Climate change and coastal vulnerability assessment methods:  
A review

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Abstract. Coastal and marine ecosystems have been threatened at local and global scales by multiple stressors – sea-level rise, rising temperatures, climate extreme events, biodiversity loss and habitat destruction. These stressors operating independently or synergistically could alter the ecosystem services while posing a significant threat to the environment, human lives and properties, as well as, result in biophysical and socio-economic losses. In this paper, we present an overview of the methods used in assessing coastal vulnerability of marine areas at local-global scales under chronic environmental stressors. Integrated and strategic methodologies that could identify, highlight and prioritise the vulnerable marine areas have been presented. The framework to assist coastal planners and managers in the conservation and management of vulnerable coastal regions and settlements from permanent inundation and loss have been suggested.

Keywords: Climate change; coastal ecosystems; vulnerability assessment; sea-level rise, marine areas

1. Introduction
In recent decades, coastal ecosystems and near-shore habitats have been under natural and anthropogenic stressors including global warming, sea-level rise, rising sea temperatures, climate extreme events, biodiversity loss, habitat destruction, and coastal erosion [1-3]. The consequences of these changes potentially impact coastal livelihoods, food security, the health of coastal and marine environments and the ecosystem services they provide [4-6]. A significant contribution to this phenomenon is the utilisation of fossil fuels and deforestation, which has subsequently increased the concentrations of atmospheric greenhouse gases globally, leading to a phenomenon known as climate change. Various researches have shown a steady increase in the amount of greenhouse gases present in the atmosphere [7]. The concentration of these greenhouse gases, mostly carbon (IV) oxide, has been on the rise since the beginning of the Industrial Revolution in the 1970s. It has also been established that this increased concentration of greenhouse gases is responsible for the change to the global climate that the world is currently experiencing [7].

Climate change has been of greater magnitude than global warming as the rise in atmospheric temperature is an indicator of the broader changes experienced globally [6,8]. These changes range from extreme temperatures to drought, flooding, increased storms, rising sea levels, human health and security challenges. Climate change has been defined by the International Panel on Climate Change (IPCC), as any change in climate over a long period due to natural variations or anthropogenic activities [9]. Though climate change is a global phenomenon with developing countries being the most vulnerable due to lack of adaptive capacity to the acidification of the oceans and sea-level rise. There has been ample evidence of rising sea levels in the last century due to the expansion of the warming oceans and the increased
melting of land ice [10,11]. Over the last century, sea level increased by 1.6 mm/year, according to [12]. Researchers had predicted that sea level may continue to rise throughout the 21st century, even if the concentration of greenhouse gases remains stable in future [13]. Changes in water storage on land have also been identified as a contributing factor [14,15,16] [7] found a general global increase in sea level throughout the 20th century, with some regions impacted by land subsidence and sediment transport. The impacts of this rise in sea level have led to health, social and economic hazards affecting marine and coastal ecosystems in different ways [17]. Hazards affecting marine and coastal ecosystems include a reduction of light accessibility to marine plants, coastal erosion and inundation. The superimposition of storms, high tides, and waves on an increasing sea level can spatially expand areas of inundation significantly, leading to widespread flooding in the region [18]. Rising sea levels can also aggravate saltwater intrusion into estuaries and aquifers, subsequently leading to contamination of groundwater in the region as well as the destruction of farmlands hence the loss of livelihoods for rural coastal dwellers. For developing nations like Nigeria to withstand the consequences of climate change, particularly sea-level rise, serious adaptation strategies need to be proposed and executed. This paper attempts to review the various methods available in literature for understanding the theory of coastal vulnerability assessment so as to aid proper planning and preparation of an acceptable framework.

2. The Concept of Vulnerability Assessment

The term, ‘vulnerability’, has been used across different disciplines to mean different things. According to the Intergovernmental Panel on Climate Change, ‘vulnerability assessment’ is the integration of sensitivity to climatic variations, adverse climate change, and adaptive capacity [19] which is dependent on sensitivity, exposure and adaptive capacity. Climate change vulnerability is long-term, has global coverage that is not uniform [20]. Vulnerability assessment involves the process of identifying a problem, quantifying it and assessing the risk rate encompassing the formulation of development approaches to reduce the risk and level of susceptibility. Since climate change is a continuous phenomenon, assessments of the risks/hazards are done with reference to a baseline scenario [20] as well as evaluation of its coastal vulnerability at regional, local, and global scales.

The perception of assigning values to vulnerability could be achieved with the use of indicators and metrics [17]. The study noted that coastal vulnerability centres could know how the variability in climate change influences communities living along the coastline, as well as understanding the functions provided by the human-built infrastructures and natural resources relative to the marine ecosystems. The study also noted that the evaluation of the impacts of climatic changes in particular coastal marine areas focuses on three fundamental factors, namely, the current capacity of coastal communities and ecosystems to adapt to and cope with climate impacts; the human, capital, and natural assets that will be exposed and impacted by climate change; and the nature and magnitude of climate variability and change in the study area [17]. The mutual interaction of both aspects of vulnerability help to create adequate adaptation policies for sustainability. These methodologies have been widely applied in academic and management purposes [36]. To achieve a widespread knowledge of vulnerability, it is necessary to integrate the physical and social aspects as this helps to provide a real picture of how the effect of any hazard affects the people [28].

3. Coastal Vulnerability Assessment Techniques

It is vital to note that two major approaches to assessing vulnerability exists, the ‘top-down’ and bottom-up' approach. The 'top-down' assessment concentrates on climatic evaluations from a global view down to a sectoral or regional point of view (for example, IPCC Common Methodology, IPCC CM). Conversely, 'bottom-up' assessments scale up from nearby sectoral evaluations to a regional and global scale at large. In broad terms, vulnerability assessment of climate change can be classified into: the use of quantitative or predictive models (i.e., the use of modelling techniques, e.g. Global Circulation Models (GCMs)), the use of empirical studies (mathematical and statistical techniques), the use of Expert judgment (through interviews of the inhabitants of such regions) and Experimentation [22]. In other terms, vulnerability assessment can also be classified as participatory, simulation-model based or indicator-based [23]. Concerning the study of climate impacts, three main types of modelling exist; socio-economic, biophysical,
and integrated system models. Biophysical modelling of sea-level rise can be achieved by quantitatively monitoring the physical processes that contribute to sea-level rise. These models are referred to as physical or process-based models. Process-based models incorporate and simulate the physical processes causing sea level rise. They consist of atmospheric and oceanic general circulation models (AOGCMs). Future projections with the use of AOGCMs combine the physical processes of the climate system, which uses future scenarios for greenhouse gases emission [23]. After the release of the IPCC AR5, the future scenarios that were approved for use consist of the Representative Concentration Pathways (RCPs). They replaced the SRES scenarios (Special Report on Emission Scenarios), which were used for previous Assessment Reports [7].

The main advantage of process-based models is that they are site-specific, however, they are complex and might require personnel training. Another disadvantage is that they require specific input conditions to operate [23]. Another method of coastal vulnerability assessment involves the exploration of the relationship between sea-level rise and other climate variables (for example, global surface temperature). This is achieved by observing past trends and making future predictions based on past observations. These types of models are known as statistical or empirical models [24]. Empirical models are derived by creating a mathematical model that best duplicates a set of observations, and predictions can then be made using the model. Though the application of these models is quite simple and easy to apply, they, however, require extensive observations and are site-specific [23]. The introduction of empirical models became necessary because it was observed that physical models were incapable of providing sufficient explanation for some changes in the past sea levels. This was due to the exclusion of some critical processes that makes significant contributions to sea-level change, thereby leading to an underestimation of the rise in sea level in the past [24]. For example, it was observed that the projected sea-level rise according to IPCC AR3 was lower than expected, as the recorded increase in sea level was higher than the projected figures. These discrepancies led to the utilisation and development of empirical models. Several studies have employed the use of the semi-empirical approach, and they have been widely accepted by the scientific community [26,28,29,13,30,31].

[32] simulated the observed and estimated global sea-level change using tide gauges reconstruction from 1900-2007 and estimates from satellite altimeters from 1993-2015. A simultaneous increase in sea level was observed in both measurements, and it was attributed to both thermal expansion of the seawater and change in mass balance. At the end of 2015, thermal expansion was concluded to be the most significant contributor to the change in sea level with an estimate of about 46% [22]. In addition, an attempt was made by [33] to include spatial resolutions into an existing empirical model. This classified technique was used to create a relationship between the changes in sea level and the sea surface temperature of the world's oceans. They discovered a linear correlation, and this method was proposed as an alternative to existing empirical methods in literature, which were usually viewed as being zero-dimensional [33]. To develop the study of sea-level rise, the introduction of dynamic system models came about due to the dissatisfaction of researchers over the linear relationship between global sea-level rise and global surface temperature. These models incorporate the observations from historical data and interactions between sea level and possible feedbacks [34].

Other approaches for evaluating coastal vulnerability associated with sea-level rise are available. These include the indicator-based approach, index-based approach, Geographic Information Systems (GIS)-based methods, and the use of dynamic models. Index-based methods include the use of indices to evaluate the rate of acceleration of sea level. The leading example that is widely used in literature is the Coastal Vulnerability Index (CVI). Other examples such as Social vulnerability index (SoVI), Sensitivity index (SI), Erosion hazard index, Sustainable capacity index (SCI), Sensitivity index, Vulnerability index are modified forms of CVI. These methods involve the use of numerical values to rank the various divisions of coastline in order of their level or rate of vulnerability [35]. Coastal managers, to identify regions where risks may be relatively high, can use these ranked values. Values obtained from the calculation of these indices are used to produce vulnerability maps, which shows the vulnerable areas. The use of GIS is used to develop spatial data with CVI variables to produce maps, which highlights CVI spatial distribution. Most coastlines, including Nigeria, have been studied with the use of CVI. CVI involves the use of seven or more variables, including shoreline change rate, sea-level change, coastal slope, mean tidal range, geomorphology, and mean wave height [29]. It involves the identification and quantification of these variables. Quantification is usually done by ranking the variables on a value of from one to five. [40] also utilised a modified form of the Coastal Vulnerability Index (CVI). They modified CVI to include some socio-economic variables to produce the Social Vulnerability Index (SVI) and Physical Vulnerability Index (PVI).

Indicator-based methods measure the intensity of communities to hazards of climate change with regards to
their vulnerabilities [39]. Although the index-based and indicator method are similar, the indices in the indicator-based method combine to give a final summary indicator [39]. An indicator refers to a content that depicts a scenario that is difficult to quantify directly, and it may aggregate diverse kinds of data. The indicator-based approach involves expressing the vulnerability of coast as a function of a set of indices that describe important shoreline characteristics or issues such as sensitivity, responses, exposure, impacts, waterways, expansion stresses, state, risk and loss. Sometimes known as variable-based indicators, they express the coast as a set of fairly independent variables [21]

The Geographical Information System (GIS) based methods involve the use of interactive maps, which allows users to visualise potential sea-level rise spots using Digital Elevation Models (DEM). The models are often referred to as "bathtub" models due to the simplicity of the approach. It applies a simple-water over-land approach without considering other physical, geographical, hydrological, and biological factors. It involves the use of data that gives information about shoreline characteristics, digital land elevation, vegetation, and land use. The significant advantage of the use of this method is the simplicity of use, even by non-experts and its ease of construction. However, they are limited due to the exclusion of some necessary information such as the built features in the region, differential land movement, ecosystem functions, and the fact that they are based on numerous assumptions. Some examples of these mapping tools are Ozcoasts by the Australian Government, United States Geological Survey sea level rise animation, National Oceanic and Atmospheric Administration (NOAA) sea-level rise viewer, etc. A Decision Support System is an experimental tool, which allows the assessment of the conditions of a system using different scenarios. It displays the magnitudes of different adaptation and mitigation measures by integrating all the relevant environmental models, databases, and assessment tools. For spatial problems like floods, which require the use of Geographical Information System (GIS) approach, these tools help to process and display the various data, thereby simplifying the spatial data integration, analysis, and visualisation [38, 40,41,42,43]

However, the use of decision support systems can also be employed in estimating the adaptive capacity of a community. The Geographical Information System (GIS-based) methods can be classified as DESYCO (Decision support system for Coastal climate change impact assessment) or DITTY-DSS. DESYCO is an open-source software programme, which enables the combination of data involving different model scenarios (this is because the use of high-resolution models as climate models could be biogeochemical, hydrological, or hydrodynamic). It provides information about the environmental and socio-economic information of the study area [38]. The application produces maps that identify highly vulnerable areas. The quick visualisation of the various indicators of the model is a major advantage of this method [36]. DITTY-DSS involves the use of mathematical and analytical models, which handles different aspects of vulnerability (i.e., biophysical and socio-economic). A major advantage of the GIS-based methods is the flexibility, which the method exhibit as it is adjusted to assess various scenarios and locations. It can also be modified to express the level of vulnerability in ranks. This is beneficial in adopting strategies for adaptation [38]. However, the major disadvantage of this method lies in the fact that the quality of the data input determines the result obtained; therefore, every uncertainty regarding the data needs to be quantified. Another demerit of the method is that the final output is not considered as an absolute prediction of the level of vulnerability. Instead, it is classified as an index, which provided information about an area.

Dynamic models are mainly categorised into two types; sector models and integrated assessment models. Evaluation of coastal processes with the use of sector models is most times, peculiar to the analysis of a particular climate change impact while integrated assessment models analyses multiple impacts of climate change. Integrated assessment models (IAMs) refer to models, which can analyse a broad spectrum of research approaches in climate change. Due to the complicated nature of climate change, researching its component needs to be interdisciplinary and multidimensional. IAM attempts to couple of technological models with economic models. It serves as the integration of energy system models, economic models, and climate science models [42]. The main advantage of integrated assessment models is that it helps to achieve models that ordinarily cannot be obtained from traditional single disciplinary research. They are undoubtedly one of the best approaches for estimating the effects of climate change on complex systems. Examples of sector models are Risk Assessment of Coastal Erosion (RACE) approach, which follows the source-pathway – receptor approach to risk analysis [42]. An example of the Integrated Assessment models is the DIVA (Dynamic Interactive Vulnerability Assessment) model, which was developed from the DINAS-COAST project (Dynamic and Interactive Assessment of national, regional, and global vulnerability of Coastal Zones to Climate Change and Sea-level Rise). It is suitable for regional to global assessment of sea-level rise while also incorporating socio-economic parameters. Another example of dynamic computer models for coastal
vulnerability assessment is the Climate Framework of Uncertainty, Negotiation, and Distribution (FUND) model of climate economics, which was developed by Richard Tol and David Anthoff. It is a useful model for global assessment; it's limited in use due to its coarse resolution and focuses on majorly economic parameters [42]. In summary, the main disadvantages of the models are that they might require great expertise.

4. Conclusion
Sea level rise, in coastal regions, is a topic of great interest in recent times due to harm that it poses to vulnerable areas like Africa. Adequate infrastructure must be provided to enhance the adaptive capacity of the inhabitants of the likely affected locality to avoid losses in the future. This might consist of the use of hard measures such as the construction of coastal defences such as polders and dikes to help obstruct rising waters and prevent permanent inundation. Another way of building adaptive capacity is by application of soft measures such as urban/coastal planning techniques and disaster risk reduction. Awareness should be made to sensitise coastal inhabitants about the dangers of sea-level rise.

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References
[1] Chollett I., Collin R., Bastidas C., Croquer A., Gayle P.M.H., Jordan-Dahlgren E. (2017) Widespread local chronic stressors in Caribbean coastal habitats. *PLoS ONE*, 12(12): e0188564. https://doi.org/10.1371/journal.pone.0188564
[2] United Nations. (2016). Global sustainable development report 2016. United Nations Publications.
[3] Mahapatra M., Ratheesh R., & Rajawat A.S. (2013). Sea Level Rise and Coastal Vulnerability Assessment: A Review. *International Journal of Geology, Earth & Environmental Sciences*, 3 (3); 67-80
[4] Ehrlich P.R. & Ehrlich A.H. (2013). Can a collapse of global civilization be avoided? Proc R Soc Lond B Biol Sci., 280: 20122845
[5] Benson, N. (2008a). Climate change, effects. In S. Philander (Ed.), Encyclopedia of global warming and climate change. (pp. 210-215). Thousand Oaks, CA: SAGE Publications, Inc. doi: http://dx.doi.org/10.4135/9781412963893.n129
[6] Halpern, B.S., Longo, C., Hardy, D, McLeod, K.L., Samhouri, J.F., Katona, S.K., (2012). An index to assess the health and benefits of the global ocean. *Nature*. 488: 615–20. https://doi.org/10.1038/nature11397
[7] Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M. M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (2014). Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of IPCC, the intergovernmental panel on climate change Cambridge University Press, Cambridge.
[8] Benson, N. (2008b). Global warming. In S. Philander (Ed.), Encyclopedia of global warming and climate change. (pp. 457-461). Thousand Oaks, CA: SAGE Publications, Inc. doi: http://dx.doi.org/10.4135/9781412963893.n281
[9] International Panel on Climate Change (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582.
[10] Bindoff, N. L., Willebrand, J., Artale, V., Cazenave, A., Gregory, J., Gulev, S., Hanawa, K., Le Quéré, C., Levitus, S., Nojiri, Y., Shum, C. K., Talley, L. D., & Unnikrishnan, A. (2007). Observations: Oceanic climate change and sea level. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.
[11] IPCC. Climate Change (2013). The Physical Science Basis. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, (Intergovernmental Panel on Climate Change, I Sydowed, 2014 Cambridge University Press, Cambridge.
[12] Church, J. A., & White, N. J. (2011). Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, 32(5), 585-602.
[13] Church, J., & White, N. (2006). A 20th-century acceleration in global sea-level rise. *Geophysical Research Letters*, 33, L01602.

[14] Konikow, L. F. (2013). Overestimated water storage. *Nature Geoscience*, 6. doi:10.1038/ngeo1659

[15] Ngo-Duc T., Laval K., Polcher J., Lombard A., & Cazenave A. (2005). Effects of land water storage on global mean sea level over the past half-century. *Geophysical Research Letters*, 32.

[16] Wada, Y., van Beek, L. P. H., Sperna Weiland, F. C., Chao, B. F., Wu, Y. H., & Bierkens, M. F. P. (2012). Past and future contribution of global groundwater depletion to sea-level rise. *Geophysical Research Letters*, 39.

[17] USAID (2009). Adapting to coastal climate change: a guidebook for development planners. US Agency for International Development, Washington, DC.

[18] Harley, C. D., Randall Hughes, A., Hultgren, K. M., Miner, B. G., Sorte, C. J., Thornber, C. S., Rodriguez, L.F., Tomanek, L. & Williams, S. L. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters*, 9(2), 228-241.

[19] Gilman, E., Ellison, J., & Coleman, R. (2007). Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. *Environmental Monitoring and Assessment*, 124(1), 105-130.

[20] Mimura, N. (2013). Sea-level rise caused by climate change and its implications for society. Proceedings of the Japan Academy. Series B, Physical and biological sciences, 89(7), 281–301. doi:10.2183/pjab.89.281.

[21] UNFCCC (2001). The Marrakech Accords and the Marrakech Declaration, FCCC/CP/2001/13 and Addendum 1–4.

[22] Fussel, H. M., & Klein, R. J. (2006). Climate Change Vulnerability Assessments: an evolution of conceptual thinking. *Climate Change*, 75(3), 301-329.

[23] Nguyen, T. T. X., Bonetti, J., Rogers, K., & Woodroffe, C. D. (2016). Ocean & Coastal Management Indicator-based assessment of climate-change impacts on coasts: A review of concepts, methodological approaches, and vulnerability indices. *Ocean and Coastal Management*, 123, 18–43. https://doi.org/10.1016/j.ocecoaman.2015.11.022

[24] UNEP. (1998). Handbook on methods for climate change impact assessment and adaptation strategies. Secondary Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies. Retrieved from http://www.cordelim.net/extra/cd forestal/Adaptacion al CC y MNR/Literatura/APF/HMC.pdf

[25] Hansen, J.E. (2016). The use of modelling tools to assess local scale inundation and erosion risk. CoastAdapt, National Climate Change Adaptation Research Facility, Gold Coast

[26] Rahmstorf, S. (2012). Sea-level rise: towards understanding local vulnerability. *Environmental Research Letters*, 7(2), 021001.

[27] Bittermann, K., Rahmstorf, S., Perrette, M., & Vermeer, M. (2013). Predictability of twentieth-century sea-level rise from past data. *Environmental Research Letters*, 8, 14-18.

[28] Aral, M. M., Guan, J., & Chang, B. (2012). Dynamic system model to predict global sea-level rise and temperature change. *Journal of Hydrologic Engineering*, 17(2), 237-242.

[29] Grinsted, A., Moore, J.C., & Jevrejeva, S. (2009). Reconstructing sea level from paleo and projected temperatures 200 to 2100AD. *Climate Dynamics*, 34(4), 461–472

[30] Vermeer, M. & Rahmstorf, S. (2009). Global sea level linked to global temperature. Proceedings of the National Academy of Sciences of the United States of America, 106 (51) 21527-21532.

[31] Jevrejeva, S., Grinsted, A., & Moore, J.C. (2009). Anthropogenic forcing dominates sea-level rise since 1850. *Geophysical Research Letters*, 36: L2070

[32] Rahmstorf, S. (2007). A semi-empirical approach to projecting future sea-level rise. *Science*, 315(5810): 368-370

[33] Schaeffer, M., Hare, W., Rahmstorf, S., & Vermeer, M. (2012). Long-term sea level rise implied by 1.5°C and 2°C warming levels. *Nature Climate Change*, 2(12), 867–870.

[34] Slangen, A. B. A, Church, J. A., Agosta, C., Fettweis, X., Marzeion, B., & Richter, K. (2016). Anthropogenic forcing dominates global mean sea-level rise since 1970. *Nature Climate Change*, 6, 701–705. doi: 10.1038/nclimate2991

[35] Chang, B., Guan, J., & Aral, M. M. (2012). Semi-Empirical Modeling of Spatial Variations in Sea Level Rise.
In World Environmental and Water Resources Congress 2012: Crossing Boundaries, 1966-1971.

[36] IPCC (2013). The physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change, 159-254.

[37] Feenstra, J. F. (1998). Handbook on methods for climate change impact assessment and adaptation strategies. United Nations Environment Programme, Nairobi, and Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

[38] ETC/ACC, (2010). Methods for assessing current and future coastal vulnerability to climate change. ETC/ACC Technical Paper 2010/8 European Topic Centre on Air and Climate Change.

[39] Alexandrakis, G. & Poulos, F.E. (2014). A holistic approach to beach erosion vulnerability assessment. Scientific Reports, 4, 6078.

[40] Serio, F. D., Armenio, E., Mossa, M., & Petrillo, A. F. (2018). How to Define Priorities in Coastal Vulnerability Assessment. Geosciences, 8(11), 415. doi:10.3390/geosciences8110415

[41] Ramieri, E., Hartley, A., Barbanti, A., Duarte Santos, F., Gomes, A., Hilden, M., Laihonen, P., Marinova, N., & Santini, M. (2011). Methods for assessing coastal vulnerability to climate change, European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation ETC CCA Technical Paper, 1, 1-93.

[42] Gold, C. M., Wright, D. J., & Bartlett, D. (2000). An algorithmic approach to marine GIS. Marine and Coastal Geographical Information Systems, 37-52.

[43] Wright, D.J., Dwyer, E., & Cummins, V. (eds.), (2011). Coastal Informatics: Web Atlas Design and Implementation. Hershey, PA: IGI-Global doi: 10.4018/978-1-61520-815-9, ISBN13: 9781615208159, 350.