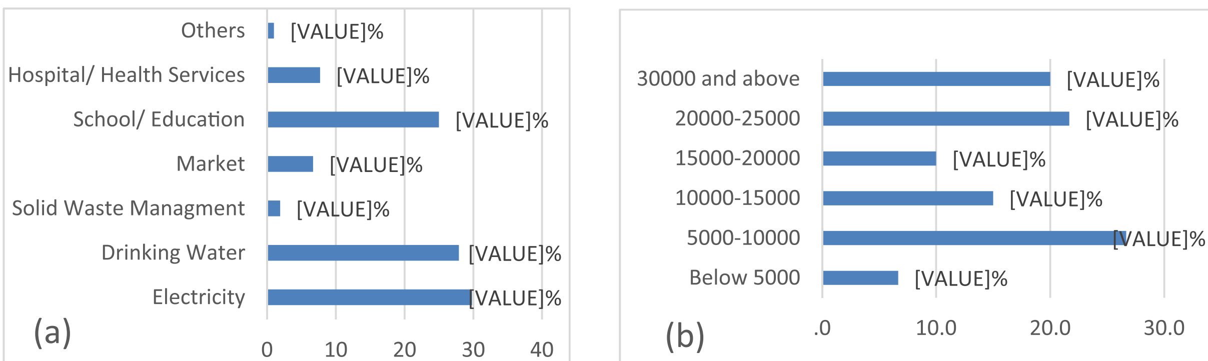

Fig. 7. Access (%) to basic services (a) and (b) Percentage monthly income by quintile (Income in Pak Rs.). Based on structured interview of 60 respondents in the Keti Bandar Indus delta conducted during April, 2013.

A low adaptive capacity is identified due to very limited access to the basic services (Index: 0.196) as depicted by Fig. 7a. Around 25–30% of the community members have access to very basic facilities like drinking water, school and electricity; while only 7% of the population has access to basic health services. This adds to low adaptive capacity of the local communities.

Over all, infrastructure (nature of dwellings), family networks, and migration are the indicators which enhance the adaptive capacity of the community and balance the adaptive capacity sub index when considered collectively.

7. Adaptation options and recommendations

In light of this vulnerability assessment, adaptation measures is the key to climate resilient development for the coastal communities in Pakistan. The National Climate Change Policy (NCCP) was introduced by the Government of Pakistan, in February 2013 providing the opportunity to refer and adhere to for all climate change related activities in the country. Based on the NCCP, the government is developing a program to identify priority adaptation activities. The following adaptation options can feed into the ongoing policy planning and implementation efforts:

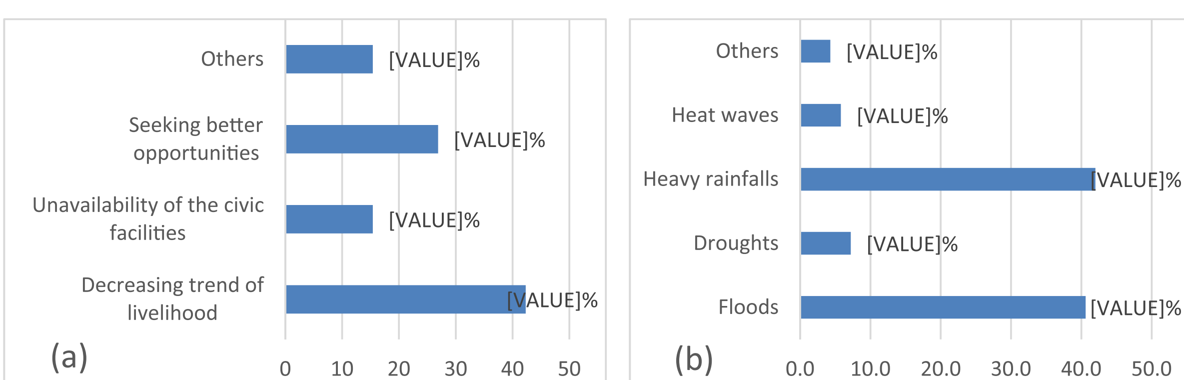

Fig. 8. General reasons (%) for migration (a) and Climatic reasons (%) for migration (b). Based on structured interview of 60 respondents in the Keti Bandar Indus delta conducted during April, 2013.

1. *Provision of safe drinking water facilities:* There is a need to understand that lack of access to safe and clean drinking water is not only a major cause of poor health status among the Indus Deltaic communities but also it is triggering both temporary and permanent out-migration in the coastal region (World Bank, 2005). Unfortunately, the ground water in the Indus delta is saline and unsuitable for drinking; and as a substitute communities have to drink untreated water from the irrigation canals, which are contaminated with industrial and agricultural effluents (SAFWCO, 2004; Ghazanfar, 2009). About 70 percent of respondents included in the study access drinking water from irrigation canals, supplied and purchased from private tankers. The situation becomes critical when water is not available in canals due to seasonal closure [at least five months in a year (Ghazanfar, 2009)] or used for agriculture purposes. Hence, coastal communities of Indus Delta needs proper water supply and its treatment facilities for year round. Such facilities can increase human capital and capacity to better adapt to risks and shocks related to climate change.
2. *Ensuring environmental flows:* Decreased fresh water flows in the past have greatly contributed to the degradation of the Indus delta ecology (Amjad et al., 2007). The resultant decrease in coastal ecosystem resources and services has shrunk the livelihood opportunities, causing widespread poverty and migration in the coastal areas. This is mainly linked with extensive irrigation developments upstream (Gowdy and Salman, 2011). In Water Accord enacted in 1991, provinces were agreed on to allocate 10 million acre feet water as environmental flows to protect the low riparian ecosystem. The accord is waiting to be implemented successfully. It is, therefore, highly recommended to ensure the water availability as 'environmental flows' for the Indus Delta, an important adaptation strategy supported by NCCP.
3. *Safeguard from climatic disasters and settlements in high-risk areas:* Keeping in view the vulnerabilities due to increasing number of extreme climate events, there is a need to develop a clear strategy that would mainstream climate change information (both scientific and local experiences) into planning processes essential for informed decision-making. It also forms the basis to develop an action plan to ensure proper and safe settlements for coastal communities that dwell in small and scattered villages usually around fringes of creeks highly vulnerable to natural calamities and even prone to medium level floods/storms. This will also ensure provision of civic facilities and protect life and property.
4. *Improving education access:* Education is a key to enhance resilience in communities both in pre and post-disaster situations (Striessnig et al., 2013) and therefore, greatly enhance the adaptive capacity to climate change risks and vulnerabilities (Wamsler et al., 2012). Thus, the government as well as private sector's involvement is essential for improving low education status of the area that would not only enhance human capital but also helped in diversifying livelihood options for alleviating wide-spread poverty.
5. *Capacity development for climate preparedness and innovations:* There is a need to strengthen coordination among national, provincial as well as civil society organizations for developing and implementing climate change adaptations and activities. For example, collaboration within research organizations (like National Institute of Oceanography, IUCN-Pakistan, Centre of Excellence in Marine Biology, etc.) having different technical capacities, is essential for evidence-based adaptation research. Similarly, different governmental departments (including provincial and federal forest, agriculture, coastal zone management authorities, fisheries, etc.) mostly working in silos require a culture of 'collective actions'.

8. Conclusion

This study assessed the climate change vulnerability of coastal communities in the Indus Delta of Pakistan while answering some key questions by relating community's perceptions with observed and projected climate change scenarios. We develop linkages between likely drivers of community's sensitivity, impacts and coping potential. Composite Vulnerability Index (CVI) approach is used in order to draw a general picture of vulnerable communities under changing climate in Keti Bandar. Based on this study, a number of conclusions can be drawn:

- Observed and projected changes in climate shows a consistent increase of mean annual air temperature (Fig. 2a and b) and declining trend in annual total precipitation (Fig. 3a and b). Variability in temperature, frequency of extreme events and sea surface temperature, which is ranked high in the study area, shows abrupt changes in exposure indicators (Table 4) and, therefore, be categorized as moderate to highly sensitive and vulnerable. This situation renders negative impact on ecosystem functions, fish biodiversity and local livelihoods.
- Though the scores of all sensitivity indicators for the Keti Bandar fall in the category of extremely sensitive and vulnerable (Table 4), they may contribute to community's sensitivity towards climate change. Notably, the inadequate and non-regulated release of freshwater flows from the Indus River impacting agriculture and fisheries production, reflects a very high impact on the economy of community, which is largely dependent on fisheries.
- In terms of coping potential the consumption patterns, income diversification, dependency ratio, schooling or education level and infrastructure (access to basic facilities) are the indicators which reflect low adaptive capacity/very high vulnerability among the community of Keti Bandar (Table 4). There are many reasons behind these circumstances, but low or nearly insignificant literacy rate (worst among the fishing community with an index value of 0) and low diversified and intervallic sources of income are the most significant reasons behind low adaptive capacity.
- Migrations in Keti Bandar were recorded as high, depicting high adaptive capacity of the community, owing to the reasons that people were capable enough to migrate at the times of natural disasters to seek shelter and job opportunities while away from their villages.
- The potential impacts that resulted from exposure and sensitivity indicators include devastation of mangroves, unavailability and low access to fuel wood, extinction of mangroves species due to increased salinity level, degradation of agricultural lands due to sea water intrusion, decrease in freshwater flows, decreased access to clean drinking water and almost absence of sanitation facilities, and increased frequency, intensity of climatic disasters and rising socio-economic costs associated with them.

Therefore, we recommend some key adaptation options that can be incorporated in the ongoing national efforts for developing climate change action plans at local levels. The recommendations focus on provision of safe drinking water and sanitation facilities, ensuring the environmental flows to the Indus delta, provision of safeguards from the climatic disaster, enhanced access to education, and adoption of the innovative livelihoods options in order to enhance the community's resilience to climate change in coastal areas of Pakistan.

a

b

Picture 1. a: Irrigation cannal in Keti Bandar, b: Water transported from irrigation cannal through tanker for drinking purpose in Keti Bandar.

Picture 2. Community toilet in Keti Bandar.

Picture 3. Survey team interacting with fishermen.

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