Science of the Total Environment 576 (2017) 888–894

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Multi-residue determination and ecological risk assessment of pesticides in the lakes of Rwanda

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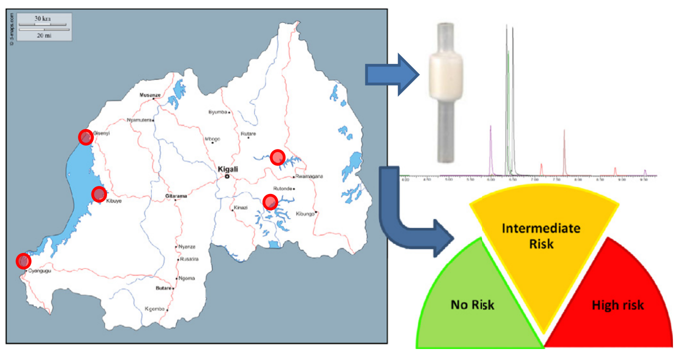
HIGHLIGHTS

- Pesticide awareness was estimated for farmers around lakes in Rwanda.
- Pesticide usage was rather high but farmers lack specialised training.
- Pesticides were present in surface water of the Rwanda lakes.
- No pesticides were present in the vertical profile of Lake Kivu.
- Species sensitivity distributions were used to in the environmental risk assessment.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form 17 October 2016
Accepted 18 October 2016
Available online xxxx

Editor: Kevin V. Thomas

Keywords:
Rwanda
Topic:
Lake Kivu
Lake Muhazi
Lake Mugesera
Risk assessment
Species
Sensitivity distributions

ABSTRACT

Background: To boost agricultural productivity for both domestic and export purposes, agricultural inputs such as pesticides are being promoted in Rwanda. Even though the use of pesticides is important for agriculture, their residues eventually end up in different environmental compartments and may negatively affect the environment. The purpose of this study was to determine the level of knowledge and awareness of the smallholder farmers towards the use of pesticides in Rwanda and to evaluate the ecological risks of pesticides in the surface water and in the vertical profile of Lake Kivu.

Results: Based on the collected data, a method to monitor 33 currently used pesticides was developed. No contamination of the lower water layer was found, indicating that the groundwater that flows into Lake Kivu has not been polluted. Of the pesticides in the surface water, malathion exceeded the risk thresholds and posed a risk towards arthropods.

Conclusion: The results of this study show that there is a lack of farmer's awareness towards the hazards of pesticides when working with these compounds. Farmers in Rwanda are in need of specialised stewardship for pesticide application training and guiding services. Surface water has been contaminated with malathion, metalaxyl and carbendazim which were the most used pesticides by the farmers in the environment.

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1. Introduction

Pesticides are essential in modern agriculture and contribute to the increase in agricultural productivity. Without pesticides in agriculture, food security would decrease dramatically and they are undoubtedly a part of the solutions to feed the increasing world (Popp et al., 2013). In Rwanda, moving away from the traditional agriculture into a modern agriculture using fertilizers and pesticides has been seen as one of the best solution for poverty reduction (Ishimwe and Manzi, 2013). This is because the income generation for 70% of Rwandan population is based on agricultural practices (UNDP, 2015). Agriculture in Rwanda, accounts for >34% of the

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http://dx.doi.org/10.1016/j.scitotenv.2016.10.127
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gross domestic product (GDP) and provides 70% of the export (Bizimana et al., 2012). Percentage of farms using pesticides in Rwanda increased from 9% in 2000 (Kelly et al., 2001) to 15.7% in 2008 (Cantore, 2011). In 2013, the percentage of large scale farmers using pesticides in Rwanda was estimated to be 19.6% (NISR, 2015). A recent survey in 2015 indicates an increase in the usage of pesticides up to 46.7% by large scale farmers (NISR, 2016). While the use of pesticides could solve the problem of food scarcity and poverty, incorrect application leads to other problems and contributes to environmental pollution.

A recent inventory of freshwater bodies in Rwanda identified 861 rivers totalling 6462 km in length (Gowa, 2009). These rivers are draining into two major water basins; the Congo River Basin which covers 33% of Rwanda's territory and which receives 10% of the total national waters, and the Nile River Basin that covers 67% and delivers 90% of the national waters (Nile Basin Initiative, 2005). The rivers included in this study discharge entirely into the Congo Basin (Lake Kivu). Recent studies report on the surface water quality of Rwandan rivers using physicochemical, bacteriological and biological assessment methods, providing environmental information about the specific sample sites across the country (Pasche et al., 2009; Lliros et al., 2010; Olapade, 2012; Sekomo et al., 2012; Wronski et al., 2015). However, while the lake and its rivers are essential for the smallholder farmers and their families, no information on the current state of pesticide levels is available. The reports highlight that many farming activities are located in valleys near rivers and streams, which can cause a contamination of surface water by pesticides (Olapade, 2012; Sekomo et al., 2012; Upton et al., 2013).

Although the pesticide usage in Rwanda is still at a lower rate compared to modern agriculture in the developed countries, the topography of Rwanda with high mountains accelerates erosion, flooding and landslides which results in easy contamination of the water bodies. In addition, Rwanda does not have a specific crop protection legislation (Van der Valk, 2001). In the absence of legislation there is no legal basis on which Ministry of Agriculture (or any other) agents can limit the import and use of pesticides to specific authorized products, or inspect pesticide distribution outlets.

Pesticides in Rwanda and neighbouring countries are often used by local farmers without knowledge on safety measures and proper usage (Ngowi et al., 2007; Dijkxhoorn et al., 2013; Okonya and Kroschel, 2015). This might result in the application of high dosages, irregular dumping of pesticides, high levels of drift to air, environmental contamination through rain wash out, soil leaching and deposition. The use of banned pesticides occurs in Rwanda as local farmers cannot afford the expensive branded products and prefer to buy cheaper products from the black markets or in the neighbouring countries (REMA, 2012). This results in the contamination of the water bodies with restricted products in Rwanda, leading to pesticide exposure though drinking water. An estimated 2 million people use Lake Kivu water as their source for drinking water without any further treatment (Olapade, 2012).

It is of great concern to protect water resources against pollution by pesticides as they are useful for society as sources of drinking water and biodiversity conservation. The general objective of this study was to assess the pesticides contamination in the column layers of Lake Kivu and in the surface water of other two small lakes, Muhazi and Mugesera. An environmental risk assessment was further conducted using species sensitivity distributions.

2. Materials and methods

2.1. Survey

A questionnaire was prepared and translated in cooperation with a local educator. The questions focused on general information about the interviewees and their farming practices (gender, age, educational level, farm acreage), on the common pesticide application practice (pesticide usage, pre-harvest interval, source of pesticide knowledge) and on the level of awareness of the hazards associated with pesticides (Table 1). Interviews were conducted during personal visits by a local educator. Farmers in the study area were contacted at random and participation was entirely voluntary. The persons responsible for the pesticide application, i.e. those who purchased and applied the agrochemical products, were interviewed face-to-face. The purpose of the interview was clearly explained in their native language to minimise any apprehension as well potential bias of the participants.

2.2. Sampling sites and sample collection

Lake Kivu has a maximum depth of 485 m and is located in the East African Rift near the active volcanoes Niyamulagira and Nyiragongo. Lake Kivu has a large number of small streams but has no major river inflow. Several groundwater sources enter the lake at various depths. The geothermal and physical properties of the lake are affected by the groundwater inflows, although these processes are still under investigation (Bhattarai et al., 2012). The lake has a strong vertical gradient profile of salinity, temperature and dissolved gasses (Lorke et al., 2004). It is believed that the hydrothermal groundwater sources supply heat and salt to the bottom of the lake and colder, less saline groundwater enters the lake at shallower depths (Ross et al., 2015). About 1.3 km^3 $year^{-1}$ of water enter the lake as sub-aquatic inflows below its mixolimnion (Bhattarai et al., 2012). Two important lakes that are used as the source for drinking water are Muhazi and Mugesera. Lake Muhazi is a small lake located in the central part of Rwanda which is 40 km long and has an area of 3412 ha, a maximum depth of 10 m and width of 2 km. The lake is fed by 13 small streams and is important for tourism activities and for fisheries (MINAGRI, 2011). Lake Mugesera is located in Eastern Province and is important for fisheries and contains a high biodiversity. The lake wetlands of Mugesera are degraded mainly due to poor conservation and occasional drought (Wong et al., 2005). Wetlands surrounding this lake also receive water potentially polluted with pesticides from Nyabarongo River. It is hypothesized that this potentially pollution water combined with agricultural activities around the lake result in a contamination of the lake with nutrients, fertilizers and pesticides (REMA, 2014).

Water sampling was targeting the Northern, Eastern and Western Basins of Lake Kivu. Water samples for pesticides analysis were taken near the city of Gisenyi, Kibuye and Cyangugu. The main crop was planted around the onset of the dry season (May to July). Sampling was performed from August to September 2015 during spraying season of the major crop in the area (potatoes) and the onset of the rain season from mid-September. A GPS Garmin 60 was used for locating the south and east coordinates for different sampling points. Lake Kivu water samples were collected at Cyangugu (2° 31.91′S 28° 95.72′E); Gisenyi (1° 41.154′S 29° 8.292′E) and Kibuye (1° 94.12′S 29° 12.28′E). Water

Table 1
Chromatographic conditions of the LC-MS/MS system.

HPLC-Instrument	Waters ACQUITY UPLC
Column	Waters HSS T3 (1.8 μm)
Injection volume	10 μL
Oven temperature	40 °C
Mobile phase A	Water + 10 mM ammoniumacetate
Mobile phase B	Acetonitrile + 0.1% formic acid
Flow	0.4 mL·min^{-1}
Gradient	0–0.25 min 2% solvent B 0–7 min linear gradient to 98% solvent B 7–8 min 98% solvent B 8–9 min linear gradient to 2% solvent B 9–10 min 2% solvent B
Detector	Triple quadrupole mass spectrometer
Spectrometer	None
Interface	Electrospray ionisation
Potential	5000 V
Temperature	500 °C
Scan type	MRM (Multiple Reaction Monitoring Mode)
Collision gas	Argon

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