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Impact of Farmer Perceptions and Land Use Pattern on Pesticide Loading into Upper Kotmale Sub-watershed of Mahaweli River Basin in Sri Lanka

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Abstract: To understand pesticide loading from farmlands, evaluation of farmers' perceptions and land use patterns of pesticide loading from the upper catena of the tropical tributary river study was conducted using Rapid Rural Appraisal (RRA), which utilized semi-structured questionnaire surveys and key personnel interviews to collect data from the farmers in the Upper Kotmale Sub-Watershed (UKSW). The results recorded 46 commercial brands of pesticide and 25 active ingredients from the sub-watershed. Cluster analysis showed four utilized insecticides (i.e. diazinon, deltamethrin, sulfur, and chlorpyrifos), four fungicides (i.e. mancozeb, propineb, metiram, and chlorothalonil), and two weedicides (mainly metribuzin); the analysis was based on the usage of the active ingredient per acre. Selection of vegetable crops and cultivation seasons greatly impacted pesticide applications based on farmers' perceptions. Toxic concentrations of chlorpyrifos and deltamethrin were observed in water, which exceeded the acute toxicity level for aquatic life (even with 1% of the pesticide load [scenario 4]). These chemicals drain into rivers from the pesticides remaining after the total pesticide usage in the sub-watershed. Therefore, farmers' perceptions on pesticide applications are highly correlated to pesticide applications and toxicity levels in river waters.

Key words: Farmers' perceptions, land use, pesticide, sub-watershed, toxicity

Introduction

Increased global populations require researchers to discover methods that will increase productivity per unit of land area. In order to achieve this goal, producers need to minimize pre-harvest and post-harvest losses from pest attacks and diseases. Therefore, many different pesticides are used for pest control, disease management, and vector control in the agricultural sector (Penrose et al., 1999; WHO, 2005; FAO, 2011; Foley et al., 2011; Thorburn et al., 2013). There is growing concern over the negative effects of pesticides on human and animal health, the environment, natural resources, and the sustainability of agricultural production; however, pesticides play a key role in increasing agricultural production by controlling pests and diseases (Shende and Bagde, 2013). In developing countries, farmers are the major pesticide users, but most are not fully aware about the risks they face, or are too poor to take preventative actions (Warburton et al., 1995; Mathews, 2008). There are also concerns regarding the environmental problems that stem from the massive

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use of pesticides in irrigated paddy and other crops in developing tropical countries (Sethunathan, 1989). Different pesticides are used in vegetable cultivation because different types and quantities of pesticides are required to ensure high crop yield and unblemished produce (Hamilton and Crossle, 2004; Sexton et al., 2007)

Sri Lanka is a tropical island located between 5° 50′ N to 9° 55′ N and 79° 30′ E to 81° 55′E. Most farmers in Sri Lanka use various pesticides to manage the pests and diseases of agricultural crops, including vegetables. Total imports of pesticides (i.e. insecticide, fungicide, and weedicide) are indicated in Figure 1. Moreover, because of pesticide-related illnesses that members of a household may suffer, researchers have conducted studies to estimate the health costs related to pesticide misuse (Ntow, 2006; Matthews, 2008). According to Wilson and Tisdell (2001), it is difficult to alter the behaviour of farmers in many developing countries (i.e., Sri Lanka, India, China) with regard to increased pesticide application, despite all of the adverse effects. Therefore, understanding the perceptions and practices of farmers regarding agrochemicals is key to determining the effects of pesticide loading in the sub-watershed. The farmers' perceptions of pesticide use are critical for the following reasons. First, they may influence decisions regarding pesticide use. Second, if these perceptions differ from expert opinions, it is useful to know why farmers feel the need to take more risks than they realize. Third, they may influence the methods used to protect against pesticides. Lastly, technical instructions given to farmers on pesticide use and crop protection may be useful even if it does not correspond with their views of pesticide health effects (Warburton et al., 1995).

Sri Lankan upland cropping patterns are broadly divided into the following categories: farming systems with perennial crops, farming systems with annual crops, farming systems in mixed gardens/homesteads/ home gardens, shifting cultivation/shifting farming systems, and integrated farming systems focused on vegetables and coarse grains that are cultivated in annual systems. Intensive vegetable farming in the hill country was a major supplier of root of vegetables to the Sri Lankan market. However, it was found that farmers were overusing fertilizers and pesticides (Dissanayake, 2004). For instance, farmers used many different doses and mechanisms to apply pesticide mixes while ignoring the recommended standards (Watawala et al., 2010). Hence, it is important to evaluate the pesticide loading effect in aquatic environments based on farmers' perceptions. Therefore, this study is focused on the impact of farmers' perception towards pesticide loading in the river basin and its impact on the aquatic environment.

Methodology

Study Area

The Mahaweli river basin is the longest (335 km long) and largest (10,448 km^2 catchment area) river basin in Sri Lanka (Arumugam, 1969). The Kotmale subcatchment is located in the Nuwara-Eliya District. It is 70 km in length, and is one of the major tributaries

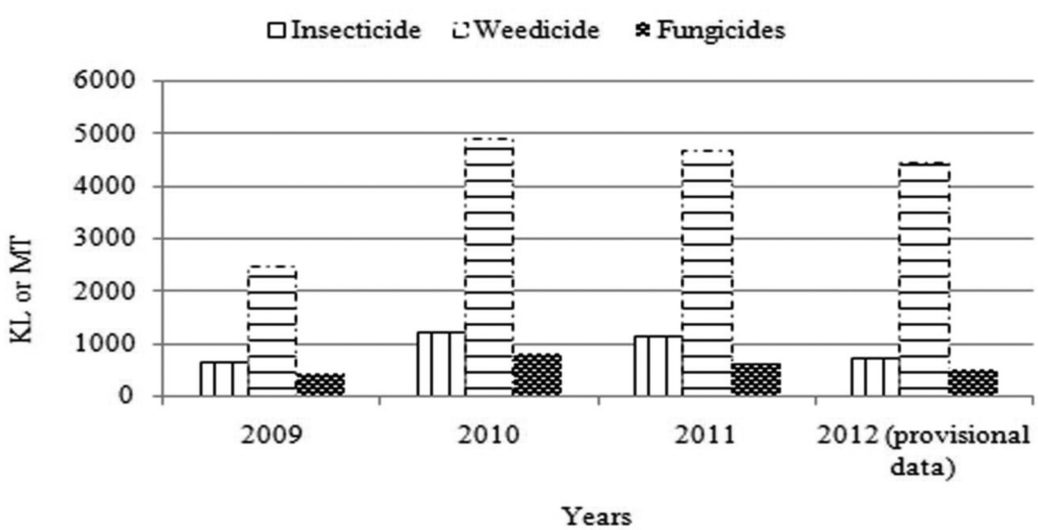

Figure 1: Pesticide (insecticide, fungicide and weedicide) import to Sri Lanka (2009-2012).
***Source:* Pesticide Registrar office, Sri Lanka**

of the Mahaweli River at the headwater. The upper Kotmale subcatchment drains an area of 304 km^2, which is approximately 10% of the total area of the Upper Mahaweli Catchment (UMC) and part of the Kotmale Oya sub-catchment. The average annual rainfall ranges from 2000 mm to over 4500 mm, and the elevation ranges from 600 m to 2524 m at Pidurutalagala. Figure 2 shows rainfall variation in the UKSW, and Figure 3 illustrates the sub-watershed map with major feeding streams in the UKSW. The Agra Oya and Dambagastalawe Oya descend along steep gradients, join at the Caledonia Estate, and flow westward towards Talawakelle. There, the stream turns sharply northward before it merges with the Nanu Oya to form the Kotmale proper (Silva, 1996).

The Nanu Oya subcatchment is the most critical area that is subject to soil erosion and sedimentation. The conversion of traditional tea lands to annual crop cultivation areas is significantly contributing to the deterioration of the aquatic environments. Compared to other subbasins, water quality evaluations from the Nanu Oya region showed greater nitrate nitrogen loads and suspended sediment loads because of the vegetable land use patterns (Amarathunga et al., 2010; Amarathunga et al., 2013). Percentages of different land use categories in the basin are listed in Table 1, and reveal that the major land use types are tea, forest and annual crops (vegetables). Therefore, increased pesticide application is expected in this basin, and Watawala et al. (2010) reported that common fungicides such as propineb and mannose are used in Nuwara Eliya, Welimada and Bandarawela.

Data Collections and Analysis

Rapid Rural Appraisal (RRA)

Rapid Rural Appraisal (RRA) is a collection of techniques developed by rural development practitioners in order to collect useful agricultural, social and cultural data from target populations without the unwieldy investment of time, which is usually required for formal, scientific studies or traditional anthropological participant observations (Robinson, 2002). To achieve objectives, the following RRA tools were used: key informant interviews and focus group discussions, reviews of secondary sources such as pesticide data from FAO and the Pesticide Registrar Office in Sri Lanka, land use data from the Survey Department and land use planning division in Nuwara Eliya district secretariat (2011/2012), discharge and rainfall data from meteorological departments, information from the irrigation department, and other publications.

Questionnaire Survey

A semi-structured questionnaire survey was conducted among 50 vegetable farmers who live in the UKSW (Table 2). The individuals were selected for the survey using random sampling techniques, with poorer and richer farmers categorized based on cultivated land size (poorer = land size < 4046.8 m^2 (1 acre) and richer = land size ≥ 4046.8 m^2 (1 acre)). The structured questionnaire included 27 questions which addressed two parts: (1) general information that included area, age group, farming experience, family status, income from each crop, other income, cost of each cropping season, and crops and cropping patterns and (2) information about

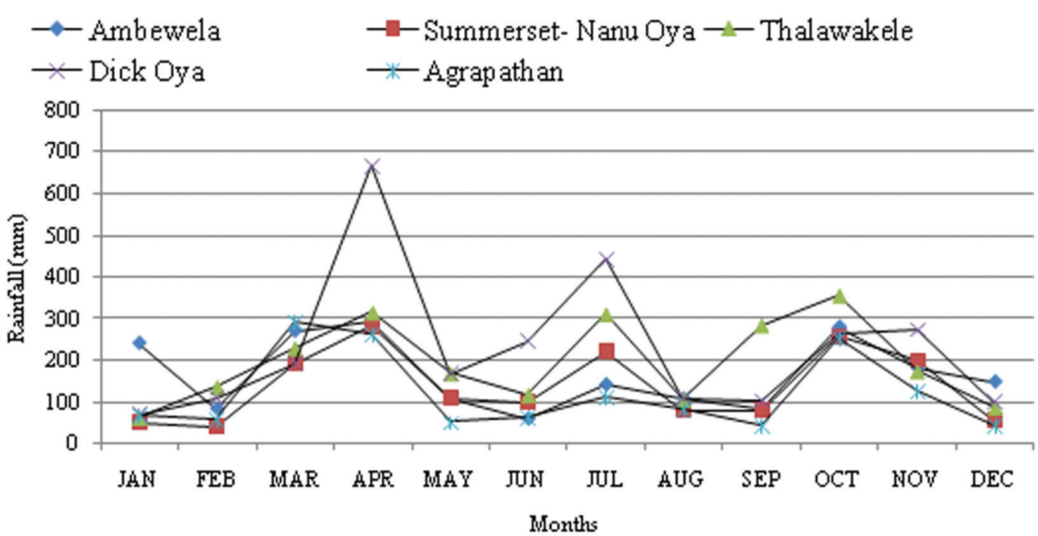

Figure 2: Rainfall variation in the UKB basin. (Source: Meteorological department)

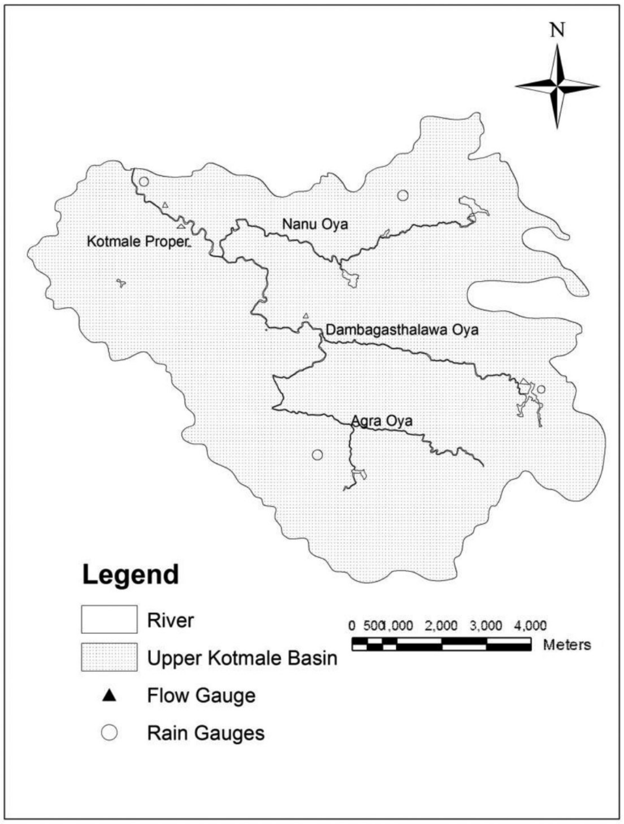

Figure 3: The sub-watershed map with major feeding streams of UKSW.

crop variety, irrigation systems, spraying instruments, spraying patterns, weeding, application of pesticides for each crop, pesticide application patterns, cost of each pesticide, drinking water source, storage material and waterborne diseases. The questionnaire was pre-tested to determine the ability of enumerators to administer it. Although sampling was random, an effort was made to ensure that the selected vegetable farmers represented different basins.

Data Analysis

Land use data and maps were processed using Arc GIS version 10.1. Microsoft Excel and SPSS were used to determine the descriptive statistics such as histograms, mean, frequency and mean comparisons. The mean (μ), standard error and standard deviation were calculated. The estimated pesticide concentration was calculated using equation (1), and total pesticide load (*TPL*) was calculated using equations (2), (3), and (4) for all 25 active ingredients.

$$C = \frac{TPL}{\text{Discharge}} \quad (1)$$

where C is concentration, TPL_{AI1} is total pesticide load from the *AI*1 used by farmers in the basin

Table 1: Land use types and their percentages in Nanu Oya, Agra Oya and Dambagasthalawa Oya in UKB

Land Use Type (%)	*Sub-catchment*		
	Nanu Oya	*Agra Oya*	*Dambagasthalawa Oya*
Buildup land	0.05	0.02	0.01
Forest - unclassified	19.73	17.2	42.93
Home gardens	8.66	3.33	2.83
Marsh	0.04	0.01	0.31
Other	9.20	0.83	2.60
Grassland	2.78	0.43	1.49
Playground	0.04	-	-
Rock	0.40	1.61	0.65
Reservoir, tank, rivers and streams, and water holes	0.96	2.27	0.82
Scrub forest	1.91	1.55	6.14
Tea cultivations	46.21	71.95	40.11
Vegetable cultivations	10.07	0.82	2.12

Source: Amarathunga et al., 2013

Table 2: Selected farmers from each sub basin of UKB for the questionnaire survey

Basin Category	*Nanu Oya Basin*		*Dambagasthalawa Oya Basin*		*Agra Oya Basin*	
	Poorer	*Richer*	*Poorer*	*Richer*	*Poorer*	*Richer*
Interviewees	12	12	6	8	6	6
Total	24		14		12	

$$TPL_{A/1} = \int_{i=1}^{n} \text{Load}\,(Veg1A * AI1) + (Veg2A * AI1) + (Veg3A * AI1)\ldots n \quad (2)$$

$$TPL_{A/2} = \int_{i=1}^{n} \text{Load}\,(Veg1A * AI2) + (Veg2A * AI2) + (Veg3A * AI2)\ldots n \quad (3)$$

$$TPA_{\text{AIN}} = \int_{i=0}^{m} \text{Load}\,(Veg1A * AIN) \quad (4)$$

where n is total number of vegetables (n = 8), and $Veg1A$, $Veg2A$ and $Veg3A$ represent the land use area of each vegetable (acre). Also, $AI1$ and $AI2$ represent each of the active ingredients and N represents the total active ingredients (25 active ingredients). Load is calculated on the basis of each active ingredient.

Cluster analyses test (Aldenderfer and Blashfield, 1984) were performed to differentiate the pesticide based on usage in the study site. The F-test was carried out to find out the differences related to applied mean pesticide usage from different vegetables by poor and richer farmers. The following four scenarios were used to estimate the potential pesticide concentration in water: scenario 1 represents 100%, scenario 2 represents 50%, scenario 3 represents 10%, and scenario 4 represents 1% of the applied pesticides draining into river water.

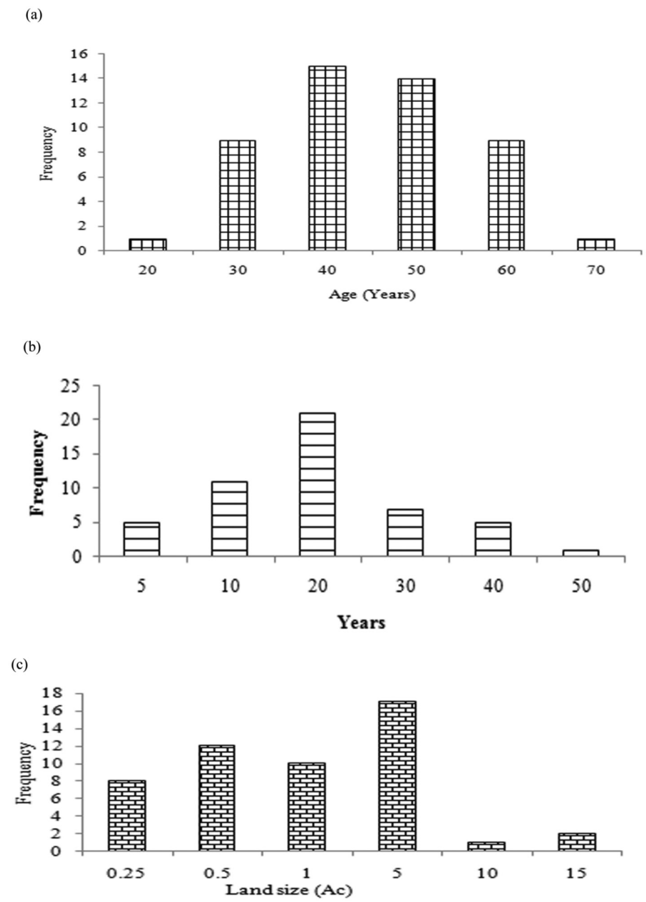

Figure 4: General characteristics of farming communities such as: (a) age distribution of the farming community, (b) farm land size distribution and (c) farming experience.

Results

Characteristics of the Respondents and Farm Lands

The farmers' ages ranged from 25 to 70 (M = 41.5, SE = 1.9) years old (Figure 4a). The mean land size with standard error is 2.59 acre ± 0.77, and the median was 1.00 acre. The land size frequency distribution is given in Figure 4b, and 42.9% were smallholders (M = 2.6, SE = 0.8). Although, 67.9% of farmers have more than 15 years (M = 17.5, SE = 2.0) of farming experience (Figure 4c), the farm income differed between richer and poorer farmers (richer farmers' land size ≥ 1.0 acre and poor farmers' land size ≤ 1.0 acre).

Farmer's Perceptions towards Selection of Crops and Pesticides

The majority of farmers (78.6%) cultivate during three seasons, but some farmers (21.4%) only cultivate during two seasons. Eight major crops were considered in the analysis, including potatoes (*Solanum tuberosum*), carrots (*Daucus carrota*), leeks (*Allium ampeloprasum*), cabbages (*Brassica oleracea*), radishes (*Raphanus sativus*), beets (*Beta vulgaris*), beans (*Phaseolus vulgaris*) and M'chilli or capsicum (*Capsicum annuum*). All of the farmers who contributed to the survey were cultivating vegetables from February to May, which includes favourable climatic conditions for potatoes. However, 10.7% of farmers cultivated other crops in this season, and 67.9% of farmers grew carrots from June to September. Different vegetable crops were also cultivated by some farmers who farm potatoes and carrots during the third season (October to January).

Different kinds of pesticides are applied to these crops, and Table 3 lists the usage of pesticides from UKSW based on the active ingredient and commercial brands from the farmer survey. Figure 5 illustrates the grouping of insecticides, fungicides and weedicides based on the usage. The active ingredient represents each case on the Y-axis, and the X-axis is a rescaled distance coefficient of pesticide usage amount. The length of the branch shows how far apart each case is from the other cases within its cluster, and cases with low distance/high similarity are clustered together

Table 3: Summary of pesticide usage in UKB

Category	*Value*
Commercial pesticide brands (total)	46
1 Insecticide	25
2 Fungicide	15
3 Weedicide	6
Active ingredients (total)	25
1 Insecticide	12
2 Fungicide	9
3 Weedicide	4

(Aldenderfer and Blashfield, 1984). Figure 6 illustrates comparison of pesticide usage by poor and richer farmers. Results show some pesticides are highly used by poor farmers than richer farmers (mainly chlorpyrifos, diazinon, profenofos, carbendazim, chlorothalonil, metiram, cooper oxychloride and metribuzin). Table 4 illustrated, 13 out of 25 pesticide active ingredients show differences related to mean pesticide application to vegetables by poor and richer farmers. For the reason that, poor farmers try to protect their crop from pest

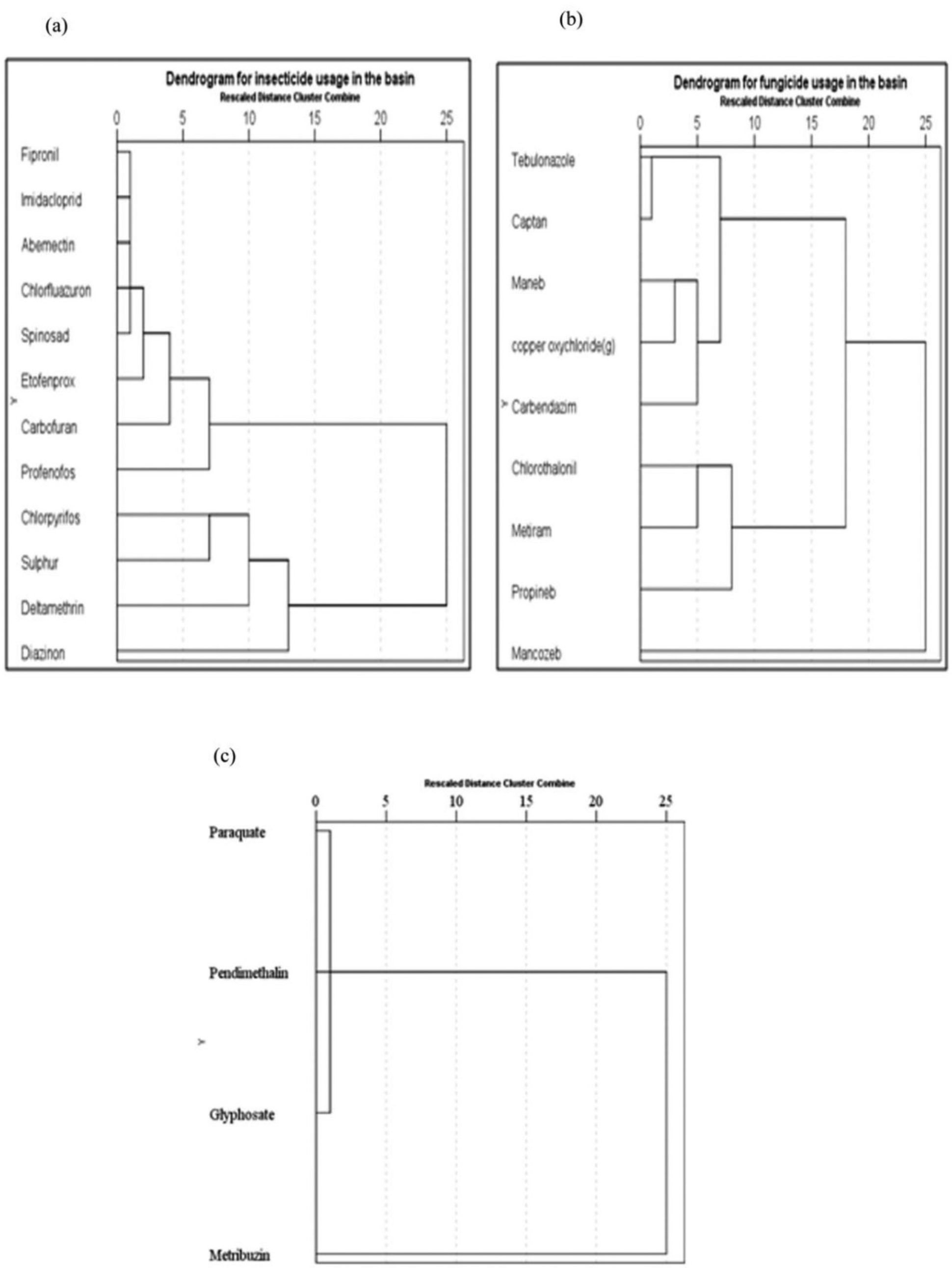

Figure 5: Cluster analysis for differentiation of active ingredients based on usage: (a) insecticide, (b) fungicide and (c) weedicide.

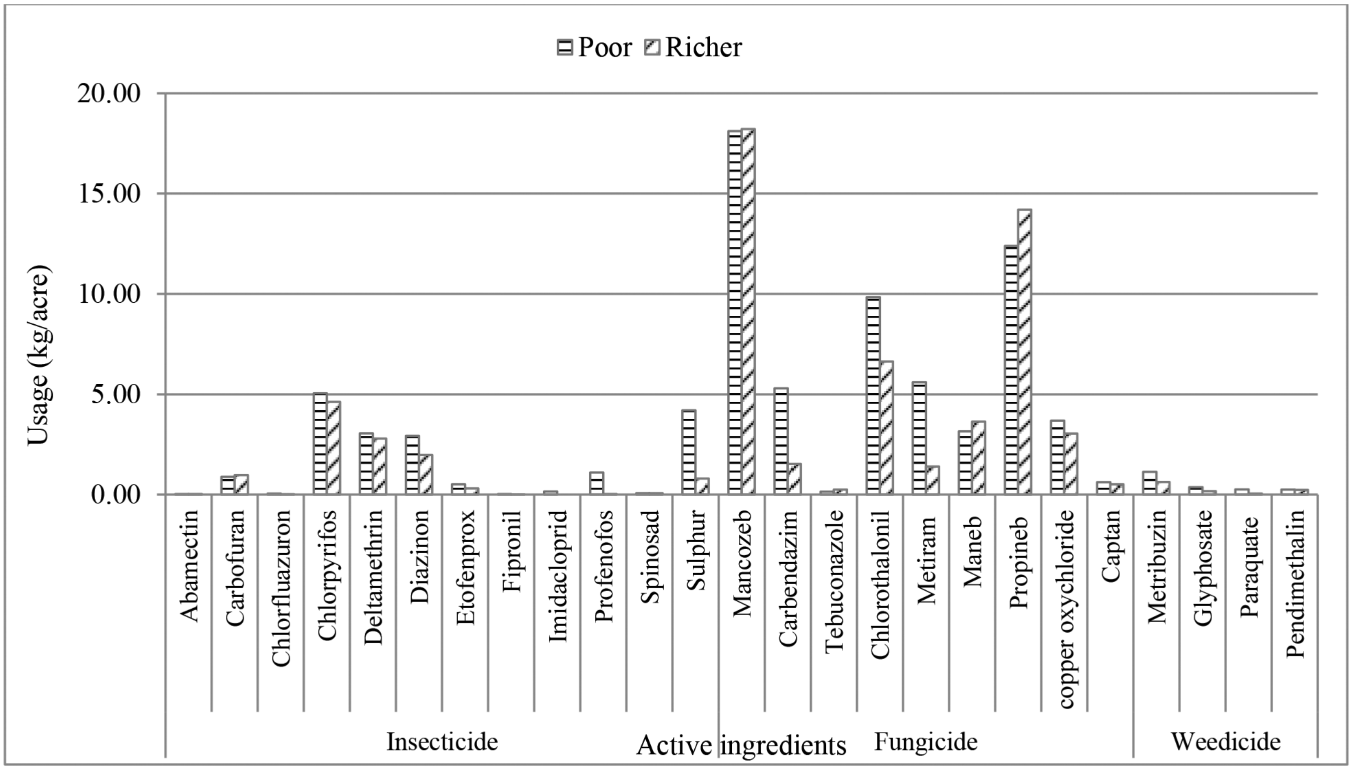

Figure 6: Pesticide usage based on different farmer's category: richer farmers and poor farmers.

attack because; cultivable land area size is very low, cultivable crop diversity also less, and if the crop fails, losses cannot be borne other than richer farmers.

Figure 7 illustrates different active ingredient usage based on vegetables land use, and the season of the UKSW basin. The results of the analysis show the consequences of the vegetable farmers' perceptions on choosing of vegetables, pesticides, application amount, application and the influence of climatic factors, specifically rainfall (Figure 2), on pesticide applications in the basin. Farmers cultivate different crops in different seasons, and the application of pesticides also differs with the crops and seasons. Figure 8 shows the total pesticide usage organized by different active ingredients used in the basin based on distinctive vegetable land use patterns. The findings of this study imply that farmers strongly depend on pesticides, and all farmers reported using pesticide applications. Also, 39% of farmers believe that if rain occurs after pesticide application, they should apply additional pesticides.

Downstream Toxicity Assessment

Table 5 shows the estimated pesticide concentration in water using four different scenarios based on pesticide draining into streams via runoff from farmlands. These scenarios are categorized on the basis of different time period (i.e. February to May, June to September and October to January). Diazinon, chlorpyrifos and deltamethrine have recorded higher loading active ingredients from insecticide category. In addition, mancozeb, propineb and chlorothalonil have recorded higher loading active ingredients from fungicide category and metribuzin from weedicide category. Moreover, greater amounts of insecticides, fungicides and weedicides were loaded from October to January and February to May based on cropping seasons and vegetable land use. Those concentrations affected aquatic organisms and different sources published toxicity levels under different active ingredients (i.e. U.S. Environmental Protection Agency (U.S. EPA) pesticide database, Pesticide Properties Database (FOOTPRINT, 2006), Pesticide Target Interaction Database (Gong et al., 2013), and the European Union (EU) Pesticide Database). The toxicity levels comparing with above data for different animals based on estimated remaining pesticide concentrations in river water are shown in Table 6. The analysis was based on the usage of the active ingredients per acre which is mean application amount by farmers in the UKSW.

Table 4: Results of the statistical analysis (F-test) for mean pesticide usage (different active ingredients) by poor and richer farmers on different vegetables

Pesticide (AI)	*F-value*	*F critical value*	*Description*
Abamectin	0.6335	0.2641	Reject H_0
Carbofuran	1.518	3.787	Accept H_0
Chlorfluazuron	0.1873	0.2641	Accept H_0
Chlorpyrifos	1.2565	3.787	Accept H_0
Deltamethrin	0.8958	0.2641	Reject H_0
Diazinon	0.4058	0.2641	Reject H_0
Etofenprox	0.36	0.2641	Reject H_0
Fipronil	0.1485	0.2641	Accept H_0
Imidacloprid	0.0154	0.2641	Accept H_0
Profenofos	0.0011	0.264	Accept H_0
Spinosad	0.9981	0.2641	Reject H_0
Sulphur	0.143	0.2641	Accept H_0
Mancozeb	3.8338	3.787	Reject H_0
Carbendazim	0.332	0.2641	Reject H_0
Tebulonazole	1.2539	3.787	Accept H_0
Chlorothalonil	0.5231	0.2641	Reject H_0
Metiram	0.1384	0.264	Accept H_0
Maneb	0.7274	0.2641	Reject H_0
Propineb	1.6123	3.787	Accept H_0
copper oxychloride	1.0584	3.787	Accept H_0
Captan	1.1271	3.787	Accept H_0
Metribuzin	0.8049	0.2641	Reject H_0
Glyphosate	0.2696	0.264	Reject H_0
Paraquate	0.3548	0.2641	Reject H_0
Pendimethalin	0.5351	0.2641	Reject H_0

Discussion

The results of the survey indicate that the farming experience in the study area ranged from 3 to 41 years. Many farmers operate small-scale farms (≤ 1 acre), and most of the small-scale farmers are poor. According to the survey results, the mean cost for vegetable farming is relatively high (e.g., 0.35 million per acre for potato cultivation). As a result, poorer farmers do not have much capital to run large-scale farming operations (≥1 acre). However, richer farmers are engaging in large-scale vegetable farming in the area with ≥ 1 acre of farmland. Many adverse natural events such as rain or drought affect production, and pest attack is also a major concern of farmers. Nevertheless, pesticides are recommended, and the survey clearly indicates that there is no common understanding within the agricultural community of Sri Lanka as to what constitutes the excessive use of pesticides. Also, most pesticides used in developing countries are insecticides, which lead

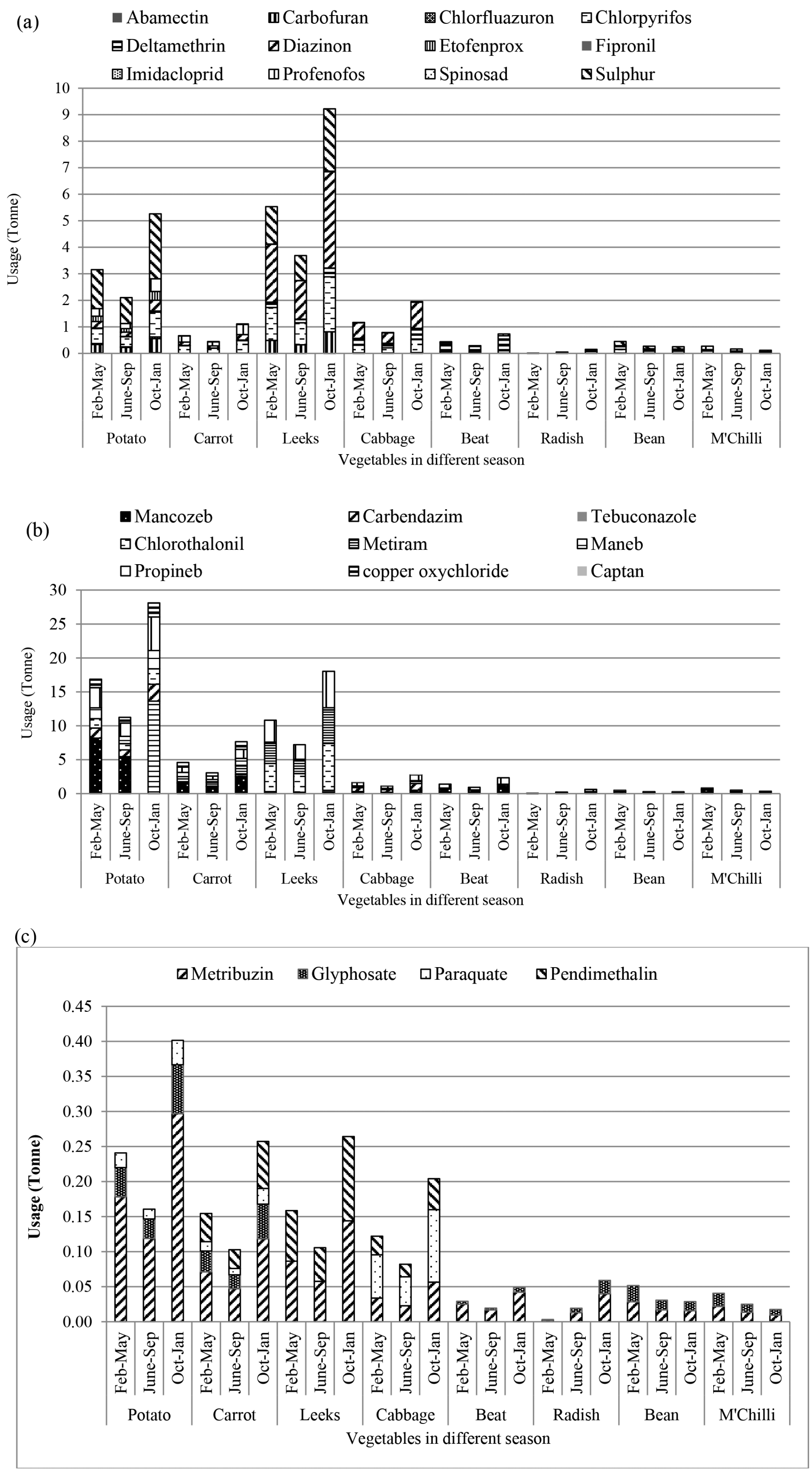

Figure 7: Pesticide usage based on vegetables, land use and the season in the basin: (a) insecticide, (b) fungicide and (c) weedicide.

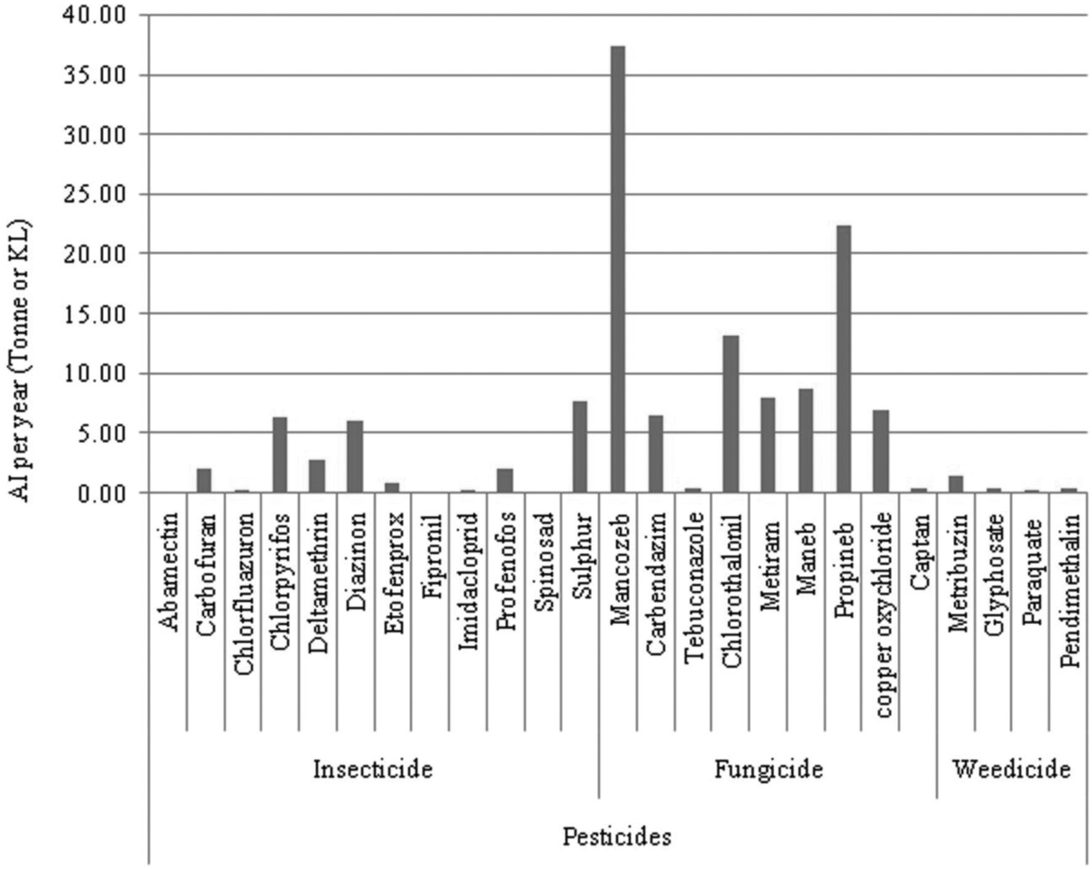

Figure 8: Total pesticide usage in the basin organized by different active ingredients used based on different vegetable land use pattern.

to insecticide-resistance in pests that causes the most damage to human health (Burleigh et al., 1998; WRI, 1998; Nkya et al., 2014).

Different pesticides were selected by farmers based on their sentiment, crop variety, neighbouring farmer's selection, etc. As a result, UKSW farmers use large amounts of pesticides and different pesticide brands compared to the total that is imported into Sri Lanka, including 12.8% diazinon, 3.8% chlorpyrifos and 9.3% mancozeb. Such highly intensive pesticide applications occur on soils, and subsequently result in some volatilization, adsorption, leaching and photodegradation directly by air and soil. Some parts of the pesticide also travel to nearby streams via runoff, and the water is used as a potable supply as well as for irrigation. Two different insecticide clusters were observed in the analysis based on insecticide usage in the basin. According to the rescaled distance, diazinon, sulfur and chlorpyrifos belong to the highly used insecticide cluster. There are significant differences in the usage of other active insecticide ingredients, which are included in the other clusters (Figure 5a).

In addition, four different fungicide clusters were recorded with mancozeb, which is the most highly used fungicide active ingredient in the basin. The second cluster includes propineb, metiram and chlorothalonil; and the third cluster comprises maneb, copper oxychloride and carbendazim. The final cluster includes captan and tebulonazole, which are used at very low levels in the basin (Figure 5b). Two major clusters were identified with weedicide active ingredients, highly used metribuzin in the first cluster and glyphosate, pendimethalin and paraquate in second cluster (Figure 5c). It is evident that the paraquate is greatly replaced by metribuzin. This study only focused on annual cropping systems and did examine the perennial crops (e.g., tea plantations). For instance, glyphosate is largely used as a weedicide in tea plantations in this area.

Results reveal that behaviour is poorly mediated by intention, but attitude of poor and richer farmers on pesticide usage is different. Therefore, greater efforts need to be used to protect the crop from climatic disaster and pest attacks. Number of rainy days increases, the number of pesticide application also increases and

Table 5: Pesticide content in the streams estimated using four different scenarios

AI	*Estimated concentration under different scenarios in different seasons (µg·L⁻¹)*											
	February to May				*Jun to September*				*October to January*			
	Scenario -1 (100%)	*Scenario-2 (50%)*	*Scenario-3 (10%)*	*Scenario-4 (1%)*	*Scenario-1 (100%)*	*Scenario -2 (50%)*	*Scenario -3 (10%)*	*Scenario-4 (1%)*	*Scenario -1 (100%)*	*Scenario-2 (50%)*	*Scenario-3 (10%)*	*Scenario-4 (1%)*
Abamectin	0.17 ± 0.07	0.08 ± 0.03	0.02 ± 0.01	0.002 ± 0.001	0.16 ± 0.06	0.08 ± 0.03	0.02 ± 0.01	0.002 ± 0.0006	0.30 ± 0.11	0.15 ± 0.05	0.03 ± 0.01	0.003±0.001
Carbofuran	6.51 ± 1.63	3.25 ± 0.81	0.65 ± 0.16	0.07 ± 0.02	6.15 ± 1.54	3.08 ± 0.77	0.62 ± 0.15	0.06 ± 0.02	12.49 ± 3.15	6.25 ± 1.58	1.25 ± 0.32	0.13 ± 0.03
Chlorfluazuron	0.32 ± 0.23	0.16 ± 0.14	0.03 ± 0.03	0.003 ± 0.003	0.30 ± 0.27	0.15 ± 0.14	0.03 ± 0.03	0.003 ± 0.003	0.61 ± 0.56	0.31 ± 0.28	0.06 ± 0.06	0.01 ± 0.01
Chlorpyrifos	20.35 ± 13.89	10.18 ± 6.95	2.04 ± 1.39	0.20 ± 0.14	19.34 ± 13.24	9.67 ± 6.62	1.93 ± 1.32	0.19 ± 0.13	37.55 ±26.15	18.77 ± 13.07	3.76 ± 2.62	0.38 ± 0.26
Deltamethrin	7.43 ± 0.41	3.72 ± 0.21	0.74 ± 0.04	0.07 ± 0.01	7.23 ± 0.40	3.62 ± 0.20	0.72 ± 0.04	0.07 ± 0.01	13.84 ±0.82	6.92 ± 0.41	1.38 ± 0.08	0.14 ± 0.01
Diazinon	27.17 ± 0.61	13.58 ± 0.30	2.72 ± 0.06	0.27 ± 0.01	25.56 ± 0.57	12.78 ± 0.28	2.56 ± 0.06	0.26 ± 0.01	48.56 ± 0.98	24.28 ± 0.49	4.86 ± 0.10	0.49 ± 0.01
Etofenprox	1.85 ± 1.18	0.93 ± 0.59	0.19 ± 0.12	0.02 ± 0.01	1.73 ± 1.11	0.86 ± 0.55	0.17 ± 0.11	0.02 ± 0.01	3.19 ± 2.24	1.60 ± 1.12	0.32 ± 0.22	0.03 ± 0.02
Fipronil	0.11 ± 0.66	0.05 ± 0.33	0.01 ± 0.06	0.001 ± 0.007	0.10 ± 0.63	0.05 ± 0.31	0.01 ± 0.06	0.001 ± 0.006	0.20 ± 1.29	0.10 ± 0.64	0.02 ± 0.13	0.002 ± 0.013
Imidacloprid	0.31 ± 0.22	0.15 ± 0.11	0.03 ± 0.02	0.003 ± 0.002	0.29 ± 0.20	0.14 ± 0.10	0.03 ± 0.02	0.003 ± ٠,٠٠٢	0.59 ± 0.42	0.30 ± 0.21	0.06 ± 0.04	0.01 ± 0.004
Profenofos	5.00 ± 1.01	2.50 ± 0.51	0.50 ± 0.10	0.05 ± 0.01	4.70 ± 0.95	2.33 ± 0.48	0.47± 0.10	0.05 ± 0.01	8.25 ± 1.87	4.13 ± 0.94	0.83 ± 0.19	0.08 ± 0.02
Spinosad	0.21 ± 0.04	0.11 ± 0.02	0.02 ± 0.01	0.002 ± 0.0004	0.20 ± 0.04	0.10 ± 0.02	0.02 ± 0.004	0.002 ± 0.0004	0.41 ± 0.08	0.21 ± 0.04	0.04 ± 0.01	0.004 ± 0.001
Sulfur	23.62 ± 3.18	11.81 ± 1.59	2.36 ± 0.32	0.24 ± 0.03	22.24 ± 2.95	11.12 ± 1.48	2.22 ± 0.30	0.22 ± 0.03	44.14 ± 5.43	22.07 ± 2.72	4.41 ± 0.54	0.44 ± 0.05
Mancozeb	89.30 ± 64.23	44.65 ± 32.11	8.93 ± 6.42	0.89 ± 0.64	84.26 ± 60.63	42.13 ± 30.32	8.43 ± 6.06	0.84 ± 0.61	166.93 ± 120.45	83.45 ± 60.23	16.69 ± 12.05	1.67 ± 1.21
Carbendazim	17.95 ± 8.00	8.98 ± 4.00	1.79 ± 0.80	0.18 ± 0.08	16.86 ± 7.55	8.43 ± 3.77	1.69 ± 0.76	0.17 ± 0.08	32.48 ± 15.12	16.24 ± 7.56	3.25 ± 1.51	0.33 ± 0.15
Tebuconazole	1.06 ± 0.30	0.53 ± 0.15	0.11 ± 0.03	0.01 ± 0.003	1.00 ± 0.28	0.50 ± 0.14	0.10 ± 0.03	0.01 ± 0.003	2.05 ± 0.58	1.02 ± 0.25	0.21 ± 0.06	0.02 ± 0.01
Chlorothalonil	46.79 ± 38.13	23.40 ± 19.07	4.68 ± 3.81	0.47 ± 0.38	44.49 ± 36.11	22.25 ± 18.06	4.45 ± 3.61	0.45 ± 0.36	89.95 ± 73.67	44.97 ± 36.83	9.00 ± 7.37	0.90 ± 0.74

(*Contd.*)

Table 5: (Contd.)

AI	Estimated concentration under different scenarios in different seasons ($\mu g \cdot L^{-1}$)											
	February to May				*Jun to September*				*October to January*			
	Scenario -1 (100%)	*Scenario-2 (50%)*	*Scenario-3 (10%)*	*Scenario-4 (1%)*	*Scenario-1 (100%)*	*Scenario -2 (50%)*	*Scenario -3 (10%)*	*Scenario-4 (1%)*	*Scenario -1 (100%)*	*Scenario-2 (50%)*	*Scenario-3 (10%)*	*Scenario-4 (1%)*
Metiram	29.49 ± 23.90	14.75 ± 11.95	2.95 ± 2.39	0.30 ± 0.24	27.91 ± 22.63	13.96 ± 11.32	2.79 ± 2.26	0.28 ± 0.23	57.10 ± 46.29	28.55 ± 23.15	5.71 ± 4.63	0.57 ± 0.46
Maneb	20.18 ± 3.59	10.09 ± 1.80	2.02 ± 0.36	0.20 ± 0.03	19.72 ± 3.62	9.86 ± 1.81	2.00 ± 0.36	0.20 ± 0.04	39.82 ± 6.42	19.91 ± 3.21	4.00 ± 0.64	0.40 ± 0.06
Propineb	64.04 ± 56.77	32.02 ± 28.39	6.40 ± 5.68	0.64 ± 0.57	61.56 ± 54.39	30.78 ± 27.20	6.16 ± 5.44	0.62 ± 0.54	125.05 ± 110.93	62.52 ± 55.47	12.51 ± 11.09	1.25 ± 1.11
Copper oxychloride(g)	16.52 ± 9.05	8.26 ± 4.52	1.65 ± 0.91	0.17 ± 0.09	15.58 ± 8.46	7.79 ± 4.23	1.56 ± 0.85	0.16 ± 0.09	29.89 ± 15.62	14.95 ± 7.81	3.00 ± 1.56	0.30 ± 0.16
Captan	1.24 ± 0.52	0.62 ± 0.26	0.12 ± 0.05	0.01 ± 0.01	1.13 ± 0.48	0.57 ± 0.24	0.11 ± 0.05	0.01 ± 0.01	1.61 ± 0.77	0.80 ± 0.38	0.16 ± 0.08	0.02 ± 0.01
Metribuzin	3.30 ± 1.64	1.65 ± 0.82	0.33 ± 0.16	0.03 ± 0.02	3.23 ± 1.61	1.61 ± 0.81	0.32 ± 0.16	0.03 ± 0.02	6.24 ± 2.88	3.12 ± 1.44	0.62 ± 0.29	0.06 ± 0.03
Glyphosate	0.82 ± 2.88	0.41 ± 1.44	0.08 ± 0.29	0.01 ± 0.03	0.81 ± 3.05	0.41 ± 1.53	0.08 ± 0.30	0.01 ± 0.03	1.35 ± 6.21	0.67 ± 3.10	0.14 ± 0.62	0.01 ± 0.06
Paraquate	1.75 ± 5.03	0.88 ± 2.51	0.18 ± 0.50	0.02 ± 0.05	1.66 ± 4.76	0.83 ± 2.38	0.17 ± 0.47	0.02 ± 0.05	3.39 ± 9.74	1.70 ± 4.87	0.34 ± 0.97	0.03 ± 0.09
Pendimethalin	1.07 ± 0.37	0.53 ± 0.19	0.11 ± 0.04	0.01 ± 0.01	1.01 ± 0.36	0.51 ± 0.18	0.10 ± 0.04	0.01 ± 0.01	2.06 ± 0.73	1.03 ± 0.37	0.21 ± 0.07	0.02 ± 0.01

Table 6: Pesticide toxicity for different aquatic species under different scenarios and seasons

AI	*Scenarios*	*Feb to May*	*Jun to Sep*	*Oct to Jan*
Abamectin	100%	Σ η	Σ η	Σ η
	50%	Σ η	Σ η	Σ η
	10%	Σ	Σ	Σ
	1%			
Carbofuran	100%	ϒ	ϒ	ϒ
	50%	ϒ	ϒ	ϒ
	10%			
	1%			
Chlorpyrifos	100%	1Σ2ϒ4η	1Σ2ϒ4η	1Σ2ϒ4η
	50%	12Σ4η	1Σ2ϒ4η	1Σ2ϒ4η
	10%	12ϒ4η	12ϒ4η	12ϒ4η
	1%	1ϒ4η	1ϒ4η	1ϒ4η
Deltamethrin	100%	1Σ2ϒ	1Σ2ϒ	1Σ2ϒη
	50%	1Σ2ϒ	1Σ2ϒ	1Σ2ϒ
	10%	1Σ2ϒ	1Σ2ϒ	1Σ2ϒ
	1%	Σϒ	Σϒ	Σϒ
Diazinon	100%	1Σ	1Σ	1Σ
	50%	1Σ	1Σ	1Σ
	10%	1Σ	1Σ	1Σ
	1%			
Etofenprox	100%	1Σ	1Σ	1Σ2ϒ
	50%	Σ	Σ	Σ
	10%	Σ	Σ	Σ
	1%			
Fipronil	100%	η	H	η
	50%			η
	10%			
	1%			
Mancozeb	100%	1Σ2ϒ3	1Σ2ϒ3	1Σ2ϒ3
	50%	Σϒ3	Σϒ	1Σ2ϒ3
	10%	Σϒ	Σϒ	Σϒ
	1%			
Carbendazim	100%	Σϒη	Σϒη	Σϒη
	50%	Σϒ	Σϒ	Σϒη
	10%	Σ	Σ	Σϒ
	1%			
Chlorothalonil	100%	Σ2ϒτη	Σ2ϒτη	1Σ2ϒτ4η
	50%	Σϒ	Σϒ	Σ2ϒτη
	10%	ϒ	ϒ	ϒ
	1%			

(*Contd.*)

Table 6:(*Contd.*)

AI	*Scenarios*	*Feb to May*	*Jun to Sep*	*Oct to Jan*
Metiram	100%	Σϒ	Σϒ	Σϒ
	50%	Σ	Σ	Σϒ
	10%			Σ
	1%			
Maneb	100%	1Σϒ3	1Σϒ3	1Σϒ3
	50%	1Σϒ3	1Σϒ3	1Σϒ3
	10%			1Σ
	1%			
Propineb	100%	Σ	Σ	Σϒ
	50%	Σ	Σ	Σ
	10%			
	1%			
Copper oxychloride	100%	Σ	Σ	Σ
	50%	Σ		Σ
	10%			
	1%			
Paraquate	100%	3	3	3
	50%	3	3	3
	10%			3
	1%			
Acute	1: Invertebrate	2: Fish	3: Algae	4: Sediment dwelling
Chronic	Σ: Invertebrate	ϒ: Fish	τ: Algae	η: Sediment dwelling

therefore, it tends to increase of pesticide usage. Many different pesticide active ingredients were applied for same pest attack by both poor and richer farmers. There are differences of pesticide usage by poor and richer farmers (Table 4). Results reveal that, poorer farmers used higher amount of insecticides in different categories of active ingredient such as chlorpyrifos, deltamethrin, diazinon, etofenprox, profenofos, sulphur, carbendazim, chlorothalonil, metiram, copper oxychloride, metribuzin, glyphosate and paraquate than richer farmers while richer farmers used much higher fungicide such as propineb and mancozeb (Figure 6). These fungicide results comply with Watawala et al. (2010), which stated that more than 60% of the farmers reported using the fungicides mancozeb and propineb in Sri Lanka. October to January and February to May are the two seasons that show higher pesticide application based on vegetables, land use and the seasons (Figure 7). Moreover, total pesticide loading from the basin indicates a greater load from fungicides and insecticides (Figure 8 and Table 6). Tang et al. (2012) reported that some of these pesticides acquire rapid pesticide transport via overland flow, subsurface lateral flow, and leaching through preferential pathways in soil. This can also be achieved through direct loss via spray drift and spillage, which likely make major contributions to the pesticides lost from surface waters on sloping farmlands. Due to excessive agriculture application, industrial pollutant discharge, and difficulty of degradation, a variety of pesticide residues exist in sediments (Sun et al., 2010).

Excessive rainfall (Figure 2) in this basin is the main source of movement from farmland to streams via runoff for these pesticides. However, some studies suggest that point sources are responsible for 20–80% of the pesticide load in rivers in different catchments (Neumann et al., 2002; Leu et al., 2004; Dai et al., 2011). Therefore, the study utilized four scenarios that assumed the estimated potential concentration of pesticide in water and the impact on downstream aquatic organisms because, when pesticide is applied to farmland, it has underway on different processors, including microbial degradation, evaporation, leaching, photodegradations, adsorption, desorption, hydrolysis etc. (Aislabie and Lloyd-Jones 1995; Hartley, 1969; Vanclooster, 2000; Amarathunga and Kazama 2014; Gerbremariam et al., 2012; Zamy et al., 2004). The results indicated that certain potential loads can be present in the streams (Table 5), which might be risks to aquatic organisms and drinking water consumers in the river basin. Hence, different levels of pesticide poisoning (i.e., acute and chronic toxicity) for different aquatic organisms during different seasons are summarized in Table 6.

The results suggest that 15 different pesticides were toxic at different levels (acute or chronic) and scenarios. Scenarios 1 and 2 show major toxic levels (acute and chronic) for four different aquatic organisms by all 15 pesticide active ingredients. Also, abamectin, chlorpyrifos, deltamethrin, diazinon, etofenprox, mancozeb, carbendazim and chlorothalonil show acute and chronic toxicity levels in scenario 3, and affect four distinct organisms during different seasons of the year. Although chlorpyrifos, deltamethrin, diazinon, maneb and paraquat exceed the acute toxicity level for different aquatic organisms at various magnitudes, the toxicity is very high from October to January compared to other seasons. Many studies suggested these enormous amounts of pesticides potentially pose a great risk to aquatic and human life (Cocco, 2002; Holland and Sinclair, 2004; Agrawal et al., 2010). With 1% of the total pesticide load in the basin, scenario 4 shows that chlorpyrifos and deltamethrin exceed the acute and chronic toxic limit for aquatic organisms. For instance, chlorpyrifos exceeded the acute toxicity (EC50-48 hour) limit for Daphnia magna and the acute toxicity (96 hour LC50) for the sediment dwelling organism. According to land use patterns in the basins and pesticide applications by farmers, the Nanu Oya subbasin (10% of vegetable land use) had a greater risk than the other two subbasins.

Conclusions

This study provides an overview of farmers' perception of pesticide loading in the river basin based on the selection of vegetable crops, insecticide, fungicide, weedicide, pesticide application sequences, and farmers' sentiments on pesticide selection. The results reveal that most of the farmers are over 30 years old and have high levels of farming experience. Farmers' perceptions were impacted by the cropping calendar, agrochemical selection, pesticide application amount and pesticide load.

In addition, land size and climate were significant influences associated with increased pesticide loading. Forty-six commercial brands and 25 active ingredients were recorded in this basin. The clustering analysis showed four used insecticides (diazinon, deltamethrin, sulfur and chlorpyrifos), four fungicides (mancozeb, propineb, metiram and chlorothalonil), and weedicides (mainly metribuzin) are highly used. Larger amounts of pesticides were applied to potatoes, leeks, carrots and cabbages, which was indicated based on the selection of vegetable crops by farmers. The results suggest that even if 1% of the total load is present in the water, both chlorpyrifos and deltamethrin are toxic to aquatic invertebrates.

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