Tidal Current Energy Resource Assessment Around Buton Island, Southeast Sulawesi, Indonesia

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Abstract- An early stage of assessing tidal current energy resources is carried out in this present work. Tidal current power is estimated around Buton Island, Southeast Sulawesi province, Indonesia. A two-dimensional, depth-integrated Advanced Circulation (ADCIRC) model has been used to simulate tidal elevation and barotropic tidal current around the island. Green's function approach has been used to improve eight tidal constituents on the open boundary conditions based on the tide gauge data. Interestingly, some very promising locations for harvesting tidal current energy were found in the vicinity of the island. In fact, around the island, tidal current speed is almost two meters per second and the highest tidal current power in the selected station is 308.7 W/m^2.

Keywords- Tidal current power, Green's functions, ADCIRC model, Buton Island.

1. Introduction

The Indonesian Ministry of Energy and Resources reported that the energy consumption in Indonesia had significantly increased in the last few years [1]. At the moment, a majority of the electricity in Indonesia is generated from oil, which relies very much on foreign import and thus depends on oil price. To reduce such dependence, other resources of energy such as renewable energy have to be sought [2, 3]. Fortunately, this matter has been taken into account of Indonesian government. In fact, the regulation for the development of renewable energy in Indonesia has been stated in the Presidential decree No. 5/2006 regarding to national energy policy [1]. According to the decree, the contribution of renewable energy is expected to be at 17% of the total primary energy mix in 2025. From this figure, 5% should come from hydro-power, which includes ocean renewable energy such as ocean wave, ocean current and tidal energy. Other sources of renewable energy are from biofuel (5%), geothermal (5%) and liquefied coal (2%). Moreover, based on the government regulation No. 79/2014, it is expected that the electrification ratio in 2020 would be 100%. Furthermore, the contribution from new energy and renewable energy should be at least 23% (was 17%) in 2025 and at least 31% in 2050.

Southeast Sulawesi is one out of four provinces in Indonesia that have a very low electrification ratio, which ranges at around 68.4%, while the lowest electrification ratio is situated in Papua (45,93%) the most easterly part of Indonesia [4]. In addition, the local government of Southeast Sulawesi has stated that they still need about 65.6 megawatts of electricity [5]. Therefore, in this study, it is important to find other resources for generating electricity in order to fulfill their needs, particularly around Buton Island, a regency in the Southeast Sulawesi province. Fortunately, some narrow straits can be found in the vicinity of Buton Island which have much potential for tidal current energy resources.

Therefore, in the present work, tidal current energy resources will be estimated around the island where 11 locations have been selected. To this end, a hydrodynamic model called Advance Circulation (ADCIRC) model will be employed [6, 7]. In particular ADCIRC-2DDI (two-dimensional, depth-integrated) will be used to simulate tidal elevation and barotropic tidal current. This model was developed by Luettich et al. [6] and Westerink et al. [7]. Moreover, ADCIRC has been tested [7] and intensively used for tidal simulations last two decades, for example in [8-13], and the references therein, [14] and [15]. It should be noted that this will be a preliminary assessment as no one has done a similar research around this place [14].

Open boundary conditions have very crucial impacts for a regional tidal model as pointed out by Zhang et al. [16], (see also: [17]). The solutions of the model are significantly influenced by the tidal open boundary conditions. Usually, the amplitudes and phases of tidal constituents are obtained from tidal databases which are results of large scale numerical solutions. However, even using data from very high-resolution tidal databases, the difference between tidal elevations obtained from the numerical simulations and tidal gauge data is still very large. Therefore, a method to optimize open boundary conditions is sought. In order to deal with this issue, Green's function approach will be employed as have been implemented in [18] and [19].

The structure of this paper is organized as follows. Buton Island and ADCIRC model will be presented in Section 2 and 3, respectively. Results and discussion, which include validation of the model, Green's function approach, barotropic tidal current and tidal current energy estimation, will be shown in section 4. Finally, a short conclusion will be drawn in section 5.

2. Buton Island, Southeast Sulawesi, Indonesia

Sulawesi is one of the five largest islands in Indonesia and consists of six provinces in which one of them being Southeast Sulawesi. Buton Island is located on the south of Kendari city which is the capital city of Southeast Sulawesi province, Indonesia as presented in the top-left of Fig. 1. The area of domain covered around this location is about 20,650 km^2. This location lies between 121.563^0 E and 123.503^0 E and latitude 5.956^0 S and 3.628^0 S.

Fig. 1. Location of the study (Source: http://eclipsefestival2016.com/sulawesi-culture/, https://upload.wikimedia.org/wikipedia/commons/9/93/Buton_Topography.png).

3. Methods

3.1. ADCIRC model

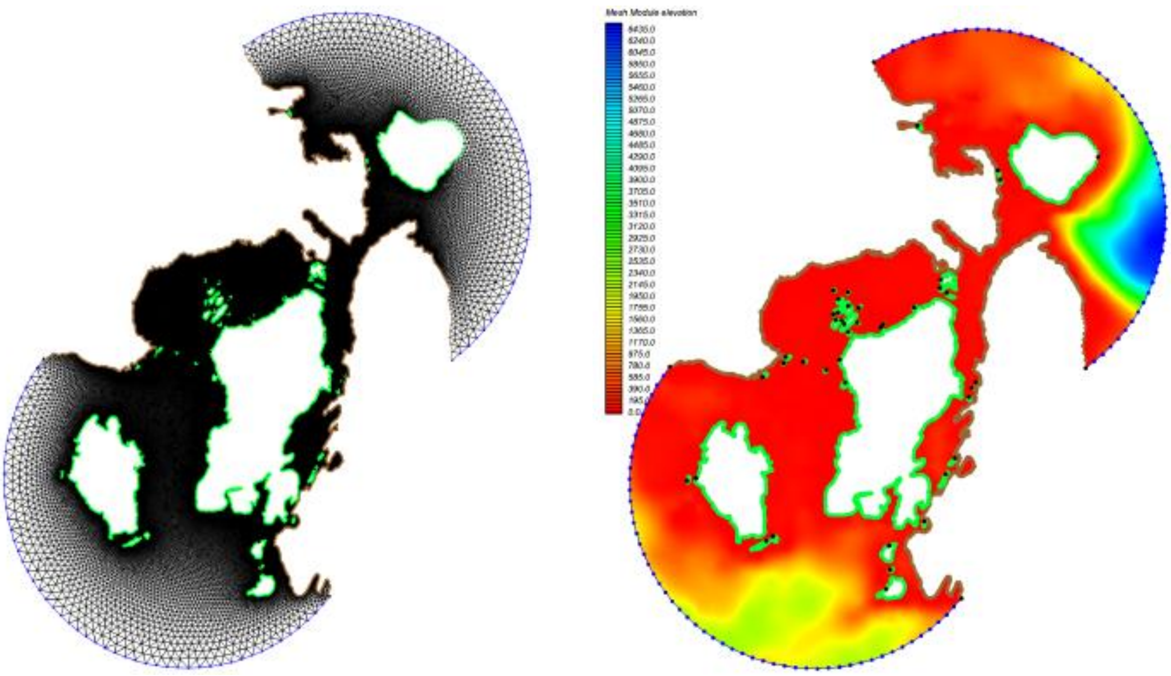
As aforementioned, tidal elevation and current simulations will be performed in this study using ADCIRC-2DDI. This model uses a depth-integrated equation of mass and momentum conservation, subject to incompressibility, Boussinesq and hydrostatic pressure approximation. Furthermore, constant hybrid bottom frictions will be used, lateral viscosity is employed and baroclinic terms are neglected. This leads to a set of conservation statements in primitive non-conservative form in a spherical coordinate system that can be found in [20, 21].

It should be noted that ADCIRC-2DDI does not solve the primitive form of the shallow water equation. It is based on the generalized wave continuity equation (GWCE) form of the shallow water equation and then solved in conjunction with primitive form of the momentum equations [7]. The GWCE equation is written in the spherical coordinate as presented in [8, 21, 22]. The equations have been discretized in space using Finite Element Method (FEM) with triangle element mesh which is highly flexible with unstructured grid. Moreover, time derivatives are approximated by central difference scheme. In particular, a 2DDI (two-dimensional, depth-integrated) solves only the depth integrated which is the external mode equation using the parametric relationship for bottom friction and momentum dispersion. A complete formulation and the numerical implementation can be found in [6], [7] and [23].

3.2. Model setup

In order to run ADCIRC-2DDI model, coastline and bathymetry files have to be prepared. The bathymetry used in this work have been obtained from the General Bathymetric Chart of the Oceans (GEBCO). GEBCO's resolution is 30 arc-seconds (about one kilometer) and it is freely available for entirely globe. The latest version of GEBCO is called GEBCO_2014 Grid (was called GEBCO_08 grid) (https://www.bodc.ac.uk/data/hosted_data_systems/gebco_gridded_bathymetry_data/). Once the coastline and bathymetric data files are available, the finite element mesh is ready to be generated. The mesh and the bathymetry data for our location are shown in Fig. 2*a* and Fig. 2*b*, respectively. The mesh contains 88,584 elements and 46,352 nodes. The minimum and the maximum grids spacing are 160 *m*, which is around coastline, and 4,670 *m* around open ocean, respectively. As aforementioned, the total area of the domain is about 20,650 km^2.

On the open boundary conditions, tidal forcing is applied where eight major tidal constituents will be applied. These eight tidal constituents are typical constituents used in the model as they are usually enough for tidal water level and current calculation which are the main goal of the present work [24]. The eight major tidal constituents used are K_1, O_1, P_1, Q_1 for diurnal tides which are about one cycle per day and K_2, M_2, N_2, S_2 for semi diurnal tides which are about two cycles per day. Complete information for tide including its theory and prediction can be found in [25-27]. Regarding to the values (amplitudes and phases) of these tidal constituents, we used the data obtained from FES2004 tidal database where its resolution is $1/8^0$ and developed by French tidal group (FTG) which was based on finite element solutions (FES) [28]. The model will be set to run for 210 days with 10 days ramp time and time step of four seconds. The starting time is 01 February 2014 at 00:00:00 Greenwich Mean Time. This chosen time is fitted with the observations in the tide gauge.



(a) (b)

Fig. 2. Features of study location. (*a*): Mesh and (*b*): Bathymetry.

4. Results and Discussion

4.1. Validation of the numerical model

In order to validate our numerical model for tidal elevation, tide gauge data have been purchased from Geospatial Information Agency, which is the national surveying and mapping agency of Indonesia. The tidal gauge station in the area of study is located at the coordinate 122.6150^0 *E* and 5.4524^0 *S*. Tidal components have been extracted from the data time series using *T_TIDE* which is a harmonic analysis toolbox [29]. As aforementioned, the simulations have been run for 4800 hours but for simple presentation, we will only show the comparison for the first 800 hours. These two comparisons are as shown in Fig. 3 and Fig. 4, respectively.

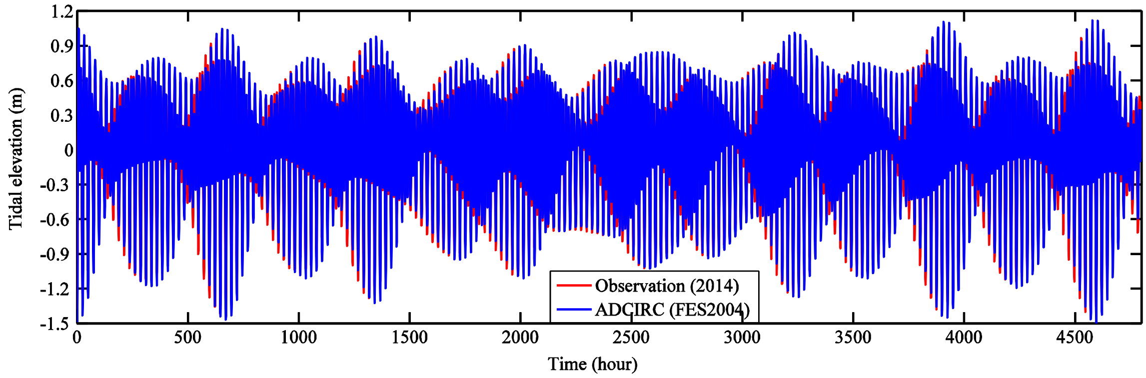


Fig. 3. Comparison between tidal elevations obtained from tide gauge data and ADCIRC model for about seven months.

As shown in Fig. 3 and Fig. 4, both tidal elevations are in quite good agreement between the results obtained from ADCIRC model and tide gauge data. However, the root mean square error (RMSE) is still large, in which the RMSE is 0.124919 *m*. This comparison has been established by using eight tidal constituents used in ADCIRC model that have been previously chosen.

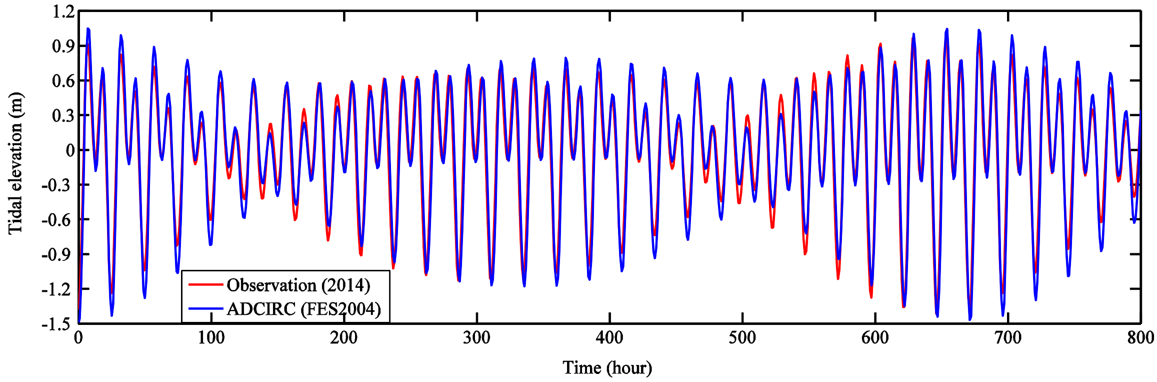


Fig. 4. Comparison between tidal elevations obtained from tide gauge data and ADCIRC model for first 800 hours.

4.2. Green's function approach

Looking at the results showing in the previous section, one can see that the root mean square error between the tidal elevations from model and tide gauge is still very large. Therefore, the input values along the open boundary conditions which are in this case the amplitudes and phases of each tidal component have to be improved. To this end, the method used by others such as in [18, 19, 30] will also be applied. This method is called Green's function approach. The main idea of this method is to improve the amplitudes and phases of tidal components based on tide gauge data. This means that one has to have at least one real observation in the domain of the study. The details of this method can be found in the all aforementioned literatures including the references therein. However, for convenience, the main equation will be reproduced as follows. The model optimum parameter η^a can be written as [18]

$$\eta^a = \boldsymbol{P}\boldsymbol{G}^T\boldsymbol{R}^{-1}\boldsymbol{y}^d$$

where $\boldsymbol{P} = \left(\boldsymbol{Q}^{-1} + \boldsymbol{G}^T\boldsymbol{R}^{-1}\boldsymbol{G}\right)^{-1}$ which an uncertainty covariance matrix. $y^d = y^0 - G(\mathbf{0})$ is the difference between observation data (y^0) and model outputs ($G(\mathbf{0})$). Superscript T is the transpose operator. $\boldsymbol{G}$ is a matrix whose columns are the Green's functions of G which can be explicitly written as

$$\boldsymbol{g}_{(j)} = \frac{G(\mathbf{e}_j) - G(\mathbf{0})}{e_j}$$

where $\mathbf{e}_j$ is a perturbation vector that is everywhere zero except for element *j*, which is set to e_j. $\boldsymbol{Q}$ is the uncertainty of the initial parameters and $\boldsymbol{R}$ is the uncertainty of the measurements. Here we assume that $\boldsymbol{R}$ and $\boldsymbol{Q}$ are diagonal matrices which imply that there is no correlation between elements of vector η in $\boldsymbol{Q}$ or ε in $\boldsymbol{R}$. Since $\boldsymbol{R}$ and $\boldsymbol{Q}$ are usually unknown, it is a plausibility to assume that the uncertainty of the measurement is very small and the uncertainty of the initial parameter is very large. It is, therefore, usually assumed that $\boldsymbol{Q}^{-1} = \mathbf{0}$ [18].

In the present study, the procedures of applying the Green's function approach are as follows. First, all of the tidal constituents that will be controlled and imposed on the open boundary conditions are listed. Since all eight tidal components will be employed, this means 16 parameters (eight amplitudes and eight phases) will be controlled. Then, all the perturbations that will be used are determined. In this case, the perturbation for the amplitudes is about 95% while the perturbation for phases is 5^0. This means that we subtract all the tidal amplitudes about 5% and add the phases for 5^0 [19]. After that, all 16 perturbations will be run. Furthermore, all the value parameters are determined and then to calculate the model optimum parameter η^a. Finally, the amplitudes of tidal components will be subtracted by corresponding amplitudes in η^a. Similarly, the phases of tidal components will be added by corresponding phases in η^a. Tidal elevations after applying Green's function approach are shown in Fig. 5 and Fig. 6.

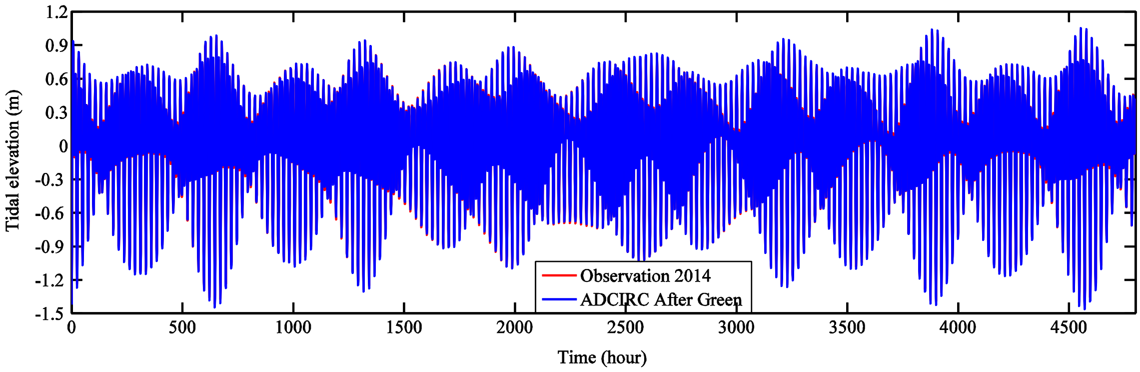


Fig. 5. Comparison between tidal elevations obtained from tide gauge data and ADCIRC model for about seven months after applying Green's functions.

Moreover, it is found that after applying Green's function approach, RMSE is reduced from 0.124919 *m* to 0.014262 *m*. This means using the Green's function approach, RMSE is reduced to about 88.58%. As shown in Fig. 5 and Fig. 6, it is difficult to differentiate between the output of ADCIRC model and data from tide gauge.

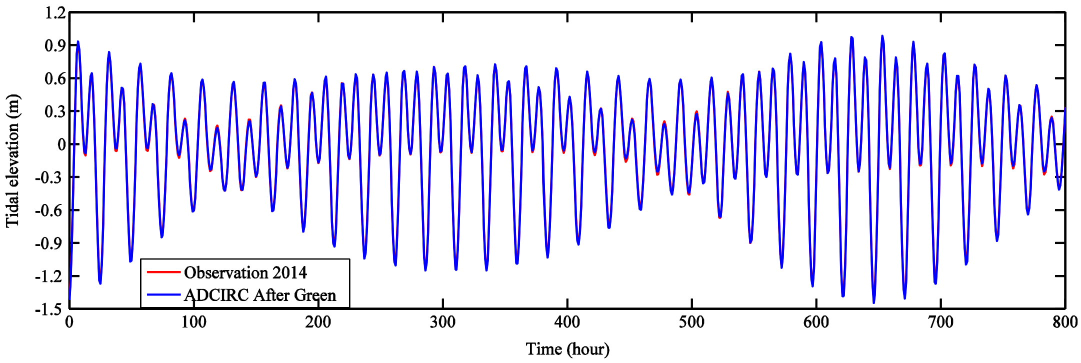


Fig. 6. Comparison between tidal elevations obtained from tide gauge data and ADCIRC model for first 800 hours after applying Green's function.

4.3. Barotropic tidal current around Buton Island

Since tidal elevations around Buton Island shows an excellent agreement with the data from tide gauge, it is plausible to conclude that tidal current obtained from the model is very close to the real tidal current around the study area. However, it should be noted that since we only use ADCIRC-2DDI model, we can only observe barotropic tidal current. The distribution of tidal current around Buton Island is shown in Fig. 7.

Looking at the details of Fig. 7 tidal current velocities reach up to about 2 *m/s*. As shown in the southeast inset, current velocities at the selected locations are very high, some reaching up to 1.9 *m/s*. In the vicinity of this location will be very promising places to deploy tidal current energy converter. However, to this end, more intensive studies have to be carried out as well as more funding is needed for such intensive research. Similarly, on the top-right inset, one can see other locations in which tidal current velocities are very promising as well.

As shown in Fig. 7, eleven monitoring stations have been set inside the domain, in which station 2 is actually tide gauge for tidal elevation. This means, at the station, tidal current is very weak and have been confirmed from numerical model. Other 10 monitoring stations are aimed for tidal current monitoring. For simplicity, only tidal current at station 6 will be shown. In this station, tidal current is dominated by meridional current velocity as shown in Fig. 8 while zonal current velocity in this station is very weak as presented in Fig. 9.

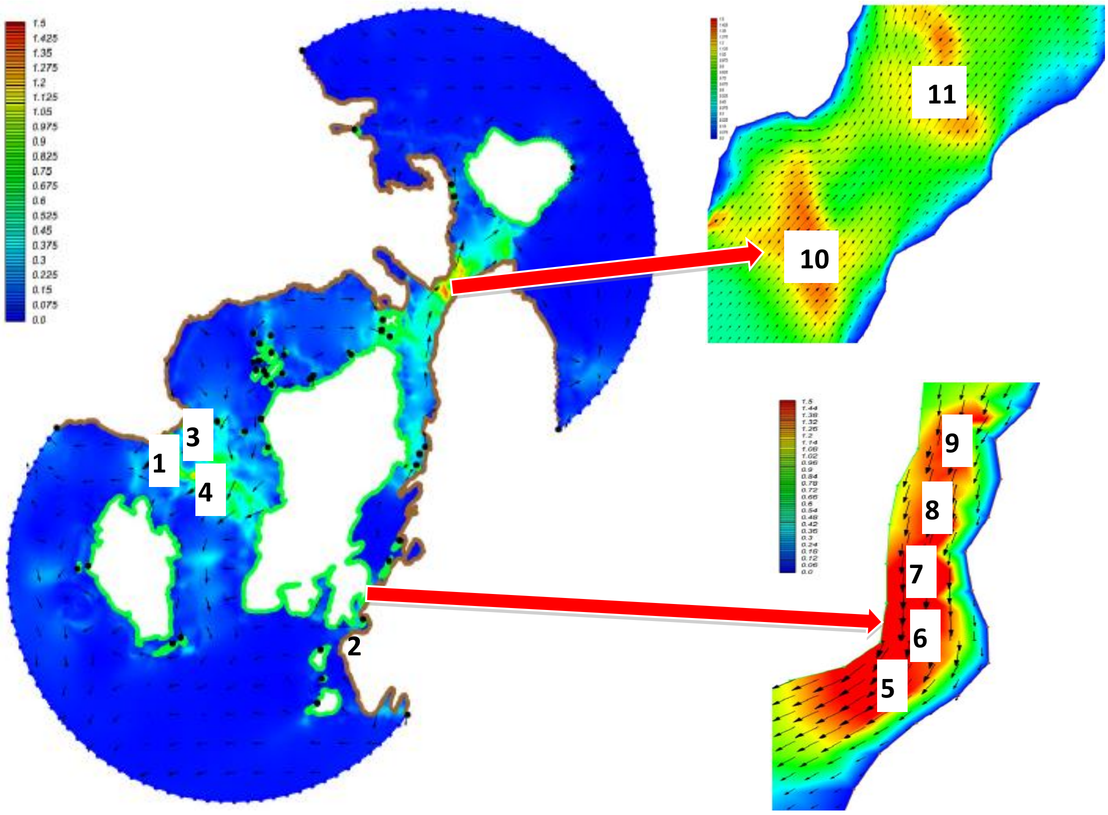


Fig. 7. Tidal current distribution around Buton Island (the number on the figures represents monitoring station).

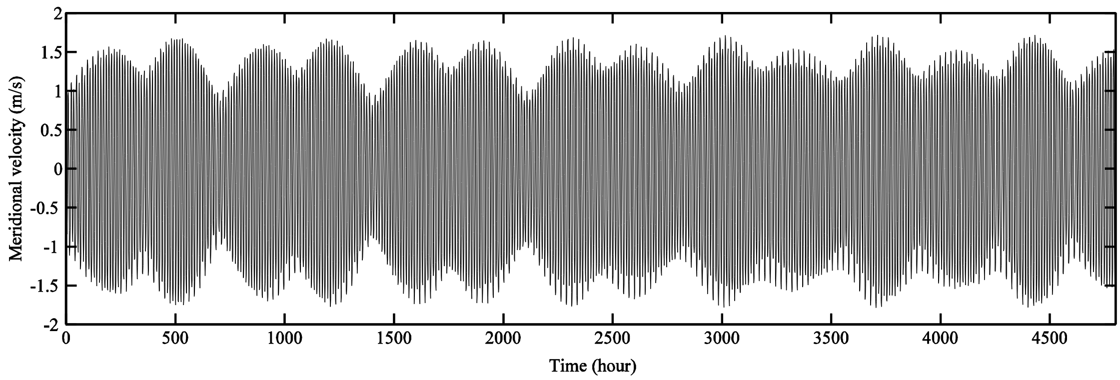


Fig. 8. Meridional current velocity in the monitoring station 6 from ADCIRC model.

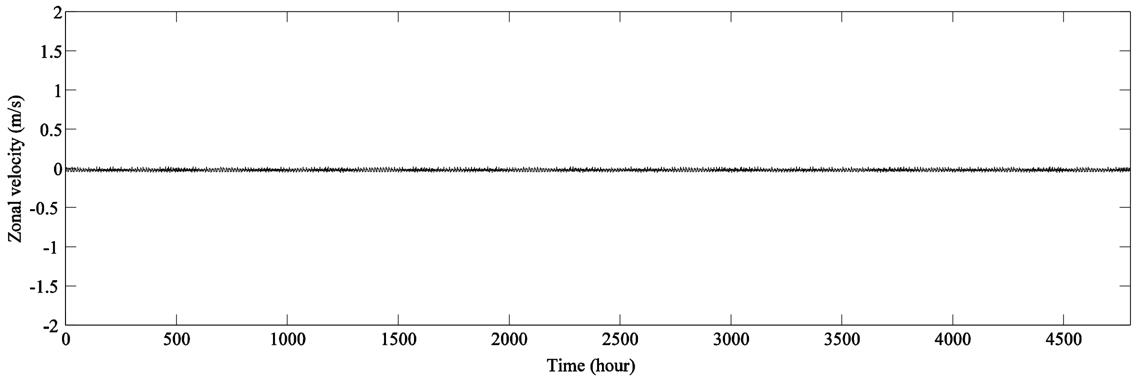


Fig. 9. Zonal current velocity in the monitoring station 6 from ADCIRC model.

Moreover, the magnitude of the current velocity in the station 6 is shown in Fig. 10. As can be seen from the figure, the magnitude of the current velocity is about 1.9 *m/s* which is a very promising result.

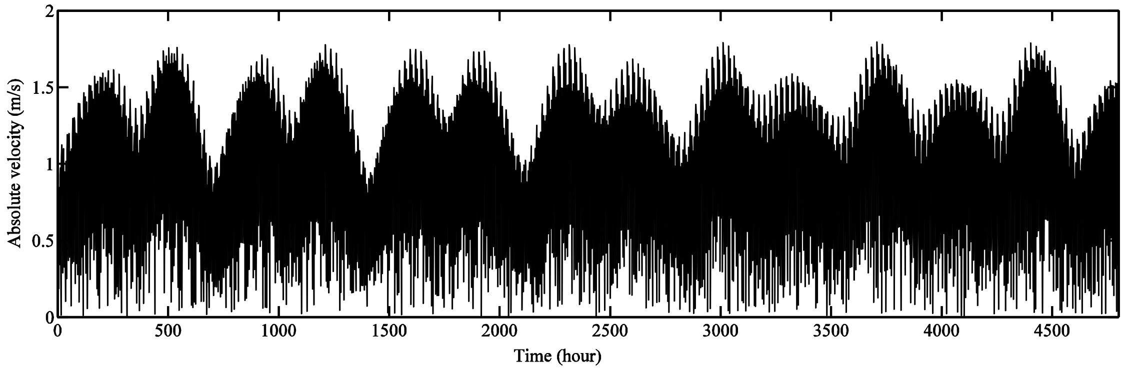


Fig. 10. Absolute current velocity in the monitoring station 6 from ADCIRC model.

4.4 Tidal current power assessment

Tidal current energy was estimated around Buton Island, in which the power of a turbine depends on its area and efficiency that can be written as the following:

$$P = \frac{1}{2}\eta\rho A U^3,$$

where η and A are the efficiency and the area in direction of flow of the turbine, respectively, and ρ is water density which varies from 1020 kg/m^3 to 1029 kg/m^3. U is the absolute current speed of the flow. Since the efficiency and the area in direction of flow of the turbine are usually constant, the power depends only on the absolute current speed. Now, let $\rho = 1025$ kg/m^3 and $\eta = 0.39$ [31]. Using this value of parameters, mean power is calculated and the results are summarized in Table 1.

Table 1. Summary of mean power due to the tidal current around Buton Island.

Stations	Longitude [*deg*]	Latitude [*deg*]	Mean speed [*m/s*]	Mean power [kW/m^2]	Max speed [*m/s*]
1	122.0508	-4.9151	0.8780	0.2079	1.6755
2	122.6150	-5.4524	0.0702	0.0001	0.1794
3	122.0947	-4.8534	0.7390	0.1204	1.3636
4	122.1917	-5.0334	0.7077	0.1184	1.4492
5	122.6419	-5.3575	0.9127	0.2293	1.6710
6	122.6436	-5.3509	1.0143	0.3087	1.7956
7	122.6429	-5.3447	0.9500	0.2670	1.8708
8	122.6451	-5.3409	0.7919	0.1520	1.4626
9	122.6466	-5.3303	0.7012	0.1065	1.3586
10	122.8812	-4.4561	0.6606	0.1017	1.3876
11	122.9324	-4.4181	0.6327	0.0895	1.3698

As can be seen from Table 1, all selected locations are very promising places for harvesting tidal current energy. However, the most favourable place to deploy tidal current energy converter is located at 122.6436^0 *E* and 5.3509^0 *S* in which mean velocity is 1.014 *m/s* that can produce mean power up to about 0.3087 kW/m^2 or 308.7 W/m^2. The depth of this location is about 12 meters based on the data obtained from GEBCO.

5. Conclusions

A preliminary assessment of tidal current energy resources around Buton Island using a hydrodynamic model has been conducted in this work. Green's function approach has been applied to improve tidal constituents on the open boundary conditions of the model based on the data from tide gauge. As a result, root mean square error (RMSE) of tidal elevations has been reduced 88.58% which is from 12.49 *cm* to 1.43 *cm*. Some locations in which tidal current are very strong have been found and tidal current power has also been estimated. The highest current speed in the area of study is about 2 *m/s* but in the selected locations, the highest current speed is 1.871 *m/s* where the mean power is 267 W/m^2. Therefore, the highest tidal current power in the selected stations is 308.7 W/m^2.

Further work of this research is to apply fully three-dimensional ADCIRC model in order to obtain full profile of tidal current velocity. Moreover, conducting observation for tidal current by measuring current velocity using, for example, ADCP (Acoustic Doppler Current Profiler) will be very beneficial. However, in order to carry out such research, more sources of funding and collaborations are needed.

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