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AN OVERVIEW OF COASTAL EROSION IMPACTS ON ROAD INFRASTRUCTURE

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Abstract- The most important areas for human and economic activities, as well as the environment, are coastal zones. To protect the natural beauty of the coasts, the vulnerability of coastal areas to natural impacts should be carefully studied. Coastal erosion is a concern at many coastal locations, and it is triggered by both natural and manmade factors. Coastal erosion places the lives of millions of people who live along the coast in jeopardy, and puts coastal infrastructure like roads and bridges at risk. Coastal erosion has a fast effect, making it a significant coastal threat. Coastal areas with road networks close to the shoreline are particularly vulnerable to the impact of climate change-related sea level rise. Coastal erosion has placed these areas road networks in jeopardy. Drastic reductions in water flow of Indus River into the delta, overexploitation of mangroves forests, dredging and channelization, various uses of coastal resources by different industries, and increase in sea level due to climate change and global warming are all anthropogenic factors leading to coastal erosion. Between 1984 and 2015, approximately 28,000 km^2 of the world's coastline is eroded, roughly twice as much as those created by accumulation processes. By 2100, the total "Cost of Coastal Environmental Degradation" (CoCED) in a group of 4 (four) countries affected by coastal flooding and erosion could exceed $3 billion. One of the main factors affecting road networks is sea level rise. When groundwater moves into the pavement base layers, sea level rise caused ground water to reach pavement layers. This groundwater results in reduction of pavement life by 50% and a up to 90% increase in rutting due to fatigue distress. Following the Hurricane Katrina, the Federal Highway Administration (FHWA) performed an inventory of coastal bridges and found that there are around 36, 000 bridges within 15 nautical miles that could be damaged by coastal storms.

Keywords- Coastal Erosion, Global Warming, Infrastructure, Pavements, Sea Level Rise

1 Introduction

The most important areas for human and economic activities, as well as the environment, are coastal zones. To protect the natural beauty of the coasts, the vulnerability of coastal areas to natural impacts should be carefully studied. The coastal zone is home to a large portion of the world's population, accounting for up to 37% of the total population [1]. The coasts have a lot of potential for economic development. Coastal waters, for example, serve as global trading highways. Ships carry approximately 90% of all global goods [2]. Coastal and maritime tourism was the largest tourism sub-sector in Europe in 2014, as well as the largest single maritime economic operation in terms of employment (3.2 million jobs) and value added (over 180 billion euros) [3]. Furthermore, the fishing industry is a significant contributor to the global economy. 90 percent of fishing boats are thought to operate in coastal waters. Mediterranean fisheries were determined to be worth $3.2 billion by the General Fisheries Commission for the Mediterranean (GFCM) [4]. Pakistan has a coastline that stretches for approximately 1001 kilometers and occupies an area of 240,000 square kilometers, bordering Iran to the west and India to the east [5]. Pakistan's fish and seafood industry is worth $1.5 billion, according to estimates [6]. This shows that coastal cities are an important part of any country's economy.

Coastal erosion is a phenomenon that affects almost all coastal states [7]. Coastal erosion is a phenomenon that affects almost all coastal states. Coastal erosion has been one of the most serious environmental problems in recent decades [8-11]. Between 1984 and 2015, approximately 28,000 km^2 of the world's coastline is eroded, about twice as many as were created by accumulation processes [12]. According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report [13], the potential scenario for coastal areas will deteriorate as a result of the steady rise in sea level and the likely increase in extreme events as a result of global warming linked to the use of fossil fuels and human pressure [14]. Only in Europe, the total coastal area lost each year due to coastal erosion (including houses and buildings) is estimated to be about 15 km^2. Mitigation initiatives are expected to cost about 3 billion euros per year, which is unacceptably high [15].

Coastal erosion puts millions of people living along the coast in danger, as well as coastal infrastructure. Coastal erosion has a lot of sudden effects, making it a significant coastal threat [16, 17]. The situation is even worse in low-lying deltaic regions of developing countries like Bangladesh, Pakistan and Philippines, which are inadequately equipped to deal with the dangers. One of the long term environmental processes like sea level rise (SLR) [18] and the increased frequency of short-term events like coastal flooding and storm surge [19], become the reason for coastal structural change and aggravate coastal erosion [20].

Infrastructure refers to the structures that allow a society to operate [21], and a community cannot survive long if all of these systems collapse completely (road networks, water supply, drainage, embankments, telecommunications etc.). These networks are often referred to as "lifelines" in disaster management and serve as the "vein" for disaster reduction strategies to propagate. The inadequacy of these infrastructure supports introduces the concept of "vulnerability due to infrastructure" and poses the issue of how well post-disaster activities can be managed. Roads are an integral part of coastal infrastructure. In case of any hazards turning into a disaster road network plays a very important role.

2 Literature Review

2.1 Coastal Erosion

Coastal erosion that contributes to the shaping of coastal landscape is mainly a natural phenomenon throughout history. Erosion, shipping, and deposition processes combine to create coastal ecosystems. Coastal erosion and accretion is the process of wave action, tidal waves, and wave currents wearing away land and removing beach or dune sediments [22]. Coastal erosion is caused by waves generated by hurricanes, wind, or fast-moving motor vessels. It may take the form of long-term loss of sediments and rocks, or simply the temporary re-distribution of coastal sediments. Erosion in one area can lead to accretion in another. Erosion is caused by a disparity of sand inputs and outputs [23]. When the inputs and outputs of sand are balanced, there is no transition, which is referred to as "steady state."Coastal erosion is impacting the coasts and road networks along the coast, as seen in figures 1 a and b.

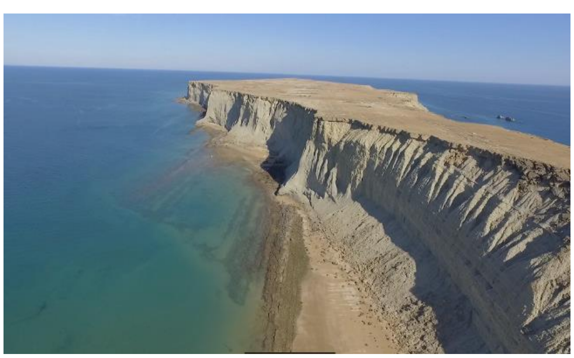
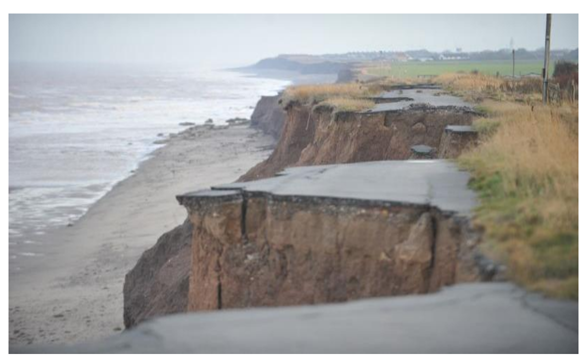
a)  b) 

Figure 1 : Coastal Erosion, a. Estola Island, Pakistan, (IUCN) and b. A crumbling cliff edge at Tunstall, UK (Image: HullLive)

The main eroding causes of the coastline are rainfall and oceanic waves. Rain, wind, and high waves appear to pick up and drag the sand and earth from exposed beaches, washing it up and out into some other areas of coast. Although natural tides and waves follow similar patterns, their effect is minor in comparison to storms. Hurricanes, in particular, have enough water and power to erode coastlines, turning them into peculiar forms [16].

2.2 Factors Leading to Coastal Erosion

Anthropogenic factors leading to coastal erosion in Pakistan include a dramatic decrease in Indus River water flows into the delta, extinction of mangroves, dredging and channelization, various uses of coastal resources by different industries, and rising sea levels due to global warming [24]. Coastal developments including drainage infrastructure, building jetties, and land reclamation also lead to erosion. Coastal erosion is more common in river deltas or coastlines with somewhat soft sediments and a large number of beaches that are easily influenced by wave and tide movement [25]. Earthquakes, wind, tides, waves, rainfall, and cyclonic activity are all natural physical factors that contribute to coastal erosion [26].

The table below depicts "erosion hotspots," or areas that are impacted by coastal erosion due to natural or human-caused processes, which are found in Pakistan's coastal region, with medium to extreme erosion intensities.

Table 1 Coastal Location and Degree of Erosion for Pakistan's Coastline [27]

District	Location	Type of Coast	Erosion Intensity
Karachi	Phitti & Gizri Creeks	Mudflats/ Creek	Moderate
	Clifton	Beach	Low
	Hawksbay	Raised	Moderate
	DHA Phase-8	Creek and plain area	Moderate
	RasMurai	Raised	Low
Thatta	Kharo Chann	Estuarine mudflat	Severe
	Keti Bunder	Estuarine mudflat	Moderate
	Mirpursakao	Creek/mudflat	Moderate
	Ghorabari	Creek/mudflat	Moderate
	Ghoro Creek	Creek/mudflat	Severe
Sujjawal	Jati	Creek/mudflat	Severe
	Shah Bunder	Creek/mudflat	Severe
Badin	Badin	Creek/mudflat	Severe
	Shaheed Fazil Rahu	Creek/mudflat	Severe
Gwadar	Jiwani	Raised/flat	Very Severe
	Shadi Kor	Estuarine	Very Severe
	Pasni	Raised/flat	Severe
	Ras Shaheed	Raised	Severe
	Gwadar Bay	Raised/flat	Moderate
	Kalmat Khor	Lagoon	Moderate
	Ras Jaddi & Zarin	Raised	Moderate
	Ormara	Raised	Low
Lasbela	Damb	Sand dune	Very Severe
	Miani Hor	Lagoon	Moderate
	Sonmiani	Raised	Moderate
	Gaddani	Raised/flat	Moderate
	Hub	Estuarine	Moderate

2.3 Impacts of Coastal Erosion on Road Infrastructure

Coastal highways are one of the most important pieces of road infrastructure along the coast. Coastal highways are roads that are affected by their location in or near a coast's specific water level, wave, and sand transport system. The Great Lakes and all other non-riverine water bodies that can be impacted by coastal storm events are included in the coastal climate, which is usually associated with the oceans [28]. Highways in every coastal state are flooded and destroyed during coastal storms. Some of these roads run parallel to the coast and are used for entry and evacuation. Figure 2a shows some of these roads that run parallel to the coast, either directly along or inland from the sea. [29]. Figure 2b shows the damage caused by coastal erosion to the road infrastructure of Makran Coastal Highway. Some of these roads are major highways of critical importance that run across or along costal bays.

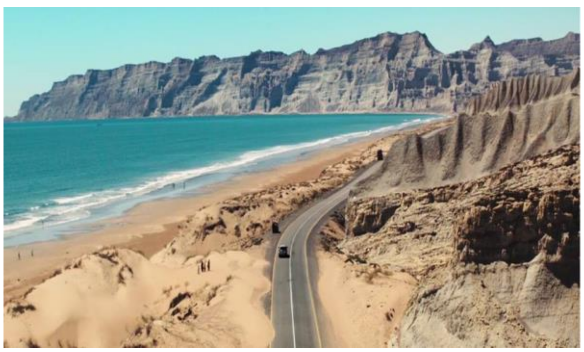
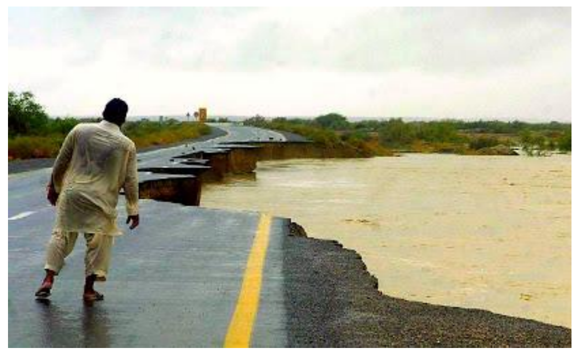
a)  b) 

Figure 2 Makran Coastal Highway, Pakistan (Image: Paki Holic)

The aggregated Cost of Coastal Environmental Degradation (CoCED) in the four countries caused by coastal flooding and erosion could exceed over US $ 3 billion by 2100, based on the worst-case scenario of regional relative sea-level rise, which corresponds to RCP 8.5. In addition, when population growth is factored in, the number of people affected in some countries could rise by 400 percent [30]. The eastern and western sides of the Indus River experienced erosion of an averaged 12.5 ± 0.55 m/year and 19.96 ± 0.65 m/year while Karachi coastline experienced erosion at a rate of 2.43 ± 0.45 m/year and accretion at a rate of 8.34 ± 0.45 m/year, respectively. Coastal erosion can be seen all over the coast. However, erosion rates vary across the study area, with the max. average erosion rate of 27.46 m/year in the Indus Delta region (IDR), which has a general pattern of erosion rising from west to east. The interdecadal transition from Karachi to the Indus River (IR) East zone showed an increasing linear pattern ($R^2 = 0.78$) from 1989 to 1999, 1999 to 2009, and 2009 to 2018. The west-to-east spatial pattern is positively associated with mean sea level rise (SLR). The mean sea level has risen from 1.1 to 1.9 mm/year, while the slope of coast line is decreasing in eastward direction and this rise is negatively corelated to the topography of the coastline [31]. Coastal road infrastructure is at risk of being damaged and destroyed as the sea level rises. Following Hurricane Katrina, the Federal Highway Administration (FHWA) performed an inventory of coastal bridges that could be damaged by coastal storms. The assessment estimated that there are over 36,000 bridges within 15 nautical miles of the coasts, based on very specific parameters [32]. About 1,000 of these bridges may be vulnerable to the same failure modes as those seen in recent coastal storms [33]. Coastal New England's sea level is forecast to rise 3.9–6.6 ft (1.2–2.0 m) by 2100. Many climate-change risk and adaptation studies have focused on surface-water flooding from sea-level rise (SLR) on coastal-road infrastructure, but few have focused on rising groundwater. The inland extent of SLR-induced groundwater rise will be three to four times that of surface-water rise. in New Hampshire's Seacoast District, potentially affecting 23 percent of the region's highways, according to groundwater modelling. As the unbound layers become saturated, the service life of the pavement is reduced. Where the ground water is expected to rise due to SLR , the pavements which are just 5 ft or 1.9 m above ground water level are at a very high risk of failure [34]. When groundwater moves into the pavement base layers, sea level rise caused ground water to reach pavement layers. This groundwater results in reduction of pavement life by 50% and a up to 90% increase in rutting due to fatigue distress [35]. This shows that not only direct affect is there on pavements by coastal erosion but also due to increased sea level the ground water is increased. The increased ground water level affects the base layers of roads and damages them causing billions of dollars of destruction.

3 Conclusion

Coastal erosion has many forms it could be in the form a Hurricane or a storm or it could be mainly due to rise in sea level. It was found that most coastal highways are at risk of getting damage by coastal erosion. These coastal roads play an important role of joining the coastal cities and are crucial part of economy. Following conclusion have been drawn from this study

- Due to global warming and climate change the coastal cities and coastal highways are at real risk of turning into disaster.
- The increased intensity of hurricane and storm affect the coastal roads and can cause major blockage of services during a catastrophic event.
- One of the main factors affecting road networks is sea level rise. When groundwater moves into the pavement base layers, sea level rise caused ground water to reach pavement layers. This groundwater results in reduction of pavement life by 50% and a up to 90% increase in rutting due to fatigue distress.
- Between 1984 and 2015, approximately 28,000 km^2 of the world's coastline is eroded, roughly twice as much as those created by accumulation processes.

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References

[1] UN, "Factsheet: People and Oceans," in *The Ocean Conference*, 2017: United Nations New York, NY, p. 7.
[2] H. W. Bange *et al.*, *World Ocean Review 2015: living with the oceans 5. Coasts-a vital habitat under pressure*. Maribus, 2017.
[3] D. Sartori *et al.*, "Guide to cost-benefit analysis of investment projects. Economic appraisal tool for cohesion policy 2014-2020," 2014.
[4] M. Randone *et al.*, "Reviving the economy of the Mediterranean Sea: actions for a sustainable future," *WWF Mediterranean Marine Initiative, Rome, Italy*, 2017.
[5] M. T. Qureshi, "Integrated Coastal Zone Management Plan for Pakistan," *IUCN-Pakistan. Qari, R., & Shaffat, M.(2015). Distribution and abundance of marine debris along the coast of Karachi (Arabian Sea), Pakistan. Pakistan Journal of Scientific and Industrial Research Series B Biological Sciences,* vol. 58, no. 2, pp. 98-103, 2011.
[6] P. Ministry of Planning Comission, "Pakistan Coastal Development through Integrated coastal zone management (ICZM)," Government of Paistan, Pakistan, 2020 2020.
[7] L. Van Rijn, "Coastal erosion and control," *Ocean & Coastal Management,* vol. 54, no. 12, pp. 867-887, 2011.
[8] N. Lenôtre, P. Thierry, D. Batkowski, and F. Vermeersch, "EUROSION Project. The Coastal Erosion Layer," *WP,* vol. 2, p. 45, 2004.
[9] A. Luijendijk, G. Hagenaars, R. Ranasinghe, F. Baart, G. Donchyts, and S. Aarninkhof, "The state of the world's beaches," *Scientific reports,* vol. 8, no. 1, pp. 1-11, 2018.
[10] M. Allen *et al.*, "Technical Summary: Global warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty," 2019.
[11] E. C. Bird, "Coastline changes. A global review," 1985.
[12] L. Mentaschi, M. I. Vousdoukas, J.-F. Pekel, E. Voukouvalas, and L. Feyen, "Global long-term observations of coastal erosion and accretion," *Scientific reports,* vol. 8, no. 1, pp. 1-11, 2018.
[13] M. Tignor and S. Allen, "Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)," *Cambridge, UK/New York, USA*, 2013.

[14] I. C. Change, "The Physical Science Basis; Stocker, TF, Qin, D., Plattner, G," *K., Tignor, M., Allen, SK, Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, PM, Eds,* p. 1535, 2013.

[15] M. Kirkby *et al.*, "Pan-European Soil Erosion Risk Assessment for Europe: the PESERA map, version 1 October 2003. Explanation of Special Publication Ispra 2004 No. 73 (SPI 04.73)," Office for Official Publications of the European Communities, 2004.

[16] C. Martínez, M. Contreras-López, P. Winckler, H. Hidalgo, E. Godoy, and R. Agredano, "Coastal erosion in central Chile: A new hazard?," *Ocean & coastal management,* vol. 156, pp. 141-155, 2018.

[17] P. Narra, C. Coelho, and F. Sancho, "Multicriteria GIS-based estimation of coastal erosion risk: Implementation to Aveiro sandy coast, Portugal," *Ocean & Coastal Management*, vol. 178, p. 104845, 2019.

[18] A. Cazenave and G. L. Cozannet, "Sea level rise and its coastal impacts," *Earth's Future,* vol. 2, no. 2, pp. 15-34, 2014.

[19] S. Rahmstorf, "Rising hazard of storm-surge flooding," *Proceedings of the National Academy of Sciences,* vol. 114, no. 45, pp. 11806-11808, 2017, doi: 10.1073/pnas.1715895114.

[20] J. Pollard, T. Spencer, and S. Brooks, "The interactive relationship between coastal erosion and flood risk," *Progress in Physical Geography: Earth and Environment,* vol. 43, no. 4, pp. 574-585, 2019.

[21] B. Mallick, U. K. Das, S. S. Islam, S. K. Das, and M. N. Islam, "VULNERABILITY DUE TO LACK OF INFRASTRUCTURE OF COASTAL LIVELIHOOD DURING CYCLONE AILA 2009 IN BANGLADESH."

[22] M. F. Azemee, "The impact of sea level rise on coastal region of Selangor, Malaysia," Universiti Teknologi Mara Perlis, 2021.

[23] A. Williams, N. Rangel-Buitrago, E. Pranzini, and G. Anfuso, "The management of coastal erosion," *Ocean & coastal management,* vol. 156, pp. 4-20, 2018.

[24] T. Bein, C. Karagiannidis, and M. Quintel, "Climate change, global warming, and intensive care," *Intensive care medicine,* pp. 1-3, 2019.

[25] E. J. Anthony, N. Marriner, and C. Morhange, "Human influence and the changing geomorphology of Mediterranean deltas and coasts over the last 6000 years: From progradation to destruction phase?," *Earth-Science Reviews,* vol. 139, pp. 336-361, 2014.

[26] C. D. Storlazzi and G. B. Griggs, "Influence of El Niño–Southern Oscillation (ENSO) events on the evolution of central California's shoreline," *Geological Society of America Bulletin,* vol. 112, no. 2, pp. 236-249, 2000.

[27] M. Pakistan, "Coastal Erosion in Pakistan: A National Assessment Report," ed: by: WWF-Pakistan, MFF Pakistan and Government of Pakistan, 2014.

[28] M. Crichlow, "Professional development programme: Coastal infrastructure design," ed: St Augustine: Construction and Maintenance. Integrated Watershed Management …, 2001.

[29] S. L. Douglass, B. M. Webb, R. Kilgore, and C. Keenan, "Highways in the coastal environment: Assessing extreme events," United States. Federal Highway Administration, 2014.

[30] A. Bolle, L. das Neves, L. De Nocker, A. Dastgheib, and K. Couderé, "A methodological framework of quantifying the cost of environmental degradation driven by coastal flooding and erosion: A case study in West Africa," *International Journal of Disaster Risk Reduction,* vol. 54, p. 102022, 2021.

[31] S. Kanwal, X. Ding, M. Sajjad, and S. Abbas, "Three decades of coastal changes in Sindh, Pakistan (1989–2018): A geospatial assessment," *Remote Sensing,* vol. 12, no. 1, p. 8, 2020.

[32] Y. D. Murray, A. Y. Abu-Odeh, and R. P. Bligh, "Evaluation of LS-DYNA concrete material model 159," United States. Federal Highway Administration. Office of Research …, 2007.

[33] M. Volovski, J. Murillo-Hoyos, T. U. Saeed, and S. Labi, "Estimation of routine maintenance expenditures for highway pavement segments: accounting for heterogeneity using random-effects models," *Journal of Transportation Engineering, Part A: Systems,* vol. 143, no. 5, p. 04017006, 2017.

[34] J. F. Knott, J. S. Daniel, J. M. Jacobs, and P. Kirshen, "Adaptation planning to mitigate coastal-road pavement damage from groundwater rise caused by sea-level rise," *Transportation Research Record,* vol. 2672, no. 2, pp. 11-22, 2018.

[35] J. F. Knott, M. Elshaer, J. S. Daniel, J. M. Jacobs, and P. Kirshen, "Assessing the effects of rising groundwater from sea level rise on the service life of pavements in coastal road infrastructure," *Transportation Research Record*, vol. 2639, no. 1, pp. 1-10, 2017.