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The Effect of Global Warming (Climate Change) on Mangroves of Indus Delta with Relevance to other Prevailing Anthropogenic Stresses A critical review

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Abstract:

The present paper critically reviews the effects of global warming (climatic change) on mangroves of Indus Delta of Pakistan with particular relevance to other anthropogenic stresses prevalent in the area. A few decades ago they were rated as comprising the fifth largest mangrove forest of the world but now they rank below fifteenth on the list because of their fast degradation due to combined effect of sea level rise and other anthropogenic stresses. The sea level rise in Indus Delta is not only due to melting of glaciers and thermal expansion of water, but is also influenced and magnified by anthropogenic stresses like significant subsidence of the Indus Delta, sharp decline in Indus River discharge of water and sediments, overexploitation of mangrove resources by local inhabitants and timber mafia and rampant urban development. This is evidenced by the fact that the seawater has intruded far inland and more than a million acres of land have been lost to the sea. There has been insignificant increase in mangrove growth which may be attributed due to intensive mangrove plantation and also to global warming but overall the mangroves deteriorated due to the overwhelming effects of other stresses. Several cyclonic storm surges struck the Indus delta in the past century among which the one that happened in 1999 caused severe damage to mangroves and property and claimed several thousand human and cattle lives. In order to manage and conserve mangroves of the delta and to protect them from further deleterious

effect of global warming a number of strategies have to be adopted like increasing the flow of the Indus river into the delta, curtailing over exploitation of mangroves, regularizing urban development, mass plantations in denuded and adjacent coastal areas. Nothing significant can be done towards subsidence of the delta because it is an irreversible process, however, ground water extraction may be prohibited to avoid further sinking of the area.

Key words: Climatic change; Mangroves; Indus Delta; Sea level rise; Seawater intrusion; Hypersalinity; Subsidence

1. INTRODUCTION

Global warming, also referred to as climate change and green house gas effect, has been a continuous growing threat to life and ecosystems of the planet earth and is indeed one of the most challenging tasks of mankind to deal with. It is the gradual continuous increase in the average temperature of earth's atmosphere and its oceans due to the green house effect caused by accumulation of greenhouse gases like carbon dioxide, methane, nitrous oxide, ozone, chlorofluorocarbons and others in the atmosphere as a result of increasing industrialization and deforestation. The global surface temperature has increased from 0.74±0.18 ºC during the last century ending in 2005 (Solomon et al. 2007) and It is proposed and projected that in the coming decades global warming will further increase at a higher rate than before, that is, 1 to 6.4ºC by 21st century(Solomon et al. 2007). This will affect the world's ecosystems through bringing drastic changes in climatic pattern, such as increases in temperature, precipitation, frequency and intensity of cyclones tsunamis and storm surges, sea level rise, acidification of seawater and others. The average mean annual temperature over Pakistan has increased by 0.6 °C during the last century (Anonymous. 2010; Sheikh et al.

2011) and is expected to increase further by 5ºC over the Indus Delta by the end of the 21st century (Rasul et al, 2012) and according to a UN Report global warming may turn Pakistan barren in 40 years (Anonymous. 2008)

Mangroves are plants that are circum-tropical in occurrence, and prefer sheltered intertidal areas for their growth. They constitute an ecosystem which is unique with regard to being interfacial between marine and terrestrial habitats and, therefore, subject to diurnal variations in temperature, salinity, exposure and inundation. They constitute one of the most important ecosystems of the world both ecologically and economically. The total mangrove cover of the world has been estimated to be 13,7760,000 ha by Giri, et al. (2011) with an economic value of $200,000 - $900,000 per km² (Wells et al. 2006) and $1.6 billion annually in ecosystem services (Polidaro et al. (2010). Besides providing many goods and services to mankind, they also sustain about 80% of the global fisheries (Ellison, 2008) and serve as a sink of greenhouse gases. They fight back global warming through carbon sequestration at a higher rate than any other ecosystems on a unit area basis (Anonymous, 2015). It is estimated that as much as 25.5 million tons of carbon are sequestered by mangroves annually (Ong, 1993). Mangrove ecosystems are resistant and also resilient to environmental changes (Alongi, 2008), nevertheless, they are seriously affected by global warming mainly due to sea level rise, increase in atmospheric temperature and precipitation and other climatic disturbances like tsunamis, cyclones and storm surges (Gillman et. al. 2008)). The present paper deals with the effect of global warming on mangroves of Indus Delta of Pakistan, which are perhaps the most seriously stressed in the entire subtropical belt.

2. MANGROVE ECOSYSTEM OF INDUS DELTA

Mangroves occur all along the 300 km long southeastern coast of Pakistan bordering the very productive North Arabian Sea, extending from Karachi to Sir Creek at the Pakistan-Indian border which constitutes Indus Delta (Fig. 1). Its total area is 41, 440 km² but the active delta is about 6000 km² (600, 000 hectares), which according to Inam, et al (2007), has reduced to 1200 km² after the construction of three large dams, namely Kotri Barrage, Mangla and Terbela on the Indus river. It is fan shaped and is traversed by 17 major and numerous minor creeks. It is subsiding at a rate of about 2-4mm yr^{-1} mainly due to continuous decrease in Indus River flow of sediments (Haq, 1997). There exist a variety of landforms in the delta but the most common ones are mud flats, creeks, mangrove habitat and marshes. The mangroves grow mostly on mud flats intervened with a network of creeks and narrow water channels.

The mangroves of Indus Delta were rated as the fifth largest mangrove forest of the world a few decades ago (Snedaker, 1984) with a cover as high as 250,000 hectares (Champion and Seth, 1965; Mirza et al. 1988), but now they rank less than fifteenth on the list (Giri et al 2011) with a present cover of 98,014 ha (Giri, et al. 2015), indicating 2-3% annual loss. Nevertheless, they constitute the largest arid climate forest of the world (Ismail, et.al, 2014). Several anthropogenic stresses account for their drastic decline (Fig. 2), the foremost among them being a sharp decrease in the Indus river discharge into the delta. Some decades ago as much as 150 MAF or more Indus water used to reach the delta (Meynell & Qureshi, 1993) and now it is almost negligible except for occasional floods during monsoon season. This is because of the construction of several dams and barrages along the course of the Indus river to meet the increasing demands of the water for agricultural and industrial purposes by rapidly growing

population of the country in response to higher birth rate and also mass migration of people from India due to partition of the subcontinent in 1947. The alluvial flow of the river has also decreased concomitantly. Forty years ago as much as 400 MT of alluvium were brought into the delta but now it has reduced to less than 100 MT (Meynell & Qureshi, 1993; Saifullah, 1997). The importance of both freshwater and alluvium for growth of mangroves cannot be overemphasized (Pool et al. 1977; Khan & Aziz 2001, Saenger, 2002). Overexploitation of mangroves for firewood and fodder and urbanization also pose serious threats to them. Saifullah (1997) has already discussed in detail these and other stresses and also strategies to address them in the Indus Delta mangroves (Fig.2). But, unfortunately, these issues still exist and have even become more severe even after a period of more than a quarter of century. One very important issue affecting mangroves which has been neglected so far is subsidence of Indus Delta due to decrease in water and sediment discharge of the Indus River and also ground water extraction in the area. It is sinking continuously and has shrunk to about one tenth of it original size and cannot be restored to original condition. (Inam et al.2007; Syvitski et al 2009).

Earlier eight species of mangroves have been reported to occur in Pakistan (Saifullah, 1982), but, later, due to overexploitation of mangrove resources presently only following four species occur in the delta (Saifullah, 1997) with *Avicennia marina* obviously being always the most dominant (Anonymous,2014; Damhoureyeh and Ghalib, 2014).

1. *Avicennia marina* (90%),
2. *Rhizophora mucronata* (8%),
3. *Aegiceras corniculatum* (1.5%),
4. *Ceriops tagal* (0.5%)

R. mucronata and *C. tagal* almost disappeard from the delta, but were reintroduced into the area through efforts of Sindh Forest Departemnt (SFU) and IUCN-Pakistan.

Recently there have been two major attempts to rehabilitate *R. mucronata* in the Indus Delta by SFU so much so that they broke the world Guinness record by planting about 0.54 million saplings in 2009 and more than 0.75 million saplings during a single day on June 22, 2013 (Anonymous, 2013) near the Delta proper, Keti Bunder. But the results were not promising and did not show significant increase in the mangrove cover. A recent satellite study by Masood et al. (2015) showed that only the plantations resulted in only 1.6 % increase in the total mangrove cover. The reasons for this setback were mainly two. The first one is that they were planted in June in the midst of the southwest monsoon characterized by high winds and high wave action which may not have allowed proper rooting of the seedlings. Secondly, only one species *Rhizohora mucronata* was planted, especially during 2009, and not any other. If *A. marina* would have also been planted along with the survival rate would have been higher because monocultures are easily susceptible to environmental vicissitudes. Besides the habitat and the environmental conditions of Indus Delta do not favor the growth of *R. mucronata* otherwise it would not have been so poor in density as compared to that of *A. marina* (Anonymous,2014; Damhoureyeh and Ghalib, 2014).

The mangroves of Indus Delta are of great economic importance to Pakistan (Saifullah, 2004)and in order to save them from further deterioration and destruction it is imperative that the effect of global warming or climatic change on them be studied with especial relevance to other prevailing anthropogenic stresses. It may not be possible to restore the mangrove of Indus Delta to the original status when it was pristine a few decades ago, but certainly things can be improved significantly and further deterioration may be prevented.

3. EFFECT OF GLOBAL WARMING ON MANGROVES

The effects of global warming may be divided into two major categories; 1) short term effects and 2) long term effects with further sub-categories (Fig. 3).

3.1 Short term effects

These include extreme water events like tsunamis, cyclones, storm surges, etc. which may last for a periods of time ranging from few hours to several days. Cyclones, hurricanes and storm surges and others of similar types occur above the surface of sea and are wind driven whereas tsunamis occur under the sea and are seismic in nature. All these events cause physical damage or destruction to mangroves through defoliation and mortality (Gilmann, etal. 2008) especially those on the sea front.

During the last century more than fifty severe cyclonic storms developed in the Arabian Sea, but only 13 struck the coast of Pakistan during the last century (Rabbani et al., 2008). The storm of May, 1999 caused serious damages to mangroves and claimed as many 6,400 human lives and 2000 live stock and as many as 500,000 people were affected. About 600,000 hectare of land were also damaged, costing more than $6 million. The worst affected areas were districts of Thatta, Badin and keti Bunder comprising the Indus Delta.

3.2. Long term effects

These include, in general, gradual and continuous increase in atmospheric temperature, precipitation, concentrations of carbon dioxide and other green house gases and sea level rise.

3.2.1. Increase in Atmospheric Temperature

The average mean annual temperature over Pakistan has increased by 0.6 °C during the last century (Anonymous. 2010; Sheikh et al. 2011) and is projected to increase further by 5 ºC

over the Indus Delta in the 21st century(Rasul et al 2012 a). The Indus Delta region has been subjected to periods of draughts and floods in the past and their frequency of occurrence is expected to increase with time (Rasul, et al. 2012 b).

Increase in temperature affects mangroves in three different ways; increase in their growth, increase in their geographical distribution and changes in their phenology (Fig.3).

3.2.1.1 Increase in growth rate

An increase in temperature within the optimum range ought to increase growth of mangroves like any other living organisms. Mangroves already exist in the upper limit of temperature tolerance because they are circum-tropical in distribution, therefore, further increase in temperature beyond the optimum limit may decrease their growth (Alongi, 2008). Cheeseman (1994) observed decline in photosynthetic rate of mangroves species above 33 ºC. Clough et al (1982) and Andrews et al (1984) reported optimum leaf temperature range between 28ºC and 32 ºC and that photosynthesis was inhibited completely at temperature above 38 ºC. However, those growing in subtropical temperatures will be benefited. The growth rate of mangrove may have increased in the Indus Delta due to increase in temperature but other anthropogenic stresses like decrease in Indus River discharge of water and alluvial flow, overexploitation, urbanization, sea level rise and others (Fig. 2), on the contrary, should have decreased their growth more than the increase due to temperature alone.

3.2.1.2 Change in geographical distribution

Due to global increase in temperature the mangroves extend to higher latitudes in their distribution (Gilman et al. 2008), provided other factors affecting them are favorable. There is no

such evidence for the Indus delta mangroves, and Karachi Harbor (24°51′ N 67°02′ E) has always been the upper limit. However, due to seawater intrusion the mangroves have intruded far inland on the northeastern side. Recently an isolated pocket off mangroves, some 100 km away from the sea shore has been recorded (Saifullah, 2007).

3.2.1.3 Phenological changes

The seasonal pattern of mangrove growth will also be affected. Flowering and fruiting season may be earlier than before. The winter season in Indus Delta will be shortened due to late start and early ending because of increasing temperatures and its effects are already visible in crops of Pakistan (Rasul, et al. 2012 b).This will result in early flowering and fruiting in a shorter span of time which will affect negatively the productivity of mangroves. The flowering and fruiting seasons of different species of mangroves have been recorded by Rasool and Saifullah (2002) in Miani Hor, a locality close to Karachi but not located within the Indus Delta. However, no such studies have been made in the Indus Delta, except for Khan (1966) and Sheikh (1993) who reported flowering in *A.marina* starting in April-May. Presently the flowering is also initiated in the same period (Farooqui et al. 2012). There does not exist any published records of flowering in *A. marina* and other species earlier than 1966 in the past, therefore, nothing can be said about the phonological changes in the Indus Delta mangroves.

3.2.2. Increase in Precipitation

Precipitation increases the productivity of mangroves indirectly. It decreases the salinity of seawater within the mangrove habitat which favors their growth (Khan & Aziz 2001, Poole et al, 1977; Saenger, 2002). Besides the runoff from the land enriches the habitat with nutrients and enhance

mangrove growth. The overall global precipitation has increased with global warming and is projected that it will further increase by 25% in 2050 (Gilman et al. 2008), except in subtropical region where it is expected to decrease during the next century (Solomon et al, 2007).

There has also been a 25% increase in the rainfall during the last century in Pakistan (Sheikh et al, 2011), however, it may decrease in future because of the geographical position (Solomon et al 2007). The Indus Delta receives 50% less rainfall than the upper half of the country (Rasul et al. 2012) . As a matter of fact there have been negligible rainfall in the Indus Delta region during the last two years, 2014 and 2015 which indicates further possible decline in mangrove growth in future.

3.2.3 Increase in Carbon dioxide concentration

There has been a 35% increase in CO_2 concentration in the atmosphere during the last century (Solomon, et al., 2007). The effect of enhanced CO_2 on mangroves is mixed. It is supposed to increase growth of some mangrove species (Ball et al. 1997; Field, 1995) and not others, however, this depends upon other factors also. For example double CO_2 concentration had hardly any effect on mangroves in hypersaline habitats (Ball et al, 1997). According to Gilman et al. (2008) the effect of increased CO_2 concentrations on mangroves has not been properly studied and understood. True mangroves possess a C3 pathway for carbon fixation, and therefore, their productivity will increase with increase in partial pressure of CO_2 (Pernetta, J.C., 1993). Unfortunately, there do not exist any study on effect of CO_2 on mangroves of Indus Delta.

3.2.4. Increase in Sea Level Rise (SLR)

The sea level has been gradually increasing due mainly to thermal expansion of water and melting of the glaciers and sea

ice on the poles as a result of global warming. This is the most serious of all climatic change threats facing mangroves (Gillman et al. 2008). According to IPCC the increase was very gradual until the start of the industrial period, where after, it accelerated and during the last century it was as high as 1.7 ± 0.5 mm per year (Bindoff et al., 2007). It is projected to increase further in the 21st century (Solomon et al. 2007). The sea level rise at Indus Delta (Karachi) has been estimated to be 1.1. mm yr^{-1} during the last century (Quraishee, 1988) (Fig.4). Unfortunately, there has been no measurement of sea level rise in the beginning of the 21st century (2001-2016). However, in view of the increase in intensity of several other anthropogenic stresses over the Indus Delta which has already been mentioned (Fig.2), the sea level might have risen more than twice this figure. Haq (1997) mentions that due to the phenomenon of subsidence of Indus Delta alone the sea level rise may be as high as 3.61 mm yr^{-1}.

Glaciers in Pakistan occupy an area of about 16933 km^2 and feed five major rivers of Pakistan namely; Indus Jehlum, Satlaj, Chenab and Ravi. Due to continuous and progressive melting there has been a decline in collective discharge of these rivers from 189 MAF in 1922 to 92.6 MAF in 2001-2002, suggesting a decrease in water quantum of the glaciers (Jilani, et al. 2007) and also SLR

The SLR poses following threats to mangrove ecosystem of the Indus Delta (Fig.5).

3.2.4.1 Submergence or Inundation

Due to increasing sea level the mangroves will be submerged longer than they can tolerate resulting in their decline or death. The mangrove species possessing longer propagules will adapt to this situation better than those with smaller ones (Robert, et al. 2015) because they can avoid submergence.

The four species of mangroves of Indus Delta possess propagules of different sizes. The longest propagule is that of *R. mucronata* (30-60 cm) and next in decreasing size order are *C.tagal* (20-25 cm), *A. cormiculatum* (5-8 cm) and finally A. *marina* (2-3 cm). The first three species are very poor in occurrence in the Delta. Several attempts have been carried out on large scale to rehabilitate *R. mucronata* in the Indus Delta so much so as to break the World Guiness Record of mangrove transplantation but with only little success (Masood et al 2015). It is suggested that *R. mucronata* will establish itself in the Indus Delta with increasing sea level because of its longer propagules (Snedaker, 1990) and there is also a similar possibility for *C. tagal* for the same reason. *A. marina* will, however, will not be able to avoid submergence due to its smaller propagule and, therefore, retreat and colonize the new adjacent coastal belt intruded by seawater. The rate of colonization of mangroves on the adjacent coast will, however, depend upon the rate of sea level rise, topography of the habitat (Wongthong, 2008) and increasing soil salinity of the adjacent coast (Ellison, 1994).

3.2.4.2 Seawater intrusion

Due to increasing sea level the seawater intrudes inland and extend mangrove growth at the cost of other terrestrial vegetation. According to an estimate, more than a million acres of land have been eroded or lost to the sea which has also intruded as far as 100km inland (Saifullah and Rasool, 1997; Inam et al 2007)

Results of a survey conducted by the Government of Sindh indicated that over 486,000 hectares land were eroded or lost to the sea within Thatta and Badin districts of province of Sindh dislocating a quarter million people, and inflicting financial losses over 2 billion dollars. The seawater has destroyed at least one-third of the land. Recent estimates put

the figure at 567,000 hectares (about 1.4 million acres) of the land lost to the sea (Memon, 2004). According to UN Report global warming may turn Pakistan barren in 40 years (Anonymous, 2008). According to another estimate the province of Sindh harboring the Indus Delta has lost abut 3.5 million acres of land to the sea since 1956, and that the two coastal districts Badin and Thatta will be submerged by 2050 and Karachi by 2060 (Mandrio, 2015).

3.2.4.3 Inland retreat of mangroves

Mangroves retreat inland as a result of seawater intrusion due to SLR. Those species which cannot tolerate submergence or inundation will retreat hinterland provided there are no obstacles along the shores like coastal installations and other urban infra-structures. The rate of colonization of mangroves on the adjacent coast will depend upon the rate of sea level rise and topography of the habitat (Wongthong, 2008) and also soil salinity (Pernetta,1993) *Avicennia marina* is a pioneer species (Snedaker, 1982) whereas others like *R. mucroanta, ceriops and A. corniculats* are seral , therefore, *A. marina* is expected to colonize the adjacent coastal land of Indus Delta affected by seawater intrusion, more readily than other species. The Indus delta is spread to about 300 km along the seashores with about 130 km belonging to the coast of Karachi on the eastern most part of the Delta. Karachi is one of the largest city in the world and definitely the largest in Pakistan with a population of about 20 million and also its industrial hub. The coastal belt of Karachi houses many different types of installations and infra structure which would not allow the landward retreat of mangroves . However, the remaining part of the Indus delta belonging to district Thatta is free from urbanization and infra structures This will allow mangroves to retreat landward easily as is evidenced by the fact that the seawater has already

intruded as far as 100km in land (Saifullah & Rasool, 2007; Inam et al. 2007).

3.2.4.4. Increase in soil salinity

The salinity of soil increases landwards in areas intruded by seawater as a result of SLR and, therefore, it will have a deleterious effect not only on mangrove (Ellison,1994) but also on the adjacent terrestrial plants. Sea level rise also poses a major threat to mangrove ecosystems through sediment erosion, inundation stress and increased salinity at landward zones. Mangroves prefer less saline water for their better growth and Khan and Aziz (2001) showed experimentally that three mangrove species of Indus Delta preferred lower salinity for their better growth. *Avicennia marina* being a highly salt tolerant species (Snedaker, 1982) may therefore flourish in such areas.

3.2.4.5. Shore erosion

Shore or soil erosion in muddy habitats of mangroves is caused by several factors including strong wave action, over cutting of mangrove trees, decrease in sediment flow through runoff (Ellison, 1994) and urbanization. This results in shrinkage of mangrove cover. Sea erosion is very rampant in the Indus Delta specially in the environs of Karachi, not only because of the SLR but also due to several other anthropogenic stresses such as cutting of trees for fodder, firewood and timber, urbanization, pollution and others (Fig.2). The local inhabitants which are mostly poor fishermen exploit mangroves for fire wood and foliage for feeding cattle in excess of the sustainable yield. The timber mafia has been overcutting mangrove trees for commercial purposes such as illegal trading of fuel wood (Ram, 2010). It is a daily sight in the Indus Delta region people carrying boat loads and camel loads of mangrove parts for domestic and commercial purposes.

The other important factor contributing to soil erosion is a drastic decline in sediment discharge of the Indus River over past few decades. Some decades ago as much as 400 MT of alluvial sediments were deposited in the delta but later it has continually decreased over the years to about about 100 MT (Meynal and Qureshi, 1993; Saifullah, 1997). According to a recent estimate the sediment discharge of Indus Delta has reduced from 193 MT in 1954 to 13MT in 2003 and thereafter almost to nil (Inam et al, 2007).

3. 2.4.6. Change in species composition

Due to SLR the species composition and also the relative proportions of species both will change with time. Those species which could not withstand the deleterious effects of SLR will either succumb or decrease in their density while others not. Presently, and also in the past *A. marina* was the most abundant species in the Indus Delta, but due to sea level rise in the delta it may be partly replaced by *R. mucronata* and also probably by *C. tagal* which possess longer propagules than *A. marina*. The endangered species of mangroves *A. corniculatum* (Saifullah,1999), which is extremely poor in occurrence, will suffer the most and may even disappear from the delta.

3.2.4.7. Change in zonation pattern

The vertical zonation of mangroves along the shore will also change because of different responses of different species to the aforementioned stresses.

Due to the overwhelming preponderance of *A. marina* and very poor occurrence of the remaining species there does not generally exist any species zonation pattern in the delta. It is all over *A. marina* everywhere except for very few localities. There is of course zonation of various size groups of *A. marina*, with larger plants facing the waterfront and smaller ones hinterland (Saifullah et al, 1994), most probably due to

increasing soil salinity landwards. Saifullah and Rasool (2002) reported occurrence of *A. marina* on the water front and *R. mucronata* and *C. tagal* behind it in, Miani Hor, a locality close to Indus Delta. However, due to sea level rise, *R. mucronata* may occur on the water front and *A. marina* landward. This may most probably due to the difference in size of the propagules of the two species which has already been discussed (Robert et al., 2015).

3.2.5. Effect of Subsidence on Sea Level Rise

The sinking of coastal areas is not only due to sea level rise but in some fringing deltaic plains especially those of Southeast Asia it may also be due to subsidence (Schmidt 2015). It is the lowering of land surface due to human activities such as groundwater extraction, fossil fuel extraction, seawater intrusion, industrial development and may surpass the effect of sea level rise significantly in submerging coastal areas. According to Syvitsky et al (2009) The Indus Delta has already collapsed and may likely be never restored to its original state due to subsidence (Renaude et al, 2013). The Indus river runs most of the year dry except for about 140 days due to extraction of water upland mainly for agriculture and industrial uses with the result that the delta has reduced to one tenth of its original size (Schmidt, 2015). During the last few decades the annual discharge of Indus has reduced from 110 km^3 to 37 km^3 down he Kotri Barage contributing hardly any sediment to the delta due to construction of three large dams on the river, namely Kotri Barage and Mangla and Tarbela Dams (Inam et al, 2007). As a matter of fact presently less than 10 MAF water reaches the delta (Inam et al. 2007). The intruding seawater has made millions of acres of land lost to the sea contaminating ground water and agriculture loss and displacement of hundreds and thousands of people (Inam et al. 2007). According to an estimate less than one fifth of the sediment flow of 1940s

reaches the delta (Pernetta, 1993) which will increase soil erosion. A few decades ago as much as 400 MT of alluvial sediments used to reach the delta (Saifullah, 1997) but currently the Indus River hardly contributes any sediment to the delta (Inam et al. 2007). Haq (1997) gave a rough estimate of rate of subsidence of about 2-4mm per yr in the Indus delta and suggested that the actual sea level rise will range from 3.1 to 6.1mm yr^{-1} instead of 1.1. mm yr^{-1}(Quraishee, 1988).

4. CONCLUSION

Alongi (2008) divided the mangroves of the world into two groups, least vulnerable and most vulnerable, on the basis of the effect of climate change on them. He included mangroves of the Indus delta in the first mentioned group most probably due to the fact that it is located in a macro-tidal area that receives significant river discharge. In fact the Indus Delta mangroves are now one of the most vulnerable forests in the world not only because of global warming alone but also because of interaction of several other anthropogenic stresses like drastic decrease in Indus river flow of water and sediments, subsidence of the delta, over exploitation of mangrove resources. All these factors have resulted in increased erosion and submergence of the mangrove habitat and, therefore, magnified the effect of SLR. As a matter of fact more than a million acres of the Indus delta has been lost to the sea (Memon, 2004) and mangrove cover decreased from 250,000 hectares (Mirza et al, 1988) to about 98,000 hectares (Giri et al. 2015) within the past few decades. Saifullah (1997) has suggested a number of strategies to address these issues (Fig. 2) but to no avail. As a matter of fact these stresses are becoming more and more serious with time. The Indus River water flow and sediment discharge into the delta both have been continually declining over the years and now have reached negligible quantities (Inam et al, 2007). The

cutting of mangrove trees for fire wood, fodder and timber is still going on unchecked. Subsidence of the Indus Delta may be perhaps the most serious problem of them all for increasing the SLR because of rate with which it is occurring and also due to the fact that it is an irreversible process (Schmidt, 2005). Haq (1997) estimated that the SLR in the Indus Delta may have increased 3.1 to 6.1 mm yr. from the figure of 1.1mm yr^{-1} given by Qursaishee (1988) due to subsidence alone. Unfortunately, there have been no measurements of sea level rise in the Indus Delta since 1988 (Quraishee, 1988), but it is speculated that it ought to be several times higher than the original figure. Due to SLR the inland retreat of mangroves will not be same along the Indus Delta. Along the 130 km coastline of Karachi, which is the industrial hub of Pakistan, the mangroves will not be able o retreat because of the presence of different infrastructures and coastal installations. However, This will not be a problem in the remaining larger south western part , including the delta proper, because the area is still pristine and rural without any industrial development.

The species composition of mangrove of the Indus Delta will probably remain the same, however, their relative proportions of occurrence and zonation may change. The species with longer propagules like *R. mucroanta* and *C. tagal* may become more relatively abundant than what is now (Anonymous 2014 ; Damhoureyeh, et al. 2014) because of the SLR but overall *A. marina* will remain dominant because it will occupy neighboring coastal areas intruded by the seawater. As regards zonation, *A. marina* will occupy preferably inhabit landward sites whereas *R. mucroata* the water front.

Mangroves are resilient to climatic change and in several areas of the world their growth has even increased as a result of global warming **(**Godoy & de Lacerda, 2015). The increase in temperature, precipitation and CO_2 may have increased mangrove growth of the Indus Delta. As a matter of fact

insignificant increase in growth of the mangroves have been reported by (Giri et al 2011; Damhoureyeh, et al. 2014;) which may also be attributed to intense plantation of mangroves in the area. But, overall the mangrove cover is reduced drastically not only because of SLR alone but also due to other anthropogenic stresses like decreased flow of the Indus river into the Delta, subsidence and rampant overexploitation of mangrove resources in the area (Saifullah, 1997).. Reforestation of denuded areas will also help significantly in maintaining the extent of mangrove cove. As a matter of fact two major attempts of mass plantation of mangrove seedlings in the delta were made recently (Anonymous, 2013) to increase the mangrove cover but, unfortunately, no significant success has yet been achieved (Masood et al, 2015).

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7. Captions for figures

Fig.1. Recent map of Indus Delta showing mangrove cover and creeks (modified after Masood et al. 2015).

Fig.2. Management issues of Indus Delta mangroves and strategies to address them.

Fig. 3. Different types of effects of global warming (climate change) on magroves.

Fig. 4. Mean sea level trend along Karachi (Quraishee, 1988).

Fig. 5. Different types of effects of sea level rise (SLR) on mangroves.

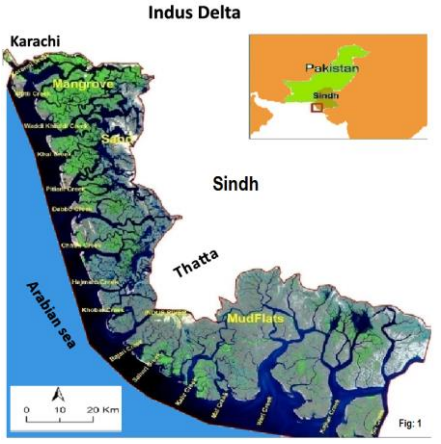

Figure 1

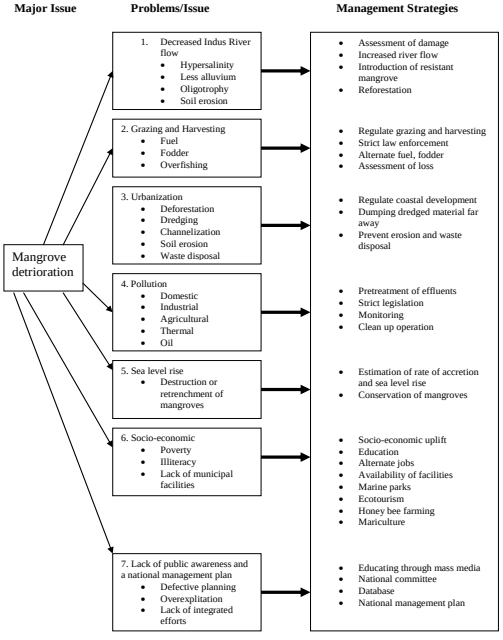

Figure 2

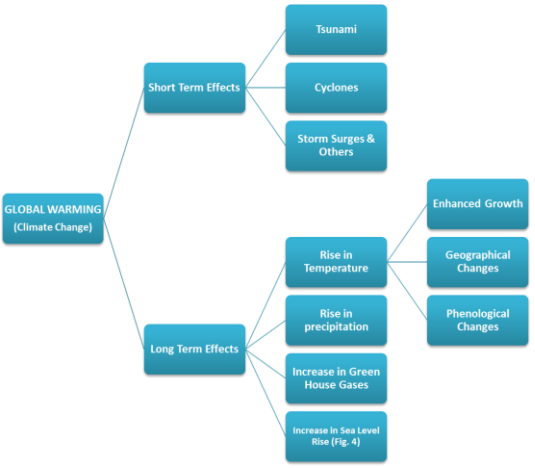

Figure 3

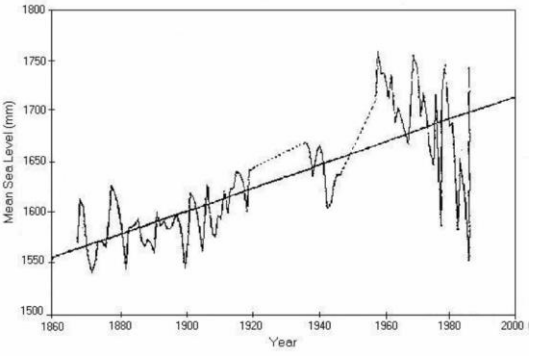

Figure 4

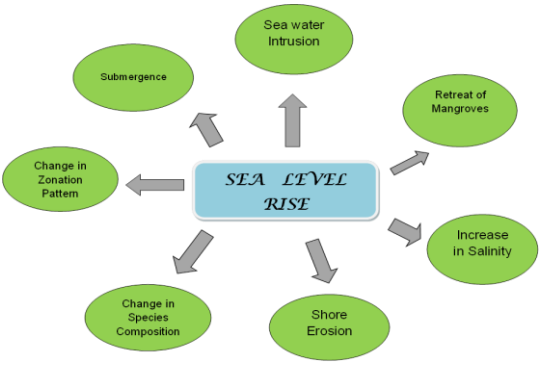

Figure 5