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Sea Level Change: Causes and Impacts: A Case Study of Pakistan

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Abstract: Sea level change is not a new phenomenon. Sea-level rises and falls locally for short duration due to tidal effect, storm surges and generation of tsunami. Glacio-eustatic and tecto-eustatic mechanisms have remained important to explain long term global and local changes in sea-level. The phenomenon of global warming due to human induced greenhouse gases and resulting sea-level rise has gained attention during last three decades particularly after the release of IPCC assessment reports. Environmentalists by and large have consensus that sea-level rise is a serious concern for coastal environment and human settlements. Like other coastal countries sea-level rise phenomenon is also a concern for the coastal environment of Pakistan but its intensity of danger is much less as compared to low-lying coastal countries and islands like Bangladesh and Maldives. Pakistan has about 1600km long coast. Several geomorphologic and archaeological evidences confirm the glacio-eustatic and tecto-eustatic change of sea-level in the Pleistocene and the Holocene epoch. The evidences of current sea level rise reveal that tectonic mechanism and intrusion of sea in the deltaic region of the River Indus is due to reduction of river inflow not because of global warming phenomenon, are the main factors of sea-level change along the coast of Pakistan.

Keywords: Sea-level change, Glacio-eustatic, Tecto-eustatic, Global warming

1. INTRODUCTION

During the last three decades environmentalists have shown deep concerns over the global and local phenomenon of sea level rise. They have considered it a disaster for human settlements and coastal environment. This aspect of sea level change gained much attention when Intergovernmental Panel on Climatic Change (IPCC) first presented his assessment report in 1990 about global rise of mean surface air temperature and consequently global rise of sea level. According to IPCC reports issued 2007 global mean surface air temperature has increased by 0.3 to 0.6 degree Celsius since the late 19th century. As a result of melting of glaciers and polar ice sheets global sea level has risen by 15 to 20 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature. The IPCC reports were criticized and serious questions were raised by climate scientists on the reliability of data and models used by IPCC researchers about global warming and consequent sea level rise (Ahmed, 2011; Legates and Soon, 2011). Despite the controversies in IPCC findings about sea level rise the topic of sea level rise has remained important for researchers particularly in collection of evidences and explaining Pleistocene and Holocene glacio-eustatic and tectonic causes of sea level change and its impacts on coastal environment.

The Mechanisms of Sea- level Change

The sea level surface is not uniform, it is affected by many short-term influences such as wind-waves or tides. Therefore, defining sea level as the mean surface elevation of the sea, the effects of short term variation in sea level must be taken into account. For example atmospheric pressure over the sea surface may affect duration of hours to months cause from 0.7 to 1.3 m change in sea level. Similarly winds (storm surges) may influence sea level from 1 to 5 days cause rise of sea level up to 5m. Similarly evaporation and precipitation may also change the volume of sea water. Movement of oceanic currents and change in water density may change the sea level up to 1m from days to weeks. The factor of El Niño in rising of sea temperature has been estimated up to 0.6 m and retains its effects up to 6 months.

Seasonal variation in sea level has also been noted caused by seasonal water balance among oceans, changes in sea water density caused by temperature and salinity, upwelling currents and discharge of river runoff and flood water, for example River Ganges can raise sea level in the Bay of Bengal by up to one metre during the monsoon season. The short-term effect of rise of sea level can also be affected by tsunami which is up to 10 m. If the effects of all of these perturbations are excluded then any long-term progressive variations in sea-level may be observed. In most locations throughout the world such local and short-term factors rise the sea-level roughly 1 to 2mm per year (Pethic, 1984). The two fundamental causes of progressive long-term sea-level change are:

i. Tectonic and Isostatic mechanism
ii. Eustatic mechanisms

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Tectonic and Isostatic mechanism

Relative sea level can change because of tectonic and isostatic movements, resulted upward and downward of the Earth's crust, mountain building, change of shape of oceanic basins, formation of oceanic ridges and subduction of ocean floor etc. Evidences of neo-tectonic reveal that as a result of tectonic uplift, oceanic floors have emerged in ocean as islands and in form of raised beaches. In many coastal areas lands have submerged as a result of earthquakes and sea proceeds toward land. Isostatic movements are adjustments in the earth's crust resulting from loading or unloading of the surface. Areas laden by the accumulation of river derived sediments in estuaries may cause isostatic submergence and rise of relative sea level in the region.

Eustatic mechanism

The term eustatic was first introduced by Suess in 1906 when it was assumed that such changes were equivalent throughout the world's oceans, but it is now realized that there have been regional discrepancies in the amount of sea level rise or fall on particular coastlines. Sea level rises when the volume of water in the ocean basins increases and falls when it is reduced. These changes are world-wide because the oceans are interconnected. There are several mechanisms involve in the eustatic change of mean sea level like thermal expansion of sea water, rise of sea-bed due to sedimentation, glacio-eustatic mechanism and current century anthropogenic mechanism of global warming and melting of glaciers and ice-sheets.

Glacio-eustatic mechanism

Major rise and fall of sea level accompanied the expansion and recession of the Earth's ice cover as a result of cold (glacial) and warm (interglacial) phases of climate change in the Quaternary Epoch. These sea level changes are termed glacio-eustatic. During glacial phases the Earth's hydrological cycle was interrupted when the climate cooled sufficiently for precipitation to fall as snow, which accumulated as glacial ice and persistent snowfields in Polar and mountain regions. Retention of large amounts of water frozen on land depleted the oceans, and there was world-wide lowering of sea level. In the interglacial phases water released from melting snow and ice flowing back into the ocean basins to produce a world-wide sea level rise, the sea at times extending above its present level.

More detailed evidence comes from deep-sea cores in which the relative proportion of the two oxygen isotopes in the skeletal material of deep-sea has been analysed. The difference of these two isotopes during cold and warm periods indicates the amount of water removed from the ocean. This indicates the maximum range of fossils coastlines up to 120 m. The exact number of glacial events occurred during the Pleistocene is controversial, 17 to 20 major glacial and interglacial events have been identified while number of minor events which are called stadia and inter-stadia have also been identified (Baker,1993). During the Last glacial phase most probably occurred in the late Pleistocene or end of Pleistocene, sea level fell about 140 m, but about 18000 years ago the polar ice sheets and mountain glaciers began to melt, initiating a world-wide sea level rise. It continued into Holocene times (10,000 years ago) and came to an end about 6000 years ago when the sea attained approximately its present level.

Human induced sea level rise

During the last two decades human-induced factors have been brought main causes of sea-level rise during the last 100 years. The issue of global warming due to man-induced increase of the amount of carbon dioxide in lower atmosphere has been very much focused by environmentalists, resulting rise of global mean sea-level (Alley,1991). A part from this global atmospheric factor, minor local factor like extraction of sub-surface water from aquifers in coastal areas has caused of land subsidence and local or relative sea-level rise. This has contributed to a relative sea level rise in the Venice region, and around Bangkok in Thailand. Relative sea level has risen where oil or natural gas has been pumped from underground strata, as in southern California and the Ravenna region in Italy. Similar submergence has occurred due to the loading of coastal land with building structures, land reclamation schemes, construction of artificial islands etc.

Global Warming and Sea level rise

Climate scientists agree that the global average surface temperature has risen over the last century (since the end of little ice age in 1880s). Within this general agreement, some individual scientists disagree with the scientific consensus that most of this warming is attributable to human activities (Ahmed, 2011). The scientific consensus was summarized after the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as follows:

1. The global average surface temperature has risen 0.6 ± 0.2 °C since the late 19th century, and 0.17 °C per decade in the last 30 years.
2. "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities, in particular emission of the greenhouse gases carbon dioxide and methane.
3. If greenhouse gas emissions continue the warming will also continue, with temperatures projected to increase by 1.4 °C to 5.8 °C between 1990 and 2100.

Accompanying this temperature increase will be increases in some types of extreme weather and a projected sea level rise 9 cm to 88 cm.

Most of the scientists agree with the first point, they disagree with Points No.2 and No.3 (that is cause and the 100-year temperature forecast)

Melting of Glaciers, Ice Sheets and Thermal expansion of sea water

Glaciers and ice sheets are large, slow-moving assemblages if ice that cover about 10 percent of the world's land area. The melting back of this ice can lead to indirect contributions on sea level rise. It is estimated that if all the ice in the world were to melt the present day sea-level would rise by 40 to 60m (Bintanja, 1995). The threat of melting of glacier and rise of sea-level has been much highlighted on the basis of IPCC released data in 2007 that global mean sea level has risen 15 to 20 cm over the last 100 years. The thermal expansion over the last 100 years is estimated to the 2-7 cm while rise of sea level due to retreat of glaciers and ice sheets for this period is estimated about 2-5 cm. The present sea level rises at rate estimated on the basis of satellite data is 1.8 to 2.8 mm per year. On the basis of one of the IPCC projected model that sea level would rise up to 38 to 55 cm by the year 2100 (IPCC, 2007).

Possible Hazards and Challenges of Sea-Level Rise

The IPCC's last 100 years estimates and projected forecast of sea-level rise has shown global concerns, challenges and threats of possible environmental hazards on the coastal countries. The United Nations warn nations and Governments of coastal countries to combat this challenge through effective coastal zone management policies. More than 600 million people live in coastal areas that are less than 10 m above the sea-level, and two-third of the world's cities of over five million populations are located in these risk areas. Low lying coastal areas and islands have serious threats of submergence like coastal areas of Bangladesh, Italy, London, Maldives islands etc. Coastal environments such as beaches, barrier islands, wetlands, and estuarine systems are closely linked to sea level. Many of these environments adjust to increasing water level by moving towards land. Submergence of coastal land, beach erosion, conversion of wet land, present estuaries and creeks into open sea and loss of subsurface aquifers and croplands due to sea-water intrusion and increasing salinity in estuaries are possible challenges that the coastal countries have been facing. Unfortunately many of countries facing these challenges belong to Less-Developed nations have neither resources nor have properly motivations and awareness.

2. RESEARCH METHODS SOURCES OF DATA

Pakistan has about 1600 kilometre long coastal region. The geomorphic and archaeological evidences in the Makran coast, Balochistan and the coastal areas of Sindh reveal that sea-level change occurred in the Pleistocene and Holocene epoch (Snead, 1967 and Kazmi, 1984). The current rise (during last three decades) in sea-level has been noticed in the Indus estuary, Badin and Karachi. However, the causes of these changes in sea-level are local rather than global. The main problem to monitor the mean sea level change during last 100 years is lack of data. Therefore, we have to rely on the evidences collected through areal photographic coverage at a scale of 1: 40,000 made by the Hunting Survey Corporation in 1952-1954, geomorphological field surveys conducted by Snead (1967), A.R.Khan (1979), Kazmi (1984) and archaeological survey of Dales (1980) and Biaji (2004). The authors also conducted several field surveys to collect evidences in 1996, 2003 and 2012 in Keti Bunder (Indus Estuary), Karachi Coast, Gadani and Sonmiani Coast of Balochistan.

3. RESULT AND DISCUSSION

The coastline of Pakistan stretches in the west from the Iranian border at the mouth of the Dasht River eastward at the eastern edge of the Indian border at the eastern edge of the Indus delta. Geomorphologically the coast can be divided into three broad parts (Fig 1). The first part consists of about 168 km of steep, rocky cliffs interspersed with small pocket beaches. On the east several mountain spurs come directly to the coast. Farther west uplifted folded and faulted mountain ranges, aligned in an east-west direction parallel to the Arabian Sea are being slowly denuded. The second major part comprises 328 km of coastline, consists of wide, sandy beaches backed by extensive desert alluvial plains. Most of these wide beaches and plains are found scalloped bays which have formed between the eroded mountain ranges. The third major division is the Indus Delta coastline which is 120 km long. Instead of a network of tidal channels, the finer silts and clays are carried into playa flats and shallow lagoons and coarser sediments from dunes and sand flats. Outside the large Indus Delta plain there are two very arid plains extending inland from the Makran coast. One of these is the Las Bela Valley, some thirty km west of Karachi. The other plain , near the Iranian border, is the Dast River plain, which is 30 km wide at the coast and extends inland over 150 km.

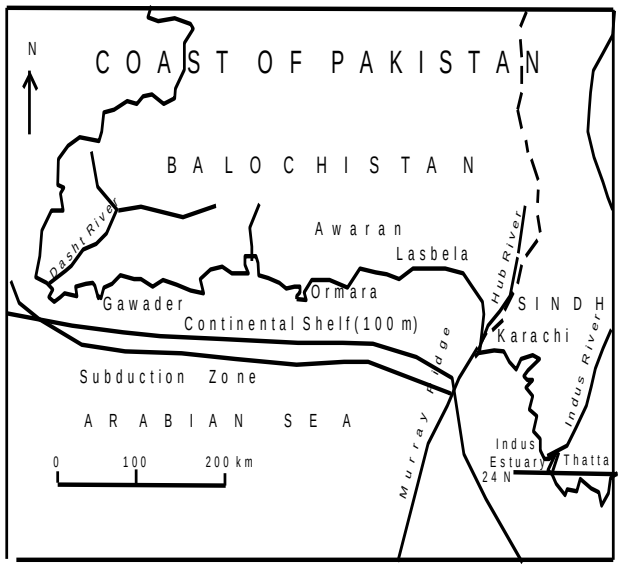

Fig 1: Coast of Pakistan

Tectonic Evidences of Sea-Level Change

Evidences of uplifting in the tertiary and quaternary landforms have been associated with Himalayan orogenic system and subduction of sea floor which continues till today. Evidences of uplift are most striking in the large individual fault blocks which had risen as islands directly off the coast. Two of these massive blocks had subsequently been connected to the coast by tombolos. One of these is called Ras Ormara and other fault block is called Gawadar, rising to an elevation of 145 metres, is also connected to the mainland by a large tombolo. Two small rocky islands formed off the Makran coast as a result of the November 1945 earthquake.

Snead (1967) reported that along with anticlinal folding and scattered fault blocks, horizontal rock platforms had been uplifted. Pleistocene shell conglomerates and sands lie on the series of tertiary rocks. Near the Hingol River there is a strand platform capped by a resistant shell conglomerate that had been uplifted to about 25 metres above present sea-level. Across the surface of this platform numerous shells and barnacles are attached. Without dating of marine benches on most of the headlands time of deposition and uplift is difficult to mention. In the south end of Haro ridge recent un-weathered oyster beds exist 10 to 14 meters above sea level and can be correlated with similar oyster beds 3 to 4 meters above sea level northeast of Sonmiani, and 2 to 3 meters above sea level near Karachi. All three sites possibly pertain to Pleistocene and Holocene epochs but difficult to find out the exact causes of their presence either because of sea-level rise or because of uplifting or both. Snead (1960) observed that at several locations it appears that sea level changes have had more influence upon the coastline than tectonic movements.

Inland from the coast, evidence of both gradual and sporadic coastal emergence exist in the form of entrenchment of drainage and rejuvenation of streams in Lasbela and Karachi Valleys. Old alluvium and conglomerate terraces pertain to Pleistocene have been found in many areas of Karachi and Lasbela.

Geological studies (Kazmi, 1984) in the Indus delta reveal that the lower Indus Plain contains a good record of the events and sediments of the Late Pleistocene. The Tandojam formation with coarse gravelly alluvial sand in the lower part and fine medium alluvial sand in the upper part represents a 150 to 200 meters deep channel filling. This channel was apparently formed as a result of the degradation of its course by the Indus due to the lowering of sea level during the last glacial period. As large portion of the continental shelf were exposed due to the falling sea level, the Indus may have extended its course across the emerging sea floor right up to the edge of the continental shelf. Towards the end of the last glaciations, as the sea level began to rise once again, the Indus aggraded its course and during the late glacial period deposited sands and gravels of the Tandojam formation. The evidence of sediments from shallow wells dug in the deltaic flood plain show non-bedded flood plain deposits of silt and clay containing abundant mollusc shells underlie the present deltaic flood plain.

Along the coast of Karachi erosional coastal features like steep cliffs, stacks, arches, sea caves and blow holes have been found. It appears that slow uplift of continental shelf continues in the coastal areas which was also confirmed by Snead in his conclusion that "the Makran coastal region is not only tectonically active, but the movements indicate a continuing uplift. This uplift resulted in the formation of rock headlands and exposed portions of continental shelf. Protected pocket bays and lagoons between the nearly formed headlands, rapidly filled by alluvial deposits. Once material was brought to the coast, currents and winds take over as the main agents in the formation of the wide, sandy beaches and extensive barchans dune masses".

Evidences collected during Field visits

During the period 2010 to 2013 several field visits in Gadani, Winder, Daun, Dam and Sonmiani in the Makran coast of Balochistan, Rehri, Cape Monze (Ras Malan), Sona Pass and Hub River of Karachi coast, Keti Bunder and Jati in the lower Indus delta were conducted and found evidences of Pleistocene, Holocene and present status of sea-level change phenomenon.

Short-term sea-level Change

The short term sea level rise had been observed in the coast of Karachi (Sindh) and Gadani (Balochistan) during the period of daily and spring tides, sea surges in monsoon season (July and August), and tropical cyclonic condition in June were studied. During the daily tidal phenomenon of rising sea level was observed in the lagoons of Gadani Harbour, Dam Bunder and Kaka Pir Island. During high tide, sea level starts to rise about 1 pm and reaches at the height of about 1 to 2 meters at 2 am than it drops which again rises about 7.am. During the time of high tides fishermen sail their boats and small ships. During the period of spring tides, it reaches up to 2 to 3 meters from the normal sea level. During high tides roots of mangroves sink under water while when sea level drops they are exposed. Sea-level also rises during monsoon season and period of tropical cyclone. Due to strong monsoon winds sea becomes violent and high surge of sea waves can be observed. It was observed that during monsoon season sea level rises up to 3 to 4 meters from normal while due to tropical cyclones sea-level rises up to 3 to 5 meters. The sea level rise can be observed from the height of transported sediments and marks of sea waves on cliffs **(Photo 1).**

Photo 1: Marks of sea surge on the cliff at Karachi coast .

Risk of Tsunami and Sea Level Change

The tectonic history of Pakistan, the presence of a number of onshore and offshore active faults from Kutch to Gawadar and occurrence of high magnitude quakes reveal that the coastal areas of Pakistan is a vulnerable region of tsunami (earthquake generating sea waves). Pakistan had a bad experience of tsunami when on November 28, 1945; a severe earthquake of 8.1 magnitudes hit the coastal areas of Pakistan. The epicentre was located in the Arabian Sea near Ormara, generated about 12 to 17 meters high sea waves which caused temporary rise of sea level and destroyed coastal settlements of Makran coast and fishing villages of Karachi and Badin. About 4000 people died including 300 deaths which occurred due to tsunami.

Glacio-eustatic Change of Sea-level

During the Pleistocene and early Holocene epoch, evidences of global change in sea level were collected in the coast zone of Karachi and Gadani. During the glacial periods sea level dropped up to 140 m below the present shore line. It is estimated that the present shore along the Makran coast and Sindh receded up to 120 m, exposing the vast continental shelf. As a result of change of base level, rivers drained into sea rejuvenated, extended their channels up to the edge of exposed continental shelf, eroded channels deep and deposited bed-loads. Similarly in the interglacial periods sea-level rose up, exposed continental shelf re-submerged into water and shoreline proceeded. Abandoned channels of rivers and old distributaries of River Indus submerged into sea water and formed creeks along the coast. Like Gharo creek which is an old abandoned channel of the Indus River (Photo 2). This also happened in small streams like Gizri creek, the mouth of the Malir River and Hub creek, the mouth of Hub River **(Photo 2).**

Photo 2: Gharo Creek, Thatta, old distributary of the River Indus

Photo 3: Uplifted conglomerate terrace of Hub River

Along with glacio-eustatic change of sea-level, the coast was also tectonically active. As a result of uplifting, old bed loads also uplifted. The remnants of conglomerate terraces of Hub Rive can be seen along and near the present course of Hub River (Photo 3).

During the glacial periods when continental shelf exposed wind derived fine sand and silts moved and spread out over the coastal areas in thick consolidated loess form or in form of unconsolidated deposits, formed coastal dunes. Due to uplifting these loess deposits are located about 30 to 60 meters above sea-level. Along the shore due to sea waves erosion loess-deposited surface have formed cliffs and formed sandy beaches.

Tectonic Change of Sea-level

The presence of uplifted Pleistocene sand and gravels beach deposits at the height of 12 to 25 meters above sea level, raised sea platforms and rocky headlands **(Photos 4 and 5)** and oyster beds indicate that the coast of Pakistan was tectonically active in the Pleistocene and Holocene epoch.

Photo 4: Pleistocene loess deposits, eroded by Sea-wave at Karachi coast.

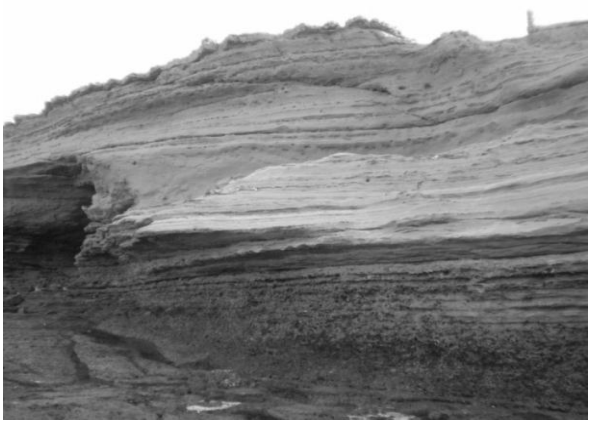

Photo 5: Ripple marked rocky raised beach at Karachi coast

In Rehri village of Karachi coast prints of mangrove leafs and fossils of mangrove in the Ras Malan coast of Karachi huge deposits of Oyster shells were found at the top of cliff and eroded hills. These oysters beds were most probably deposited on the beach or continental shelf and then uplifted most probably in early Holocene **(Photo 6).**

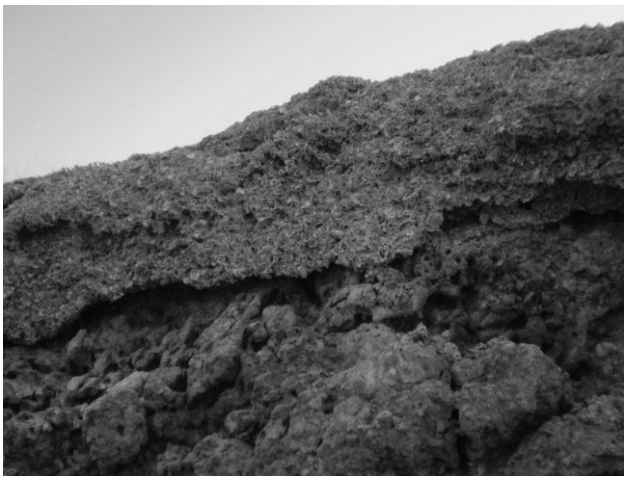

Photo 6: Oyster shells deposited at the top of cliff along Karachi coast

Archaeological Evidences

Archaeological evidences are good sources of information about the Holocene sea-level change in the coastal areas of Karachi and Lasbela. Dales in 1960 (Dales 1964) identified pre-historic Harappan site of Kot Bala near Winder, at the height of 20 meters and 8 km. inland. Claimed it as Harappan port. Snead (1967) rejected that uplifting of coast about 2500 B.C which was too early. A. R Khan, Italian Archaeologist Paolo Biaji and the authors found no marine evidences there. In 1976 A.R Khan discovered a Harappan port Settlement on the conglomerate terrace near the mouth of the Hub River. Several marine shells were collected during field visits.

Along the coast at Sonari, a Neolithic and Pre-Harappan site was also discovered by A.R.Khan in 1976. During field visits the authors found shell maidens, dated about 4000 to 5000 B.C located at 4 meters high hillock **(Photo 7).** In Daun and Lake Sirinda, shell maidens dated 5000 to 6000 B.C were collected (Biaji, 2006). These two sites are located not at the height of 3 meters above the shore. The archaeological evidences reveal that no major uplifting of coast was recorded during the last 8000 years ago. All Harappan, pre-Harappan and Neolithic sites were developed on terraces or on hillocks lifted up before their existence.

Photo 7: Shell maddens at the Pre-Harappan site at Sonari, Karachi coast.

Current Sea Level Rise and its Impacts

The evidences found in the off shore and on shore regions of the coast of Pakistan reveal that the region has been tectonically active. During October 2013 Awaran earthquake a small island has emerged at Gawadar offshore **(Photo 8)**. This also happened as result of 1945 offshore earthquake and in 1997. Because of the small size of emerged island , no significant rise of sea-level has been reported. It has been investigated through local fishermen of Karachi and Lasbela that no permanent rise of sea level took place during last 60 years in Karachi-Lasbela coast.

In South Badin, due to submergence of lands in Rann of Cutch during the period 2002 to 2003, sea water intruded into cultivated lands. This happened possibly because of two reasons: (i) the southern areas of Badin and Thatta were affected by 2002 Gujrat quake when lands in many areas submerged and sea water came up on ground. Farmers and fishermen left their villages and their cultivated lands. Subsidence of lands in the southern areas of Badin continues; (ii) the extraction of natural gas from subsurface strata may be the other cause of land subsidence.

Fig 8: An island emerged at Gawadar off shore as a result of Awaran earthquake 1st Oct., 2013.

Environmental degradation of the Indus estuary and deltaic plain have been linked to sea water intrusion. There is no doubt that salinity in the tidal channel has increased up to the level of sea water. The covering area of Mangrove forest has reduced during last 40 years. Rise of salinity and intrusion of sea water has badly affected the quality of freshwater in the downstream of Kotri Barrage. The main reason of sea water intrusion in the Indus delta has been considered reduction of Indus water inflow which has reduced after construction of barrages over the Indus River. Because of the presence of active faults like Allah Bund fault in the region threat of submergence of present estuary exist however satellite images of last 20 years have not shown any significant submergence of the estuary and its conversion into open sea **(Photo 9)**.

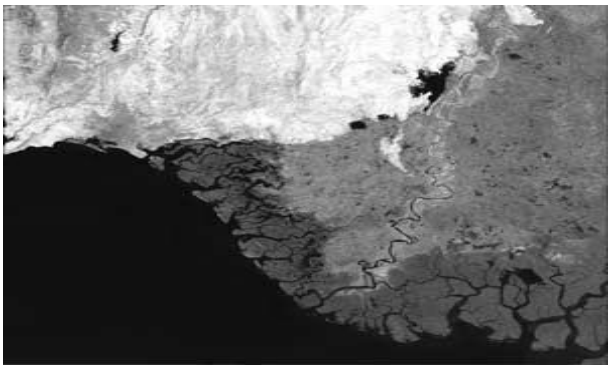

Photo 9: Estuary of Indus River

Sea water intrusion can also be observed in small rivers like Hub River. Hub River is about 200 km long perennial river. After the construction of Hub dam and large reservoir in 1985, down reservoir water flow has nearly stopped. As a result seawater has intruded into the channel (Photo 9). The threat of land subsidence and sea-level rise also exist along Clifton beach. During

last 20 years a large number of high-rise buildings have been constructed in the area as well as off shore lands have been reclaimed for housing purposes. It is important for urban developers to restrict such large-scale construction works along the beach.

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