Agricultural Pesticide Use in the Upper Citarum River Basin, West Java, Indonesia

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1. Introduction

Pesticides are used in order to protect valuable assets such as crops and human health against potential adverse impacts from pest, insects, weeds, and pathogens. As such, pesticide use is a major foundation of the agricultural intensification observed since the middle of the 20th century (Masiá et al., 2014; Silva et al., 2019). The global amount of pesticides used has been estimated at approximately 6 billion pounds in 2011 and 2012 (USEPA, 2017). This amount keeps increasing, particularly in low and middle income countries (Akter et al., 2018; Balmer et al., 2019; Phillips McDouglas Agribusiness Intelligence, 2019). The extensive and improper use of pesticides can also have negative impacts, e.g. on the crop itself, on human health and on ecosystems, especially in aquatic environments (Verger and Boobis, 2013; Tsaboula et al., 2016; Kapsi et al., 2019). In order to prevent such negative impacts, the marketing and use of pesticides are strictly regulated in most countries.

Appropriate management of pesticides requires information on the types and amounts of pesticides used. Eurostat (2008) advocates collection of usage statistics in particular for: (1) provision of annual usage estimates in countries; (2) monitoring changes over time (Coupe and Capel, 2016); (3) environmental protection; (4) consumer protection: providing information for residue monitoring; (5) operator protection (improving or optimizing use); (6) monitoring the potential movement of pesticides into water; (7) policy advise during review programs (reviewing use of existing pesticides); (8) providing information for approval of new pesticides. However, the public availability of pesticide use data is generally scarce, i.e. because of proprietary data issues, poor registration, lacking regulations or the costs involved. Eurostat (2008) stipulates that the cost benefits for gathering actual usage statistics far outstrip the investments. An excellent example of collecting usage data is the Pesticide Use Reporting Program in California in which farmers are required to monthly report pesticide use (California Department of Pesticide Regulation, 2000).

Pesticide use data can take the form of sales data and usage data. Sales data are more generic and cannot be related directly to the actual use in time and space since they do not provide details on crop, timing, spatial variation and the dose applied (Eurostat, 2008). These details are needed in order to estimate pesticide emissions, model surface water contamination, estimate risks, set priorities and identify mitigation measures (Herrero-Hernández et al., 2017; Bidleman et al., 2002; Konstantinou et al., 2006; Al-Khazrajy & Boxall, 2016; Van Gils et al., 2019). Usage data do provide the kind of detail needed to satisfy this kind of governance, research and management needs. Unfortunately, usage data is typically unavailable or difficult to obtain for all crops produced in an area, particularly in low and middle income countries like Indonesia (Mariyono et al., 2018).

The aim of the present study was to determine the pesticide use by farmers in the Upper Citarum River Basin (UCRB) and make the data open access. The study was initiated to obtain input data required for predicting surface water concentrations of pesticides in the UCRB. In order to acquire the data, a survey among 174 farmers was conducted, focusing on the types and amounts of pesticides used on major crop types.

2. Material & Methods

2.1 Description of the Surveyed Area

The Upper Citarum River Basin (UCRB) is located between 107°15'36"- 107°57'00" E and 06°'43'48" - 07°'15'00" S (**Fig.1**). It is the upstream part of the Citarum River Catchment and drains into the Saguling Reservoir, west of the Bandung City. The UCRB covers a total area of approximately 1,822 km^2, consisting of 93 districts in 6 regencies and 2 cities (Harlan et al., 2018; Statistics Indonesia, 2015). Agricultural area dominates the area where about 200,000 people work as farmers (Statistics Indonesia, 2015). According to a study by Rochmanti (2009), pesticide usage is high in this area. The main agricultural crops grown are vegetables and rice. Flowers and fruits are also grown but in small-scale fields. **Table 1** presents an overview of the most common crop types in UCRB and their corresponding surface areas.

Crops	Area (Ha)	Percentage (%)
Rice	41183.3	37.92
Corn	10376.8	9.55
Potato	6154.8	5.67
Cabbage	6091.1	5.61
Chili	4329.8	3.99
Cassava	3894.7	3.59
Coffee	1788.6	1.65
Tomato	1689.4	1.56
Sweet potato	1336.1	1.23
Spring onion	626.4	0.58
String beans	447.2	0.41
Carrot	439.2	0.4
Strawberry	83.8	0.08
Broccoli	38.1	0.04
Others	30124.7	27.74
Total	108604	100

Table 1: Crop types, their surface area and percentage of total agricultural area in UCRB (Statistics Indonesia, 2015) This is a caption

The average annual rainfall in the UCRB varies from 1200 mm to 3000 mm, with an average of 2215 mm. Almost 70% of this rainfall occurs in the wet season. The wet season typically starts in November and ends in April, with an average monthly rainfall of approximately 250 mm (typical range: 100-500 mm).

During the dry season from June to September, monthly rainfall is usually less than 50 mm (Deltares, 2010). Other months constitute a transitional period. The high annual rainfall and the mean daily temperature that varies between 18@C and 30@C provide favorable climatic conditions for growing vegetables in the UCRB.

2.2 Survey Design and Data Collection

A questionnaire was designed to obtain information about the amount and types of pesticides used by farmers living in the UCRB agricultural area. The questionnaire comprised 21 questions (see **Supplementary Data 1**) that focused on: 1) general information about the respondents (name, gender, age, address); 2) farmland information such as area, type of crops, harvest, planting period, and planting frequency per year; 3) pesticide application data such as brands purchased, type of pesticide, quantity, and frequency of application.

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`Suplementary Data 1_pesticide questionnaire_final version.docx` available at https://authorea.com/users/286733/articles/423709-agricultural-pesticide-use-in-the-upper-citarum-river-basin-west-java-indonesia

To test the questionnaire, a pre-survey was conducted among 20 farmers who were not included in the final survey. The pre-survey aimed to evaluate the feasibility of the questionnaire draft, the time needed for planning the survey, and whether the results were in line with the survey goals. Based on the results, the questionnaire draft was slightly edited, resulting in the final questionnaire.

For the final questionnaire, 174 farmers were surveyed in eight districts at different elevations along the UCRB (Figure 1), i.e. Lembang (n=26), Cihampelas (n=32), Solokan Jeruk (n=28), Ciparay (n=18), Majalaya (n=20), Pacet (n=7), Pangalengan (n=12), and Ciwidey (n=31). The survey was conducted between January and March 2016. For every location, we were accompanied by a local guide who was known in the local community and farmers were selected by walking the area and randomly selecting farms to visit.

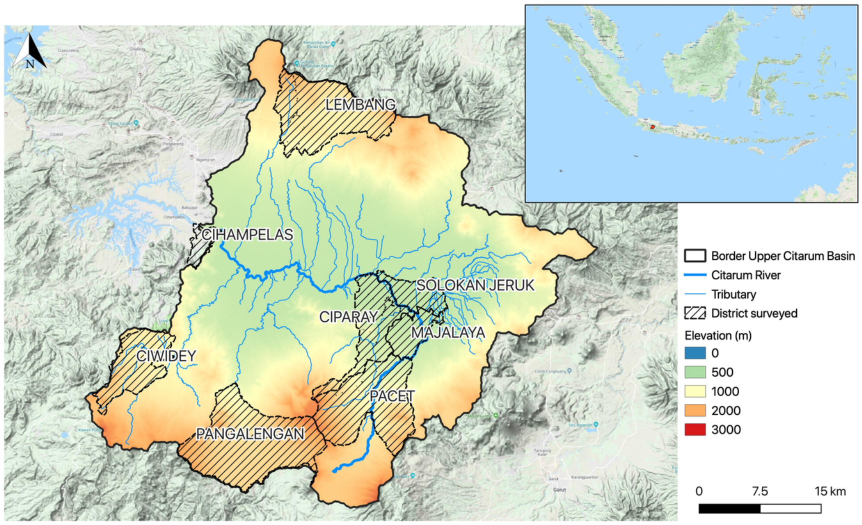

Figure 1: Location of the Upper Citarum River Basin (UCRB) in Indonesia (red dot in top right overview map). Districts (*Kecamatan*) in which the respondents were located, elevation and drainage system are shown in the main map. The respondents are stratified across elevation. Cihampelas, although just downstream of the UCB drains to the Citarum and represents respondents growing lowland crop types. The Pangalengan district extends across the mountain range, however all respondents in this district are located inside the Citarum River Basin.

The surveys were conducted by personal visits to the farmers in the daytime by two interviewers. The interview was face-to-face, participation was entirely voluntary, and farmers were free to deny information without further justification. In practice, no farmer objected and all questionnaires included in the final dataset were complete for the pesticide use data. To protect the rights, dignity, safety, and well-being of the respondents, ethical clearance was sought and issued by the Commission for Ethic of Health study from Dustira Hospital Cimahi, West Java. Each participant received a gift of staple food as compensation, such as instant noodles, coffee/tea, cooking oil, and sugar. The questionnaire forms were filled in by the interviewers. During the survey, interviewers did not only record the respondent answers but also performed a crosschecking to confirm his or her response to avoid misunderstanding, especially regarding the pesticide application practice. For example, farmers were asked to show the interviewer the materials and equipment they used or to demonstrate their pesticide application practices in order to avoid confusion. Interviewers checked the weight percentage or concentration of pesticide from each product, amount of application, and the brand package was also photographed for further reference. Whenever farmers used a container or spraying tank in their pesticide preparation, the container's or tank's dimensions or volume were measured.

2.3 Estimation of Pesticide Usage

Equation 1 was applied to calculate the pesticide use (i.e., expressed in active ingredient or a.i.) per year. Throughout the paper, the words pesticide and active ingredient are used as synonyms. We use the term "pesticide brand" to refer to a product of pesticides sold as a specific formulation.

$$Pa = \frac{C \times V \times f}{A} \quad \textbf{(1)}$$

Where, Pa is the annual amount of pesticide usage per hectare (g /ha/year), C is the concentration of the active ingredient in the product (g/l), V is the total spraying volume of pesticide brand (l/application), f is frequency of pesticide application (times/year), and A is the size of surveyed agricultural area of each individual farmer (ha).

In case the applied pesticide was in solid form, its concentration was expressed as a weight percentage (**Equation 2**).

$$Pa = \frac{\%w \times W \times f}{A} \quad \textbf{(2)}$$

With the following new parameters, i.e. $\%w$ is weight percentage of a.i. in the pesticide brand (%) and W is the total weight of the pesticide brand used (g/application).

2.4 Comparing Prescribed vs. Actual Use

For rice, which covered almost 65% of the surveyed area, the prescribed use of pesticide was compared to the actual use. The data on the prescribed use was mostly taken from the Indonesian national guidelines (Directorate of fertilizers and pesticides, 2019). This was done per brand, since prescription instructions are brand-specific. When information on the minimum and maximum prescribed use per hectare were available, these were compared with the actual use. When only prescribed dilution ranges were available, these values were also compared with the actual dilution value from the survey result. In case the brand was not recommended for use on rice, we used the minimum and maximum prescribed use values from other crops.

3. Results

3.1 Profile of the Respondents and Study Area

The total number of respondents was 174, consisting of 30 female farmers (17.2%) and 144 male farmers (82.8%). The average age of surveyed farmers was 52 (± 11) years for female respondents, and 53 (± 12) for male respondents. From the 174 surveyed farmers, 156 (90%) used pesticides. **Table 2** summarizes the characteristics of the respondents and their farms.

Information	Total	Percentage (%)	Average	SD
Gender				
Female	30	17.24	-	-
Male	144	82.76	-	-
Total respondents	174	100	-	-
Age				
Female	-	-	51.9	11.1
Male	-	-	53.3	12.5
Total respondents	-	-	53.1	12.3
Pesticide Use				
Nr. respondents using	156	89.66	-	-
Nr. respondents not using	18	10.34	-	-
Crops				
Average number of crops per farmer	-	-	1.4	-
Crop types	23	100	-	-
Area of pesticide use (m2)				
Used	669196.0	90.3	-	-
Unused	72080	9.7	-	-
Size of surveyed area				
Area (m2)	741276	100	-	-
Area per farmer (m^2)	-	-	4260.2	5285.7

Table 2: Characteristics of the respondents and surveyed area.

The surveyed farmers manage in total an agricultural area of 74.13 ha, with an average of 0.43 ha per farmer. The majority of farmers were fulltime involved in agriculture. The respondents mentioned 23 crop types of which rice was the most common crop (64.84%). Pesticides were applied on 90% of the surveyed area, no pesticides were used on banana and tumeric field. **Table 3** summarizes the types, areas and periods of the surveyed crops.

Crop	Number of farmers planting	Total surveyed area (m2)	% Area	Planting period (months)		Frequency of planting per year (times/year)	
				Range	Average	Range	Average
Rice	111	480640	64.84	3 - 5	3.79	1 - 3	2.14
Chili	35	42676.67	5.76	3 - 6	3.86	1 - 4	2.69
Tomato	21	26763.33	3.61	3 - 4	3.19	1 - 4	2.33
Cabbage	19	29726.67	4.01	1 - 3.5	2.39	1 - 10	3.53
Coffee	8	81430	10.99	6 - 12	10.5	1 - 1	1
Broccoli	6	15960	2.15	2 - 3	2.33	2 - 5	2.5
Corn	5	9720	1.31	3 - 6	4.2	2 - 3	2.4
Spring onion	5	2940	0.4	2 - 3	2.2	4 - 6	5.4
Strawberry	5	4186	0.56	3 - 6	3.6	2 - 4	3.6
Carrot	4	3640	0.49	3 - 3	3	3 - 4	3.75
Potato	3	6300	0.85	3 - 3	3	3 - 4	3.33
String beans	3	2566.67	0.35	2 - 2	2	3 - 3	3
Cassava	3	6966.67	0.94	12 - 12	12	1 - 1	1
Sweet potato	3	3266.67	0.44	3 - 3	3	3 - 3	3
Chayote	2	8400	1.13	4 - 4	4	2 - 2	2
Lettuce	2	5600	0.76	1.5 - 3	2.25	2 - 2	2
Long bean	2	1446.67	0.2	3 - 3	3	3 - 3	3
Cauliflower	1	1166.67	0.16	-	2.5	-	2
Banana	1	1400	0.19	-	3	-	2
Eggplant	1	980	0.13	-	2.5	-	3
Tumeric	1	700	0.09	-	12	-	1
Bitter gourd	1	2800	0.38	-	2	-	5
Cucumber	1	2000	0.27	-	2	-	6
Total		741276.02	100				

Table 3: Type, area and planting period of crops in UCRB.

3.2 Types of Pesticides, Pesticide – Crop Type Combinations and Frequency of Application

The survey showed that 31 types of pesticides were used by 156 farmers. These pesticides consist of 18 insecticides, 8 fungicides, 2 plant growth regulators (PGR), one rodenticide and 2 herbicides (**Table 4**).

Pesticide	CAS number	Pesticide group*)	Chemical group**)
2-Nitrophenol sodium salt	824-39-5	PGR	Sodium nitrocompound
4-Nitrophenol sodium salt	824-78-2	PGR	Sodium nitrocompound
Abamectin	71751-41-2	I	Avermectin
Alpha-cypermethrin	67375-30-8	I	Pyrethroids
Azoxystrobin	131860-33-8	F	Methoxy-acrylates
Beta-cyfluthrin	68359-37-5	I	Pyrethroids
Brodifacoum	56073-10-0	R	Hydrocoumarin
Carbofuran	1563-66-2	I	Carbamates
Chlorantraniliprole	500008-45-7	I	Diamides
Chlorfenapyr	122453-73-0	I	Pyrroles
Chlorothalonil	1897-45-6	F	Chloronitriles
Chlorpyrifos	2921-88-2	I	Organophosphates
Cypermethrin	52315-07-8	I	Pyrethroids
Deltamethrin	52918-63-5	I	Pyrethroids
Difenoconazole	119446-68-3	F	Triazoles
Dimehypo	52207-48-4	I	Nereistoxin analogues
Emamectin benzoate	155569-91-8	I	Avermectin
Endosulfan	115-29-7	I	Organochlorines
Imidacloprid	138261-41-3	I	Neonicotinoids
Lufenuron	103055-07-8	I	Benzoylureas
Mancozeb	8018-01-7	F	Dithio-carbamates
Maneb	12427-38-2	F	Dithio-carbamates
Mefenoxam (Metalaxyl-M)	70630-17-0	F	Acylalanines
Methomyl	16752-77-5	I	Carbamates
Metiram	9006-42-2	F	Dithio-carbamates
Metsulfuron-methyl	74223-64-6	H	Sulfonylurea
MIPC (Isoprocarb)	2631-40-5	I	Carbamates
Paraquat dichloride	1910-42-5	H	Bipyridylium
Profenofos	41198-08-7	I	Organophosphates
Propineb	12071-83-9	F	Dithio-carbamates
Spinetoram	187166-40-1	I	Spinosyns

Table 4: Pesticides used in UCRB, including CAS number, pesticide and chemical group. *) PGR: Plant Growth Regulator; I: Insecticide; R: Rodenticide; F: Fungicide; H: Herbicide. **)Classification of the chemical group was based on MoA (Mode of Action) classification of Insecticide Resistance Action Committee (IRAC, 2019), Fungicide Resistance Action Committee (FRAC, 2019), Herbicide Resistance Action Committee (HRAC, 2010), and Rodenticide Resistance Action Committee (RRAC, 2015).

The raw results of the pesticide survey are listed in **Supplementary Data 2** , consisting of concentration or weight percentage of the pesticide (based on information on the brand package), actual use, i.e. the application frequency and amount for each crop. Of the surveyed crops, the number of different pesticides used was highest in rice (15 types), chili and tomato (13 types for each), and cabbage (11 types). From the pesticides, Mancozeb and Profenofos were most often mentioned by the respondents with a total of 67 and 63 times, respectively. The pesticide – crop type combinations are summarized in **Figure 2** . The size of the squares indicates the number of fields that respondents report as a pesticide - crop type combination.

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`Suplementary Data 2_pesticide survey result.xlsx` available at https://authorea.com/users/286733/articles/423709-agricultural-pesticide-use-in-the-upper-citarum-river-basin-west-java-indonesia

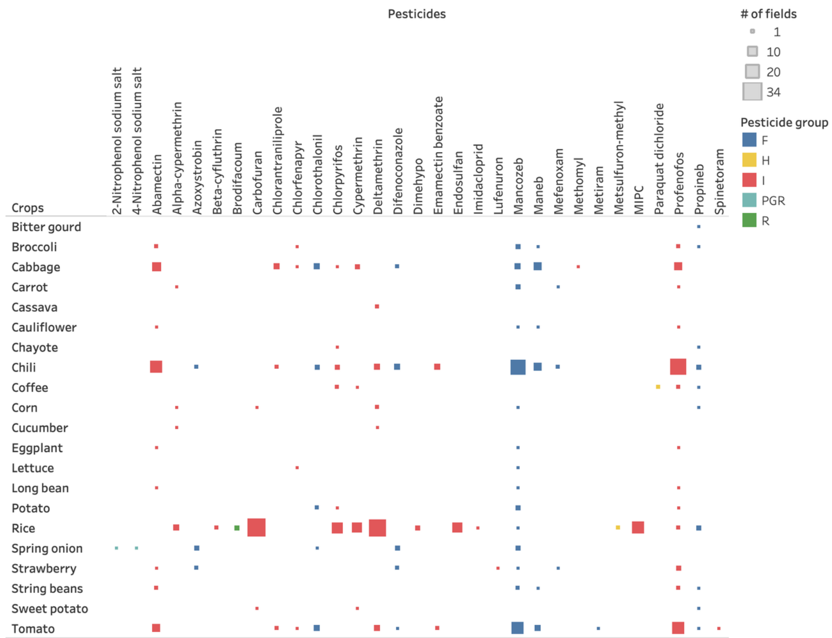

Figure 2: The number of agricultural fields per pesticide - crop type combination. The size of the squares corresponds to the number of fields on which the pesticide is applied, the colour indicates pesticide group (PGR: Plant Growth Regulator; I: Insecticide; R: Rodenticide; F: Fungicide; H: Herbicide).

We found that Carbofuran and Deltamethrin were the two most frequently mentioned pesticides in rice farming, i.e., 34 rice fields were applied with Carbofuran and 32 rice fields with Deltamethrin. Carbofuran is one of the most toxic Carbamate pesticides and it is used to control aphids, stem borers, and golden snails. Deltamethrin is used to control insect pests such as cutworm and diamond back moth (Fabro & Varca, 2012). The usage of rodenticides (Brodifacoum) and herbicides (Metsulfuron-methyl) in UCRB rice fields was low compared to the insecticides. Brodifacoum is typically used to control rats, while Metsulfuron-methyl is typically used to control weeds (Derbalah et al., 2019).

Profenofos and Mancozeb were widely used in vegetables cultivation, e.g. in chili and tomato fields (**Fig. 2**). 26 chili fields were treated with Profenofos, and 24 fields with Mancozeb. For tomato, 15 fields were treated with Profenofos and 14 fields with Mancozeb. From the 13 types of pesticides which were used on tomato, 10 pesticides were also used on chili. It is because most tomato farmers also grow chili in this area. The result revealed that farmers generally used the similar pesticides for different vegetable types; only the frequency and amount applied varied based on area and vegetable types.

To estimate the amount of pesticides used, the concentration or weight percentage of each pesticide and its frequency of application are needed. These parameters vary per pesticide, crop type and farmer. The survey results show that farmers in the UCRB have developed their own dosage regimes, application frequencies and recipes for pesticide mixtures for their crops based on their experience. Almost all of them mixed multiple pesticides in the application, except for lettuce, chayote, cassava, and bitter gourd. The application frequency of each pesticide per crop type is depicted in **Figure 3** .

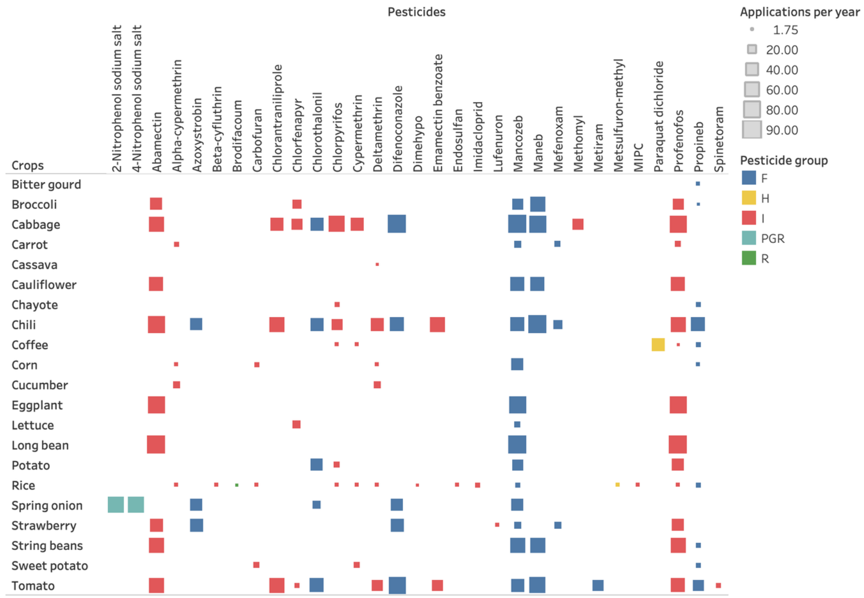

Figure 3: Number of pesticide applications per year. The size of the squares gives the number of applications per year, the color indicates pesticide group (PGR: Plant Growth Regulator; I: Insecticide; R: Rodenticide; F: Fungicide; H: Herbicide).

The number of pesticide applications per year is based on the monthly average number of applications (**Supplementary Data 3**). In case the farmer used more than one pesticide brand containing the same pesticide, this was counted as one application event. **Figure 3** shows that the number of applications per year is highest on vegetables, most notably Abamectin, Mancozeb, and Profenofos in long bean, Difenoconazole and Mancozeb in cabbage, and Maneb in chili. In vegetables such as chili, tomato, and broccoli, Profenofos and Mancozeb were applied 5-7 times/month on average. Application frequency was even higher in cabbage with an average frequency of 8 - 10 times per month. These two pesticides are typically used to control caterpillars, whiteflies, and mealy bugs (Profenofos), and leaf diseases such as leaf spot and rust (Mancozeb) (Derbalah et al., 2019). For rice, as the most surveyed crop, the application frequency is mostly less than once per month, or 1-3 times per growing season (3 - 4 months). Overall, Abamecetin, Mancozeb, Maneb, and Profenofos are pesticides that are applied at the highest frequency for most crops.

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`Suplementary Data 3_table of average frequency of pesticide application.xlsx` available at https://authorea.com/users/286733/articles/423709-agricultural-pesticide-use-in-the-upper-citarum-river-basin-west-java-indonesia

3.3 The Estimation of Average Annual Use of Pesticide per Crop Type

The estimation of annual average amounts of pesticide usage per hectare (g/ha/year) as calculated with **Equations 1** and **2** are listed in **Table 5**.

Pesticide	CAS number	Average pesticide usage by farmers (g/ha/year)																				
		Rice	Chili	Tomato	Cabbage	Coffee	Broccoli	Corn	Spring onion	Strawberry	Carrot	Potato	String beans	Cassava	Sweet potato	Chayote	Lettuce	Long bean	Cauliflower	Eggplant	Bitter gourd	Cucumber
2-Nitrophenol sodium salt	824-39-5	-	-	-	-	-	-	-	77.14	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Nitrophenol sodium salt	824-78-2	-	-	-	-	-	-	-	115.71	-	-	-	-	-	-	-	-	-	-	-	-	-
Abamectin	71751-41-2	-	460.31	311.73	189.67	-	112.58	-	-	280.52	-	-	141.87	-	-	-	-	66.86	199.35	15.71	-	-
Alpha-cypermethrin	67375-30-8	97.5	-	-	-	-	-	108.0	-	-	25.71	-	-	-	-	-	-	-	-	-	-	216.0
Azoxystrobin	131860-33-8	-	8057.14	-	-	-	-	-	9571.43	3051.43	-	-	-	-	-	-	-	-	-	-	-	-
Beta-cyfluthrin	68359-37-5	107.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brodifacoum	56073-10-0	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbofuran	1563-66-2	1281.39	-	-	-	-	-	1714.29	-	-	-	-	-	-	1285.71	-	-	-	-	-	-	-
Chlorantraniliprole	500008-45-7	-	2771.43	5371.43	9307.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorfenapyr	122453-73-0	-	-	771.43	642.86	-	7346.94	-	-	-	-	-	-	-	-	-	7346.94	-	-	-	-	-
Chlorothalonil	1897-45-6	-	2485.71	[illegible]	[illegible]	-	-	-	14464.29	-	-	11571.43	-	-	-	-	-	-	-	-	-	-
Chlorpyrifos	2921-88-2	1484.25	26150.26	-	1714.29	695.24	-	-	-	-	-	355.56	-	-	-	71.43	-	-	-	-	-	-
Cypermethrin	52315-07-8	155.68	-	-	[illegible]	[illegible]	-	-	-	-	-	-	-	-	487.93	-	-	-	-	-	-	-
Deltamethrin	52918-63-5	95.58	130.71	92.14	-	-	-	180	-	-	-	-	-	75	-	-	-	-	-	-	-	360

The pesticide-crop combination with the highest annual average amount of pesticide used per ha was Chlorothalonil on tomato with 32.2 kg/ha/year, followed by Mancozeb on corn with 28.6 kg/ha/year, and Chlorpyrifos on chili with 26.1 kg/ha/year. The pesticide-crop combination with the lowest average amount of pesticide used per ha per year was Brodifacoum on rice with $2 \cdot 10^{-4}$ kg/ha/year, then followed by Metsulfuron-methyl on rice and Cypermethrin on coffee with $7.2 \cdot 10^{-3}$ kg/ha/year and $1 \cdot 10^{-2}$ kg/ha/year, respectively.

3.4 Comparison of Prescribed vs. Actual Use

A comparison between prescribed and actual use was conducted to evaluate whether the pesticides were used according to the brand-specific prescriptions. The comparison was made for rice only, representing more than 64% of the total surveyed area in this study. Prescribed use was specified as the amount of pesticide brand per ha or sometimes as the amount of pesticide brand per L fluid per application. **Table 6** summarizes prescribed and actual use data reported in amount of pesticide brand per ha and **Table 7** in amount of pesticide brand per L fluid applied. **Table 6** shows that 4 out of 15 brands (i.e., Curater 3 GR, Akodan 35 EC, Megathane 80 WP, and Allyplus 77 WP) had lower average values of actual use than the prescribed use range. Three out of 15 brands (i.e., Columbus 600 EC, Winder 100 EC, and Decis 25 EC) had higher average actual use values than the prescribed use range. **Table 7** shows that the average actual use of 4 out of 10 brands (i.e., Dursban 200 EC, Rizotin 100 EC, Mipcinta 50 WP, and Curacron 500 EC) was lower than the prescribed use range, while only 1 brand (i.e., Winder 100 EC) had a higher value than prescribed. Comparison between prescribed and actual use in other crops are listed in **Supplementary Data 4**.

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`Suplementary Data 4_table of actual use vs prescribe use for all crops.xlsx` available at https://authorea.com/users/286733/articles/423709-agricultural-pesticide-use-in-the-upper-citarum-river-basin-west-java-indonesia

Pesticide	Brand	Occurrence	Prescribed use range		Actual use*)	Unit	Note
			Lowest	Highest	Average		
Alpha-cypermethrin	Fastac 15 EC	4	0.2	1.5	1.23	l/ha	palm oil tree, soya bean, tea, chili
Beta-cyfluthrin	Buldok 25 EC	2	0.25	2	1.7	l/ha	chili, soya bean, tea, corn, cotton tree, pepper, tobacco, melon
Brodifacoum	Petrokum 0005 BB	3	1	2	1.92	kg/ha	rice
Carbofuran	Curater 3 GR	3	12.75	17	3.69	kg/ha	rice
Carbofuran	Furadan 3 GR	32	8.5	25.5	12.27	kg/ha	rice
Chlorpyrifos	Columbus 600 EC	1	0.5	1	2.38	l/ha	shallot
Cypermethrin	Arrivo 30 EC	8	0.5	2	0.9	l/ha	corn, oil palm tree, tea, cotton tree
Cypermethrin	Columbus 600 EC	1	0.5	1	2.38	l/ha	shallot
Deltamethrin	Decis 25 EC	32	0.08	0.5	0.78	l/ha	palm oil tree, cucumber, melon, tobacco
Endosulfan	Akodan 35 EC	10	1.24	2.47	0.75	l/ha	all crops in general
Imidacloprid	Winder 100 EC	1	0.13	0.25	0.95	l/ha	rice
Mancozeb	Megathane 80 WP	1	2.63	2.63	0.11	kg/ha	potato
Metsulfuron-methyl	Allyplus 77 WP	2	0.32	1.5	0.31	kg/ha	rice
MIPC (Isoprocarb)	Mipcinta 50 WP	14	0.25	2	0.82	kg/ha	rice
Propineb	Antracol 70 WP	3	0.25	1	0.76	kg/ha	rice

Table 6: Comparison of prescribed and actual use of pesticide per hectare for rice. For pesticides without prescribed use for rice the lowest and highest were taken from the other recommended crop types. *)Black color: the actual use is in the range of prescribed use, green color: the actual use is lower than the prescribed use, red color: the actual use is higher than the prescribed use.

Pesticide	Brand	Occurrence	Prescribed use range		Actual use*)	Unit	Note
			Lowest	Highest	Average		
Alpha-cypermethrin	Fastac 15 EC	4	0.38	2	1.69	ml/l	cabbage, cacao tree, tobacco, tomato, watermelon
Beta-cyfluthrin	Buldok 25 EC	2	0.15	3	1.41	ml/l	orchid, grape, garlic, corn, orange, potato, coffee, apple, oil palm tree, shallot, soya bean, starfruit, chili, long bean, cacao tree, cabbage, manggo, melon, watermelon, tobacco, tomato
Chlorpyrifos	Dursban 200 EC	12	1.5	3	1.06	ml/l	chili, cacao tree, cabbage, tomato
Cypermethrin	Rizotin 100 EC	1	1.5	2	0.63	ml/l	cabbage
Cypermethrin	Arrivo 30 EC	8	0.5	4	2.25	ml/l	shallot, chili, orange, soya bean, potato, cucumber, melon, tomato, cashew tree, cacao tree, pepper, watermelon, tobacco
Deltamethrin	Decis 25 EC	32	0.25	2	1.71	ml/l	orchid, Jatropha curcas, orange, long bean, coffee, apple, starfruit, shallot, chili, corn, green bean, watermelon, cacao tree, soya bean, tea, potato, cabbage, mango, melon
Imidacloprid	Winder 100 EC	1	1	1	1.96	ml/l	rice
MIPC (Isoprocarb)	Mipcinta 50 WP	12	3	3	1.61	g/l	rice
Profenofos	Curacron 500 EC	2	1.13	2.25	0.75	ml/l	shallot, chili
Propineb	Antracol 70 WP	3	0.7	6	0.78	g/l	grape, cabbage, apple, Jatropha curcas, cucumber, krisan flower, mango, palm oil tree, shallot, orange, petsai, tobacco, garlic, chili, clove, strawberry, peanut, potato, kina, coffee, pepper

Table 7: Comparison of prescribed and actual dilution of pesticide per liter in rice. For pesticides without prescribed dilution for rice the lowest and highest were taken from the other recommended crop types. *)Black color: the actual use is in the range of prescribed use, green color: the actual use is lower than the prescribed use, red color: the actual use is higher than the prescribed use.

4. Discussion

4.1 Pesticide Use

We interviewed 174 farmers to obtain an impression of pesticide use on the farmed crops. The majority (154) was using pesticides and the most frequently used pesticide groups were insecticides and fungicides. Most of the pesticides that we found in our survey were introduced on the market in the 20^{th} century with the insecticides Chlorantraniliprole (2008) and Spinetoram (2007) as notable exceptions. Fourteen of the 31 pesticides that we identified were also reported by Sekiyama et al. (2007) who performed a study on the use of pesticides in the Citarum River Basin in 2006. The widest used pesticides in our survey were Profenofos (in 13 of 21 crop types) and Mancozeb (in 15 of 21 crop types) which is in line with the results of Sekiyama et al. (2007) who reported 13.5% and 24.3% of their respondents using these two pesticides, respectively. Of the 10 most frequently used pesticides reported by Sekiyama et al. (2007), we did not find Permethrin (insecticide), Spinosad (insecticide), Iprodione (fungicide), Dimethomorph (fungicide) and *Bacillus thuringiensis* (biological). This illustrates the dynamic nature of pesticide use which is governed by a variety of factors such as supply by industry, authorization by the government and farmer-specific considerations (Mariyono et al. 2018).

The average pesticide usage was influenced by the frequency of application on each crop type. The frequency of pesticide application on vegetables was highest (7-10 times/ month) while for rice the lowest (1-3 times/growing season). The annual average of pesticide usage in UCRB range from $2 \cdot 10^{-4}$ kg/ha (Brodifacoum on rice) to 32.2 kg/ha (Chlorothalonil on tomato). On average, 24.6 kg/ha pesticide is applied annually on UCRB agricultural land, which is lower than Bahamas and Mauritius with 59.4 kg/ha and 25.5 kg/ha, respectively (Ly, 2013). But it is relatively higher compare to other Asian countries, such as 14 kg/ha in China (Yang et al., 2014), 7.2 kg/ha in Malaysia, 13.1 kg/ha in Japan, and 0.2 kg/ha in India (Ly, 2013). This high estimation is plausible because our study area represents a densely populated and intensively farmed landscape.

Maggi et al. (2019) estimated crop-specific pesticide use (kg/ha) globally. When comparing overlapping crop types and pesticides used in Maggi et al.(2019) and our study, we notice a mismatch: for rice and corn all applied pesticides differ; for cabbage we share one common pesticide (Chlorothalonil); Chlorpyrifos and Azoxystrobin are also present in Maggi et al.(2019) but for different crops. We conclude that pesticide use is very region specific and are not sure a global map of pesticide use distribution is representative for actual use.

Our results on prescribed versus actual use on rice show that farmers use pesticides for rice that are not recommended for rice farming. Most types of pesticides are used (per hectare or as diluted with water) more than the lowest recommended amounts; about a quarter are used more than the highest recommended amount. For rice farmers in Sulawesi, Indonesia, Batoa et al. (2019) found that the prescribed frequency (influencing use-per-hectare) and dose were followed by about 1/3 of the interviewed farmers, while 2/3 deviated from recommended frequency and dose in both higher and lower than recommended. Zhang et al. (2015) reported under- and overuse for Chinese farmers for various crops. Mariyono et al. (2018) reported overuse on Java Island, Indonesia, but they did not specify the pesticide type. A study by Fan et al. (2015) in China showed that most of the farmers surveyed lacked the ability to understand the instruction manuals and pesticide labels. Additionally, the farmers often failed to select an appropriate pesticide to resolve a specific pest problem (Akter et al., 2018). These kinds of problems are also common in other agricultural areas (Fan et al., 2015; Houbraken et al., 2016; Akter et al., 2018). It stresses the importance of having transparent national pesticide usage guidelines and training farmers thoroughly in pest management, i.e. the diagnosis as well as the application of pesticides and alternative pest control strategies.

The survey showed that some rice farmers still used Endosulfan, usually to control stem borers, and green and brown leafhoppers (Fabro & Varca, 2012; Derbalah et al., 2019). Endosulfan is an organochlorine compound that was internationally banned in 2011 via the Stockholm Convention (UNEP, 2011; Balmer et al., 2019). Another banned insecticide found in the survey was Chlorpyrifos. The use of Chlorpyrifos in Indonesia is banned in rice agriculture (Ministry of Agriculture Republic Indonesia, 2011; Ministry of Agriculture Republic Indonesia, 2015). Sousa et al. (2018) found that concentrations of Chlorpyrifos and Endosulfan in most developing Asian countries, e.g. India, exceeded the values of the European Environmental Quality Standards (EQS) suggesting potential harm for aquatic ecosystem. Therefore, it is very important to monitor and enforce the usage guidelines, especially for these two pesticides.

4.2 Gathering Usage Statistics

Public availability of pesticide use data is generally scarce, i.e. because of proprietary data issues, poor registration and lacking regulations. Sales statistics in combination with recommended use of national institutions offer some insight in the types and amounts of pesticides used, but such data are generally only available at higher spatial scales. More detailed pesticide use statistics are needed for local environmental risk assessments, consumer protection (guiding residue monitoring), operator protection (improving or optimizing use) and monitoring the potential movement of pesticides into water (Eurostat, 2008). For example, our results show that farmers do not always apply the pesticides to the prescribed crop types. Secondly, the amounts applied vary, sometimes exceeding the highest recommended dose. In some cases, brands containing the same pesticide are applied simultaneously. Finally, the frequency of application also varies per farmer.

Although pesticides are among the most toxic substances released into the environment, very little public information is available on their use patterns, especially at the level of brands, active ingredients and at refined spatial scales. Information on which pesticide is used where and when, and in what quantities, is essential for protection of human health and the environment, as well as for effective pest management. In our opinion, a data should be public because people have a right to know when, where, and how pesticides are being applied so that they can take the appropriate measures to protect themselves and the environment. Accurate information on pesticide use enables better risk assessments and supports the identification of problematic use practices so they may be targeted for developing alternatives (PAN Germany, 2003). Comparison of our results with a previous study on pesticide use in the UCRB (Sekiyama et al. 2007) shows considerable differences in pesticide use over time, indicating that results of single surveys are representative for a limited timeframe only. Gathering representative data over a longer timeframe requires the establishment of a pesticide use reporting system. California's pesticide-use reporting system represents the largest undertaking of this kind, and can act as a model for future pesticide disclosure programs (CDPR, 2000).

4.3 Reducing Pesticide Use

Our results may be used to identify management options for reducing the pesticide use. For example, the results show that crops like tomatoes, chili and cabbage require more pesticides than rice, cauliflower and eggplant. Also, Mariyono et al. (2018) reported that pesticide use even differs between local varieties and cultivated varieties within a crop type, where local varieties need more pesticides. Managers may consider to stimulate the production of crops, or crop varieties, that demand less pesticides. Another option is to replace more toxic pesticides by less toxic alternatives. However, most of the pesticides used in the UCRB fall in WHO class 5 ("may be harmful if swallowed"), with only a few pesticides falling in categories 2 or 3 ("fatal/toxic if swallowed"; IPCS, 2010). A more refined identification of management interventions would be possible if we would understand why farmers choose various pesticides, why they use the dosages and application frequencies as they do and sometimes overrule the prescriptions. In Sulawesi, Indonesia, Batoa et al. (2019) found that 73% of rice farmers interviewed state to know the use rules, whereas about 27% knows little or nothing about prescribed use. So the majority seem to know the recommendations and knowingly deviate. However, in contrast, Zhang et al. (2015) reported both under- and overuse for Chinese farmers and say it may be related to lack of knowledge. Bagheri et al. (2019) studied the drivers of farmers' intentions to use pesticides. Including an assessment of knowledge and motivations of use could improve understanding and estimations of pesticide use especially when extrapolating survey data. With insights in farmers' motivations, the extrapolation of the data to other regions can be more precise or can be applied in intervention scenarios to estimate effects of social- or financial interventions.

5. Conclusions

The survey found that 90% of the farmers in UCRB use pesticides on their fields. In total, 31 pesticide types were found in the survey area with Mancozeb and Profenofos as two most commonly used pesticides by the farmers, especially in chili and tomato fields. In terms of application frequency, highest frequencies were recorded for Abamectin, Mancozeb, and Profenofos in long bean, Difenoconazole and Mancozeb in cabbage, and Maneb in chili. These variations in pesticide application frequency influenced the yearly amount of the pesticides applied for each crop in the UCRB. The highest annual average amount of pesticide used per ha of pesticide-crop combination was Chlorothalonil on tomato, followed by Mancozeb on corn, and Chlorpyrifos on chili. Overall, the pesticide use estimation is relatively high with annual average of 24.6 kg/ha/year. Comparing prescribed and actual use on rice showed that most pesticides are used (per hectare or as diluted with water) more than the lowest recommended amount, and about a quarter is used more than the highest recommended amount. This comparison also indicated that some farmers use pesticides for rice that are not recommended for rice farming.

The presented data in this study is useful to estimate pesticide use for environmental risk assessment, especially because data on pesticide use in Indonesia and other low- and middle income countries are scarce. With these data a first scoping can be done on the potential impact of regional pesticide use for example to develop a monitoring programme of water quality targeting specific chemicals for analysis. Furthermore, an advanced research on motivations of pesticide use (types, under- or overuse) is recommended to improve estimates and facilitate sustainable pest management. It is also important to document pesticide usage on a national and regional level periodically as a means to more accurately evaluate associations between chemicals usage and human health or ecosystem disruption.

Conflict of interest statement

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject materials discussed in this study.

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