Appraisal of Climate Change Impacts on the Coastal Areas of Sindh Using Remote Sensing Techniques

'Aamir Alamgir, 'Moazzam Ali Khan, 'S. Shahid Shaukat,
'S. Jamil Kazmi, 'Salman Qureshi and 'Farheen Khanum

'Institute of Environmental Studies, University of Karachi, Karachi 75270, Pakistan

Abstract: This study focuses on the pattern of changes in climatic norms in the coastal areas of Sindh whose vulnerability is reflected by a number of severe climatological events that has not only influenced physical and biological environments of the area but has also responsible for serious socioeconomic problems. In order to interpret climatological impacts, both remote sensing and ground-truth measurements were employed. The metrological parameters used in the study were minimum temperature, ii, maximum temperature and the rainfall. The effect of these on available water resources, vegetation cover, land mass and dry land and degradation of Indus delta were examined. Yearly mean maximum temperature fluctuated between 32.3 to 35.1°C, while that of minimum mean temperature ranged between 18.8 to 20.8°C which revealed that mean minimum temperature was towards higher side. The average rainfall was quite low and the area is facing severe drought since last 3 decades with occasional cloud burst. The water bodies on an average comprise of an area of 5806.894 sq km. during 1972 to 2010. Overall marked reduction in water resources was observed that’s further supplemented the idea of severe drought prevails in the area. Mean vegetation cover of the study area from the period 1972 to 2010 was 1957. 64 sq. km. The minimum vegetation cover was in2000 while the maximum vegetation cover was observed in 2006. Except from 1988 and 1990 marked reduction in the vegetation cover has been seen. Changes is climatic pattern have resulted in dramatic changes in the vegetation. Species diversity has been reduced considerably and currently the vegetation is dominated by salt tolerant shrubs. It was found that family Chenopodiaceae and Tamericaceae were the largest families having greater abundance. A gradual increase in land mass area has been observed from 2006 to 2010 that’s shows total increment of 73.69%. However, from the data it has been depicted that the area would experience marked increase in barren land due to shortage of water and erratic rainfall pattern. The data further disclosed that the coast line is degraded at a distressing rate and the net coastline degradation from the period 2006 to 2013 was found to be 57.85 sq. km. The degradation of Indus delta is mainly due to reduced flow at downstream which allow accelerated sea water progression. The study reveals that the climatological variabilities are responsible for depletion of environmental resources that are exacerbating socioeconomic problems with increased level of poverty.

Key words: Climate Change - Sindh - Coastal areas - Remote Sensing

INTRODUCTION

Climate change is seriously felt around the world and now formerly recognized by IPCC [1]. It has been pointed out that there are twelve countries in the world, which are facing and expected to be faced the devastating effects of climate change, while Pakistan is one of those countries. Since 1900 the coastal areas of Pakistan has experienced rise in mean temperature from 0.6 to 1.0 °C while net reduction in rain fall up to 10 to 15% [2]. Sindh coastline is about 270 km [3] is suffered severely due to sporadic pattern of rainfall and acute shortage of water in River Indus which cannot satisfy the domestic and agriculture requirements [4].

Corresponding Author: Moazzam Ali Khan, Institute of Environmental Studies, University of Karachi, Karachi 75270, Pakistan. E-mail: sherwanis66@gmail.com.
The coastal areas of Sindh experienced a severe drought from 1996-2003. In addition, the coastal belt of Sindh has also recorded fourteen cyclones from 1970-2000. The latest cyclones named Phet (2010) and Neelofar (2014) landed at the coast of Sindh very recently.

River Indus is not only considered as lifeline of Pakistan but the entire agriculture particularly in the coastal areas of Sindh is largely dependent on flow of River Indus. River Indus was formed about 45 million years ago after the collision between the Indian and Eurasian plates [5]. The total length of the river is 3000 km (IUCN, 2003) while the total drainage area of the Indus River is 106 Mha. In fact, the river has changed its position several times when it formed about 45 million years ago after the collision between the Indian and Eurasian plates [5]. The major source of water in River Indus is the snowmelt that accounts for 80% discharge. It is estimated that approximately 80% of the River Indus flow occurs during June to September [6]. Seasonal and annual river flow is highly variable [7-9].

The coastal belt of Sindh is highly vulnerable for floods as the drainage basin is occupied for agriculture. However, the silt left after the floods have reseeded it extraordinary fertile. It has been reported that 178855 m$^3$ water enters the Indus basin annually of which 128282m$^3$ is directed for irrigation through canals where 35% of the water is lost during distribution [6]. The flow in River Indus particularly at downstream drastically reduced in the last few decades, which is mainly attributed by irregular rainfall and construction of physical structures in the upper riparian areas. In 1950 the average annual flow was 185022m$^3$ which has reduced to only 888m$^3$ in 2006. The annual sediment load before the construction of dams varies between 270 and 600 million tons which has now reduced into fractions [9-10]. Reduced flow of River Indus is responsible for the degradation of mangroves at a rate of 2% per year [9]. River Indus after covering a distance of 3000 km [11] finally enters into the Arabian Sea in the coastal district of Thatta, Sindh where it forms the fifth largest delta in the world that occupies an area of 60,000 ha. Seawater intrusion is enhanced due to the reduced flow in Indus that is affecting the deltaic system. It has been reported that seawater has introduced up to 67 km inland gravelly affecting not only the deltaic area but also resulted in groundwater contamination [12]. Before the establishment of extensive irrigation system of Indus delta the coastal district particularly Thatta was rich in agriculture productivity. Due to severe droughts in the past decades the fertile agriculture land is encroached by the sea and many of the areas are presently devoid of vegetation.

There are various climatological impacts on the vegetation that are constantly changing the vegetation density and diversity. The main climatological factors may include high temperature, reduced rainfall and high aridity. Among anthropogenic factors, overgrazing and harvesting of shrubs and small trees are common.

This study research covers two sub districts of coastal district Thatta in Sindh. These two sub districts are Keti Bundar and Shah Bundar. The total population of Keti Bundar is approx. 28000 and the number of households are 3915 while the population of Shah Bundar is 100575 [13]. District Thatta (KetiBundar and Shah Bundar) is least urbanized with only 11% of the population living in urban areas according to census of 1998.

The overall scope of this research is to study the pattern of changes in climatic norms in the coastal areas of Sindh whose vulnerability is reflected by a number of droughts and reduced rainfall. It has been noticed that these changes have drastically affected physical and biological environments of coastal areas of Sindh. In addition, socioeconomic problems are also emerging due to climate change.

In this context, a combination of remote sensing and ground-truth measurements, analyzed within a geographic information systems (GIS) platform, is found to be highly advantageous [14].

In the present study, the following meteorological parameters have been analyzed to observe the overall pattern of climate change in the coastal area of Sindh. The parameters analyzed include:

- Minimum temperature
- Maximum temperature
- Rainfall

The impacts of these parameters on water resources, vegetation cover, land mass and dry land and degradation of Indus delta were examined.

**MATERIALS AND METHODS**

The climatological data of last 48 years (1961-2008) were procured from Pakistan Meteorological department.
The climatological variables used in the present study were minimum and maximum temperature and the rainfall. As such, there is no metrological station available in district Thatta. The nearest metrological station is located in neighboring district; Badin, that share the boundary between Thatta. Therefore, in the present analysis data of district Badin was used. Moreover, before 1961 no records of metrological data were available at the station.

For a candid analysis of the coastal erosion in the study area, remote sensing techniques have been employed to extract the magnitude of eroded areas after the impact of recent climatic changes. We used the recently compiled data set, which is a collection of SPOT data that provides near global coverage with generally cloud-free images. Multi-temporal satellite images of the respective years were used for monitoring water bodies, vegetation cover, land mass, dry land and built-up land. For this purpose, the Google-Earth platform has been used to monitor the changes on the span of 10 years. The high resolution imageries of QuickBird and GeoEye have been downloaded on a higher resolution. In addition to that SPOT 2.5 meters and Landsat 30 meters imageries have been used to monitor the synoptic coverage.

The entire coast of the study has been reviewed in zoom-in tool with the help of the historical imagery tool in Google-earth. Each imagery zoomed-in to the extent of pre-pixilated condition. Both most old and most recent images have been procured. These files then imported in ArcGIS 10.1 and geo-referenced with the help of Geo-Referencing Tool, which was relatively a difficult task because of varying resolution in old and recent imageries. The imageries then exported to ERDAS Imagine 9.1 Software, overlaid and visually examined through blend, flicker and swipe tools. The selected imageries were then classified in the larger sets of classes through unsupervised ISODATA classification technique. The resultant classes were recoded and reclassified into smaller groups to extract dominant classes. As a result, the imageries were identified with significant changes were chosen for the further change detection analysis.

The eroded areas have been identified with the output raster in IMG format, on the basis of which the area has been calculated in square kilometers. The old and recent images along with the Change Detection IMG integrated in ArcGIS layout format to display the eroded areas very sharply. The output showed tremendous results in depicting the eroded areas very clearly. These classes were then converted into Tables to show the significant change in percent.

RESULTS AND DISCUSSION

Analysis of Climatological Variables: The data of minimum and maximum temperature are presented in Fig. 1 to Fig. 3. The mean maximum temperature of district Badin was 42.6°C reported in the month of May 1962, whereas, mean minimum temperature of Badin was 5.6°C observed in the month of January 1967. The mean year wise maximum temperature fluctuated between 32.3 to 35.1°C. While year wise mean temperature ranged between 18.8 to 20.8°C. The overall trend of mean minimum temperature was towards higher side that needs to be further investigated. In general the maximum temperature is within the range of 30.9 to 33.1°C, whereas mean minimum temperature range between 19.6 to 21.8°C.

The minimum precipitation in district Badin was 0.3 mm in January 1993 and the mean maximum precipitation reported was 459 mm in August 1979. In the first decade (1961-1970) the average rainfall in the area was 215.76mm. However, from 1971 -1980 gross reduction in the rainfall was observed where the decadal average was 185.58mm. This could be considered as severe drought spell. From 1981 to 2000 the trend was similar as in former decade it was 243.38 mm, while of later was 241.85 mm, respectively. The data from 2001 to 2008 again showed decline in the rainfall when the average came to be 168.8mm. However, in 2011 the area experienced severe cloud burst when the average rainfall of one day was 228.6mm. In general district Badin followed dry spell with severe drought as can be seen from Fig. 4. The decadal fluctuation in rainfall is presented in Table 1. From the Table 1 it can be seen that from 1980 to 1990 only 5 years showed rainfall more than 200mm. While, from 1991 -1999 only 3 years showed rainfall more than 200mm. However, from 2000 to 2008 there were only 2 years that showed the same amount of rainfall.

The minimum Relative humidity in district Badin was 17% in January 1967 and March 1973, while the maximum relative humidity was 75% in July 1961 and August 1994. In general, relative humidity fluctuates between 31 to 75%. The maximum and minimum wind velocity in district Badin ranged between 1.0 to 15.7 knots/hour. High wind velocity reported in the month of June and July. The wind velocity trends do not seems to have any significant change in wind velocity at Karachi and in the range between 6.5 to 8.8 knots/hr.
Table 1: Decadal fluctuation in rainfall (mm) in the study area

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<thead>
<tr>
<th>S.No</th>
<th>Amount of precipitation (mm)</th>
<th>Year</th>
</tr>
</thead>
</table>

Fig. 1: Mean minimum temperature of the study area (Badin district)

Fig. 2: Mean maximum temperature of the study area (Badin district)

Fig. 3: Mean of minimum and maximum temperature of the study area (Badin district)
Water Resources: Emerging trends in the water scarcity were carefully examined with respect to climatic variability in the study area. In addition to remote sensing, the analyses were further supplemented with field surveys and interviews conducted with the local farmers, government officials and representatives of NGOs.

The results of remote sensing pertaining to the overall fresh water resources available in the area are shown in Table 2 and Fig. 5-6. From the Table 2 it can be seen that in 1988 the water resources available in the area has increased up to 98.16%. This was due to heavy rainfall up to 226mm during the period of monsoon. It is interesting to note that in 1987 there was no rainfall at all recorded at the station. In the subsequent year, the trend continues and the rainfall was 318 and 351mm in the years 1989 and 1990 respectively. Later in 1990 up till 2006 marked reduction the water resources have been observed. In 2010, again there was flash flood in the entire country which has changed the hydrological regime of the area.

Pakistan has already traversed the verge of water stress and the condition become severe by 2035 [15]. However, these approximations would not describe the real scenario, as these forecasts were based on the amount of water availability and lower population density. It is anticipated that, the future situations become worse than they would expected [16].

The study area comprises of semi-arid to arid climate. The water availability in the area is particularly dependent on the monsoon system of which southwest monsoon brings adequate rain from May to September. Since the creation of Pakistan the monsoon system is highly disturbed and the rainfall pattern is quiet erratic while the spells of droughts are frequent and common in the study area. The surface water resources in the area are available in the form of River Indus and the associated canal system. The extensive creeks system is virtually devoid of water and the creeks are gradually become salinized as can be seen from Fig.5-6. Owing to reduced flow in River Indus at downstream the canal system of lower Sindh virtually devoid of water. During the drought spell, the situation even worse as was seen in 2000 to 2003. During this period, virtually there was no flow to support the ecosystem of the area, which allows progressive intrusion of the seawater towards land particularly in deltaic region [16].
Fig. 5: Changes in coastline of Sindh from 1972 to 1998

Fig. 6: Changes in coastline of Sindh from 1990 to 2010
As reported earlier, the frequency of occurrence of droughts has increased in recent years in the study area as very limited rain occurred from 1961-2008 which in fact confirming the extent of drought in the last 5 decades.

As a part of normal climate cycle of the area in earlier 3 decades since the creation of Pakistan the drought phase appears every other year within 10 years. This would mean that in one year there was enough rain while in other it was devoid of rain. After careful examination of the data and field conditions it has been noticed that the extent of drought persist even up to 5 years as was noticed from 1997-2000 where the rain was exceptionally low which has caused tremendous losses to agricultural productivity in the area. This also proves grave shortcomings in the water sector of the area that was responsible for occurrence of lethal diseases of both humans and plants. The drought conditions also responsible for food shortage and involuntary displacement of the people. Unavailability of surface water at the downstream of River Indus has rendered the seawater to progressively moves towards land as can be seen in Fig. 5 and 6. This condition is responsible for marked decline in vegetation cover and salinization of ground water aquifers. Nasir and Akbar [17] reported consistent and gradual decline in flow of River Indus from 1890 that results in loss of primary productivity of coastal ecosystems which has reduced to almost one-third.

Vegetation Cover: The results of vegetation cover in the study area are presented in Table 3. Fig. 5 and 6. On an average, the vegetation cover of the study area from the period 1972 to 2010 was 1957. 64 sq. km. The minimum vegetation cover was observed in 2000 when the vegetation covered an area 501.67 sq. km. The maximum vegetation cover was observed in 2006 when the vegetation was found on an area of 3296.66 sq. km. During 1988 and 1990 the vegetation cover has increased which was due to heavy rainfall in the two consecutive years that was more than 200 mm in average rainy days. However, in 2000 to 2010 marked reduction in the vegetation cover has been seen. This was the period when the area was facing severe drought which was attributed to loss of vegetation cover. However, from 2006 onward the period of wet spell started during which maximum vegetation cover was observed.

Due to the scarcity of rainfall, the area belongs to semi-arid region. The vegetation of the area includes open communities mostly dominated by shrubs, small trees or perennial herbs while a variety of annuals and ephemerals appear in summer. The main species of the mainland include Acacia senegal, Prosopis juliflora and Calotropis procera which appeared as disturbed vegetation on sandy plains. During the survey 69 inland natural plant species were identified belonging to 75 genera and 23 families.

In the hyper saline area (coastal area) the predominant terrestrial species includes Suaeda fruticosa, Aeluropus lagopoides, Arthrocnemum macrostachyum, Tamarix indica and Halostachys belangerana. In many areas Salvadora persica was also common, the presence of which indicates saline environment. The assessment revealed that Chenopodiaceae and Tamaricaceae emerge as larger families with respect to abundance in the study area.

As informed earlier that disruption in climatic scenario of the area the rainfall pattern becomes erratic which has resulted in the form of prolonged dry spells. A relevant example is Thar desert where there has been very little rainfall over the last three years. Due to high temperature and consequent increased evaporation from the soil surface, salinity is increasing due to which salt tolerant plants such as population of halophytes is in abundance and acquiring greater dominance in the vegetation.

Overgrazing and cutting of bushes and trees are other major causes of deterioration of vegetation. Therefore, climate change is emerging as one of the significant causes of marked decline in the species diversity. The general change in climatic pattern is that the area is facing extreme drought conditions in the form of prolonged dry spells and shorter wet spells. The vegetation is directly affected by drought. In particular, the seedlings of plants that are more vulnerable to adverse conditions such as impoverished soil moisture regime are more severely affected often resulting in mortality. Thus seedling survival rate is constantly declining causing lesser recruitment, thereby decreasing the density of species more sensitive to depleted moisture regime.
Table 4: Area (sq.km) of land mass in the study area

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Year</th>
<th>Area (sq.km)</th>
<th>Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1972</td>
<td>13272.6</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>1975</td>
<td>13396.6</td>
<td>-0.93</td>
</tr>
<tr>
<td>3.</td>
<td>1988</td>
<td>10305.03</td>
<td>23.08</td>
</tr>
<tr>
<td>4.</td>
<td>1990</td>
<td>7103.39</td>
<td>31.07</td>
</tr>
<tr>
<td>5.</td>
<td>2000</td>
<td>8094.64</td>
<td>-13.95</td>
</tr>
<tr>
<td>6.</td>
<td>2006</td>
<td>3599.55</td>
<td>55.53</td>
</tr>
<tr>
<td>7.</td>
<td>2010</td>
<td>6251.91</td>
<td>-73.69</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>8860.531</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td>3599.55</td>
<td></td>
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<tr>
<td>Maximum</td>
<td></td>
<td>13396.6</td>
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</table>

**Land Mass:** The average area cover under the land mass from the period 1972 to 2010 was 8860.531 sq km. The maximum land mass cover (13396.6 sq km) was observed in 1975. In 1988 and 1990 the area was reduced sharply up to 23.08 to 31.07%. In 2006 it was declined even up to 55.53%. Built up land were only marked in 1988, which comprises of 236.15 sq km. The results of land mass are reported in Table 4 and Fig. 5 and 6. The land mass area comprises of development of physical structures. This may include the development and extension of villages, towns and cities. Other facilities such as road network and telecommunication facilities are also included in this section.

As can be seen from Table 4 the gradual increase in land mass area has been observed. A net increase of 73.69% has been observed from 2006 to 2010 in the total landmass area. However, form the data no conclusive conclusion can be drawn except from the fact that land mass area is declining from 1972 to 2010 (52.89%).

**Barren Land:** Barren Land comprises of virgin land, which only has one third of the area covered with vegetation and can hardly support life forms. Such types of land comprises of thin layer of recent alluvial deposits where the soil type is sandy. This also represents rock area. Vegetation cover is highly sparse. Immediately after cloud burst the area flourishes with number of perennial grass species. Since the study, area has semi-arid climate with erratic rainfall, the vegetation cover is only limited with profound wind erosion. In general, barren land is classified on the basis of its location and circumstances. Sometime it may be overlapped with the agriculture fields devoid of crops and left fallow. In the present study the barren land included sandy areas, beaches near the sea and gravel pits.

The results of dry land are reported in Table 5 and represented in Fig. 5 and 6. The average dry land area of the period was found to be 702.85 sq km. The minimum dry land area was observed in 2010, which confirm the present findings that indicated the start of wet spell after 2004. Moreover, the study area has experienced severe flash flood in 2010 which has caused decline in barren land. The maximum dry land area was observed in 1975 when the area badly suffered from severe drought and the similar situation also exist in 2000 which was the period of extensive drought. However, the data depicted that the area would experience marked increase in barren land due to shortage of water and erratic rainfall pattern.

The people all around the world suffer badly from drought than any other natural hazard as the fertile land become barren due to shortage of water, which has serious socio-economic impacts [18]. However, the phenomena of drought is complex and least understood [19].

**Degradation of Indus Delta:** The delta occupied an area of 600,000ha and the 5th largest delta of the world [21]. The delta has now deprived of fresh water due to the construction of physical infrastructure at upper reaches of the River. This unsustainable development together with erratic rainfall has caused devastating effect on the deltaic ecosystem. The seawater also progressively approaching towards land and the silt load has been reduced tremendously due to unavailability of fresh water at downstream of the river. This has caused irreplaceable losses to ecosystem of the deltaic region [17].

Seawater intrusion in the Indus deltaic region is causing devastating effect on coastal ecosystem such as mangroves forests, loss of spawning ground of fisheries and other marine life forms. It could also have long-term socioeconomic implications in the coastal areas in terms...
Fig. 7: Coastal change in Indus river

...of threat to food production, deterioration of water quality and dilapidation of mangrove and coastal ecosystems. Many of the archeological sites of local and international importance found elsewhere along the coast of Sindh may become inundated which may cause cultural devastation.

The results of coast line degradation and the loss of Indus delta is given in Fig. 7. From the Fig. 7 it is clearly depicted that the coast line is degraded at an alarming rate. The net coastline degradation from the period 2006 to 2013 was found to be 57.85 sq. km.

The degradation of Indus delta is largely attributed to reduced flow at downstream due to which the sea water has already encroached up to 1,700 km² in the Indus delta in the last 50 years [22]. Flow in River Indus at deltaic region is insufficient to push the sea water at its original position. Intrusion of seawater also increased the salinity of ground water aquifers. The soils at the coastal areas become salinized thereby having no value for agriculture which is another cause of involuntary displacement of the local people. The situation becomes more devastating if the flow in the Indus will continue to inadequate.

During extreme weather condition particularly during monsoon high tides from the sea causing breaching of drains, which is causing devastating losses in the districts, Badin and Thatta. In Badin alone more than 500 villages inundated in the sea due to extensive flow of the sea towards land.

CONCLUSIONS

The major problem associated with the climate change impact is the reduction of fresh water resources in the area that has changed both the natural resource base and the livelihood patterns of the people, particularly the poor. Agriculture land has shrunken and those engaged in agriculture are now relying on fishing or other manual labour. The alarming situation is emerging as the communities are highly vulnerable and climate change is creating social unrest that needs to be addressed immediately. The floral diversity is reducing with respect to palatable grasses, trees and shrubs because of reduced supply of fresh ware in the River Indus, sea water...
intrusion, overgrazing and overexploitation etc. Salinity level in soil is on the increase, indicated by the dominance of halophytic species even in the mainland flora. The degradation of and shrinkage in forested area is occurring not only due to hyper salinity but local pressure of wood and fodder harvest. This is responsible for marked increment in the land devoid of vegetation cover.

**ACKNOWLEDGEMENT**

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**REFERENCES**

1. IPCC, Intergovernmental Panel on Climate Change (2007). Fourth Assessment Report, Climate change. WMO, UNEP.
