Quantitative Evaluation of Spatial Distribution of Nitrogen Loading in the Citarum River Basin, Indonesia

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Abstract

Human population growth has led to increases in energy and food production, use of fertilizers, and wastewater flows. Enhanced availability of nitrogen is a cause of eutrophication of rivers, lakes, and estuaries worldwide. In this study, Citarum River Basin, West Java, Indonesia was selected as a target area, supplying 80% of domestic water to Jakarta Metropolitan. Meteorological and hydrological data from 1996 to 2009, and spatial data such as topography, land use, soil properties were collected for model simulation. Conceptual nitrogen balance model, which has three nitrogen pools, was developed and combined with rainfall runoff model. Proposed model was applied to the Citarum River Basin and simulated river discharge and nitrogen load in 1 km × 1 km resolution to check the model applicability. By using the model, spatial distribution of nitrogen loading in whole basin level was estimated and histograms of nitrogen load from different land use also evaluated. The results provide a first insight into the magnitude and the spatial distribution of nitrogen loading in Citarum River Basin.

Key words: Diffuse pollution, Land use, Nitrogen runoff, Point sources, West Java.

1. Introduction

During the past century, human activities have changed rapidly. Most importantly, human population growth has led to increases in energy and food production, use of fertilizers, and wastewater flows (Pieterse et al., 2003). Nitrogen plays an important role in controlling the trophic status of surface waters. Increased nitrogen loading from anthropogenic activity (agriculture, wastewater disposal, and atmospheric emissions) has resulted in widespread enrichment of nitrogen in surface waters and associated problems of eutrophication linked to excessive accumulation of algal biomass, toxic algal blooms, and dissolved oxygen depletion (Grizzetti et al., 2005). If surface water withdrawal were directly affected by water quality degradation, domestic water intake could be cut off for sanitary reasons. Therefore, evaluation of nitrogen polluted level in whole basin is important to discuss river environmental management under the impacts of intensified human activities.

The Citarum River is largest river in West Java, Indonesia (Fig. 1). The Citarum River Basin is a region known for its highly palatable rice and the most important basin in West Java, supplying water for Bandung and Jakarta City, with 80% of domestic water in Jakarta being withdrawn from this basin (Loebis and Syamman 1993; Fares 2003). As the population and economic growth in this basin, sediment accumulation and eutrophication have become serious issues in downstream reservoirs due to inflows of wastewater from urban areas and fertilizer components from hilly upland fields into the river (Hart et al., 2002). Eutrophic nutrients flow into the closed waterbodies from many kind of sources such as point sources and non-point sources. It is important to identify the spatial distribution of nutrient effluent in basin wide level for establishing the best practice to maximize the efficiency of countermeasures. However, few scientific researchers were conducted about spatial distribution of pollutant sources, because observed water quality data was limited and only available along the main stream. Therefore, the purpose of this study was quantitative evaluation of spatial distribution of nitrogen loading in Citarum River basin. Hydrological based nitrogen load assessment model was proposed as a useful tool to evaluate the magnitude of spatial nutrient effluent.

2. Study Area

Having a length of 350 km and catchment area of 6,600 km², the Citarum River is the largest river in West Java (Fig. 1). Annual mean precipitation varies from 1,600 to 2,800 mm/year, and 70% of the annual precipitation falls during the rainy season from November to March. Bandung city is located along the upstream reach of the Citarum River. The river has three large dams: the Saguling dam in the upstream reach, Cirata dam in the middle reach, and Jatiluhur dam in the downstream reach. Table 1 lists the characteristics of the Saguling, Cirata, and Jatiluhur reservoirs. The Citarum River is the most important river in West Java. It supplies water for the cities of Bandung and Jakarta, with 80% of

Received; August 21, 2015.
Accepted; July 26, 2016.
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DOI: 10.2480/agrmet.D-15-00020
the domestic water in Jakarta being withdrawn downstream of the Jatiluhur dam (Loebis and Syamman 1993; Fares 2003). The problem of water quality degradation in the Citarum River has increased from year to year due to increasing pollutant loads, particularly those from the Bandung region located in the upper areas of the river basin when released without treatment. Therefore, it is important issue to evaluate the magnitude and the spatial distribution of pollution load quantitatively in this basin (Abery, 2005; ADB, 2007). However, water quality data is limited and most of monitoring stations are located in mainstream of Citarum River so that it is difficult to evaluate the spatial distribution of nutrient loading.

The land uses in the Citarum River Basin are paddy (35%), upland crop (25%), forest (23%), urban (12%), water (2%), and others (3%). Figure 2 shows a land use map of the upper Jatiluhur dam basin in 2000. In this study, only the area upstream of Jatiluhur dam was analyzed. The elevation of the downstream area is quite flat, so a suitable river line could not be extracted from GIS analysis in the downstream area. However, this analytical boundary is sufficiently satisfied to evaluate the water resources or water quality for the downstream or Jakarta metropolis water supply. For the model run, historical observation data and spatial information were collected, as shown Table 2. The available data were quite limited, especially long-term water quality data were ob-

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**Table 1. Characteristics of the three reservoirs in the Citarum River basin.**

| Characteristics | Saguling Reservoir | Cirata Reservoir | Jatiluhur Reservoir |
|-----------------|--------------------|------------------|--------------------|
| Catchment area (km²) | 2283               | 4061             | 4500               |
| Dam height (m)   | 99                 | 125              | 96                 |
| Volume (M m³)    | 603                | 1927             | 2448               |
| Purpose          | Electricity        | Electricity      | Multiple/irrigation |
| Surface area (ha) | 4869               | 6200             | 8200               |
| Effective volume (M m³) | 598.4            | 784.9            | 1869               |
| Annual inflow (km³) | 2.59              | 4.5              | 5.6                |
| Installed capacity (turbins × MW) | 700(4 × 175)     | 1000(8 × 125)    | 180(6 × 30)        |

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**Fig. 1.** Citarum river basin.
served only at the Nanjung station (Fig. 1). Meteorological data collected at the Bandung station were used to calculate evapotranspiration rate by the Penman-Monteith equation.

Figure 3 shows the statistical population increase in West Java Province and the estimated population increase in the upper Citarum River Basin from 1996 until 2010. In this study, population data and distribution of population density data were available only in 2010 (shown in Fig. 4); therefore, population in the upper Citarum River Basin was estimated by using the population increase ratio of West Java Province and the pattern of population density distribution in 2010 was applied to the entire analysis period.

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**Table 2.** Summary of data used for model simulation.

| Data (frequency)          | Description                                                                 | Sources      | Period        |
|---------------------------|-------------------------------------------------------------------------------|--------------|---------------|
| Meteorological data       | Bandung station (including air temperature, relative humidity, sunshine duration, windspeed, rainfall) | BMKG         | 1996-2009     |
| (daily)                   | Cirata station (rainfall only)                                                | PT PJB       | 1996-2005     |
| Hydrological data         | River discharge at Nanjung station (5 km upstream from Saguling dam)        | RCWR         | 1996-2009     |
| (daily)                   | Cirata station (Inflow to Reservoir)                                          | PT PJB       | 1996-2009     |
| Water quality data        | Jatiluhur station (Inflow to Reservoir)                                      | PT PJB       | 2007-2009     |
| (every 6 month before 2007)| Total nitrogen concentration at Nanjung station (5 km upstream from Saguling dam) | RCWR         | 1996-2009     |
| (every 2 month after 2007)| Cirata station                                                                | PT PJB       | 2007-2009     |
| Water Storage in Reservoir| Jatiluhur station                                                             | PT PJB       | 2007-2009     |
| (daily)                   | Cirata station                                                                | PT PJB       | 1996-2009     |
| Topography                | DEM(digital elevation map) (2000)                                             | PUB          |               |
| Land use                  | Digital landuse map (2000)                                                   | PUB          |               |
| Soil Clay content         | FAO Digital soil map of the world (2007)                                     | FAO          |               |
| Population density        | Population census (2010)                                                      | BPS          |               |

Notes: BMKG: Badan Meteorologi, Klimatologi, dan Geofisika in Bandung, RCWR: Research Center for Water Resources in Bandung, PT PJB: PT Pembangkitan Jawa-Bali, Cirata, PUB: Ministry of Public Works in Bandung, FAO: Food and Agriculture Organization, BPS: Badan Pusat Statistik.
3. Rainfall-Runoff Model

3.1 TOPMODEL

To evaluate nitrogen transportation according to the river flow and water flow in soil, a distributed rainfall-runoff model was developed and applied to Citarum River Basin. In this study, TOPMODEL was employed for the rainfall-runoff analysis. This distributed model can include the spatial distributions of topography, land use, and soil characteristics. Therefore, TOPMODEL is used widely for hydrological characteristic analysis, water management, water quality analysis, and future forecasting. TOPMODEL was proposed by Beven and Kirkby (1979) based on the contributing area concept in hillslope hydrology. Figure 5 illustrates the TOPMODEL structure, including three soil layers: the root zone, unsaturated zone, and saturated zone. Because TOPMODEL requires only three parameters (i.e., $m$, $T_0$, and $S_{z_{\text{max}}}$), the model is easy to link with GIS data (for details, see Ao et al. 1999 and Nawarathna et al. 2001). By using TOPMODEL, the water balance in the Citarum Basin was calculated at a resolution of 1 km × 1 km, and runoff from each grid cell was accumulated.

Fig. 3. Population change in West Jawa and estimated upper Citarum population (1996–2010).

Fig. 4. Human population density in the upper Citarum Basin.
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3.2 Water storage in paddy

In the Citarum River Basin, the agricultural sector is the main user of water (BPSDA-WSC, 2006). Paddy is a special land use especially in Asia Monsoon region and paddy water storage will make a significant influence to regional water cycle. In this study, surface water storage was under consideration in case of paddy cell grid (Fig. 6).

Paddy water storage was calculated by using paddy water balance equation as follows.

\[ h^{t+\Delta t} = h^t + \left( I^t + R^t - Q^t - P^t - ET^t \right) \Delta t \]  \hspace{1cm} (1)

where \( h \) : paddy water level (m), \( I \) : irrigation (m/s), \( R \) : precipitation (m/s), \( Q \) : surface drainage (m/s), \( P \) : percolation (m/s), \( ET \) : evapotranspiration (m/s), \( t \) : time (s), \( \Delta t \) : time step (86400s). Surface drainage and percolation were calculated as a function of paddy water level as following equation.

\[ Q = B_w \times \sqrt{g} \times \left( h^t - H_w \right)^{3/2} / A_{paddy} \]  \hspace{1cm} (2)

\[ P = T/86400 \times h^t \]  \hspace{1cm} (3)

where \( B_w \) is a width of drainage weir (= 0.11 m), \( H_w \) is a height of drainage weir (= 0.16 m), \( A_{paddy} \) is area of paddy field (m²), \( g \) is gravitational acceleration (m/s²), \( T \) is percolation parameter \( T \) (= 0.2) (1/day). The value of \( B_w, H_w, T \) were averaged value mea-

Fig. 5. TOPMODEL structure.

Fig. 6. Schematized paddy water storage.
Evapotranspiration ET can be calculated from Penman-Monteith equation by using observed meteorological data at Bandung station. Irrigation I was estimated by comparing paddy water demand to river discharge in each grid cell.

\[ I = \min(Q_{\text{in}}, Q_{\text{demand}}) \times A_{\text{paddy}} \]  

(4)

\[ Q_{\text{demand}} = (H_{\text{target}} - h) \times A_{\text{paddy}}/\Delta t \]  

(5)

where \( Q_{\text{in}} \) is river discharge at target grid cell \((\text{m}^3/\text{s})\), \( Q_{\text{demand}} \) is water demand for irrigation \((\text{m}^3/\text{s})\), \( H_{\text{target}} \) is target water depth in paddy \((=0.03 \text{ m})\). When paddy water depth \( h \) become less than target depth \( H_{\text{target}} \), farmers put irrigation water to their paddy until the target depth. And then, river discharge was reduced to \((Q_{\text{in}} - Q_{\text{demand}})\).

### 3.3 Dam operation model

Large scale dam having quite huge water storage capacity makes significant effect to control river water discharge (Juthithep et al., 2014). Normally, dam reservoir store water in rainy season and release water in dry season so that downstream river discharge become stable compare to the variation of natural river flow. In Citarum River Basin, there are three large dams having more than 500 million \( \text{m}^3 \) capacity which are mostly used for electric generation. In this study, simple dam storage model was applied to describe river discharge stabilization effect (Hanasaki et al., 2003). The storage of a reservoir \( V_{\text{res}} \) \((\text{m}^3)\) can be calculated by following equation.

\[ V_{\text{res}}^{t+\Delta t} = V_{\text{res}}^t + (Q_{\text{in}}^t - Q_{\text{out}}^t) \times \Delta t \]  

(6)

\[ Q_{\text{out}} = Q_{\text{min}} + C_{\text{Release}} \times V_{\text{res}}^t \]  

(7)

Where \( Q_{\text{in}} \) is the inflow of a reservoir \((\text{m}^3/\text{s})\) calculated by flow accumulation along the upstream river network, \( Q_{\text{out}} \) is the outflow of a reservoir \((\text{m}^3/\text{s})\), \( Q_{\text{min}} \) is a minimum flow for electric generation \((\text{m}^3/\text{s})\), \( C_{\text{Release}} \) is coefficient \((1/\text{s})\).

### 4. Nitrogen Balance Model

#### 4.1 Sanitary condition in Citarum River Basin

In the Citarum River Basin, the population density and wastewater treatment systems are quite different between rural and urban areas. For example, based on the population census in 2010, population density varied from 238 to more than 50,000 persons/km\(^2\) (Fig. 4), although the total population in the upper Jatiluhur basin was 9.82 million. For wastewater treatment in the rural areas, a septic tank system is normally used, but only 5% of the nitrogen can be removed by this system and the wastewater then runs off to the river after absorption or denitrification in soil (ADB, 2013). In the case of the urban area, Bandung city has a centralized wastewater treatment plant (WWTP). The plant, called Bojongsoang WWTP, has a capacity of 89,000 \( \text{m}^3/\text{day} \) and covers treatment for the eastern part of the city (Fig. 1). The nitrogen removal ratio of Bojongsoang WWTP is reported to be about 80% (ADB, 2013). However, in the western region of the city, there is no treatment plant. Therefore, average percentage of WWTP connected household was 35% in whole Bandung city (ADB, 2013). Unfortunately, the information of WWTP covered area was not available, therefore we applied following assumption to entire Bandung city. Point-source nitrogen from humans and livestock was calculated by multiplying the respective population by the unit nitrogen loading, as shown in Table 3 (Tanaka et al. 2013). Then, in the case of the urban grid cells, values of 80% of the nitrogen from 35% of the people were assigned to purification by the centralized WWTP, and other waste from 65% of the people was treated by septic tank system and runoff to the river through soil absorption. In the case of other land use grid cells, we assumed that waste from all people was connected to a septic system having a 5% nitrogen removal ratio. Calculated point-source nitrogen (waste from human and livestock) was assumed to pass through decomposition, absorption and denitrification processes in soil as a non-point source before runoff to the river.

#### 4.2 Nitrogen balance model in soil of non-point sources (diffuse pollution)

To estimate the spatial distribution of nitrogen loading from point and diffuse sources, a variety of methods has been used. Conceptual and physically based models (Arheimer and Brandt, 2000; Billen and Garnier, 2000; Conan et al., 2003; Lee et al., 2006) describe the processes responsible for nitrogen runoff into surface water and leaching into groundwater in large heterogeneous basins. They allow forecasting and a better understanding of the processes. However, even though these facts are well known, few scientific works had been published until recently on water quality in developing countries because available data are normally quite limited in such regions.

As the first step toward our objectives, we first considered conceptual model on mass balance of nitrogen as a tool for quantitative evaluation of nitrogen load distribution. In this study, a conceptual nitrogen balance model was developed by considering three pools in soil, organic N, ammonium N, and nitrate N, as shown in Fig. 7 following the models by Lin et al. (2000) and

### Table 3. Population and nitrogen load from point sources.

| population (person or head) | N loading unit (kg/head/year) | N load (t/year) | (%) |
|---------------------------|-------------------------------|----------------|-----|
| human                     | 9,818,279                     | 3.2            | 31,418 | 61.4 |
| cattle                    | 29,886                        | 73             | 2,182  | 43  |
| pig and goat              | 228,130                       | 14.6           | 3,331  | 6.5  |
| chicken                   | 20,319,807                    | 0.7            | 14,224 | 27.8 |
| Sum                       |                               |                | 51,155 | 100.0 |
Suga et al. (2005). In this study, organic N here is assumed as nitrogen contained in relatively firstly decomposed organic matter which can be obtained by autoclave-extractable nitrogen test.

The budget of each pool is expressed as following equations:

\[
\frac{dN_{\text{org}}}{dt} = PSNL - \text{MinerN} - \text{RunoffN}_{\text{org}}
\]  

\[
\frac{dN_{\text{ammo}}}{dt} = \text{DepoN}_{\text{ammo}} + \text{FertiN} + \text{MinerN} - \text{PupN}_{\text{ammo}}
\]

\[
\frac{dN_{\text{nitra}}}{dt} = \text{DepoN}_{\text{nitra}} + \text{NitriN} - \text{PupN}_{\text{nitra}} - \text{DenitN} - \text{LeachN}_{\text{nitra}} - \text{RunoffN}_{\text{nitra}}
\]

where \(N_{\text{org}}\) is organic nitrogen (kg/ha), \(PSNL\) is input N from point-sources (kg/ha/day), \(\text{MinerN}\) is mineralization rate (kg/ha/day), \(\text{RunoffN}\) is nitrogen loss by surface runoff (kg/ha/day), \(\text{DepoN}_{\text{ammo}}\) is ammonium nitrogen (kg/ha), \(\text{DepoN}_{\text{nitra}}\) is nitrate nitrogen (kg/ha), \(\text{PupN}_{\text{ammo}}\) is plant uptake rate (kg/ha/day), \(\text{NitriN}\) is nitrogen deposition (kg/ha/day), \(\text{DenitN}\) is nitrate nitrogen loss by denitrification (kg/ha/day), and \(\text{LeachN}_{\text{nitra}}\) is nitrate nitrogen loss by leaching (kg/ha/day). In Citarum river basin, livestock manure also used but the amount was not so many because of poor traffic condition. Therefore, we assumed that nitrogen input from manure was not included in \(\text{fertiN}\) but in \(PSNL\) from livestock.

Each flux was calculated according the equations below:

\[
PSNL = \left(\left(1 - \text{Rnrate}\right) \cdot \text{POP}_{H} \cdot \text{UNL}_{H} + \sum \text{POP}_{j} \cdot \text{UNL}_{j}\right) / 365
\]

\[
\text{MinerN} = e_T \cdot \left(1 - e_m\right) \cdot k_{\text{miner}} \cdot N_{\text{org}}
\]

\[
\text{NitriN} = e_T \cdot \left(1 - e_m\right) \cdot k_{\text{nitra}} \cdot N_{\text{ammo}}
\]

\[
\text{DenitN} = e_m \cdot k_{\text{denit}} \cdot N_{\text{nitra}}
\]

\[
\text{DepoN}_{\text{ammo}} = \text{CRAIN}_{\text{ammo}} \cdot R \cdot \frac{100 \times 100}{1000 \times 1000}
\]

\[
\text{DepoN}_{\text{nitra}} = \text{CRAIN}_{\text{nitra}} \cdot R \cdot \frac{100 \times 100}{1000 \times 1000}
\]

\[
\text{PupN}_{\text{ammo}} = \text{PupN} \cdot \frac{N_{\text{ammo}}}{N_{\text{ammo}} + N_{\text{nitra}}}
\]

\[
\text{PupN}_{\text{nitra}} = \text{PupN} \cdot \frac{N_{\text{nitra}}}{N_{\text{ammo}} + N_{\text{nitra}}}
\]

\[
\text{RunoffN}_{\text{org}} = \text{rf}_{\text{org}} \cdot q_{\text{of}} \cdot N_{\text{org}}
\]

\[
\text{RunoffN}_{\text{ammo}} = \text{rf}_{\text{ammo}} \cdot q_{\text{of}} \cdot N_{\text{ammo}}
\]

\[
\text{RunoffN}_{\text{nitra}} = \text{rf}_{\text{nitra}} \cdot q_{\text{of}} \cdot N_{\text{nitra}}
\]

\[
\text{LeachN}_{\text{nitra}} = \text{lf} \cdot q_{\text{b}} \cdot N_{\text{nitra}}
\]

where \(\text{Rnrate}\) is removal rate by the sanitation system, \(\text{POP}_{H}\) is the population of humans (person/ha), \(\text{UNL}_{H}\) is the unit nitrogen loading of humans (kg/person/year), \(\text{POP}_{j}\) is the population of livestock species \(j\) (head/ha), \(\text{UNL}_{j}\) is the unit nitrogen loading of livestock species \(j\) (kg/head/year), \(e_T\) is the temperature modified.

![Nitrogen balance model](image-url)
Table 4. Planted area and fertilizer input of TOP10 Crops in Cianjur Regency.

| Crops            | 1996 (ha) | 1999 (ha) | 2002 (ha) | 2005 (ha) | 2008 (ha) | Average Ratio (%) | N Fertilizer (kg/ha/season) |
|------------------|-----------|-----------|-----------|-----------|-----------|------------------|-----------------------------|
| Paddy            | 107,338   | 116,326   | 97,828    | 114,923   | 109,243   | 49.2             | 140                         |
| Rain-fed rice    | 19,700    | 20,359    | 18,656    | 18,323    | 20,124    | 8.8              | 95                          |
| Vegetables       | 16,673    | 16,098    | 13,935    | 16,911    | 16,269    | 7.2              | 110                         |
| Tea              | 13,897    | 14,608    | 14,217    | 13,499    | 14,608    | 6.4              | 250                         |
| Fruit            | 10,624    | 14,756    | 12,170    | 14,272    | 14,756    | 6.0              | 120                         |
| Corn             | 12,841    | 16,513    | 12,801    | 10,739    | 11,885    | 5.8              | 95                          |
| Groundnut        | 12,440    | 9,361     | 11,252    | 13,096    | 10,967    | 5.1              | 30                          |
| Cassava          | 10,544    | 8,855     | 8,351     | 11,317    | 9,394     | 4.4              | 75                          |
| Maize            | 8,934     | 8,272     | 5,844     | 10,480    | 8,288     | 3.8              | 95                          |
| Coconut          | 7,294     | 7,826     | 7,299     | 7,617     | 7,826     | 3.4              | 150                         |
| Total            | 220,285   | 232,974   | 202,353   | 231,177   | 223,360   | 100              |                             |

Fig. 8. Cropping schedule of rice and upland crops.

The temperature modified parameter, $e_r$, soil moisture modified parameter $e_m$, and denitrification parameter $k_{denit}$ were calculated by following equations (Johnson et al., 1987; Suga et al., 2005), respectively.

\[
e_r = 2^{[\left(\frac{T_a}{20}\right)/10]} \tag{23}
\]

\[
e_m = \frac{Srz}{Srz_{max}} \tag{24}
\]

\[
k_{denit} = 1 - \exp\left(-\frac{0.28T_a}{T_a + \exp(9.93 - 0.312T_a)}\right) \tag{25}
\]

where $T_a$ is air temperature (°C), $Srz$ is water storage in the root zone (m) which is calculated by TOPMODEL, and $Srz_{max}$ is maximum storage in the root zone (m).

In the paddy field of the Citarum River Basin, urea (46% N) was used mostly as the fertilizer. The average amounts of the fertilizer used, learned from conversation with farmers, was 70 kgN/ha at 15 days after transplanting as a basal application and an additional 70 kgN/ha at 30 days after transplanting. Hydrolysis of urea takes from one day to one week depending on temperature. In Indonesia, temperature is high enough and almost stable, so soil enzymes convert urea into ammonium N and CO$_2$ gas very quickly. Therefore, nitrogen from urea was assumed as ammonium N form in this study (Chowdary et al., 2004). The plant uptake rate PupN was observed at the Cihie irrigation district located in the middle stream of the Citarum River (Fig. 1). In 2011 and 2012 harvest season, rice samples were taken from 13 paddies and measured straw and grain yield. And then, nitrogen content in straw and grain were measured by CN coder. The observed value of PupN was 0.44 kgN/ha/day. In the upland area in this region, especially the tea plantation area, more than 300 kgN/ha/season was fertilized (Harashina et al., 2003). However, it is difficult to know which crops were cultivated in each upland grid cell exactly.

Therefore, planted area weighted average fertilizer amount was calculated and applied to all upland cell, based on the historical statistic data of crop planting area in Cianjur Regency (Table 4). Figure 8 shows cultivation schedule of rice paddy and upland crops used in this study.

All the components of nitrogen, which runoff or leach to the river, were accumulated along the river line based on the river flows. In this study, nitrogen removal based on the biological
process along the river network was neglected because it was relatively small compared to nitrogen removal in soil (Skop and Srensen, 1998). However, lentic water bodies (lakes or reservoirs) have the potential to act as important sinks due to their relatively long water residence. Studies on nitrogen removal in large-scale reservoirs are few because of limited water quality data in Citarum basin. Therefore in this study, nitrogen removal model was employed and applied to large scale reservoirs based on the previous researches of N removal in lakes and reservoirs (Alexander et al., 2002; Harrison et al., 2009).

Nitrogen removal ratio can be calculated by following equations;

\[
\text{Remove}_N = 1 - \exp\left(-\frac{Vf}{Hl}\right)
\]

(26)

Where \(Vf\) is the apparent settling velocity for nitrogen by reservoir sediments (m/year), and \(Hl\) is the hydraulic load for a given reservoir (m/year). In this study, \(Vf\) in reservoirs are fitting parameters.

\(Hl\) was calculated as following equation;

\[
\text{Removal}_N = \frac{Vf \times \text{calibrated parameters}}{Hl}
\]

Table 5. Calibrated parameters in this model calculation.

| parameters       | definition                          | value       |
|------------------|-------------------------------------|-------------|
| \(SR_{max}\)     | maximum storage capacity of the root zone (m) | 0.024-0.48  |
| \(m\)            | decay factor of lateral transmissivity (m) | 0.005-0.008 |
| \(To\)           | lateral transmissivity under saturated condition (m²/h) | 8-20        |
| \(Q_{min,Saguling}\) | minimum flow from Saguling dam (m³/s) | 38.5        |
| \(Q_{min,Cirata}\)   | minimum flow from Cirata dam (m³/s) | 50.4        |
| \(C_{Release,Saguling}\) | release coefficient of Saguling dam (1/s) | \(0.39 \times 10^{-6}\) |
| \(C_{Release,Cirata}\) | release coefficient of Cirata dam (1/s) | \(0.31 \times 10^{-6}\) |
| \(Vf_{Saguling}\)  | apparent settling velocity of Saguling dam (m/year) | 38.9        |
| \(Vf_{Cirata}\)    | apparent settling velocity of Cirata dam (m/year) | 61.3        |
| \(k_{min}\)       | mineralization parameter (1/day) | 0.012       |
| \(k_{nitr}\)      | nitrification parameter (1/day) | 0.15        |
| \(r_{f,org}\)     | runoff factor of organic N (1/mm) | 0.0017      |
| \(r_{f,ammo}\)    | runoff factor of ammonium N (1/mm) | 0.0056      |
| \(r_{f,nitra}\)   | runoff factor of nitrate N (1/mm) | 0.0056      |
| \(l\)             | leaching factor N (1/mm) | 0.0068      |

Fig. 9. Comparison of observed and calculated river discharges (1996–2009).
where $Q_{\text{inflow}}$ is annual mean inflow to reservoir (km$^3$/year) and $A_{\text{surface}}$ is surface area of individual reservoir (km$^2$).

5. Results and Discussion

By using the proposed model, water and nitrogen balances in the Citarum Basin were calculated at a resolution of 1 km x 1 km from 1996 to 2009. The first 5 years of data were used for parameter calibration, and the latter 9 years of data were used for validation. Parameters of $S_{\text{szmax}}$, $m$, $T_0$, $k_{\text{min}}$, $k_{\text{am}}$, $r_{\text{forg}}$, $r_{\text{min}}$, $r_{\text{am}}$, $r_f$ were calibrated by try and error method in order to maximize the Nash-Sutcliffe efficiency (NSE) of discharge and nitrogen load at Nanjung station. Then, $Q_{\text{bais}}, C_{\text{release}}, V_f$ values were calibrated to maximize the NSE value of discharge and nitrogen load at Cirata and Jatiluhur reservoir. In this model, parameters related to nitrogen transformation, runoff, and leaching were set as constants in the whole basin. Therefore, the fate of nitrogen was controlled by the temperature modified parameter $e_T$ and the soil moisture modified parameter $e_m$. Before the numerical simulation from 1996 to 2009 was begun, a pre-analysis was conducted by using the data from 2009 to 1996 (backward) to calculate the initial condition of each nitrogen pool in grid cell. For the inverse analysis, climate data and cropping schedule were re-ordered, although population data was set as the constant value of 1996. The calibrated parameters are listed in Table 5.

$S_{\text{szmax}}$ is a distributed parameter based on land use and $m$, and $T_0$ is a distributed parameter based on soil clay content which is strongly related with soil permeability. The calculated river discharge was in good agreement with the amounts observed at the Nanjung and the Cirata stations from 1996 to 2009 (Fig. 9). At the Nanjung station, NSE were 0.59 and 0.55 in the calibration and validation periods respectively. Model performance can be evaluated as “satisfactory”, if NSE > 0.50 (Moriasi et al., 2007). At the Cirata station, the NSE were 0.62 and 0.57 in the calibration and validation periods respectively. Figure 10 shows calculated versus observed water storage at Cirata reservoir from 1996 to 2009. The NSE were 0.60 and 0.53 in the calibration and validation periods respectively even though a simple dam operation model was used. However in 2004 and 2007, 2009 estimated error became relatively large, because inflow discharge to Cirata reservoir was overestimated in 2004 and underestimated in 2007 and 2009 (Fig. 9).

The observed and calculated daily nitrogen load change at the Nanjung station is shown in Fig. 11. Estimated Nash-Sutcliffe efficiency (NSE) in calibration and verification period were 0.53 and 0.59, respectively. According to the literature reviews by Chowdary et al. (2004), the value of mineralization rate $k_{\text{min}}$ ranged in 0.0075-0.02 (1/day) and nitrification rate $k_{\text{am}}$ ranged in 0.02-0.25 (1/day). In this study, the optimized value of $k_{\text{min}}$ (≈ 0.012) and $k_{\text{am}}$ (≈ 0.15) were within the literature range. The water quality data in the Citarum River Basin were measured only once or twice both in the wet season and in the dry season until 2007, and after 2007 it was improved to almost every two month. By the frequent observation, relatively high discharge data can be detected and such data is quite beneficial for model calibration.

Figure 12 shows observed and calculated nitrogen load inflow at Saguling, Cirata and Jatiluhur reservoirs. For Cirata and Jatiluhur reservoir, only 3 years water quality data was available. NSE were 0.57, 0.44, and 0.50 at Saguling, Cirata and Jatiluhur reservoirs, respectively. The Cirata reservoir has a large catchment area, which had no water regulation facility, except the catchment area of the Saguling reservoir, therefore river runoff also changed in wide range. However, in current situation, there was no available calibration data for this sub-basin. Probably that was one reason that NSE at the Cirata reservoir presented low performance.

In this study, simple nitrogen removal model in lentic water was employed. Estimated value of nitrogen removal ratio in Saguling and Cirata reservoir were 0.52 and 0.57 respectively, and both reservoirs has significant function to mitigate the extreme nitrogen accumulation in the downstream of Citarum river. According to the literature review by Harrison et al. (2009), average...
N removal ratio in 18 tropical reservoirs ranged 0.0004-0.685, and the value relatively high in large scale reservoir. Both Cirata and Saguling have more than 500 million m$^3$ capacity, so removal ratio became relatively high value. Optimized $V_f$ value of the apparent settling velocity for N was larger in Cirata reservoir (61.3 m/year) than Saguling (38.9 m/year). The reservoirs having more than 25 m/year $V_f$ value are classified as sedimentation dominant reservoir (not denitrification dominant reservoir) which have more potential of eutrophication risk (Alexander et al., 2002). The estimated average annual nitrogen load was 6,222 t/year at the Saguling, 7,257 t/year at the Cirata, and 4,260 t/year at the Jatiluhur reservoir. Hart et al. (2002) estimated nitrogen inflow to the Saguling reservoir as 6,140 t/year and annual N removal ratio as 0.55 from their monitoring data during 1990–1995. Therefore, the value simulated in this study seems a reasonable compared with their estimation.

Figure 13 shows estimated spatial distribution of annual nitrogen loading from each grid cell to the river in Citarum river basin. Nitrogen load per unit area widely ranged from 8.1 kg/ha/year to 156.3 kg/ha/year. Especially, nitrogen load from central Bandung city was quite high because of high population density. Ushijima et al. (2006) reported extreme high concentration of total nitrogen, total phosphorous and COD by the direct measurement of drainage canal water. However nitrogen load from urban area occupied only 14.1% in total, whereas 34.6% from paddy, 36.3% from upland and 14.2% from forest area. To make clear the characteristics of nitrogen load from different land use, the histograms of nitrogen load from each land use were evaluated (shown in Fig. 14). In urban grid cell, nitrogen load ranged very widely compare to other land use, however average nitrogen load was 35.4 kg/ha/year, and it was not so larger than that of paddy (33.3 kg/ha/year) and upland (41.1 kg/ha/year). On the other hand, nitrogen load in forest was relatively small (13.3 kg/ha/year). This result shows that land use change from paddies or upland fields to urban area may not lead nitrogen load increase, however land use change from forest area (deforestation) has significant potential to accelerate the water quality degradation risk in the downstream. Estimated nitrogen load from paddy was relatively larger compare to literature value 20.6 kg/ha /year which was measured several paddies in Japan (Haruta et al., 2015).
reason was that farmers can cultivate paddy 2.1 time per year in average in Citarum River Basin, and annual precipitation also larger compare to that of Japan which leads much amount of drainage water. Another reason was that estimated nitrogen load from paddy included nitrogen input from point-sources.

6. Conclusion

In this study, conceptual nitrogen balance model combined with TOPMODEL was developed and applied Citarum River Basin, West Java as the quantitative evaluation tool of the spatial distribution of nitrogen loading from different land use. Nash-Sutcliffe efficiency both in river discharge and nitrogen load at Nanjung station were more than 0.5 which model performance can be evaluated as “satisfactory”. The estimated average annual nitrogen load at Saguling reservoir was 6,222 t/year and estimated nitrogen removal ratio was 0.52, which were relatively close value compare to the previous study, whereas nitrogen inflow to Cirata reservoir expressed less accuracy. By using the proposed model, spatial distribution of annual nitrogen load was estimated and histograms of nitrogen load from each land use was evaluated.
a result, nitrogen load from central Bandung city was quite large, however nitrogen load from urban area contributed only 14.1% in total. On the other hand paddy and upland contributed 34.6% and 36.3% respectively.

To improve the model accuracy, further research is needed both in field observation and model development. In Citarum river basin, long-term observed water quality data is limited, however even in short-term observation, basin wide monitoring data in tributary level may be helpful for more accurate parameter calibration. In this study, we employed many assumptions to simplify the nitrogen balance model. For example, we neglected N uptake in forest, assuming that most of forest are mature with no net accumulation of biomass. This would be changed for well-managed, semi-natural or disturbed natural forest where uptake of N occur. Because of sparsity of data, we ignored the spatial and temporal heterogeneity in fertilizer management within the basin (e.g. difference of N application rate and timing of application). These problems may cause errors in the calculation of N transformation processes. Despite all the uncertainties, our results provide a first insight in the magnitude and spatial distribution of nitrogen loading in Citarum River Basin, and this kind of model can be used in the impact assessment of different management strategies for sanitation systems or farming practices.

Acknowledgement

This research was supported by the Environment Research and Technology Development Fund (E-1104: Development and Practice of Advanced Basin Model in Asia) and the Japan Society for the Promotion of Science (JSPS) Grant-in-Aid for Scientific Research (KAKENHI) no. 15H05254 and no. 16K15002.

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