Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 1, No. 2, January : 2024

AN ANALYTICAL RESEARCH OF CHANGING CLIMATE ON COASTAL GEOLOGY

Santosh Tudu Assistant Professor, Department of Geology Government Engineering College, Banka, Bihar, India

Abstract—
Sea level and coastal dangers are rising in reaction to the melting of ice sheets and glaciers, which is altering the Earth's climate. Low-lying coastal areas are among the most vulnerable to the effects of climate change, with over 300 million people living along the coasts worldwide, including 20 of the 33 megacities on the planet (with over 10 million residents). High tide flooding is currently a common occurrence for many of the major American cities along the Atlantic coast; as sea levels rise more quickly in the 21st and beyond, these events will become more frequent, profound, prolonged, and expansive. Extreme weather events combined with other elements that heighten coastal risk are also having an impact on cities in Southeast Asia and islands in the Indo-Pacific and Caribbean. Sea-level rise is a long-term permanent change of state, but short-term catastrophic occurrences like hurricanes, El Niños, and severe storms come and go and will do greater damage in the near term. However, additional risks like heightened wave activity or the disappearance of ecosystems exacerbate the impacts of sea level rise.

Keywords-— *Sea Level, Coastal Dangers, Low-Lying Coastal Areas, Melting Ice Sheets, Glaciers, Climate Change.*

INTRODUCTION

For as long as there has been an Earth and a Sun, the climate has changed. The Milankovitch cycles, which regulate the distance between Earth and the Sun, have had a major role in the variations in the quantity of solar energy that the Sun has given us over tens of thousands of years. Climate change and ocean warming are closely related to sea level. Global sea levels increase as a result of saltwater expanding due to rising temperatures during warm or interglacial times and the melting of mountain glaciers, Greenland, and Antarctica. As saltwater cools and absorbs less volume during colder (glacial) eras, sea level decreases and more precipitation falls as snow turns to ice, enabling ice sheets and glaciers to broaden. But because of the concentration of greenhouse gases throughout the past century, there has been a worldwide warming that has raised sea levels due to ice sheet melting and ocean thermal expansion. Future sea level rise will pose a serious danger to low-lying coastal communities. Given the inertia in ocean processes, the Paris Agreement's objective to keep the increase in global temperature well below 2 °C over pre-industrial levels may not exclude the possibility of high-end sea-level rise. Sea level rise's effects are especially dangerous for coastal areas. But sea level rise is not the only way that coasts are impacted by climate change. The inter-annual and long-term variations in winds, storm surges, and wave action are some of the ways that climate change impacts coastal zone processes and dynamics. Sea level, strong waves, wind patterns, and severe waves all have a significant impact on beaches. Yet, these variations occur on a seasonal, inter-annual, and long-term temporal scale across different areas and coasts, leading to diverse local effects including erosion and floods. The services that coastal ecosystems provide, such fisheries, coastal protection, and carbon sequestration, will be significantly impacted by anticipated increases in sea temperatures and ocean acidification. The requirement for adaptation is critical because of the rise in coastal risks, as well as the growth and population concentration in coastal areas. However, due to significant technical, financial, economic, and social challenges, the implementation status is still restricted along many coastlines. Coastal towns need to address the current and future costs and consequences of sea level rise and climate change with focused responses, strategies, and educated action. Rising sea levels may have long-term effects on the coastal area's sustainable community and important environment, which includes mangroves, salt marshes, and coral reefs (Barbier et al., 2008). According to a 2001

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 1, No. 2, January : 2024

assessment by the "Inter Governmental Panel on Climate Change (IPCC)," the coastal environment is the most dynamic interface on Earth, supporting the most variety of productive ecosystems, and it is located where land and sea meet (Hauer et al., 2020). Humans began to utilise every part of the coastal region, and as a result, the natural environment began to see a surge in urbanisation and tourism (Camargo, 2013). Deforestation, fertiliser runoff from agricultural land, and untreated sewage pose serious threats to both human health and coastal ecosystems (Barbier et al., 2011). According to the UNEP in 2002, about 40% of the world's population lives within 60 km of a shoreline, and pollution in coastal areas is causing a grave health catastrophe. With the rising danger of anthropogenic activities, the strong and dynamic physical process has been significantly influencing the formation of the coastal zone and its environment (Crossland et al., 2005). The IPCC (2001) states that "tropical cyclone, wave, storm surges, river flooding, tsunamis, shoreline erosion, and inrush of biohazards characterise the coastal environment and exposed too" are among the land and marine-induced risks that settlement and development activities are open to. The "coastal squeeze," which results in wild birds and wader species being in problematic conditions on mudflats and marshes, is what causes habitat loss (Galbraith et al., 2002).

LITERATURE REVIEW

Coastal towns need to address the current and future costs and consequences of sea level rise and climate change with focused responses, strategies, and educated action. Rising sea levels may have long-term effects on the coastal area's sustainable community and important environment, which includes mangroves, salt marshes, and coral reefs (Barbier et al., 2008). According to a 2001 assessment by the "Inter Governmental Panel on Climate Change (IPCC)," the coastal environment is the most dynamic interface on Earth, supporting the most variety of productive ecosystems, and it is located where land and sea meet (Hauer et al., 2020). Humans began to utilise every part of the coastal region, and as a result, the natural environment began to see a surge in urbanisation and tourism (Camargo, 2013). Deforestation, fertiliser runoff from agricultural land, and untreated sewage pose serious threats to both human health and coastal ecosystems (Barbier et al., 2011). According to the UNEP in 2002, about 40% of the world's population lives within 60 km of a shoreline, and pollution in coastal areas is causing a grave health catastrophe. With the rising danger of anthropogenic activities, the strong and dynamic physical process has been significantly influencing the formation of the coastal zone and its environment (Crossland et al., 2005). The IPCC (2001) states that "tropical cyclone, wave, storm surges, river flooding, tsunamis, shoreline erosion, and inrush of biohazards characterise the coastal environment and exposed too" are among the land and marine-induced risks that settlement and development activities are open to. The "coastal squeeze," which results in wild birds and wader species being in problematic conditions on mudflats and marshes, is what causes habitat loss (Galbraith et al., 2002). The M.S. Swaminathan Research Foundation projects that by 2050 and 2100, the sea level will have risen by 16 and 32 cm, respectively. There are 73 coastal locations in the country, and "sea level rise" due to "climate change" poses a major danger to those areas. 593 coastal districts, or 17% of the nation's total population, were included in a 2017 report by the India Government's "Central Water Commission (CWC)" titled "A Report on Problem of Salinization of Land in Coastal Areas of India and Appropriate Protection Measures." Coastal sea level rise affects more than seven million households that depend on fishing and farming along the shore. The Ganga, Cauvery, Krishna, and Godavari deltas in the east, as well as the Mumbai Coast, Kutch Region, Southern Kerala, and Lakshadweep Island in the west, are the most vulnerable regions. Thirteen coastal districts in Tamil Nadu, the southern state with the third-longest coastline in the nation, are at risk from sea level rise. There are 591 coastal fishing communities in this state. According to a 2017 centre research study for "Climate Change and Adaptation Research at Anna University (Chennai)," Tamil Nadu's coast would typically see a 4.51 to 4.94 cm rise in sea level due to climate change. The districts of Thiruvallur, Chennai, and Kanyakumari would experience a 4.94 cm rise in sea level. A different research study conducted in 2010 predicted that the Kanyakumari district, which has a 13 km2 coastline land area, will also be affected by coastal sea level rise. The coastal zone alteration process will have an influence on the coastal ecology, causing the coastal region to be restlessly flooded and lands to be lost (Woodworth, 1999).

CHANGING CLIMATE ON COASTAL GEOLOGY

These days, climate change, often known as global warming, is a significant problem that has been named as a primary worldwide challenge. Climate change is recognized to be caused by both natural and human influences, although human factors are now more powerful (Van Aalst 2006). The primary source of "global warming," or "anthropogenic climate change," is the release of greenhouse gases into the atmosphere. When human energy is absent, solar radiation heats the earth and atmosphere and is counterbalanced by thermal (long wave) radiation sent back into space. However, radiation cannot escape into space because to greenhouse gases, which are mostly produced by the burning of fossil fuels, agriculture, and other biological activities. Global warming has also been exacerbated by variations in aerosol concentration, surface covering, and solar radiation. Because of its connections to the fast urbanization of the world, concentrations of carbon dioxide (CO2), the primary greenhouse gas, have increased dramatically. In pre-industrial periods, the amount of CO2 in the atmosphere was 280 parts per million (ppm); by 2005, that amount had risen to 379 ppm. This is far higher than the normal range of 180–300 ppm that has been seen over the last 650,000 years (World Nuclear Association, 2012). The atmosphere reacts to increased greenhouse gas concentrations by increasing its average temperature. The warming trend over the 50 years from 1956 to 2005 was nearly twice as large as that of the 100 years from 1906 to 2005 (an average rise of 0.74 °C), according to the Intergovernmental Panel on Climate Change (IPCC). This translates to an increased rate of 0.13 °C (0.10–0.16 °C) for every decade. By the end of this century, global temperatures are expected to rise by 1.1–6.4 °C (Intergovernmental Panel on Climate Change, 2007: Summary for Policymakers on Climate Change, 2007). Furthermore, the severity of human-induced climate change is greater since China is the greatest emerging nation, as seen by its fast industrialization and high population density. The average temperature has increased by 1.1 °C over the last 50 years, above the average rate of growth worldwide. According to predictions, average temperatures will rise by 1.3–2.1 °C by 2020, 1.5–2.8 °C by 2030, and 2.3–3.3 °C by 2050 as compared to 2000 (Ding et al. 2006). Two variables that increase human vulnerability to catastrophes are urbanization and climate change, according to Brigitte Leoni, the spokeswoman for the United Nations International Strategy for Disaster Reduction (UNISDR) (Leoni et al. 2011). Numerous tragedies are connected to climate change every year, and this phenomena is growing in frequency and intensity. Coastal locations are thought to be particularly vulnerable to the effects of climate change since they are located where land meets the sea. China is more susceptible to climate change than many other countries due to the effect of the East Asian Monsoon. Southeast China's coastal regions are urbanizing at the quickest rate in the nation, despite the unique geological characteristics mentioned above. Thus, in the context of climate change, the frequency of human activity has also made the geological catastrophes in Southeast China's coastal zone worse.

GEOLOGICAL DISASTERS RELATED TO CLIMATE CHANGE

(i) Land subsidence- According to Hu et al. (2004), land subsidence is a progressive geological phenomenon that is characterised by the differential sinking of a ground surface in relation to the surrounding terrain or sea level. The 1920s saw the first reports of land subsidence in Shanghai and Tianjin City, but the 1950s and 1960s saw a significant increase in the phenomenon (Xue et al. 2005). Land subsidence started to affect the major cities of the Yangtze River Deltaic Plain (YRDP), Tianjin Plain, and Eastern Hebei Plain successively in the 1970s. Land subsidence across an area that progressively grew has plagued small-to-medium-sized cities and rural sections of the nation in the aforementioned regions since the 1980s. Statistics show that by 2005, ground subsidence was present in over 90 Chinese cities, and the total area approximately 90,000 km2 of land were submerged, with over 80% of that area being in the southeast coastal districts (Xu et al. 2008). YRDP, the North China Plain (NCP), and the Fenwei Plain (FP) are now the three primary regions in China where land subsidence is most common. The land subsidence in YRDP is the worst of all three locations.

(ii) Storm surge- Due to a dramatic disturbance on the sea surface, strong winds, and an abrupt reduction in air pressure, a storm surge causes an exceptionally large shift in sea level (Feng 1982). Some of the most significant natural disasters in coastal areas are brought on by storm surges. Typhoon storm surges occur often because typhoons regularly affect China's southeast coast. China leads the world in both storm surge frequency and storm surge-related losses, according to data (Ye and Yu 2002). The Northwest Pacific's sea surface temperature will rise as a result of global warming, increasing the frequency of tropical storms that make landfall in China. On the other hand, as a result of global warming, sea levels will rise overall, affecting both high and low tides in coastal locations. Occasionally, this will lead to the superposition of a high tide level storm tide, which increases the storm surge. Sea level rise will exacerbate storm surges in coastal hollows by accelerating the invasion's pace, broadening its area, and intensifying the tidal jacking action.

(iii) Slope disasters- In the coastal regions of southeast China, landslides are another significant and frequent source of geological catastrophes. Such incidents can occur in conjunction with debris flows and collapses to form "slope disasters." In the research area, strong rainstorms are typically the cause of slope catastrophes, and climate change may be making these storms more frequent. This is due to the fact that typhoon activity and continuous sea level rise are causing an increase in rainstorms, particularly in Southeast China's coastal regions where these storms are frequently powerful and concentrated. On the one hand, the soil's shear strength decreases with intense rainwater infiltration. However, the subsequent rise in groundwater causes lateral runoff, which increases the sliding force and hydrostatic pressure. As a result, during the rainy season, a number of rainfall-induced slope catastrophes occur, which cause significant mortality and economic losses throughout the southeast coastal region. These disasters are distinguished by their concentrated period of occurrence, high frequency, powerful "burstiness," and enormous damage.

(iv) Sea-level rise- One theory linking sea level rise to human-caused climate change is this one. Global sea level rises as a result of the melting of polar ice and the thermal expansion of ocean water brought on by rising temperatures. Numerous places' coastal sediments provide evidence that sea level rise accelerated in the middle to late 19th and early 20th centuries (National Aeronautics and Space Administration 2007). The IPCC Fourth Assessment Report states that during the twentieth century, global sea levels have risen by approximately 0.12–0.22 m at an average rate of 1.7 mm per year. The average rate of global sea-level rise during 1993–2003 skyrocketed to about 3.1 (2.4–3.8) mm per year, which is significantly higher than that during 1961–2003, which saw an increase. The forecast of sea-level rise is a dynamic issue due to many unknowns. New research has improved sea-level rise projections using statistical techniques based on the observed link between temperature and sea level (Rahmstorf 2007). Sea level is predicted to rise globally by 1.1 m by 2100, based on the credible estimate of sea-level rise values from post-IPCC studies and analysis conducted by different research institutions (Australian Department of Climate Change 2009).

EFFECTS OF CLIMATE CHANGE IN COASTAL AREAS

(i) Nuisance Flooding- Due to the fact that sea level rise increases the likelihood of catastrophic floods, a large portion of research on the effects of sea level rise to date has concentrated on the incidence and destruction of sea level extremes, such as those caused by tropical cyclones or other storms. But because of sea level rise, nuisance flooding also referred to as sunny day floods has become more common on the east coastlines of the United States in recent decades. Coastal nuisance flooding refers to minor flooding from the sea that results in issues like flooded roadways and overflowing drainage systems. These issues can create significant inconveniences for people and serve as a breeding ground for mosquitoes and germs. An analysis based on more than 70 years of U.S. data discovered that, since 1950, the overall number of nuisance flooding incidents brought on by tidal variations has grown exponentially, with an additional 27% of such occurrences in 2019. Because of tidal variations brought about by human modifications including channel dredging, land reclamation, altered river flows, and other activities, estuaries exhibit the most changes. Regular flooding during high tide also has an impact on the local economy. For instance, regular high-tide floods in Annapolis, Maryland, have been found to have decreased visitors to the historic downtown by 1.7%; however, high-tide floods would decrease visits by 3.6% and 24%, respectively, with an additional 8 and 30 cm (3 and 12 inches) of sea level rise.

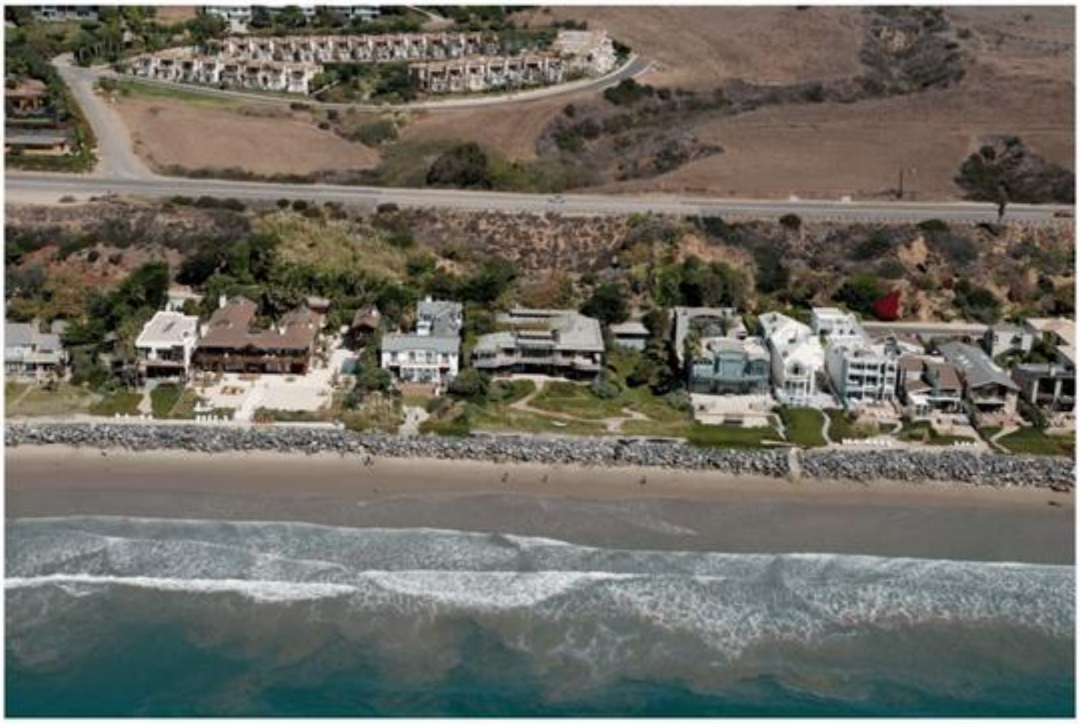

Figure 1- Rip-rap revetment armoring a section of the Malibu, California (USA) shoreline

(ii) How Future Sea-Level Rise Will Affect Coastal Areas- Future sea level rise-related losses of commercial development and governmental infrastructure will have a significant negative economic impact on coastal countries worldwide. However, due to differences in their geography, geology, regional climates, and development patterns, various coastal locations present different risks. Different landforms such as beaches, dunes, high cliffs, low bluffs, steep mountains, and estuaries can be found along the coast, along with varying densities of urbanization. Because to the interaction of hurricanes, big storm waves, extremely high tides, and projected future sea levels, lower-lying coastline regions are more susceptible to flooding. Higher-elevation regions, such cliffs, mountains along the coast, and bluffs, are more susceptible to wave assault during high tides or higher sea levels, which can cause coastal erosion. However, future sea level rise will result in:

- more frequent and elevated flooding of low relief shoreline areas, which will be followed by permanent inundation and the loss of beaches and coastal wetlands and
- more frequent wave impact and reach of the base of coastal cliffs, bluffs, and dunes, which will accelerate erosion rates.

The extent, kind, and ownership of development, as well as its public or private nature, will all influence the economic effects of coastal risks differently. Along heavily urbanized and armored coasts, passive erosion the slow loss of beaches due to ongoing sea level rise when the back beach has been stabilized by a barrier, rock revetment, or some other structure will be a significant issue. For instance, 38% of the heavily populated 233-mile (~325 km) southern California coastline, which is frequented by millions of people, is currently armored (Figure 1), and as sea levels rise, the problem of passive erosion and beach loss will only get worse.

CONCLUSION

We also need to keep focusing our efforts and innovative thinking on adaptation strategies that can read the world's cities and coastlines for sea level rise, given the shortcomings of our current efforts to significantly reduce global greenhouse gas emissions and the fact that anything we manage to implement or accomplish in the near future to mitigate climate change and its impacts will not have immediate effects. There is no denying that sea levels are rising globally; the questions are not "if" but rather "how much" they may increase in certain places and when in the future. The science is unambiguous, the future is regrettably becoming more and more definite, and immediate action is required. While there are no easy answers or fixes, we must include all relevant parties in the development and execution of well-thought-out plans and policies for the unavoidable future, along with established cutoff points for when action will be done.

REFERENCES

[1] Nicholls, R.J.; Cazenave, A. Sea-level rise and its impact on coastal zones. Science 2010, 328, 1517–1520.
[2] Allan, J.C.; Komar, P.D. Climate Controls on US West Coast Erosion Processes. J. Coast. Res. 2006, 22, 511–529.
[3] Barnard, P.L.; Short, A.D.; Harley, M.D.; Splinter, K.D.; Vitousek, S.; Turner, I.L.; Allan, J.; Banno, M.; Bryan, K.R.; Doria, A.; et al. Coastal vulnerability across the Pacific dominated by El Niño/Southern Oscillation. Nat. Geosci. 2015, 8, 801–807.
[4] Barnard, P.L.; Hoover, D.; Hubbard, D.M.; Snyder, A.; Ludka, B.C.; Allan, J.; Kaminsky, G.M.; Ruggiero, P.; Gallien, T.W.; Gabel, L.; et al. Extreme oceanographic forcing and coastal response due to the 2015–2016 El Niño. Nat. Commun. 2017, 8, 14365.
[5] Reguero, B.G.; Losada, I.J.; Méndez, F.J. A global wave power resource and its seasonal, interannual and long-term variability. Appl. Energy 2015, 148, 366–380.
[6] Reguero, B.G.; Méndez, F.J.; Losada, I.J. Variability of multivariate wave climate in Latin America and the Caribbean. Glob. Planet. Chang. 2013, 100, 70–84.
[7] Reguero, B.G.; Losada, I.J.; Méndez, F.J. A recent increase in global wave power as a consequence of oceanic warming. Nat. Commun. 2019, 10, 205.
[8] Vousdoukas, M.I.; Mentaschi, L.; Voukouvalas, E.; Verlaan, M.; Jevrejeva, S.; Jackson, L.P.; Feyen, L. Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard. Nat. Commun. 2018, 9, 2360.
[9] Wang, X.L.; Feng, Y.; Swail, V.R. Changes in global ocean wave heights as projected using multimodel CMIP5 simulations. Geophys. Res. Lett. 2014, 41, 1026–1034.
[10] Morim, J.; Vitousek, S.; Hemer, M.; Reguero, B.; Erikson, L.; Casas-Prat, M.; Wang, X.L.; Semedo, A.; Mori, N.; Shimura, T.; et al. Global-scale changes to extreme ocean wave events due to anthropogenic warming. Environ. Res. Lett. 2021, 16, 74056.
[11] Young, I.R.; Ribal, A. Multiplatform evaluation of global trends in wind speed and wave height. Science 2019, 364, 548–552.
[12] Morim, J.; Trenham, C.; Hemer, M.; Wang, X.L.; Mori, N.; Casas-Prat, M.; Semedo, A.; Shimura, T.; Timmermans, B.; Camus, P.; et al. A global ensemble of ocean wave climate projections from CMIP5-driven models. Sci. Data 2020, 7, 105.
[13] Woodruff, J.D.; Irish, J.L.; Camargo, S.J. Coastal flooding by tropical cyclones and sea-level rise. Nature 2013, 504, 44–52.
[14] Cooper, J.A.G. Others Sandy beaches can survive sea-level rise. Nat. Clim. Chang. 2020, 10, 993–995.
[15] Martínez, M.L.; Intralawan, A.; Vázquez, G.; Pérez-Maqueo, O.; Sutton, P.; Landgrave, R. The coasts of our world: Ecological, economic and social importance. Ecol. Econ. 2007, 63, 254–272.
[16] Barbier, E.B.; Hacker, S.D.; Kennedy, C.; Koch, E.W.; Stier, A.C.; Silliman, B.R. The value of estuarine and coastal ecosystem services. Ecol. Monogr. 2011, 81, 169–193.

[17] Antans P, Hristo S (2009) Risk for the population along the Bulgarian black seacoast from flooding caused by extreme rise of sea level. Info Secur 24:65–75.
[18] Australian Department of Climate Change (2009) Climate change risks to Australia's coast. Australian Department of Climate Change, Sydney.
[19] Ding YH, Ren GY, Shi GY et al (2006) National assessment report of climate change (I): climate change in China and its future trend. Adv Clim Chang Res 2(1):3–8.
[20] Feng S (1982) Introduction to storm surge. Science Press, Beijing.
[21] Gao S, Liu AM, Huang ZG, Zheng WW (2010) The character analysis on heavy rainfall including geo- logical hazards in Fujian Province. Geol Fujian 1:64–71.
[22] Gemmer M, Yin YZ, Luo Y, Fischer T (2011) Tropical cyclones in China: county-based analysis of landfalls and economic losses in Fujian Province. Quatern Int 244(2):169–177.
[23] Gong SL, Li C, Yang SL (2008) Land subsidence and urban flood prevention safety in Shanghai. Hydrogeology and engineering geology 4:96–101.
[24] Zhejiang Provincial Department of Geology and Mineral Resources (2005–2010) Zhejiang Geological
Environmental Bulletin.
[25] Zhao LD, Wang HY, Hu MZ (2011) Research on division of storm surge lost risk of coastal provinces. China Mar Environ Sci 30(2):275–278.
[26] Yin YZ, Gemmer M, Luo Y, Wang Y (2010) Tropical cyclones and heavy rainfall in Fujian Province. China Quat Int 226(1–2):122–128.
[27] Ye L, Yu FJ (2002) The long-range change and forecast of storm surge disasters in China. Mar Forecast 19(1):89–96.
[28] Yang GS (2000) Historical change and future trends of storm surge disaster in China's coastal area. J Nat Disasters 9(3):23–30.
[29] Xu YS, Shen SL, Cai ZY, Zhou GY (2008) The state of land subsidence and prediction approaches due to groundwater withdrawal in China. Nat Hazards 45(1):123–135.
[30] Tian Y, Xu YP, Booij MJ, Lin SJ, Lin SJ, Zhang QQ, Zhang HZ (2012) Detection of trends in precipitation extremes in Zhejiang, east China. Theor Appl Clim 107(1–2):201–210.
[31] de Ruig, L.T.; Barnard, P.L.; Botzen, W.J.W.; Grifman, P.; Hart, J.F.; de Moel, H.; Sadrpour, N.; Aerts, J.C.J.H. An economic evaluation of adaptation pathways in coastal mega cities: An illustration for Los Angeles. Sci. Total Environ. 2019, 678, 647–659.
[32] Werners, S.E.; Wise, R.M.; Butler, J.R.A.; Totin, E.; Vincent, K. Adaptation pathways: A review of approaches and a learning framework. Environ. Sci. Policy 2021, 116, 266–275.
[33] Haasnoot, M.; Kwakkel, J.H.; Walker, W.E.; ter Maat, J. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Glob. Environ. Chang. 2013, 23, 485–498.
[34] Griggs, G.; Davar, L.; Reguero, B.G. Documenting a Century of Coastline Change along Central California and Associated Challenges: From the Qualitative to the Quantitative. Water 2019, 11, 2648.
[35] Rupp-Armstrong, S.; Nicholls, R.J. Coastal and Estuarine Retreat: A Comparison of the Application of Managed Realignment in England and Germany. J. Coast. Res. 2007, 23, 1418–1430.