“Assessing payment for ecosystem services to improve lake water quality using the InVEST model”

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ASSESSING PAYMENT FOR ECOSYSTEM SERVICES TO IMPROVE LAKE WATER QUALITY USING THE INVEST MODEL

Abstract

Payment for ecosystem services is a conservation strategy designed to offer farmers financial incentives for managing land to provide ecological benefits without disturbing livelihoods. However, the distribution of spatial financial feasibility is challenging when implementing this strategy on watershed scale. This study aimed to develop payment for ecosystem services model to improve quality in lake water catchment. The model estimated incentive values based on the costs of farmers' losses, water yields, and pollution loads. The potential loss was calculated by determining the income of farmers in lake water catchment spent on land conversion from intensive agriculture to agroforestry. Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) modeling tool was used to calculate water yield and pollution load. The model was tested with case study approach at Lake Rawa Pening in Indonesia, consisting of nine sub-basins and 75 village administrations. The results showed that the reference compensation for farmers was 1,255.97 USD/ha/year. Considering the spatial distribution of water yields, the incentive for each village varied widely from 891.54 USD/ha/year to 1,557.06 USD/ha/year, even within the same sub-basin. Ten villages had an incentive above 1,450.00 USD/ha/year. However, considering the water pollution load, 26 villages had an incentive above 1,450.00 USD/ha/year with a maximum of 2,024.17 USD/ha/year. Therefore, village boundary should be an analysis unit for determining spatial incentive feasibility rather than a sub-basin boundary. Moreover, the level of water pollution load can become an additional variable to justify the amount of incentives received by farmers.

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INTRODUCTION

Payment for Ecosystem Services (PES) is an environmental economic instrument designed to incentivize land users for engaging in environmentally friendly behavior, particularly agricultural land management. PES schemes use the principle that users or beneficiaries should compensate those who provide ecosystem services, such as water purification or carbon sequestration. This concept requires clearly defining the environmental service supply, understanding the influence range of services, identifying stakeholders, and establishing the appropriate incentive.

PES approach has been widely studied and implemented in various contexts globally, reflecting the adaptability and potential for addressing environmental challenges through economic mechanisms. However, challenges to implementation on watershed scale still exist, including addressing perceived unfairness, overcoming financial pressures, navigating the complexity of establishing payment schemes, balancing economic growth with environmental conservation, as well as ensuring social acceptability and spatial financial feasibility. Addressing these challenges is crucial for the successful implementation and sustainability of PES initiatives.

1. LITERATURE REVIEW AND HYPOTHESES

Assessing ecosystem services entails evaluating the benefits offered to humans. Assessment process typically includes identifying and quantifying ecosystem services, understanding the value to human societies, and determining sustainable management. Mapping and Assessment of Ecosystem Services (MAES) provides a comprehensive approach to understanding the capacity to provide many services essential for human well-being and environmental sustainability (Sieber et al., 2022). Numerous ecosystem services are beneficial to humans, such as providing water and food (Ioannidou et al., 2022), controlling flood and erosion (Udawatta, 2021), regulating climate (Pandey & Ghosh, 2023), serving tourism (Rosehan et al., 2020), and presenting educational facilities (Banela et al., 2024). However, the main challenge to maintenance is balancing human development and environmental conservation, such as managing agricultural land to provide profits without damaging the environment (Kremen, 2020).

Human activities could affect sustainable ecosystem services; for example, agriculture negatively influences water quality (Anderson et al., 2021), biodiversity (Sharma et al., 2018), carbon stocks, and soil retention (Wang et al., 2022). Consequently, the growth of agricultural land, specifically intensive agriculture, is often considered an enemy of sustainable water ecosystem services due to the production of pollutants, including fertilizer and chemical inputs (Rashmi et al., 2020), as well as the tendency to reduce water supply through irrigation (Munyaradzi et al., 2022). Increasing agricultural land is urgently needed to meet the rising population growth estimated to reach 9.7 billion globally by 2050 (UN, n.d.).

Economic valuation of ecosystem services in lake water catchment (LWC) is one of the efforts to integrate water and food demands. LWC has an important role in maintaining the quantity and quality of lake water because it functions as a natural basin to collect rainfall and channel into lake. However, the system tends to be vulnerable due to intensive agriculture, for example, farming cereal and peas influences spatial and seasonal variability in lake water balance (Tigabu et al., 2019). Additionally, the use of pesticides on agricultural land in the upper basin caused water pollution (Jayawardana et al., 2023). Moreover, changes in one ecosystem service affect others, for example, efforts to increase the supply of clean water could reduce the capacity for flood control and water purification (Wang & Xu, 2023). These results showed that the nexus of human activities and water ecosystem services at watershed scale was still challenging; hence, trade-offs between ecosystem services must be managed wisely.

Several previous studies have discussed the trade-off between the provision of ecosystem services and the impact of human activities, where compensation was given to parties willing to spearhead improvement and maintenance, in the form of PES. The field of PES investigation includes reducing agricultural pollution (Zhu & Chen, 2022), enhancing forest ecosystem services (Tesfaw et al., 2022), conserving endemic species (Talukdar et al., 2022), and restoring grassland (Tang et al., 2022).

The PES scheme could be an alternative environmental economic instrument for attracting people in LWC to participate in efforts to reduce pollution load. The society uses the LWC as a space for crop cultivation, negatively impacting lake water quality (Jayawardana et al., 2023). The conflicts between agriculture and the provision of water ecosystem services upstream can not be avoided, but sustainable land management might minimize these conflicts (Zhao et al., 2023). Accordingly, LWC might be used for cultivating agriculture and providing water ecosystem services when PES model recognizes agricultural activities as providing food and controlling pollution loads entering lake waters. Agriculture design should be agroforestry system due to the positive correlation with improving water quality (Ye et al., 2023). Moreover, increasing forest cover can improve water quality due to the function as pollutant filters, reduce erosion, and maintain the hydrological cycle (Qiu et al., 2023). For example, increasing forest cover by 1% of the basin can reduce water turbidity by 3%, while raising built-up land by 1% increase turbidity by 3% (Warziniack et al., 2017).

Converting intensive agriculture into agroforestry requires conversion costs and compensation due to the loss of farmers' income (Paudel et al., 2022;

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Wondimenh, 2023). Consequently, compensation is needed for sacrificing land to support conservation measures. Previous studies showed that people tended to reject compensation as the value did not match the losses incurred (Nuñez Godoy & Pienaar, 2023). PES schemes that do not consider social justice, such as the distribution of benefits and risks and community needs that could lead to refusal in supporting conservation programs (Lliso et al., 2021). To overcome this gap, there is an urgent need to assess the compensation scheme that considers economic losses and the risk of land conversion. For example, the land with the highest water yield and pollution load should have more compensation than other places.

Several studies have discussed water-food nexus in agricultural land (Luo et al., 2023; Miralles-Wilhelm, 2023; Mwendera et al., 2023). The contribution of environmental factors to this relationship has become significant concern, such as climate change (Khamidov et al., 2022), soil attributes (Sellami & Terribile, 2023), and water availability (Li et al., 2023). Pissarra et al. (2021) used soil characteristics and water production parameters to determine the PES value represented in land vulnerability. Other studies selected land vulnerability, human pressure, and land use suitability to assess the priority landscape interventions (de Mendonça et al., 2023; Sahu et al., 2024). However, climate change factors have not been discussed to calculate the PES value. Previous studies only selected the data of observed river water discharge and neglected water cycle, such as precipitation, evapotranspiration, and the ability of plants to store water in calculating water ecosystem services in the basin (Pissarra et al., 2021). Therefore, water yields can only be presented at the level of hydrological boundaries (sub-basin) but not administrative boundaries (villages). Chen et al. (2022) estimated the value of ecosystem services at the forest level, making implementation at the administrative level difficult, specifically for forests located in more than one administrative area. Considering water yields in one catchment differ between upstream and downstream, assessing PES values based on hydrological boundaries might generate a biased value that does not reflect the actual value and difficult to apply at the administrative scale. Furthermore, climate change parameters, such as precipitation and evapotranspiration, should be included in calculating ecosystem service value. To close this knowledge gap, this study aims to create PES model to improve lake water quality (MPES), which can calculate PES values by considering water ecosystem services and pollution loads at village administrative scale. Therefore, the proposed hypotheses are:

H1: The PES value for each village in the same sub-basin is different.

H2: The level of water pollution loads could increase the PES value.

2. METHODS

The study area was Lake Rawa Pening, located in Central Java province, Indonesia, with a total basin area of 27,307.25 hectares (ha). This area consists of 1,994.93 ha of lake water and 25,312.32 ha of catchment (Figure 1). A total of nine main rivers feed lake, namely Galeh, Kedungringin, Legi, Panjang, Parat, Rengas, Ringis, Sraten, and Torong. On the other hand, only one outlet exists, namely the River Tuntang.

Rawa Pening is one of the 15 National Priority Lakes for the central government due to the important roles and functions as agricultural irrigation, the source of drinking water, hydropower plants, flood control, and tourism destinations. However, anthropogenic activities in lake basin caused water pollution. Data from the Environment and Forestry Department of Central Java Province (2023) showed that Rawa Pening was lightly polluted in 2018–2022. This pollution emanated from various sources, including agricultural, livestock, domestic, and aquaculture waste. Land cover in the basin was dominated by agricultural land with a total area of 16,028.41 ha (58.76%), consisting of dryland (12.03%), mixed dryland (33.20%), and rice fields (13.53%). The land used for settlement was estimated at 6,617.91 ha (24.26%), while the forest cover (secondary and plantation forest) was relatively small, with an area of 1,561.66 ha (5.72%).

There are four steps to set up the MPES model (Figure 2):

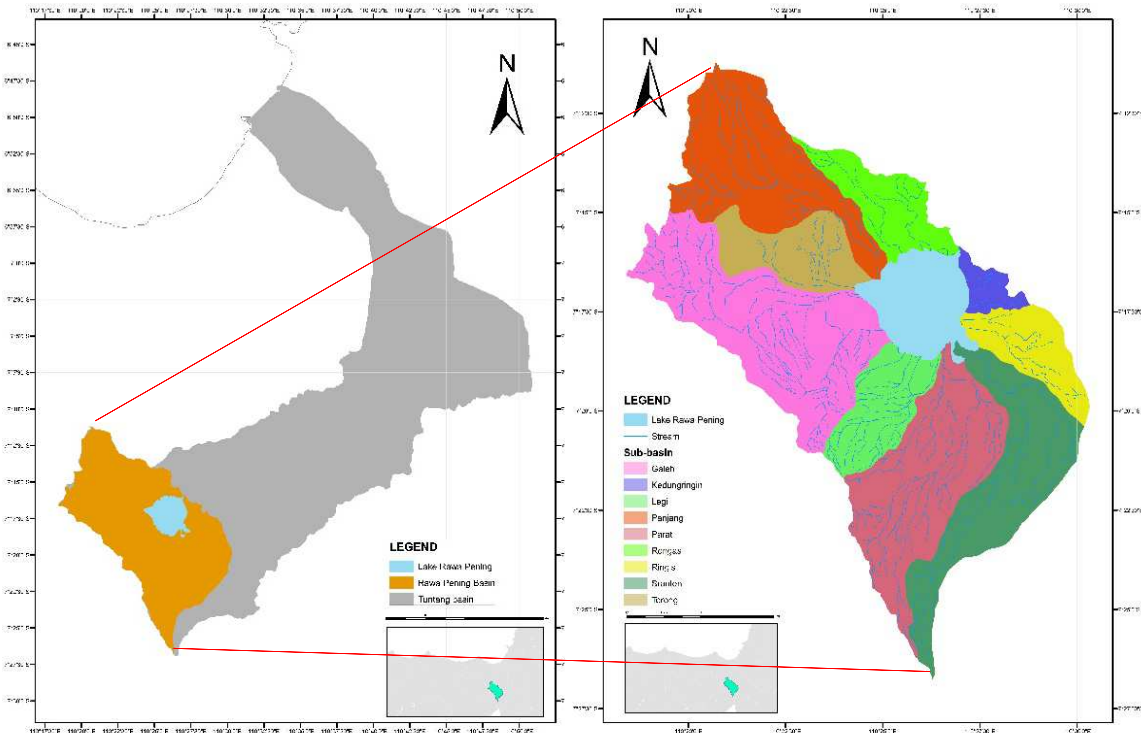

Figure 1. Lake Rawa Pening basin

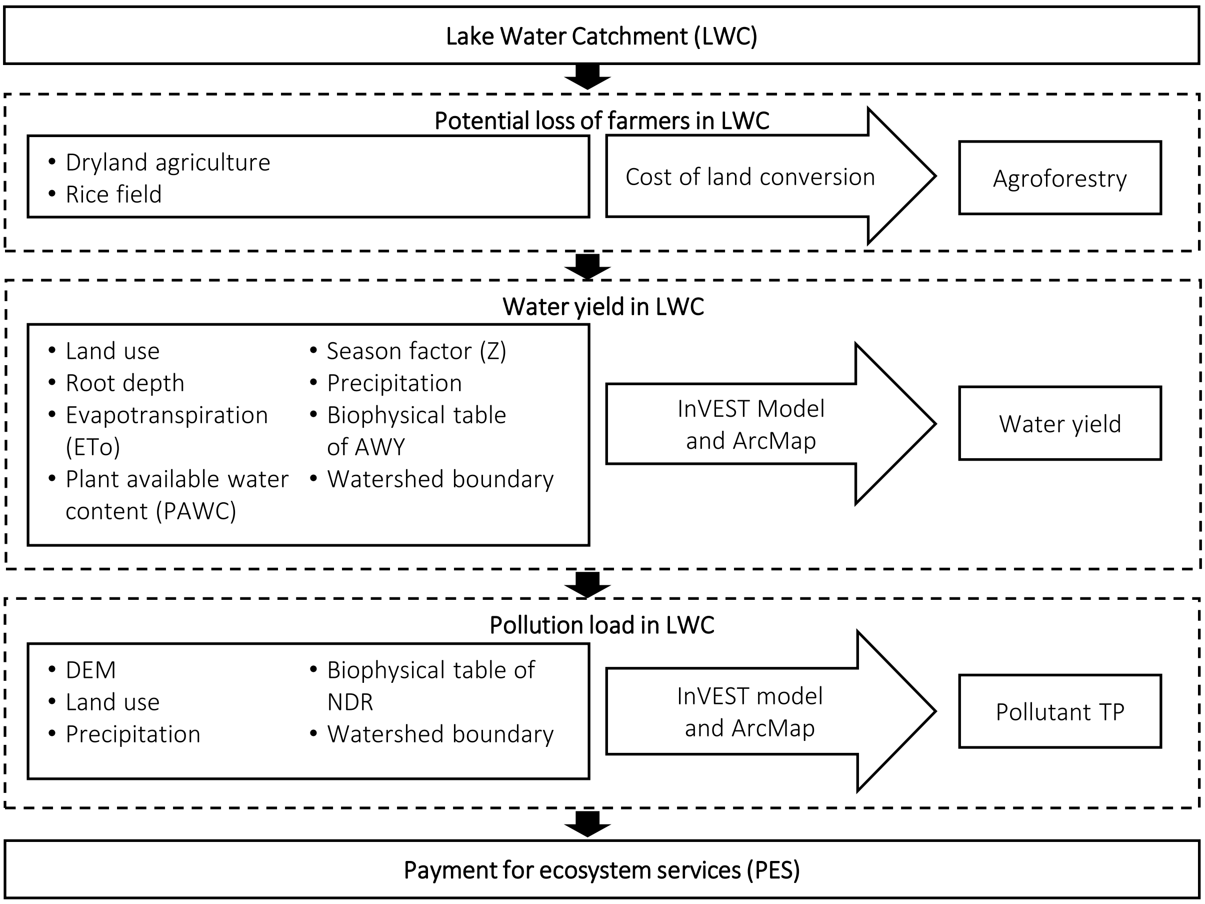

Figure 2. Workflow of MPES model

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(1) calculate the average income of farmers in the LWC, represented by the value of agricultural production per hectare for one year;

(2) calculate the potential water yield in the LWC;

(3) assess the potential pollution load in the LWC using total phosphate (TP) parameters; and

(4) estimate the PES value by considering farmer's loss, water yield, and pollution load.

This model selects statistical analysis to analyze agricultural production, while the InVEST 3.14.1 software was used to assess water yield and pollution load. The output was presented using ArchMap 10.8 software. The unit analysis of the result was village administration boundary.

2.1. Potential loss of farmers

To estimate the potential loss of farmers for implementing agroforestry, a proxy of the average economic value of agricultural production per hectare in the LWC for one year was used. Data from the Bureau of Statistics of Semarang Regency (2022a, 2022b, 2022c, 2022d, 2023) were selected as a source of information on agriculture in Lake Rawa Pening, with the products being vegetable and food crops. The total economic value of agricultural production in the LWC for a year was divided by the size of used land to obtain the average value of output for one year. The average economic value represents the revenue of farmers per hectare per year. The revenue from agriculture was selected as a reference source to obtain the potential loss of farmers. According to Asfawi et al. (2021), the cost of intensive farming was 42% of the revenue and the net income of farmers was 58%. Pissarra et al. (2021) considered 50% of farmers' net income to calculate the loss of farmers. Therefore, in this model, the potential loss of farmers was 0.29 of revenue (trade-off coefficient). Calculations to obtain the potential loss of farmers are as follows:

$$Lc = Pc \cdot 0.29, \tag{1}$$

$$Pc = \frac{NE}{L}, \tag{2}$$

$$NE = \sum_{i=1}^{n} Ti \cdot Hi, \tag{3}$$

where: *Lc*: Potential loss of farmers per hectare per year (USD/ha/year); *Pc*: Average revenue of farmers per hectare per year (USD/ha/year); *NE*: Total revenue of farmer for one year (USD/year);

Table 1. Input parameters for the InVEST model

Data	Format	Sources	Description	Model
Basin boundary	SHP	Indonesia Ministry of Environment and Forestry data (as of 2022)	Area of study based on hydrological boundary	AWY, NDR
Administrative boundary	SHP	Indonesia Ministry of Internal Affairs data (as of 2022)	Area of study based on administrative village	AWY, NDR
Land use in 2022	Raster	Indonesia Ministry of Environment and Forestry data (as of 2022)	Land use in the area of study	AWY, NDR
Monthly temperature (°C)	Numeric	NASA data (as of 2022)	Raw data to calculate annual evapotranspiration. The reference evapotranspiration is presented in Table A1, Appendix A	AWY
Annual evapotranspiration (ETo)	Raster	Formula 4	Using the method of Thornthwaite-Mather with input data of monthly temperature	AWY
Plant Available Water Content (PAWC)	Raster	Local Management Unit of Pemali Jratun data (as of 2022)	PAWC is a water content in the plants, represented by the amount of water used in the soil. Description of PAWC value is presented in Table B1, Appendix B	AWY
Root depth	Raster	Li et al. (2022b)	Root depth is a soil characteristic that functions as water storage. In that soil, there is 90% of root biomass. The depth value is influenced by soil type and land cover	AWY

Table 1 (cont.). Input parameters for the InVEST model

Data	Format	Sources	Description	Model
Z parameter	Coefficient	Ningrum et al. (2022)	*Z* parameter describes the relationship between evapotranspiration and precipitation. Usually, the *Z* parameter used for tropical areas is 4	AWY
Biophysical table for AWY	CSV	Li et al. (2022b)	The table contains land use class information. In each land use class, there is a root depth (mm), a plant coefficient (Kc), and the presence or absence of vegetation cover in a land cover class (LULC-veg). Biophysical table for AWY is presented in Table D1, Appendix D	AWY
Annual precipitation	Raster	CHRS data (as of 2022) and Kopeng Klimatologi Station data (as of 2022)	It selects data from 6 climatology monitoring stations. 1 from Kopeng Klimatologi Station and 5 from CHRS. The data was processed with the help of ArcMap (v10.8) to perform interpolation, projection, resample, mask by extraction, and presentation of spatial distribution maps in the Rawa Pening basin. The average annual precipitation is presented in Table C1, Appendix C	AWY, NDR
DEM	Raster	Earth Explorer website data	Downloaded from the USGS website, then processed with the help of ArcMap to obtain river flow patterns in the watershed. There are nine sub-basins in the Rawa Pening basin	NDR
Flow accumulation threshold (FAT)	Coefficient	Sharp et al. (2016)	FAT indicates that when the water flow path stops, the retention capacity will stop so that the remaining nutrients will mix with river water. The FAT value used is 1000 pixels	NDR
Borselli K	Coefficient	Sharp et al. (2016)	The default value used is 2	NDR
Biophysical table for NDR	CSV	Table E1, Appendix E	The table contains land use class information. Each land use class has a pollution load value in units of kg/ha/year. This value reflects the estimated amount of pollutants produced by each land use	NDR

L: Total area of agricultural land used for agricultural cultivation (ha); *Ti*: Total agricultural output per year on commodity *i* (kg); *Hi:* Average price of agricultural products for commodity *i* (USD).

2.2. Water yields

The InVEST model for annual water yield (AWY) was used to estimate water yields in the LWC. This model is based on water balance method and assumption of Budyko (1974) for water and heat balance. The primary principle is that the higher water production, the greater water supply for lake waters. The input data for water yield are land use map, root depth, evapotranspiration, plant available water content (PAWC), precipitation, *Z* parameter (Zhang coefficient), watershed boundary, and biophysical table. Each data item is explained in Table 1. The input data were in raster format with a resolution of 30 meters, presented in Figure A1, Appendix A. According to Sharp et al. (2016), the calculations for estimating annual water yield are as follows:

$$Y(x)=\left(1-\frac{AET(x)}{p(x)}\right)p(x), \quad (4)$$

$$\frac{AET(x)}{p(x)}=\frac{1+w(x)+R(x)}{1+w(x)\cdot R(x)+1/R(x)}, \quad (5)$$

$$w(x)=Z\cdot\frac{PAWC(x)}{p(x)}, \quad (6)$$

$$R(x)=\frac{k(x)\cdot ETo}{p(x)}, \quad (7)$$

where *Y*(*x*): Average annual water yield (mm); *AET*(*X*): Average annual evapotranspiration (mm); *P*(*x*): Average annual rainfall (mm); *R*(*x*): Budyko drying coefficient; *PAWC*(x): Water content in plants, which by the amount of water in the soil used by plants (mm); *Z*: Zhang coefficient was obtained from calculations based on the Budyko curve; *W*(*x*): Non-physical parameters; *ETo*: Annual evapotranspiration.

Model result was compared with observed data of water discharge downstream feeding lake for validation. Based on the number of the main rivers feeding lake, nine monitoring stations of water discharge were selected. The observed data in 2022 were collected for the dry season (July 12, 2022) and the rainy season (November 10, 2022) obtained from the Environment and Forestry Department of Central Java Province. The model result was in units of m3/year, while the observed data were in units of m3/second. For comparative consistency, observed data were converted into m3/year. The average percentage of bias between

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model result and observed data was calculated based on the method of Moriasi et al. (2007):

$$\%bias = \frac{(model\,result - observed\,data)}{observed\,data} \cdot 100. \quad (8)$$

The value of water ecosystem services was assessed based on water yield at the scale of village boundary (ES_AWY). In other words, the ES_AWY value is the proportion of water yield per village (AWY) to the average water production per village in the LWC ($\overline{AWY}$) as presented in formula (9). This formula was adopted from Pissarra et al. (2021) with ES_AWY = 1 denoting the average value of water ecosystem services for all villages. When water ecosystem services produced by village were more than the average, the ES_AWY value ≥ 1, suggesting village produced more water than others. Meanwhile, when the value of water ecosystem services was below the average, the ES_AWY value ≤ 1, implying less water was produced.

$$ES\_AWY = \frac{AWY}{\overline{AWY}}. \quad (9)$$

2.3. Water pollution load

According to the Indonesia Minister of Environmental Regulation Number 28 of 2009, the total phosphate (TP) concentration in water could determine lake's trophic status. Previous studies also reported that the TP parameter was an indicator of eutrophication (Wu et al., 2021). The level of water pollution was represented by the potential TP pollutant (TP nutrient export) in the basin. In this study, the InVEST model for nutrient delivery ratio (NDR) was selected to calculate the TP pollutant. This model uses a mass balance approach that describes the amount of pollutants in the basin but does not represent the nutrient cycle in detail. It represents the amount of nutrient concentration in each land pixel for a year, influenced by land use, runoff, and pollution load coefficient in each land use (Sharp et al., 2016). The equation for calculating TP pollutant is presented in formula (10). The data needed for this model included watershed boundary, land use map, digital elevation model (DEM), precipitation (nutrient runoff proxy), flow accumulation threshold, Borsellu K, and biophysical table, as shown in Table 1.

$$Xexpton = \sum Xexpi, \quad (10)$$

where *Xexpton*: Total TP pollutant in LWC (kg/year); *Xexpi*: The amount of TP pollutant from each land pixel (kg/year).

The result was compared to observed water quality data to validate the InVEST model. A total of nine monitoring stations were used based on the number of main rivers feeding lake. The observed data were obtained in 2022 during the dry season (July 12, 2022) and the rainy season (November 10, 2022) from the Environment and Forestry Department of Central Java Province. The result was in units of kg/year, while the observed data was in units of mg/liter. For comparative consistency, observed data were converted into kg/year. The average percentage of bias between model result and observed data was calculated based on the method of Moriasi et al. (2007) as presented in formula (8).

The level of pollution load was calculated based on the average TP pollutant in every village (TC). The value of TC was classified into four classes, namely lightly (class 1), moderately (class 2), heavily (class 3), and extremely polluted (class 4) with a TP value < 0.0100 kg/ha/year, 0.0100-0.0119 kg/ha/year, 0.0120-0.0139 kg/ha/year, and > 0.0139 respectively. The TC value reflects the impact (increase) of land conversion costs, contributing to pollution load. In this study, the increase amounted to 1% (class 1/no increase), 10%, 20%, and 30% for classes 2, 3, and 4 respectively.

2.4. PES value

PES value is a function of farmers' income loss, water ecosystem services, and water pollution load. The loss of farmers' income (Lc) was calculated based on the revenue of agriculture in the LWC times the tradeoff coefficient (factor X = 0.29). Water ecosystem services (ES_AWY) were calculated based on the proportion of water yield per village (AWY) to the average water yield per village in the LWC ($\overline{AWY}$). Meanwhile, water pollution load (TC) level was calculated based on the increase in land conversion costs due to TP pollutants in land use. The calculation of PES to improve lake water quality (USD/ha/year) is presented as:

$$PES = (Lc \cdot factor\ X) \cdot ES\_AWY \cdot TC. \quad (11)$$

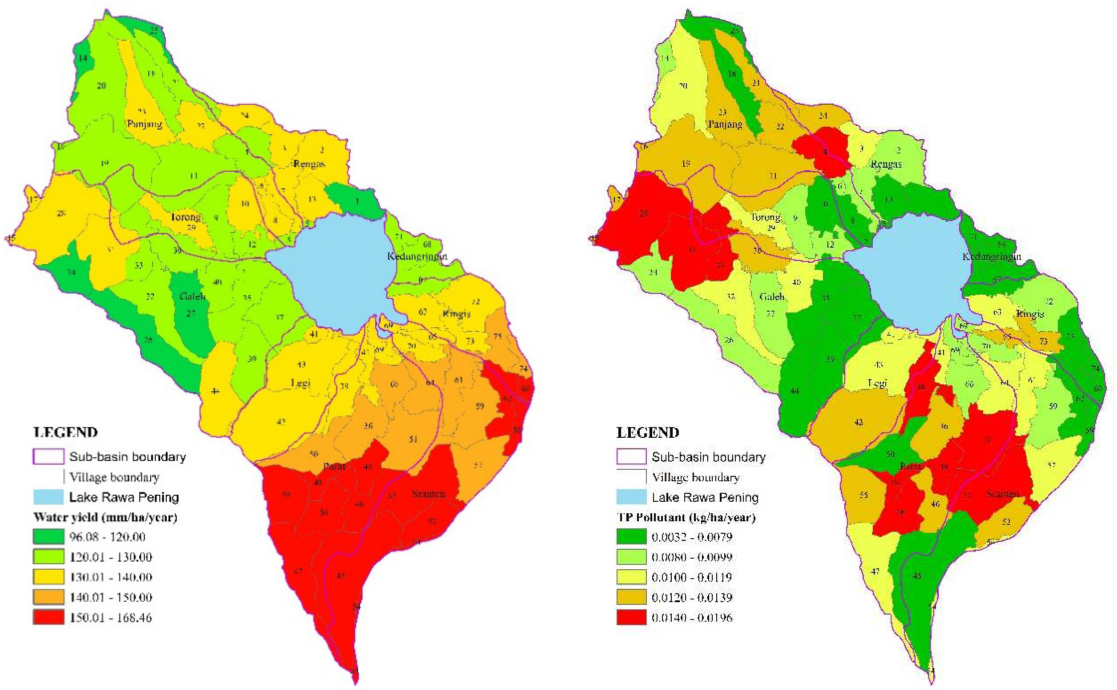
3. RESULTS

Based on the calculated economic value of 14 commodities cultivated in the LWC of Rawa Pening, the average revenue of farmers was 4,329.97 USD/ha/year (Table F1, Appendix F). Considering the cost of cultivation and land conversion, the tradeoff coefficient was 0.29. Therefore, the average potential loss of farmers for implementing agroforestry was 1,255.69 USD/ha/year. This value served as the basic reference for calculating the PES value.

The InVEST model result was the estimated water yield (AWY) (Table G2, Appendix G) and validation was carried out by comparing the results with the observed water yield (Table G1, Appendix G). The bias percentage in the Ringis, Ringas, and Legi sub-basin was significantly large, with values of 26.22%, 23.62%, and 17.44%, respectively. This was due to the relatively small size of the sub-basins, affecting water flow variation between the rainy and dry seasons. The smallest bias percentage was found in the sub-basins of Panjang, Torong, and Galeh, with the value of 0.68%, 1.10%, and 1.32%, respectively. The estimated water yield was generally greater than the observed in all sub-basins, with a bias percentage of 5.63% (Table G3, Appendix G); hence, the result could be used to establish the MPES model.

Based on the results, the amount of estimated TP (Table H2, Appendix H) is lower than the observed in all sub-basins (Table H1, Appendix H) because the input data to estimate TP pollutants were only from non-point sources, such as agriculture and urban land. This calculation did not consider point sources, such as cage animal husbandry and industry. Consequently, the bias percentage of estimated TP was significantly large, reaching 44.26% (Table H3, Appendix H). This result is very logical despite the large bias percentage; hence, the estimated TP would be used to calculate the PES value.

The spatial distribution of AWY within each village in LWC of Rawa Pening is presented in Figure 3a. Based on the results, most villages in the sub-basin of Parat and Sraten tended to have high AWY (red color) with a value of more than 150 mm/ha/year, specifically upstream due to the



a. Annual water yield (AWY)   b. TP pollutants

Figure 3. Spatial distribution of the result of the InVEST model

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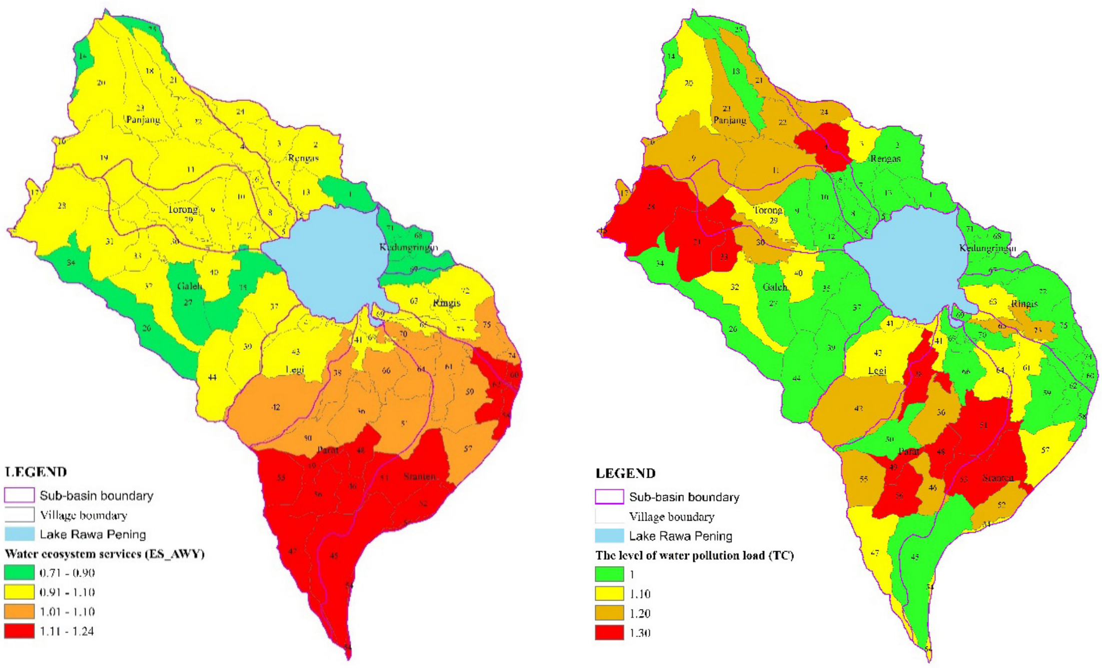
high precipitation. In contrast, the lowest AWY was found within villages in the sub-basin of Galeh, Panjang, and Rengas, with a value of less than 120 mm/ha/year. AWY value in every village varied even within the same sub-basin but the average was 135.66 mm/ha/year. The highest was found in Wates village (56), with an AWY of 168.46 mm/ha/year, while the lowest was in Sidomukti village (25), with 96.08 mm/ha/year. This result shows significant differences in AWY within the same catchment. A total of 10 villages had the largest AWY with a value above 155 mm/ha/year (Figure 3a in red).

Based on Figure 3b, the spatial distribution of TP pollutants in the LWC was relatively diverse with the average TP in each village of 0.0101 kg/ha/year. Furthermore, villages in the same sub-basin had a variety of pollution loads. For example, in the Parat sub-basin, some villages had high TP pollutants (Figure 5b, number 56) while others had low TP pollutants (Figure 5b, number 50). The largest TP pollutant was in Ngrawan village (49), at 0.196 kg/ha/year, while the lowest was in Salatiga (74) and Kalicacing village (60), with a TP of 0.0032 kg/ha/year. The different TP pollutants in every village may be attributed to land use, elevation, and runoff.

The ES_AWY in LWC, reflecting village's potential to supply lake water was calculated according to formula (9). The highest value was found in Wates village (56) at 1.24, while the lowest was in Sidomukti village (25), at 0.71. The spatial distribution of ES_AWY values was quite diverse, as presented in Figure 4a. The TC reflects the impact of land conversion costs contributing to pollution load. Based on Figure 4b, the most extreme TC values were found in 10 villages illustrated in red. These villages had higher precipitation with lower evapotranspiration due to the highlands.

The PES value is a function of water ecosystem services per village (ES_AWY) on the potential loss of farmers' income (Lc) due to land conversion. As previously mentioned, farmers' revenue in the LWC amounted to 4,329.97 USD/ha/year, and the trade-off coefficient was 0.29; hence, the reference compensation value for farmers was 1,255.69 USD/ha/year. Considering the spatial distribution



a. Water ecosystem services (ES_AWY) b. The level of water pollution load (TC)

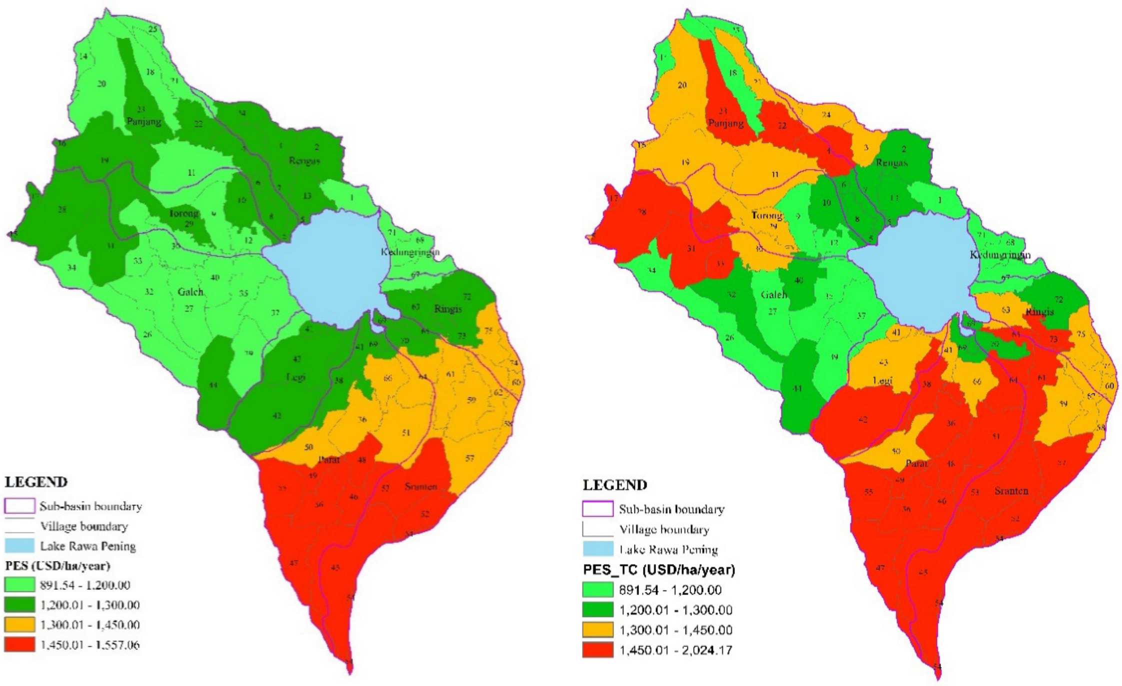
Figure 4. Spatial distribution of ES AWC and TC

of ES_AWY values in the LWC (Figure 4a), the PES value for each village varied from 891.54 USD/ha/year to 1,557.06 USD/ha/year (Figure 5a), despite these villages existing in the same sub-basin. For example, in the Parat and Sraten sub-basins, the PES value per village ranged from 1,200.01 to 1,557.06 USD/ha/year. This diverse value was caused by the different spatial distribution of climate change parameters, such as precipitation and evapotranspiration in every topography. This result supports *H1* stating that the PES value for each village in the same sub-basin is different.

A total of 10 villages had PES values above 1,450.00 USD/ha/year (Figure 5a in red). However, considering the TC, 26 villages had a PES value above 1,450.00 USD/ha/year with a maximum of 2,024.17 USD/ha/year (Figure 5b in red). With the TC consideration, the average PES value increased to 1,389.70 USD/ha/year from 1,255.86 USD/ha/year. This increase was caused by the potential pollution generated by land use, topography, and runoff. For example, upstream villages with massive human activities (agriculture) tend to have higher pollution load than downstream. This result supports *H2* stating that the level of pollution loads could increase the PES value. The distribution of PES value within each village in LWC of Rawa Pening is presented in Table J1, Appendix J.

4. DISCUSSION

The MPES model was applied to the LWC of Rawa Pening, consisting of nine sub-basins with 75 villages. It estimated the compensation value to attract farmers based on water ecosystem services within each village in the LWC (Figure 4a). The reference compensation value calculated according to the potential losses of farmers due to land conversion was 1,255.69 USD/ha/year. Meanwhile, water ecosystem services were estimated based on AWY obtained from the InVEST model. AWY was classified according to village boundary with a volume of water yield between 96.08 mm/ha/year to 168.46 mm/ha/year (Figure 3a). The value of water yields was obtained with a value range of 0.71-1.24 (Figure 4a). Based on these calculations, the compensation value for each village in LWC of Rawa Pening varied widely from 891.54 USD/ha/year to 1,557.06 USD/ha/year (Figure 5a).



a. The PES value

b. The PES value considering TC

Figure 5. Spatial distribution of PES value

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Within one sub-basin, the compensation value for each village varied relatively because the value of ecosystem services was estimated based on modeling results that considered land topography, land cover, and precipitation. In previous studies, the value of water ecosystem services was calculated using water production approach in each sub-basin leading to each village in the same sub-basin having a similar compensation value (Pissarra et al., 2021). Therefore, the calculation of incentives using sub-basin analysis units could be less precise and probably cause bias in the value of compensation given to farmers.

Chen et al. (2022) estimated the value of ecosystem services by ecosystem area units, making implementation at the administrative area level difficult, specifically for ecosystem in more than one administrative area. In addition, other studies predicted the economic value of ecosystem services using the contingent valuation method (Guo et al., 2023; Admasu et al., 2024), where the value obtained depends on the perception (Lee & Kim, 2024), and the respondent's experience (Sulistiyono et al., 2023), without considering the actual value. Incentive assessment based on the results of the InVEST model with village administrative analysis unit could be a novelty in this study. This approach can reduce bias in calculating ecosystem services with a simple method of application at the policy level.

The people use LWC for intensive agriculture, which is not sustainable and produces pollutants capable of polluting water. Meanwhile, the MPES model estimates the compensation given to farmers for converting agricultural land into agroforestry to improve lake water quality. The maximum value of compensation ranged from 1,450.00 USD/ha/year to 2,024.17 USD/ha/year, with this value being influenced by the level of pollution load on the land (Figure 4b). According to Pissarra et al. (2021), the estimated PES value in the Fazenda Gloria basin (Brazil) ranged from 284.35 USD/ha/year to 749.45 USD/ha/year depending on the level of land vulnerability. In the Santee River basin (USA), the value of PES was predicted to reach USD 4.6 million to USD 6.2 million per month, depending on geographic position, type of intervention, and environmental service targets (Ureta et al., 2022). Similar results were also observed in the Xin'an River watershed (China), where the PES value in the upstream and downstream watersheds was 22.54 USD/month and 8.63 USD/month respectively (Li et al., 2022a). Li and Zipp (2019) estimated the value of PES to control Chesapeake Bay (USA) pollution between 35 USD/ha to 390 USD/ha, depending on pollution level. These results show that the value of PES for improving ecosystem services differs in each case, depending on local conditions and objectives. However, the MPES model is a suitable alternative for estimating PES values in other regions, provided that agricultural production, water yield, tradeoff coefficients, and pollution load levels can be adjusted to the characteristics. As the smallest administrative unit, village boundaries can be a unit of analysis for determining PES values for easy application at the policy level.

Agroforestry system should provide ecological and economic benefits for the people to ensure that converting intensive agriculture into agroforestry could improve water ecosystem services in Lake Rawa Pening and be accepted by the community. Ecologically, agroforestry system must be able to control water pollution (Zhu et al., 2020), prevent soil erosion (Meetei et al., 2020), increase biodiversity (Islam et al., 2022), and improve soil fertility (Fahad et al., 2022). Moreover, agroforestry plant species should adapt to local environmental conditions, such as climate, soil type, and topography, to ensure that trees and crops can grow side by side (Rinady et al., 2023). Selecting trees and crops is important (Sopacua et al., 2021). Economically, agroforestry products including timber, fruit, root, and leaves must have economic and market value (Atiso & Fanjana, 2020; Wondimenh, 2023). In the context of LWC at Rawa Pening, the selected tree species had significant market value. The species could grow together with crops in tropical areas, such as *Paraserianthes falcataria* (Hossain et al., 2023), *Tectona grandis*, *Leucaena leucocephala* (Wiersum, 1983), and *Swietenia macrophylla* (Ávila-Lovera et al., 2021). Crops adapt under the shade of trees, such as sweet potato (Oswald et al., 1995), cassava (Johnston & Onwueme, 1998), eggplant (Efendi et al., 2022), leeks (Hudha et al., 2023), and cayenne pepper (Asharp & Sivachandiran, 2018).

The MPES model classifies the PES values based on the potential losses of farmers by considering water ecosystem services and the level of pollution load. Farmers in the LWC should receive two types of PES packages based on land conversion and crop maintenance costs. In the first year, land conversion costs could be between 891.54 USD/ha/year to 2,024.17 USD/ha/year. In the second to fifth years, plant maintenance costs might reach 891.54 USD/ha/year to 1,557.06 USD/ha/year. In this period, it is necessary to evaluate whether water quality has improved and the difference in farmers' income before and after land conversion. When the income after receiving PES is the same as before or even more, the PES system can be stopped. However, when the income after land conversion is less than before, it is necessary to adjust the PES value by considering the losses.

Implementing the MPES model to improve water ecosystem services in the LWC of Rawa Pening is challenging because it depends on budget availability and community participation. Appropriate compensation is an important element in attracting community participation to improve ecosystem services, where the feasibility of PES depends on the availability of funds (White et al., 2022; Guo et al., 2023). The sources of funds include companies, such as water conservation in the Cidanau watershed (Sunaedi et al., 2019) and downstream jurisdictional areas (city) receiving benefits from water ecosystem services (Febrian et al., 2018).

In the case of Rawa Pening Lake, enterprises such as PT Indonesia Power, Perum Jasa Tirta 2, and PT Sido Muncul have potential funding sources for PES because these companies are direct beneficiaries of lake water. However, the payment mechanism from enterprises to farmers should be legally regulated. The Governmental Regulation Number 46 of 2017 concerning Environmental Economic Instruments needs to regulate PES payment mechanism. The results of the MPES model can be a reference for the PES value that must be paid to the community in the LWC. However, to determine the costs and benefits of implementing PES, further studies are needed to compare the costs with the economic benefits of improving lake water ecosystem services. Future studies should also develop the PES model by adding a poverty level variable to determine priority areas for implementation due to limited funding sources.

CONCLUSION

The MPES model estimated the incentive to compensate for the loss of farmers by implementing agroforestry to improve water ecosystem services. The PES value was calculated based on the costs of farmers' losses, water yields, and pollution loads. Based on the results, the potential loss of farmers was approximately 1,255.69 USD/ha/year. Considering these losses, farmers would receive PES value between 891.54 USD/ha/year and 1,557.06 USD/ha/year. PES values varied even among villages in the same sub-basins. Therefore, calculating PES value based on village boundary is better than a sub-basin boundary. Considering the level of pollution load, the number of villages with PES above 1,450.00 USD/ha/year increased to 26 from 10 with a maximum PES of 2,024.17 USD/ha/year. This result proved that the level of pollution load would increase the PES value.

Agroforestry system should provide ecological and economic benefits for the community to overcome the failure of the MPES model, underscoring the need to select appropriate tree species and crops. Therefore, the mechanism for providing PES must consider planting and maintenance costs of agroforestry trees as well as the period for providing PES. The MPES model could be a reference for policymakers to improve lake water quality without disturbing community economic activities. Implementing this model is challenging due to budget availability and community participation, underscoring the need to indulge beneficiaries of improved lake ecosystem services as a funding source. To determine the costs and benefits of implementing PES, further studies are needed to compare the costs with the economic benefits of improving lake water ecosystem services.

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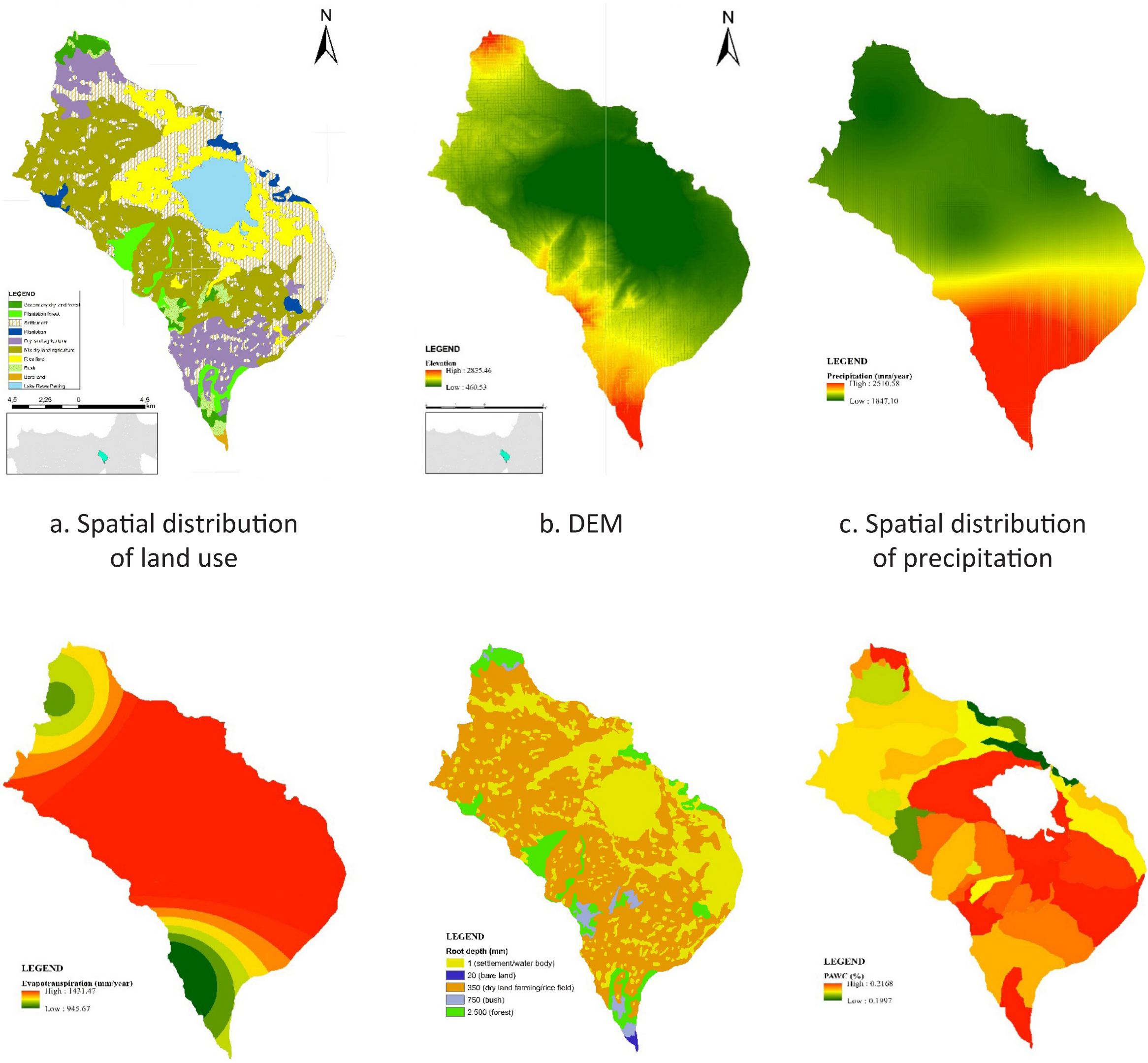
APPENDIX A. Calculating annual evapotranspiration



a. Spatial distribution of land use

b. DEM

c. Spatial distribution of precipitation

d. Spatial distribution of evapotranspiration

e. Spatial distribution of root depth

f. Spatial distribution of PAWC

Figure A1. Input data for InVEST model

Calculation of annual evapotranspiration is based on temperature data from NASA from 2018–2022 processed using the Thornthwaite-Mather method. The resulting value is monthly data, which need to be accumulated into an annual value. These calculations are carried out based on formulas (A1), (A2), and (A3). The potential evapotranspiration distribution map was obtained using inverse distance-weighted spatial interpolation. Next, the map is converted into raster format.

$$ETo = 16 \cdot \left[\frac{(10 \cdot t)^a}{1} \right] \cdot \left[\frac{N}{12} \right] \cdot \left[\frac{1}{30} \right], \quad \text{(A1)}$$

$$a = (675 \cdot 10^{-9}) \cdot 1^3 - (771 \cdot 10^{-7}) \cdot 1^2 + (179 \cdot 10^{-4}) \cdot 1 + 0.492, \quad \text{(A2)}$$

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$$I = \sum_{m=1}^{12} \left(\frac{t}{5} \right)^{1.51}, \tag{A3}$$

where *ETo*: reference evapotranspiration (mm/month); t: monthly average temperature (oC); *N*: monthly average solar radiation; a: coefficient; *I*: annual heat index.

Table A1. Reference evapotranspiration station

Station	Latitude	Longitude	Evapotranspiration (mm/year)
Station 1	–7.224	110.337	1,069.00
Station 2	–7.275	110.417	1,172.33
Station 3	–7.273	110.452	1,430.53
Station 4	–7.298	110.406	1,431.47
Station 5	–7.395	110.403	945.68

APPENDIX B. Calculating PAWC value

Plant Available Water Content (PAWC) is the water content in plants, represented by the amount of water in the soil used by plants. Calculation of PAWC values using the approach developed by Zhou et al. (2005) is based on the composition of the soil layer (sand%, silt%, and clay%) and the organic matter (OM) of the soil layer for each land use. The soil layer data were obtained from the Local Management Unit of Pemali Jratun (2022). Calculations for PAWC are presented in formula (B1).

$$PAWC(\%) = 54.509 - 0.132 \cdot sand - 0.003 \cdot (sand)^2 - 0.055 \cdot silt - 0.006 \cdot (silt)^2$$
$$-0.738 \cdot clay + 0.007 \cdot (clay)^2 - 2.688 \cdot OM + 0.501 \cdot (OM)^2 . \tag{B1}$$

Table B1. Description of PAWC value

Code_1	Description	PAWC
Bb	Baranco Breccia	0.2065
BIb	Breccia Intrusion Hill	0.2027
BICs	Mount Sumbing Steep Intrusive Hill	0.2128
BIk	Kaligetas Intrusion Hill	0.2066
BIs	Mount Sumbing Intrusion Hill	0.2126
BIs2	Mount Sumbing Intrusion Hill Location 2	0.2136
BIt	Mount Telomoyo Intrusion	0.2101
Bt	Baranco Mount Telomoyo	0.2072
BtC	Baranco Steep Mount Telomoyo	0.2139
DA	Alluvial Plain	0.2113
KLS	Cleft Lava Dome	0.2093
KM	Merbabu Volcano Cone	0.2134
Ks	Mount Suropati Crater	0.2084
KU	Ungaran Volcano Cone	0.2169
LAm	Upper Slopes of Mount Merbabu	0.2087
LAt	Upper Slopes of Mount Telomoyo	0.2142
LAU	Upper Slopes of Mount Ungaran	0.2061
LBm	Lower Slopes of Mount Merbabu	0.2146
LBt	Lower Slopes of Mount Telomoyo	0.2105
LBU	Lower Slopes of Mount Ungaran	0.2080
LGAs	Upper Slopes of Suropati Volcano	0.2100
LGBs	Lower Slopes of Suropati Volcano	0.2043

Table B1 (cont.). Description of PAWC value

Code_1	Description	PAWC
LI	Kaligetas Intrusion Slope	0.2042
LKm	The foot slopes of Merbabu Volcano	0.2111
LKPp	The Foothills of the Umbrella Hills	0.2074
LKt	The foot slopes of Telomoyo Volcano	0.2125
LKu	The foot slopes of Mount Ungaran	0.2069
LTm	Middle Slope of Mount Merbabu	0.2098
Pk	East Kaligetas Hills	0.1997
Pks	West Kaligetas Hills	0.2077
Pksc	West Kaligetas Hills Steep Slopes	0.2085
Pp	Umbrella Hills	0.2083
RP	Lake Rawa Pening	0.2102

APPENDIX C. Calculating precipitation

In calculating precipitation value, the data are annual rainfall for 2018–2022. Only one climatological station is available in the Rawa Pening basin, so rainfall data from other monitoring points are needed. Rainfall data were obtained from the CHRS satellite to complete the data. Therefore, six rainfall monitoring stations are carried out: one from the Koppeng climatological station and five from CHRS. The data were processed by ArcMap (v10.8) for interpolation, projection, resample, mask by extraction, and presentation of spatial distribution.

Table C1. Average annual precipitation in the Rawa Pening basin

Station	Latitude	Longitude	Precipitation (mm/year)
Titik 1	–7.2656	110.4234	1,885.10
Titik 2	–7.3010	110.3998	1,873.90
Titik 3	–7.2610	110.4526	1,845.50
Titik 4	–7.2288	110.3499	1,847.10
Titik 5	–7.3975	110.4200	1,881.50
Titik 6 (Kopeng)	–7.3976	110.4201	2,510.58

APPENDIX D. Biophysical table of InVEST model for AWY

Table D1 contains land use class information. In each land use class, there is a planting depth (mm), a plant coefficient (Kc), and the presence or absence of vegetation cover in a land cover class (LULC-veg).

Table D1. Biophysical table

Source: Li et al. (2022b).

No.	Land use	LULC_veg	root_depth	Kc
1	Secondary forest	1	2500	0.93
2	Plantation forest	1	2500	0.93
3	Bush	1	750	0.63
4	Plantation	1	2500	0.93
5	Settlement	0	1	0.25
6	Bare land	1	20	0.40
7	Water body (lake)	0	1	1.00
8	Dryland farming	1	350	0.75
9	Mix dry land farming	1	350	0.75
10	Rice field	1	350	0.75

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APPENDIX E

The biophysical table for the NDR model was obtained from various sources. It contains land use class information. Each land use class has a pollution load value in units of kg/ha/year. This value reflects the estimated amount of pollutants produced by each land use.

Table E1. Biophysical table of InVEST model for NDR

No.	Description	Load_p (kg/ha/t)	Eff_p	Crit_len_p	Source
1	Secondary forest	0.162	0.7	0	White et al. (2015)
2	Plantation forest	0.162	0.7	0	White et al. (2015)
3	Bush	0.84	0.6	0	White et al. (2015)
4	Plantation	1.5	0.15	0	Edwards and Miller (2001)
5	Settlement	2.55	0.24	0	White et al. (2015)
6	Bare land	0.18	0.24	0	Edwards and Miller (2001)
7	Water body (lake)	0.1	0.69	0	Withers and Jarvie (2008)
8	Dryland farming	4.46	0.15	0	White et al. (2015)
9	Mix dry land farming	4.46	0.15	0	White et al. (2015)
10	Rice field	10	0.5	0	Edwards and Miller (2001)

APPENDIX F

Table F1. Potential loss of farmer's income

No.	Commodity	L (ha)	Ti (kg/year)*	Hi (IDR/kg)**	NE (IDR/year)	Pc (IDR/ha/year)	Pc (USD/ha/year)	Factor x	Lc (USD/ha/year)
1	Onion	1.00	5,600.00	25,295.46	141,654,576.00	141,654,576.00	9,443.64	0.29	2,738.66
2	Large chili	13.00	49,900.00	24,941.83	1,244,597,317.00	95,738,255.15	6,382.55	0.29	1,850.94
3	Cayenne peppers	666.00	8,237,400.00	22,736.89	187,292,857,686.00	281,220,507.04	18,748.03	0.29	5,436.93
4	Potato	97.00	1,092,000.00	8,980.84	9,807,077,280.00	101,103,889.48	6,740.26	0.29	1,954.68
5	Cabbage	620.00	10,924,400.00	3,368.50	36,798,841,400.00	59,352,970.00	3,956.86	0.29	1,147.49
6	Tomato	376.00	11,914,100.00	4,103.64	48,891,177,324.00	130,029,726.93	8,668.65	0.29	2,513.91
7	Mustard green	878.00	13,082,800.00	3,614.30	47,285,164,040.00	53,855,539.91	3,590.37	0.29	1,041.21
8	Leeks	855.00	6,552,900.00	6,686.11	43,813,410,219.00	51,243,754.64	3,416.25	0.29	990.71
9	Eggplant	220.00	5,243,200.00	4,159.20	21,807,517,440.00	99,125,079.27	6,608.34	0.29	1,916.42
10	Corn	1,253.24	1,942,357.12	4,930.09	9,575,995,428.53	7,640,990.89	509.40	0.29	147.73
11	Peanut	42.60	19,020.00	13,215.08	251,350,821.60	5,900,254.03	393.35	0.29	114.07
12	Rice	9,581.00	106,174,878.32	5,425.00	575,998,714,886.00	60,118,851.36	4,007.92	0.29	1,162.30
13	Cassava	231.00	168,230.00	2,011.65	338,419,879.50	1,465,021.12	97.67	0.29	28.32
14	Sweet potato	313.20	172,570.00	3,166.45	546,434,276.50	1,744,681.60	116.31	0.29	33.73
	Total	15,147.04	–	–	983,793,212,574.13	64,949,535.52	4,329.97	0.29	1,255.69

Note: Lc: Potential loss of farmers per hectare per year (Rp/ha/year); *Pc*: Average revenue of farmer per hectare per year (Rp/ha/year); NE: Total revenue of farmer for one year (Rp/year); *L*: Total area of agricultural land used for agricultural cultivation (ha); Ti: Total agricultural output per year on commodity *i* (kg); *Hi*: Average price of farming products for commodity *i* (Rp); *Bureau of Statistics of Semarang Regency (2022a, 2022b); **Bureau of Statistics of Semarang Regency (2022c, 2022d, 2023).

APPENDIX G. Water discharge monitoring data and comparison estimated water yield and observed water yield

Water discharge monitoring data were conducted downstream of rivers that feed the lake. The data were collected from the Environment and Forestry Department of Central Java Province (data as of 2022).

Table G1. Data of observed water discharge

No.	Rivers	Latitude	Longitude	Water discharge (m3/second)		Average (m3/second)	Observed water yield (m3/year)*
				Dry season (Jul 12, 2022)	Rainy season (Nov 10, 2022)		
1	Galeh	–7.2844	110.4049	1.00	3.95	2.48	78,051,600.00
2	Kedungringin	–7.2890	110.4570	0.09	0.30	0.19	6,117,984.00
3	Legi	–7.3184	110.4381	0.20	1.24	0.72	22,564,008.00
4	Panjang	–7.2745	110.4144	0.97	2.78	1.87	59,098,464.00
5	Parat	–7.3630	110.4261	0.89	3.82	2.36	74,314,584.00
6	Rengas	–7.2647	110.4237	0.09	1.09	0.59	18,622,008.00
7	Ringis	–7.2994	110.4599	0.09	1.05	0.57	17,896,680.00
8	Sraten	–7.3166	110.4629	0.95	2.91	1.93	60,801,408.00
9	Torong	–7.2815	110.4043	0.25	1.39	0.82	25,891,056.00

Note: * Observed water yields are calculated based on the average water discharge multiplied by one year (31,536,000 seconds).

Table G2. Data of estimated water yield

No.	Sub-basin	Size_ha	precip_mn	PET_mn	AET_mn	wyield_mn	wyield_vol (m3/year)
1	Galeh	5,684.38	1,913.49	946.87	522.06	1,391.23	79,082,979.17
2	Kedungringin	487.82	1,877.79	798.45	531.65	1,346.09	6,566,502.02
3	Legi	1,761.21	2,003.55	942.97	498.81	1,504.65	26,500,062.61
4	Panjang	4,197.89	1,866.07	765.00	448.67	1,417.41	59,501,302.87
5	Parat	4,508.35	2,162.96	798.25	453.99	1,708.52	77,026,220.24
6	Rengas	1,630.73	1,881.21	750.80	469.63	1,411.67	23,020,473.09
7	Ringis	1,492.45	1,945.96	654.58	432.35	1,513.61	22,589,894.52
8	Sranten	3,772.64	2,129.45	703.82	450.40	1,679.01	63,343,095.17
9	Torong	1,818.06	1,888.46	847.13	448.64	1,439.81	26,176,741.32

Note: Size_ha: the size of sub-basin (ha); precip_mn: mean precipitation per pixel in the sub-basin; PET_mn: mean potential evapotranspiration per pixel in the sub-basin; AET_mn: mean actual evapotranspiration per pixel in the sub-basin; myield_mn: mean water yield per pixel in the sub-basin; myield_vol: volume of water yield in the sub-basin.

Table G3. A comparison of estimated water yield and observed water yield

No.	Sub-basin	Size (ha)	Water yield (m3/year)		Bias (%)
			Estimated	Observed	
1	Galeh	5,684.38	79,082,979.17	78,051,600.00	1.32
2	Kedungringin	487.82	6,566,502.02	6,117,984.00	7.33
3	Legi	1,761.21	26,500,062.61	22,564,008.00	17.44
4	Panjang	4,197.89	59,501,302.87	59,098,464.00	0.68
5	Parat	4,508.35	77,026,220.24	74,314,584.00	3.65
6	Rengas	1,630.73	23,020,473.09	18,622,008.00	23.62
7	Ringis	1,492.45	22,589,894.52	17,896,680.00	26.22
8	Sranten	3,772.64	63,343,095.17	60,801,408.00	4.18
9	Torong	1,818.06	26,176,741.32	25,891,056.00	1.10
	Total		383,807,271.01	363,357,792.00	5.63

APPENDIX H. Water quality monitoring data and comparison estimated and observed TP pollutants

Water quality monitoring data were taken downstream of rives that feed the lake. This data were collected from the Environment and Forestry Department of Central Java Province (data as of 2022).

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Table H1. Data on observed water quality

No.	Rivers	Latitude	Longitude	TP (mg/liter)		TP pollutant		Water Discharge (m3/year)	TP pollutant (kg/year)
				Dry season (Jul 28, 2022)	Rainy season (Oct 25, 2022)	mg/liter	kg/m3		
1	Galeh	–7.2844	110.4049	0.18	0.10	0.14	0.00014	78,051,600	10,927.22
2	Kedungringin	–7.2890	110.4570	0.30	0.10	0.20	0.00020	6,117,984	1,223.60
3	Legi	–7.3184	110.4381	0.40	0.30	0.35	0.00035	22,564,008	7,897.40
4	Panjang	–7.2745	110.4144	0.16	0.10	0.13	0.00013	59,098,464	7,682.80
5	Parat	–7.3630	110.4261	0.24	0.03	0.14	0.00014	74,314,584	10,032.47
6	Rengas	–7.2647	110.4237	0.40	0.18	0.29	0.00029	18,622,008	5,400.38
7	Ringis	–7.2994	110.4599	0.30	0.10	0.20	0.00020	17,896,680	3,579.34
8	Sraten	–7.3166	110.4629	0.17	0.10	0.14	0.00014	60,801,408	8,208.19
9	Torong	–7.2815	110.4043	0.10	0.10	0.10	0.00010	25,891,056	2,589.11

Table H2. Estimated data of the InVEST model

No.	Sub-basin	Size (ha)	MEAN (kg/pixel/year)	MEAN (kg/ha/year)	SUM (kg/year)
1	Galeh	5,684.38	0.11	0.01	6,854.90
2	Kedungringin	487.82	0.05	0.00	249.95
3	Legi	1,761.21	0.13	0.01	2,483.51
4	Panjang	4,197.89	0.13	0.01	5,800.17
5	Parat	4,508.35	0.14	0.01	6,628.40
6	Rengas	1,630.73	0.10	0.01	1,764.75
7	Ringis	1,492.45	0.09	0.01	1,465.07
8	Sranten	3,772.64	0.11	0.01	4,506.46
9	Torong	1,818.06	0.12	0.01	2,321.98

Table H3. Comparison of estimated and observed TP in Lake Rawa Pening

No.	Sub-basin	Size (ha)	TP (kg/year)		Bias (%)
			Estimated	Observed	
1	Galeh	5,684.38	6,854.90	10,927.22	37.27
2	Kedungringin	487.82	249.95	1,223.60	79.57
3	Legi	1,761.21	2,483.51	7,897.40	68.55
4	Panjang	4,197.89	5,800.17	7,682.80	24.50
5	Parat	4,508.35	6,628.40	10,032.47	33.93
6	Rengas	1,630.73	1,764.75	5,400.38	67.32
7	Ringis	1,492.45	1,465.07	3,579.34	59.07
8	Sraten	3,772.64	4,506.46	8,208.19	45.10
9	Torong	1,818.06	2,321.98	2,589.11	10.32
	Total		32,075.19	57,540.51	44.26

APPENDIX J

Table J1. Distribution of PES value of each village in LWC of Rawa Pening

No.	Villages	Lc (USD/ha/year)	ES_AWY	TC_TP	PES (USD/ha/year)	PES_TC (USD/ha/year)
1	Asinan	1,255.69	0.77	1.00	966.88	966.88
2	Bawen	1,255.69	0.96	1.00	1,205.46	1,205.46
3	Doplang	1,255.69	0.96	1.10	1,205.46	1,326.01
4	Baran	1,255.69	0.96	1.30	1,205.46	1,567.10
5	Bejalen	1,255.69	0.96	1.00	1,205.46	1,205.46
6	Kranggan	1,255.69	1.01	1.00	1,268.25	1,268.25

Table J1 (cont.). Distribution of PES value of each village in LWC of Rawa Pening

No.	Villages	Lc (USD/ha/year)	ES_AWY	TC_TP	PES (USD/ha/year)	PES_TC (USD/ha/year)
7	Kupang	1,255.69	0.98	1.00	1,230.58	1,230.58
8	Lodoyong	1,255.69	0.98	1.00	1,230.58	1,230.58
9	Ngampin	1,255.69	0.95	1.00	1,192.91	1,192.91
10	Panjang	1,255.69	0.98	1.00	1,230.58	1,230.58
11	Pasekan	1,255.69	0.94	1.20	1,180.35	1,416.42
12	Pojoksari	1,255.69	0.94	1.00	1,180.35	1,180.35
13	Tambakboyo	1,255.69	0.97	1.00	1,218.02	1,218.02
14	Jubelan	1,255.69	0.82	1.00	1,029.67	1,029.67
15	Kebonagung	1,255.69	0.96	1.20	1,205.46	1,446.56
16	Lanjan	1,255.69	0.96	1.20	1,205.46	1,446.56
17	Ngadikerso	1,255.69	0.97	1.20	1,218.02	1,461.62
18	Bandungan	1,255.69	0.91	1.00	1,142.68	1,142.68
19	Banyukuning	1,255.69	0.96	1.20	1,205.46	1,446.56
20	Candi	1,255.69	0.95	1.10	1,192.91	1,312.20
21	Duren	1,255.69	0.92	1.20	1,155.24	1,386.28
22	Jetis	1,255.69	0.97	1.20	1,218.02	1,461.62
23	Kenteng	1,255.69	0.97	1.20	1,218.02	1,461.62
24	Mlilir	1,255.69	0.96	1.20	1,205.46	1,446.56
25	Sidomukti	1,255.69	0.71	1.00	891.54	891.54
26	Bedono	1,255.69	0.87	1.00	1,092.45	1,092.45
27	Brongkol	1,255.69	0.86	1.00	1,079.89	1,079.89
28	Genting	1,255.69	0.97	1.30	1,218.02	1,583.43
29	Gondoriyo	1,255.69	0.96	1.10	1,205.46	1,326.01
30	Jambu	1,255.69	0.95	1.20	1,192.91	1,431.49
31	Kebondalem	1,255.69	0.96	1.30	1,205.46	1,567.10
32	Kelurahan	1,255.69	0.93	1.10	1,167.79	1,284.57
33	Kuwarasan	1,255.69	0.95	1.30	1,192.91	1,550.78
34	Rejosari	1,255.69	0.82	1.00	1,029.67	1,029.67
35	Banyubiru	1,255.69	0.89	1.00	1,117.57	1,117.57
36	Gedong	1,255.69	1.08	1.20	1,356.15	1,627.38
37	Kebondowo	1,255.69	0.94	1.00	1,180.35	1,180.35
38	Kebumen	1,255.69	1.03	1.30	1,293.36	1,681.37
39	Kemambang	1,255.69	0.91	1.00	1,142.68	1,142.68
40	Ngrapah	1,255.69	0.94	1.10	1,180.35	1,298.38
41	Rowoboni	1,255.69	0.98	1.10	1,230.58	1,353.63
42	Sepakung	1,255.69	1.02	1.20	1,280.80	1,536.97
43	Tegaron	1,255.69	0.98	1.10	1,230.58	1,353.63
44	Wirogomo	1,255.69	0.97	1.00	1,218.02	1,218.02
45	Batur	1,255.69	1.17	1.00	1,469.16	1,469.16
46	Getasan	1,255.69	1.22	1.20	1,531.94	1,838.33
47	Kopeng	1,255.69	1.23	1.10	1,544.50	1,698.95
48	Manggihan	1,255.69	1.16	1.30	1,456.60	1,893.58
49	Ngrawan	1,255.69	1.19	1.30	1,494.27	1,942.55
50	Nogosaren	1,255.69	1.08	1.00	1,356.15	1,356.15
51	Polobogo	1,255.69	1.09	1.30	1,368.70	1,779.31
52	Samirono	1,255.69	1.19	1.20	1,494.27	1,793.13
53	Sumogawe	1,255.69	1.16	1.30	1,456.60	1,893.58
54	Tajuk	1,255.69	1.22	1.10	1,531.94	1,685.14
55	Tolokan	1,255.69	1.18	1.20	1,481.72	1,778.06
56	Wates	1,255.69	1.24	1.30	1,557.06	2,024.17
57	Kumpulrejo	1,255.69	1.06	1.10	1,331.03	1,464.14
58	Tegalrejo	1,255.69	1.12	1.00	1,406.37	1,406.37
59	Dukuh	1,255.69	1.08	1.00	1,356.15	1,356.15
60	Kalicacing	1,255.69	1.11	1.00	1,393.82	1,393.82

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Table J1 (cont.). Distribution of PES value of each village in LWC of Rawa Pening

No.	Villages	Lc (USD/ha/year)	ES_AWY	TC_TP	PES (USD/ha/year)	PES_TC (USD/ha/year)
61	Kecandran	1,255.69	1.07	1.10	1,343.59	1,477.95
62	Mangunsari	1,255.69	1.12	1.00	1,406.37	1,406.37
63	Candirejo	1,255.69	0.98	1.10	1,230.58	1,353.63
64	Gedangan	1,255.69	1.05	1.10	1,318.48	1,450.32
65	Jombor	1,255.69	1.00	1.20	1,255.69	1,506.83
66	Kalibeji	1,255.69	1.06	1.00	1,331.03	1,331.03
67	Kesongo	1,255.69	0.90	1.00	1,130.12	1,130.12
68	Lopait	1,255.69	0.89	1.00	1,117.57	1,117.57
69	Rowosari	1,255.69	0.98	1.00	1,230.58	1,230.58
70	Sraten	1,255.69	1.02	1.00	1,280.80	1,280.80
71	Tuntang	1,255.69	0.90	1.00	1,130.12	1,130.12
72	Blotongan	1,255.69	0.96	1.00	1,205.46	1,205.46
73	Pulutan	1,255.69	1.00	1.20	1,255.69	1,506.83
74	Salatiga	1,255.69	1.09	1.00	1,368.70	1,368.70
75	Sidorejo Lor	1,255.69	1.06	1.00	1,331.03	1,331.03
Total		–	75.01	82.70	94,189.38	104,227.38
Minimal		–	0.71	1.00	891.54	891.54
Maximal		–	1.24	1.30	1,557.06	2,024.17
Average		–	1.00	1.10	1,255.86	1,389.70

Note: Lc: potential loss of farmers per hectare per year; ES_AWY: the value of water ecosystem services; TC_TP: the level of pollution load of TP pollutant; PES: payment for ecosystem services.