Hydrodynamical model during east season at Gosong Coastal West Borneo as candidate location of nuclear power plant in Indonesia

A T Prasetyo\textsuperscript{1*}, Muslim\textsuperscript{2}, H Suseno\textsuperscript{3}

\textsuperscript{1)}Department of Marine Science – Diponegoro University, Semarang – Indonesia
\textsuperscript{2)}Department of Oceanography – Diponegoro University, Semarang – Indonesia.
\textsuperscript{3)}Marine Radioecology Group – Center for Radiation Safety and Metrology – National Nuclear Energy Agency, Jakarta – Indonesia

Email: akhmadtriyoyo@gmail.com

Abstract, Indonesia planned to build the first nuclear power plant in Gosong Coast, Bengkayang Regency, West Kalimantan. This research examined the hydrodynamical conditions in the ocean of Gosong Coast during the eastern season. This hydrodynamic model can be considered in estimating the distribution of various radionuclide wastes that release to the ocean. It was simulated using the Delft3D flow module application for 15 days which included the neap and spring tide conditions. Based on the result of the hydrodynamical model, Gosong Coast had a mixed semidiurnal type of tide with low amplitude. The wind parameters involved higher impacts to the hydrodynamical conditions. The model result did not find significant differences between neap and spring tide periods. There was a flow collision between 2 opposite water currents which was occurred at Burung Archipelagic during flood tide and at the Coastal area of Singkawang City during ebb tide. Therefore, the ocean currents at Gosong Coast flowed directly offshore through Burung Archipelagic during ebb tide. Meanwhile during flood tide, these ocean currents moved to Singkawang and Sambas Coastal area before they deflected toward offshore.

1. Introduction
The construction of nuclear power plants near the coastal area is feared to release radioactive compounds into ocean. In normal operation, treated radioactive waste is stored in underground tanks and should not discharged into the environment [1]. Radioactive waste can be dumped into ocean only if nuclear emergency [2] or natural disaster occurs [3]. The release of radioactive waste can threaten aquatic organisms in the sea [4].

The hydrodynamic conditions are the main parameters that determine the distributional pattern of liquid waste which discharges into the ocean, apart from the characteristics of each radionuclide element on the mass of water [5]. The simulation of ocean dynamics provides the ocean current patterns temporally in the large area [6]. Furthermore, the hydrodynamical model defines the movement pattern of a liquid pollutant into 2 dynamic concepts, namely advection, and diffusion [7]. The advection process describes the displacement of liquid waste at a point in the water due to the water current, while the diffusion process illustrates the propagation of the concentration of waste in water due to its dissolved nature [8].
Various liquid wastes have different diffusion characteristics to the ocean which are expressed in the form of coefficient number [9]. Understanding the chemical characteristics of radionuclides in water is quite important while estimate the spreading of radionuclide waste in the ocean [10]. Radioactive compounds are divided into 2 characteristics in the water area, such as conservative and non-conservative. Conservative radionuclides are volatile and dissolve in water mass, then their presence tends to persist in the water column [1]. Therefore, the advection process remains a more dominant part of the dynamic process of conservative radionuclide in the ocean [5]. Non-conservative radionuclides are reactive with high affinity for suspended particulates, therefore these radionuclides will easily swallow and accumulate in sediment bottom [1].

This research is a further study of the previous research, which examined the hydrodynamic model of Gosong Coast during the west monsoon. Gosong Coastal Area, which is located in West Kalimantan Shoreline, was assumed to have a considerable influence on monsoon winds which can change significantly to ocean flow patterns [11]. This assumption was the reason for this study which the purpose is to illustrate the hydrodynamic conditions of Gosong Coast during the east monsoon. Furthermore, the result can be the basis for estimating the distribution patterns of radionuclide waste in the ocean.

2. Methods

2.1 Design model

The hydrodynamical model was built using the Delft3D application which covered the Sambas Regency to Mempawah Regency and around 30 km offshore from the nuclear power plant candidate point (Figure 1). The model grid was constructed through the Delft3d-rggrid module with a resolution of 100 meters x 100 meters ± 50 meters. The model is simulated by Delft3d-flow module for 15 days starting on September 10th, 2016 at 00:00 to September 25th, 2016 at 00:00. The simulated time adjusted the measurement of ocean currents by previous research [12] which were used to verify the ocean current simulation in this research.

Figure 1. Research location.
2.2 Methodology

The Delft3D flow module was applied in the building of model. The required parameters in this research were water elevation, surface wind, bathymetry, and coastline maps. Table 1 showed all files with their format which were entered into Delft3D Software. The bathymetry data and coastline map delivered by pushidrosal marine map were processed by Arc Map 10.6. National Bathymetry derived of BIG was an additional data to decide the water depth in near shoreline. The coastline map was converted into land boundary format as a reference for constructing the model grid and defining entire islands in the model area by Grid Module Delft3D. Furthermore, the bathymetry data in .xyz format was interpolated into the grid model. BIG tidal Station in Pemangkat (West Kalimantan) is used as tidal data in this study which is downloaded through the website http://inascalelevelmonitoring.big.go.id/ipasut/ [13]. The 15-day tidal data was intended to consider the period of neap and spring tide. Astronomical components of tidal elevation were calculated to decide the tidal type of water area through the Formzhal formula [14]. Surface wind, included of u and v components, was derived from the European Center for Medium-Range Weather Forecasts (ECMWF) website. ERA 5 Land Hourly Data with resolution ± 9 km was chosen as 10 meters wind components for this research [15]. Furthermore, these components were calculated to obtain original direction and wind speed followed by these formulas [16]:

\[
U_{10} = \left( U_a^2 + V_a^2 \right)^{\frac{1}{2}}, \quad \theta = \tan^{-1} \frac{U_a}{V_a} \tag{1}
\]

Where \(U_{10}\) is the wind speed (m.s\(^{-1}\)), \(\theta\) is the original wind direction, then \(U_a\) and \(V_a\) are the wind components by longitudinal and latitude pattern. The output model of this research defined coordinate system in universal transverse Mercator (utm).

### Table 1. The input data with their format.

| No | Data               | Filename | Definition                                           |
|----|--------------------|----------|------------------------------------------------------|
| 1  | Land Boundary      | <name.ldb> | Shoreline, island, and boundary in the model area    |
| 2  | Grid               | <name.grd> | Mesh of model                                        |
| 3  | Dry Point          | <name.dry> | Varied grids which located in the island             |
| 4  | Depth              | <name.dep> | Water bathymetric                                    |
| 5  | Boundary           | <name.bnd> | The entire open boundary (water to water)            |
| 6  | Water level        | <name.bct> | Tide variable by type time-series                    |
| 7  | Wind               | <name.wnd> | Included of speed and direction                      |
| 8  | Monitoring         | <name.obs> | Current monitored site and tide station              |

2.3 Equation model

This research applied two fundamental concepts as hydrodynamical model guideline, such as the Continuity equation and Conservation of Momentum. These concepts was shared into equations adjusted to the user manual Delft-flow [17]. Continuity Equation:

\[
\frac{\partial \zeta}{\partial t} + \frac{1}{\sqrt{g_x g_y}} \frac{\partial ((d + \zeta) u \sqrt{g_y})}{\partial x} + \frac{1}{\sqrt{g_x g_y}} \frac{\partial ((d + \zeta) v \sqrt{g_x})}{\partial y} = (d + \zeta) Q. \tag{3.1}
\]

\[
U = \frac{1}{d + \zeta} \int_{-H}^{H} u \, dz = U_0 \, d\phi \tag{3.2}
\]

\[
V = \frac{1}{d + \zeta} \int_{-H}^{H} v \, dz = V_0 \, d\phi \tag{3.3}
\]

Momentum equations on the longitude (x) and latitude (y) axis:
\[ \frac{\partial u}{\partial t} + \frac{u}{\sqrt{\rho_o f}} \frac{\partial u}{\partial x} + \frac{v}{\sqrt{\rho_o f}} \frac{\partial u}{\partial y} + \frac{\omega}{\partial z} \frac{\partial u}{\partial z} - \frac{\omega^2}{\partial z^2} \frac{\partial u}{\partial y} + \frac{u v}{\sqrt{\rho_o f}} \frac{\partial u}{\partial x} + \frac{u v}{\sqrt{\rho_o f}} \frac{\partial u}{\partial y} = f v = 
\]
\[ - \frac{1}{\rho_o f} P_x + F_x + \frac{1}{(a+\xi)^2} \frac{\partial}{\partial z} \left( V^2 \frac{\partial u}{\partial z} \right) + M_x \] (4)

\[ \frac{\partial v}{\partial t} + \frac{u}{\sqrt{\rho_o f}} \frac{\partial v}{\partial x} + \frac{v}{\sqrt{\rho_o f}} \frac{\partial v}{\partial y} + \frac{\omega}{\partial z} \frac{\partial v}{\partial z} + \frac{u v}{\sqrt{\rho_o f}} \frac{\partial v}{\partial x} + \frac{u v}{\sqrt{\rho_o f}} \frac{\partial v}{\partial y} = f u = 
\]
\[ - \frac{1}{\rho_o f} P_y + F_y + \frac{1}{(a+\xi)^2} \frac{\partial}{\partial z} \left( V^2 \frac{\partial v}{\partial z} \right) + M_y \] (5)

The explanation: \(\xi\) = Water Level (m), \(G_x, G_y\) = Transformed Coefficients of Coordinates from curvilinear into rectangular, \(d\) = Depth (m), \(u, v, \omega\) = Water velocity in x, y, z direction respectively (m.s\(^{-1}\)), \(Q\) = Other Contributions per unit area, \(P\) = Hydrostatic pressure gradient (kg.m\(^{-2}\).s\(^{-2}\)), \(M\) = Moment Value (m.s\(^2\)), \(F\) = Turbulent motion flow (m.s\(^{-1}\)), \(f\) = Coriolis impact, \(V_o\) = Vertical Edy Viscosity (m.s\(^{-1}\)), \(\rho_o\) = Reference density of water (kg.m\(^{-3}\))

2.4 Model verification

Model verification is quite important to analyze whether the models have illustrated sufficiently the real conditions in general or do not describe it at all. This research verified tidal and water current data between simulation and field measurement. Time-series tidal data by the BIG station in Pemalang was decided to verify the simulated water level, while the measured water current by Kushadiwijayanto et al (2017) was used to verify the simulated ocean current. Kushadiwijayanto et al (2017) measured hourly water velocity for 24 hours on September 10th–16th 2016 in the Cina Coast of Lamukutan Island (Figure 1). Mean relative error (MRE) approach was chosen to determine the level error of the model [18].

\[ MRE = \frac{\sum n}{X_n} \times 100\% \] (6.1)

Symbol \(c\) and \(x\) indicated the value of the model and observation, respectively. The amount of data was illustrated as "n". The simulation is acceptable if the verification value is not larger than 10% for water elevation and 40% for water velocity [19].

3. Result and discussion

3.1 Bathymetry

The northern ocean of West Kalimantan is included in shallow waters with a low level of slope, while water depths range from 0 to 68 meters (Figure 2). Gosong coast through the near islands (Tempurung and Semesak Island) is quite shallow waters with a depth ranging from 0 - 5 meters. This topography constructs the intertidal area around Gosong coast. However, two grooves up to 70 are found by the bathymetry map (Figure. 2) which are located in the northwest ocean of Lamukutan Island and the western ocean of Penata Besar Island. The Frictional forces between water mass and bottom sediments involve highly in inhibiting the velocities of water flow in shallow water [20]. It indicated that the water velocities around Gosong Coast are at low rate. However, other parameters influence water flow, such as surface wind and tidal ocean [21].
3.2 Data verification
This research verified the water velocity and water elevation between simulation and observation. The compared graph of model data and field measurement is illustrated in Figure 3. The MRE value on the validation of water elevations and water velocities data were respectively 7.58% and 39.63%. The different rates between simulation results and real conditions were caused by the existence of many parameters that involved the hydrodynamic which were not entered in the required data of the model, such as storms or coastal community activities [14]. In addition, the effect of the grid domain model resolution can change the hydrodynamical simulation results of the Delft3D Output [22]. Nevertheless, these MRE values were acceptable to determine that simulation had illustrated the real conditions.

Figure 2. Bathymetry map

Figure 3. Validation data; (a) water elevation, (b) depth average velocity
3.3 Wind condition

The hydrodynamical model in this study was constructed during the east monsoon, which indicated the dry season period in Indonesia [8]. Figure 4 shows the data on variations in the speed and original direction of the wind around Gosong Coast. Era 5 satellite calculated that the southwest and south wind had shown dominance in September in the coastal area of West Kalimantan. It means that the transition season (from east to west season) had occurred in September in West Kalimantan. These winds were involved to construct the water currents which flowed towards the northern site. Meanwhile, the surface wind speed showed relatively low figures. The dominant wind speed ranged from 2.10 - 3.6 m.s$^{-1}$. In transition season, Sun’s radiations spread through the equator area, therefore this period does not make significant differences in atmospheric pressure between north and south of the earth. Thus, the averaged surface air pressure of north and south earth did not show sharp differences. The different gradients of air pressure among various areas generate the energy of wind. Finally, the surface wind would move with a low speed during transition season [8].

![Wind distribution](image)

**Figure 4. Wind distribution**

3.4 Hydrodynamical model

The simulation showed that the tidal type of Gosong Coast was a mixed semidiurnal ($F = 1.06$). It means that this ocean experiences twice low and twice flood tides in a day with different periods and amplitudes of the tide. This research considered neap and spring tide periods to define the ocean dynamic pattern. The neap tide period is characterized by the smallest amplitude of the water elevation for low to flood tide, while the Springtide period is characterized by the occurrence of the highest and lowest tide during one day. The simulated ocean currents were presented in the average values of depth rates. However the current velocities can be changed in various depths, the directions and velocities of water currents are relatively similar during various water depths in shallow water [20].

The neap tide occurs when the position of moon is perpendicular to the earth and the sun [8]. Figure 5 illustrated the hydrodynamical model curing neap tide. The amplitudes of water levels were around 0.6 m during neap tide. The northern offshore experienced slightly lower tidal propagations instead of the southern offshore. Flow velocities in the coastal area during neap tide ranged from 0.01 - 0.3 m.s$^{-2}$, while the offshore water currents increased sharply. The high gradient of offshore depths triggered water flows to increase their speed [23]. The water velocities appeared to be homogeneous during the neap tide, although these velocities decreased slightly around Burung Archipelagic at the flood tide. There was two approached water current from north and south which crashed around Burung Archipelagic during flood tide. It caused the decreased value of current speeds. However, ebb tide showed different ocean flow patterns instead of flood tide. The collision of the two opposite water masses occurred around the Singkawang coast during flood tide. This phenomenon constructed the current deflection which spread water masses in high proportion from coastal area to offshore.
Figure 5. Water current and water level during neap tide; (a) flood tide, (b) ebb tide

The dynamics of water flows during the springtide were presented in Figures 6a and 6b. This period is conducted while the moon position is parallel to the earth and sun, therefore it triggers the high astronomical force against the ocean [8]. Generally, the tidal range in this ocean reached about 1 m during springtide, except in the coastal area of Singkawang City. Singkawang coast always showed the highest tidal propagation either spring and neap tide. At the springtide, the tidal amplitude at Singkawang Coast reached about 1.37 m. The low slope of bathymetry around the Singkawang Coastal Area was assumed as an influence of fluctuation in water elevations. Current patterns during spring tide did not appear the significant changes compared to the neap tide period. However current speed during spring tide increased sharply instead of neap tide. Relatively water currents moved parallel to the shoreline either during high and ebb tide. This current pattern usually occurs in the open sea [21,23]. On the other hand, the dynamics of water move away from the coastline at ebb tide and approach the coastline at flood tide in the closed sea, such as bay or estuary [14,24].

Based on the previous research (at west season), the current pattern of the West Kalimantan Coastal Area is strongly influenced by surface wind parameters. There were some different results between both seasons on water dynamics. Additionally, a previous study in similar place [10] concluded that the influence of the wind monsoon was quite significant influence on the hydrodynamical changes in West Kalimantan. This ocean, which is located near the equator, indicates that the Coriolis influence involves rarely flow deflection by wind force [25]. Therefore, the current patterns relatively flowed following the direction of surface wind motion. However, tidal propagation and bathymetry remain the parameters which are more influence the current pattern in coastal waters.
The flow deflection which was conducted around Burung Archipelagic at flood tide and around Singkawang Coast at ebb tide involved expanding radionuclide liquid derived by nuclear power towards offshore. During ebb tide, firstly the radioactive disposal from Gosong Coast was estimated to spread to the Coastal Area of Singkawang before it was diverted to the offshore. The part distribution of radioactive liquid was also estimated to reach the water area of Sambas Regency. However, at the flood tide, this radioactive waste is assumed to directly move offshore through Burung Archipelagic. The water areas of Singkawang City and Burung Archipelagic, and Sambas Regency were estimated to receive the radioactive waste if nuclear power plant (NPP) was built in the Gosong Coast, Bengkayang Regency. Several previous studies reported many important ecosystems that grew around these areas, such as mangroves, seagrass, and marine coral [26–29].

The radioactive waste from nuclear reactor should be treated before be saved at disposal facility, such as reprocessing, decontamination, and decommissioning. These treatments divided the radioactive waste into high-level waste (HIW), low-intermediate level waste (LILW) and very low-level waste (VLLW). These radioactive wastes were stored in underground tanks with depths base on their levels for some decades (IAEA, 2009). Therefore, the radioactive waste during the normal operation of nuclear reactor should not pollute the marine environment [19]. This study warned that if an accident occurs in the application of nuclear energy. Radioactive wastes without treatment will discharge into the ocean and atmosphere, thus they can pollute the marine environment [3].

Figure 6. Water current and water level during spring tide; (a) the highest flood tide, (b) the lowest ebb tide
4. Conclusion
Location of the waters of Gosong Coast, West Kalimantan, is located in a tropical area that is heavily influenced by the monsoon. There was the flow collision between 2 different water currents which was occurred at Burung Archipelagic during flood tide and at the Coastal area of Singkawang City during ebb tide. This collision influenced the deflection of ocean currents towards offshore. Water currents during flood tide were estimated to spread the radioactive waste from Gosong Coast towards the coastal area of Singkawang City and Sambas District, while the water currents during ebb tide spread the radioactive waste to offshore through Burung Archipelagic. This research estimated that the radionuclide dynamic from Gosong Coast would be received by water areas of Singkawang City, Burung Archipelagic, and Sambas Regency. Nevertheless, Further study about baseline data and disposal scenarios of various radioactive compounds should be carried out to estimate the impact rate for marine ecosystems.

References
[1] Periáñez R, Bezhenar R, Brovchenko I, Duffa C, Iosjpe M, Jung K T and Kim K O 2019 Marine radionuclide transport modelling : Recent developments , problems and challenges 122
[2] Zhao C, Wang G, Zhang M, Wang G, de With G, Bezhenar R, Maderich V, Xia C, Zhao B, Jung K T, Periáñez R, Akhir M F, Sangmanee C and Qiao F 2021 Transport and dispersion of tritium from the radioactive water of the Fukushima Daiichi nuclear plant Mar. Pollut. Bull. 169
[3] Bailly du Bois P, Laguionie P, Boust D, Korsakissok I, Didier D and Fiévet B 2012 Estimation of Marine Source-Term Following Fukushima Dai-ichi Accident J. Environ. Radioact. 114 2–9
[4] Fulghum C M, DiBona E R, Leaphart J C, Korotasz A M, Beasley J C and Bryan A L 2019 Radiocesium (137Cs) accumulation by fish within a legacy reactor cooling canal system on the Savannah River Site Environ. Int. 126 216–21
[5] Kawamura H, Furuno A, Kobayashi T, In T, Nakayama T, Ishikawa Y, Miyazawa Y and Usui N 2017 Oceanic Dispersion of Fukushima-Derived Cs–137 Simulated By Multiple Oceanic General Circulation Models J. Environ. Radioact. 180 36–58
[6] Ouni H, Sousa M C, Ribeiro A S, Pinheiro J, Ben M’Barek N, Tarhouni J, Tlatli-Hariga N and Dias J M 2020 Numerical modeling of hydrodynamic circulation in Ichkeul Lake-Tunisia Energy Reports 6 208–13
[7] Nie B, Yang J, Wang W, Gu Z, Yuan Y and Li F 2020 Numerical Study on Tritium Dispersion in Coastal Waters : The Case of Hangzhou Bay, China J. Hydrol. 590 125532
[8] Trujillo A P and Thurman H V T 2011 Essentials of Oceanography Essentials of Oceanography (PEARSON) p 551
[9] Sakuma K, Kitamura A, Malins A, Kurikami H, Machida M, Mori K, Tada K and Kobayashi T 2017 Characteristics of radio-cesium transport and discharge between different basins near to the Fukushima Dai-ichi Nuclear Power Plant after heavy rainfall events J. Environ. Radioact. 169–170 137–50
[10] Bacchi V and Tassi P 2019 Three-dimensional Modelling of Radionuclides Dispersion in a Marine Environment with Application to the Fukushima Dai-ichi Case Environ. Model. Assess. 24 457–77
[11] Akbar A A, Sartohadi J, Djohan T S and Ritohardoyo S 2017 The Role of Breakwaters on The Rehabilitation of Coastal and Mangrove Forests in West Kalimantan, Indonesia Ocean Coast. Manag. 138 50–9
[12] Kushadiwijayanto A A and Apriansyah 2017 Pemodelan Arus Musiman di Perairan Lemukutan Kalimantan Porseding Semirata 2017 Bid. MIPA BKS-PTN Wil. Barat
[13] Irawan A M, Marfai M A, Munawar, Nugraheni I R, Gustono S T, Rejeki H A, Widodo A, Mahmudiah R R and Faridatunnisa M 2021 Comparison between averaged and localised subsidence measurements for coastal floods projection in 2050 Semarang, Indonesia Urban Clim. 35 100760
[14] Wisha U J, Tanto T Al, Pranowo W S and Husrin S 2018 Current movement in Benoa Bay water, Bali, Indonesia: Pattern of tidal current changes simulated for the condition before, during, and after reclamation Reg. Stud. Mar. Sci. 18 177–87

[15] Ssenyunzi R C, Oruru B, D’ujiang F M, Realini E, Barindelli S, Tagliaferro G, von Engeln A and van de Giesen N 2020 Performance of ERA5 data in retrieving Precipitable Water Vapour over East African tropical region Adv. Sp. Res. 65 1877–93

[16] Akpınar A, van Vledder G P, Kömürcü M I and Özger M 2012 Evaluation of the numerical wave model (SWAN) for wave simulation in the Black Sea Cont. Shelf Res. 50–51 80–99

[17] Deltares 2014 3D/2D modelling suite for integral water solutions: Hydro-Morphodynamics 710

[18] Hou J, Kang Y, Hu C, Tong Y, Pan B and Xia J 2020 A Gpu-Based Numerical Model Coupling Hydrodynamical and Morphological Processes Int. J. Sediment Res. 35 386–94

[19] Muslim M, Suseno H and Saodah S 2016 Condition of 137Cs Activity in Karimunjawa Waters and Its Distribution When an NPP Jepara is Operated ILMU Kelaut. Indones. J. Mar. Sci. 21 143

[20] Hendrawan I G and Asai K 2014 Numerical Study on Tidal Currents and Seawater Exchange in The Benoa Bay, Bali, Indonesia Acta Oceanol. Sin. 33 90–100

[21] Mayerle R, Niederndorfer K R, Fernández Jaramillo J M and Runte K H 2020 Hydrodynamic method for estimating production carrying capacity of coastal finfish cage aquaculture in Southeast Asia Aquac. Eng. 88 102038

[22] Dagestad K F and Röhrs J 2019 Prediction of ocean surface trajectories using satellite derived vs. modeled ocean currents Remote Sens. Environ. 223 130–42

[23] Miramontes E, Garreau P, Caillaud M, Jouet G, Pellen R, Hernández-Molina F J, Clare M A and Cattaneo A 2019 Contourite distribution and bottom currents in the NW Mediterranean Sea: Coupling seafloor geomorphology and hydrodynamic modelling Geomorphology 333 43–60

[24] Hakim B Al, Wibowo M, Kongko W, Ifani M, Hendriyono W and Gumbira G 2015 Hydrodynamics Modeling of Giant Seawall in Semarang Bay Procedia Earth Planet. Sci. 14 200–7

[25] Yin X, Yang L, Liu Q, Su J and Wu G 2018 Structure of equatorial envelope Rossby solitary waves with complete Coriolis force and the external source J. Chaos, Solitons, and Fractals 111 68–74

[26] Nurrahman Y A, Suhara D O and Rostika R 2012 Struktur dan Komposisi Vegetasi Mangrove di Pesisir Kecamatan Sungai Raya Kepulauan Kabupaten Bengkayang Kalimantan Barat J. Perikan. dan Kelaut. 3 99–107

[27] Sudarso J 2012 Strategi Pengembangan Ekowisata Terumbu Karang di Pulau Lemukutan dan Pulau Rendayan, Kabupaten Bengkayang, Kalimantan Barat (Universitas Terbuka)

[28] Yulianti and Sofiana M S J 2018 Kelimpahan Kepiting Bakau (Scylla sp.) di Kawasan Rehabilitasi Mangrove Setapu, Singkawang J. Laut Khatulistiwa 1 25–30

[29] Suraimah, Thamrin E and AM I 2019 Persepsi Masyarakat Terhadap Keberadaan Hutan Mangrove di Dusun Setingga Asin Desa Sebubus Kecamatan Paloh Kabupaten Sambas J. Hutan Lestari 7 482–91

[30] IAEA 2009 Policies and Strategies for Radioactive Waste Int. At. Energy Agency No. NW-G-1 1–57