3D LAND-MARINE PROPERTIES ADMINISTRATION IN THE CONTEXT OF SEA LEVEL RISE (SLR) – ISSUES & CHALLENGES

A. Abdul Rahman[1], M. I. Hassan[1], I. A. Musliman[1], H. Rashidan[1], W. M. Mutiarasari[1], A. Zamzuri[1]
G. Buyuksalih[2], C. Gazioglu[2] & I. Bayirhan[2]

[1]3D GIS Research Lab, Universiti Teknologi Malaysia, UTM, 81310 Skudai, Johor, Malaysia
[2] Institute of Marine Sciences and Management, Istanbul University, Istanbul, Türkiye
alias@utm.my, imzan@utm.my, ivinamri@utm.my, mhanis27@gmail.com, wahyu.marta.m@gmail.com, ainnalfatihah@gmail.com, gurcanb@istanbul.edu.tr, cemga@istanbul.edu.tr, ibayirhan@istanbul.edu.tr

KEY WORDS: 3D land and marine data, data fusion, digital twin, 3D visualization, LADM edition II, Global Warming, Climate Change, DEM, Land Use/Cover, SLR

ABSTRACT

The current scenario of understanding spatial objects with regards to land and marine environment seems lacking. Inevitably, the scenario in line with the global warming issues as being highly mentioned by world-bodies such as the United Nations (UN) on climate change, etc. Recently the statistics on earth surface temperature point towards high record temperatures that lead to sea-level rise and degradation of land surface area, in general. These situations caused other spatial objects (land and marine properties) to be affected by their physical properties' changes (including geometries and locations). Thus, this paper attempts to review various aspects related to digital twins of land and marine spatial objects with respect to issues and challenges of multiple data acquisition techniques considering accuracy, data standard, seamless and integrated georeferenced data within the scenario as being reported in the 6th IPCC document. The situation warrants us to explore different types of land and marine properties (static and dynamic) where static properties are defined as immovable objects and vice versa for the dynamic environment. This paper also discusses on a brief experiment utilizing MERIT DEM (Multi-Error-Removed Improved-Terrain Digital Elevation Model), existing building footprints, simulated bathymetry, and land use datasets. The experiment reveals the prediction of the sea level rise according to the IPCC report. The gist of this paper to serve a motivation for our near-future research in the context of geospatial components and sea level rise (SLR).

1. INTRODUCTION & MOTIVATION

This paper aims to investigate the state-of-the-art on the seamless 3D land-marine properties administration. The review of this situation definitely helps in administering land and marine properties with respect to multiple data acquisition techniques considering accuracy, data standard, data format and georeferenced data. The other aspects as indicated in Figure 1 (the 3D land-marine properties framework) will be reviewed and elaborated in Section 3. Based on our readings (Atilola, 2012; Boulus and Wilson, 2023; Satpalda, 2023), all the six aspects need to be looked into, however, the three most important ones such as data management, data integration, and data visualization and dissemination will be the focus. Here, in this study, we believe that climate change and global warming issues very much related to the geospatial components (aspects). Several qualitative analyses will be conducted by using some datasets such as MERIT DEM (Multi-Error-Removed Improved-Terrain Digital Elevation Model), existing building footprints, simulated bathymetry, and land use datasets. GIS software (ArcGIS Pro) will be utilized for the analyses.

Recent works point to the effect of climate change and global warming as being reported by many international and national agencies like United Nations on Climate Changes as well as other bodies (UN-GGIM). Global warming, climate change and the associated sea level rise are increasing threats on the coastal regions. Authorities need to plan and implement variation measures to cope with these impacts to continue to protect the economic, social, and environmental security of the local and regional communities (Tribbia & Moser, 2008). Worldwide measurements from tidal gauges indicate that global mean sea level has risen by 18 cm on average, with a range of 10 – 25 cm, during the last 100 years (Warrick et al., 1996). The IPCC's 6th Assessment Report (IPCC, 2021) shows that emissions of greenhouse gases from human activities are responsible for approximately 1.1°C of warming since 1850-1900, and finds that averaged over the next 20 years, global temperature is expected to reach or exceed 1.5°C of warming. Same report provides sea-level rise (SLR) projections not only for 2100 but also for the centuries beyond. While SLR in the low carbon emission scenario (SSP1-2.6) is unlikely to exceed 0.62m by 2100, this could increase to over 3m by 2300. In the high emission scenario (SSP5-8.5) SLR could approach 2m by 2150 (0.98–1.88m) and 7m by 2300 (Vernimmen and Hooijer, 2023). In addition, the relative SLR is expected to be higher in coastal or deltaic zones affected by subsidence and increases the intensity and frequency of storm surge, causing flooding of low-lying areas, erosion of beaches and saline intrusion of aquifers (Gazioğlu, 2010).

According to Kirezci et al., 2020, for the case of, no coastal protection or adaptation, and a mean RCP8.5 scenario, there will be an increase of 48% of the world's land area, 52% of the global population and 46% of global assets at risk of flooding by 2100. A total of 68% of the global coastal area flooded will be caused by tide and storm events with 32% due to projected regional sea level rise. The situation is serious as like this. In addition, the SLR will increase in coastal erosion, flooding in coastal areas at sea level, degradation of coastal ecosystems and saltwater intrusion into estuaries and aquifers. Coastal erosion will cause sandy coastal areas to disappear and coast to become more vulnerable to storms and high waves, resulting in the destruction of the beach ecosystem, including coastal highlands (Mimura, 2013). It should be known that the habitats of many living species will disappear as a result of the disappearance of these areas, which also serve as important coastal habitats (e.g., sea turtle nesting areas) (Pink, 2018). Moreover, sea level rising will increase the salinity of estuarine waters, changing the turbidity and nutrient dynamics (Cereja et al., 2023) and this can

https://doi.org/10.5194/isprs-archives-XLVIII-4-W9-2024-1-2024

affect the distribution, abundance of living things and the food web. Saltwater intrusion, which is one of the consequences of SLR, brings problems such as the degradation of freshwater resources that are important for humans and living life. Such a change to aquatic ecosystems would make it almost impossible for marine creatures to adapt to the environment in which they live. It is also known that SLR causes the destruction of breeding grounds for some seabirds and fish (Eissa and Zaki, 2010). In the long term, community of the coastal area and ecosystem (coral reefs, salt marshes and mangroves) can be affected as well (Roy et al., 2023). Coral reefs, which allow creatures to create a safe breeding ground and nest, will gradually encounter deeper waters due to SLR until light levels prevent photosynthesis, at which point the reef may drown (Woodroffe and Webster, 2014).

This study reveals several major aspects of land-marine properties digital twin progression, especially the qualitative analyses based on several datasets. SLR could cause severe problems especially in the areas with less coastal protection and brings the possibility of losing land to sea. For example, Marmara Sea coastlines along with highly developed, industrialized, and built-up districts of Istanbul lived with this danger. To pre-estimate the effect and the dimension of this phenomena requires the application of global digital elevation models (GDEMs) together with other thematic map layers (including satellite images, line maps, 3D models and socioeconomic datasets) in the GIS environment. In such a way, it can be foreseen the influence of SLR on land use/land cover together with the human settlements along the coast and will be possible to generate a coastal zone management for the area to meet with the threats brought by the environmental disasters.

The next section (Section 2) discusses the issues and challenges, and Section 3 shows the results of GIS analyses related to SLR effects on Istanbul city as a case study area. Paper will conclude with the conclusion part in Section 4.

2. ISSUES & CHALLENGES

Figure 1 illustrates the framework in general. It consists of data availability, georeferenced & datum, data management, data integration, standardization & interoperability, data quality, and data visualization & dissemination.

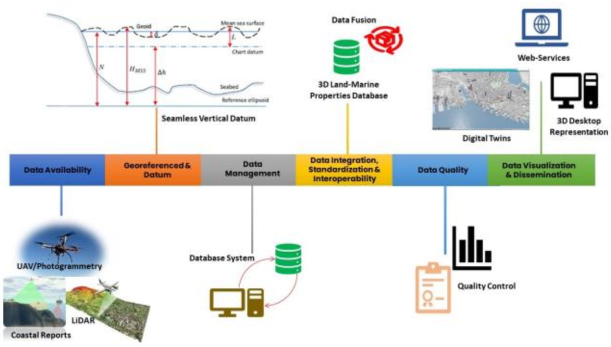


Figure 1. The 3D land-marine properties framework.

In this paper, data sources like MERIT DEM, existing building footprints, simulated bathymetry, and land use datasets will be explored according to the research questions, especially the fusion of the multi-sources data. It is important to address this issue since accurate data normally comes from fused datasets, thus, accurately generated building/properties.

The pursuit of seamless 3D land-marine properties administration represents a significant endeavour aimed at harmonizing land and marine data to enable comprehensive property management. On the terrestrial side, the focus revolves around city structures and terrains, whereas the marine coastal aspect primarily deals with dynamic elements such as shorelines, seafloor depths (bathymetry), and sea levels. These elements play pivotal roles in constructing digital representations, functioning as both static and dynamic features. Some elements (such as buildings and terrains) remain static, while others (like water levels and shorelines) exhibit changes over time. The following subsections discuss issues and challenges.

2.1 Data availability

Geospatial data availability has grown significantly in recent years with diverse sources such as, satellites, aerial imagery, drones, GPS devices, sensors, etc. According to UN-GGIM (2020), the development of 3D models of the urban and built environment has surged rapidly, driving the increased availability of 3D spatial data. However, there can be several challenges to obtain accurate and up-to-date data (land-marine) where the data access needs to be balanced with privacy and security concerns. Additionally, land-marine objects spanning both terrestrial (land) and marine (ocean) environments are inevitably hard and difficult to obtain. For instance, marine data collection is often monitored by different government agencies, research institutions, and private organizations, thus difficult to access as stated by Trice et al. (2021).

2.2 Georeferenced and datum

The issue of vertical datum comes into place when combining seafloor (bathymetry) and land topography – both are using different height datum (i.e., Lowest Astronomical Tide (LAT) for marine, Mean Sea Level (MSL) for land). The different datum problem could be overcome by using geoid-based as seamless vertical datum where the combination between land and marine data can then be approximated, thus continuous between marine and land.

Different georeferenced data creates problems during the integration process. Combining datasets with different datums (land and marine) can be challenging, as it often requires converting one or more datasets to a common datum. Datum transformations can be complex and introduce errors if not performed correctly.

2.3 Data management

3D spatial data for system development requires specific tasks and follows rules so that all are relevant and meet the system requirements. Recent reports suggest that 3D city model and digital twins deal with large data which requires substantial database management capability, thus, issues such as geometry of different objects within 3D models (for city models and digital twins) needs to be addressed. Janecka and Khaki (2016) related to the 3D cadastre objects and on 4D data; Uggla et al. (2023) more on the quality aspect of 3D city models. However, not much is being reported for the digital twins especially related to the land and marine objects. The scenario warrants such investigation on managing the 3D data that covers various objects especially the geometrical (and topological) and the semantics.

https://doi.org/10.5194/isprs-archives-XLVIII-4-W9-2024-1-2024

2.4 Data integration, standardization, and interoperability

However, within this context, various challenges arise, with a central issue being seamless data integration. The necessity for standardization and robust data models becomes evident when consolidating diverse datasets that encompass 3D city structures, topography, and bathymetry from multiple sources as reported by Büyüksalih et al. (2019). This standardization is imperative for addressing disparities in data formats and standards. Properties data is stored in various formats and is not centralized in a coherent and unified data model. This fragmentation makes it challenging to execute queries, visualize data, and ensure consistency across different datasets.

2.5 Data quality

It is important to address this issue within the framework since quality data generates accurate buildings/properties information. High data quality ensures that the data can be trusted and effectively used for analysis, decision-making, and other applications. Several authors discussed this issue as reported by Drummond (1991) and recently by Stoter (2020). Stoter emphasized that the presence of data quality issues, specifically 3D data errors, hinders the data sharing with other applications or platforms. She pointed out that modelling software can play a crucial role in incorporating ISO 19107 as 3D geometry standards to prevent and minimize these errors and suggested that the application of automatic repair algorithms could be explored as a potential solution to address this issue. In light of this, the utilization of management processes and tools to maintain and improve the quality of the data is indispensable.

2.6 Data visualization, and dissemination

Effective data visualization and dissemination are crucial aspects of 3D land-marine properties administration. Given the complexity and dynamic nature of the data involved, its essential to address several challenges in this area, one of them is scalability. As the volume of 3D land-marine data continues to grow, systems must be able to handle increasingly large datasets efficiently. This requires robust infrastructure and software solutions that can scale to meet the demands of users and applications. User-friendliness is critical when it comes to data dissemination. Stakeholders, including government agencies, researchers, and the public, should be able to access and understand the data easily. Developing intuitive user interfaces and tools for exploring and interacting with 3D land-marine data is essential to ensure broad accessibility and usability.

2.7 Digital Twin (3D City Models)

Digital twins are digital replicas of physical objects or systems, in this case marine-land interactions, and they provide a powerful tool for monitoring the effects of climate change, e.g., SLR in low-lying vulnerable areas close to shoreline. Once processed with different algorithms and statistical tools (machine learning, big data, cloud computing, and artificial intelligence, using various geo navigation and referencing platforms, the data can be monitored and visualised for information exchange between city decision makers and stakeholders in order to implement mitigation measures (Riaz, et al., 2023).

All the sea level predictions made up to the present day have realized the worst-case and even worse-case scenarios. Especially in the mapping of the coastal areas that will be submerged due to the rising sea levels, a linear approach is being used. However, it is evident that there is an urgent need for new geoinformatics approaches that consider not only the inland progression of saltwater but also the associated land-use inefficiencies beyond the coastline. Therefore, a 3D land-marine administration plan has to be made for the disaster preparation based on semantic 3D city models showing the landscapes and urban areas of the city with high accuracy in terms of the changes and events.

As mentioned by AbdulRahman et al., 2019, 3D city models can be visualized using the 3D Tiles format on the Cesium platform. The visualization uses Unity3D game engine, widely adopted in VR/AR environments to provide fast navigation and rendering. However, we are in the Metaverse era, which may give us an opportunity to integrate our digital twin of land and marine environments to the virtual world and obtain an immersive 3D experience for various scenarios that can be simulated, for example, what impact sea level rise would have on settlements and nature.

3. SLR CASE STUDY – ISTANBUL CITY

In this study, application of the MERIT DEM and GIS datasets to determine the vulnerability of Istanbul coastlines along the Marmara Sea against the SLR has been realized based on the scenarios given in the recent IPCC report. MERIT DEM (see Fig. 2) is based on the SRTM dataset but with the enhanced vertical accuracy (Jarvis et al., 2008). Figure 3 and Figure 4 show the qualitative analyses of the SLR for Istanbul area (Fatih and Beyoglu districts) based on years 2023, 2100, and 2300 respectively. In year 2100, Figure 3 (b) illustrates the prediction of 3 metres sea level rise, i.e., maximum 200 metres inundated land from coastline. The inundated areas depend on the terrain elevation. For year 2300, Figure 3 (c) illustrates the visualization of 15 metres sea level rise, i.e., maximum 600 metres inundated land from coastline. The Figure 4 (b) and (c) illustrate fully and partially inundated buildings.

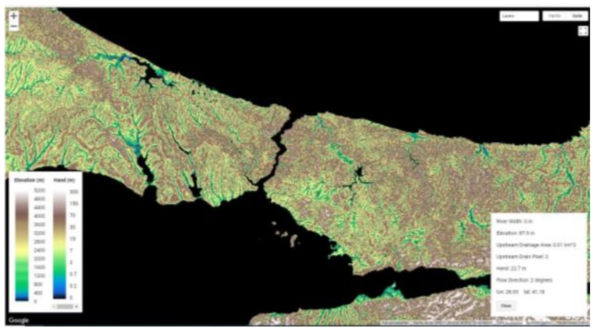
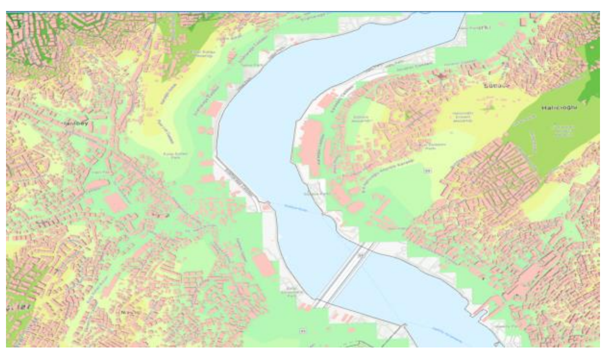


Figure 2. MERIT DEM showing Istanbul city 3D topography.



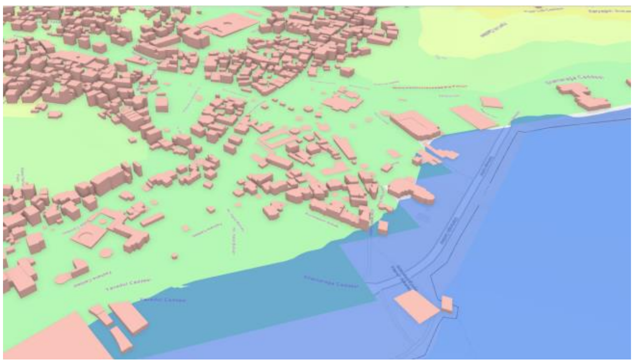
(a)

(b)

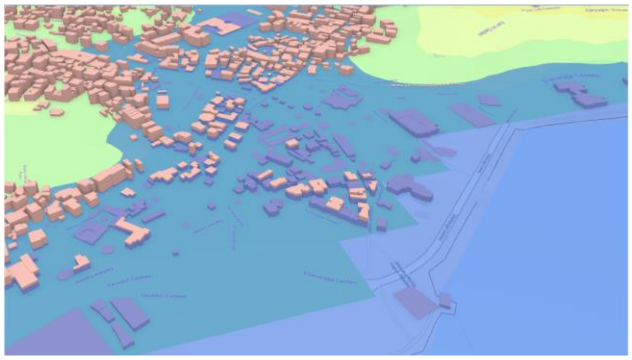
(c)

Figure 3. (a) Map of the current sea level of Istanbul, (b) the predicted worst-case scenario sea level rise by 3 metres in the year 2100, (c) the predicted worst-case scenario sea level rise by 15 metres in the year 2300.

(a)



(b)



(c)

Figure 4. 3D visualization of the inundated areas - (a) year 2023, (b) year 2100, and (c) year 2300.

Figure 5 illustrates cross section of sea level and terrain around Fatih and Beyoglu areas where some buildings inundated by 15 metres sea level rise.

Figure 5. Cross section of sea level and land by year 2023 and 2300 in Fatih and Beyoglu areas.

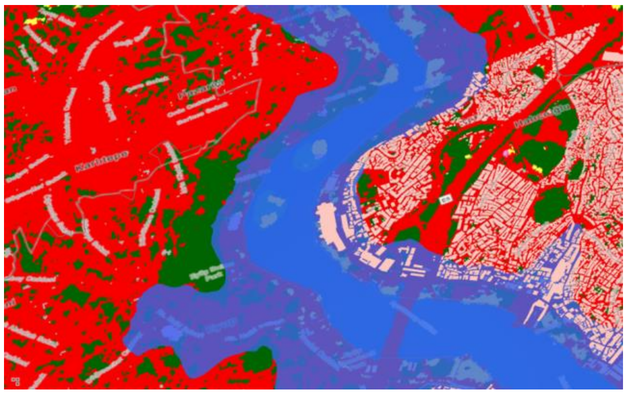


Figure 6. Land use map of Fatih and Beyoglu shows built-up area (red), tree cover (green), grass land (yellow), and the inundated areas (transparent blue) overlayed with the land use map from ESA Worldwide landcover mapping dataset.

Figure 6 shows the Fatih and Beyoglu areas based on land use cover with inundated areas. Looking at these two examples (Fatih and Beyoglu), the settlement areas, buildings (especially lower storeys), industrial facilities, transportation infrastructures (subway entrances) and recreation areas on the coasts of Istanbul are in danger. Figure 7 shows the situation clearly in the coast of Uskudar district, which is one of the very historic and touristic part of Istanbul. Considering that approximately 6 million people live in these areas, some measures need to be taken urgently. When we zoom into the MERIT DEM data, we immediately see that many rivers join the sea and pass-through residential areas. The rise in sea level will also affect the settlements in these areas along these streams and some riverbeds may be flooded. Apart from this, along the entire

Bosphorus, especially the mansions, palaces, religious and historical buildings (e.g., Dolmabahce Palace, Beylerbeyi Palace, Ortakoy Mosque) located on the shores, is expected to be affected by the change in sea level. It can also cause physical damage to the wastewater network. The fact that certain amounts of salt remain in the wastewater after treatment is the most important obstacle to the use of this water in agricultural irrigation. If precautions are not taken, it is inevitable that more seawater will mix with the wastewater system. Therefore, SLR on the coast of Istanbul along Sea of Marmara should be followed carefully, because it generates problems for the human life and the ecosystem.

Figure 7. Road under seawater in Uskudar coast of Istanbul city (https://www.star.com.tr/guncel/uskudarda-kara-ile-deniz-birlesti-haber-890810/).

4. CONCLUSIONS

In the integrated coastal area planning, it is essential to consider the effects that are likely to occur in the future due to numerous climate change effects, which are almost inevitable, unlike years when natural hazards were less prevalent in the past. Among these effects, the complete destruction of infrastructure along the coast and the decrease in agricultural productivity stand out as primary concerns. In urban areas, the deterioration of the coastal line will result in an escalating impact towards the city from point zero, necessitating infrastructure activities not only to mitigate the effects but also to compensate for the incurred damages and reduce urban vulnerability.

This study demonstrates what kind of data can be used for decision support mechanisms. It also indicates that point-based planning in urban areas is not highly effective and emphasizes the necessity of adhering to a sea-level change parameter that aligns with the geographical reality of the city in regional planning. The early focus of coastal management primarily centered on beach communities that historically bore the brunt of shoreline changes and coastal storms. However, insufficient attention has been paid to the loss of coastal wetland ecosystems, rapidly diminishing due to hindrances to their natural migration caused by inland development blocking estuarine habitats amidst rising sea levels. With urban areas increasingly exposed to these changes, major population centers face escalating risks. It is seen that by 2100, 70% of the world's population will be connected to the coast. The increasing population behind the coast and the associated socio-economic demands will need to be shaped against the SLR, which will be the enemy of our common future and, one of the most obvious effects of climate change, will pay the price for not taking countermeasures, not the generations hundreds of years later, as in the past, but the first or second generations at most.

REFERENCES AND BIBLIOGRAPHY

Abdul Rahman, A., Rashidan, H., Musliman, I., Buyuksalih, G., Bayburt, S., Baskaraca, P. “3D Geospatial Database Schema for Istanbul 3D City Model” Geospatial Kuala Lumpur 2019, Kuala Lumpur, Malaysia, 2019.

Atilola, O. (2012). Climate Change and the Environment: Issues and Geoinformation Challenges. FIG Working Week 2012. Rome, Italy, 6-10 May 2012

Büyüksalih, İ., Alkan, M., & Gazioğlu, C. G. (2019). Design for 3D city model management using remote sensing and GIS: A case study for the Golden Horn in Istanbul, Turkey. Sigma Journal of Engineering and Natural Sciences, 37(4), 1450-1466

Boulos, M. N. K., & Wilson, J. P. (2023, January 27). Geospatial techniques for monitoring and mitigating climate change and its effects on human health. International Journal of Health Geographics. https://doi.org/10.1186/s12942-023-00324-9.

Cereja, R., Brotas, V., Brito, A. C., & Rodrigues, M. (2023). Effects of droughts, sea level rise, and increase in outfall discharges on phytoplankton in a temperate estuary (Tagus Estuary, Portugal). *Regional Environmental Change*, *23*(3), 111.

Drummond, J. E. (1991). Determining and Processing Quality Parameters in Geographic Information Systems. University of Newcastle upon Tyne, Ph.D. Thesis.

Eissa, A. E., Zaki, M. M. (2011). The impact of global climatic changes on the aquatic environment. Procedia Environmental Sciences, 4, 251-259.

Gazioglu C., Burak S., Alpar B., Turker A., Barut I. F., (2010). Foreseeable impacts of sea level rise on the southern coast of the Marmara Sea (Turkey), Water Policy, 12(6), pp.932-943.

Janecka, K., and S. Karki (2016). 3D data management. FIG Workshop on 3D Cadastre. Athens. Greece.

Kirezci, E., Young, I.R., Ranasinghe, R., Muis, S., Nicholls, R.J., Lincke, D., and Hinkel, J (2020). Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st century. Scientific reports, 10(1):1–12.

Mimura, N. (2013). Sea-level rise caused by climate change and its implications for society. *Proceedings of the Japan Academy, Series B*, *89*(7), 281-301.

Pink, J. (2018). 5 Ways That Climate Change Affects the Ocean. Updated in 2021. (https://www.conservation.org/blog/5-ways-that-climate-change-affects-the-ocean#:~:text=Critical%20coastal%20habitats%20)

Riaz, K., McAfee, M., Gharbia, S.S., 2023. Management of Climate Resilience: Exploring the Potential of Digital Twin Technology, 3D City Modelling, and Early Warning Systems. Sensors 2023, 23, 2659. https://doi.org/10.3390/s23052659

Roy, P., Pal, S. C., Chakrabortty, R., Chowdhuri, I., Saha, A., Shit, M. (2023). Effects of climate change and sea-level rise on coastal habitat: Vulnerability assessment, adaptation strategies and policy recommendations. *Journal of Environmental Management*, *330*, 117187.

Satpalda. (2023, September 2). How modern Geospatial technology can be an asset in climate change studies? Satellite Imagery and Geospatial Services -. https://satpalda.com/blogs/how-modern-geospatial-technology-can-be-an-asset-in-climate-change-studies/

Stoter, J. E. (2020). State of the Art in 3D City Modelling, Six Challenges Facing 3D Data as a Platform. GIM International. Accessed May 2020.

Tribbia, J., Moser, S. C. (2008). More than information: what coastal managers need to plan for climate change.Environmental Science Policy, 11, 315– 328.

Trice, A., Robbins C., Philip, N. and Rumsey, M. (2021). Challenges and Opportunities for Ocean Data to Advance Conservation and Management, Ocean Conservancy, Inc. 2021.

Uggla, M., P. Olsson, B. Abdi, B. Axelsson, M. Calvert, U. Christensen, D. Galdivern, G. Hirsch, E. Jeansson, Z. Kadric, J. Lord, A. Loreman, A. Persson, O. Setterby, M. Sjorbeger, P. Stewart, A. Rudena, A. Ahlstrom, M. Bauner, K. Hartman, K. Pantazatou, W. Liu, H. Fan, G. Kong, H. Li, and L. Harie (2023). Future Swedish 3D City Models—Specifications, Test Data, and Evaluation. ISPRS International Journal of Geo-Information. Vol. 12(2), 47. https://doi.org/10.3390/ijgi12020047

UN-GGIM (2020). Future trends in geospatial information management: the five to ten year vision – third edition. *United Nations Committee of Experts on Global Geospatial Information Management.*

Vernimmen, R., Hoojier, A, 2023. New LiDAR-Based Elevation Model Shows Greatest Increase in Global Coastal Exposure to Flooding to Be Caused by Early-Stage Sea-Level Rise. Earth's Future 11(1), DOI: 10.1029/2022EF002880.

Warrick, R. A., Provost, C. L., Meier, M. F., Oerlemans, J. & Woodworth, P. L. (1996). Changes in sea level. In ClimateChange 1995: The Science of Climate Change.

Woodroffe, C. D., & Webster, J. M. (2014). Coral reefs and sea-level change. *Marine Geology*, *352*, 248-267.