The Estuaries Contribution for Supplying Nutrients (N and P) in Jepara Using Numerical Modelling Approach

Lilik Maslukah1, Sri Yulina Wulandari1, and Indra Budi Prasetyawan1

1Department of Oceanography, Faculty of Fisheries and Marine Science, Diponegoro University, Jl. Prof. H. Soedarto, SH, Tembalang, Semarang 50275, Indonesia

E-mail: lilik_masluk@yahoo.com

Abstract. Coastal water is dynamic area since it is influenced by both ocean and land. It has high primary productivity that determined fishing ground area. Increased supply of nutrients in coastal water is significantly influenced by seasons and the presence of the river estuaries carrying water masses from the mainland. This study focused on the rivers (Serang, Wiso, Grenjengan Mlonggo and Pasokan rivers) contributed nutrients supply spatially and temporally to Jepara water using numerical modeling. The results showed nutrients content of N (Nitrate) and P (Phosphate) from those rivers were 39.19 tons N/month and 2.26 tons P/month in June, 19.94 tons N/month and 1.96 tons P/month in August. From simulation modeling nutrient of N and P showed that the distribution pattern of N and P was larger during the neap tide than the spring tide. Furthermore, compared with the other rivers, Serang river was the highest nutrient supplier to Jepara water.

Keyword: Contribution, N and P nutrients, estuaries, numerical modeling, Jepara waters

1. Introduction

The Indonesian waters as part of the tropical sea are characterized by sufficient sun exposure but have low nutrient concentrations [1]. It leads to an extremely low primary productivity. However, in some coastal waters have high primary productivity, uniqueness, ecological and economic value [2]. The high primary productivity in waters makes potentially to be fishing ground areas.

Fishing ground is a region or an area in which a population of an organism is abundant. The abundance of these organisms is strongly influenced by physical and chemical parameters of the seas such as temperature, salinity, pH, brightness, current, depth, seabed topography, dissolved oxygen, and nutrient. The increase of the nutrients supply in the fishing ground is positively correlated with the primary productivity as the basis of the food chain [3].

The dynamic of nutrient supply in coastal waters is greatly affected by the presence of the river estuaries that carry water mass from the mainland. The river estuary that plays a significant role as a major exporter of nutrients into coastal waters also considered as fertilizing agents in coastal areas [4]. According to Libes [5], the land is the largest contributor to the various chemical compounds in the marine environment. The distribution of the nutrients from the land that are discharged to the river is strongly influenced by hydro oceanography processes including currents and tides. Then, It is distributed through a dilution process and accumulated through deposition process in the sediment. The precipitated nutrients may release to the water column through the resuspension process by current and waves [6].

The increased upstream area utilization, particularly for agriculture, transportation, and settlement has led to the enrichment of organic matter and nutrients. Nitrogen (N) and Phosphorus (P) nutrients are key parameters of quality of the waters. The concentration of these nutrients will vary depending on the terrestrial environment, the season and the condition of geology [7]. N and P are directly or indirectly affect the growth of phytoplankton [8] and oxygen concentration.

The Jepara water gets fresh water supplies from several rivers that have the different characteristic of the region and the level of human activities. The rivers that flow into the Jepara Water
is divided in two zones: (1) under the administration of Jratun Seluna river basin (located in the west) and (2) Wiso Gelis for rivers that are in the east [9]. The existence of rivers that run into the Jepara water provides an overview of the influence of land regarding supply of nutrients and so influence the existence of fishing grounds. On the other hand, the water quality of each river is also influenced by the upstream. The characteristics and the level of nutrients will vary from one location to the others. It is also affected by the upstream and the season. Due to the intensive rainfall, the flow rate of the river during the west season is higher compared with the dry season [10][2]. During the west season, the water bodies receive more nutrients leading to the increment of primary productivity in a wider area. Nutrients are inorganic materials which are the result of organic materials decomposition by decomposers. The existence of nutrients in the waters is very important to enhance the primary productivity. Some elements of the main nutrients have an important role in primary productivity are Nitrogen (N) and Phosphorus (P). Some research regarding the measurement of N and P had been carried out in the coastal waters and the sea, however, in conjunction with the amount of supply and fluctuation of each river had never been carried out yet. Therefore, this study was aimed to determine the contribution from four rivers (Serang, Wiso, Grenjengan Mlonggo and Pasokan) toward the supply of nutrients (especially N and P) into the around water.

2. Materials and Methods

The experiment was conducted in June and August 2016 in the waters of Jepara. The data collected were seawater samples, bathymetry, tides and ocean currents. To determine the location of the research, purposive sampling method was used. At this stage, the water sampling station was determined by considering the presence of watershed management. There are four locations namely Serang river, the Wiso river, Grenjengan Mlonggo river, and the Pasokan river. The field data of ocean current measurement at one station will be used for current data verification of model at the same station. The ocean current measuring station is determined by considering that the station may represent the state of overall waters. Water samples were taken using Nansen bottles from the surface. After arriving at the laboratory, filtering is done with Millipore filter paper (size 0.45 m) followed the analysis of phosphate and nitrate [2].

2.1. Laboratory analysis of the phosphor: Spectrophotometric phosphomolybdate blue method was used in determining phosphate. The principle works are ammonium molybdate, and potassium antimonyl tartrate react with orthophosphate (in acid condition) to form orthophosphomolibdate acid. Phosphomolybdate acid is then reduced by ascorbic acid up to blue color appeared. This color is proportional to the concentration of phosphorus. Absorbance reading at a wavelength of 880 nm [11][12].

2.2. Laboratory analysis of the nitrate: Analysis of Nitrate in the water samples were carried out in the laboratory using a method of [13] with UV-Vis spectrophotometer with a wavelength of 543 nm.

Preservation and Storing Water Samples: Nansen bottle was used to take water samples and then the samples were inserted into the sample container. The sample container such as a bottle PET (Poly Ethylene Terephthalate) needed to be washed with distilled water before the storing stage. Moreover, water samples should be refrigerated at 4°C in a coolbox to avoid samples damaged due to temperature change, and they could last for 48 hours. Water samples obtained from the field and then taken to the laboratory for analysis of phosphate and nitrate content [15].

2.3. The Measurement of River Flow Rate: The calculation of flow rate was performed by measuring the flow velocity and cross-sectional area [14]. Calculation of river flow rate was done at The river using formula as follows:

\[ Q_d = F_d \times V_d \]

\[ F_d = b \times \frac{c + 2d + e}{4} \]
2. Calculation of Flux and Nutrient Load of N and P

The Flux ($F$) rate of N and P are calculated by multiplying the value of the concentration with the current velocity at that section.

The nutrient load input ($L$) of N and P from the river is calculated using the following formula [13]

- $L = Q \times C$
- $Q = A \times V$

The flux rate was calculated using the formula:

$$F = v \times C$$

In which, $L$ is nutrient load input in monthly basis (ton/month), $F$ is flux ($m^2.s^{-1}$), $Q$ is flow rate ($m^3.s^{-1}$), $A$ is cross-section of wet river stream ($m^2$), $V$ is velocity ($m.s^{-1}$), $2592000$ is conversion factor (month to second), $1000000$ is conversion factor (ton to gram), $C$ is the concentration of each type of nutrients which are N dan P in monthly basis (mg.L$^{-1}$)

2.5. Hydrodynamic Modelling in the Jepara Waters

Hydrodynamic modeling in this study was executed using a software module of Hydrodynamics DHI MIKE 21 Flow Model Flexible Mesh. DHI MIKE is a mathematical program that can provide a solution for a hydraulic simulation in a wide range of waters environments including lakes, estuaries, bays, coastal, and marine areas. In the simulation model, bathymetric and tides data were needed as model inputs. Bathymetric data were extracted by digitizing the depth point from Bathymetry map published by Dishidros Navy. Tidal forecasting was used to define the input of boundary condition. Hydrodynamic simulations using a hydrodynamics module simulates the water level variations and flows. Two-dimensional unsteady flow is applied to identify the numerical solution by using equation conservation of mass and momentum [16].

2.6. The Nutrient Distribution Model

The simulation of nutrient distribution in Jepara waters with inputs of nutrients from four different estuaries was done using numerical modeling approach of equation advection-diffusion material. According to the results of numerical modeling using this module, the distribution of nutrients N and P were influenced by currents. The distribution of nutrient N and P in waters of Jepara in June and August 2016 will be modeled in this research. The nutrients of N and P in this study is assumed has a conservative character. Therefore the distribution pattern is influenced by the current. The equation used in numerical modeling of the distribution of nutrients N and P are as follows [17]:

![Diagram of depth and flow velocity measurements](image-url)
In which $u, v$ is the velocity of current at the direction of $-x$ (east-west) and direction of $-y$ (north-south), $C$ is nutrient concentration, $D_h$ is coefficient of horizontal diffusion, $k_p$ is the rate of linear shading, $C_s$ is concentration of the nutrients at the source point.

3. Result and Discussion

The concentration of nitrogen in some waters in Jepara was identified based on the concentration of nitrate (NO$_3^-$) and nitrite (NO$_2^-$). Meanwhile, the phosphorus concentrations were represented by the amount of PO$_4$. The element nitrogen (N) and phosphorus (P), which is considered as nutrients, are required by the flora (marine plants) as the growth booster. The importance of the availability of phosphate and nitrate for the growth of phytoplankton can be seen from the general equation of chemical photosynthesis occurring in the sea which was described by [18] as follows:

$$106\text{CO}_2 + 16\text{HNO}_3 + \text{H}_3\text{PO}_4 + 122\text{H}_2\text{O} + \text{trace elements} \& \text{vitamin} \rightarrow \text{C}_{106}\text{H}_{263}\text{O}_{110}\text{N}_{16}\text{P} + 138\text{O}_2$$

According to the result of the measurement, the concentration of N was ranging from 0.336-3.444 mg.L$^{-1}$ and P is ranging from 0.0201-0.0528 mg.L$^{-1}$. The more detail result can be seen in Table 1.

| No. | Location         | Flow rate (m$^3$.s$^{-1}$) | Concentration of N (mg.L$^{-1}$) June | Concentration of N (mg.L$^{-1}$) August | Concentration of P (mg.L$^{-1}$) June | Concentration of P (mg.L$^{-1}$) August |
|-----|------------------|-----------------------------|--------------------------------------|----------------------------------------|---------------------------------------|----------------------------------------|
| 1   | Grenjengan, Mlonggo | 1  13.14                    | 0.609                                | 0.371                                  | 0.0344                                | 0.0227                                  |
|     |                  | 2  11.07                    | 0.77                                 | 0.378                                  | 0.0528                                | 0.0238                                  |
|     |                  | 3  -                        | 0.69                                 | 0.385                                  | 0.0390                                | 0.0227                                  |
|     | Mean             | 5.64                        | 3.444                                | 0.42                                  | 0.0505                                | 0.0465                                  |
| 2   | Wiso             | 1  -                        | -                                    | -                                      | -                                     | -                                      |
|     |                  | 2  3.7                      | 1.673                                | 0.434                                  | 0.0528                                | 0.0475                                  |
|     |                  | 3  -                        | 1.659                                | 0.434                                  | 0.0517                                | 0.0455                                  |
|     | Mean             | 2.587                      | 0.4293                               | 0.4293                                 | 0.0517                                | 0.0465                                  |
| 3   | Serang           | 1  72.75                    | 0.336                                | 0.364                                  | 0.0344                                | 0.0486                                  |
|     |                  | 2  49.2                     | 0.35                                 | 0.378                                  | 0.0321                                | 0.0465                                  |
|     |                  | 3  -                        | 0.392                                | 0.378                                  | 0.0528                                | 0.0455                                  |
|     | Mean             | 0.3593                     | 0.3733                               | 0.3733                                 | 0.0398                                | 0.0468                                  |
| 4   | Pasokan          | 1  -                        | -                                    | -                                      | -                                     | -                                      |
|     |                  | 2  14.48                    | -                                    | 0.462                                  | -                                     | 0.0207                                  |
|     |                  | 3  -                        | -                                    | 0.441                                  | -                                     | 0.0217                                  |
|     | Mean             | 0.4573                     | 0.0214                               | 0.0214                                 | 0.0214                                | 0.0214                                  |

Based on Table 1, overall, the concentration of N and P fluctuate in every area of the river mouth. Wiso river which is located in the urban center of Jepara has a fairly high concentrations of N and P compared with other rivers. In June, the river Wiso had a concentration of N five times higher than in August. This condition was caused by the rain that was occurred during sampling. The existence of resident area along the upstream to the downstream of the river caused domestic sewage was discharged into coastal waters consistently. The water traffic of fishing boat around the river mouth of Wiso caused resuspension process in this river resulting in the increase of nutrient from the sediment into the water column rose significantly [19].
Ignatiades et al. [20] Classified waters by the tropical level based on the concentration of N and P. Based on this classification, the seas around Jepara were included in the eutrophic category. The concentration of N nutrient in the Jepara waters (1.89 mg.L⁻¹) was nearly two hundred and seventy times the concentration of N nutrient in eutrophic waters (0.007 mg.L⁻¹) and the mean concentration of phosphate (0.036 mg.L⁻¹) was almost three times the mean average concentrations of phosphate in eutrophic waters (0.011 mg.L⁻¹). Furthermore, when compared with the seawater quality standard of Ministry of Environment in 2004 (that was 0.015 mg.L⁻¹ for phosphate and 0.008 mg.L⁻¹ for nitrate), so the average concentration of phosphate (0.036 mg.L⁻¹) and nitrate (1.86 mg.L⁻¹) in the Jepara water in June and August 2016 was higher. This means that the Jepara water was rich in nutrients and considered as fertile waters. The conditions and processes that occurred in water related to the ratio between N and P can be seen in Table 2.

| Location   | Ratio June | Ratio August |
|------------|-----------|--------------|
| Grenjengan | 16.41667  | 16.36364     |
| Wiso       | 43.68859  | 9.232258     |
| Serang     | 9.027638  | 7.976496     |
| Pasokan    | **        | 21.36916     |

The ratio value of N and P in Wiso river was the highest in June (Table 2). A high ratio illustrated that N nutrient was abundant compared with P nutrient. However, this ratio was lightly decreased in August. The high ratio in June was related to the rainy seasons that had brought the run-off from the mainland.

To understand the contribution of N and P from several rivers into the Jepara water, the flux values and nutrient loads of N and P came from the river to the sea were presented in Fig. 2 and 3.
Based on fig 2 and 3, loads of nutrient input of N ranged 4.177 to 67.76 ton/month with a mean value of 29.56 ton/month, and P ranged from 0.446 to 5.90 ton/month to an average value of 2.11 ton/month. The N flux value was between 0.043 to 0.226 kg.m\(^{-2}\).s\(^{-1}\) and P between 0.002 to 0.010 kg.m\(^{-2}\).s\(^{-1}\).

Compared with the results of the research that have been conducted by Zhang et al. [21], the N value load in Coastal water of Jepara is a relatively smaller than total nitrogen and phosphorus loadings into the Gulf of Finland from the Neva River and St.Peterburg. Annual nutrient flux of total nitrogen and phosphorus from the Nova River 219 and 7.64 kg.km\(^{-2}\).yr\(^{-1}\). Mayor rivers discharging into the Baltic sea, ranging 594-798 kg.km\(^{-2}\).yr\(^{-1}\) (TN) and 15-56 kg.km\(^{-2}\).yr\(^{-1}\) (TP) [22].

Table 3. showed the results of calculation of nutrient loads carried by [23] in some of the waters of the Jakarta Bay.

| The Name of River | Total Nitrogen Loads (tons/yr) |
|------------------|--------------------------------|
| The Citarum river | 18.1                           |
| The Ciliwung river| 7.1                            |
| The Sunter river  | 3.7                            |
| The Cisadane river| 2.5                            |
| The Cengkareng river of Jang | 1.9                        |

**Numerical model of Nutrient N & P**

The results of numerical model simulations show the movement of currents in vector form and distribution of the concentration of nitrate and phosphate concentrations in June and August 2016. The simulation models adapted to the tidal conditions in the waters of Jepara and divided into two tidal...
conditions, i.e. neap tides and the spring tides in which are divided into two periods of high tide and low tide.

Based on Fig 4 and 5, the river of Serang supplies a load of nutrients N and P to Jepara water in the highest rate compared to other rivers, causing Jepara waters near the Serang became more fertile. These waters include the waters around Kedung District, Demak Regency. Another fishing ground is situated in the district Keling and Donorejo, Jepara Regency. In these areas, perch, pomfret, tuna, mackerel, mackerel, Banyar fish, crab, and squid were easy to find. The high production of fish in these waters was assumed related to the nutrient input of N and P from Pasokan river, which at second ranks.

![The high tide during neap tide](a)

![The low tide during neap tide](b)

![The high tide during spring tide](c)

![The low tide during spring tide](d)

Fig 4. The Distribution Model Of N in various Condition in the Jepara Waters (a,b) neap tide (c,d) spring tide
The high tide during neap tide
(a)

The low tide during neap tide
(b)

The high tide during spring tide
(c)

The low tide during spring tide
(d)

Fig 5. The Distribution Model Of P in various Condition in the Jepara Waters (a,b) neap tide (c,d) spring tide

Fig. 4 and 5 also illustrated the distribution pattern of N and P nutrient from modeling simulation during a neap tide and the spring tide. The simulation results showed that during in the neap tide, the distribution area of nutrients N and P is wider than in the spring tide. This was due to the velocity of tidal currents that was higher during the spring tide than the neap tide that caused the water intake from the river on the full tide conditions more restrained in coastal waters [24]. According to research that was conducted by Dick et al [25] in the Wadden Sea, the process of hydrodynamics waters would affect the distribution of nutrient concentrations as well as the water quality.
4. Conclusion

The results showed that, contributing nutrients N (Nitrate) and P (Phosphate) from four rivers in Jepara were 19.94-39.19 ton N/month with a mean value of 29.56 tons N/month and 1.96-2.26 tons P/month with a mean value of 2.11 tons P/month respectively. It was also identified, that N load entering the seas around Jepara in June was higher than in August. The results of simulation modeling nutrient N and P showed that during the neap tide, the distribution pattern of N and P is wider than the spring tide. Furthermore, Serang River was the highest supplier of nutrients compared with Wiso, Grenjengan Mlonggo, and Pasokan river. It could be concluded that a number of nutrients supply was high related to the width of the river as well as its flow rate.

References

[1] Moore C M et al 2013. www.nature.com/naturegeoscience. acceso on January 22th 2017
[2] Li R H et al 2014 Biogeosciences. 11 481–506. doi:10.5194/bg-11-481-2014.
[3] Bouwman A F, Bierkens M F P, Griffioen J, Hefting M M, Middelburg J J, Middelkoop H and Slomp C 2013 Biogeosciences. 10 1–22 doi:10.5194/bg-10-1-2013
[4] Wang X, Olsen L M, Reitan K I, Olsen Y 2012 Aquacult. Environ.Interact. 2 267-283
[5] Libes S M 1992 An Introduction to Marine Biogeochemistry (New York: Wiley) p 734
[6] Zhang L et al 2014 J. Earth Sci. 25 197–206 doi: 10.1007/s12583-014-0413-y.
[7] Jia J, Gao J F, Liu Y F, Gao S and Yang Y 2012 J. Asian Earth Sci. 52 158–168.
[8] Thongdonphum B, Meksumpun S, Meksumpun C, Thawonsode N, Sawasdee B 2014 Int. J. of Environ and Rural Develop., 5-2. January 30th 2017.
[9] http://bpsda-seluna.jatengprov.go.id/database/das.php
[10] Struyf E, Van Damme S, Meire P 2004 Est., Coast. and Shelf Sci. 60 649-661
[11] Murphy J and Riley J P 1962 Analitica Chimica Acta 27 31-36.
[12] Liu S M, Zhang J and Li D J 2004 Est. Coast. and Shelf Sci. 59 209-218.
[13] Parsons T R, Maita Y and Lalli C M 1984. A manual of Chemical and Biological Methods for Seawater Analysis (USA: Pergamon Press) p 173
[14] Waller P, Yitayew M 2016 Irrigation and Drainage First ed (USA: Springer) p 742
[15] Gordon N D, Mahon M T A and Finlason B L. 1992. Stream Hidrology and Introduction for Ecologists (England: Chichester)
[16] Plawsky J L 2014 Transport Phenomena Fundamentals 3rd ed (USA: CRC Press) p 838
[17] DHI Water and Environment, 2012. MIKE 21 Flow Model FM, Hydrodinamic and transport Module Scientific Documentation (Denmark) p14
[18] Paytan A and Laughlin K M 2007 Chem. Rev. 107 563–576 doi: 10.1021/cr0503613
[19] Dzialowski A R, Shih-Hsien W, Niang-Choo L, Beury J H and Huggins D G 2008 Lake Res. Manag. 24 313-320 doi: 10.1080/0743814080935 4841.
[20] Ignatiades L, Karydis M and Vounatsou P 1992. Mar. Poll. Bull. 24 238-243.
[21] Zhang C Y et al 2006 Remote. Sens. Environ 102 250.
[22] Stälinnace P, Grimvall A, Sundbland K, Tonderski A 1999 Environ. Monit. Assess. 58 173-200
[23] Wulp S A, Damar A, Ladwig N, Hesse K J 2016 Mar. Poll. Bull. 110 675–685.
[24] Suntoyo H et al 2015 Procedia Earth and Planetary Sci. 14 144 – 151.
[25] Dick S et al 1999 German J.I Of Hydrography 51 182-219.