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Pesticide contamination of water used for urban market gardening in Bamako (Mali)

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ABSTRACT

The use of natural and synthetic pesticides is increasingly common in developing countries, particularly in pest control efforts to improve crop yields. Misuse of these plant protection products can lead to a loss of efficacy on crops and the development of certain diseases. Among the most widely used insecticides in the world, pyrethroids are generally very fast acting against all insects but are also very toxic to the aquatic environment. In Mali, there are few studies on the risks of these phytosanitary products for market gardening on the health of rural populations and on the environment. It is in this context that we are conducting our research on phytosanitary products intended for various vegetable crops. The objective is to determine the level of pesticide contamination of water used for urban market gardening in Bamako, particularly by pyrethroids. In order to carry out these analyses, we collected water from wells, boreholes, marigots and the Niger River during the dry season and in winter. We chose a solid phase extraction (SPE) for the active substances present in the water. For their separation, we used an Ultra Performance Liquid Chromatography (UPLC) chromatograph, which allows a single separation for the active substances present in the water. The analytical results show the presence of *cypermethrin residues*. Market gardening uses a large quantity of synthetic pesticides, but there is a change in practice with the use of biopesticides, which would eventually reduce the risks for the environment and the health of the applicators.

1. Introduction

Today, half of the world's population lives in urban centers. This strong urban growth is even more noticeable in Africa, particularly in sub-Saharan Africa (Bayendi Loudit et al., 2017). Large African metropolises such as Bamako in Mali are facing strong demographic growth (3.6% per year) and environmental changes that are leading to changes in people's lifestyles, particularly in food consumption patterns. In the South, urban agriculture plays an important role in reducing poverty and supplying urban markets (De Bon et al., 2010; Crush et al., 2012; Robineau and Soulard, 2017).

This type of agriculture is characterized by a variety of agricultural and pastoral activities that can take place within or on the outskirts of urban areas. Market gardening, which is an excellent source of income for the inhabitants of urban and peri-urban areas, plays an important socio-economic role (Dubbeling et al., 2010). The significant income generated by urban agriculture plays an important role in the balance of the family economy (Poulsen et al., 2015).

However, urban agriculture in Southern countries is threatened by the problems of land pressure, land shortage due to the extension of built-up areas for residential, commercial or industrial purposes (Aubry et al., 2012). The majority of vegetable plots are located on reserves (administrative and private) and are either loaned or rented. These plots are located along rivers and areas considered unsuitable due to a shallow water table. Urban agriculture is faced with soil nutrient depletion due to overexploitation. In addition, crops are vulnerable to attack by pests (weeds, pests and pathogens) (Agnandji et al., 2018). To cope with these constraints, market gardeners use chemical fertilizers and synthetic pesticides (herbicides, fungicides, insecticides) to improve nutrient availability, protect crops from pests and increase yields at harvest

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(Agnandji et al., 2018; Balasha, 2019 (a), Selvaraj et al., 2021).

Today, Africa is the continent that uses the least amount of pesticides in volume due to poverty. The arsenal of pesticides used in agriculture is very vast and information on their impact on health and ecosystems is rarely known by suppliers, technical advisors and farmers. However, the use of wastewater, pesticides, fertilizers and urban waste in market gardening constitute a source of physical, chemical and microbiological contamination. (Agbohessi et al., 2015). This common agricultural practice could have a negative impact on human health and the environment (Worapitpong et al., 2017; Tseng et al., 2021). Wastewater, polluted soils and agricultural inputs can be sources of contaminants in vegetable products (Samaké et al., 2011; Kamga et al., 2013; Mahmud et al., 2021). Research addresses the technical problems of urban agriculture in the South, including the use of grey water and urban waste, and the health problems that this can cause (Muliele et al., 2017; Null et al., 2018). Thus, the health services are recording more and more cases of illnesses related to the consumption of products maintained with polluted water from various sources: drains, gutters, marigots and even the surroundings of cemeteries, etc. Some studies show that farmers have little knowledge of the active substances they use, the doses to be applied, the frequency of treatment and their effects on human health and the environment (Banjo et al., 2010, Balasha et al., 2019 (b); Toumi et al., 2019). Obsolete or unregistered products are regularly found on the market or on farmers' farms. However, in 1992, the member states of the Inter-State Committee for Drought Control in the Sahel (CILSS) signed a common regulation for the registration of pesticides (CILSS, 1999). Also, the Sahelian Pesticide Committee (CSP), an executive body, evaluates the registration dossiers submitted by phytopharmaceutical firms each year and grants sales authorizations for all member states. In Mali, there is an awareness of these different issues but there is little work on urban agriculture and its health and environmental impacts. (Haggblade et al., 2018).

Pyrethroid insecticides are one of the most widely used domestic (for mosquito control in tropical countries) and agricultural pesticides, comprising one-quarter of the world market as early as 1995, rising in popularity because they are generally more toxic to insects than nontarget species (DeMicco et al., 2010; Méjanelle et al., 2020). In the 1970s, these represented an alternative to older molecules (organochlorines, organophosphates, carbamates, etc.), whose ecotoxicity was beginning to be denounced (USEPA, 2011). A number of previous studies have demonstrated that pyrethroids are toxic to diverse types of invertebrates. Their toxic effects include disruption of the function of the neurons' sodium channels as they provoke repetitive after-discharges in neurons and muscle cells that produce repeated stimulation. At high concentrations of pyrethroids, the sodium intake may block conduction, causing paralysis (Aznar-Alemany et al., 2017). Despite their toxicity to aquatic organisms, due to their high affinity to organic materials, pyrethroid insecticides bind to terrestrial substrates and are less likely to enter aquatic systems. (Hua and Relyea, 2019). Even though pyrethroids are degraded faster than other pesticides with half-life between 21 and 87 days (Footprint, 2016). They have been shown to occur in water bodies, allowing their transfer to the aquatic food webs (Méjanelle et al., 2020). Although pyrethroids are often considered to be "safer" pesticides because of their low to moderate acute toxicity to nontarget species such as bees, butterflies etc., their increased use raises concerns of potential adverse effects, particularly in sensitive populations such as children (DeMicco et al., 2010). Several acute and chronic effects on humans have been reported, these studies have associated Parkinson's and Alzheimer's diseases as well as the lateral sclerosis amyotrophic or Charcot's disease to the exposition with pyrethroids (Aznar-Alemany et al., 2017; Guo et al., 2018; Martínez et al., 2020). In developing countries, the impact of current-use pesticides on freshwater quality is a growing concern (Schulz and Stehle, 2008; Li et al., 2014).

Increasingly, biopesticides such as *emamectin benzoate* (a microorganism derivative), which are less toxic than chemical pesticides, are being used as insecticides in conventional agriculture, mostly as part of integrated pest management strategies (Fanigliulo and Sacchetti, 2008; Mpanga et al., 2021).

In Mali, market gardening, which allows the cultivation of plants for food use, is a widespread practice in the urban and peri-urban areas of Bamako. Its development can be explained by a strong demand for vegetables linked to the significant growth of the urban population and the evolution of living standards and food habits. Market gardening is mainly carried out by women. Market gardening is now being questioned because of the urban development. The expansion of built-up areas for residential, commercial, administrative and industrial purposes is a threat to the survival of the sector, and even to its eventual development. Competition is unfavourable to market gardening, which results in the significant reduction or marginalisation of available land. In fact, market gardening is relegated to the areas subject to flooding: more than half of the plots are located near Niger river and its affluents, as these are areas that are difficult to build on. The cultivated plots are identified as small gardens of very small area. In Mali, there are few studies on the risks of these phytosanitary products for market gardening on the health of rural populations and on the environment. It is in this context that we are carrying out our research on phytosanitary products intended for various vegetable crops which are salads, onions, carrots, cabbages, cucumbers and tomatoes. Our article is part of this perspective to identify the risk factors for the environment of populations in urban areas. The objective was to determine the level of pesticide contamination of water used for urban market gardening in Bamako, particularly by pyrethroids.

2. Material and methods

Our study was conducted in the urban areas of Bamako (Mali) between 2019 and 2020 (Fig. 1) as part of the FSPI[1] project entitled "Urban Agriculture and Nutritional, Health and Environmental Impacts in Bamako" (AgriSan).

2.1. Pesticide data collection for market gardening

To determine the inventory of pesticides available and used for market gardening, we conducted surveys of input stores and market gardeners in Bamako (Mali). We have developed a database of available pesticides used in market gardening in Mali, in addition to the list of products approved by the Sahelian Pesticide Committee (CSP).

2.1.1. Pesticide data collection

To implement our database on pesticides used for market gardening, we conducted different surveys. The purpose of the surveys of stores and market gardeners was to complete the list provided by the CSP each year (Comité Sahélien des Pesticides, 2019 and 2020). This included identifying products not available on this list and whether or not these products were registered.

- A survey of the main suppliers and small input stores in Bamako was conducted to identify the products available for sale, their origins, their packaging, the concentrations and doses recommended for application, and also to obtain data on the targets treated by these products.
- A survey of 88 market gardeners was carried out in Bamako in 2019 to identify the products actually used and the applied doses. For the selection of market gardeners, we covered all the market garden production areas of Bamako, and chose those that were closest to a well, a marigot or those that used water from the Niger River to irrigate their crops (Fig. 1). Among the 88 market gardeners in Bamako, 56 irrigate their crops with water from shallow wells

[1] Solidarity Fund for Innovative Projects (FSPI) financed by the Service de Coopération et d'Action Culturelle (SCAC) of the French Embassy in Mali.

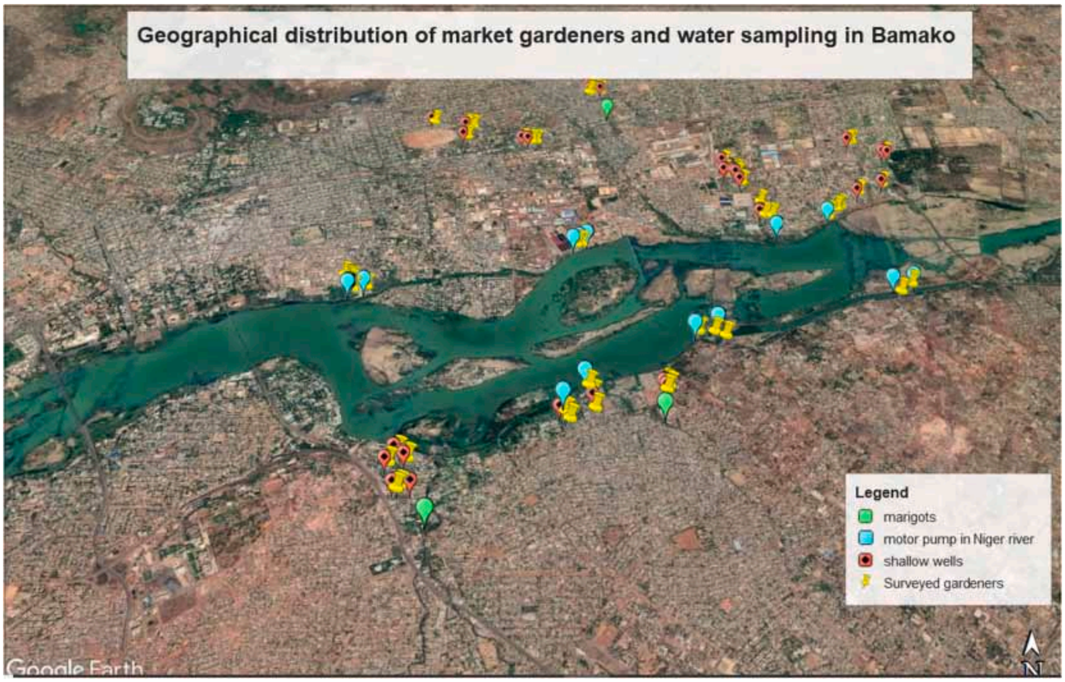

Fig. 1. Geographical distribution of market gardeners surveyed (yellow) and water sampling sites (shallow wells in red, marigots in green, motor pumps in blue) in the district of Bamako (Mali) (source: Google Earth Pro, 2022 may).

(maximum 5 m) some in red dots, 10 with water from marigots using a motor pump or bucket in green, and 22 with water from the Niger River using a small motor pump (in blue dots). Surveyed gardeners are in yellow dots (Fig. 1)

For ethical reasons, we have deliberately chosen not to mention the names of these pesticides in this article, but to present our results on all the different active substances present in these products.

2.1.2. Identification of the active substances used in the inventoried pesticides

To characterize the active substances present in the inventoried pesticides, we used pesticide database resource (The Pesticide Properties Database, PPDB), which is updated every month (FootPrint, 2016; Lewis and Tzilivakis, 2017). Thus, the data collected for each pesticide inventoried are: the associated active substance(s) and its chemical family, their concentrations, the registered doses, the firm that manufactures it, the supplier in Mali, and its registration or not by the CSP. These data were entered into the Excel spreadsheet and processed by the EtoPhy software (Caubel et al., 2019) to determine which active substance pose the greatest risk to the environment (soil and water environment).

2.2. Sampling and analysis of surface water among market gardeners in Bamako (Mali)

2.2.1. Water sampling

Among the 88 market gardeners in Bamako, we took 36 water samples (about 41%): 29 surface water samples from wells, 5 samples from marigots and 2 samples from the Niger River (Fig. 1). The collected water samples were stored in a refrigerator at 4 °C in the laboratory (Laboratoire de Biologie Moléculaire de Bamako) before their analyses.

2.2.2. Extraction and purification of active substances

In this study, the method used to extract the different active substances from liquid matrices is solid phase extraction (SPE). This type of extraction has the advantage of reducing the amount of organic solvent to be used compared to the liquid-liquid extraction method. It also helps to reduce the interferents present in the matrix to be analyzed. Thus, the cartridges (Oasis HLB Cartridge, 6 cc) were first conditioned with 10 ml of methanol and then loaded with 20 ml of each water sample in each cartridge. In order to remove unwanted analytes that might have been adsorbed on the stationary phase, washing was performed with 10 ml of the water-methanol mixture in the proportions 95:5 *v*/v respectively. Likewise, in order to effectively unhook the active substances of the pesticides of interest, we eluted with 2 ml of methanol due to the effective eluting power of this organic compound (Dujaković et al., 2010; Kuivila et al., 2012). Finally, each eluent was decanted into a 2 ml glass vial and the set of vials was placed in the UPLC-MS for analysis.

2.2.3. Chromatographic analysis

Ultra performance liquid chromatography (UPLC, H-Class, Waters) combined with a mass spectrometer (MS) was used to analyze all water samples. Two microliters of each water sample were injected into the UPLC-MS. The pesticides of interest were separated on a stationary phase (ACQUITY UPLC BEH C18 Column, 130 Å, 1.7 μm, 2.1 mm × 100 mm, Waters) where the flow rate was set at 0.3 ml/min. A Vanguard guard column (ACQUITY UPLC BEH C18 Van Guard Pre-column, 130 Å, 1.7 μm, 2.1 mm × 5 mm, Waters) protected the analytical column. Pesticide elution was performed by stepwise mixing of solvent A (ultrapure water plus 0.1% formic acid) and solvent C (99.9% methanol plus 0.1% formic acid). The UPLC-MS elution gradient was started with 2% of solvent C over 0.8 min, followed by a 70% C gradient over 7.7 min and a second 95% C gradient over 1 min. The column was equilibrated with 95% C for 1.3 min, then with 2% C for 2 min before the next injection. The separated molecules were transferred to the mass spectrometer where they were then ionized by an electrospray source (ESI) following optimized detection parameters.

2.2.4. Identification and quantification of pesticides residues in water samples

The parent ions were obtained by direct infusion of each compound into the TQD in ES (+) and (−) in MS Scan mode at a concentration of 500 ng/ml with a flow rate of 20 μL.min^{-1}. They were then selected in the first quadruple by optimizing certain parameters. The daughter ions were determined in Daughter Scan mode. These were obtained following the breakage of the parent ions in the second quadruple or collision quadruple q2 where an argon flow circulates. They are finally selected in the third quadruple by optimizing the collision energy. Table 1 below provides information on ionisation modes, precursor ions, majorities, cone tensions and collision energies.

2.3. Data analysis

2.3.1. Chemical classification

Since 2009, the CLP regulation (Classification, Labelling, and Packaging) is the implementation of the General Harmonized System (GHS) in Europe. Its objective is to guarantee a high level of protection of health and the environment in relation to chemicals. The CLP concerns most chemicals and establishes rules for the classification, labelling and packaging of pesticides.

Environmental hazard classifications are based on data on biodegradation, bioaccumulation and toxicity of substances. Available information on hazardous properties is used, including animal experimental and epidemiological data. The CLP regulation sets out criteria for five different classification categories for active substances and mixture with regard to environmental hazar (Sobek et al., 2013). Classifications also include hasard statements and in some case precautionary statements. Species-specific limits on LC_{50} and EC_{50} values determine the toxicity categories (Table 2). A chemical considered as not rapidly degradable and/or to be bioaccumulative is classified in one of the chronic categories. Chronic category 4 is an additional category for substances that do not requierements in the other categories but that still possess properties that might pose a threat to the environment (Sobek et al., 2013).

2.3.2. Index of mobility of active substances in water

It is important to take into account the mobility data of active substances for public health because surface water or well water are used daily for food. Therefore, the calculation of the mobility of active substances will allow to determine their fate in surface or groundwater, either by runoff or by leaching. The GUS (Groundwater Ubiquity Score) index will allow to rank the active substances from the most mobile to the least mobile in water (Gustafson, 1989).

This index is based on two physico-chemical properties of a compound:] 1 the coefficient of adsorption on organic carbon (K_{oc} in ml/g). The lower its value, the more active substance is immobile in the soil and the lower its leaching potential. But, it can be leached into surface water during heavy rainfall.] 2 The coefficient corresponding to the half-life of the active substance (DT_{50}) in the soil. It provides information on the persistence or not of the active substance in the soil at the level of the agricultural fields. The higher it is, the more persistent the molecule is.

This GUS index following the formula: GUS = log [(DT_{50}[2]) x (4 - log (K_{oc})].

Its interpretation is as follows: if the GUS index <1.8, then the leaching potential is low. If the GUS index ≥1.8 and this GUS index <2.8, then the leaching potential is medium. If the GUS index ≥2.8, then the leaching potential of the active substance is high.

3. Results

3.1. Pesticide diversity for vegetable gardening

We have inventoried 288 pesticides for vegetables and rice, as it has already been done for cotton (Le Bars et al., 2020). Among these 288 phytosanitary products, herbicides are largely represented with 179 products (62% of all pesticides) of which 48 are not registered (36.6%). We found 109 insecticide-fungicides (38% of all pesticides) of which 32 are not registered (29.4%) (Table 3). Among these 288 pesticides, we identified 30 products used by market gardeners in Bamako: 12 herbicides of which 4 are not registered by the CSP (i.e. 33%); 18 insecticides of which 5 are not registered by the CSP (i.e. 28% of all used products).

3.2. Database: pesticides inventoried and their active substances

The 288 pesticides inventoried (Table 3) are formulated from 91 active substances in 49 chemical families. Among these active substances, 46% (42/91) are banned in Europe because of their negative impact of health and environment (Pesticide Properties DataBase, PPDB, 2022) and are found in 115 inventoried products (i.e. 40% of the products available). For herbicides, we have 48 active substances from 28 chemical families. It should be noted that for C*hloroacetamides*, which are not very soluble in water and cause accumulation problems in organisms and soils, five (05) of those active substances have been withdrawn from registration in Europe because of the health related risks such as skin irritation and infertility (Pesticide Properties DataBase, PPDB, 2022). The T*riazine* family has a very important role in the contamination of groundwater. In this chemical family, we find for (04) active substances that have not been registered in Europe since the 2000s, alone or combined in thirteen (13) products, two (02) of which have been registered by the CSP. It should be noted that *diuron* (family of *substituted ureas*), which is present in three herbicides registered in Mali, was banned in the 2000s in Europe for its significant impact on health and the environment (toxic to fish and aquatic invertebrates) (Haynes et al., 2000). For insecticides, we have forty-three (43) active substances divided into two (02) main classes: biopesticides (04 active substances) and standard pesticides (39 substances) from twenty-one (21) chemical families. For biopesticides, four (04) active substances: *emamectin benzoate, spinosad, abamectin, Bacillus thuringiensis Kurstaki* are found alone or combined in eleven (11) insecticides (10%).

3.3. Pesticides used for gardening in Bamako

From the 288 pesticides available for market gardening, we retained in the database only those pesticides used by market gardeners in Bamako (12 herbicides and 9 insecticide-fungicides). Among the products used by the Bamako market gardeners, we identified 6 active substances in herbicide Table 4): *glyphosate* present in the vast majority of products (8 herbicides out of 12, i.e. approximately 66%), *haloxyfop P-methyl* and *nicosulfuron* present in one product each, and *paraquat* present in 2 products not registered by the CSP. For the insecticides used, we have 13 active substances from 6 chemical families (Table 5). The pyrethroid family is the most important (4 active substances present in 10 products, i.e. 50% of insecticides): *bifenthrin, cypermethrin, deltamethrin and lambda-cyalothrin.*

3.4. Mobility of active substances in water

For each active substance present in the inventoried pesticides, we have indicated the coefficient of adsorption on organic carbon (K_{oc} in ml/g), half-life of the active molecule (DT_{50}) and Groundwater Ubiquity Score (GUS) (Table 4, Table 5).

Two classes can be distinguished for herbicides (Table 4). Of the 6 active ingredients in the herbicides, 3 have a low leaching potential (GUS below 1.8). *Paraquat* is highly absorbed into the soil (with K_{oc} > 10,000 ml/g) and very persistent in soils. *Glyphosate* is weakly persistent in soils (DT_{50} of 24 days). It is slightly mobile to immobile in soils with a low leaching potential. It is therefore not likely to contaminate groundwater. *Atrazine* has a medium leaching potential but close to the upper limit (GUS of 2.6; between 1.8 and 2.8). The uptake constant of atrazine on organic carbon is low (K_{oc} of 100 ml/g). It is therefore moderately mobile in soils. Its persistence in soils is high (100 days) and, at high doses, residues can persist for about a month and strongly contaminate groundwater by soil leaching. *Nicosulfuron* has a high

[2] half-life of the active molecule (DT_{50})

Table 1
Ionisation modes, precursor ions, majorities, cone voltages and associated collision energies.

Active substance	Ionisation mode	Retention time	Precursor ions	Quantification ion			Confirmation ion		
				m/z	Collision energy (V)	Cone voltage (V)	*m/z*	Collision energy (V)	Cone voltage (V)
Prometryn	ES+	7,92	242	158.0	22	50	200.22	22	50
Atrazine	ES+	8,14	216	174.11	27	50	104	27	50
Emamectin benzoate	ES+	10,37	886.6	81.9	38	50	126	38	50
Cypermethrin	ES+	10,3	433	190.9	25	19	–	–	–
Alpha cypermthrin	ES+	10,57	433,1	190.9	25	19	–	–	–
Deltamethrin	ES+	10,49	523	280.9	30	19	–	–	–
Bifenthrin	ES+	13,3	440.1	181,2	26	19	–	–	–

Table 2
CLP aquatic hazard classifications with associated hazard statements and category levels based on ecotoxicity, biodegradability and bioaccumulation properties.

CLP Classification	Hazard statement (CLP)	LC_{50} or EC_{50} mg L^{-1}
Aquatic acute 1	H400: Very toxic to aquatic life	≤1
Aquatic chronic 1	H400, H410: Very toxic to aquatic life with long lasting effects	≤1
Aquatic chronic 2	H411: Toxic to aquatic life with long lasting effects	>1 to ≤10
Aquatic chronic 3	H412: Harmful to aquatic life with long lasting effects	>10 to ≤100
Aquatic chronic 4	H413: May cause long lasting harmful effects to aquatic life	No acute toxicity

Table 3
Pesticides types, approved or not used for gardening crops in Mali.

Type	Registered products by CSP (%)	Unregistered products by CSP (%)	Total (%)
Herbicides	131 (73.2)	48 (26.8)	179 (62.1)
Insecticides-fungicides	77 (70.6)	32 (29.4)	109 (46.9)
Total	208 (72.2)	80 (27.8)	288 (100)

leaching potential (GUS greater than or equal to 2.8). It is therefore mobile but not very persistent in the soil (20 days). It can therefore contaminate groundwater by leaching and surface water by runoff.

Of the 13 active ingredients in insecticides (including biopesticides), 8 are poorly mobile (62%) with a GUS of <1.8 (Table 5). *Deltametrin, lambda-cyhalothrin, bifenthrin, cypermethrin and emamecin benzoate* have a very high organic carbon uptake constant (K_{oc} > 10,000 ml/g). These 5 active ingredients have a low leaching potential and are immobile in soils but can contaminate surface water by runoff. The other active ingredients are not very persistent in the soil (DT_{50} <20 days). They also have a low leaching potential but are slightly mobile in soils and degrade very rapidly by hydrolysis in neutral and alkaline media.

Two active ingredients have a medium leaching potential (GUS index between 1.8 and 2.8): *carbofuran and methomyl*. The absorption constant of *methomyl* on organic carbon is low (K_{oc} of 72 ml/g). It is therefore moderately mobile and persistent in soils (DT_{50} of 7 days). *Acetamiprid* is the only active ingredient with a high leaching potential (GUS index greater than or equal to 2.8). It is moderately mobile in soils (K_{oc} of 200 ml/g). Since it is persistent (DT_{50} of 175 days), its leaching potential is high. It can therefore strongly contaminate surface water by runoff.

3.5. Water samples analysis

We have conducted initial water analyses on the following active substances to quantify potential residues: *promethrin and atrazin* (Triazine family*), emamectin benzoate* (biopesticide, Micro-organism derived) and *cypermethrin, alpha cypermethrin, deltamethrin and bifenthrin (*Pyrethroid family). The choice of these active substances is due to the fact that they are the most used by the different market gardeners in the district of Bamako. The first results of the chromatographic analyses showed the presence of *cypermethrin* in two samples out of a total of 36 water samples analyzed (5.5%). The concentrations of *cypermethrin* are well above the Limit Of Detection (LOD, 12.58 μg/L) and are respectively 15 and 20.987 μg/L. In contrast, residues of the other active substances (*promethrin, atrazine, emamectin benzoate, cypermethrin, alpha cypermethrin, delta cypermethrin and bifenthrin*) were measured at values below their detection limits (LOD).

4. Discussion

The family of pyrethroids is the most important (5 active substances present in 32 products, or 29% of insecticides). Today, this chemical family dominates the global insecticide market. The current trend of replacing organophosphates with the supposedly safer pyrethroids is not without risks. Pyrethroids paralyze and kill insects rapidly by acting on their nervous system. When pyrethroids are used, their aerosols can be dispersed by wind, rain can runoff into water bodies, and they can also be dispersed through groundwater or sewage systems. Because of their high affinity for particulate matter, pyrethroids tend to accumulate in sediments rather than disperse in the water column, although redissolution (desorption) remains possible (Hénault-Ethier, 2015). Among the pyrethroids identified, *bifenthrin and permethrin* are no longer registered in Europe because they present long-term health risks, and very high toxicity to the aquatic environment. Other chemical families also have active substances that are no longer registered in many countries. For example, among the Organophosphates, the 4 identified active substances are no longer registered in Europe. In general, these results can be explained by the fact that insecticides (pyrethroid family) are mainly used by market gardeners compared to herbicides (triazine family) and biopesticides (*emamectin benzoate*). The intensive use of insecticides is due to the fact that in Sahelian countries, particularly in Mali, climatic conditions (low rainfall, high temperatures, etc.) often favor the proliferation of different types of insects. This proliferation of insect pests often leads to a significant drop in agricultural yields. Thus, the majority of market gardeners surveyed in the Bamako district use different types of insecticides intensively in order to eliminate insects that destroy fruit and vegetables.

These results also show a significant use of pesticides (e.g. from the pyrethroid family) approved by the Comité Sahelien de Pesticides (CSP) that are intended for cotton but are used by market gardeners in the Bamako district. This means that the use of regulated pesticides in agriculture is not often followed by farmers and/or market gardeners. Indeed, the use of *endosulfan* (a pesticide toxic to human health and the environment) has been reported in market gardening in Togo (Ance-Togo, 2010), Burkina Faso (Bassole and Ouedraogo, 2007) and Senegal (Sow et al., 2004). The Compagnie Malienne du Textile (CMDT)

Table 4
Active substance in Herbicide used in Bamako and their environmental features.

Chemical group	Active substance	European Regulation 1107/2009 status	presence in pesticides	CLP "H" Environment	DT 50 degradation data field (days)	interpretation DT $_{50}$	K_{oc} (ml/g)	interpretation K_{oc}	GUS Index	interpretation GUS index
Aryloxyphenoxypropionate	haloxyfop P-méthyl	Approved	1	H400, H410	0.5	non-persistent	ND		ND	ND
Bipyridylium (1)	paraquat	Not approved	2	H400, H410	2800	very persistent	1,000,000	No mobile	−6.89	Low leachability
Phosphonoglycine (1)	glyphosate	Approved	6	H411	23.79	non-persistent	1424	Slighty mobile	−0.29	Low leachability
Sulfonylurea (1)	nicosulfuron	Approved	1	H400, H410	19.3	non-persistent	30	mobile	3.44	High leachability
	atrazine	Not Approved	4	H400, H410	29	non-persistent	100	Moderately mobile	2.57	High leachability
	prometryn	Not Approved	7	H400, H410	41	Moderately persistent	400	Moderately mobile	0.59	Low leachability

DT $_{50}$: half-life of the active substance in the soil; K_{oc}: coefficient of adsorption on organic carbon; GUS: Groundwater Ubiquity Score; ND: No Data.

Table 5
Active substance in Insecticide-fungicide used in Bamako and their environmental features.

Chemical group	Active substance	European Regulation 1107/2009 status	presence in pesticides	CLP "H" Environment	DT $_{50}$ degradation data field (days)	interpretation DT $_{50}$	K_{oc} (ml/g)	Interpretation K_{oc}	GUS Index	interpretation GUS index
Carbamate (2)	carbofuran	Not approved	2	H400, H410	14	non-persistent	ND	–	2.36	Transition state
	methomyl	Not approved	1	H400, H410	7	non-persistent	72	mobile	2.19	Transition state
Micro-organism derived (2)	abamectin	Approved	1	H400, H410	1	non-persistent	ND	–	ND	ND
	emamectine benzoate	Approved	1	H400, H410	1.1	non-persistent	377,000	Non mobile	ND	ND
Neonicotinoid (2)	imidacloprid	Approved	1	H412	3	non-persistent	ND	–	0.94	Low leachability
	acetamiprid	Approved	3	H400, H410	174	persistent	200	Moderately mobile	3.69	High leachability
Organophosphate (2)	profenofos	Not approved	2	H400, H410	7	non-persistent	2016	Slightly mobile	0.59	Low leachability
	chlorpyriphos	Approved	1	H400, H410	27.6	non-persistent	5509	Non mobile	0.58	Low leachability
Oxadiazine (1)	indoxacarb	Approved	1	H400, H410	113.2	persistent	4483	Non mobile	0.27	Low leachability
Pyrethroid (4)	bifenthrin	Not approved	1	H400, H410	86.8	non-persistent	236,610	Non mobile	−2.66	Low leachability
	cypermethrin	Approved	3	H400, H410	21.9	non-persistent	307,558	Non mobile	−1.99	Low leachability
	deltamethrin	Approved	2	H400, H410	21	non-persistent	10,240,000	Non mobile	−3.98	Low leachability
	lambda-cyhalothrin	Approved	4	H400, H410	26.9	non-persistent	283,707	Non mobile	−2.09	Low leachability

DT $_{50}$: half-life of the active substance in the soil; K_{oc}: coefficient of adsorption on organic carbon; GUS: Groundwater Ubiquity Score; ND: No Data.

distributes phytosanitary products for cotton every year. These products are approved by the CSP. This makes it possible to control the use of these products in the cotton sector. On the other hand, there is no such distribution for market gardening, which would explain the importance of non-homologous products and the use of products for cotton in market gardening.

However, the use of unregistered pesticides is not without consequences for the health of vegetable growers and consumers of vegetable products. Misuse of these products also leads to contamination of soil and water resources. Pyrethroids, in view of their degree of toxicity and environmental persistence, therefore present major risks for human health and the environment. Despite the intensive use of insecticides by some vegetable growers, others have understood the advantage of using chemical products that are less toxic to health in the short term, such as biopesticides based on *emamectin benzoate*. This active substance is used in the various market gardening sites in the district of Bamako and has the advantage of being environmentally non-persistent. This active substance is used as an alternative to pyrethroids or any other toxic pesticide with the aim of practicing an agriculture that is not only sustainable and profitable but also capable of satisfying the food needs (in fruit, vegetables etc.) of the population of Bamako. The scaling up of such an initiative to all market gardeners in the district of Bamako has the advantage of practicing sustainable and profitable agriculture in the long term without the use of toxic pesticides and also of safeguarding the sanitary quality of agricultural soils and water resources.

In view of these first research results, several alternatives to pyrethroids can be envisaged in order to counter any growing resistance of insects to these dangerous chemicals but above all to eliminate the intensive use of these chemicals by the various vegetable growers. Effective solutions to ensure sustainable agriculture through physical interventions, biological actions, use of complex extracts of natural plants. For example, biological control of insect pests can be effective against a wide range of agricultural pests without using synthetic pesticides (Hénault-Ethier, 2015). Nowadays, intensification of sustainable agriculture is very beneficial for all farmers and/or market gardeners in African countries, particularly those in Mali, who are frequently confronted with climatic hazards (droughts, high temperatures, food shortages, etc.) and are obliged to use large quantities of chemical inputs (fertilizers and pesticides) in agriculture every year.

Finally, this theme raises the issue of food safety and the use of synthetic pesticides on crop pests. These pesticides have the capacity to reduce pests and increase crop yields but at the same time also present significant risks for health and the environment (Le Bars et al., 2020). For sustainable agriculture, it would be necessary, on the one hand, to avoid the reduction of biodiversity by using more adequate synthetic products against specific crop pests (Balasha, 2019). On the other hand, it is necessary to find solutions to regulate their persistence in the environment and their accumulation in aquatic, animal and human organisms. It is under these conditions that it would be possible to ensure sustainable food and health security in the coming decades.

5. Conclusions

The results of the surveys carried out among the different market gardeners in the Bamako district showed that market gardeners use a variety of chemical families of pesticides in the production of fruits and vegetables. These chemical families are used in order to significantly ensure sustainable and profitable agriculture and above all to meet the long-term food needs of the rapidly growing population of the Bamako district. Among this variety of chemical families of pesticides, pyrethroids are the most dominant, followed by herbicides and biopesticides respectively. The first results of chromatographic analyses of all water samples showed a possible contamination by pyrethrinoids compared to herbicides and biopesticides. The intensive use of such pesticides may constitute a potential risk to human and environmental health. In order to definitively eliminate the use of such pesticides in the market gardening environment of the Bamako district, the alternative solutions adopted are essentially based on the intensive use of biopesticides such as emmamectin benzoate and also physical actions and biological control techniques in order to guarantee the application of a sustainable and profitable agriculture capable of leading towards food self-sufficiency.

In order to complement the first results obtained in this study, further studies will be extended to a more significant number of market gardeners in the Bamako district. Participatory approaches will allow us to raise awareness and show individual farmers the effective actions to take in order to practice sustainable and profitable agriculture.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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