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Decision Support System for An Eco-Friendly Integrated Coastal Zone Management (ICZM) in Indonesia

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***Abstract*— With the second longest coastline in the world (after Canada), Indonesia has a big challenge in managing its coastal zone. Ecologically, Indonesia's coastal zone is rich with fascinating biodiversity; socioeconomically, it has played a long-time role as a sustainable source for food, as well as various development programs in Indonesia, such as interisland connectivity, shipping, fisheries, and logistics industries. The integrated coastal zone management (ICZM) concept is considered to be appropriate approach to deal with multi-stakeholders and multi-decision makers complexity in the coastal zone. In this paper, a decision support system (DSS) is developed based on ICZM by integrating numerical modelling and multi-parallel computing. This application system can be used as an interactive tool for managing the coastal area in Indonesia from various point of view, among other policymakers, industries, and coastal planners. The impacts after implementation of a scenario can be seen directly in the system to represent both the benefits and shortcomings. A test case is carried out in the Northern Jakarta coastal area. The system merits are highlighted in delivering direct effects after artificial islands instalment in the domain. DSS-ICZM development is intended to help policymakers in Indonesia improve the quality of their decisions and improve transparency for broad stakeholders.**

***Keywords*— integrated coastal zone management; coastal management; decision making; decision support system.**

I. INTRODUCTION

Indonesia is the largest archipelagic country in the world with 16,056 islands and a coastline of 108,000 km [1]–[3]. This coastal length is the longest in the world after Canada [1]. In Indonesia's biosphere, coastal zone is one of the major assets representing ecological richness and socio-economic potentials. Ecologically, coastal areas in Indonesia are very productive, with a variety of fascinating biodiversity such as mangrove forests and tidal swamps, besides supporting various marine culture activities [4]–[6]. Socioeconomically, for a long time the coast has played an important role as a sustainable source for food and various development programs in Indonesia, such as increasing interisland connectivity, shipping industry, fisheries and logistics. [4], [7]. Despite its potential, it should be noted that the policy regarding structuring coastal zones in Indonesia seems far from satisfying. As consequence, several issues arise, such as ecosystem degradation, coastline erosion/sedimentation and port inefficiencies [4], [8]–[10].

Integrated coastal zone management (ICZM), introduced in the 1990s, is an interdisciplinary approach to protect natural ecosystems while at the same time developing the economy [11]–[13]. This integration considered necessary because coastal zone is naturally a dynamic area – constituting a habitat of the sea and the land – which involves different stakeholders and decision makers [14]. Interdisciplinary perspectives are required to manage its complexity. ICZM is considered to be an appropriate approach for coastal zone management [15]–[17]. In the context of Indonesia, ICZM implementation faces many problems due to different interests of various stakeholders and bureaucratic imperfection (e.g. lack of transparency and contradictory inter-institutional policies) [18]–[20]. Hence, an analytic and transparent approach is required in the decision-making process to reduce the aforementioned shortcomings [21], [22]. From decision making theory, the use of a numerical model can help decision makers to make the best possible decisions [23]–[25]. Application systems to help decision-making process are known as decision support systems (DSS), which are designed to help understand the connections between variables so that it can improve the quality of decisions [14], [26], [27].

Research on DSS to support the ICZM developed along with the increasing problems of coastal area management [17], [28], [29]. DSS-ICZM can help show the processes that occur in the coastal area as a result of computer simulations in the form of analyzing the effects of project plans to be carried out. This system can help decision makers (government, industry or other stakeholder) in making the best decisions based on the analysis of these effects. The application of ICZM DSS recently done by integrating geographical information system (GIS) and web development [30], [31].

In this paper, the use of DSS-ICZM to help improve decision-making quality in managing the coastal zone in Indonesia is presented. For model validation, we use the case of the Northern Jakarta coastal area. This area was chosen because of the high dynamics in terms of socio-economics and policies. There are three contributions from this research. First, this research developed based on the ICZM concept using a numerical model by integrating multi-parallel computing. Different with recent research from [31] which uses a computer clustering system with a single parameter so that output is limited to hydrodynamic-sediment, this paper uses multi-parallel computing that is open attributes and multi-parameter so that it is more comprehensive which can include temperature, speed, water level and sediment. To the best of our knowledge, this is the first attempt to develop DSS-ICZM using a real case numerical model by including direct impact of changes in parameters. Second, DSS-ICZM research is still rarely done in the Indonesian context. In fact, with the longest coastal area in Asia and second in the world, it is fair to assume that it holds enormous potential both ecologically and socio-economically. This research contributes to the literature by with specific test cases focusing on Indonesia context. Third, practically, this research contributes to Indonesia's national innovation system by providing support system for relevant policy makers and decisions makers across stakeholders to improve the quality of their decisions, as well to improve transparency to the society.

II. Materials and Method

A. DSS Architecture

The independent platform is developed by integrating three elements, namely coastal manager, numerical model and a decision model for allowing complex assessment in the coastal system. The manager acts as a user whose using the platform to assess the impact after plans are implemented into the system. After some inputs are given, simulation is automatically conducted by using multi-parallel computing. Model results are then delivered into decision system, which can be accessed, by both government and private sectors for further analysis. Fig. 1 illustrates data processing in the system. The project is started after coastal manager/stake holder providing input command for the model layer. This stage can involve more than one decision maker both from private and government sectors to accommodate different concerns within the managers. The next stage is the modelling procedure. Different with the user layer where several changes in the system are allowed, the simulation procedure is absolute. Commercial modelling suits to maintain model accuracy implement a similar concept. In the last stage, the result is delivered into the decision module. We provide as much as possible, both parameters and clients in this module to unravel more necessity from the platform. Moreover, to attract more users, a simple visualization tool is provided for analyzing purposes.

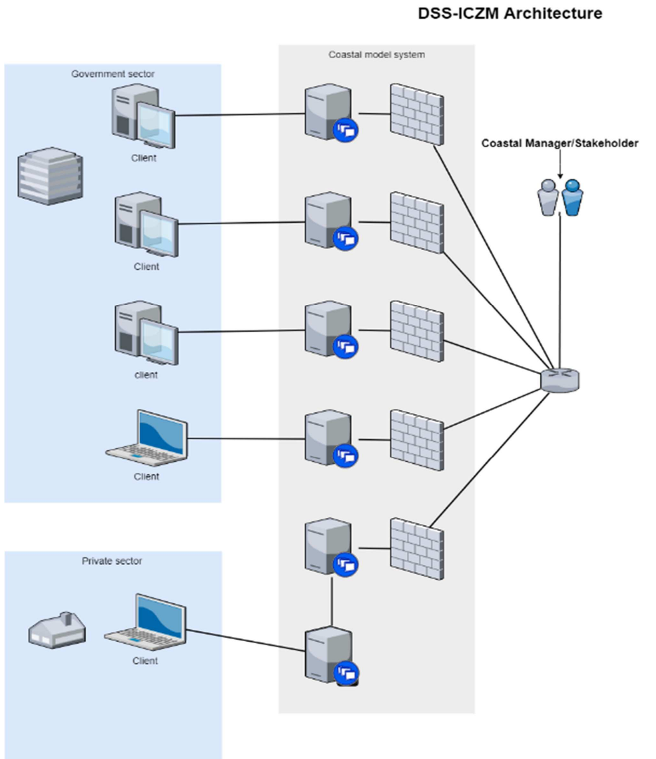

Fig. 1 DSS-ICZM architecture

1) User's layer: A user operates in the business domain layer. It is a map service zone with the ability to provide input as well as analyzing the results. In this beginning stage of the research, the layer only shows single map of Jakarta Bay for the sake of simplicity. We deliver simple and user-friendly interface due to the different users' background. Following [15] concept to keep up to date with water-land interaction, the user has given the capability to change the numerical domain. It is worth to note that event single artificial island can change the coastal flow and affect coastal processes.

2) Numerical model: Numerical modelling is used as a forecasting mechanism in the simulation layer, which is absent in the regular ICZM technique. Adopting the previous technique into DSS delivers both great opportunities and challenges. The requirement of performing simulation in the system is very demanding from a computational point of view; however, it will improve the quality of the decision. To solve this issue, we propose a parallel computing technique while on the forecasting stage. Hydrostatic, 3D numerical modelling is adopted into DSS where continuity and Navier-Stokes equations are solved. The Runge-Kutta numerical scheme is adopted to solve equations. Following [32], the governing equations are defined as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho_o}\frac{\partial P}{\partial x}+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)+F_u+\frac{\partial \tau_u}{\partial x} \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}-fu=-\frac{1}{\rho_o}\frac{\partial P}{\partial y}+\frac{\partial}{\partial z}\left(K_m\frac{\partial v}{\partial z}\right)+F_v+\frac{\partial \tau_v}{\partial y} \tag{3}$$

$$\frac{\partial P}{\partial t}=-\rho g \tag{4}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\frac{\partial}{\partial z}\left(K_h\frac{\partial T}{\partial z}\right)+F_T \tag{5}$$

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}=\frac{\partial}{\partial z}\left(K_h\frac{\partial S}{\partial z}\right)+F_S \tag{6}$$

$$\rho=\rho(T,S) \tag{7}$$

Where x, y, and z are the axes in Cartesian coordinate; u, v, and w are the velocity components for x, y, and z coordinates; F_u and F_v, F_T, F_S, are the horizontal momentum diffusion terms for velocity in the x and y-directions; temperature, and salinity, respectively. fv and fv are corriolis force in the x and y directions. ρ is the seawater density. K_m and K_h are the vertical eddy viscosity coefficient for momentum and scalars equations. The terms $\frac{\partial \tau_u}{\partial x}$ and $\frac{\partial \tau_v}{\partial y}$ represent the fluctuations in x and y directions, respectively. P is the pressure while T and S are temperature and salinity. To close the equations, six boundary conditions are used.
The surface and bottom boundary conditions for temperature are defined as:

$$\frac{\partial T}{\partial z}=\frac{1}{\rho c_p K_h}[Q_n-SW] \text{ for } z=\zeta(x,y,t) \tag{8}$$

$$\frac{\partial T}{\partial z}=\frac{A_H \tan\alpha}{K_h}\frac{\partial T}{\partial n} \text{ for } z=-H(x,y) \tag{9}$$

Q_n is the surface net heat flux and SW is the shortwave flux incident at the sea surface. c_p and A_H are the specific heat of seawater and the horizontal diffusion coefficient for thermal. α is the bed slope and n represents horizontal coordinate. Similar with the boundary conditions for temperature, the surface and bottom boundary conditions for salinity are defined as:

$$\frac{\partial S}{\partial z}=\frac{S(P-E)}{\rho K_h}\cos\gamma \text{ for } z=\zeta(x,y,t) \tag{10}$$

$$\frac{\partial S}{\partial z}=\frac{A_H \tan\alpha}{K_h}\frac{\partial S}{\partial n} \text{ for } z=-H(x,y) \tag{11}$$

$P-E$ represents rates of precipitation and evaporation. In addition, two boundary conditions are used for momentum equations:

$$K_m\left(\frac{\partial u}{\partial z},\frac{\partial v}{\partial z}\right)=\frac{1}{\rho_o}(\tau_{sx},\tau_{sy}) \quad , \quad w=\frac{\partial \zeta}{\partial t}+u\frac{\partial \zeta}{\partial x}+v\frac{\partial \zeta}{\partial y}+\frac{E-P}{\rho}$$
$$\text{for } z=\zeta(x,y,t) \tag{12}$$

$$K_m\left(\frac{\partial u}{\partial z},\frac{\partial v}{\partial z}\right)=\frac{1}{\rho_o}(\tau_{bx},\tau_{by}), w=-u\frac{\partial H}{\partial x}-v\frac{\partial H}{\partial y}+\frac{Q_b}{\Omega}$$
$$\text{for } z=-H(x,y) \tag{13}$$

(τ_{sx},τ_{sy}) and (τ_{bx},τ_{by}) are the surface and bottom components of shear stress. Q_b is the ground water flux and Ω represents the source area of groundwater.

Despite the user has been given access to change the domain, adding new term into model equation is not possible. The reason behind this policy is to maintain the synchronization between the models with the user interface. Any changing in the model equations may create bugs during the computation.

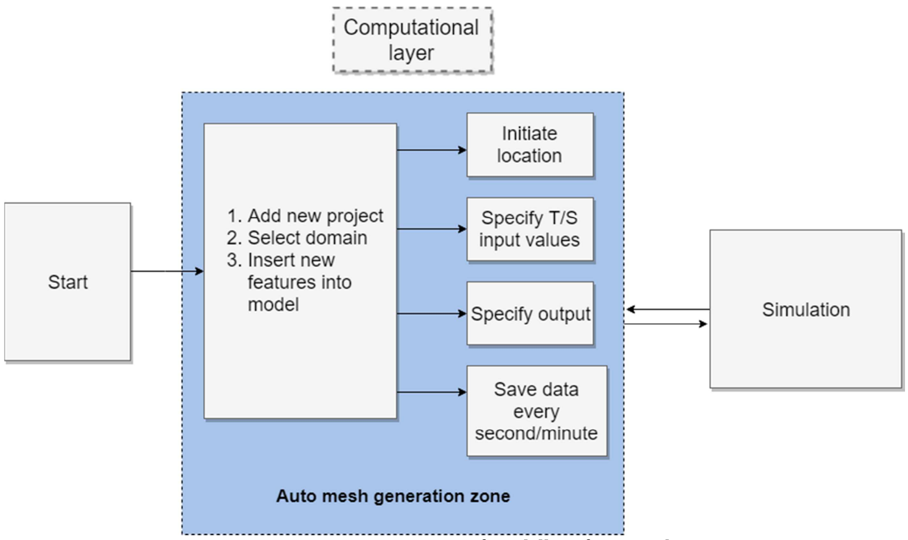

Fig. 2 Automation concept of modelling framework

Fig. 2 explains the automation of computational modelling workflow. Basic information such as domain, length, and width of new structures in the domain, input value for T/S, and data output period are specified at this stage. The model result parameters are saved into NETCDF format. We create a specific function to read and analyse the data by using matplotlib library in python.

3) Decision module: The concept of the system is to fully support policy makers during initiation stage. Therefore, an amount of high quality data is required to show the possible consequences after implementation [33]. From this point of view, an issue directly showed up referring to system dependency on numerical simulation. In contrast to the regular ICZM where an amount of spatial data with different spatial/temporal resolution is collected and analyzed, multi-parameter data with equal resolution is adopted in the present case. Moreover, it is very difficult to organize and manage coastal spatial data in Indonesia.

III. Result and Discussion

The system performance was tested for assessing artificial islands impact in water intake temperature around a steam power plant site in Northern Jakarta known as PLTU Pluit. The test aims are to examine computational time in forecasting water temperature after the artificial island being added into the system and to assess the system accuracy after simulation. In this scenario, DSS is used to assess whether the existence of the artificial islands affects the water temperature to cool the power plant or not.

A. PLTU Pluit site

Pluit steam power plant, which located in the Jakarta was built in 1979. It is home to two Mitsubishi TCTDF turbines and generates approximately 7.900 GWh for supporting electricity in Java and Bali islands. High concern arose in the last two years due to the mega project of reclamation in this region. Researchers have identified possible threats when four artificial islands are developed in front of stream power plant water intake. This scenario was used in the present research to examine system performance.

B. Water intake test case

Development of new islands has a dominant effect on coastal circulation at power plant site. The hydrodynamics system changes as a result deceleration and/or acceleration of current speed in some points can be expected during the simulation. Furthermore, reduction of water fluxes has a significant influence in recirculation process and contributes to change the water temperature around the intake site.

1) Domain modification: The testing is started by creating a new project and insert existing domain into user layer. Domain modification is conducted at this stage by using user interface tools. In the present test, the four islands are developed in front of the steam power plant site (rectangular zone) as shown in Fig. 3.

Fig. 3 Domain in the user interface

Other input parameters are shown in the Table 1.

TABLE I.
Input Parameters

No	Parameters	Value
1	Intake temperature	30^0C
2	Outfall temperature	35^0C
3	River discharge	20 m^3s^{-1}

Steady state condition is achieved after 30 minutes computational time for 7x8 km domain with a time step of five seconds. Additionally, a similar duration is obtained when simulation is conducted in stand-alone mode.

2) System validation: The validation result shows good agreement with field data for surface elevation. Testing indicates system capability of coupling with the numerical model under low computational cost. Despite difference phase of surface elevation was observed from model result, the magnitude is in similar order with the field data as shown in Fig. 4.

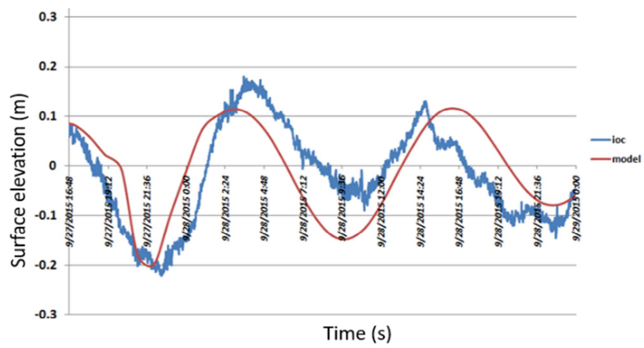

Fig. 4 Validation result between field (blue line) and model data (red line)

3) Temperature and current speed changing: Taking action in the decision module the assessment of temperature and velocity changing are conducted at this stage by using visualization tool. Firstly, the data, which consists of current speed and temperature, are extracted from seven locations as shown in Fig. 5. However, only regions with significant changing are showed in this section.

Fig. 5 Extraction points

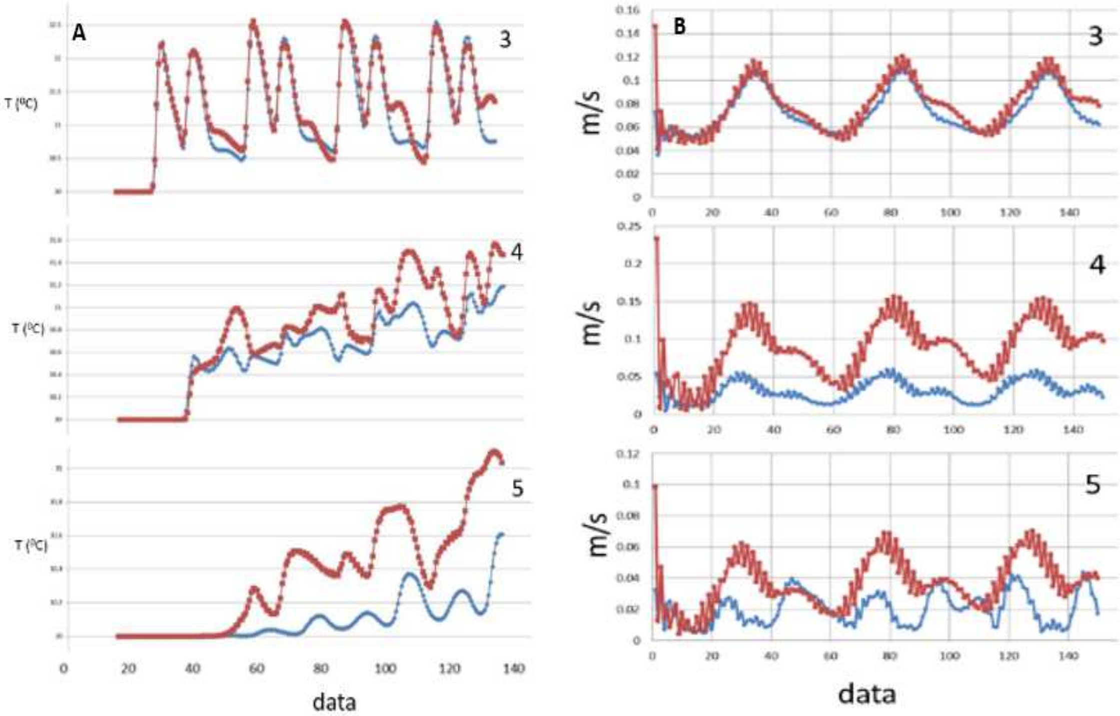

Fig. 6 Temperature (A) and Current speed (B) for points 3, 4, and 5 before (blue line) and after (red line) island instalment

Unsurprisingly, the presence of the islands significantly elevates the current magnitude compared to the existing condition. Moreover, current speed at points 3, 4, and 5 were observed two times higher after the islands instalment as illustrated in Fig. 6. Consistent with the velocity magnitude, water temperature experiences similar condition where it values twice higher from the existing condition. The system capable to capture complex coastal circulation after instalment was conducted. This performance indicated that well integration between layers in the platform is achieved.

IV. Conclusions

The DSS is developed based on ICZM concept, numerical model and multilayer computing. System is tested for water intake case near artificial island in Northern Jakarta. Model performance shows good agreement with measured data and mild computational cost for forecasting physical changing in coastal zone. This DSS-ICZM allows related stakeholders and policy makers in Indonesia to test various policy scenarios based on real data and see the impact directly in real time and transparent. This is expected to improve the quality of policy making related to the coastal zone in Indonesia.

Theoretically, this study is the extension research from [31] by using multi-parallel computing with multi-parameters, which include temperature, speed, water level, and sediment. In addition, DSS-ICZM in the study used a real case numerical model by including the direct impact of changing the parameters. This study also contributes to the literature by using empirical research with a test case in Indonesia, the second longest coastal zone in the world, where only limited empirical research on DSS-ICZM has been done to date. In practical terms, especially from the cost and benefit perspective, the implementation of the system developed in this study offers several advantages. First, the cost of implementing the system is not expected to be high because the required data is available. It is a different matter if the data does not yet exist and researchers need to carry out extensive surveys, driving the cost up. Second, this program is a one-time development and can subsequently be used for numerous coastal zones in Indonesia, thus delivering a significant level of efficiency. The open system design application used in this system will be useful in aiding decision making in many coastal areas in Indonesia. If any customization is required, it will be minor in nature.

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