Climate Change

Assessing the impact of seawater intrusion on Soil, Water & Environment on Indus delta using GIS & Remote Sensing Tools

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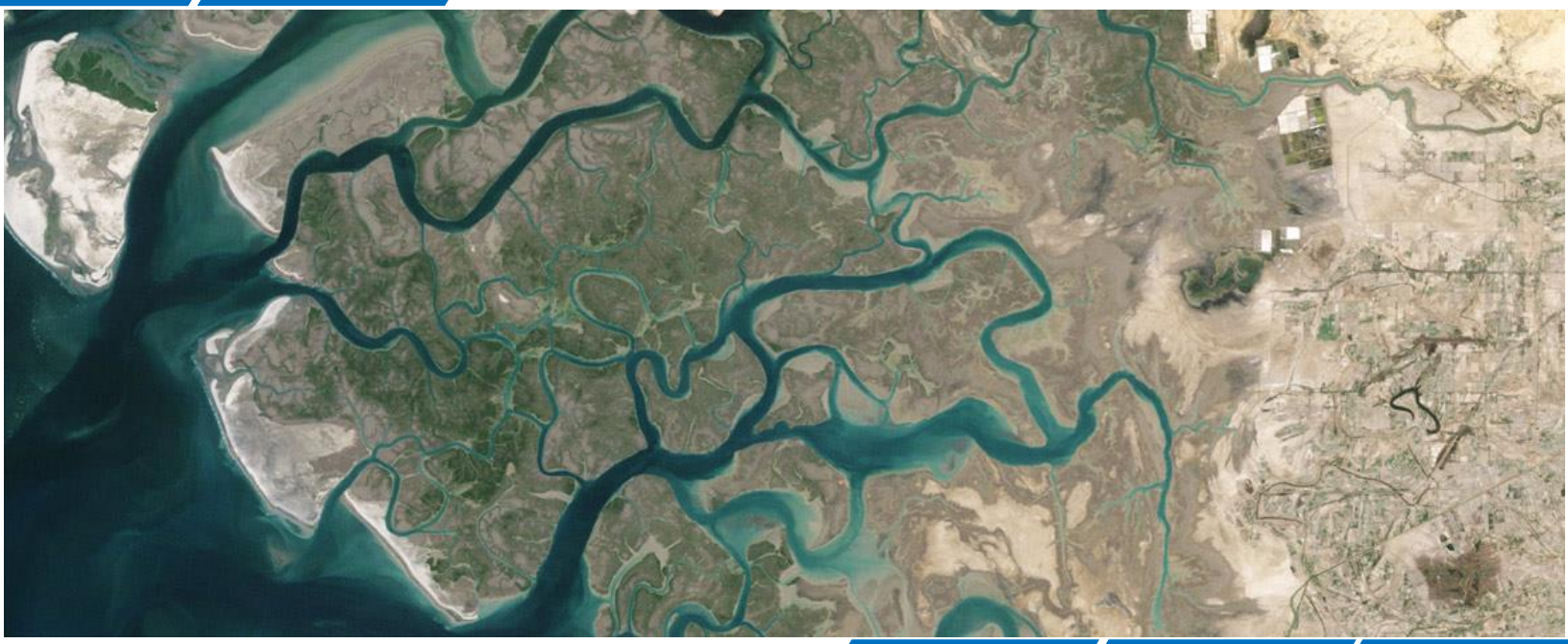

EXECUTIVE SUMMARY

Indus Delta, a designated Ramsar wetland, is the 5th largest delta of the world which spreads from Sir Creek in the east to Phitti creek in the west with the apex at Banoo town district Sujawal, Sindh, Pakistan. This fan-shaped delta supports seven[th]largest mangrove system in the world in vast tidal mud floodplains. No doubt mangrove forest system of the Indus delta is largest in arid regions of the world. The shoreline of the delta is exposed to withstand the highest average wave energy compared to other major deltas in the world. At a depth of 10 meters from the Indus delta shoreline, waves with the power of about 950 joules/sec/unit crest width are generated. The Indus Delta is reported as one of the world's most vulnerable large deltas. Due to a decrease in the river flows to the delta and resulting in a reduction in sediment deposition, subsurface seawater intrusion, land subsidence, and sea level rise and low rainfall due to climate change and anthropogenic activities, one of the largest ecosystems of the world is shrinking and degrading. During flourishing days of Delta, there were seventeen river mouths (creeks) which have now decreased to only two active creeks *viz*. Khobar and Khar. The active delta occupied an area of about 1.29 million hectares in 1833 which has now shrunk to only 0.1million hectares (about 92% reduction in the area).

Most of the reports about the gravity of problem are based on sampling surveys conducted time to time without any scientific evidence and application of latest scientific tools and techniques. Hence, there is significant variability in the data about land, water, vegetation and socioeconomic conditions of the coastal communities affected by seawater intrusion. Without any scientific approach/evidence, these reports are usually not considered worth and hence do not get due considerations from the policymakers. Hence, keeping in view above facts the present study was conducted to assess the impacts of seawater intrusion on freshwater, land, vegetation, environment and socio-economic conditions of the people using remote sensing and geospatial tools so that to develop a strategic action plan for mitigation and adaptation measures to save the biodiversity of delta, mitigate adverse impact on environment and other socio-economic conditions of people under current and future climate change scenarios.

The first most difficult task was a delineation of the boundaries of Indus delta as different researchers have delineated different boundaries and given different areas of the delta. Based on the old maps of Talpur (1833) and British era (1893), the Indus delta was delineated taking Bano as an apex of the delta while Sir Creek on the East and Phitti Creek on the West as two bottom points of the delta. The active delta occupied an area of about 1290 sq. km in 1833.

The vegetated area of Delta during the month of February varied between 2568 km^2 (19.6% of the entire delta) during 2015 and 47000 km^2 (35.9% of the delta) in 2010. No specific trend in temporal variation of vegetation was observed as it increased gradually from 1990 to 2010, but later it decreased significantly. The area covered with mangrove forests was 103413 ha or 16% of tidal floodplains during 1990 which slowly decreased to 63296 ha or 9.81% of tidal floodplains in 2005 which again increased to 81324 ha or 12.6% of tidal floodplains in 2017. Nearly 60% of the tidal floodplain was barren in 2017 while about 31.5% was under water. Dense mangrove forests covered only 36245 ha or 5.6% while sparse forests are on 45079 ha or 7% of the tidal floodplains. Thus, mangrove forests occupied only 12.6% of the total tidal floodplains or about 6.2% of the Indus delta.

On average, there was an increase of 1.74 ^{0}C in Land surface (LST) of the Indus delta in last 27 years. There was a fair but negative statistical correlation between normalized difference vegetation index (NDVI) and the LST of the delta with a coefficient of determination of R^2 = 0.65. Mean monthly air temperature of Indus delta from February to November for the period 1991-2016 was 0.7 to 1.3 ^{o}C higher compared to period 1960-1990. While the mean monthly temperature in December and January has dropped 0.6 to 0.7 ^{o}C (3 to 4%) for the period 1991-2016 compared to the period 1961-1991. Thus, summers of the delta are getting warmer while winters are turning colder. A significant decrease up to 23% in mean monthly rainfall was observed during the period 1991-2016 for June, July and August compared to the 1960-1990 period. While an increase in mean monthly rainfall up to 100% was observed for September and October during the later period compared to 1960-1990 period. The analysis of river flow below Kotri barrage revealed that about 80% of Indus river flow to the deltais decreased from 1935 to now.

Indus delta is dominated with soils which have fine textural class. It reflects that silty clay and clay loam textural classes are dominant in the top 0-20 cm layer of the soils. About 44.5% of soil samples hade silty clay, and 23.6% of soil samples had clay loam, 8.1% soil samples had clay, 7.2% had loam, 7.2% had silty clay loam, and 6.3% had silt loam texture. The dry density of soil in 0-20 cm soil depth varied from 1.20 to 1.40 g/cm^3 with an average value of 1.30±0.008 g/cm^3. EC of 56 to 66 % soil samples collected from 0 to 60 cm depth of the delta was beyond the permissible limits given by FAO. Similarly, pH of 14 to 17% and ESP of 72 t0 79% soil samples was beyond the permissible limits. It depicts that Sodium salts are dominant cations in these soils. About 46% of soils were saline-sodic, 22% sodic and 16% saline and 16% were normal soils. The spatial distribution soil salinity maps showed that there is most substantial level of salinity in those samples which were taken from the coast of the Arabian Sea which might be due to seawater intrusion.

Analysis of water samples collected from surface water bodies revealed that about 66% of the water samples had EC, 64% had TDS concentration, and 58% had chloride concentration beyond the permissible limits suggested by FAO (1985). About 80% of the natural surface water bodies (lakes) had saline water unfit for drinking purpose. Hence, based on FAO water quality guidelines for irrigation purpose, sampled water bodies were unsuitable even for the irrigation purpose. The analysis of satellite imagery revealed that water bodies in the entire delta have doubled in last 27 years (from 1600 sq. km to 3000 sq. km).

The groundwater quality analysis indicated that about 62% of water samples had salty and bitter taste, while pH, odor, and color values in most of the groundwater samples were within the permissible limits. However, about 34% of the samples had turbidity, 89% had EC, 67% had calcium, 56% had magnesium values beyond the permissible limits. It is also indicated that 94% of groundwater samples had chloride concentration higher than the safe limits. Analysis for arsenic demonstrated that only 23% of water samples had an arsenic concentration beyond the allowable limit described by WHO. Groundwater contaminated with arsenic is found in areas adjacent to the river Indus. As high as 1999 ppb (parts per billion) arsenic concentration was observed in some samples. Even RO plant installed by Government at Keti Bandar had an arsenic concentration above WHO permissible limit of 10 ppb.

Based on high Chlorides concentration (>250 mg/L), Simpson ratio (>2.8), chloride and bicarbonate ratio (> 0.6) in groundwater, it is estimated that subsurface seawater intrusion has affected about 1.15 Mha (88.3% of Delta) while only 0.15 Mha (11.7%) is still unaffected.

The temporal variation in the shoreline of Indus delta was analyzed for statistical parameters End Point Rate (EPR), Net Shoreline Movement (NSM) and Linear Regression Rate (LRR)using DSAS and compared with manual calculations. The study concluded that the left side of the river Indus was more vulnerable to coastal erosion compared to the right side of the river. It might be due to low mangrove population, oil extraction, flat land slope on the left side of the delta compared to the right side of the delta. The net inward shift in the shoreline was quantified as 860±92 m using DSAS software and 1295 m±260 through manual calculations. Higher shoreline change rate (34.3±3.5 m/year) was observed for the period 1990-2017 compared to the period 1972-2017 (28.4±3.9 m/year).

About 42607 ha land of Indus delta is degraded due to surface seawater intrusion. Thus, there was an increase of about 7.1% in the tidal floodplains of the delta in last 45 years. Out total degraded land of about 42607 ha, about 31656 haof land are now under the seawater while about 10951 ha of new land is converted into the tidal floodplain area. It was further investigated that tidal floodplain area on the left bank of Indus is about 4208 km^2 or about two times larger than the right side (2220 km^2). Permanent water in tidal flood plains has increased from 7.1% to 18.1% of total tidal floodplain area. In case of a tsunami wave of 5 m height or a cyclone capable of raising sea level up to 5 m comes in the coastal belt of Indus delta, about 9376 km^2 (71% of the delta) will be flooded which reflect the high vulnerability of submergence of delta and risk of life of coastal communities of the delta.

The socio-economic survey of the Indus delta revealed that about 39.3% of the peopled were engaged in agriculture followed by fishing (16.6%). Whereas, about 15.0% people were engaged in govt. /private jobs, about 12.7% were daily wage labors. About 16% of the population of Delta had monthly income less than Rs. 10000; 62% had income between Rs. 10000 to Rs. 30000 while only 3% had income more than Rs. 70000. About 76.5% of people believe that the temperature in last 25 years has increased. While, about 97.2% report a decrease in rainfall, about 92.5% reported about the increase in wind blowing/velocity during the summer season in the delta, while 88.9% feel an increase in humidity in the delta. About 20.4% people suffered from gastro, diarrhea, and chest and stomach problem, about 14.8% affected by skin diseases, 16.4% had hepatitis, 9.2% had cancer, and 8.4% had cholera, sugar, blood pressure, heart, and kidney problems. About 88.4% of the population of the Indus Delta was below the poverty line, in which 31.4% very poor, 27.8% moderate poor and 29.2% poor.

Based on the present study it is recommended:

- To expand already constructed 38 km long coastal highway up to 200 km on the left bank of the Indus by putting a bridge over the river Indus at Kharo Chhan. It will not only provide coastal communities with quick and easy access to the markets of Karachi but will also attract the tourists and flourish tourism in the delta. Hence, socio-economic conditions of poor communities of the delta will be improved. The proposed coastal highway will also

function as a defense-line against the surface seawater intrusion thus will impede further swallowing of the delta by sea.

- A5000 cusecs of water throughout the year below Kotri Barrage should be insured to check seawater intrusion, accommodate the needs for fisheries, environmental sustainability, and to maintain the river channel as recommended by International Experts (IPOE) in 2004. Also, the total volume of 25 MAF in any five years period (an annual equivalent amount of 5 MAF) be released below Kotri as flood flows (Kharif period).

- The environmental river flow is useful in controlling seawater intrusion only in the active delta, therefore for minimizing surface and subsurface seawater intrusion in the entire delta, enough water flow in the river Indus as well as canals, originating from Kotri Barrage, should be ensured to minimize subsurface sweater intrusion, provide drinking water to coastal communities, fulfill freshwater needs of flora and fauna and thus mitigate adverse impacts on the ecosystem of the delta. During field survey & satellite images, it is observedthat irrigation channels in the delta have a significant impact on the control of seawater intrusion in areas far from the river Indus.

- If possible relic river channels, such as Ochito and Old Pinyari should be restored. These channels should be used to carry extra flood water to the sea during peak flood to shun the flood pressure on the mainriver and thus minimize the possibility of the levee breach. This will also supply fresh water to the coastal communities living far from the main river course. These channels will carry silt-laden water during floods and discharge into the sea away from the main river estuary. This will be supportive in silt deposition in areas in areas where river water and silt usually do not reach. Thus, it will be supportive in revitalizing the delta.

- Mangrove plantation on the tidal flood-plains along coastline should be encouraged by establishing community-based natural resource management committees. Thick mangrove forests provide defense-line against natural calamities such as extreme tides, cyclones, and tsunamis; trap river silt to support accretion process along the coast; provide natural breeding ground for fish, shrimps and other marine life; provide wood, fodder, and livelihood to the coastal communities.

- Biosaline agriculture should be encouraged especially in tidal floodplains and over vast barren salt-affected soils lying between tidal floodplains and the canal irrigated areas of the delta. Cultivation of Pal grass,*Quinoa,* Salicornia, Sea Aster, Spartina alterniflora, etc. should be introduced and encouraged by the Government. Biosaline agriculture will undoubtedly be a source of food and fodder for the coastal communities and livestock.

- Most of the natural lakes in the delta are saline, which should be revived by adding fresh water during the monsoon period. Freshwater lakes will provide drinking water to communities and will work as groundwater recharge hotspots.

- Shrimp and crab farming in natural water bodies, lakes and ponds of the delta should be encouraged.

- Plantation of mangroves on the tidal floodplains especially on the left bank of river Indus should be initiated and encouraged on an emergency basis.

- The Government should ban on overgrazing and cutting of mangroves for wood, and on the use of fine mesh nets for catching small size fish and shrimps.

- Tourism Industry should be encouraged, especially boat cruising in the mangrove laden creeks in the Delta to improve socioeconomic conditions of poor local communities.