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3D Marine Cadastral System to Support Marine Spatial Planning Implementation in Indonesia: A Case Study of Penanjung Bay, Indonesia

Abstract: The ocean is a formation that has a volume and consists of a surface layer of water, a column, and a bottom. Visualization of the sea on a digital map is important to support the acceleration of marine spatial planning (MSP), which is generally two-dimensional on a flat plane. A marine cadastre is defined as an instrument used in managing spatial boundaries, which describes, visualizes, and realizes legally defined boundaries as well as rights, restrictions, and responsibilities related to activities in the marine environment. Therefore, visualization in 3D will open a wider perspective than conventional maps. The 3D marine cadastral system was built using the Penanjung Bay pilot project and the QGIS2ThreeJS plugin with JavaScript. The results obtained can provide a 3D visualization of the position and boundaries for each component of the marine cadastre in Penanjung Bay with a broader picture of the sea spatial layout in the region.

Keywords: marine cadastre, 3D marine cadastral system, marine spatial planning (MSP)

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1. Introduction

The management of marine space is positively related to the marine spatial planning (MSP) system to produce spatial planning priorities in the ocean, which are incorporated into national policy. The effectiveness of MSP facilitates the adaptation of the national government in developing the spatial management of waters [1, 2]. MSP is also a practical way of managing the interaction between marine space and its visual usage in maps. It helps to protect marine ecosystems in a relaxed and planned manner [3]. However, it cannot be separated from the public process of analyzing and allocating the distribution of activities in an integrated approach. Spatial and temporal relationships between humans, the sea, and political activities in general are involved in achieving this process [4].

For coastal countries, the sustainable management of marine resources is an urgent task, including many cases of non-environmental violations due to the inefficiency of marine management mechanisms. The management of marine space has previously been conducted on the basis of sectoral and fragmented interests, which have failed to encourage the sustainable use of the marine environment. Consequently, the cumulative impact on the ecosystem has been neglected because the concentration is directed entirely toward industrial interests [5]. MSP was developed as part of a neutral process through a transformative governance approach to fundamentally change how humans interact and regulate the seas [2]. The MSP in Indonesia is officially regulated through Government Regulation number 32 of 2019 concerning the marine spatial plan. The management of marine space, which includes planning, utilization, supervision, and control, is carried out to protect resources and the environment as well as to utilize the potential of resources or activities in marine areas on a national and international scale. MSP is the jurisdiction of a country but in a global context, it can be observed through the IHO (International Hydrographic Organization) S-100 project with more specific topics, namely S-122 marine protected areas and S-126 physical environment.

Population growth with increasingly massive activities and urban development in coastal areas [6], combined with depleting critical natural resources, exacerbate marine environmental conflicts [7, 8]. The available natural resources are increasingly scarce, and the target areas of human activities are becoming more concentrated. Various stakeholders are involved in conflicts over issues related to conservation and development, especially in marine areas [8–10]. In managing sustainable coastal areas and resources, direct friction between interests and conflicts are usually common in the field due to increased population growth in coastal zones. Therefore, conflict resolution techniques are needed to avoid latent conflicts that grow and are resistant to management solutions [8].

Geographic information systems (GIS) and geospatial information are considered appropriate methods for dealing with conflicts in the management of the MSP [6, 11]. GIS have ability with multiple criteria for decision-making (MCDM) and spatial decision support systems (SDSS), any potential conflicts can be identified and mapped by observing the landscape from various angles, as well as scanning to find certain opportunities to optimize profits and simultaneously avoid conflict [8].

The application of GIS in the field of marine management, known in that field as marine cadastre, is developed through a GIS system by considering aspects of data standardization, interoperability between systems, and capabilities such as DSS (decision support system) [7], including implementing spatial decision support systems. Marine cadastre is relatively similar to land cadastre, with higher complexity, such as the absence of physical boundaries, including markers, piles or fences [12]. A marine cadastre is built by considering a country's form and institutions. As an archipelagic country, Indonesia cannot directly adopt concepts from other non-archipelagic coastal countries. The depiction of marine space in a system needs to consider whether the sea in the context of the real world is an object that has a volume which cannot be described perfectly through 2D (two-dimensional) printed and digital maps [13].

This study aims to describe the spatial sea space to achieve the MSP acceleration with a 3D (three-dimensional) approach. A 3D marine cadastral map provides detailed pictures of objects in a location and their important attributes in GIS [14]. Therefore, the area and volume of legally recorded property can be visualized on each side [15]. Legal aspects originating from government regulations and laws are described by considering the spatial dimensions of an area to depict the 3D spatial area of the legal volume.

The Indonesian Marine Cadastre Information System (IMCIS) has a visualization base in 2D and 3D. It was developed by considering the shape of Indonesia as a sovereign archipelagic state and providing a more significant appearance in delineating the rights and boundaries of marine space management [13]. As an information system, the marine cadastre is designed as a tool and mechanism for providing data and information as a source for planning and decision-making processes, as well as legal evidence of a particular sea, sea rights, and leases. Among the technical aspects of marine cadastre, spatial data infrastructure plays a very important role [7].

2. Methods and Material

2.1. Methods – Key Features

This study analyzed the application of technology (GIS field) by considering the applicable legal aspect or statute approach through government policy [13]. The technology-based study has the characteristics to form structures and procedures in building new systems whose main features can function well and are easy to understand. The outcome is a system that can use a visual technology approach to describe changes continuously, as well as objectify technology information into visual instruments through structured governance [16]. Integrating technology with applicable legal aspects can provide flexibility in understanding the context of a problem from various perspectives [13].

2.2. Study Site

This study site was in the Penanjung Bay area, located at the border of two provinces, Central Java and West Java. Penanjung is a large bay with a configuration of two small bays (Parigi and Citandui) as illustrated in Figure 1. Due to its location on the boundary between two provinces, this study involved the zoning plan for coastal areas in both regions.

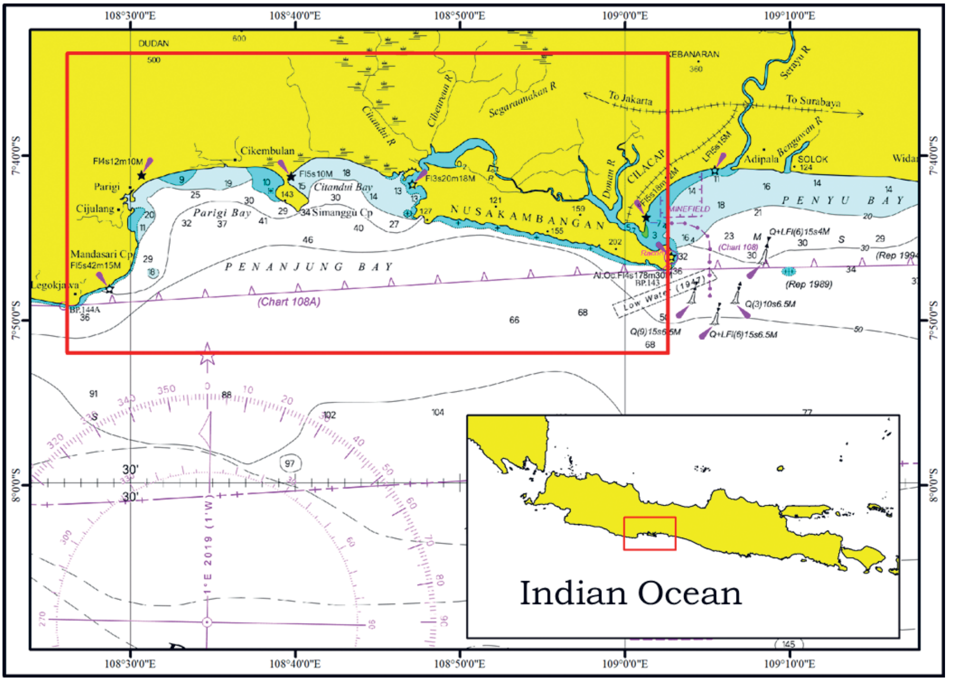

Fig. 1. Study site
Source: processed by the authors from [17]

2.3. Materials and Instruments

This study used GIS for marine applications, in the construction of the 3D marine cadastral system, study materials and instruments were divided into two categories, namely, legal and technical aspects. The legal aspect is a collection of laws and regulations that have direct implications for the regulation of marine space management.

The technical aspect category includes instruments used to build 3D marine cadastral system. The instruments employed include 1) GIS-based software to manage and process raster data into vectors, as well as 2) QGIS software and EqDistant and QGIS2ThreeJS plugins.

Table 1. Sources of data on legal aspects and information that can be obtained

No.	Legal aspect	Additional information
1	Regional Regulation number 13 of 2018	Zoning plan for coastal zone and small islands in Central Java Province 2018–2038
2	Regional Regulation number 5 of 2019	Zoning plan for coastal zone and small islands in West Java Province for 2019–2039
3	Government Regulation number 32 of 2019	Marine spatial planning (the legal basis for managing marine space, especially using a spatial approach)
4	Law number 23 of 2014	Local government (rights and obligations of local governments in managing the sea, along with their boundaries)
5	Minister of Home Affairs Regulation number 141 of 2017	Regional boundary demarcation
6	Indonesian Nautical Chart number 69 Central Java	Spatial data source
7	BATNAS (National Bathymetry)	Topography of waters

2.4. 3D Deep Sea Concept (Three-dimensional)

The 3D concept was built to answer the urgency of depicting the marine environment as it is in the field. The vertical composition, which is not considered on conventional maps, becomes the main component to provide an overview of the water column elements in the case of 3D, including the structure of the layers below. In 3D, depth is displayed with volume considerations for the methods and parameters used [18]. Legally provided 3D information can accurately describe the registered field on the surface or underneath. Stakeholders, directly or indirectly, will benefit from understanding exploration rights and authorities in a 3D framework and their impact on the environment or other management rights in the same or adjacent fields [19]. It is common for rights and boundaries between two or more properties to overlap. Another condition that might occur is two intersecting sea rights under water, rather than at the surface in general, in the water column, or even on the seabed. Therefore, in regulating marine space, the accurate visualization of rights is necessary [20, 21].

2.5. Definition of Marine Cadastre

The marine cadastre is an instrument for managing spatial boundaries, which describes, visualizes, and legally realizes boundaries along with rights, restrictions, and responsibilities attached to activities in marine space for more effective management, as illustrated in Figure 2. A marine cadastre gives users the ability to "describe, visualize, and realize" spatial information in the marine environment [12]. It includes location and spatial information regarding the rights, boundaries, and responsibilities of property in defined marine space, planning guidelines, and legal definitions. Due to accurate and comprehensive digital spatial data instruments, the area of the property in the form of "non-spatial" and its inherent legal aspects can be absolutely described. The sea has physical characteristics, including topography, which must be described properly with appropriate resolution. This physical realization will assist in activities such as managing and creating newly designated fisheries or aquaculture areas, monitoring, exploration, as well as laying cables and pipes. This will facilitate integrated maritime territorial management [12].

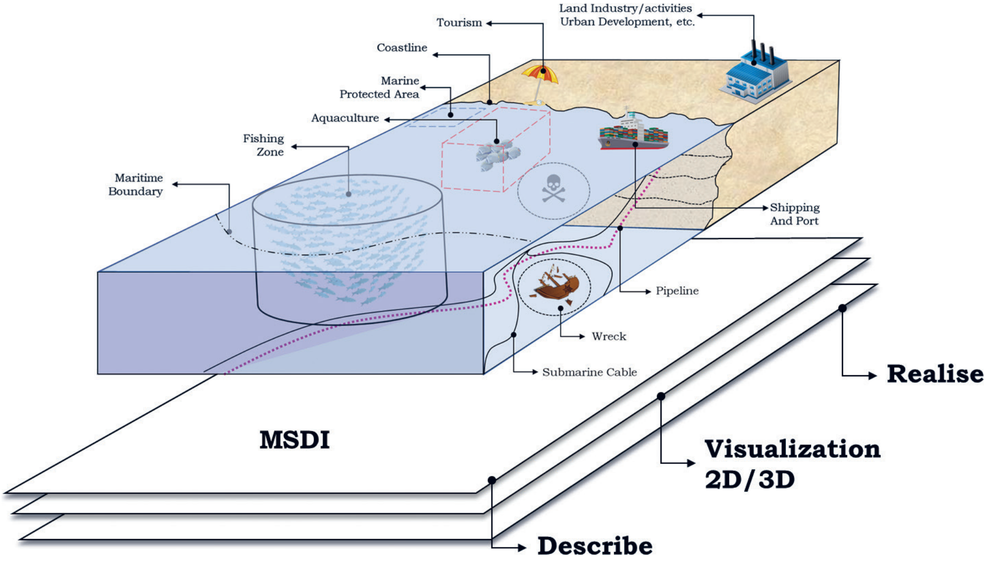

Fig. 2. Marine cadastral diagram concept

2.6. Marine Cadastre Components

An object above the sea requires a digital vehicle, especially a map, to find its exact position. A specific location which can be referenced in the real world will show the object's position between the boundaries of the spatial zone for a particular designation in the sea. Spatially delimited zones are referred to as marine cadastral components. According to [13], the marine cadastral components are:

1. *Sea boundaries*
   This component is the most crucial in dividing the sea area according to the government that manages it administratively and in a tiered manner.
2. *Tourism*
   This component is a strategic area to encourage the acceleration of development and economy in coastal areas.

3. *Marine protection and conservation*
   Marine protection and conservation components are used to represent areas protected by the government for ecosystem sustainability.
4. *Shipping*
   This component involves all matters relating to shipping at sea.
5. *Submarine cables and pipelines*
   The seabed surface is a location for humans to place various important instruments to support life, including cables and pipes for different purposes.
6. *Aquaculture and fisheries*
   This component is closely related to fishery product commodities, capturing fisheries and aquaculture. Therefore, the boundaries must be clearly described spatially.
7. *Energy and Minerals*
   Human life requires supporting resources, and one location containing human needs is the sea. The boundaries must be delineated on the energy and mineral components.
8. *Disposal of waste (dumping) and hazardous areas at sea*
   The sea is an area that cannot be physically marked and there are often undetected dangerous areas. Therefore, the boundaries must be delineated through maps of the dumping component and hazardous areas in the sea.

3. System Development and 3D Visualization

This 3D system was built using the QGIS2ThreeJS plugin from QGIS, in general, the development stage of the 3D marine cadastral system begins with the preparation stage, which includes regulatory studies and data collection, stages of data conversion from textual regulations into graphics with geographic references, as well as 3D dissemination as depicted in Figure 3.

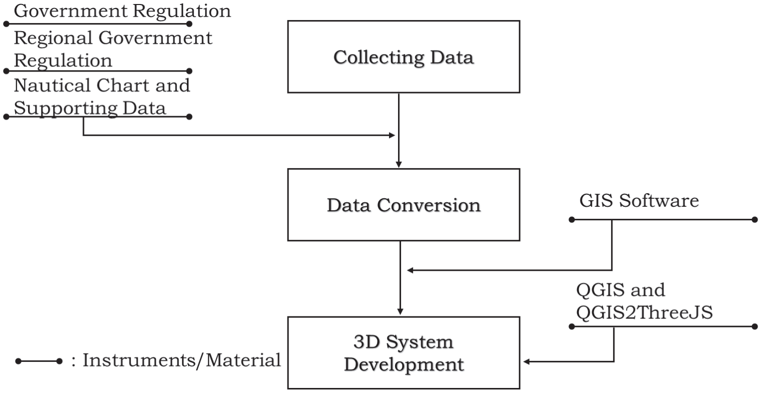

Fig. 3. 3D development flowchart

The QGIS2ThreeJS plugin provides facilities for visualizing DEM and vector data in 3D in the browser as illustrated in Figure 4. Users can create various 3D objects with a simple settings panel and generate files for web publishing in a simple procedure. In addition, it can save 3D models in glTF format for 3DCG or 3D printing. The 3D model was built using the Java Script programming language as depicted in Figure 4 and automatically recorded along with the model design carried out in QGIS. Meanwhile, the interface page was built using the HTML language structure.

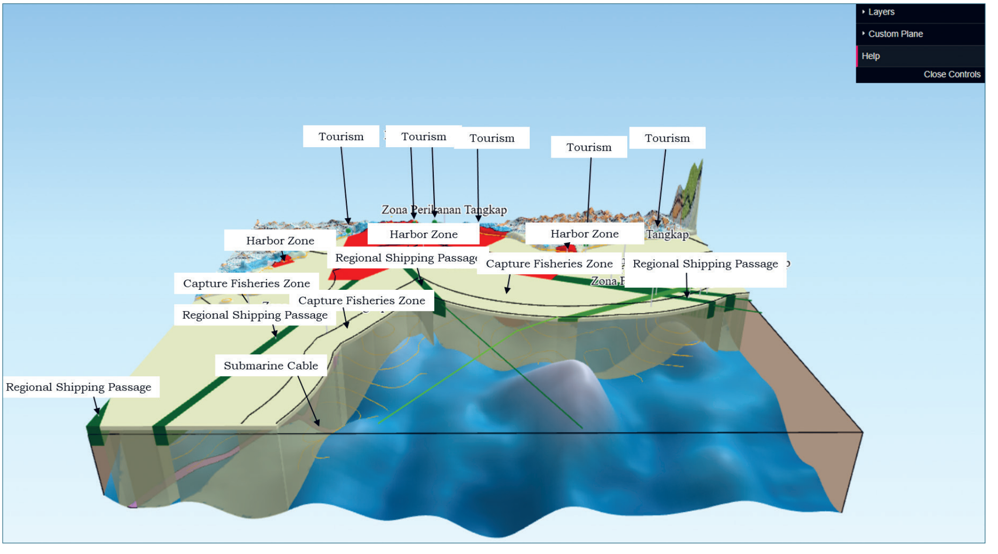

Fig. 4. 3D marine cadastral system development scheme on the Indonesian Marine Cadastre Information System (IMCIS)

Source: [13]

4. Discussion

Penanjung Bay is strategically located between West Java and Central Java provinces. Being in a location bordering the sea between two provinces, the sea area boundary must clearly and accurately divide the two sea areas. The sea area boundaries for the two regions are obtained through calculations using the equidistant method as shown in Figure 5, which can obtain the maritime boundaries of two adjoining regions. This refers to the Minister of Home Affairs Regulation number 141 of 2017 concerning the Determination and Affirmation of Regional Boundaries. According to the Minister of Home Affairs Regulation, the coastline used to draw the boundaries of the regional sea is the coastline at the highest tide position. The marine map was chosen because it uses the Mean High Water Springs (MHWS) as the shoreline position.

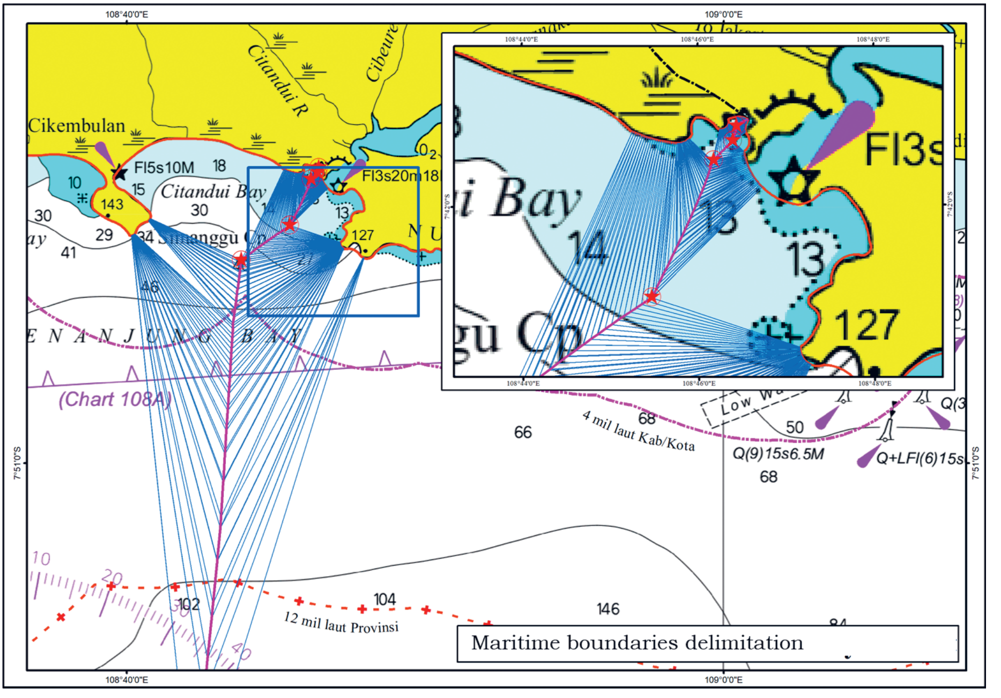

Fig. 5. Reconstruction of the withdrawal of maritime boundaries between West Java and Central Java provinces

Source: processed by the authors from [22]

Reconstruction of marine boundaries was carried out using a plugin from QGIS, namely the EqDistant plugin, which produced three outputs, including, 1) a construction line culminating from geometric calculations to obtain the midpoint of two shorelines, 2) the equidistant which is the meeting point between two construction lines, and 3) the median line which is the boundary line of the sea area and is connected by equidistant points. The boundary line obtained is then adjusted to an area of 12 nautical miles for the province, and 4 nautical miles for the Regency/City appropriate to Law number 23 of 2014 concerning Regional Government. Furthermore, the other marine cadastral components are derived from secondary data obtained through laws and various maps of Sea Spatial Allocation Map of West Java Province and Central Java Province, as well as Indonesian Marine Map number 69 as summarized in Table 2.

The marine cadastre components converted into vector data can become the main input in constructing the 3D marine cadastral system in Penanjung Bay. Using the QGIS software and the QGIS2ThreeJS plugin, the system was built using the HTML and JavaScript programming languages.

Table 2. Derivative information on the obtained marine cadastral component

Marine cadastre components	Information passed down	Marine cadastre components	Information passed down
Sea boundaries	Sea boundaries	Submarine cables and pipelines	Underwater pipe
Tourism	Tourism	Aquaculture and fisheries	Capture fisheries zone, aquaculture zone
Marine Protection and Conservation	Turtle migration and certain fish migration	Energy and minerals	–
Shipping	Port zones, fishing ports, regional shipping lanes, custom shipping lanes	Disposal of waste (dumping) and hazardous areas at sea	Mine area

a)

b)

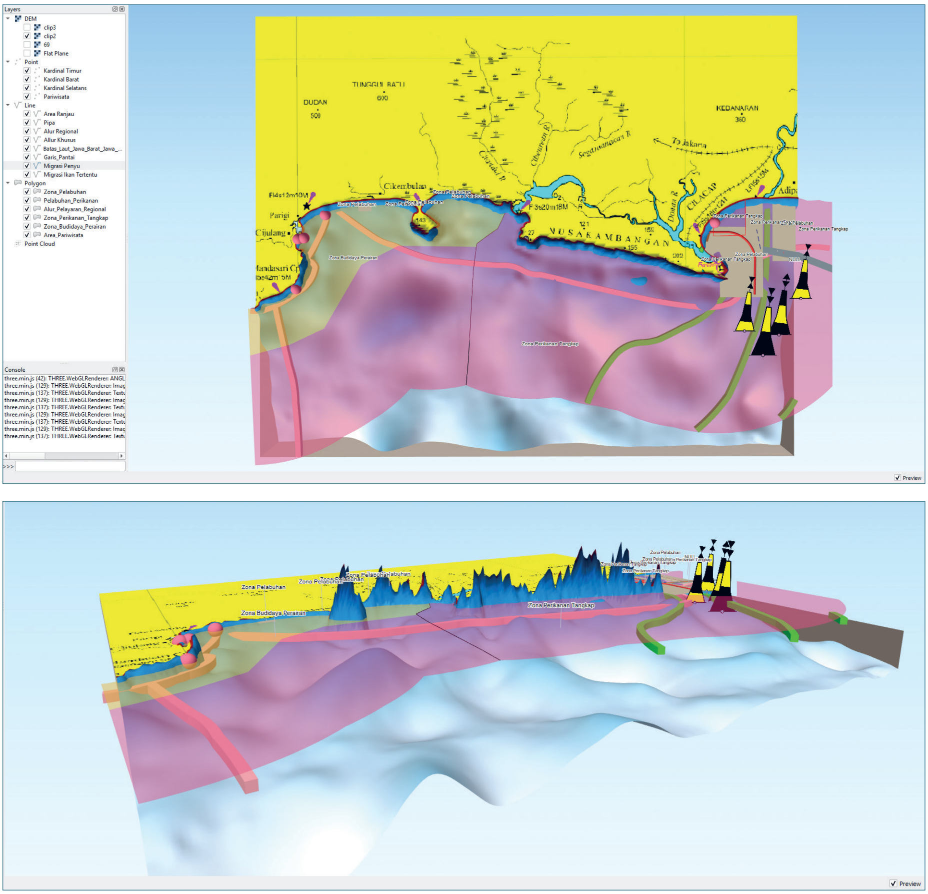

Fig. 6. 3D marine cadastral view of Penanjung Bay: a) from above; b) from the side

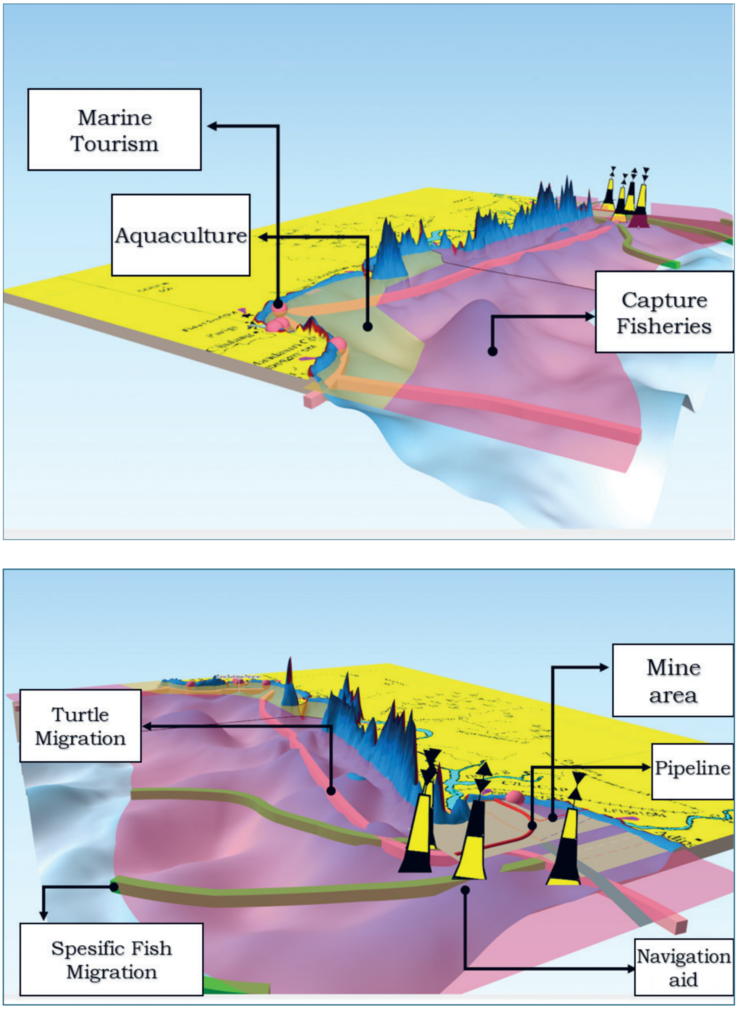

Fig. 7. Describable components of the marine cadastre

The important point to consider is the depth data used to display the basic shape of the waters. The volume of the sea must have the same reference in the use of data. When there is a significant difference, this will lead to floating data, hence, the displayed depth still contains elevation figures from the mainland. The 3D marine cadastral system, especially for the Penanjung Bay pilot project, provides a broader picture of understanding the marine spatial plan in the context of the sea as a 3D formation. Meanwhile, the S-100 represents the depiction of the sea in the 3D realm by international standards from the IHO (International Hydrographic Office) as part of the Universal Hydrographic Data Model. Marine cadastre, in a broader perspective, is directly related to marine spatial data infrastructure [22].

5. Conclusion

The 3D marine cadastral system, built with the pilot project of Penanjung Bay, can provide a broader picture of the sea in a 3D context. 3D models are built in the flexible Javascript programming language and technically designed via QGIS. There are seven components needed to build a 3D marine cadastral data model including, sea boundaries, marine protection and conservation, shipping, submarine cables and pipelines, aquaculture fisheries, energy and minerals, disposal of waste (dumping) and hazardous areas at sea. In order to compile the seven marine cadastral components into a 3D construction, conversion into vector data of the entire data is required. To build a 3D model, apart from the seven marine cadastral components, depth data is important, and all components are projected in the same type of projection system. Based on the 3D marine cadastral data model with the Penanjung Bay pilot project, a broader picture of the marine spatial plan in the bay can be produced, as well as supporting the acceleration of the S-100 Universal Hydrographic Data Model. The model developed in Penanjung Bay can be a recommendation for the development of 3D-based MSP in other regions and on an international scale. Since it is 3D-based, this model has an absolute advantage in terms of clearer visualization to avoid overlapping interests. Therefore, information on the water surface, column, and bottom can be distinguished. It can also help the territorial interpretation process to support the acceleration of a more complex and comprehensive marine spatial plan. The issue of marine spatial planning in Indonesia will continue to evolve in accordance with the need for sustainability and conservation of aquatic resources. The 3D marine cadastre system plays a role in providing a broader and clearer picture of the contents and components of the marine space. Further research will be focused on standards and specifications that are able to provide the best 3D information based on the scale considered. To date, data specification has been a considerable challenge in building 3D systems.

Author Contribution

Author 1: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft preparation, writing – review and editing, visualization, supervision, project administration, funding acquisition.

Author 2: methodology, writing – review and editing, validation, funding acquisition, validation, supervision.

Author 3: methodology, formal analysis, investigation, supervision, funding acquisition.

Author 4: resources, data curation, supervision, project administration, funding acquisition.

Author 5: methodology, formal analysis, investigation, supervision.

Author 6: methodology, formal analysis, investigation, supervision.

Author 7: investigation, resources, data curation.

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References

[1] Ritchie H., Ellis G.: *'A system that works for the sea'? Exploring Stakeholder Engagement in Marine Spatial Planning*. Journal of Environmental Planning and Management, vol. 53(6), pp. 701–723. https://doi.org/10.1080/09640568.2010.488100.

[2] Flannery W., McAteer B.: *Assessing marine spatial planning governmentality.* Maritime Studies, vol. 19, 2020, pp. 269–284. https://doi.org/10.1007/s40152-020-00174-2.

[3] Ehler Ch., Douvere F.: *Marine spatial planning: a step-by-step approach toward ecosystem-based management*. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme, IOC Manual and Guides no. 53, ICaM Dossier no. 6, UNESCO, Paris 2009.

[4] Jones P.J.S., Lieberknecht L.M., Qiu W.: *Marine spatial planning in reality : Introduction to case studies and discussion of findings*. Marine Policy, vol. 71, 2016, pp. 256–264. https://doi.org/10.1016/j.marpol.2016.04.026.

[5] Kelly C., Ellis G., Flannery W.: *Conceptualizing change in marine governance: Learning from transition management*. Marine Policy, vol. 95, 2018, pp. 24–35. https://doi.org/10.1016/j.marpol.2018.06.023.

[6] Tuda A.O., Stevens T.F., Rodwell L.D.: *Resolving coastal conflicts using marine spatial planning*. Journal of Environmental Management, vol. 133, 2014, pp. 59–68. https://doi.org/10.1016/j.jenvman.2013.10.029.

[7] Tamtomo J.P.: *The needs for building concept and authorizing implementation of marine cadastre in Indonesia*. [in:] *3rd FIG Regional Conference, Jakarta, Indonesia, October 3–7, 2004*, FIG, 2004, pp. 1–15.

[8] Brody S.D., Highfield W., Arlikatti S., Bierling D.H., Ismailova R.M., Lee L., Butzler R.: *Conflict on the coast: using geographic information systems to map potential environmental disputes in Matagorda Bay, Texas*. Environmental Management, vol. 34(1), 2004, pp. 11–25. https://doi.org/10.1007/s00267-004-0256-x.

[9] Jay S.: *Built at sea: Marine management and the construction of marine spatial planning*. The Town Planning Review, vol. 81(2), 2010, pp. 173–191. http://www.jstor.org/stable/40660676.

[10] Smythe T.C.: *Marine spatial planning as a tool for regional ocean governance?: An analysis of the New England ocean planning network*. Ocean and Coastal Management, vol. 135, 2017, pp. 11–24. https://doi.org/10.1016/j.ocecoaman.2016.10.015.

[11] Triana K., Wahyudi A.J.: *GIS developments for ecosystem-based marine spatial planning and the challenges faced in Indonesia*. ASEAN Journal on Science and Technology for Development, vol. 36(3), 2019, pp. 113–118. https://doi.org/10.29037/ajstd.587.

[12] Binns A.: *Defining a marine cadastre: legal and institutional aspects*. February 2004 [M.Sc. thesis].

[13] Kurniawan A.: *Rancang Bangun Purwarupa Indonesian Marine Cadastre Information System (IMCIS): Sebuah Kajian Teknis Dalam Perspektif Dua dan Tiga Dimensi*. Universitas Gadjah Mada, 2020 [bachelor of applied science thesis].

[14] Janečka K., Souček P.: *A country profile of the Czech Republic based on an LADM for the development of a 3D cadastre*. ISPRS International Journal of Geo-Information, vol. 6(5), 2017, 143. https://doi.org/10.3390/ijgi6050143.

[15] Stoter J., Ploeger H., Roes R., van der Riet E., Biljecki F., Ledoux H., Kok D., Kim S.: *Registration of multi-level property rights in 3d in the Netherlands: Two cases and next steps in further implementation*. ISPRS International Journal of Geo-Information, vol. 6(6), 2017, 158. https://doi.org/10.3390/ijgi6060158.

[16] Astor Y.: *Pola Penyelenggaraan Kadaster Kelautan Di Indonesia Dalam Perspektif Indonesia Sebagai Negara Kepulauan (Wilayah Studi : Selat Madura Provinsi Jawa Timur) (Wilayah Studi: Selat Madura Provinsi Jawa Timur)*. Institut Teknologi Bandung, 2016 [Ph.D. thesis].

[17] Indonesian Navy, Hydro-Oceanography: *Indonesian Nautical Chart Number 69*. Jakarta, Indonesia 2019.

[18] Abdullah A., Omar A.H., Lim C.K., Arof Z.M., Jamil H., Hua T.C.: *The Development of Marine Cadastre Conceptual Model for Malaysia*. [in:] *XXV FIG International Congress: Engaging the Challenges – Enhancing the Relevance, Kuala Lumpur, Malaysia 16–21 June 2014*, FIG, 2014, pp. 1–16.

[19] Ng'ang'a S., Sutherland M., Cockburn S., Nichols S.: *Toward a 3D marine cadastre in support of good ocean governance: A review of the technical framework requirements*. Computers, Environment and Urban Systems, vol. 28(5), 2001, pp. 443–470. https://doi.org/10.1016/j.compenvurbsys.2003.11.002.

[20] Ng'ang'a S., Nichols S., Sutherland M., Cockburn S.: *Toward a multidimensional marine cadastre in support of good ocean governance: New spatial information management tools and their role in natural resource management*. [in:] *International Conference on Spatial Information for Sustainable Development, Nairobi, Kenya, 2–5 October 2001*, FIG, 2001, pp. 1–11.

[21] Athanasiou K., Sutherland M., Kastrisios C., Tsoulos L., Griffith-Charles C., Davis D., Dimopoulou E.: *Toward the development of a marine administration system based on international standards*. ISPRS International Journal of Geo-Information, vol. 6(7), 2017, 194. https://doi.org/10.3390/ijgi6070194.

[22] IHO: *Spatial Data Infrastructures "The Marine Dimension": Guidance for Hydrographic Offices*. 2nd ed., v. 2.0.0. International Hydrographic Organization, Monaco 2017.