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Pesticide Concentrations in Drinking Water from Farm Homes: Variation between Community Water Supply and Well-Water

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Abstract: Atrazine, one of the most commonly used herbicides in the United States, has been found to contaminate groundwater. Atrazine is an endocrine disrupter in animals, and could possibly have carcinogenic effects in humans. A study involving farm families in four Kentucky Counties has been designed to assess exposure to atrazine through drinking water by a quick, reliable, and effective assay that could be performed in non-specialized laboratories. Data were obtained on farming practices and pesticide applications; and drinking water samples were collected from each household. Water consumption for the participants showed that 72% of the households consumed municipal water, 24% had private wells, and 4% used spring water as their source of drinking water. The analytical method used was based on Enzyme Linked Immuno Sorbent Assay. The results were obtained using a magnetic-particle-based analysis with spectrophotometric reading and showed presence of atrazine in more than 90% of the samples. Results showed that community drinking water sources had significantly higher atrazine concentrations compared to non-community sources (p-value < 0.01). The results of this study may be used to conduct further exposure assessments for drinking water protection from pesticide contamination.

Key words: Atrazine, immunoassay, drinking water, exposure assessment.

1. Introduction

Water for potable use is "finite", as fresh water resources are limited, and the same quantity of water is being recycled again and again in the water cycle. According to the United Nations Environment Program, there is a necessity for safe drinking water and adequate sanitation, as today more than two billion people lack access to safe drinking water worldwide [1]. There are many causes of water contamination which make it unsafe for drinking. In particular, the presence of herbicides in agricultural regions of the United States has been a nonpoint source of surface water contamination [2]. In recent years there has been a significant increase in the use of herbicides and pesticides in the production of corn and soybeans, and other agricultural crops [3]. Increased reliability on the efficiency and efficacy of these substances has caused many environmental threats, affecting not only the ecosystem in general but the human population and its health [4]. Bioaccumulation of these organic compounds in various stages of the

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food web is of great concern due to the increased risk of biomagnification and toxicological effects [5]. Even when water is considered safe for drinking, it may contain contaminants at concentrations below the permissible levels, whose adverse health effects have not been fully determined.

Atrazine, a triazine herbicide, has a primary use of controlling weeds in corn, sorghum, sugarcane and wheat fields. This product came into wide usage in the 1970s. First introduced in 1958, utilization of this herbicide has increased steadily over the past 50 years. In 2002 approximately 76 million pounds of Atrazine were applied in the United States [6]. According to the United States Environmental Protection Agency's (US EPA) National Survey of Pesticides in Drinking Water Wells, atrazine was found to be the second most frequently detected pesticide [7]. Atrazine is transported to water bodies by run-off from fields, in rainfall, misapplication, and improper disposal. Transport is of great concern when water bodies used as source water for drinking water supplies become contaminated, thus the risk of exposure through consumption is increased. Ingestion of water that contains herbicides forms a major and a direct route of exposure. Atrazine, being a potential carcinogen to humans, can then be transported from the environment to the human body through drinking water [8].

Atrazine is currently regulated by the Safe Drinking Water Act (SDWA) as a synthetic organic compound [7]. A Maximum Contaminant Level (MCL) of 3 parts per billion (ppb) was established by the U.S. Environmental Protection Agency [7]. Under the SDWA, community water systems are required to monitor for atrazine and maintain a yearly average below the MCL [6]. However, until now, there has not been a comparative study between the atrazine levels in community and non-community water sources in Kentucky. The current study was designed to obtain this comparison by using drinking water samples to measure exposure of farm families to atrazine. Further goals of the study were to determine whether there is any difference in atrazine concentration in community and non-community water sources, and to identify potential behavioral and environmental risk factors associated with pesticide exposure through drinking water in farm populations. The research hypotheses are:

- Drinking water pesticide levels will be significantly higher than the MCL for atrazine;
- Detectable atrazine levels will be found in drinking water of farm families that do not use the city/county water supply and these levels will be affected by environmental factors such as location and purification practices;
- The concentration of atrazine in community water sources will be different than non-community sources considering that community water undergoes purification processes.

2. Literature Review

Atrazine has endocrine-disrupting effects on aquatic organisms, such as frogs [9]. It has been found to cause demasculinization of frogs, even at concentrations below the Maximum Contaminant Level (MCL) and as low at 0.1 ppb [9]. Atrazine causes reduction in olfactory-mediated endocrine functions in Salmonids [10]. Studies on rats showed that this herbicide and its metabolites bind effectively to the red blood cells and to the tissues of some of the major organs. Cardiac toxicity was observed in dogs after long-term oral administration of atrazine. Experimental studies in rats and mice have shown reduced food intake, decreased weight gain, and toxic effects, such as muscle and retinal degeneration, necrosis of the liver, and hematological effects. In addition, an increase in mammary tumors was observed in rats [11]. Some of the toxic effects of atrazine may be due to its direct impact on dendritic cell maturation and function [12].

Although there is clear evidence of the real potential of atrazine to directly cause adverse effects to aquatic biota, the human health effects of atrazine are still being investigated and documented. It is known that xenoestrogens promote cancer by enhancing the production of genotoxic estrogens and mutations in cells. The fact that atrazine is a dubbed estrogen increases the importance of exploring the possibility of the carcinogenic potential of triazine herbicides. Exposure to excess estrogen is considered to be a risk factor for the development of breast cancer [13]. Since atrazine has estrogenic properties, there is a possibility for it to cause hormonal imbalance that may result in an increased chronic incidence of breast cancer by consumption of atrazine-contaminated water. Atrazine was also related to an elevated incidence of prostate cancer in men. This observation was made at the St. Gabriel atrazine plant in Louisiana where the employees had markedly elevated rates of prostate cancer, which were significantly higher than the statewide average [14]. The National Institute of Environmental Health Sciences has been conducting significant research for determining the role of environmental estrogens and toxicological substances in initiating and/or promoting breast cancer. Atrazine may cause its tumor development effects by a number of possible mechanisms. It can cause induction of aromatase, the rate limiting enzyme in conversion of androgen to estrogen [15]. It can also disrupt the hypothalamic control of pituitary-ovarian control and alter the Luteinizing Hormone and Prolactin levels in blood [16]. The EPA has classified atrazine as a “possible” human carcinogen, as it was placed in category “C” under the cancer assessment guidelines [6]. However, research done till now has been inconclusive and, at many times, contradictory. For example, a population based study in Wisconsin did not find an increased risk of breast cancer due to atrazine exposure in drinking water [17].

Atrazine has a potential to cause many acute health effects. These occur especially when the exposures are above the MCL. Some of the acute health effects include muscle spasms, congestion of heart, lungs and kidneys, hypotension, antidiuresis, adrenal degeneration, etc. [18]. Documented chronic health effects in humans, due to the consumption of atrazine contaminated water, are weight loss, mammary tumors, muscle degeneration, cardiovascular damage, and retinal degeneration. Atrazine is thought to have carcinogenic potential when there are lifetime exposures above the MCL [17]. It can be manifested as cancer of various organs in males and females. Studies have also been done to link atrazine exposure with Intra Uterine Growth Retardation, Small for Gestational Age and preterm babies [19].

The environmental fate of atrazine is very complex. It can be present in soil, with a half-life of more than one year. Atrazine is considered to be mobile and is transported throughout the environment due to its solubility in water of 30 mg/L. It is transported to surface water via run-off, spray drift and atmospheric transport. Atrazine has a history of being detected in rainfall, groundwater, and surface waters. These characteristics make atrazine a potential contaminant of all types of freshwater bodies. The increased risk of atrazine contamination of community water supplies can be attributed to its mobility and resistance to metabolism [12]. The resistance of atrazine to abiotic hydrolysis and direct aqueous photolysis, and its moderate susceptibility to degradation in soil, supports the fact that atrazine doesn’t undergo rapid degradation on foliage. Atrazine has been observed to be more persistent in a colder climate, suggesting the site specific nature of the product [2]. The result is significant variation in the persistence of atrazine in the environment. Atrazine is known to be relatively persistent in soils with a half-life ranging from 4 to 57 weeks [20]. However, limited data exists as to the soil conditions and watershed processes that may enhance transport. The above discussion describes the complexity of the environmental transport of atrazine, stressing the importance of field studies to determine and identify the reasons for the persistence of concentrations in drinking water, which could potentially lead to human health concerns.

3. Methods

3.1 Study Population and Recruitment

The study involved a survey of 70 farm families in Butler, Grayson, Logan and Warren counties of Kentucky. These four counties were chosen because of the presence of large farming communities and the proximity of the counties to Western Kentucky University. After approval from WKU Human Subjects Review Board, families living on farms and having at least 100 acres of tillable cropland, as mentioned in the Kentucky Agricultural Census, were chosen randomly, contacted, and recruited for the study. Information on drinking water supply, pesticide usage, farming practices, and demographics was gathered through a questionnaire. The data obtained were analyzed to evaluate factors that could influence atrazine levels in drinking water of these families.

3.2 Sample Methods

The sampling procedure involved the collection of water samples from the drinking water sources of the study participants. Two samples were collected from the drinking water source at each participant's house. A pair of field duplicate samples was also collected for every ten samples. The samples were collected in 40 mL amber glass VOA bottles after rinsing them three times. After collection, the bottles were preserved in a container at 2°-8° Celsius and brought to the Environmental Health Research Laboratory at Western Kentucky University. Samples were refrigerated upon arrival at WKU and stored at 2°-8° Celsius. Analysis of samples was done within 14 days of collection.

3.3 Analytical Method for Analysis of Atrazine in Water

Drinking water samples were analyzed using Strategic Diagnostics Inc. (SDI) RPA-RaPID Analyzer and RaPID Assay Atrazine Test Kits. The analytical method used was based on Enzyme Linked Immuno Sorbent Assay with the test having a Minimum Detection Limit of 0.046 parts per billion of atrazine, and Limit of quantitation of 0.1 parts per billion. The samples were added, along with an enzyme conjugate, to a disposable test tube, followed by paramagnetic particles with antibodies specific to atrazine attached. After incubating the tubes for 15 minutes, a magnetic field was applied to hold the paramagnetic particles (with atrazine and labeled atrazine analog bound to the antibodies on the particles, in proportion to their original concentration) in the tube and to decant the unbound reagents. The presence of atrazine was detected after adding an enzyme substrate and a chromogen. Color developed in the test tube was inversely proportional to the concentration of atrazine in the sample. Determination of the atrazine level in the sample was done by using spectrophotometric analysis at 450 nm. Results obtained were atrazine concentrations in parts per billion (ppb) [21].

4. Results

All statistical analyses were performed using SAS system software, version 9.2 (SAS Institute, Inc., Cary, NC). All significance testing was performed at the 0.05 level of significance.

The study involved 70 participants (46 males and 22 females). The mean age of the participants was 54.7 years. Study participants involved in farm related work were 66.7% and those that handled pesticides were 49.2%. Out of 70 households, water samples from community sources were analyzed from 50 households, water samples from non-community water sources were analyzed from 17 households, and water samples from both community and non-community sources were analyzed from 3 households. The mean concentration of atrazine in the community and non-community water sources is shown in Table 1 and its distribution in the four counties is shown in Table 2. Although, on an average,

Table 1 Average concentrations of atrazine in community and non-community water sources for the four counties.

Avg. conc. of atrazine in community water sources (ppb)	Avg. conc. of atrazine in non-community water sources (ppb)	p-value [A]
0.46 [X]	0.14 [Y]	<0.01

[A] Student's t-test with p-value < 0.05 considered statistically significant; [X, Y] Arithmetic means with the same letter are not significantly different from each other.

the participants had used water from their sources for 17.9 years, in 71.4% of the households their water supply had never been sampled for quality purposes. Study results showed that 30% of the participants used a water filter and 62.9% do not use any kind of filter.

Table 2 also shows the proximity of fields to the houses and pesticide application in the four counties. The most commonly grown crop was hay (50.7%), followed by corn (13.4%), pastures (9%) and soybeans (6%). Of all the participants, 70% owned livestock and 52.2% applied insecticides on them. The minimum amount of insecticides used was 0.5 lbs and the maximum was 27 lbs while the average amount used was 7.38 lbs.

Of all the households that participated in the study, 10.5% had sprayed insecticides in their houses within a month prior to the study; 20.9% had sprayed within 12 months prior to the study; 13.4% had sprayed pesticides in their lawns within a month prior to the study; and 19.4% had sprayed within 12 months prior to the study. Of the participating households, 44.8% owned a garden, 23.9% had sprayed pesticides in their garden within a month prior to the study, and 26.9% had sprayed within 12 months prior to the study. The number of participants from each county who sprayed pesticides in their homes is shown in Table 3.

5. Discussion

In this study, two drinking water samples were collected from each of the 50 homes that have community water supply and from each of the 20 homes that have well water as their drinking water supply; and samples were analyzed for atrazine. The mean concentration of atrazine in community sources was 0.46 ppb and in non-community sources was 0.14 ppb. A t-test was done to find any significant difference between the atrazine concentrations in water from the different sources. The results showed a significant difference between atrazine concentrations in the community and non-community sources; (2 sample t-test (54.47) = 4.64; p-value < 0.01). When the community and non-community water sources were analyzed individually, the average atrazine concentrations in drinking water from community water systems were not significantly different than those of well water for each of the four counties. This could be because of the small sample size for each county. However, the mean difference in water samples from the two sources for all four counties together showed that community sources had significantly higher atrazine concentrations in drinking water compared to non-community sources. The reason for this finding is not known through the extent of this study. It is possible that the purification processes used for community water sources in these four counties may not be adequate for removal of atrazine. At the same time there may be contamination of drinking water in the supply chain through the community water delivery systems, which could have resulted in the observed values. Further studies are

Table 2 Drinking water atrazine concentrations (ppb) and pesticide application in the four counties.

County	Community sources avg. conc.	Non-community sources avg. con	Proximity of field to house (feet)	Total acres sprayed with pesticides	Total number of livestock	Total amount of insecticides sprayed (lbs)
Butler	0.31 [X, Z] (n = 9)	0.06 [Z] (n = 3)	74.5	65 (n = 1)	36 (n = 6)	1.83 (n = 3)
Grayson	0.69 [X, Y] (n = 23)	0.25 [X, Z] (n = 5)	53.3	31 (n = 3)	55 (n = 16)	8.25 (n = 12)
Logan	0.17 [X, Z] (n = 6)	0.13 [X, Z] (n = 11)	99.38	194 (n = 7)	48 (n = 9)	8.61 (n = 9)
Warren	0.27 [X, Z] (n = 12)	0.24 [X, Z] (n = 1)	91.25	15 (n = 1)	456 (n = 5)	6.71 (n = 7)

[X, Y, Z] Arithmetic means with the same letter are not significantly different from each other based on p-value < 0.05 obtained from ANOVA; n = number of households.

Table 3 Pesticide application in the four counties.

County	No. of households	Insecticide application	Home pesticide application	Garden pesticide application
Butler	10	3	6	5
Grayson	25	5	8	14
Logan	19	6	5	11
Warren	13	7	3	4

required to discern the factors influencing these concentrations in drinking water.

6. Conclusion

Pesticides are inherently toxic substances and much animal and epidemiological research is required to explore potential associations between pesticide exposures and health risks. The presence of atrazine concentrations in drinking water, even though they are below the MCL of 3 ppb, raises concern for farm families' exposure to pesticides through drinking water. This is one of several routes of exposure to pesticides that can contribute to the overall body burden for pesticide exposures. Epidemiological studies in this area suffer from a lack of exposure data; documentation of the potential presence and level of pesticides. Data collected in this study may be used to design exposure assessments for atrazine contamination in drinking water. As such, exposure assessment of pesticides in drinking water is a critical need as part of national and global environmental public health initiatives.

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