IMPACT OF CONTROLED ENVIRONMENTAL FLOW & EARTHQUAKE ACTIVITIES ON INDUS DELTA CAUSES IRREVERSIBLE POVERTY

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Abstract

Indus, the 23rd largest river in the world originates from the glaciers of world's highest Himalayan mountainous region. It has five main tributaries originating from lower Himalayan ranges. Indus flows over a distance of 3000km draining 595,000km^2 from Tibet through Kashmir across length of Pakistan forming fertile plains, big delta and one of the largest submarine fans in Arabian Sea. Indus is the lifeline of Pakistan and plays a major role in development of socio-economics of the country. During early1800-century, one of the largest irrigation systems of world was developed utilizing waters of Indus and its tributaries. Water divergence of three rivers to India and construction of dams, barrages, channels, and embankments/dikes on remaining three rivers in upstream areas of Pakistan for irrigation network and hydroelectric generation has drastically reduced water discharge into delta region. In down-stream, environmental flow has been controlled to level of acute crisis, which has created tensions between people of upstream and downstream over sharing of water resources. Present study on discharge data shows that environmental-flow downstream Kotri barrage remained below 1.00maf since 1995 instead of 10maf. It is estimates that Indus River used to throw 400 million tons/year of silt in the sea, which now reduced to <<100 million tons/year. Prior to 1830, when Punjab first time started developing its agricultural activities, the lower riparian Sindh used to get 150maf of water only in Indus delta. Today, such quantum of water is not available even in whole of Indus River system under influence of upstream water divergence. Indus delta has now shrunken drastically due to insufficient environmental-flow, consequently, affecting marine life and causing seawater intrusion in deltaic areas that literally kills life in all forms - livestock and vegetation on land and fish and other edible marine varieties and the rich mangroves forest in the sea. During the present study, it is also observed that the earthquake activities in offshore surrounding areas are creating compressional conditions in deltaic areas causing saline water rise as a result of liquefactions and/or low-amplitude sea-invasion (like Tsunami on micro-scale) as revealed by the satellite image analyses and field observations along coastal areas. Based on initial environmental impact study, it is concluded that current water crisis is affecting production and living conditions, jeopardizing poverty reduction and sustainable development, which resulted in mass-migration of younger inhabitants from their ancestral places in search of new livelihood leaving behind women, children and older people to suffer from nutritional deficiency-related illnesses and consequent deaths. In order to develop rational environmental model(s) for the Indus delta and its surroundings, two research studies have been initiated based on initial findings of the present study: 1) Geomorphological degradation of Indus delta and its impact on Ecosystem, and 2) Poverty-Environment Nexus: Addressing poverty minimization through optimum environmental flows.

Introduction

Indus River originates from the huge glaciers of the world's highest Himalayan Mountains. It has five main eastern tributaries (Jehlum, Chenab, Ravi, Sutlej, Beas) also originating from the Himalayan ranges and several other tributaries (Swat, Kabul, Khurram, Gumal, Gaj) draining from western Karakoram, Hindukush and Kirthar ranges (Fig. 1). The river flows over a distance of 3000-km draining 595,000 km^2 from Tibet across the length of Pakistan forming vast plains, a big fertile delta and one of the largest submarine fans of the world at the eastern margin of the Arabian Sea.

In fact, Indus is the lifeline of Pakistan and plays a major role in the development of the socio-economics of the country. Since prehistoric time to present, the Indus river valley is rich in its enormous potential for the development of high quality food and irrigated regions (water resources, agriculture, livestock, fisheries, wildlife, etc), cultures, civilizations and ports along its banks. In the history, the Indus was known as `*Abasin*', that means "the father of rivers" probably based on its size, enormous flow and excellent development of ancient to modern civilizational activities, which are now being deteriorated very fast, particularly in the lower Indus basin, as a possible result of huge divergence of Indus water in the upstream region and the consequent climatic variation.

In fact, the Nature Mother gave strength to Indus River System by adding one more contributory, the Sutlej river, about 4000 years ago. In the geological recent-past, the Sutlej was not the contributory of the Indus River system. During 4,000-5,000 years BP, another significantly giant river system existed towards eastern side flowing independently more or less parallel to the Indus river-system (Fig. 2). This system was known as Sarasvati-Hakra river-system, which has now lost in the mist of the history due to the drastic seismo-tectonic deformational activities associated with the Himalayan region (Wilhelmy, 1969; Zaigham, 1994; Zaigham, 2002; Zaigham et. al, 2005). An integrated research study of the seismicity, satellite geoidal anomalies and the tectonic activities associated with the western Himalayan region have revealed the causative factors for the dramatic flow changes of the Sarasvati-Hakra system. These changes had resulted due to the geologic structural deformation and forced to divert the Satluj River into Beas River and the Jamna River into Delhi River (now known as Yamuna River, a contributory of Ganges River system). The divergence of the contributory rivers consequently resulted extinction of the Sarasvati-Hakra river system, which was comprised of its contributory rivers, namely Sutlaj, Ghaggar and Jamuna and usued to flow about 4000BP parallel to Indus River. At present the Sutlej flows as on of the contributory of Indus River, and the Jamuna River had become the part of the Ganges River System.

This paper describes the impact of the enormous water divergence of the Indus River system in the catchment-upstream areas causing almost irreversible degradation of the river ecology, particularly the lower riparian Indus delta region.

Water Divergence of Indus River System

One of the largest irrigation systems of the world was developed about 175 years before mainly in the upper and middle parts of Indus basin utilizing waters of Indus and its tributaries for the conventional flood irrigation (Fig. 3). Since then, numerous dams, barrages, headworks, and other reservoirs have been built on each of the contributories of the system. Moreover, during 1960 the waters of three tributaries (Ravi, Beas and Satlej rivers) have been diverted to India under Indus Basin Treaty between Pakistan and India, which is also one of major factors for the enormous water depletion of Indus River system. Now, the availability of water to Pakistan is limited to three rivers, namely Indus, Jhehlum and Chenab, which is again under threat due to construction of various reservoir structures on these rivers in the Indian territories. Presently, Indus is the main river contributing 65% of water supplies, while the Jhehlum and Chenab are supplementing 17% and 19% respectively, which are not sufficient to meet the present Pakistan's water requirements (Kahlown and Majeed, 2002).

Only in Pakistan, the system presently includes three major reservoirs (i.e., Terbela, Mangla and Chashma dams) and several other smaller ones, 19 barrages/headworks, 12 link canals, 45 canal commands and some 99,000 watercourses. The total length of the canal system is about 58,450 km with watercourses, farm channels and field ditches running another 160,000 km in length.

In order to maintain the flood irrigated agricultural activities in upper and middle Indus basin through the construction of channels, barrages, embankments, dikes and dams for hydroelectric power and irrigation, the water discharge into the lower Indus basin including the delta region has reduced to the level of crisis. Down Kotri barrage the duration of river flow has also been controlled allowing for less than two months during the monsoon season. According to the Sindh Irrigation Department, river flow downstream Kotri barrage reached its lowest level in year-2000 in the Sindh's recorded history, which further remained only 2.1 maf during monsoon flood period and 0.04 maf during almost remaining period of year 2001-2002 (Figure 4). According to a accord of 1991, 10 maf/year water discharge was agreed as environmental flow down Kotri barrage. From the water discharge, it is evident that only in 1992 the agreement was observed, otherwise except the monsoon flood season the water discharge down the Kotri barrage remained at the highest level of crisis.

Climatic Variability

The imbalance in the water distribution within the Indus basin seems to modify the climatic conditions in Pakistan longitudinally. On one end, the massive water divergence in the upstream-catchment region and the manmade increase in the residence time of Indus water-flow by arresting in dams, barrages and reservoirs, the over all development of greenery has enormously improved the greenhouse gas effects. On the other end, the depletion of Indus water supply has created adverse impact causing verse greenhouse gas conditions in the downstream region including the Indus Delta region as revealed from the analyses of the climatic data.

The decadal means of the last 50-years' climatic data show a significant climatic variability from the northern to the southern areas of Pakistan. In the northern Indus plains of Punjab province, it is observed that all the decadal means of temperatures show a decreasing trend ranging from 0.5° to 0.6° C whereas the decadal mean of precipitation shows a significant increase of 269.6 mm. On the other hand, the climatic pattern is different in the southern Indus plains of Sindh province. The decadal means of temperatures though show slight increasing trend, but the decadal data of rainfall show a considerable decrease of about 31.1 mm.

An analysis of 50-years site-specific decadal climatic data of Peshawar city, situated in northern part of Pakistan, reveals an increase of 133.9 mm precipitation, a decrease of 0.2º C in minimum temperature and an increase of 0.1º C in maximum temperature, but at the southern most Karachi city a decrease of 104.2 mm in precipitation, an increase of 0.5º C in minimum temperature and an increase of 0.4º C in maximum temperature have been estimated. It is inferred that locally climatic warming is increasing in the southern part as compared to the northern part of Pakistan.

Tsunamis & Impact on Indus Delta

Shallow undersea earthquakes are responsible for most tsunamis though at time landslides triggered by smaller seismic events can also generated potentially lethal waves. Strong earthquakes cause a displacement of the crust. When they occur underwater, this crustal movement disturbs a large volume of water like a giant paddle and ripples spread out in all directions at speeds of 600-800 km per hour, comparable to commercial aircraft. In the open ocean, they go unnoticed but once they reach shallower waters they slow down and begin to crest. They are scientifically described as a series of very long wavelength ocean waves caused by the sudden displacement of water by earthquakes, landslides, or submarine slumps and are mostly caused by earthquakes of magnitude 7.5 or greater. The majority of the reported tsunamis are from the littoral countries of the Pacific Ocean, but there are also a few hot spots of tsunamis in the Andaman Sea, the Indian Ocean and the Arabian Sea. In the Arabian Sea along the Pakistan and Indian coastal areas, off and on Blochistan, Karachi and Rann of Kutch coastal belt, have Tsunamic generating history associated with the historical earthquakes. The oldest record of tsunami is available from November 326 BC earthquake near the Indus delta/Kutch region. That time, Alexander the Great was returning to Greece after his conquest and wanted to go back by a sea route, but a tsunami due to an earthquake of large magnitude destroyed the mighty Macedonian fleet (Lisitzin, 1974; Murty & Bapat, 1999).

The approximate length of the Pakistan coast is about 1000 km. The coast runs in east-west direction from the eastern edge of the Indus Delta to western limits of the Jiwani-Makran coastal belt. The coastal belt of Pakistan and the eastern region of Indus Delta, i.e., the Rann of Kutch areas of India, are seismically active (Fig. 5). In this region, earthquakes of +3 to +8 magnitudes' have occurred since history to date. The significantly large earthquakes (Oldham, 1883; Zaigham, 2001) are i) 893-894AD (Debal:Lower Sindh, Pakistan, Mw 7.5 TS, in which nearly 1,50,000 people were killed and several towns were destroyed in the region), ii) 2May1668 (Shahbunder: Lower Sindh, Pakistan, M 7.6 TS, 24.00N, 68.00E), iii) May1688 (Shahbunder: Lower Sindh, Pakistan, 24.00N, 68.00E), iv) 16June1819 (Allahbund: Indo-Pak Border region, Mw 7.5, 23.60N, 69.60E, in which about 3200 people were killed and dozens of towns and villages were destroyed in Kutch and adjoining parts of southern Pakistan), v) 27November1945 (Off the Makran coast of Balochistan, Pakistan, Mw 7.9, 24.50N, 63.00E, 25 kms depth, in which at least 2000 people killed in southern Pakistan and neighbouring Iran), vi) 5August1947 (Off the Makran coast of Balochistan, Pakistan, Mw 7.2, 25.10N, 63.40E), vii) 26January2001 (Bhuj-Gujarat, India: Mw 7.6, 23.399N, 70.316E, 22 km depth, in which at least 11,500 were killed in Gujarat and 20 killed in southern Pakistan). During these earthquakes, the tsunamis or tidal waves have affected the coastal areas of Pakistan and India, inclusive of Indus Delta on either micro or mega scale.

The worst case was in 1945 when an earthquake of magnitude 7.9 struck the Makran coast. The earthquake was also characterized by the eruption of mud volcanoes (Wadia, 1981; Pendse, 1945), a few miles off the Mekran Coast (Fig.6), which are common feature in Western Pakistan and Myanmar. A large volume of gas that erupted from one of the islands, sent flames leaping "hundreds of meters" into the sky. A total of 4,000 deaths occurred during that earthquake.

The most significant aspect of this earthquake was the tsunamis that it triggered. The tsunami reached a height of more than 13 meters in some Mekran ports and caused great damage to the coastal regions of Pakistan, India, Iran, and Muscat-Oman. The towns of Pasni and Ormara were badly affected. Both were reportedly "underwater" after the tsunami. The fishing village of Khudi, some 30 miles west of Karachi, was completely obliterated. At Dabo creek of Indus delta, 12 fishermen were swept into the sea. At Karachi, the tsunami flooded the Keamari habour area, where the waves were 2 meters high. There was no damage either to the port or to boats in Karachi Harbour.

On the other hand, the tsunami had a height of 11.0-11.5 meters in Indus delta and the Rann of Kutch. A drop in the rate of Indus River flow and energy has been inferred associated with the occurrence of the historical earthquakes (Snelgrove, 1979; Flam, 1993; Jorgeson & et al., 1993). Both the events, 893-894 as well as the 1819 earthquake might have resulted in affecting the distributaries of the Indus Delta. The coastline has also dramatically been altered since then. Arab historian records that in 719 AD a number of harbour towns flourished on the shores of the Indus delta and Rann of Kutch, which were then navigable upto Nagarparkar – the eastern most extension of the Rann, which were reported in 1361 AD as the region of a "howling desert" (Siveright, 1907).

After the occurrence of 1819 earthquake, the Sindri fort was submerged immediately within a span of a few hours, and residents sought refuge on the upper parts of the fort from where they were rescued the next morning (Wynne, 1872). The surrounding area was converted into a lake in the Rann of Kutch. More high tide waves at the time of the earthquake could have aggravated the situation. Moreover, it was also reported that the flow stopped for 3 days in all the channels of the Fullalee River in the districts south of Hyderabad, the northern limit of the Indus delta (Frere, 1870). The Nara River was dammed too, forming a pool and the downstream section dried up. Another distributary of the Indus River flowing through the delta region was also thought to have dried up as a result of the quake (Glennie and Evans, 1976). Similarly based on the satellite image analysis, distinct sea wave have been noticed after the devastating Bhuj-earthquake of 26January2001 in the Rann of Kutch region (Zaigham, 2001).

From all of the above cases of the historical earthquakes and the consequently resulting tsunamis and/or the high tidal sea waves, it is inferred that the Indus Delta has significant landward compressional wave energy forcing the saline water up into the delta region. In freshwater depleting condition created due to the limited water flow of Indus River down the Kotri barrage might have further enhanced the saline water induction in the delta from the Arabian Sea under the coastal hydrological laws of freshwater verses seawater equilibrium. In future, detailed studies need to be carried out to observe the above phenomena in Indus Delta region after every significant earthquake.

Impact of Water Divergence, Climate Variability and Tsunamis on Indus Delta

It is besides the fact that prior to 1830, when the Punjab first time started developing its agricultural activities, the lower riparian Sindh used to get 150 maf of water only in the Indus delta, which had created one of the largest submarine fans of the world and also formed a densely populated delta covering an area of about 29,500 km^2. Literature study shows that the delta was formed in an arid climate under conditions of high river sediment discharge (~400 million metric tons of sediment per year), a moderate tide range (2.62 m), extremely high wave energy (14 x 10^7 ergs/sec/m coast and a root mean square wave height of 1.84 m), and strong monsoonal winds from the southwest in the summer and from the northeast in the winter (Dawn, 2005; Coleman and Huh, 2004; Eckholm, 2003).

Today, such quantum of water is not available in whole of the Indus River system under the influence of the massive water divergence, the climate changes and the possible seawater push on the Indus Delta causing due to the tsunamis along the Pakistan coastal areas and the Rann of Kutch region. It needs to be adequately planned considering the facts that the down Kotri barrage, the Indus travels over 100 km to the Arabian Sea traversing the districts of Hyderabad, Badin and Thatta. Millions of people depend on this stretch of the river for drinking & other domestic uses, agriculture, forests, and aquaculture. The Thatta district alone has a population of over 1.1 million, as well as 250 thousand cattle heads, and a forest spread over 425,000 hectares.

The river water flowing downstream of Kotri Barrage to the sea has the vitality to sustain the life of Indus delta which is not a small area but is a vast region with more than a million human population, many millions of livestock, the seventh biggest mangrove forest of the world flourishing in it, about 150 islands with great potential of tourism, and fish product worth billions of rupees per annum.

In natural conditions, the impact of seawater invasion is abated by freshwater inflow from the river. The freshwater current exerts a pressure against the incoming sea water invasion limiting its active intrusion by maintaining affective interface between freshwater and seawater in the coastal region. Moreover, in such conditions the freshwater also dilutes the tidal seawater effect and washing out much of its deposits. However, when the freshwater inflow in the river declines as a consequence of upstream massive water divergence, the regular tidal impact causes more soil erosion of the coastal margins and simultaneously critical angle of the fresh-saline-water interface becomes acute or even zero in highly degraded conditions. Aquifers start yielding non-potable saline water and, ultimately, the areas become a part of the sea. Later situation has prevailed in the Indus delta under the complex phenomena of natural and anthropogenic activities. In general, the reduced quantity of outflow and discharge of the nutrient-rich sediments load of the Indus River have adversely affected the marine life, not only in the estuary but also in the near shore areas of the delta. The diversion of river's flow has also caused the intrusion of seawater towards up-land areas of the Sindh from the Arabian

Sea, particularly in the coastal area that literally diminishes livestock and vegetation on land and fish and other edible marine varieties and the rich mangroves forest in the sea.

A study shows that the Indus Delta mangroves forest were spread over an area of approximately 600 million square meters between Karachi and the country's border with India (Dawn, 2005). They used to support thousands of botanical, aquatic and wildlife species and provide a nursery for most of the 44 commercial fish and shrimp species in the deltaic area. The hyper saline conditions in the coastal belt are resulting in gradual destruction of the ecology. Salinity has been caused by the non-release of Indus water into the sea over the past several years, badly affecting the arid climatic mangroves. It is inferred that the mangroves' cover has been reduced to about 54%, of which only 31% are healthy whereas another 31% are dying (Memon, 2000). The remaining mangroves are in moderate condition. As these mangroves and their environment were the natural nurseries of shrimp and a number of fish species, their depletion had ultimately hampered production and growth of these species. In this context, the precious fish species like the Palla and Danger whose annual catch till 1986 was 600 tons but has reduced to 200 tons now. Similarly, the annual average catch of shrimp, a most valuable item, was 27,541 tons (97 per cent of the total catch at national level), but has now reduced to 92 per cent (Dawn, 2005).

The satellite image clearly shows the distinction between the abandoned and active deltaic areas of the Indus delta, as well as the barren uplands fold belt in the northwest, Thar desert in the east, and the Rann of Kutch region in the southeast (Fig.7). The lower or active deltaic plain is roughly delineated by the landward boundary of salt-water intrusion, the position of which is easily seen on the image by the abrupt color change associated with vegetative cover. This lower deltaic plain is crossed by a complicated network of meandering tidal channels that daily inundate the region with salt water and fine-grained suspended sediment. The margins of these tidal channels are commonly lined by salt-tolerant mangrove vegetation on a sand to silt substrate, while barren flats are common in the inter-channel areas. During the field investigation it is observed that along the creek margins, small crevasses/splays build sediment wedges into inter-channel regions. These features are generally too small to be clearly delineated on the image. During the storm tides of the southwest monsoon in summer, vast areas of both the active and lower abandoned deltaic plain are inundated with salt water as the tide range of the Indus is relatively low (~2 to 3 m). As a result of this yearly cycle, combined with an arid climate, low-relief areas trap salt water that evaporates to create rather extensive salt flats.

In the present freshwater depleted situation, the waves are the single most important process-variable in shaping the Indus delta. The bell-shaped channels associated with river mouths and tidal creeks are the distinct indicators of the strong tidal influence on the delta's morphology. The study based on the comparison of the topo-maps of 1945 and 1988 (Fig. 8) shows that the sea wave energy has dominated the periphery of the Indus Delta. The islands and the creeks show constant and continuous changes in their shapes and sizes.

The consequent strong shore-currents have straightened and as well as deeply eroded the coastline as revealed by the east west aligned shelf cross-section on the western margin of the delta (Fig. 9).

Area of the Indus delta is now shrinking drastically (Fig.7& 10) due to diminishing flow of river water as evident from the downstream water discharge statistics of the Kotri Barrage (Fig.4). The vast network of distributaries with rich silt that once used to yield abundant crops in the past now have adversely affected by the sea invasion and practically has converted into creeks. The delta has 16 major creeks and extensive mudflats. The abandoned delta is some 6.4 times the size of the active delta region and the subaerial delta is 8.2 times larger than the subaqueous delta. Within the abandoned deltaic plain many remnants of once-active distributaries and their associated alluvial features are still apparent. Numerous small lakes, representing former interdistributary bays dot the abandoned delta plain.

Seawater intrusion has resulted in tidal infringement over 1.2 million acres of land in the Indus Delta. This makes up no less than 33 percent of the total land in the districts of Badin and Thatta. Millions-more acres inland has also been impaired or destroyed by salt deposits left by the tidal seawater. Taking a closer look of area namely Ghorabari has lost 31,490 acres; Shah Bunder, 590,000 acres; Kharo Chaan, 117,823 acres; Mirpur Saskro, 60,178 acres; Jati, 226,663 acres; Keti Bunder, 113,900 acres; Golarchi, 30,625 acres; and Badin, 49,179 acres.

During the recent past, the extended drought cycle has also reduced the availability of freshwater in the southern and the western regions of the country. It is expected that the climatic variability will increase this stress more in the Indus deltaic region. If we fail to mitigate the current water crises and keep reducing the river flow, then our next generation would have a completely different Indus-ecosystem from today similar to that of Sarasvati-Hakra River System. Because of long drought cycle and the man's intervention in the natural delta-building processes of the Indus, the delta's future is uncertain.

The social and environmental damages are most visible in the Indus delta itself, which used to be a vast network of freshwater distributaries surrounded by rich silt that yielded abundant rice and pulses crops. Current water crisis has led to the nutritional deficiency related illnesses and deaths. Worse sufferers are the women, children and aged-people. The ultimate increase in poverty of the rural people has resulted mass migration of inhabitants from their ancestral places in search of livelihood. If this trend continues, one can expect the delta to evolve into a more wave-dominated form characterized by the extensive beach, beach ridges, and the dune formation, probably accompanied by substantial coastal retreat.

Conclusions

Dams and canals were built in Pakistan and India to provide irrigation and power, but little thought was given to consequences affecting the downstream region. Consequently, here at the mouth of the Indus, the river has almost dried up and seawater has rushed in to replace its flows. Indus river distributaries at the delta have now become creeks of the Arabian Sea.

Under both the decreasing precipitational environment in the lower Indus Basin and extensive diversion of waters of the Indus River system for the irrigation use during the 20th century have adversely depleted the Indus River discharge in multifold, which has brought about shortages of fodder pasture and potable water causing depletion of sources for livelihood (agriculture, forestry, fishing & animal husbandry etc.).

It is recommended that since we cannot turn back the clock and restore the original flow of the river, but we must do efforts for the rational water management to save the ecosystem of the Indus delta strictly based on the basic research studies. In order to develop rational environmental model(s) for the Indus delta and its surroundings, two research studies have been initiated: 1) Geomorphological degradation of Indus delta and its impact on demography, and 2) Poverty-Environment Nexus: Addressing poverty minimization through optimum environmental flows.

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