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Distribution of agricultural pesticides in the freshwater environment of the Guayas river basin (Ecuador)

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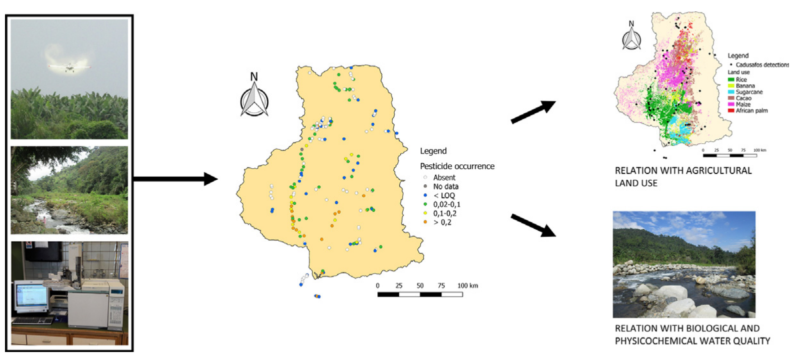
HIGHLIGHTS

- Pesticide residues were determined in Guayas river basin's freshwater environment.
- Guayas river basin's freshwater environment was widely contaminated with pesticides.
- Pesticide residues were linked to agricultural activities in the Guayas river basin.
- Banana and rice industries were identified as main causers of pesticide pollution.
- No direct relation was found between pesticide residues and biological water quality.

GRAPHICAL ABSTRACT



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ABSTRACT

The rapid increase and transition to more intensive agricultural activities in developing nations are often leading to misuse and overuse of pesticides, making their environment vulnerable for pesticide accumulation. In the present study, the Guayas river basin was taken as a representative case study to evaluate pesticide contamination of the Ecuadorean freshwater environment. Pesticide contamination was determined at 181 sampling sites by a multi-residue method using solid phase extraction (SPE) and pesticide residues were linked with agricultural land use activities to identify the main pollution sources. Moreover, the biological water quality status based on macroinvertebrate communities was determined at every location and the relation with the occurrence of pesticide residues was further investigated. Results showed that pesticide contamination of the freshwater environment was widely present in the Guayas river basin with detections at 108 sampling sites (60%). A total of 26 pesticide products were identified. Most frequently detected pesticides included cadusafos (62 locations), butachlor (21 locations) and pendimethalin (21 locations), with concentrations up to 0.081, 2.006 and 0.557 $\mu g \cdot L^{-1}$ respectively. Pesticide residues detected in this study did not significantly influence the biological water quality ($p = 0.69$), but were observed to be positively correlated with ammonium concentrations, supporting the assumed combined application of chemical fertilizers and pesticides in agriculture. These pesticide residues were also associated with one or more agricultural crops, with in particular the banana and rice industries identified as major pollution sources. Both high consumption rates and non-specific application methods, such as aerial spraying of banana plantations and application directly into the water layer of irrigated

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rice fields, may attribute to pesticide contamination of the freshwater environment of the Guayas river basin. It is therefore suggested that measures, e.g. legal regulations and awareness campaigns, taken to prevent environmental pollution and accumulation of pesticides primarily focus on these industries.

1. Introduction

The world population almost tripled since 1950 and is estimated to be approximately 1.5 times the current population by 2100 (UN, 2017). At the present time, the immediate response to the need for increasing food production is a more intensive use of agrochemicals, which largely include chemical fertilizers and pesticides (Carvalho, 2006). Approximately 2.7 million metric tons of active ingredients are annually used worldwide in the environment, mostly in agriculture to prevent crop losses (EPA, 2017). Moreover, due to adaptation and resistance developed by pests to chemicals, every year larger amounts and new chemical compounds are used to protect crops (Carvalho, 2006). Since nearly all of the world population increase will take place in developing nations, agricultural production is increasing rapidly in those regions, often coupled with increased pesticide use (Carvalho, 2006; FAO, 2009). Whereas developed countries tend to use fewer agrochemicals and less persistent products, developing countries are going in a different direction often using cheap products such as persistent organochlorines, despite the fact that most of these pesticides are banned or restricted by the Stockholm Convention of Persistent Organic Pollutants (POPs) and local regulations by several countries (e.g. Carvalho, 2006; Navarrete et al., 2018; Pokhrel et al., 2018; Polanco Rodríguez et al., 2015). Especially in tropic regions, pesticides are often applied in massive amounts, both in small farms and cash crops, i.e. industrial plantations of e.g. banana, coffee or cotton (Carvalho, 2006).

In Ecuador, an average of 15,630 metric tons of active ingredients was annually used on agricultural fields during the period 2010–2014, which represents the most recent data published by the FAO (FAOSTAT, 2017). Nowadays, Ecuador has the world's largest export-based banana industry, which is amongst the most pesticide-intensive crop in the world, with fungicides as the main group of pesticides, followed by a wide range of insecticides, nematicides and herbicides (Brisbois, 2011; Diepens et al., 2014; Henriques et al., 1997). Especially the Guayas river basin, located in the coastal region in the central-western part of Ecuador, is economically a particularly valuable region with an intensive agricultural production (Damanik-Ambarita et al., 2016a). Nearly 40% of the national population is living in the area and 68% of the national crops, including 88% of the Ecuadorean bananas, are cultivated there (Borbor-Cordova et al., 2006). Consequently, high pesticide application rates are expected in the Guayas river basin, potentially leading to accumulation of these pesticides in the environment.

The accumulation of pesticides in the natural environment is considered as one of the major pollution problems associated with agriculture (FAO, 2011). The vast majority of the applied pesticides never reaches the target but drifts into the surrounding environment. Non-specific application methods, such as aerial spraying from airplanes or direct application into the water layer of irrigated rice fields, and a lack of training, technical services, regulations and control regarding the safe use of pesticides are major contributors to pesticide accumulation in the environment, especially in developing nations (Barraza et al., 2011; Bonicelli et al., 2015; Castillo et al., 1997; Noldin et al., 2012). Moreover, the adoption of rational pest management strategies, such as Integrated Pest Management (IPM) and organic agriculture, is typically very low in these nations due to a lack of sufficient information, training and coordination amongst farmers, and the perception that organic practices are not as effective as conventional methods (Hammond Wagner et al., 2016). IPM as a strategy integrates biological and synthetic control, utilizing multiple techniques and methods to control pest populations, with the goal of benefiting farmers, society and the environment by preventing pesticide application as much as possible (Parsa et al., 2014). Since pesticides are designed to be biologically active, they can also affect non-target organisms, including humans, thereby posing a potential threat to natural ecosystems and the services they provide, such as water supply, food production and ecotourism, which are vital for human welfare and economic wealth (Carriquiriborde et al., 2014; Costanza et al., 1997; Miyamoto et al., 2008). Pesticide residues accumulating in the environment can therefore directly affect human and environmental health, for example by contaminating drinking water supplies, food sources and swimming water or reducing biodiversity (Sabatier et al., 2013; Syberg et al., 2016). The compartments of the natural environment (e.g. air, water, biota, soil and sediment) where a specific pesticide is posing a potential risk is described by its environmental fate, depending on their physicochemical properties, such as hydrophobicity, sorption coefficient and persistence, and the environmental conditions, such as pH, temperature, light intensity and salinity (Linde, 1994; Zacharia, 2011).

Although freshwater is abundant in the Guayas river basin, pesticide contamination of surface water bodies is threatening many drinking water reserves (Buckalew et al., 1998). Pesticides can drift directly into the aquatic environment by aerial transport, or finally end up there via runoff, erosion, drainage, volatilization followed by wet deposition or leaching to groundwater (Miyamoto et al., 2008). However, monitoring data of pesticide residues in the freshwater environment of the area are scarce. Damanik-Ambarita et al. (2016a) assessed the water quality in the region and indicated that pesticide measurements are strongly recommended in future studies assessing the water quality of the area. In the present study, a pesticide contamination assessment is conducted for the Guayas river basin. The aims of this study were (i) to determine pesticide residue levels in surface water bodies of the Guayas river basin in order to map the spatial distribution of pesticide contamination in the freshwater environment of the study area, (ii) to link the occurrence of the most abundantly detected pesticide products to typical agricultural crops in the region to identify the main polluters and present alternative management strategies to reduce pesticide contamination and (iii) to assess the impact of pesticide contamination on the biological water quality status based on the benthic macroinvertebrate community composition.

2. Material and methods

2.1. Study area and sampling sites

The Guayas river basin is located in the coastal region in the central-western part of Ecuador. The basin is one of the major watersheds in Ecuador, together with Esmeraldas and the Amazon, and covers an area of 33,700 km^2. The basin drains the water towards the Gulf of Guayaquil and the two main rivers are the Daule and Babahoyo rivers which merge together in the Guayas river near Guayaquil, the largest city of Ecuador (Damanik-Ambarita et al., 2016a). The streams of the Guayas river basin enrich the region with soils carried down from the Sierra, making it Ecuador's most fertile agricultural zone (Buckalew et al., 1998). The main economic activities are agriculture, fisheries and hydropower generation. The major environmental pressures on the freshwater ecosystems today are pollution from sewage and agriculture, changes in land use and two hydro-electrical power dams located in the upper catchment of the basin (Alvarez-Mieles et al., 2013; Nguyen