



Farmer Practices and Risk of Water Contamination by Pesticides Used in Vegetable Cropping in Ouagadougou, Burkina Faso

Sylvain Ilboudo^{1,2,*}, Sountong-Noma Faizatou Sorgho³, Paul Windinpsidi Savadogo^{2,3,4}, Geoffroy Gueswindé Ouedraogo¹, Félix dit Bondo Kini¹, Sylvain Ouedraogo¹

¹Institute of Research in Health Science, (IRSS/CNRST), Ouagadougou, Burkina Faso

²Joint International Research Unit - Environment, Health and Society (UMI 3189, ESS) CNRST/CNRS/UCAD/UGB/USTTB, Ouagadougou, Burkina Faso

³Institute of Environmental Engineering and Sustainable Development (IGEDD), Joseph KI-ZERBO University, Ouagadougou, Burkina Faso

⁴Institute of Environment and Agricultural Research (INERA/CNRST), Ouagadougou, Burkina Faso

Email address:

sylvain.ilboudo@gmail.com (S. Ilboudo)

*Corresponding author

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Abstract: Vegetables are grown world-wide in almost 200 countries, but they are regularly subject to pest pressure. To cope with the multiple pests, farmers resort to pesticides whose use in developing countries carries health and environmental risks. This study aimed to investigate the practices of vegetable farmers from Ouagadougou when using pesticides, and to examine the potential for contamination of ground and surface water. Based on the use of questionnaires and field observations, this study investigated farmers' practices on vegetable pest management using pesticides. The physicochemical properties of the active ingredients of pesticide were analysed, and Goss and GUS algorithms were applied to estimate the risk of surface and ground water contamination, respectively. The majority of producers were male (58%), illiterate (80%) and use pesticide in their vegetable crops (97.72%). The products used by the farmers in the study areas were insecticides (28), herbicides (5), fungicides (1), and nematicide (1), although more than 50% of these pesticides were registered for the treatment of cotton crops but not for vegetables. Depending on the crop, 88% of the farmers applied pesticides up to 5 times or more per cropping season. Among active ingredients from pesticides used by farmers, eight are highly solubles, nine are readily degradable, six are moderately mobile, and five are immobile. Five have high potential to contaminate surface water while one has high potential to contaminate ground water. These results can be used for the development of tool to predict water contamination by pesticides in pest management by vegetable farmers. This could contribute to the reinforcement of pesticides policy for advance their health, environmental and economic consequences.

Keywords: Vegetable, Farmer Practices, Pesticides, Goss Algorithm, GUS Index, Water Contamination

1. Introduction

Vegetables are grown world-wide in almost 200 countries. They are vital to the general good health of human beings, providing essential vitamins and minerals, dietary fiber and phytochemicals, and reducing risk from dangerous diseases and other medical conditions [1]. In many parts of

sub-Saharan Africa, indigenous vegetables have added important nutritional value to the diets of locals for hundreds of years. Beyond its nutritional interest, the economic importance of vegetables pushes the populations of cities and suburbs of developing countries to turn to urban and peri-urban agriculture, especially vegetable production which contributes to the reduction of unemployment, fight against poverty and food insecurity in households with limited

resources [2]. Vegetable remains the most popular agricultural activity in the main cities of Burkina Faso, with an increase of areas intended for vegetable production in the order of 225% from 1996 to 2009 [3].

Despite its contribution to the socio-economic development of the city, the sector faces many challenges including land pressure, organizational and regulatory difficulties and pest pressure. Crop losses due to damage caused by pests, diseases, nematodes and weeds are a major agricultural problem for producers [2]. In 2010, losses attributed to pathogens, insects, virus, and weeds in six major crops (rice, wheat, maize, potatoes, soybean, and cotton seeds) amounted to US\$16.16 billion in Africa [4].

Up to date, pesticides constitute the key control tactics for management of pests and diseases and the productivity of crops depends on their effective control [5]. Pesticides are a class of chemicals designed to kill pests (rodents, insects, or plants) that may affect agricultural crops. In the area of vegetable production, about 59 to 100% of vegetable farmers periodically apply pesticides against pests [6, 7]. However, controversy exists over the global dependence on such agents, given their excessive use: misuse, their volatility, long-distance transport and eventual environmental contamination in colder climates [8]. Furthermore, pesticides are poisons and, unfortunately, they can harm more than just the “pests” at which they are targeted. They are toxic, and exposure to pesticides can cause a number of health and environment effects. The unsafe and indiscriminate use of pesticides in agriculture represents a major hazard to the environment and human health [9]. A growing number of studies from some zones of Burkina Faso have shown anarchic use of plant protection products and contamination of surface and groundwater in areas of pesticides use [7, 10, 11].

Although misuses of pesticide increase environmental risks in high population-density areas, few papers have been published on the environmental impacts of pesticide use in tropical areas and particularly in Africa [4]. The aim of this paper was to understand farmers’ pest management practices in vegetable crops in Ouagadougou, and to derive some implications for pest management in future. Through the study of cropping practices among vegetable farmers in Ouagadougou and characterization of pesticides used, this work is aimed to provide a better understanding of the potential risk of pollution of ground and surface water.

2. Materials and Methods

2.1. Study Area

The study took place in Ouagadougou (Figure 1), town located in the centre of Burkina Faso (12°20' and 12°26' north latitude and 1°28' and 1°36' west longitude). Ouagadougou has Sudano-Sahelian climate characterized by alternating between a short rainy season lasting from May to September, and a long dry season from October to April [12]. The soils are

leached, shallow and nutrient-poor tropical ferruginous types. They are formed on sandy, sandy-clayey or clayey materials [13]. The rainwater of the city of Ouagadougou is drained towards three main dams through topographic depressions arranged in canals. The city of Ouagadougou is experiencing a strong unprecedented demographic explosion, due to the rural exodus and to immigrants who are seeking well-being [14]. This situation leads to an extension and an increase in the city's food needs, at the origin of the spontaneous development of urban agriculture, including market gardening [3]. Agricultural activities in and around the city of Ouagadougou focus on cereals cultivation, market gardening, forestry (nursery and florists) and livestock. An inventory of agricultural sites reveals 71 vegetable production sites generally located in shallows, along rivers, allotments, non-construction areas, and undeveloped areas on the outskirts of the city [15, 3]. Based on the approach used by Nguyen *et al.* [16], the sites were selected for the survey based on the importance and scale of vegetable production, agro-ecology, types of crops produced, and accessibility.

2.2. Questionnaire Development and Delivery for Farmers Practice and Risk

Exploratory field visits on the study area helped to identify and appreciate the importance of vegetable farm sites. A sample of 88 male and female vegetable producers from the selected sites were included systematically in the study, after their free and informed consent. Diagnostic surveys, formal interviews, and field observations were used to gather information on farmers’ knowledge of pesticides and safety practices. The questionnaires were individually administered to producers. The direct observations focused on the type of soil, the distance between the treated surface and the water body, the slope, the presence of a buffer zone and the behavior of farmers in their place of work, particularly with regard to transport, preparation, and application of pesticides and the management of leftovers and empty packaging of pesticides.

The questionnaire was designed in french and translated into the local language that are understood by majority of the farmers. The questionnaire, inspired from Jallow *et al.* [9], included closed and open-ended questions, and was pre-tested by randomly interviewing twenty farmers not included in this study. The questionnaire contained three main sections. The first section one was designed to collect information on personal characteristics of the farmers including age, educational level, and years of farming experience. The second section focused on collecting information on farmers’ level of awareness of pesticide laws and regulations, and knowledge and understanding of pesticides with respect to the environmental and human health. The third section included questions regarding pesticide handling and safety practices including reading and following label instructions, storing and disposing of pesticides and empty containers, and use of PPE and other protective practices during and after pesticide application.

2.3. Prediction of the Risk of Ground and Surface Water Contamination with Pesticides

2.3.1. Physico-chemical Properties and Environmental Fate of Pesticides

When a pesticide is applied in the environment, it becomes distributed among the four major compartments: water, air, soil, and biota. The fraction of the chemical that will move into each compartment is governed in part by the

physicochemical properties of that chemical. The transfer of the pesticide from one compartment to another depend to processes such as volatilization, drift, retention, leaching and runoff, to which is added the degradation process which also plays an important role in environmental contamination. For the purpose of the study, the main pesticide properties as solubility in water at 20°C, coefficient of adsorption in organic matter (Koc), and typical half-life in soil (DT₅₀) [17].

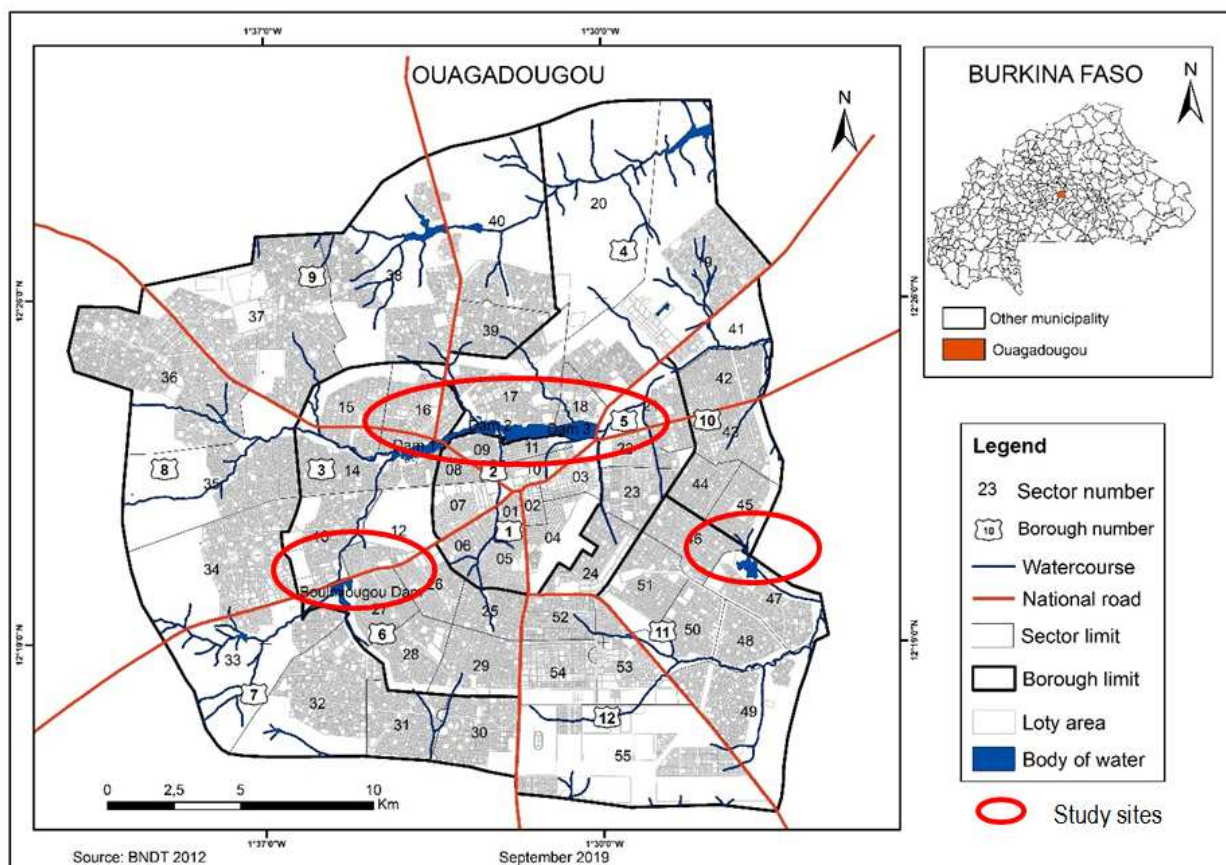


Figure 1. Municipality of Ouagadougou with its hydrographic network sheltering the study sites.

Solubility is a measure of the amount of chemical that can dissolve in water. Pesticide solubility is an important factor in waste disposal. Solubility can indicate the maximum amount of pesticide in solution in any accidentally contaminated water.

The solubility of a compound in water is given in mg/L at 20°C. According to the values taken by this parameter, compound will be considered Not soluble (<0.10); Slightly soluble (0.1–1); Moderately soluble (1–10); Readily soluble (10–100); Highly soluble (>100).

The partition coefficient Koc is defined as the ratio of pesticide concentration in a state of sorption (i.e. adhered to soil particles) and the solution phase (i.e. dissolved in the soil water). Thus, for a given amount of pesticide, the smaller the Koc value, the greater the concentration of the pesticide in solution. Pesticides with a small Koc value are more likely to leach into groundwater than those with a large Koc value. Because of the large range of Koc values, the logarithm of Koc is already used. Based on chemical Log Koc, the values

considered for each parameter are: Highly mobile (<1); Mobile (1–2); Moderately mobile (2–3); Slightly mobile (3–4); Hardly mobile (4–5); Immobile (>5).

The organic compounds in soil undergo a lot of changes. Most pesticides break down or degrade over time as a result of several chemical and microbiological reactions in soils. Some are broken down by sunlight. The value of the degradation is given by half-life DT₅₀. Half-life DT₅₀ is a measure of the amount of time (in days) it takes for 50 percent of the parent compound to disappear from soil or water by transformation. The important degradation processes are biological processes (biodegradation) and physicochemical processes (hydrolysis, photolysis, etc.). The values considered for each parameter are: Readily degradable (DT₅₀<20); Fairly degradable (20–60); Slightly degradable (60–180); Very slightly degradable or persistent (DT₅₀>180).

2.3.2. Evaluation of Surface Water Contamination Potential

The evaluation of pesticide potential to reach the surface

water was performed in application of criterion proposed by Goss [18] as described by Kortekamp [19]. This criterion considers the half-life (DT_{50}) of the chemical in soil, its water solubility and the soil sorption coefficient (K_{oc}). According to this criterion, the active ingredients of pesticides are divided into six groups: High Sediment-Transport Runoff Potential (HSTRP); Medium Sediment-Transport Runoff Potential

(MSTRP); Low Sediment-Transport Runoff Potential (LSTRP); High Water-Phase-Transport Runoff Potential (HWTRP); Medium Water-Phase-Transport Runoff Potential (MWTRP); Low Water-Phase-Transport Runoff Potential (LWTRP). The values considered for each parameter are presented in table 1.

Table 1. Goss' algorithm for evaluating a pesticide's contamination potential in surface water.

Transportation	Contamination potential		
	High	Low	Medium
Associated to soil (AD)	$DT_{50} \geq 40$ and $K_{oc} \geq 100$ or $DT_{50} \geq 40$ and $K_{oc} \geq 500$ and solubility ≤ 0.5	If $DT_{50} \leq 1$ or If $DT_{50} \leq 2$ and $K_{oc} \leq 500$ or If $DT_{50} \leq 4$ and $K_{oc} \leq 900$ solubility ≥ 0.5 or If $DT_{50} \leq 40$ and $K_{oc} \leq 500$ solubility ≥ 0.5 or If $DT_{50} \leq 4$ and $K_{oc} \leq 900$ solubility ≥ 2	All others
	If solubility ≥ 1 and $DT_{50} \geq 35$ and $K_{oc} \leq 100000$ or If solubility ≥ 10 and solubility ≤ 100 and $K_{oc} \leq 700$	If $K_{oc} \geq 100000$ or If $K_{oc} \geq 1000$ and $DT_{50} \leq 1$ or If solubility ≤ 0.5 and $DT_{50} < 35$	All others

Source: [18, 20].

2.3.3. Evaluation of Ground Water Contamination Potential

Table 2. Algorithm for determination of GUS indexes.

Equation	Classification			
	High	Low	Very low	Medium
$GUS = \log(DT_{50}) \times (4 - \log(K_{oc}))$ (equation 1)	≥ 2.8	≤ 1.8	$<$ or solubility < 1 and $DT_{50} < 1$	All others

Source : [18, 20].

The potential of pesticides to contaminate groundwater was estimated through the leaching potential index determination following the Groundwater Ubiquity Score (GUS) methodology [21]. The GUS index is based on the partition coefficient between soil organic carbon and water-sorption coefficient (K_{oc}) and the half-life (DT_{50}) in soil for each pesticide active ingredient. The GUS index was calculated according to equation 1 [20].

2.4. Data Analysis

Survey data were coded, entered, and then analyzed using EpiData V2.2.3.187. Descriptive results were expressed as frequencies and percentages. The Excel software was employed to treat the data and to apply the Goss and Gustafson algorithms. The physicochemical properties of each active ingredient were extracted from the website of the International Union of Pure and Applied Chemistry (<https://sitem.herts.ac.uk/aeru/iupac/>).

of the farmers interviewed were male. The average age of producers is about 42 years, with 51% aving up to 40 years. The majority of producers (80%) were illiterate or had only primary school education (10%). Oluwole and Cheke [22] in a previous study was found that the majority of the farmers who were either illiterate or with only primary school education depended on explanations from other farmers and/or pesticide suppliers. These results suggest that no more than 10% of vegetable farmers in Ouagadougou are able to read the label instructions for proper use of pesticides. Only 37% of survey respondents received training related to pesticide safety or safe and effective pesticide application. The lack of training on pesticides use is commonly reported by several authors [7, 6, 11]. The lack of training and the illiteracy of the study population may encourage bad practices including non-compliance with doses and schedules of treatment, with risks of environmental contamination.

3. Results and Discussion

3.1. Social and Professional Characteristics of the FARMERS

The results of the survey (table 3) describe the social and professional characteristics of the farmers. The majority (58)

Table 3. Social and professional characterizations of vegetable farmers.

Characteristics	N (n=88)	%
<i>Gender</i>		
Male	51	58
Female	37	42
<i>Member of an association</i>		
Yes	29	33

Characteristics	N (n=88)	%
No	25	28
NR	46	39
<i>Age groups</i>		
[20 - 30]	16	18
[31 - 40]	28	32
[41 - 50]	23	26
[51 - 60]	18	21
[61 - 70]	3	3
<i>Education level</i>		
Illiterate	70	80
Primary school	9	10
Secondary school	9	10
<i>Professional training on pesticide use</i>		
Yes	32	37
No	56	63

3.2. Vegetable Produced by Farmers of Ouagadougou Town

According to the results of the survey, a very large diversity of crops are produced in the study area. The main vegetable crops identified in the study are long cycle (cultivation duration of two to three months before harvest) and short cycle (cultivation duration of one to two weeks before harvest) crops. Short-cycle vegetables identified include *Spinacia oleracea* (Spinach), *Apium graveolens* (Celery), *Amaranthus hybridicus* (Amaranth), and *Petroselinum crispum* (Parsley). Long-cycle vegetables include *Lactuca sativa* L. Var. *battavia* (Lettuce), *Brassica oleracea* L. Var. *capitata* (Cabbage), *Cucumis sativas* (Cucumber), *Phaseolus vulgaris* (Green beans), *Pisicum sativum* (Peas), *Pisicum sativum* (Peas), *Fragaria* sp (Strawberry), *Capsicum frutescens* (Pepper), *Capsicum annum* L. (Sweet peppers), *Daucus carota* (Carrot), *Brassica napus* (Turnip), *Beta vulgaris* (Beet), *Allium porrum* (Leek), *Raphanus napus* (Radish), *Solanum tuberosum* (Potato), *Allium cepa* (Onion), *Hibiscus sabdariffa* (Sorrel), and *Solanum melongena* L. (Eggplant). This diversity had already been reported by Nabie in 2018 [15]. Otherwise, the respondents indicated that each type of crop is exploited for a fixed period of the year.

3.3. Pesticides Commonly Used by Farmers and Practices

The results showed a great diversity of pesticides used for vegetable production. Table 4 summarizes information about pesticides used, their active ingredient (s), chemical family, WHO classification according to their toxicity, physical appearance, crop on which it is registered, and their registration status. 35 formulations containing 17 active substances have been identified. Although formulations were in the majority (65.71%) registered by the CSP (Comité Sahélien des Pesticides), almost the half of them (17/35) were registered for cotton crops. Only 13 out of 35 were registered for use on vegetables. Such misuse of pesticides appears to be widespread practice among farmers, especially in developing countries as reported by several studies [7, 11, 6, 23]. In addition to asking the residue problem in the food chain, such practices are potentially polluting for water, as the cotton farms agropedological situation is different from that of vegetable crops field.

Mostly (97.72%), vegetable producers in Ouagadougou make pesticide use in their production operations. The frequency of pesticides use varied by crop. The crops most subjected to treatment are Lettuce, Cabbage, Amaranth, Sorrel,

and Eggplant. Some farmers report that cabbage must undergo 24 insecticide treatments during their production cycle. The main practices of vegetable farmers of Ouagadougou are reported in table 5. The majority of the respondents uses pesticides every week for pests management on vegetable production. Similar results were found by Ngowi et al. [24] who had noted that more than 15% of farmers in the Northern Tanzania reported applying pesticides 16 times or more per cropping season. This recurrent use of pesticides is justified by the constant pressure of pests targeting these crops [7]. Also, producers seem to be inclined to meet the demands of consumers who want high quality products. Vegetable producers tended to use more pesticides in order to preserve their crops or vegetables to pest alteration for more economic benefits [25]. The important use of pesticides may result in frequent release of pesticides in environment with potential contamination of soils and water.

Producers acquire their pesticides mainly from the market (46%) and retailers (37%). These pesticides are delivered to producers in reconditioned form. In these circumstances, it is obvious that there is no label accompanying the delivery of these products, and there is therefore no possibility of having instructions on the proper use of plant protection products. In general, it is the reseller who advises the producer on the choice of pesticides and how these products should be used. However, as also reported by Toe et al. [11], resellers do not have training to give such advice. From this observation, we can admit that the packaging proposed by pesticide manufacturers is not adapted to the farmers needs. Indeed, they have small areas and it is neither practical nor economic for the small farmers to pay a whole box of a pesticide and use only a small part.

The majority of producers (86%) use backpack sprayers for pesticide application. However, a minority of them use watering cans and buckets with tree branches to spray their crops. These practices are highly polluting for the environment. It is not possible to meet the doses under these conditions, and the pesticide is not uniformly distributed on the crop. The use of inappropriate instruments for the application of pesticides has often been reported. Thus, Tarnagda et al. [26] reported the use of branches of trees for pesticides spray in Ouagadougou.

The vegetable farmers irrigate their crops by drawing water from dams (69%) or wells (59%), or both. 34% of the fields are within 10 meters of the water body, and only 11% of the fields are located more than 100 meters from the water body. This indicates that there is not a good safety distance between fields and water points, which would increase the risk of water contamination by different transfer mechanisms. Furthermore, between the field and the water body, buffer zone are absent (78%) or is devoid of vegetation (22%). Management of empty pesticide packaging remains problematic. The majority of producers (54%) abandon them in the field. This mismanagement of empty packaging is one of the threatening practices commonly reported in producer surveys [22, 27-29]. As abandonment in the field, burial or incineration, these practices generate risks for the environment and human health. It is difficult, if not impossible, to clean the

container of traces of pesticides.

Overall, vegetable producers followed a number of pest control practices by variety of chemical pesticides to control pest infestation and minimize crop losses. As previously reported by Jeyanthi and Kombairaju [5], the lesson that emerging from the results of the study are that pesticides were used by farmers without taken into account pest ecology, economic injury level, types of pesticides to control specific insect pests, their quantities and methods of application. The consequences of these

inappropriate practices are environmental contamination and effects on human health and biodiversity. Once introduced into the environment through their multiple use, pesticides become distributed among water, air, soil, and biota (living organisms) by physical processes such as sedimentation, adsorption, and volatilization. The fraction of the chemical that will move into each compartment is governed by the physico-chemical properties of that chemical [17]. Some of these physico-chemical properties were analyzed and discussed below.

Table 4. List of pesticides recorded during the survey.

Trade name	Active ingredients	Pesticide chemical family	Pesticide type	WHO class*	Physical appearance	Target crop	Registration status **
DECIS 25 EC	Deltamethrin 25 g/l	Pyrethroid	Insecticide	II	Liquid	Tomato	Yes
EMIR 88 EC	Cypermethrin 72 g/l	Pyrethroid	Insecticide	II	Liquid	Cotton	Yes
ATTACK	Acetamiprid 16 g/l	Neonicotinoid	Insecticide	NK	Liquid	Vegetable	No
LAMBDA POWER	Emanectin benzoate	Avermectin	Insecticide	II	Liquid	Vegetable	Yes
SAVAHALER	Lambda-cyhalothrin 25 g/l	Pyrethroid	Insecticide	II	Liquid	Vegetable	Yes
LAMBDA SUPER 2.5 EC	Methomyl 250 g/kg	Carbamate	Insecticide	II	Powder	Vegetable	Yes
EMACOT	Lambda-cyhalothrin 25 g/l	Pyrethroid	Insecticide	II	Liquid	Vegetable	Yes
INSECTOR	Emanectin benzoate 50 g/kg	Avermectin	Insecticide	II	Powder	Cotton	Yes
LIMANEB	Imidacloprid 350 g/kg	Neonicotinoid	Insecticide/Fungicide	III	Powder	All crops	Yes
BOMEK 18 EC	Thiram 100 g/kg	Thiocarbamate	Nematicide	NK	Powder	Vegetable	Yes
AVAUNT 150 EC	Maneb 30 à 40 g/l	Thiocarbamate	Insecticide	II	Liquid	Tomato	Yes
EMIR FORT 104 EC	Abamectin 18 g/l	Avermectin	Insecticide	III	Powder	Cotton	Yes
LAMBDA MASTER	Indoxacarb 150 g/l	Carbamate	Insecticide	II	Liquid	Cotton	Yes
ADWUMA MMOA	Cypermethrin 72 g/l	Pyrethroid	Insecticide	II	Liquid	Vegetable	Yes
HEROS 360 SL	Acetamiprid 32 g/l	Neonicotinoid	Insecticide	II	Liquid	Rice	No
BIN'FLA 720 WG	Lambda-cyhalothrin 25 g/l	Pyrethroid	Insecticide	III	Liquid	Rice	Yes
ADWUMA WURA	Glyphosate 410 g/l	Phosphonoglycine	Herbicide	III	Liquid	Cotton	Yes
CURACRON 500EC	Glyphosate 360 g/l	Phosphonoglycine	Herbicide	III	Liquid	Rice	No
CIGOGNE P186 EC	Glyphosate 720 g/kg	Phosphonoglycine	Herbicide	III	Liquid	Cotton	Yes
CYPERCAL	ADWUMA WURA	Phosphonoglycine	Herbicide	III	Liquid	Cotton	Yes
CAPT 88EC	CURACRON 500EC	Organophosphate	Insecticide	III	Liquid	Cotton	No
DJIGIKAN 800EC	Profenofos 150 g/l	Organophosphate	Insecticide	III	Liquid	Cotton	No
HICTEL 440EC	Cypermethrin 36 g/l	Pyrethroid	Insecticide	III	Liquid	Tomato	Yes
CAPT 96EC	Cypermethrin 50 g/l	Pyrethroid	Insecticide	III	Liquid	Tomato	Yes
CYPERCOT 336EC	Acetamiprid 16 g/l	Neonicotinoid	Insecticide	II	Liquid	Cotton	Yes
SUMITEX 40EC	Cypermethrin 72 g/l	Pyrethroid	Insecticide	II	Liquid	Cotton	Yes
POLYTRINE C 186 EC	Cypermethrin 72 g/l	Pyrethroid	Insecticide	II	Liquid	Cotton	Yes
SUNHALOTHRIN2.5%EC	Profenofos 300 g/l	Organophosphate	Insecticide	II	Liquid	Cotton	No
GRAMOPAT SUPER	Cypermethrin 36 g/l	Pyrethroid	Insecticide	II	Liquid	Cotton	No
ATTAKAN C 344SE	Dimethoate 400 g/l	Organophosphate	Insecticide	II	Liquid	Vegetable	No
BENCO	Cypermethrin 36 g/l	Pyrethroid	Insecticide	II	Liquid	Vegetable	No
CAIMAN B19 EC	Profenofos 150 g/l	Organophosphate	Insecticide	II	Liquid	Cotton	No
DUEL 186EC	Cypermethrin 36 g/l	Pyrethroid	Insecticide	II	Liquid	Cotton	No
BON OPTIMALE	Acetamiprid 20 g/l	Neonicotinoid	Insecticide	NK	Liquid	Vegetable	No
BLAST 52 EC	Lambda cyhalothrin 15 g/l	Pyrethroid	Insecticide	II	Liquid	Vegetable	No
	Lambda cyhalothrin 36 g/l	Pyrethroid	Insecticide	II	Liquid	Cotton	No

*II – moderately hazardous; III – slightly hazardous; U – unlikely to present acute hazard in normal use; – not listed.

**Sahelian Committee of Pesticides.

3.4. Analysis of Physico-chemical Properties of the Active Ingredients

Table 5. Pesticide use practices by vegetable production farmers in Ouagadougou town.

Practices	N (n=88)	%
<i>Frequency of recourse to pesticides</i>		
A treatment every four days	8	9
Two treatment every week	3	3
A treatment every week	77	88
<i>Pesticide sources</i>		
Market	40	46
Retailer	33	37
Market and retailer	4	5
Shopkeeper	11	12
<i>Instruments for pesticides application</i>		
Watering can	2	2
Bucket*	10	12
Knapsack sprayers	75	86
<i>Water source for crops irrigation</i>		
Well	52	59
Dam	61	69
<i>Distance of field from water source (m)</i>		
≤10	30	34
10 to 50	35	40
50 to 100	13	15
>100	10	11
<i>Instruments for crops irrigation</i>		
Bucket	2	2
Watering can	43	49
Motor-pump	29	33
<i>Instrument of concentrated formulation measuring</i>		
Pesticide bottle cap	73	83
Bucket	11	12
Bottle	4	5
<i>Pesticide packaging management**</i>		
Abandonment in the field	54	61
Burying in the ground	24	28
Incineration in the open air	15	18
<i>EPI washing practice and location of washing</i>		
Farmers washing their EPI	60	68
Washing in the field	43	49
Washing in the dam	8	9
<i>Compliance with pre-harvesting interval</i>		
7 days	45	51
14 days	27	31
21 days	7	8
30 days	9	11
<i>Weather conditions taken into account when applying pesticides (n=31)</i>		
Wind	7	8
Rain	1	1
Sunshine	23	26
<i>Soil nature (n=43)</i>		
Clay soil,	22	25
Sandy soil	4	4
Sumus soil	17	20
<i>Presence of buffer zone</i>		
Yes	19	22
No	69	78

** A practice doesn't exclude the others ones.

3.5. Water Contamination Potential

In this study, the Goss Algorithm Method was used for surface water contamination assessment. This method distinguishes the transport potential of pesticides in dissolved form or in form adsorbed to soil particles. Under both assumptions, the assessment of transport potential to surface

water yielded the results displayed in table 6. For the transport in dissolved form, seven and eight pesticides have low and medium transport potential respectively. Two have high potential (imidacloprid and thiram). Admitting transport under adsorbed form, eight and four pesticides have respectively low and medium transport potential. Five (deltamethrin,

emanectin benzoate, indoxacarb, lambda-cyhalothrin, and paraquat chloride) have high potential.

The two last columns of Table 6 display the value of the GUS index for each pesticide and its interpretation. Regarding the GUS indexes in this table, nine pesticides were classified as having “Very low” leaching potential. Six pesticides have low leaching potential. Soarez *et al.* [20] are found that most of active ingredients (52.73%) listed in a previous study they conducted were classified as having low leaching potential. In the present study, one pesticide has medium leaching potential (methomyl) and one also has high leaching potential (imidacloprid).

The models give a good prediction of environmental contamination, and the results corroborate the analysis data. Interestingly, previous work reported the presence of pesticide residues in both ground and surface water in vegetable growing areas [32, 28]. In addition, the use of models lets

acquisition of complementary data to those of field measurements, and helps to identify the contamination sources or to implement mitigation measures. However, in addition to the intrinsic properties of pesticides that allow estimate the potential for contamination of surface water, some practices of producers in the field can be factors of exacerbation of the phenomenon. Indeed, the absence of buffer zone, using sprinklers for pesticide application and watering practices can increase transport of pesticides to surface water, either in pesticides dissolved form or in its form associated to soil particles. Also, soil characteristics as its texture can affect chemical movement. Soil texture is an indication of the relative proportions of sand, silt, and clay in the soil. Pesticides tend to be adsorbed mostly on clay and organic matter. The higher the clay content, the greater the number of binding sites for pesticide retention [31].

Table 6. Pesticides physico-chemical properties and water contamination potential.

Pesticides	Solubility (mg/l)	DT ₅₀	K _{oc}	Log K _{oc}	Goss algorithme		GUS index	
					Goss (dissolved)	Goss (adsorbed)	GUS	GUS-based classification
Abamectin	0.020	25.3	23,103	1	Low	Medium	0.25	Low
Acetamiprid	2950	1.6	200	2	Medium	Low	0.40	Low
Cypermethrin	0.009	22.1	307558	5	Low	Medium	-2.00	Very low
Deltamethrin	0,0002	58.2	10240000	7	Low	High	-4.37	Very low
Dimethoate	25900	2.5	50	2	Medium	Low	1.01	Low
Emanectin benzoate	24.0	300	377000	6	Low	High	-1.63	Very low
Glyphosate	10500	15.0	1424	3	Medium	Low	-0.25	Very low
Imidacloprid	610	191	255	2	High	Medium	3.74	High
Indoxacarb	0.2	113.2	4483	4	Medium	High	0.72	Low
Lambda-cyhalothrin	0.005	175	283707	5	Low	High	-3.28	Very low
Malathion	148	0.17	1800	3	Low	Low	-1.28	Very low
Mancozeb	6.2	0.05	998	3	Medium	Low	-1.45	Very low
Maneb	178	1	2000	3	Medium	Low	-0.88	Very low
Methomyl	55000	7	72	2	Medium	Low	2.19	Medium
Paraquat chloride	620000	3000	1000000	6	Low	High	-7.40	Very low
Profenofos	28	7	2016	3	Medium	Medium	0.59	Low
Thiram	18	4.89	676	3	High	Low	0.01	Low

4. Conclusion

The environmental risk assessment of pesticides is a growing issue, particularly for the protection of the environment, and requires evaluation methods that include different types of impacts. This work made it possible to observe the different modes of transport, storage, preparation and application of pesticides in vegetable farmers and to highlight the different practices and risk behavior of producers when using pesticides. The results of the survey on the knowledge and use of pesticides around water bodies are very worrying. The Goss and GUS indexes can be used for the development of tool to predict water contamination by pesticide in pest management by vegetable farmers. This could contribute to the reinforcement of pesticide policy for advance their health, environmental and economic consequences.

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