Hydro-oceanographic mapping to support coastal eco-tourism activities in Bawean Island, East Java

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Abstract. Bawean is a small island located around 80 miles north of Gresik, East Java Province, Indonesia. In the recent years, the island is renowned as a new destination for marine and coastal eco-tourism. Sustainable eco-tourism management in a small island is a very important concept not only for increasing income of local people but also in protecting the island itself from environmental degradation due to natural and anthropogenic factors. This paper discusses the methodology of mapping the hydro-oceanographic condition of Bawean Island. In this respect a methodology to analyze the suitability of the island and formulate strategies towards sustainable management of Bawean Island as a coastal eco-tourism destination will also be discussed.

1. Introduction

Bawean Island is located approximately 80 nautical miles north from the city of Gresik, East Java province in Indonesia, as shown in Figure 1. Total area of the island is around 196.27 km² with population according to the 2015 census was approximately 70,000 people. Comparing this to the mainland of East Java, this island is relatively unknown for its ecology and economic potential. The island has quite high suitability values (76-96%) for 3 eco-tourism activities, namely beach recreation, diving, and snorkeling. It was supported by the fine condition of coral reefs and the white sandy beaches surrounding the island. Based on Analytical Hierarchy Process (AHP) analysis from previous study, the sustainable management of eco-tourism in Bawean Island can be managed through the protection of coastal natural resources, providing economical-based income and education on environmental conservation [1]. This paper will discuss the methodology of mapping the hydro-oceanographic condition of Bawean Island; and also to present the methodology to analyze the suitability of the island as a coastal eco-tourism destination.

Marine eco-tourism is defined as travel to relatively undisturbed marine and coastal areas with the specific objective of admiring, studying, and enjoying the scenery. Other common activities that can be done in relation with marine eco-tourism including marine based activities such as diving, snorkeling, fishing, and many others [2]. The common landscapes offered by marine eco-tourism destination are sandy beaches, pristine coral reef ecosystem or unique marine species [3,4]. Marine eco-tourism may provide specific opportunities for learning and discovery, and in some definitions, includes a social and environmental ethic. Furthermore, well-managed eco-tourism provides revenue for coastal communities and jobs for residents. Government of Indonesia has prioritized marine based tourism as one of the leading sectors in national maritime development. Therefore, discovery and assessment of new and potential small islands as a tourist destination is necessary.
Figure 1. The map of Bawean Island [1]

According to information from the Ministry of Marine and Fisheries in 2014, small island is an island with an area smaller or equal to 2,000 km² along with the unity of its ecosystem. On a small island with its limited resources, social and economic activities tend to be concentrated on coastal zone [5]. Furthermore, interconnectivity between economic, environment, social and cultural is strong and extensive. When uncontrolled tourism development occurs in small island destinations with limited environmental carrying capacity, environmental degradation is most likely to happen [6]. Thereby reducing destination attractiveness [7,8]. This pattern is particularly prevalent in small island destinations in developing countries, where local government capacity is often lacking, resident populations have limited education and environmental awareness is poor [9]. In such conditions, effective environmental conservation and sustainable management strategies are likely to be initiated and it requires collaboration between relevant stakeholders.

Sustainable island management is a very important approach not only for increasing income from tourism but also protecting the island itself from environmental degradation due to natural and anthropogenic factors [10]. Eco-tourism is related to small scale tourism where number of tourist and type of activities are limited. On the contrary, mass tourism development in small island have been avoided in many counties. There are a lot of evidence show that the practice of mass tourism development in small islands has sacrificed environmental stability and disrupted the natural pace of island life [11]. The placement of large-scale beach resorts, marinas and infrastructure along delicate coastlines has altered shorelines and depleted endemic species and archaeological artefacts. Moreover, sand mining dredging and cruise ship and yacht anchoring can damage coral reefs ecosystems. Therefore, in order to develop marine tourism in a small island, it is imperative not only to study the potential natural attraction but also the island’s carrying capacity and sustainability.
2. Methodology

2.1 Location and Time of Study
This hydro-oceanographic survey was carried out located in Bawean Island especially in the area designated to support marine eco-tourism activities. The geographical coordinates of Bawean Island are 05° 47'23″ Latitude and 112° 39'20″ Longitude. The study took 7 months, starting from April to November 2019.

2.2 Survey Activities
Hydro-oceanographic data has been collected by field survey to evaluate the existing physical condition of marine environment including tidal and current observation, bathymetric survey, sediment samplings. Other physical aspect of marine environment such as water temperature, suspended sediment and chemical compound were also investigated. The collected data can be used to conduct a preliminary environmental assessment prior to development or construction in the area. In addition, for a numerical modelling, these primary data can be used as input of ocean environmental model to predict the long-term conditions and create what-if scenarios. The general outputs from hydro-oceanographic surveys are in the form of thematic maps. The survey activities include planning, preparation, survey executions, collecting data and preparing reports.

Survey planning is the activities of outlining planning program, collecting initial information of the survey area, collecting secondary data and collecting reference books related to data acquisition methods, data processing and data analysis. Some of these activities can be explained in the following Table 1.

| No | Activities | Description |
|----|------------|-------------|
| 1  | Preparing survey plan outline | An outline plan is a preliminary draft of survey activities that contains a general plan of survey activities, a planned implementation schedule and an overview of budget requirements. |
| 2  | Preliminary (reconnaissance) survey | The preliminary survey includes collecting initial information of survey area. Minimal information collected includes:  
- How to reach the location  
- Assessment of the location for measurement / observation:  
  - Reference point for positioning  
  - Tidal monitoring stations  
  - Current observation stations  
  - Wave observation stations |
| 3  | Readiness of facilities and infrastructure in supporting survey activities | Checking the availability of survey support facilities such as land transportation, boat, local survey assistant, accommodation, logistic supplies, etc. |
| 4  | Secondary data collection | Collecting data related to survey area. Secondary data collected includes:  
  - Topographic / RBI or DEM maps  
  - Bathymetric map  
  - Land use map  
  - Aerial / satellite image |
| 5  | Supporting literature | Reports or results of previous studies related to the survey area. |

Survey preparation is the activity of preparing for technical and non-technical supplies needed for survey, such as administrative preparation (letter of survey permit), preparation of personnel and equipment as well as preparing operational plans, as listed in Table 2.
Table 2. Survey preparation

| No | Activities                          | Description                                                                                                                                 |
|----|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Personnel and equipment preparation | The preparation of survey personnel and equipment is carried out to ensure the personnel and equipments are available and in proper condition.       |
| 2  | Preparation of survey equipment     | The equipment needed for survey depends on the objectives and the method of survey activities. All equipments need to be checked and confirmed in good condition and still functional. |
| 3  | Preparing of operational research plan | Operational research plan contains methods of conducting field surveys, including:                                                               |
|    |                                     | • Boundary of survey area; adjusted to the study area.                                                                                         |
|    |                                     | • Determination of survey standardization, such as in measurement and observation methods. These standard methods guides the process of collecting field data for the survey team. |
|    |                                     | • Design of track for bathymetric survey, by considering the general seabed profile in the area.                                                |
|    |                                     | • Design of output map as final product, including types of information should be included in the maps, coordinate systems, and symbols.         |

2.2.1 Survey execution

The execution of hydro-oceanographic survey is basically a process of collecting hydro-oceanographic data. A description of the activities during survey execution is explained in Table 3 below.

Table 3. Survey execution

| No | Activities                          | Description                                                                                                                                 |
|----|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Installation and calibration of equipment | Install the equipment on the boat and calibrate the depth for echo sounder and positioning water level recorder. Setting and installation of Acoustic Doppler Current Profiler (ADCP) prior to deployment in the target location. |
| 2  | Bathymetric Survey execution        | Performing survey according to tracking route that has been prepared previously.                                                            |
| 3  | Sediment sampling                  | Performing seabed sampling.                                                                                                                  |
| 4  | Current and wave measurements       | Performing current speed and direction as well as wave height and period using ADCP deployed in particular location.                         |
| 5  | Tidal observation                   | Observation of water level on tide bar.                                                                                                      |

2.2.2 Data processing

Data processing is carried out in two ways, i.e. directly in the field and in the laboratory (office). Data processing directly in the field is intended to ensure that data obtained in the field is adequate and reliable to be used. In the laboratory (office), the raw data collected from field will be analysed and presented in the form or format needed.

2.2.3 Reporting result

The final steps in survey activities is reporting the results. Reports are made in descriptive form complemented with tables, graphics, and maps. Therefore, all activities carried out in the filed survey are explained properly. This paper is part of reports made for hydro-oceanographic study in Bawean Island funded by Sepuluh Nopember Institute of Technology (ITS).
2.3 Research Equipments and Materials

This study requires a variety of survey equipment to measure and observe hydro-oceanographic parameters. The type of equipments is selected according to type of observed parameters and analysis methods. Table 4 below explains the main equipment needed, while Table 5 presents the materials for the study.

### Table 4. Type of survey equipment

| No | Survey Equipments                | Usage                                                                 |
|----|----------------------------------|----------------------------------------------------------------------|
| 1  | Acoustic Doppler Current Profiler (ADCP) | Measuring the speed and direction of current and wave height          |
| 2  | Side Scan Sonar (Single Beam)     | Seabed mapping / bathymetric survey                                   |
| 3  | Tide Bar                         | As sea level observation reference during tides.                      |
| 4  | Global Positioning System (GPS)   | Coordinat positioning equipments                                     |
| 5  | SCUBA Diving Equipments          | Supporting equipments for ADCP deployed underwater                   |
| 6  | Digital Camera                   | Taking underwater pictures / photos and survey documentation.         |
| 7  | Personal Computer (PC)/Laptop    | Storage and processing survey data                                    |

### Table 5. Materials for study

| No | Materials                        | Source                                      | Usage                                              |
|----|----------------------------------|---------------------------------------------|---------------------------------------------------|
| 1  | Meteorological and Geophysics Data | Indonesian Meteorological Climate and Geophysics Agency | Supporting data for field measurements and observation |
| 2  | Bawean Island Satellite images   | Google Earth, USGS                         | Satellite image is used to determine the position of the survey points |
| 3  | Bathymetric and Topographic Maps | Indonesian Geospatial Information Agency (BIG) | As a base map for developing thematic maps          |
| 4  | Demographic Data                 | Badan Pusat Statistik                      | Supporting Secondary Data                         |

2.4 Data Analysis

2.4.1 Analysis of current

Acoustic Doppler Current Profiler (ADCP) was used to measure current speed and direction in the study area. ADCP not only measure currents but can also measure pressure (related to tide) and waves (height and direction), as exhibited in Figure 2. When measuring current, ADCP not only measure at one location at single water column but can also measure several locations at the same time. Therefore, a series of current profile in a water column can be obtained.

![Figure 2. Current measurement using ADCP](image-url)
The ADCP working principle is based on Doppler effect to estimate speed both horizontally and vertically to calculate the relative radial velocity, between the instrument and the scattering water column. Three acoustic beams in different directions are a minimum requirement for calculating the three speed components. ADCP transmits a ‘ping’, from each transducer element once every second, roughly. Echoes returning to the instrument exceed the additional period, with echoes from shallow waters arriving earlier than echoes from a wider range. The speed profile is generated from the range obtained. In the end, the relative speed and other parameters are collected on the boat using the Data Acquisition System (DAS) which also optionally records navigation information which is produced by GPS. Flow measurements are carried out at several representative observation stations in Bawean Island.

From the field measurement, the magnitude and direction of the total current is obtained. The magnitude and direction of the current are separated into $U$ (east-west) and $V$ (north-south) components. The intensity of $U$ component is obtained from the formula:

$$U = V_{total} \sin \left( \frac{\text{Dir} \pi}{180} \right)$$

while $V$ component obtained from:

$$V = V_{total} \cos \left( \frac{\text{Dir} \pi}{180} \right)$$

where $\pi$ is 3.14 and $\text{dir}$ represents the direction of current. The results of the calculation of components $U$ and $V$ are then plotted into a graph.

2.4.2 Analysis of wave

Data obtained from wave measurements were analyzed following method as follows:

$$H_s = \frac{H_1+H_2+...+H_n}{n}$$

$$T_s = \frac{T_1+T_2+...+T_n}{n}$$

The Significant wave height ($H_s$) is calculated from 33.3% ($= n$) of the highest wave height events, while the significant wave period ($T_s$) is averaged from the corresponding period of 33.3% of largest wave height events. The waves can also be hindcasted from wind (secondary data) obtained from nearest wind observation station. The results of wave hindcasting are in the form of height, period, length and dominant wave data. Secondary data of wind speed and direction obtained from the wind observation station are sorted according to the direction and speed. Furthermore, the data is processed and plotted in the form of a wind rose diagram. Based on the wave generation in the sea, wave formation is not only developed from the same direct ion as the wind direction but also in various angles to the wind direction. From these angles the effective fetch is determined using the following formula:

$$F_{eff} = \frac{\sum X_i \cos \alpha}{\sum \cos \alpha}$$

where $X_i$ is the length of single fetch and $\alpha$ is the angle between single fetch.

The determination of fetch direction is based on the direction of the incoming wind at the location of study. From the wind speed ($U_A$) data, length of fetch ($F$), the wave height and period ($H$ and $T$) can be estimated using the following formula:

$$H = 1.616 \times 10^{-2} U_A F^{1.1}$$

$$T = 6.238 \times 10^{-1} (U_A F)^{1.3}$$

2.4.3 Analysis of tide

Tidal data analysis is carried out to obtain tidal component, reference water level elevation and other important elevations. To obtain these parameters, tidal data analysis is performed using the Admiralty
Method by first filtering the data obtained from observation in the field. Furthermore, based on tidal constituent obtained from tidal analysis, the nature and characteristics of the tides in the waters of Bawean Island can be evaluated. Vertical movement of sea water level caused by tidal processes can be expressed as a harmonic superposition of tidal constituents:

\[ Y(t) = S_0 + S_{S0} + \sum_{n=1}^{N} F_n A_n \cos(\varpi n t + \nu n - g n) \]  

where:
- \( Y(t) \) = sea water level
- \( S_0 \) = reference level
- \( S_{S0} \) = average sea level
- \( F_n \) = correction factor for the nth component
- \( A_n \) = the amplitude of the nth components of tides
- \( \varpi n \) = the angular frequency of the nth components of tides
- \( t \) = time
- \( \nu n \) = astronomical argument of the nth components of tides
- \( g \) = gravitational acceleration
- \( n \) = number of tide components

\[ S_0 + S_{S0} \text{ obtained from } = \frac{1}{m} \sum_{i=1}^{m} y_i \]  

where:
- \( y_i \) = observed (measured) sea water level
- \( m \) = number of observations

The results of tidal data processing using Admiralty method are presented in the form of tidal analysis table. The final result of tidal decomposition is the amplitude and phase difference parameters of each tidal component. Tidal components obtained by the Admiralty analysis method are 9 (nine) components, namely M2, S2, N2, K2, K1, O1, P1, M4, and MS4. The period and speed of tidal components are listed in Table 6.

| Symbol | Name                                | Period (hours) | Speed (°/hour) |
|--------|-------------------------------------|----------------|----------------|
| M2     | Principal Lunar semidiurnal         | 12.42          | 28.98          |
| S2     | Principal Solar semidiurnal         | 12.00          | 30.00          |
| N2     | Larger lunar elliptic               | 12.66          | 28.44          |
| K2     | Luni-solar semidiurnal              | 11.97          | 30.08          |
| K1     | Luni-solar diurnal                  | 23.93          | 15.04          |
| O1     | Principal Lunar diurnal             | 25.82          | 13.94          |
| P1     | Principal Solar diurnal             | 24.07          | 14.96          |
| M4     | Shallow water overtides of Principal Lunar | 6.21       | 57.97          |
| MS4    | Shallow water quarter diurnal       | 6.1            | 44.025         |

Also calculated and analyzed the nature and characteristics of the tides in the waters of the area include:
- Chart datum, Mean Sea Level (MSL), Mean High Water Level (MHWL), Mean Low Water Level (MLWL), Mean Lowest Low Water Level (MLLWL).
- Type of tides
- Tidal range, maximum and minimum water level
- Prediction of water level over time
- Formzahl number to determine type of tides is calculated using:
\[ F = \frac{A K_1 + A O_1}{A M_2 + A S_2} \]  

(10)

where:

\( F \) = Formzahl number

\( A K_1 \) = the amplitude of the average daily tidal wave affected by the declination of the moon and the sun

\( A O_1 \) = the amplitude of a single daily tidal wave is affected by the declination of the sun

\( A M_2 \) = the amplitude of the average daily double tidal wave affected by the moon

\( A S_2 \) = the amplitude of the average daily double tidal wave child is affected by the sun

The value of \( F \) will indicate the type of tide as in the followings:

- \( 0 < F < 0.25 \) : the type of tide is Semi Diurnal
- \( 0.25 < F < 1.50 \) : the type of tide is mixed with Semi Diurnal tendency
- \( 1.50 < F < 3.0 \) : the type of tide is mixed with Diurnal tendency
- \( 3.0 < F \) : the type of tide is Diurnal

After the nine tidal components are obtained, the prediction of the water level elevation is performed over an interval longer than the interval of tidal observation to setup the reference water level, as illustrated in Figure 3. To determine the reference water level elevation, the characteristic of water level from 18.6 years prediction is used. To predict the elevation of the tidal water level, the principle of trigonometric addition of each amplitude value and the phase difference of each tidal component that previously estimated. The computer program used to predict tides in this study is the NaoTIDE.

![Figure 3. Illustration of tidal observation.](image-url)

### 2.4.4 Bathymetric survey

In general, bathymetric survey methods include:

- Bathymetry survey is carried out to obtain images of seabed profile in a scale of 1: 10,000.
- The survey grid line is 25 m parallel to the coastline and 25 m perpendicular to the coastline.
- Measurement of sea bed profile is carried out using an echosounder placed in the boat. The coordinates of the measurement points are obtained using a GPS device. During bathymetry measurements, tidal observation are also taken at intervals of 10 minutes.
The seabed elevation is evaluated by taking the Mean Sea Level (MSL) as reference point. The MSL is obtained from the analysis of the water level elevation obtained from tide observation.

- Actual water depths and seabed contour lines are obtained by superimpose bathymetric measurement data and elevation of water level at the time of measurement as a correction number.
- The Bathymetry measurement in this study refer to: IHO 44 standards, LPI SNI 19-6726-2002 and LPI SNI 19-6727-2002, IHO S-57. A portable echo sounder was used for bathymetric survey. In principle, the echosounder emits acoustic waves to the seabed, which reflected back by the seabed and received by the echosounder. Based on to way travel time of waves from the transducer - sea floor - transducer, and the information of acoustic wave propagation in the seawater, the depth of the sea can be determined, as follows:

\[ d = 0.5 \times (T \times c) + k \]  

where:
- \( d \) = depth
- \( T \) = two way travel time,
- \( c \) = acoustic wave propagation in seawater,
- \( k \) = a correction factor consisting of tidal correction and draft correction.

**Figure 4.** Bathymetric depth calculation scheme

Bathymetric survey is an activity to measure water depth, horizontal position measurement and observation of tides at the same time, as illustrated in Figure 4. The survey is carried out on the sounding lines that have been prepared on a digital map. This map can be read on a computer with navigation software used by GPS receivers and echosounders in the following ways:
- The echosounder that is connected to a special software which connected with GPS for horizontal reference position. The recording process can be done automatically at desired coordinate point along the survey line. The Echosounder will not record data, if the position is not at the planned location. In this system, every depth point (\( Z \)) recorded automatically with horizontal coordinates (\( X, Y \)) on the computer. Before survey were started, the echosounder must be calibrated using a barcheck, an iron plate used to ensure that the recording depth from echosounder is match with the actual depth of seabed (after sound speed in the seawater adjusted). This checking procedure must also be carried out if there is a change in the position of the echosounder and part replacement.
• Positioning and Navigation. The determination of the position point is performed by GPS. The signal is sent from the reference station to the GPS. To guide the boat survey maneuver following the predetermined survey line, a computer-based digital navigation system is used. Since the Selective Availability (SA) capability is no longer activated by the United States Government, the accuracy of measurements obtained by stand-alone GPS 12 channels can only reach 3 to 7 meters. However it is planned to use a GPS differential in post-processing to obtain accuracy less than 3 meters in general.

2.4.5 Sediment data analysis

The initial sample analysis was sediment stratification analysis. The analysis performed by direct observation of visual appearance of sediment samples in a layer of ±1 m. In this analysis the color of the old and new layer and the materials compound of sediment samples at each point are recognized before laboratory analysis. Furthermore, an analysis of the sediment size to determine the type of sediment. The samples of substrate taken from various location are dried separately according to the label printed on the sedimentary bag. Next, the separation between each layer of sediment sample into coarse material (non-cohesive) which is easily decomposed such as sand and cohesive (fine or lumpy) material such as mud or clay. The method used for the analysis of sediment samples is the wet analysis and dry analysis method or the so-called Buchanan method. Non-cohesive sediment samples that are easily decomposed will be analyzed by a dry analysis method using a sieve shaker or stacked sieve. Whereas cohesive sediment samples are difficult to decompose, the size analysis is performed using a wet analysis method using pipette or hydrometer [12].

Statistical parameters used to determine the characteristics of the constituent materials of sediments, in this study are Mean, Skewness, Sorting and Kurtosis. The sediment data is processed using Sieve Graph Software, by entering the sample code and percentage of passing value to obtain the phi (ϕ) value; i.e. ϕ5, ϕ16, ϕ25, ϕ50, ϕ75, ϕ84, and ϕ95. These values represent the grain size at 5%, 16%, 25%, 50%, 75%, 84% and 95% of the sample by weight.

The parameter values are given in the following subsection, comprise the mean, sortation, skewness, and kurtosis. Mean is the size of the sediment concentration calculated by the following formula:

\[ \text{Mean} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3} \]  \hspace{1cm} (12)

Sortation or sediment sorting is given by the following formula [14]:

\[ \text{Sorting} = \frac{\phi_{84} - \phi_{16}}{2} \] \hspace{1cm} (13)

Classification of sediment by sorting is presented in Table 7.

| No | Sorting Limit       | Values   |
|----|---------------------|----------|
| 1  | Very well sorted    | < 0.35   |
| 2  | Well sorted         | 0.35 – 0.50 |
| 3  | Moderately sorted   | 0.50 – 1.00 |
| 4  | Poorly sorted       | 1.00 – 2.00 |
| 5  | Very Poorly sorted  | 2.00 – 4.00 |
| 6  | Extremely Poorly sorted | > 4.00 |

Skewness parameter may be derived as follows:

\[ \text{Skewness} = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - Q_{16})} + \frac{\phi_{5} + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - Q_{5})} \]  \hspace{1cm} (14)

Classification of sediment by skewness is presented in Table 8.
Table 8. Classification of sediment skewness [14]

| No | Skewness Limit       | Value      |
|----|----------------------|------------|
| 1  | Very negative skewed | (-1.00 – (-0.30) |
| 2  | Negative skewed      | (-0.30 – (-0.10) |
| 3  | Nearly symmetrical   | (-0.10 – (+0.10) |
| 4  | Positive skewed      | (+0.10 – (+0.30) |
| 5  | Very positive skewed | (+0.30 – (+1.00) |

Kurtosis parameter may be derived as follows:

\[
Kurtosis (K) = \frac{\psi_{95} - \psi_{5}}{2.44 \left(\psi_{75} - \psi_{25}\right)}
\]

Classification of sediment by kurtosis is presented in Table 9.

Table 9. Kurtosis classification [14]

| No | Kurtosis Limit       | Value   |
|----|----------------------|---------|
| 1  | Very platykurtic     | < 0.67  |
| 2  | Platykurtic          | 0.67 – 0.90 |
| 3  | Mesokurtic           | 0.90 – 1.11 |
| 4  | Leptokurtic          | 1.11 – 1.50 |
| 5  | Very leptokurtic     | 1.50 – 3.00 |
| 6  | Extremely leptokurtic| > 3.00  |

3. Discussions

Bawean Island consists of 2 sub-districts, i.e. Sangkapura Sub-District and Tambak Sub-District as shown in Figure 1. Sangkapura Sub-District consists of 17 villages with an area of 118.72 km² and has a population of 31,519 people. Meanwhile Tambak Sub-district consists of 13 villages with an area of 78.70 km² with a population of 36,372 people. Brief data on each sub-district is presented in Table 10 and Table 11.

Table 10. Sub-district administrative data on Bawean Island

| Data                              | Sub-district Sangkapura | Sub-district Tambak |
|-----------------------------------|-------------------------|---------------------|
| Number of villages                | 17                      | 13                  |
| Male population                   | 27,007                  | 14,459              |
| Female Population                 | 27,105                  | 21,823              |
| Total Population                  | 54,112                  | 36,372              |
| Number of households              | 12,738                  | 9,093               |
| Population Density (people/km²)   | 460                     | 462                 |
| Area (km²)                        | 118.72                  | 78.70               |

Source: BPS District Gresik, 2017; Sub-district offices Sangkapura and Tambak, 2018

Table 11. Description Sub-district Sangkapura and Sub-district Tambak

| No | Description                      | Sub-district Sangkapura                                                                 | Notes                                                                 | Sub-district Tambak                                                                 |
|----|----------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 1  | Conditions of villages           | The villages in Sangkapura District are mostly coastal villages. The largest village area is Desa Daun (18.23 km²) while the smallest village is the Kota Kusuma City and Sawah Mulya village, which covers only approximately 0.72 km². | Tambak Sub-district consists of 13 villages with a total area of 78.70 km². The most wide village is Sukaoeng with a total area of 10.40 km², while the smallest village is Sukalela and Tambak with an area of only about 0.90 km². |
According to the Gerbangkertosusila National Strategic Zoning Plan (RZ-KSN) document, Bawean Island to be visited by cruise ships originating from within and outside the country. Generally, the range of cruise ship are between 350 – 1,000 DWT. This requires an adequate port, while, Sangkapura Port, can only accommodate 200 – 300 DWT vessels.

Therefore, in the future Bawean Island needs to develop a larger and more modern port. These developments certainly require complete and accurate hydro-oceanographic data. The availability of hydro-oceanographic data for port construction is very important to find the safe and suitable location for new port facilities. Furthermore, the availability of hydro-oceanographic data and information directly is also useful for the protection and conservation of coral reefs. The existence of coral reefs around Bawean Island needs to be maintained to avoid damages by shipping activities. Hydro-oceanographic information, especially bathymetry, is very useful in determining the shipping routes of commercial vessels and fishing vessels by avoiding waters full of coral reefs.

At the time of writing this paper, the survey had just been completed and was in the process of analyzing and compiling results. The complete survey results will be presented in the next paper. In general, it can be said that the oceanographic conditions on Bawean Island are very supportive for the development of coastal eco-tourism, although in some cases supporting infrastructure such as the marina and breakwaters are still needed. The data obtained from the hydro-oceanography survey can be utilized for the purposes of infrastructure planning for marine eco-tourism support in Bawean. Some of the conditions related to water conditions for marina development are wave height and period less than 0.3m and 12 second, current speed less than 0.5m/sec and tidal range is not more than 1.5 m
The pattern of current surrounding Bawean Island refers to the general pattern of current movement that occurs in the Java Sea. Currents in the Java Sea are strongly influenced by monsoons. In general, the current flows to the east during the West Season between November to March and flows to the west during the East Season from May to September. During the transition period in April and October, the current direction changes. At that time, currents near the coast of Java generally move eastward and currents near the coast of Kalimantan move westward. In the western Java Sea, the current moves eastward with a maximum speed of 1.1 knots, in the central Java Sea the maximum current velocity is 1.6 knots and in the southeastern Java Sea the current from the Makassar Strait reaches 2.0 knots. Currents moving west reach a maximum speed of 1.0 knot in the western part of the Java Sea, 1.4 knots in the middle part of the Java Sea and 1.7 knots in the eastern part of the Java Sea.

Current velocity does not change much in March. However, there is a change in the direction of the current in the northern part of the Java Sea, where the direction of the current starts to change to the east. The direction and speed of the currents in the Java Sea are relatively constant in April. In April current flow pattern, the mass of water originating from the north coast of Central Java moving east changes direction to the west on the north coast of East Java.

The Formzahl number is referred in the determination of tidal type. The mathematical expression for Formzahl numbers is shown in equation (10). The constants in the equation are tidal constants obtained from admiralty analysis. The analysis shows that the tidal type at the study site is the diurnal type. This type explains that there are 1 high tide and 1 ebb / low tide in a 24-hour period. Further, the typical values of seawater level in Bawean is presented in Table 12 based on admiralty’s tidal constant shown in Table 13.

| Water Level Categories          | Calculation            | Results (m) |
|--------------------------------|------------------------|-------------|
| Higher Water Spring            | HWS                    | S₀+(M₂+M₄+K₁+O₁) | 2.27        |
| Mean High Water Spring         | MHWL                   | MSL+(M₂+S₂)   | 1.52        |
| Mean Sea Level                 | MSL                    | S₀          | 1.45        |
| Mean Low Water Spring          | MLWL                   | MSL-(M₂+S₂)  | 1.37        |
| Lowest Water Spring            | LWS                    | MSL-(M₂+S₂)-(O₁+K₁) | 0.62 |
| Tidal Range                    |                        | (HWS-LWS)    | 1.65        |
|                               |                        | (MSL-LWS)    | 0.82        |

| Table 13. Admiralty’s tidal constant |
|-------------------------------------|
| Constant | S₀ | M₂ | S₂ | N₂ | K₁ | O₁ | M₄ | MS₄ | K₂ | P₁ |
| A        | 145.10 | 2.85 | 4.53 | 0.27 | 49.25 | 26.01 | 0.04 | 0.20 | 1.22 | 16.25 |
| g²       | 66.20 | 51.39 | 268.03 | 288.99 | 214.44 | 234.77 | 303.37 | 51.39 | 288.99 |
| F value  | 10.20 | Diurnal |

4. Conclusions
Bawean Island of East Java Province has a potential to be developed as a tourist destination area. Previous analysis showed that the sustainable management of eco-tourism in Bawean Island can be managed through the protection of coastal natural resources, providing economical-based income and education on environmental conservation. Further study to evaluate hydro-oceanographic condition by filed survey has been conducted. Hydro-oceanographic survey results show that Bawean Island can be developed as marine eco-tourism destination area when supporting infrastructures such as marina and protecting breakwater is provided.

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