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Estimation of Pesticide Concentrations from Agricultural Land in Cangkringan and Pakem Subdistricts on Runoff in the Upper Opak Watershed

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Abstract

Agricultural activities in the Opak Watershed, especially in the upper part located in Sleman Regency, require special attention because they have the potential to have a negative impact on river water quality. The use of pesticides on agricultural land contributes to polluting river water through rainwater runoff. Runoff containing residual organophosphate pesticide residues will reduce river water quality. In order to prevent pesticide pollution in the Upper Opak Watershed (UOW) in a sustainable manner, effective management is needed. However, the lack of information regarding estimates of pesticide concentrations in runoff in the UOW could hamper the management process. Therefore, it is crucial to estimate pesticide concentrations from agricultural land in the Cangkringan and Pakem Subdistricts contained in runoff in the UOW. Estimation of pesticide concentrations in runoff can be done by conducting hydrological modeling. The Soil Conservation Service-Curve Number (SCS-CN) model is the simplest compared to other models, but this model needs to be combined with the Predicted Environmental Concentrations (PEC) model to be able to estimate pesticide concentrations contained in runoff in the UOW. The research results show that the Cangkringan Subdistrict is the larger contributor to the concentration of organophosphate pesticides in the runoff of the UOW. The runoff contains three types of active pesticide substances, with the highest concentration in the two subdistricts being the active substance Diazinon. Active pesticide substances from rice fields in Pakem Subdistrict did not contribute too much to the pesticide pollution on the UOW runoff. Most of the pesticide concentrations in the UOW runoff came from agricultural land.

Keywords: PEC, Pesticide, Runoff, SCS-CN.

1. Introduction

The Opak River is of immense importance as a primary source of clean water within the Special Region of Yogyakarta. However, the physical condition of the Opak Watershed (DAS) is influenced by human activity and volcanoes (Widaryanto et al., 2021). In the Upper Opak Watershed (UOW) in Sleman Regency, human activities related to agriculture can have a significant impact on the physical condition of the area. The agriculture in the Cangkringan and Pakem Subdistricts, as reported by the Technical Implementation Unit (UPT) Agriculture of Sleman Regency, has been extensive. These activities have potentially negative effects on the quality of river water in the region. The use of pesticides and fertilizers in these areas has increased along with agricultural productivity, as reported in the 2007 Sleman Regency environmental status report. Research results from Prananda (2017), Kizlyara (2019), and Rahmawati (2021) indicate that the risk of pesticide use in Cangkringan and Pakem Subdistricts is very high, with a risk level of 13% in Cangkringan Subdistrict and 31% in Pakem Subdistrict.

The use of pesticides in agricultural land located in the UOW is one of the significant factors that can contribute to water pollution in the Opak River in future. Pesticide residues left on plants and soil can be carried by water runoff in larger quantities into the river when rainfall in the watershed is high. Potentially hazardous substances, such as pesticides, are often released directly or indirectly into the aquatic environment. When large amounts of pesticides or pesticide mixtures reach rivers, they can have immediate impacts as measured by increased mortality of aquatic organisms. Moreover, there are long-term impacts, as measured by chronic damage and accumulation of those contaminants in the aquatic organisms (Burkina et al., 2018; Clasen et al., 2018; Jia and Chen, 2013; Gonçalves et al., 2019).

Effective watershed management minimizes the long-term impact of pesticide pollution in the Opak Watershed, particularly in the Upper area, where agricultural activities dominate. Knowing the concentration of pesticide pollutants carried by runoff before entering the river is one part of the Effective Watershed Management Strategy. However, the lack of information on pesticide concentrations in runoff presents a challenge. Consequently, estimating pesticide concentrations from agricultural land in the Cangkringan and Pakem Districts carried in runoff in the Upper Opak Watershed is necessary.

Pesticide concentrations in runoff can be estimated through the use of hydrological modeling. Watershed hydrological modeling is an effective method to study and understand watershed processes and predict their response to changes (Ferijal, 2012). Various hydrological models, such as the Watershed Model (WM), the Soil Water Assessment Tool (SWAT) model, and the Soil Conservation Service (SCS)-Curve Number (CN) model have been developed to estimate runoff. In this study, the estimation used the SCS-CN model and the Predicted Environmental Concentrations (PEC) model.

The SCS-CN (Soil Conservation Service Curve Number) model is a widely used method for simulating surface flow events under specific rainfall, soil, and land use conditions (Puspaningsih et al., 2018). Nurqalbi (2022) used the SCS-CN model to examine surface flow within the Citarum Watershed and to identify variations in CN values, surface runoff, and the proportion of surface runoff in relation to rainfall across various Sub-watersheds. The model is favored for its simplicity and ease of obtaining required watershed information. It is also supported by tables, graphs, and computer programs, providing specific condition results. In cases where data is unavailable, alternative methods can be used to determine certain rainfall values. The SCS model links various watershed characteristics, including soil, vegetation, and land use, with runoff curve number, indicating the potential runoff during specific rainfall events.

In this research, the estimation of pesticide concentrations in runoff in the Opak Watershed combines the SCS-CN model with the PEC model. The PEC model is a new approach to modelling and relies on the latest data on the use of Contaminants of Emerging Concern (CECs) as a primary requirement. Utami et al. (2021) applied the PEC model to predict the concentration of pesticide-type CECs (PECs) in the flow of the Upper Citarum River. This model estimates pesticide concentration based on the percentage of the pesticide application dose contained in runoff water entering the river flow as a solute. The PEC model has the advantage of not necessitating laboratory monitoring and analysis, which can reduce the time and resources required for assessing and implementing this model.

2. Methods

2.1. Time and Location

This research was conducted in the Upper Opak Watershed (UOW), encompassing the Special Region of Yogyakarta and Central Java. The research lasted from March 2023 to August 2023, focusing on the Pakem and Cangkringan Subdistricts, and building on previous research. The UOW is situated in the Sleman, Bantul, and Klaten Regencies with Sleman Regency playing a crucial role in watershed management, covering 73.2% of the Upper Opak Watershed. This research was specifically carried out in Sleman Regency, covering the Cangkringan (4553.25 ha), Kalasan (3474.93 ha), Ngemplak (3745.64 ha), and Pakem (5330.50 ha) Subdistricts. Figure 1 displays a map of the research area in the UOW.

The research utilized secondary data from reputable sources and did not involve the use of specialized equipment or sensors. The dataset includes information such as precipitation records, pesticide application rates, land cover classifications, soil type delineations, Digital Elevation Models (DEM), Opak River Basin boundary delineations, Opak River flow maps, and Indonesian Landscape Map (RBI). The processed data were then visually represented as surface runoff through maps using Geographic Information System (GIS). The processing of the data is shown in the flowchat in Figure 2. Due to the limitation of the data, time, and other resources, this study did not conduct any data validation and model calibration.

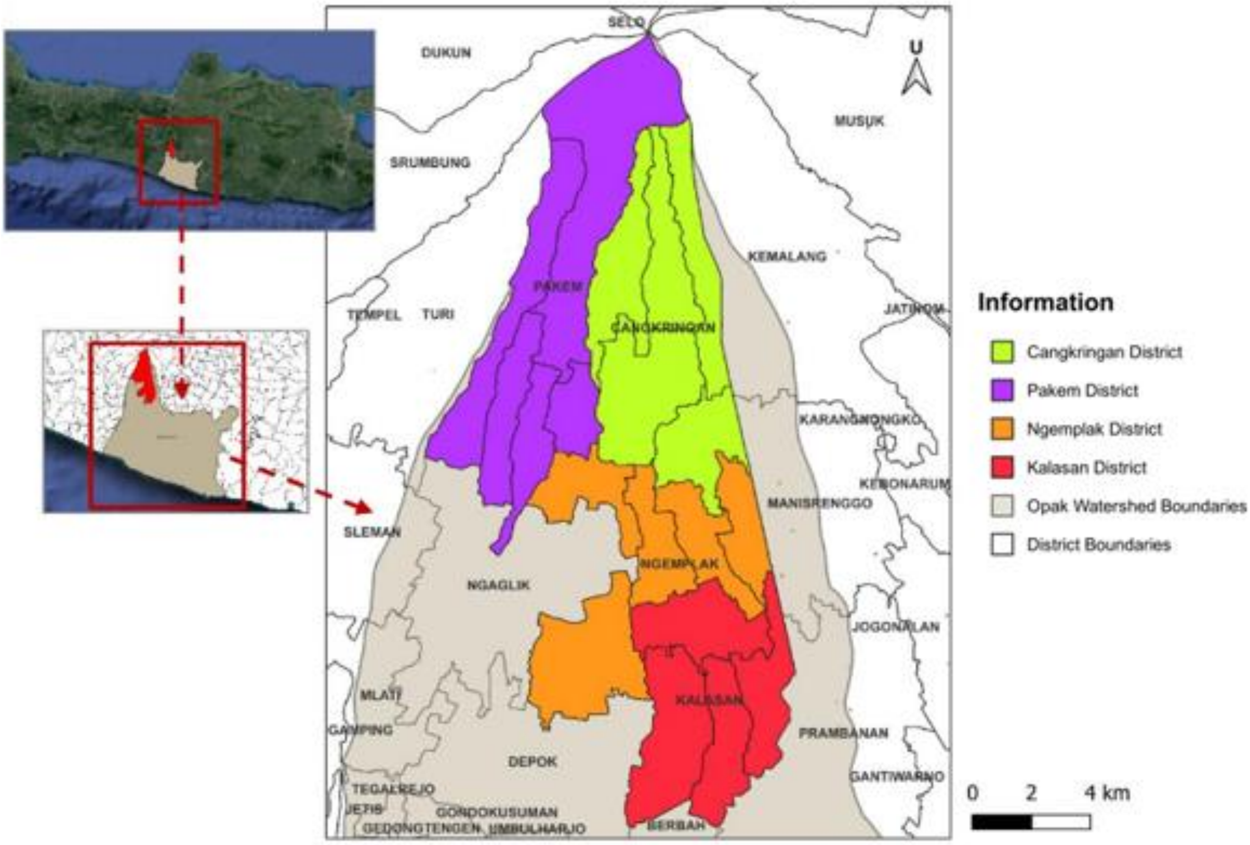

Figure 1. Map of the research area in the Upper Opak Watershed (UOW)

2.2. Determining the value of Curve Number (CN)

Determination of the CN value is carried out to determine the correlation between land cover, soil, and Antecedent Moisture Condition (AMC). The data used in determining the CN value include the Soil Hydrology Group (SHG), AMC, and land cover data. The AMC and CN values of surface runoff for each land map unit are calculated every day for 365 days using daily rainfall data for 2018-2020. The AMC I (CN1) and AMC III (CN3) condition curve numbers require conversion from AMC II (CN2) using the following Equations 1 and 2 from Arnold et al. (2011).

$$\mathrm{CN}_1 = \mathrm{CN}_2 - \frac{20 \text{ x } (100 - \mathrm{CN}_2)}{(100 - \mathrm{CN}_2 + \exp[0.00636\ (100 - \mathrm{CN}_2)])} \qquad \text{(Equation 1)}$$

$$\mathrm{CN}_3 = \mathrm{CN}_2 \text{ x} \exp[0.00673\ (100 - \mathrm{CN}_2)] \qquad \text{(Equation 2)}$$

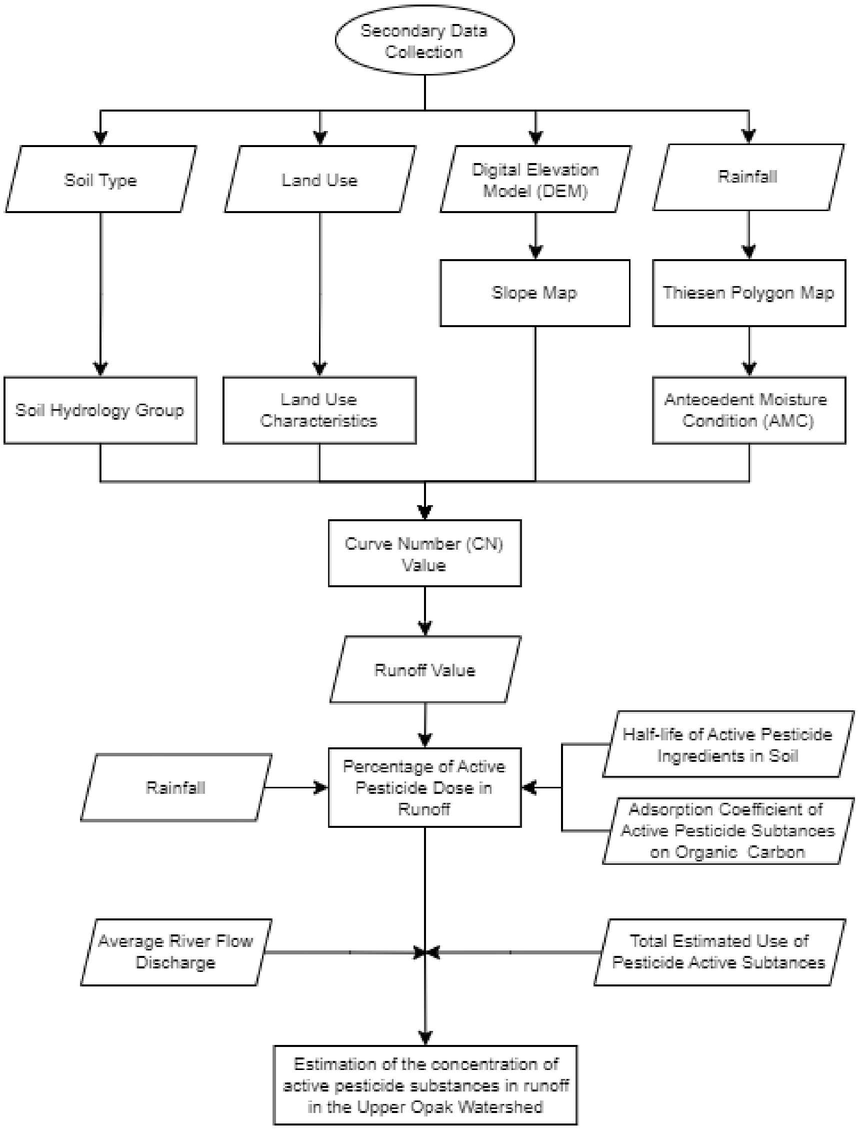

Figure 1. Data Processing Flowchart

2.3. Surface Runoff Analysis

SCS-CN model is used to determine the volume of surface runoff in the Upper Opak Watershed. After the CN value is obtained, Equation 3 is used to calculate the total value of surface deposits (S). To calculate the volume of surface runoff (Q) Equation 4 is used which includes the values of S and Rainfall (P) in the calculation.

$$S = \frac{25.400}{CN} - 254 \qquad \text{(Equation 3)}$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{(Equation 4)}$$

2.4. Determination of the Percentage of Pesticide Application Dose

To estimate pesticide concentrations in runoff, it is necessary to calculate the percentage of pesticide use dose contained in surface runoff using Equation 5 (Berenzen et al., 2005; Utami et al., 2020).

$$L\%_{runoff} = \frac{Q}{P} \; x \; f.\exp\left(-x.\frac{\ln 2}{DTsoil}\right) x \frac{100}{1 + Kd} \quad \text{(Equation 4)}$$

with,

Q : Volume of surface runoff (mm)
P : Instantaneous rainfall (mm)
f : Correction factor
f_1 : Slope factor
f_2 : Plant interception factor
f_3 : Buffer zone factor
x : Time between runoff events that affect the decay time for 50% of the material active in soil (DT_{50soil})
DT_{50soil} : Half-life of the active pesticide ingredient in the soil (days)
K_d : The ratio of the dissolved pesticide active ingredient to the absorbed pesticide concentration
K_{OC} : The absorption coefficient of the active pesticide ingredient on organic carbon

2.5. Determination of the Estimated Pesticide Concentration in Runoff

After knowing the percentage of pesticide use dose contained in surface runoff. Equation 6 (Berenzen et al., 2005; Utami et al., 2020) is used to estimate the concentration of active pesticide substances in the UOW runoff by including the estimated concentration of active pesticide substances in the runoff (PUCRB), runoff discharge (Q_{runoff}), and annual duration (ΔT).

$$PEC = L\%_{runoff} \; x \; P_{UCRB} \; x \frac{1}{Q_{runoff} \; x \; \Delta T} \quad \text{(Equation 5)}$$

3. Results and Discussion

3.1. Characteristics of the Upper Opak Watershed

3.1.1. Topography (Slope)

The Upper Opak Watershed (UOW) is located on the slopes of volcano and has varying slopes. The slopes in the UOW are classified into 6 classes, namely flat, very gentle, gentle, slightly steep, steep, and very steep. Most of the UOW area has very sloping topography (38.56%) and gently sloping (34.56%) which is spread across Pakem, Cangkringan, Ngemplak, and Kalasan Subdistricts (Table 1).

Table 1. Percentage and area of slope of the Upper Opak Watershed

No.	Slope		Area (Ha)	%
1	Flat	0 - 2%	1,328.56	7.77
2	Very Sloping	2 - 6%	6,595.91	38.56
3	Sloping	6 - 13%	5,910.83	34.56
4	Somewhat Steep	13 - 25%	1,718.80	10.05
5	Steep	25 - 55%	1,135.76	6.64
6	Very Steep	> 55%	414.36	2.42
		Total	17,104.22	100

3.1.2. Soil Type

The Upper Opak Watershed has three types of soil, namely Vertic Luvisol, Mollie Andosol, and Eutric Regosol. The Upper Opak Watershed is dominated by the Eutric Regosol soil type, covering 99.81% of the total area. The regosol soil type is widely distributed in volcanic areas because it is formed from new volcanic ash deposits which have coarse grains. Soil types of the UOW has three different types of soil texture, namely clay, clay, and sandy loam. The percentage and area of land types in the Upper Opak Watershed are presented in Table 2.

Table 2. Percentage and area of land types in the Upper Opak Watershed

No.	Soil Type	Soil Texture	Area (Ha)	%
1	Vertic Luvisol	Clay	11.11	0,06
2	Mollie Andosol	Loam	21.77	0.13
3	Eutric Regosol	Sandy Loam	17,071.34	99.81
		Total	**17,104.22**	**100**

Source: Food and Agriculture Organization (FAO)

3.1.3. Land Use

Land use in the Upper Opak Watershed is classified into sixteen land use types such as airports, conservation forests, settlements, moors/fields, and other types of use. The percentage and area of land use types in the Upper Opak Watershed are presented in Table 3. Most of the lands in the UOW are used as agricultural land, residential areas, and rice fields with an area of 2,585.26 Ha (15.11%), 5,005.28 Ha (29.26%), and 6,074.63 Ha (35.51%), respectively. Vegetation land use in the UOW is more dominant than built-up land (68.66% of the total area). An important note, based on the land use map, the slope around the Merapi Mountain area mostly is covered by conservative forest. Conservative forests have an important role in maintaining biodiversity and ecosystems in the UOW area. Conservative forests can act act as natural water catchment, so it may reduce some of the surface runoff.

Table 3. Land use area in the Upper Opak Watershed

No.	Land Use Type	Area	
		Ha	%
1	Airport	3.28	0.02
2	Prambanan temple	13.24	0.08
3	Lake/Reservoir	4.84	0.03
4	Emplacement	3.78	0.02
5	Conservation Forest	1,839.54	10.75
6	Industry	5.73	0.03
7	Agricultural land	2,585.26	15.11
8	Fresh Water Pool	2.67	0.02
9	Sports field	61.57	0.36
10	Grave	1.51	0.01
11	Settlement	5,005.28	29.26
12	Grass/Vacant Land	565.29	3.30
13	Ricefield	6,074.63	35.52
14	Shrubs	150.49	0.88
15	River	258.62	1.51
16	Moorland/Field	528.48	3.09
	Total	**17,104.22**	**100**

3.1.4. Rainfall

Rainfall data from five rain stations (Bronggang, Cepit, Kalasan, Kemput, and Plunyon stations) were used in this study. The average annual rainfall in the region during the 2018–2020 period was 2,585.65 mm/year. In 2018, rainfall was 2,489.83 mm/year and decreased to 2,359.80 mm/year in 2019. However, in 2020 there was an increase of 2,907.31 mm/year due to the La Nina event which caused extreme weather. La Nina can cause crop failure due to excessive air availability and flooding. This event lasted for almost three years, resulting in more rainy days and overall rainfall than usual. To determine the distribution of rainfall intensity in the UOW, researchers interpolated the rainfall data as shown in Figure 3.

3.2. Runoff in the Upper Opak Watershed

3.2.1. Soil Hydrology Group (SHG)

The Upper Opak Watershed is dominated by SHG B which is included in the moderate hydrology group. Land with a greater percentage of sand than the percentage of clay is classified as SHG B. SHG B has a sandy texture and has moderate runoff potential with a texture range of 50–90% sand and 10–20% clay. In contrast, SHG D has a clay texture with a lower infiltration rate compared to SHG B. SHG B dominates the Upper Opak Watershed, covering an area of 17,093.11 Ha or 99.94% of the total area, with a sandy and loamy texture. There are different SHGs in the upper Pakem area, namely SHG D covering an area of 11.11 Ha or 0.06% of the total area of Pakem. SHG in the UOW is characterized as having a low infiltration rate and poor water infiltration properties which can result in prolonged waterlogging.

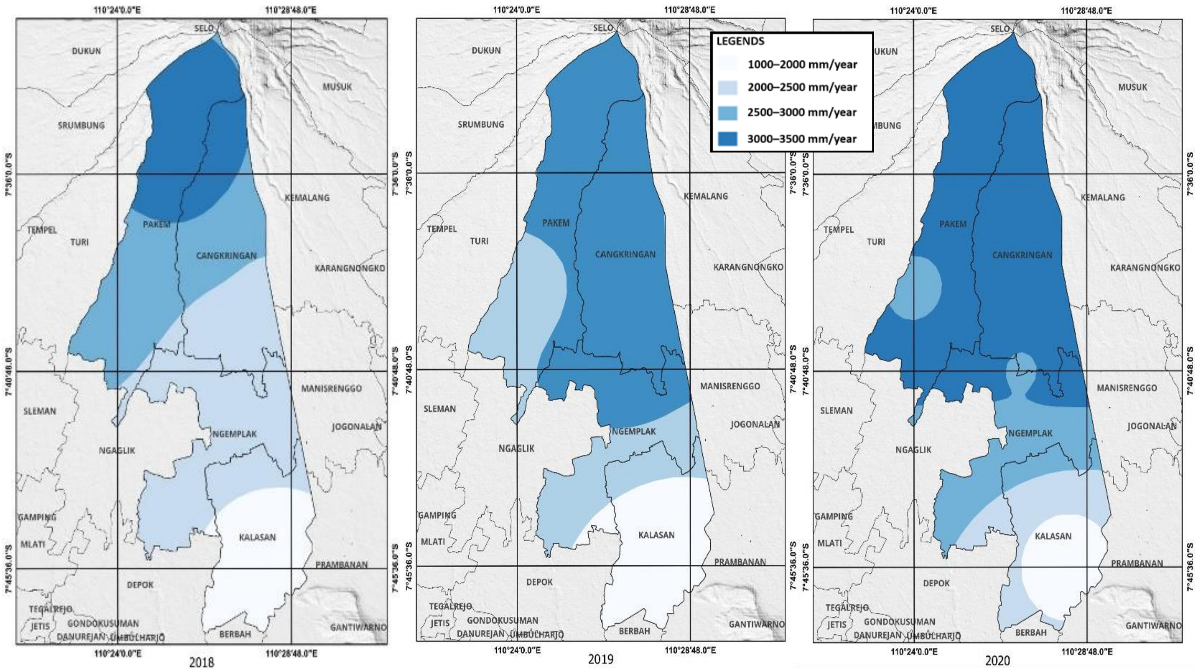

Figure 3. Distribution map of rainfall intensity for the UOW during 2018–2020 made from RBI map and the rainfall data from UPTD Timur of Sleman Regency.

3.2.2. Antecedent Moisture Condition (AMC)

The AMC value is calculated every day for 365 days, taking into account rainfall in 2018–2020. The AMC value varies every day, including AMC I, II, and III. The CN value is modified based on the SHG and AMC values can influence the soil infiltration capacity. Soil with high water content or saturated conditions causes increased surface runoff, while soil with low water content or dry conditions results in small surface runoff. Dry soil conditions (AMC I) have a higher infiltration capacity and lower surface runoff, while moist soil conditions (AMC III) have a lower infiltration capacity and higher surface runoff. The 2018–2020 period was initially dominated by AMC III, then changed to AMC I due to low rainfall.

3.2.3. Curve Number (CN) Value

Agricultural land and rice fields are the main land uses in this research. The CN value of land units varies for each AMC, both AMC I, AMC II, and AMC III. A map of CN values at AMC I, II, and III in the study area is shown in Figure 4. Water bodies have the highest CN value of 100, while conservation forests have the lowest CN values of 36, 55, and 74 for AMC I, II, and III, respectively. The land unit value influences the infiltration capacity of land use, where a low land unit value results in a high infiltration capacity. Table 4 presents the composite CN values of agricultural land and rice fields in the UOW.

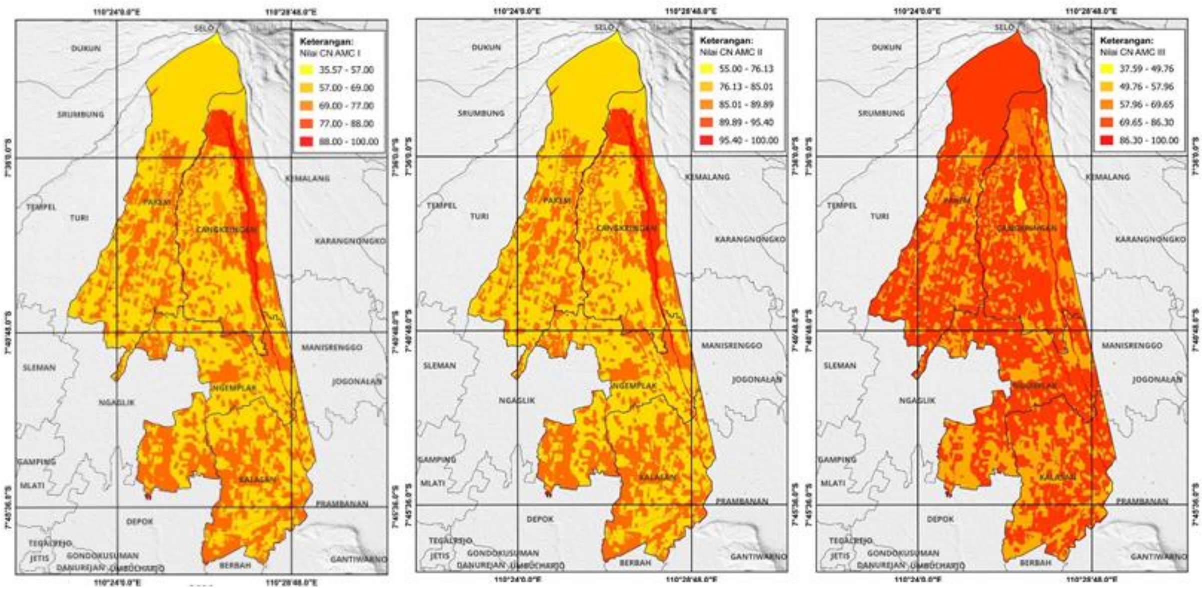

Figure 4. Distribution map of AMC I, II, and III of the Upper Opak Watershed (UOW)

Table 4. Composite CN values at AMC I, II, and III in agricultural land and rice fields

Land Use	SHG	Area (Ha)	Area (%)	CN Value	Weighted CN
Agricultural land	B	2.585,26	15,11	67	173.212,09
	D			80	206.820,40
			Composite CN II numbers		67
			Composite CN III numbers		84
			Composite CN I numbers		48
Rice Field	B	6.074,63	35,52	71	431.298,85
	D			81	492.045,17
			Composite CN II numbers		71
			Composite CN III numbers		86
			Composite CN I numbers		52

3.2.4. Runoff

The amount of surface runoff in the UOW is mainly influenced by rainfall, land use and soil moisture. Lakes/reservoirs, freshwater ponds and rivers contributed the highest runoff volume with an average of 2,570.12 mm/year, while conservation forests had the lowest runoff volume with an average of 88.84 mm/year due to their high infiltration rate. Even though there are settlements in the Upper Opak Watershed, the presence of forests has helped reduce water runoff. Vegetated land in watersheds can increase soil infiltration capacity and prevent natural disasters such as floods and erosion. Moist soil moisture conditions (AMC I) help reduce runoff. Figure 5 presents runoff mapping in the Upper Opak Watershed in 2018–2020.

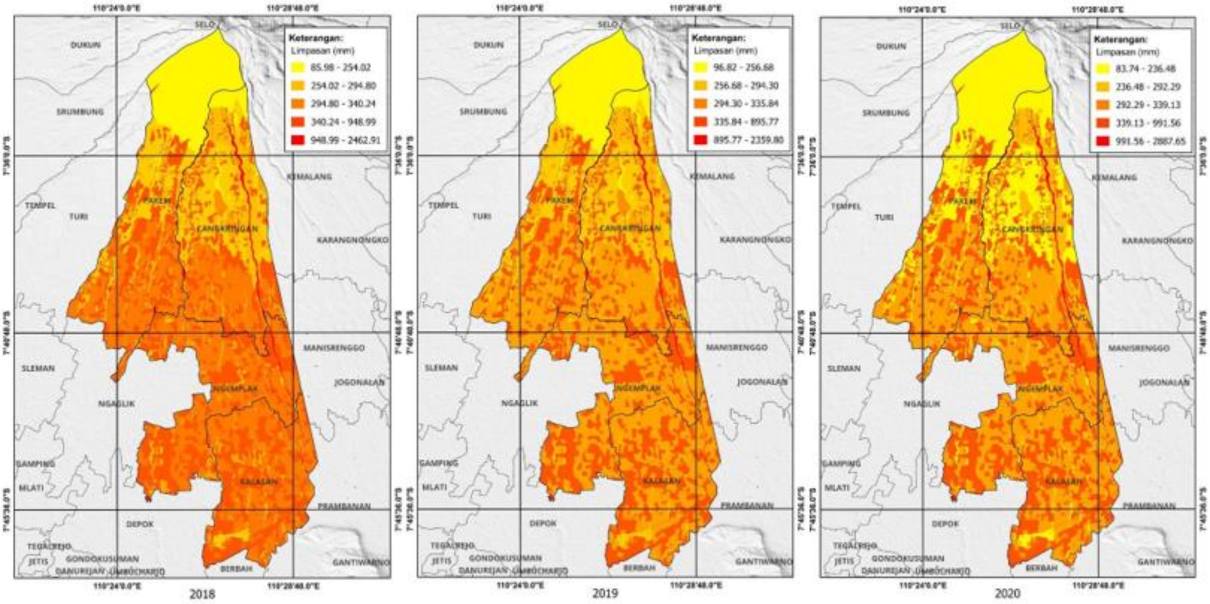

Figure 5. Runoff distribution map of the UOW) in 2018, 2019, and 2020

The runoff data in this research from model results and was not subjected to further calibration or data correction procedures. The decision to forgo calibration of the runoff data from the model was mainly attributed to the scarcity of accurate and representative observation data required for the calibration process. Calibration relies heavily on precise observation data to adjust the model effectively. When such data is unavailable or inadequate, the calibration process may be rendered less effective or even misleading. Consequently, it was determined that utilizing the model results without calibration was warranted, acknowledging that these results may be constrained in accuracy.

3.3. Application of Organophosphate Pesticides on Agricultural Land and Rice Fields

3.3.1. Types and Application Doses of Organophosphate Pesticides

Research conducted by Prananda (2017), Kizlyara (2019), and Rahmawati (2021) found that the active substance of organophosphate pesticides used on agricultural land in the Pakem and Cangkringan Subdistrict is toxic and dissolves easily in water. These active substances include Diazinon, Profenofos, and Chlorpyrifos. Profenofos is the active ingredient most commonly used, especially on chili and cucumber plants, while Diazinon and Chlorpyrifos are used on rice plants. Farmers in the Pakem Subdistrict adjust the frequency of pesticide spraying to the rainy and dry seasons, while farmers in the Cangkringan Subdistrict maintain the same frequency throughout the season. This difference affects the amount of pesticide applied to agricultural land. In addition, the plantation pattern in both locations hardly changed throughout the last five years; therefore, data validation for organophosphate application can be considered unnecessary. Table 5 shows the application doses of organophosphate pesticides in the Cangkringan and Pakem Subdistricts.

The area of agricultural land and rice fields is not too large, but Harjobinangun Village uses excessive amounts of pesticides, with an annual dose of 26,239,423.44 µg/Ha.year, while Pakembinangun Village, with a larger agricultural land area of 82 Ha, uses a higher dose. lower. amounting to 1,195,335.28 µg/Ha.year. Wukirsari Village in Cangkringan Subdistrict with an area of 49 Ha also uses excessive amounts of pesticides compared to Argomulyo Village. The use of pesticides in agriculture can pose a serious threat to human health, especially if pesticide residues reach water bodies. Research conducted by Taufik (2011) shows that rice cultivation along the watershed contributes to the entry of pesticides into the water. Research of Prananda (2017) and Kizlyara (2019) collected data of pesticide application rates and spraying practices through calibration and validation exercises with farmers in two subdistrict agricultural regions. This process entailed the use of questionnaires and direct field observations.

Table 5. Application dose of organophosphate pesticides per year

No.	District Name	Village Name	Area (Ha)	Dosage per Ha (µg/Ha.year)	Dose (µg/Ha.year)
1	Cangkringan	Argomulyo	49	1.319.966,39	64.678.352,97
		Wukirsari	24	4.690.550,83	229.836.990,81
2	Pakem	Pakembinangun	82	1.195.335,28	58.571.428,57
		Hargobinangun	87	11.315.811,23	1.954.733.209,07
		Harjobinangun	42	26.239.423,44	3.056.679.117,15
		Candibinangun	84	11.056.354,36	968.181.818,18
Total			**368**	**55.817.441,53**	**6.332.680.916,76**

3.3.2. Percentage of application dose of organophosphate pesticides in runoff

To estimate the concentration of organophosphate pesticides in the runoff, it is necessary to calculate the percentage of pesticide application dose that contributes to the runoff. This calculation requires parameters such as soil DT_{50}, KOC, and %OC. Table 6 shows that the percentage of organic carbon in the soil of the Cangkringan and Pakem Subdistricts is different. This can be caused by the use of different pesticides in each region. Excessive use of pesticides has a negative impact on the organic carbon content in the soil because it kills microorganisms that contribute to the formation of organic carbon.

Table 6. Percentage of active substance dose of pesticide that contributes to the runoff

Subdistrict	Active substance	DT_{50} soil	K_{OC}	%OC
Pakem	Diazinon	74.4	609	42.3
	Profenofos	7.0	2016	
Cangkringan	Diazinon	74.4	609	35.7
	Profenofos	7.0	2016	
	Klorpirifos	160	5509	

3.4. Estimated organophosphate pesticide concentrations in runoff

Determination of pesticide concentrations in runoff takes into account various parameters, such as the percentage of organophosphate pesticide application doses contained in the UOW runoff, the estimated concentration of active pesticide ingredients from agricultural land and rice fields in Cangkringan and Pakem Subdistricts, and the runoff discharge from the UOW. The estimated value of organophosphate pesticide concentrations in the UOW runoff per year are shown in Tables 7, 8, and 9 and visualized in the Figures 6.

The results indicate that the concentration of organophosphate pesticides from rice fields in the Pakem Subdistrict in the runoff on the UOW is relatively low compared to agricultural land. It is also known that the highest concentration of organophosphate pesticide contained in the upper Opak watershed runoff is Diazinon, while Chlorpyrifos produces the lowest concentration. This study also found a decreasing tendency in the concentration of active pesticide substances from 2018 to 2020. However, the decrease is not always appear significant.

In a study of pesticide pollution in the Babon River (Semarang City) by Prabowo and Subantoro (2012), it was found that land use contributed to the high level pesticide contamination through surface runoff. The decrease in organophosphate concentrations in the UOW runoff could be caused by land use in the area and the dilution of pesticides by rainwater.

In addition, some pesticide-active substances can bind to soil particles and are not carried away by surface runoff.

The pesticides concentration in the runoff may be decreasing in the year of 2019 and 2020. It might be linked into the reduced global activities due to the pandemic around 2020. With the increasing activity after pandemic was over in the last two years, this study need a further validation and exploration using the more recent observation data.

Table 7. Organophophate concentration in runoff from agricultural land in the Pakem Subdistrict

Active substance	Year	L%$_{runoff}$ (%)	P$_{UCRB}$ (µg year)	Q$_{runoff}$ (L/second)	ΔT (second)	PEC (µg /L)
Diazinon	2018	2.272	17,280,000.00	405.00	31,540,000	0.0031
Profenofos		0.673	68,654,351.74			0.0036
Diazinon	2019	2.370	17,280,000.00	400.30		0.0032
Profenofos		0.705	68,654,351.74			0.0038
Diazinon	2020	1.802	17,280,000.00	372.75		0.0026
Profenofos		0.531	68,654,351.74			0.0031

Table 8. Organophosphate concentration in runoff from rice fields in the Pakem Subdistrict

Active substance	Year	L%$_{runoff}$ (%)	PUCRB (µg year)	Q$_{runoff}$ (L/second)	ΔT (second)	PEC (µg /L)
Diazinon	2018	1,818	6.500.000,000	324,10	31.540.000	0,0012
Profenofos		0,538	4.184.907,834			0,0002
Diazinon	2019	1,890	6.500.000,000	319,21		0,0012
Profenofos		0,562	4.184.907,834			0,0002
Diazinon	2020	1,586	6.500.000,000	328,20		0,0010
Profenofos		0,467	4.184.907,834			0,0002

Tabel 9. Organophosphate concentration in runoff from agricultural land in the Cangkringan Subdistrict

Active substance	Year	L%$_{runoff}$ (%)	PUCRB (µg year)	Q$_{runoff}$ (L/second)	ΔT (second)	PEC (µg /L)
Diazinon	2018	2,682	53,448,163.3	405.00	31.540.000	0.0112
Profenofos		0,823	56,849,405.0			0.0037
Klorpirifos		0,309	9,102,386.7			0.0002
Diazinon	2019	2,789	53,448,163.3	400.30		0.0118
Profenofos		0,834	56,849,405.0			0.0038
Klorpirifos		0,322	9,102,386.7			0.0002
Diazinon	2020	2,128	53,448.163.3	372.75		0.0097
Profenofos		0,652	56,849,405.0			0.0032
Klorpirifos		0,245	9,102,386.7			0.0002

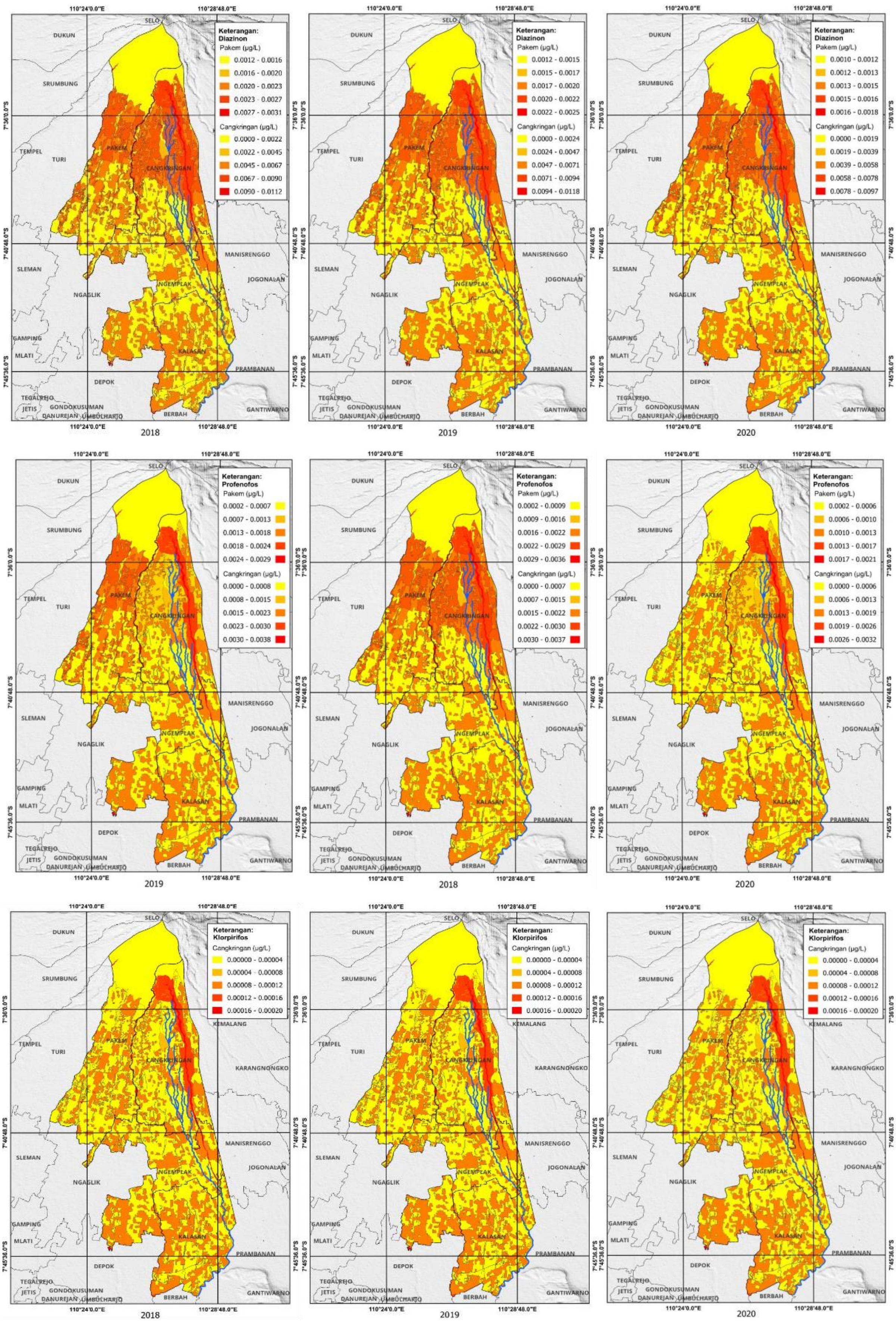

Figure 6. Distribution map of the concentration of pesticide active substances: Diazinon (top), Profenofos (middle), Chlorpyrifos (bottom) in 2018 (left), 2019 (middle), and 2020 (right).

3.5. Reducing the concentration of organophosphate pesticides in the surface runoff

The uses of pesticides are indispensable since a long time ago, especially with the significant increase of the world population in the 20th century, there is also an increasing demand of the food production. Tudi et al. (2021) stated that the pesticides in agricultural production plays an important role. Without the utilization of pesticides, the production of fruit and vegetable will have a 78% and 54% loss, respectively (Zhang et al., 2011). However, the recent knowledge and technology should be able to tackle this issue.

There are some ways to reduce the uses of pesticides such as the promotion of alternative pest management: integrated pest management, organic agriculutre, Good Agricultural Practices, agronomic practices, and resistant crops (Sapbamrer et al., 2023). The integrated pest management has a specific set of criteria for choosing the appropriate pesticide: (1) effectiveness against the target organism and low risk of resistance; (2) low acute and chronic toxicity to humans; (3) low toxicity to non-target organisms; (4) fast degradation in the environment; (5) good cost and profit margins for farmers (Damalas et al., 2011).

Other than the preventive way utilizing management framework, phytoremediation can be considered as one of the solution. Phytoremediation for agricultural runoff is more suitable to be implemented as a constructed wetland. The popularity of constructed wetland for treating agricultural runoff and wastewater has been increasing in the last few decades (Wang et al., 2017). A plant that can be used for removing heavy metals and organic wastes from water is Vetiver grass (Danh et al., 2009). Danh et al. (2009) argued that Vetiver grass is a good choice for treating the waste water because it has special characteristics in which it can resist the extremely adverse conditions of climate and growing medium. Nguyen et al. (2023) found that *Vetiveria zizanioides* can treat organic matters in contaminated surface water and could enhance pollutant removal as a green and eco-friendly solution. In the most recent study, Fajri et al. (2024) recommends to add endophyte bacteria in a floating treatment wetlands of *Vetiveria zizanioides* since wetland using *Vetiveria sp.* is reported of being lack of consistency and had low degradation in toxic conditions (Tara et al., 2019).

4. Conclusion

The research shows that the Cangkringan Subdistrict contributes the most to the concentration of organophosphate pesticides in the runoff of the Upper Opak Watershed (UOW). The runoff contains three types of active pesticide substances, with the highest concentration of the active substance Diazinon found in both Cangkringan and Pakem Subdistricts. In 2019, surface runoff from the Upper Opak Watershed was estimated to contain 0.0118 µg/L of the active substance Diazinon, 0.0038 µg/L of the active substance Profenofos, and 0.0002 µg/L of the active substance Chlorpyrifos from agricultural land in Cangkringan District. In Pakem Subdistrict, the runoff contained 0.0031 µg/L of the Diazinon and 0.0036 µg/L of the Profenofos. The presence of the active substance Chlorpyrifos in the UOW runoff was found to be very low for three consecutive years, at 0.0002 µg/L. Pesticide concentrations in the UOW runoff mainly come from agricultural land.

Further study is needed to update the recent conditions of the pesticide concentration since it has been a while after the latest data observed in this study. The future research could also be directed to a more comprehensive study by doing a model validation for the estimated pesticide concentration in surface water.

5. References

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