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Occurrence and Risk Assessment of Atrazine and Diuron in Well and Surface Water of a Cornfield Rural Region

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Abstract: Herbicides have contributed to increased agricultural production. However, their residual amount can cause negative effects on environmental and public health. Therefore, this work aimed to determine the occurrence of both atrazine and diuron in surface and well water and investigate their link with drinking use. The samples were collected during dry and rainy seasons in three wells and surface water from a river and a pond located in the low plains of the Ixcatepec catchment, at the Amacuáhuitl community of the municipality of Arcelia, Guerrero State, in the center south of México, which is a rural community where farming is the main activity. The compounds were obtained by solid phase extraction and determined by HPLC-MS quadrupole with positive electrospray ionization mode. A geomorphic analysis was conducted inside the Ixcatepec catchment using the digital elevation model of the Shuttle Radar Topography Mission, SRTM-v4. The human risk for drinking water was calculated according to the Hazard Quotient. The concentrations of atrazine and diuron were between 5.77 and 402 ng L^{-1}. Atrazine was the most abundant and frequent pesticide found with an average concentration of 105.18 ng L^{-1}, while that of diuron was 86.56 ng L^{-1}. The highest levels were found in pond Ushe, likely being the result of the lowest flow and stagnation of water, and during the cold-dry season a consequence of mobilization by irrigation runoff. The morphological analysis indicated that the compounds mainly reached body water located in the lower surfaces from cultivated areas. Therefore, the occurrence is mainly linked to agriculture activity within the rural community. However, chemical properties of compounds, crop irrigation, and environmental conditions could be contributing to the dispersion of residual amounts of herbicides within the hydrological system. The estimation of risk showed that atrazine can mainly generate health problems for children using the Azul well as a source of drinking water.

Keywords: atrazine; diuron; water; well; corn; crop

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1. Introduction

The fast-growing global population has exerted strong pressure on food production. The use of pesticides is among the more economically effective and successful alternatives to have addressed productivity in modern agriculture. In spite of their contribution to increased agricultural yield, there is increasing concern about their negative effects on the environment and potential risk for human health [1,2].

Atrazine and diuron are among the five most widely used pesticides in the world and applied to control unwanted vegetation in the field [3]. Their physic-chemical properties and polar functional groups make them more water-soluble herbicides, having high mobility through soil and aquatic environmental compartments [4,5]. They have been frequently detected in surface, underground, and well water [6]. The residual amount applied on soil can undergo either sorption or could eventually reach different waterways directly by run off or indirectly through leaching and erosion processes mainly from soil in agriculture areas.

Atrazine and diuron have both been associated with distinct effects on the development, reproduction, and behavior of many aquatic organisms [7]. Their occurrence in the environment is thus a risk for aquatic microorganisms and fauna. Atrazine cause alterations in hematological and biochemical parameters as well as DNA damage in snow trout at low concentrations [8] and induces malformation in *Podocnemis unifis* embryos derived from exposed egg [9]. *Caiman latirostrics* embryonic exposure to atrazine leads to thyroid alterations long after exposure ends [10]. Moreover, it is a risk to the health of phytoplankton in lakes [11], and autophagy is involved in oxidative stress and immune organ damage induced by atrazine [12]. It was suggested that atrazine is toxic to the nervous system of mammals, can disrupt immune system, damage the liver and kidneys, degenerate muscles of the heart, and affect the normal function of hormone systems [13,14]. Diuron was found to be toxic toward zebrafish [15] and *Vibrio fischeri* [16]. Embryos of marine fish showed changes related to cellular protein localization [17]. Interaction of Diuron with other pesticides has caused different toxic responses than those predicted by the individually tested compounds on invertebrates [16,18]. Furthermore, effects on energy metabolism were observed in diuron-treated rats' liver [19]. Exposure to atrazine and diuron may also affect human health. An imbalance in cytokine production caused by atrazine and diuron is toxic [20]. Atrazine likely could induce long-term toxicity [21], while Diuron metabolites were found to be toxic in human cells [6]. Rather, diuron causes cytotoxicity in human cells [15] and may exert harmful effects on fetal development [22].

There are maximum levels of atrazine and diuron permitted in drinking and surface water. However, they might not be enough to protect human health [23]. The people living near crop areas may be exposed through drinking water consumption to pesticides, such as atrazine and diuron, coming from well water. Furthermore, with their unsustainable practice of their use on crops, atrazine and diuron might be toxic. Since water ingestion is thought to be the major route of atrazine exposure for people who have had no occupational contact [24], the occurrence of the determined pesticides in water from wells could have a potential risk for people living near areas where pesticides were intentionally applied to crops. The presence of atrazine has been linked with chronic toxicity for humans due to oral exposure through drinking water consumption from wells, being higher for children than for adults [25].

Corn is one of the main products in the Mexican diet. The land used for this crop accounts for close to 6 million hectares in Mexico [26]. Guerrero, a southern state of Mexico, is one of the medium size agriculture-based economy with a production value of little more than USD$832 million in 2020; that is 2.6% of national agriculture production [27]. Primary economic activity represents 5.6% of the BIP in this state [28], and the corn crop contributes with 34.3% of its total production value. There are 495,000 hectares available for this product in Guerrero (53.5% of the entire surface), and more than 8100 hectares are used as cornfields in the municipality of Arcelia, that is close to 11% of the municipality surface [27]. Particularly, the agriculture in Arcelia is based on little more than ten crops, with a production value equivalent to USD$15.7 million in 2020. Corn is the major crop representing the 36.1% of the total production in the location, and this is a representative percentage of this crop in the Amacuáhuitl community within Arcelia. Although atrazine and diuron could have serious impacts on public health and environment, given climatic conditions, the economic importance of cornfields in this region, and their unregulated sale, farmers use them to protect and increase the yield of the cornfields.

Hence, this work aims to analyze association of residual herbicides atrazine and diuron in surface and well water with agriculture activity within a cornfield rural area, where people have frequently used wells for drinking water.

2. Materials and Methods

2.1. Chemicals and Materials

Individual standard solutions of both herbicide atrazine (98.9%) and diuron (99.9%) at acetonitrile were purchased from Chem Service. Raw samples were separately filtered through a 47 mm glass fiber filter (Whatman, Maidstone, UK), while their extract was filtered with PTFE syringe filter (13 mm, 0.45 um) purchased from Pall Life Sciences (New York, NY, USA). Solid phase extraction (SPE) tubes packed with 0.5 g of octyl-silica (C8) were purchased from Water. HPLC grade acetone, water, methanol, and acetonitrile were acquired from Meyer (Jersey, UK). Formic acid mass spectrometry grade was supplied by Sigma-Aldrich (Saint Louis, MO, USA). Connections and pipes used for the load of samples were made of PTFE. Ultrapure water was prepared by Milli-Q purifier system and N_2 chromatographic grade was obtained from INFRA (Burlington, MA, USA).

2.2. Sampling and Study Area

The samples were obtained from three wells, Azul (100°15′27″ O, 18°15′3″ N), Brocal (100°15′19″ O, 18°13′48″ N), and Tello (100°15′27″ O, 18°13´52″ N), used by people living near crop areas, a surface water stream, Arroyo (100°15′14″ O, 18°14′24″ N), and a puddle, Ushe (100°15′27″ O, 18°15′3″ N), set through a sown field and collected during dry (April) and rainy (July) seasons, all of them located in the low plains of the Ixcatepec catchment, in the Amacuáhuitl community of the municipality of Arcelia (18°13′53.37″ N, 100°15′20.31″ W), Guerrero State in the center south of México, which is a rural community where farming is the main activity. The town is located close to the outlet of the Ixcatepec creek catchment, sitting in the lower part of the basin where the flow of the entire drainage system converges. The catchment has an approximate area of 138.36 km^2 (Figure 1). This hydrological system is part of the river Balsas-Zirándaro basin, a tributary of the main river Balsas that run from east to west [29]. This basin has a topography characterized by lowlands surrounded by ranges at the north and southern sides. The climate in this region is characterized by a warm sub-humid climate with an average annual temperature of 27.9 °C (Min: 20.4, Max: 35.5 °C), an average annual precipitation of Sampling1,181 mm, having a remarkable summer rain regime with 94.2% of the precipitation [30]. The predominant vegetation in the Ixcatepec catchment is oak forest in high lands and deciduous forest in mid and lowlands. Meanwhile, agriculture is extended in the lower plains, having corn as one of the main crops. Corn is a temporal crop that develops twice a year in the Arcelia region, and most production occurs in a period between two and three months during the rainy season (summer season). Nevertheless, such periods have been extended due to alterations of the rainy cycle in the region. Therefore, the corn cultivation has suffered modifications in its temporal processes, amounting to a change in the opening and closing dates of the corn crop, which currently runs from June to October. Corn develops in two phases: vegetative and productive. The vegetative phase begins at mid-June and ends at late July, when the planting grows. The productive phase occurs in the following two months, when the plants reach their maximum height and the cob has developed to maturity.

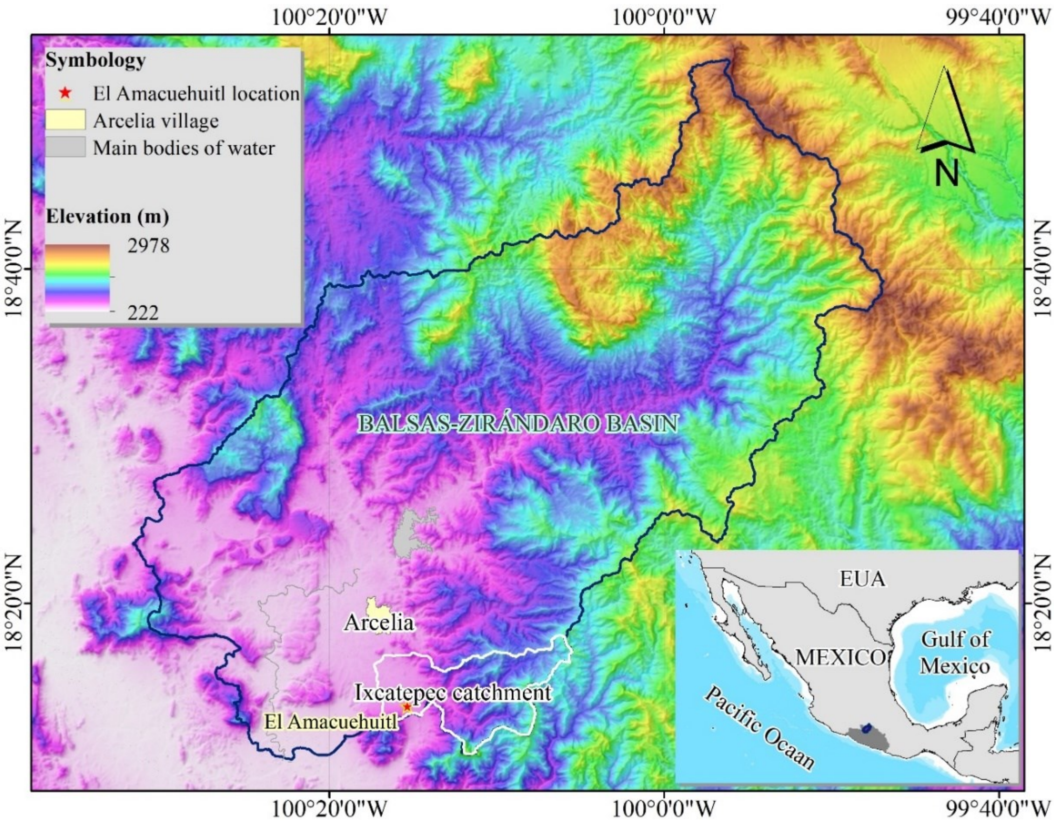

Figure 1. Topographic map of the study area based on the digital elevation model (Data sources: https://srtm.csi.cgiar.org/ (accessed on 15 November 2021) [31].

2.3. Sample Preparation

Samples were quantitatively transferred to graduated cylinders at room temperature and the sampling volume was accurately measured, individually filtered through a 47 mm glass fiber filter (Whatman, Buckinghamshire, United Kingdom), and collected in an amber bottle. The filtered samples were passed through reverse solid phase extraction tube packed with 0.5 g of C_8 (Waters) by applying a vacuum, which was previously conditioned with 5 mL of methanol and followed by 6 mL of ultrapure water by gravity. The elution of compounds was carried out by 10 mL of methanol, collected in a round-bottomed flask, concentrated almost to dryness in a rotatory evaporator (Buchi, Flawil, Switzerland), then passed through a Teflon filter (0.45 μm) and adjusted with acetonitrile to 1.00 mL.

2.4. Analysis of Herbicides

Atrazine and diuron were quantified using a HPLC-MS quadrupole G6545 (Agilent, Santa Clara, CA, USA) with positive electrospray ionization mode. The standards and samples solution were injected automatically and separated through a C_{18} column (68 mm × 2 mm, 4 μm) at 30 °C. The mobile phase solutions were 0.1% formic acid in water (A) and 0.1% formic acid in acetonitrile (B) at a flow rate of 0.25 mL/min. The MS acquisition parameters were as follows: drying gas N_2, 350 °C, nebulizer 35 psi, capillary voltage 3000 V. The data were analysed by MassHunter Software.

2.5. Quality Control

Fortified water samples were used for validation of analytical method, blanks of the instrumental and sample preparation method were monitored for signals corresponding with target compounds. Correlation coefficients (r) were higher than 0.98 ($p < 0.05$), the detection limit of the method was obtained as 3 signal/noise and were 1.05 ng/L for atrazine and

1.88 ng/L for diuron. Recoveries of pesticides analyzed were 96.15 and 107.17% for atrazine and diuron, respectively.

2.6. Geomorphic Analysis

A geomorphic analysis inside the Ixcatepec catchment was done using the digital elevation model (DEM) of the Shuttle Radar Topography Mission, SRTM-v4, this is worldwide-model with a spatial resolution of 3 arc-seconds (~90 m) and particularly the version 4 has been enhanced by filling in data gaps to facilitate the landscape analysis [31,32]. The topography properties and river channel configuration help us to recognize the aptitude of the ground into the regional context. On the other side, the remote sensing and Landsat imagery were used to classify the land use inside the catchment. Particularly, the croplands identification was performed considering that corn is the predominant crop affected during the rainy season. Three images were employed from the Landsat-8, the most recent satellite platform and contemporaneous to the sampling campaign in 2018. Images available and corresponding to the period of transition from the vegetative to productive stage of the corn in the Arcelia region, which is between July and October (8 September 2016; 12 July 2018; and 5 October 2020), were selected (https://earthexplorer.usgs.gov/ (accessed on 15 November 2021)), i.e., an image during the sampling, one image two years before, and two years after the sampling. This multi-temporal analysis was designed to know the spatial configuration of the land use in the short term. The method of supervised classification based on well-identified region of interest (ROIs) was applied to analyze the three images. Both the topography and satellite imagery delineated potential areas for the origin and concentration of pollutants.

2.7. Risk Assessment

The human health risk from oral exposure associated to pesticides through drinking water obtained from well was assessed according to the Hazard Quotient (HQ), which was computed as the ratio of the estimated intake amount of individual pesticide per kilogram body weight (CDI_i) to the acute toxicity reference dose (RfD), which were 0.035 and 0.002 for atrazine and diuron, respectively [33]. The exposed part of population is under health risk when HQ value is equal or greater than 1 [34].

$$HQ = CDI_i / RfD \tag{1}$$

The CDI_i was calculated as

$$CDI_i = \frac{D_{IP} \times EF_i \times ED_i}{BW_i \times AT} \tag{2}$$

where D_{IP} is the average daily intake, EF_i is the exposure frequency, 365 days per year, the exposure duration (ED) is defined as the total period time over which contact occurs between the agent and a target, i.e., the individual who is exposed to atrazine and diuron. ED in Equation (2) considered that the worlds population life expectancy is 72.6 in 2009 [35] and for Mexicans living in the state of Guerrero (Mexico), where this studied location is (Arcelia), this was estimated as 70.3 years for male [36], so the value selected was 70, while for the child population we consider an ED of 6 years old based on Parladis et al. [37]. The body weight (BW_i) is 70 and 20 kg and average lifespan (AT) 2190 and 25,500 days for children and adults, respectively. DIP was obtained by the Equation (3)

$$D_{IP} = Ci \times IR_i \tag{3}$$

where Ci (μg/L) is concentration of pesticide residues and IR_i is the intake rater of water [38,39], which is 0.87 L/day for children and 1.41 L/day for adults.

2.8. Statistical Analysis

The estimation of HQ was assessed using a probabilistic method. Herbicides data were simulated from the original data by Monte Carlo simulations, through the generation of random numbers, obtaining a new data set with the same probability distribution as the original phenomenon. Prior to the simulation, the original data corresponding to Azul, Brocal, and Tello well were interpolated to obtain the Atrazine and Diuron concentration levels. The relationship between the original and simulated data was evaluated by the Pearson correlation tests, obtaining R^2 greater than 0.99. For the simulation of the data, the Mersenne Twister pseudorandom number generator algorithm [40] was applied to obtain normally distributed numbers; it was implemented in Python 3.0. In addition, 10 different seeds were established in the algorithm to guarantee the randomness of the simulated data. Thus, 10,000 simulated data were obtained from each of the original PAH data [41].

3. Results and Discussion

3.1. Herbicides in Surface Water

The detection of atrazine and diuron indicated that application on nearby cropped field had impact on water quality of the sampling sites. The analysis indicated that herbicide atrazine was the compound more frequently found, this was determined in 50% and diuron in 20% of the analyzed samples. The herbicide atrazine was also the compound more abundant with an average concentration of 105.18 ng L^{-1} ranging from 5.77 to 402.00 ng L^{-1}, while diuron had the lowest average concentration 86.56 ng L^{-1} and ranged from 15.45 to 157.66 ng L^{-1}. The higher occurrence and detection patterns of atrazine than diuron have been attributed to differences in the sorption of both herbicides in soil, since log K_{ow} of atrazine (2.50) is lower than that one of diuron (2.85), so atrazine sorbed less than diuron in soils, especially in sandy and low organic carbon soils [42,43]. Although atrazine has a higher potential to leach and reach underground and surface water, the individual concentrations of atrazine (Table 1) were at 100% below maximum contaminant levels (MCLs) established by WHO (2000 ng L^{-1}), EPA (3000 ng L^{-1}), Canada (5000 ng L^{-1}), and México (100,000 ng L^{-1}) [44–48]. There were only two measurements exceeding the European MPL (100 ng L^{-1}) [45] being determined in Ushe ponds (402 ng L^{-1}) and Azul well (286.15 ng L^{-1}). Table 1 shows that the maximum level for atrazine in this study was lower than those reported in México, Venezuela, and Greece and higher than those reported in USA, Spain, and China, while the maximum concentration of diuron is lower than in most other studies.

Table 1. Concentrations of herbicides in surface and well water.

Herbicide	ng/L	Type of Water	Country	Reference
Atrazine	90,000 ± 200,000 140,000 ± 290,000	Surface	Mexico	[49]
	1.00–1990	Surface	Venezuela	[50]
	20–450	Well	Greece	[37]
	5.77–402	Surface and well	México	This study
	180–360	Well	EE.UU	[51]
	90.00 ± 10.00	Well	Spain	[52]
	2.38–8.18	surface	Italy	[53]
	0.057–0.102	Surface	China	[54]
Diuron	2000–28,000	Surface and ground	EE.UU	[55]
	130–1780	Reservoir's surface	EE.UU	[56]
	50–400	Surface water	EE.UU	[57]
	2–180	Ditch and surface	Italy	[58]

Table 1. *Cont.*

Herbicide	ng/L	Type of Water	Country	Reference
	15.45–157.66	Surface	Mexico	This Study
	10.4–87	Stream surface	EE.UU	[59]

Notes: LOD: limit of detection.

3.2. Spatial Pattern

The atrazine and diuron concentration varied greatly through sampling points. The spatial variation of those herbicides, shown in Figure 2, suggested a combined effect of the distinct impacts from agricultural areas nearby to sampling sites. The abundance order of both herbicides was consistent between sampling sites. Thus, the highest concentration of atrazine was found at pond Ushe, followed by Azul, Tello, Arroyo, and Brocal wells. While diuron that was detected in two samples and was also more abundant at Ushe pond followed by Azul well (Table 2), their remaining concentrations were close to, or below, detection limit. The stagnant water at pond Ushe also had the highest value of turbidity (86.2 NTU), exceeding the maximum admissible concentration of 5 NTU in México, which could be caused by the input of fertilizer from crop areas, as suggested by [60], who found that turbidity was significantly associated with elevated levels of nitrate and phosphate. This could be also a result from the lowest flow in its stagnant water. Because the herbicides and fertilizer are flushed from the system slowly, they could have undergone lower dilution than in surface water [61]. Relatively high concentrations of atrazine and other herbicides have been observed in reservoirs long after inputs of those compounds from agricultural crops have declined [62–64]. Reservoirs are repositories of herbicides, which are detected more frequently in reservoirs than in stream water [65]. On the other hand, those higher levels of atrazine at Azul and Arroyo than at Tello and Brocal (Figure 2) were due likely to a more direct input of herbicides from cultivated areas. Figure 3 shows that Azul and Arroyo are located within agricultural land use type areas (yellow zone), which accounted for 55% in Ixcatepec Catchment (Table 2).

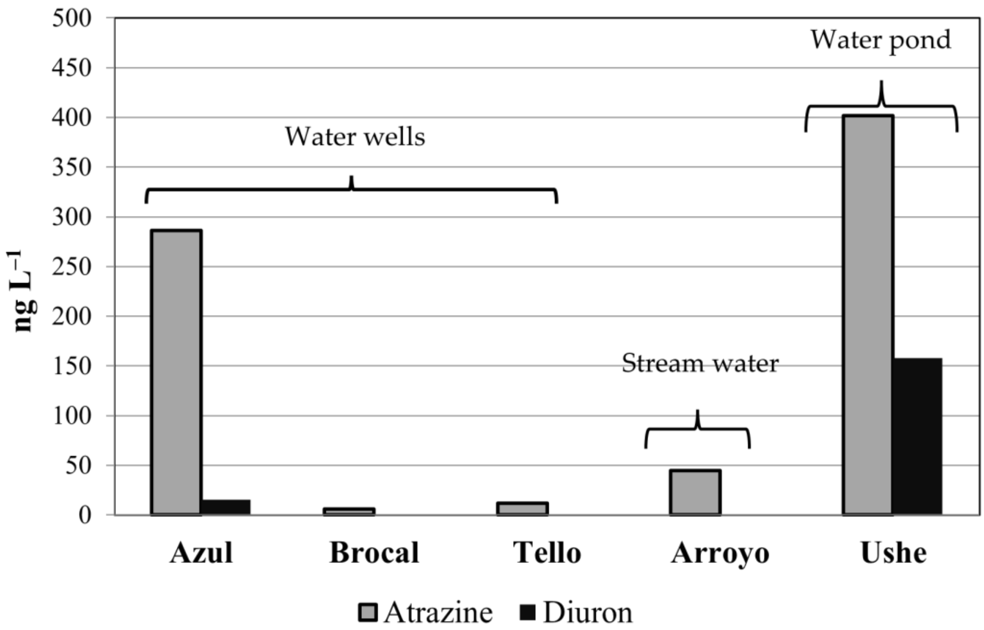

Figure 2. Classification of sample sites and herbicide concentrations.

Table 2. Summary of the area (km^2) detected from remote sensing into the Ixcatepec catchment.

Land Use	8 September 2016	12 July 2018	5 October 2020	Average	Std. Dev.
Agriculture	41.9	66.5	58.1	55.5	10.2
Bare ground	20.0	5.2	6.0	10.4	6.8
deciduous/Oak Forest	73.7	58.9	71.6	68.1	6.6
Total Surface *	135.7	130.6	135.7		

Notes: * Total surface differs from the catchment area (138.36 km^2) due to the presence of clouds during the satellite pass or the minimal percentage of surface corresponding to bodies of water.

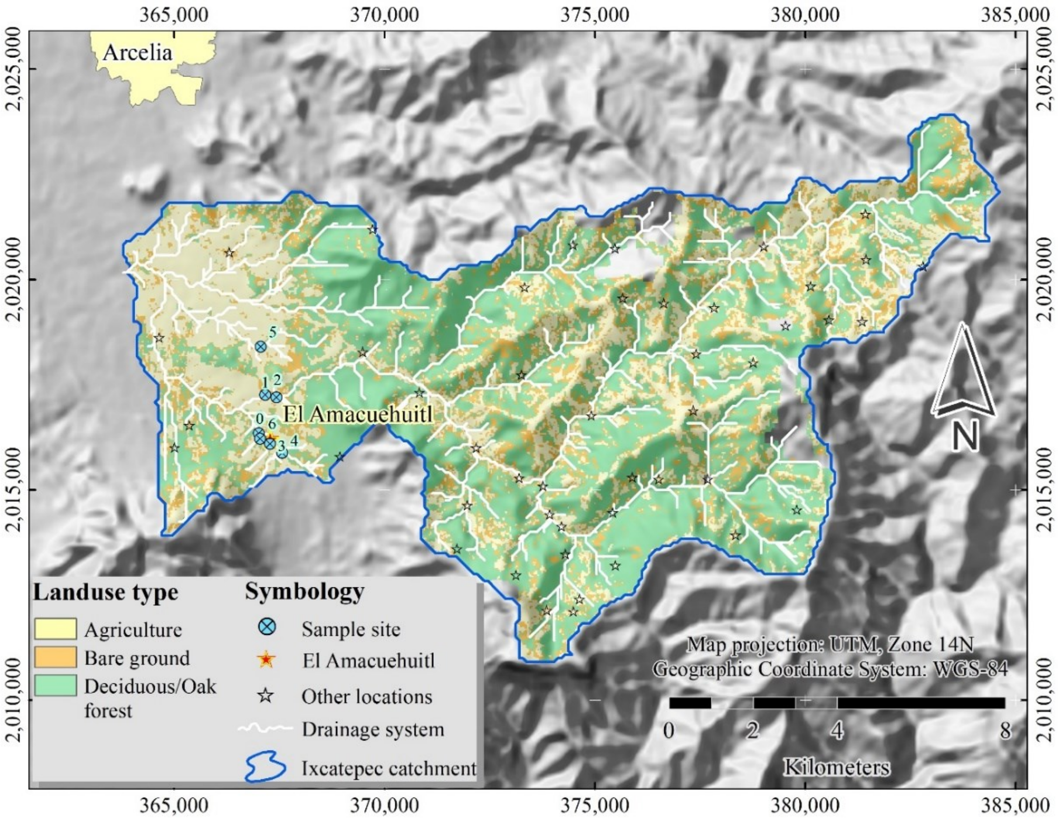

Figure 3. Land use inside the Ixcatepec catchment. Sample sites: Wells (Drinking water, 0; Brocal, 3; Azul, 4; Tello, 6); Stream water (Ixcatepec river and Arroyo, 1 and 2); pond (El Ushe, 5).

3.3. *Influence of Weather Conditions*

The highest individual concentrations of atrazine and diuron were found during the cold-dry season at Ushe (Figure 4). Although precipitation events stopped in the cold-dry season, it is likely that those herbicides could have reached surface water from agricultural area by excessive irrigation applied over the cold dry-season. Since the pH, conductivity, and hardness had significant seasonal variation ($p < 0.05$), the averaged measurements being higher over the cold season than rainy season, these herbicides could have been mobilized toward surface water by runoff either being dissolved from agricultural soils into irrigation-generated runoff or by transport on suspended sediment in runoff. The highest concentration of herbicide atrazine in cold season, its highest frequency of detection in rainy season, and its highest water solubility, suggest that mobilization could be favored mainly by irrigation-generated runoff, instead of bound to sediments [66].

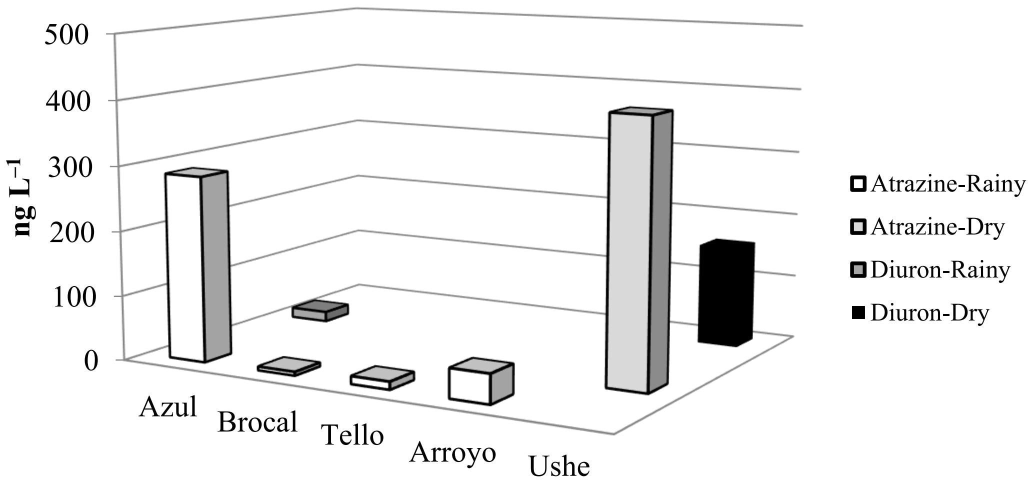

Figure 4. Seasonal distribution of herbicides atrazine and diuron.

3.4. Effect of Catchment Morphology

The mobility of herbicides could have been also favored by geomorphologic characteristics of Ixcatepec Catchment. The highest concentrations of both herbicides in Ushe pond site could be also a result of the effect of gentle topography undulations. The analysis of the distribution of the slope classification showed that 47.4% of the surfaces preserve steepness less than 15°, a similar percentage corresponds to surfaces with 15 to 30°, and only little more than 5% are above 30°. Particularly, semi plains (slope less than 7°) could contain a major quantity of ground undulations and ponds that favor the flooding of the soil as in Ushe sampling site, which correspond with orange and yellow colored area of map in Figure 5. This surface class accounts for 24.6% of the total area, and widely extended in the lower part of the Ixcatepec catchment.

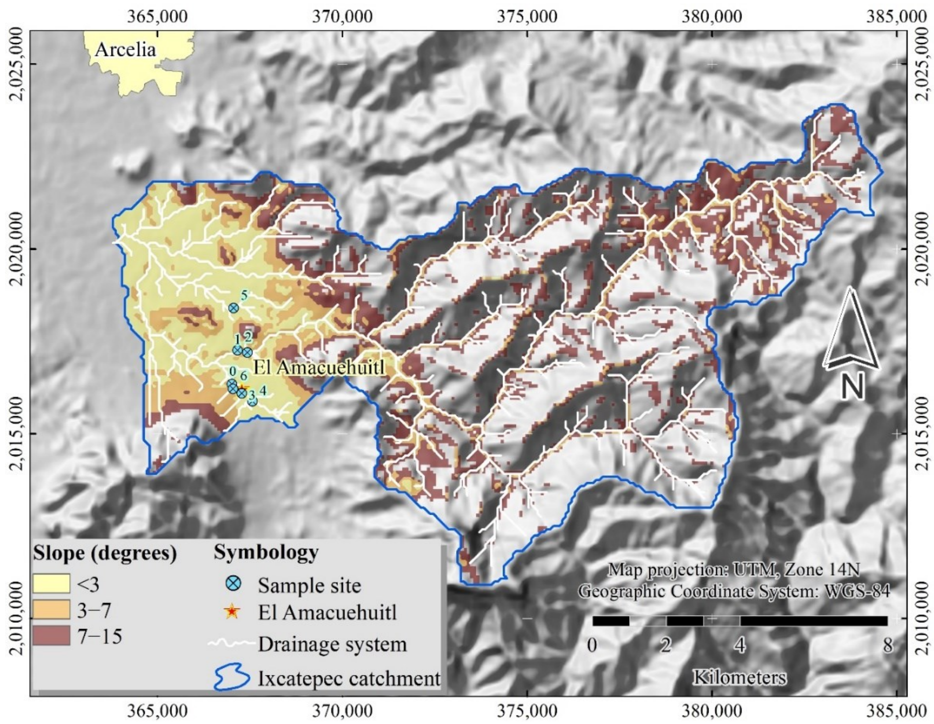

Figure 5. Map of the slope less than 15° into the Ixcatepec catchment (47.4% of the total catchment). Sample sites: Wells (Drinking water, 0; Brocal, 3; El Azul, 4; Tello, 6); Stream water (Ixcatepec river and Arroyo, 1 and 2); pond (El Ushe, 5).

The presence of atrazine in stream water during rainy season showed that there are pollutants sources upstream from arroyo site, which were likely transported from croplands, located in the ridges, towards surface water by run-off as consequence of slope of the surface. Morphological analysis indicated that agriculture and bare ground corresponding to surfaces used commonly as croplands are widely established in the ridges (the higher interpluvial surfaces), the valley floors, and lowland plains. The croplands located on the ridges and valley floors of the mid and upper catchment work as sediment sources feeding the lower places. The valley floors are transitional surfaces where sediment load from the higher surfaces could be deposited for short periods, this is before being removed by stream currents and eventually carried out to lower plans.

The detection in water well suggested the effect of location on the way between the cultivation areas and the downward slope direction. The lower plains and valley floors concentrate the hydrological system of the entire and local catchment, respectively. These are topographies which could be suitable for reducing the speed of water flow (surface and underground) and increasing its residence time in the ground. Such physical features could favor the retention of atrazine and diuron in suspension or dissolved in the water, becoming potential areas of contaminant accumulation (Figure 5).

3.5. Human Health Exposure

The estimation of hazard quotient showed that sampled wells could still have a possible risk for human health from oral exposure as a consequence of residual amounts mainly found for atrazine, with the risk being higher for children than adults (Table 3) as has been recently reported [37]. Although the levels of both determined pesticides were lower than those allowed in drinking water and HQ values did not exceed 1 for individual herbicides, people who rely on well water for drinking may be exposed to both pesticides from Azul well in rainy season, where the highest hazard quotients associated to atrazine and diuron were found (Table 3).

Table 3. Summary statistics for HQ of pesticides through Monte Carlo simulation.

	Children				Adults			
	Atrazine		Diuron		Atrazine		Diuron	
Site	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**
Azul	3.57×10^{-1} (1.39×10^{-1})	(3.55×10^{-1}, 3.60×10^{-1})	3.38×10^{-1} (1.32×10^{-1})	(3.35×10^{-1}, 3.40×10^{-1})	1.66×10^{-1} (6.47×10^{-1})	(1.64×10^{-1}, 1.67×10^{-1})	1.57×10^{-1} (6.11×10^{-1})	(1.55×10^{-1}, 1.58×10^{-1})
Brocal	7.21×10^{-3} (3.00×10^{-3})	(7.15×10^{-3}, 7.26×10^{-3})	-	-	3.34×10^{-3} (1.30×10^{-3})	(3.32×10^{-3}, 3.37×10^{-3})	-	-
Tello	1.51×10^{-2} (6.00×10^{-3})	(1.50×10^{-2}, 1.52×10^{-2})	-	-	6.99×10^{-3} (2.70×10^{-3})	(6.94×10^{-3}, 7.05×10^{-3})	-	-

Notes: SD: standard deviation, CI: confidential interval.

For most of the population in the area where the study was performed, drinking water is consumed directly from the well or the tap. Unfortunately, no formal treatment is conducted, so it is suggested as a public health policy to implement one conventional drinking water treatment with a final step, including an activated carbon filter or at least a filter with gravel, sand, and activated carbon to adsorb these pollutants [67].

4. Conclusions

The detection of both herbicides, atrazine and diuron, in surface and well water showed that their occurrence is mainly linked to agriculture activity within rural community. Chemical properties of compounds, crop irrigation, and environmental conditions could be contributing to the dispersion of residual amounts of herbicides within the hydrological system. Nevertheless, the water body located in the lower surfaces from cultivated areas becomes a potential zone for accumulation, increasing the residence time of this king of compounds in the ground. Similarly, the presence of herbicides in well water suggests a potential risk to people who rely on well water for drinking, where children could be at the highest risk of exposure to atrazine as the herbicide more frequently detected in this work.

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