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TEMPORAL AND SPATIAL PATTERNS OF ATRAZINE AND METOLACHLOR, WITH A COMPARATIVE ANALYSIS OF CANCER INCIDENCES IN IOWA

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ABSTRACT: Increasing concerns about agricultural chemicals, especially estrogenic ones, have raised questions about agricultural chemicals and cancer incidence. This study focuses on two common agricultural chemicals: Atrazine and Metolachlor, neither of which is currently treated by conventional drinking water treatments and both of which are suspected endocrine disruptors (environmental estrogens). Atrazine only started being monitored in Iowa with regularity in 1989, despite evidence of being a carcinogen with an estrogenic effect. Metolachlor, commonly used in combination with other pesticides as a pre-emergent, broad spectrum herbicide, has been classified as a possible human carcinogen, but no maximum contaminant level has been set for it yet. As US standards for herbicide use are generally set through controlled experiments with a single pesticide, the reality of farmers using mixtures of pesticides has serious implications for the run-off generated from agricultural land.

Using Atrazine and Metolachlor data measured in surface and ground water from the U.S. Geological Survey over the measurement record (1988-2004), we mapped their concentrations temporally and spatially. From the SEER Cancer registry website, the spatial occurrence and temporal incidence of varying types of cancer were mapped for the period 1973-2002 as ten year aggregates. In this paper, we examine possible spatial associations between herbicide contamination in water and cancer incidence in Iowa, specifically cancers possibly linked to environmental estrogens. Cancer incidences appear to have increased over the last three decades. Similarly, levels of pesticide in specific areas of Iowa show repeated patterns of increase. Areas showing increases in both herbicides also show significant increases in cancer incidences.
KEY TERMS: herbicides, GIS, environmental estrogens, endocrine disruptor

INTRODUCTION

Atrazine is one of the most commonly applied pesticides in the United States, having been detected in 78% of the water samples monitored by the U.S. Geological Survey nationwide (Schettler et al., 1999). From the Atrazine applied to fields, less than 1 to 2 percent moves into the water via runoff or by infiltrating into groundwater. About 90 percent of the herbicide found in streams in early summer is the result of runoff, with the other 10 percent being from groundwater infiltration (Battaglin et al., 2003). Iowa farmers used somewhere between 7,162,000 and 8,911,000 pounds of Atrazine on their corn crops in 2001 alone (NRDC, 2004), so that transfer of 1-2% of this volume represents a significant addition into the aquatic ecosystems.

Metolachlor, commonly used in mixture with other herbicides to control a greater range of species (O'Connell et al., 1998), is used on crops such as corn and soybeans and was registered for use in 1976. Metolachlor is considered to be moderately to highly mobile and is highly susceptible to runoff. While Metolachlor has a relatively short half life in soil, it is highly persistent in water with approximately 6.6% degradation in 30 days of sunlight (Crawford, 2001).

Both of these commonly used herbicides have been linked to reproductive and immune system problems. It is often hard to establish direct evidence due to the non-point nature of chemicals. This study aims to shine light on the relationship between the measurement of Atrazine and Metolachlor in Iowa watersheds and cancer across the state. In this study, we will utilize GIS to analyze maps of measured levels of Atrazine and Metolachlor in Iowa watersheds, and cancer incidence in Iowa over a

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30 year period. Using an overlay method, we can identify geographic correlations between watershed levels of these chemicals and cancer incidence. While there are many variables contributing to cancer incidence across the state, the fact that these chemicals are suspected or known carcinogens should be examined in relation to the changing cancer rates.

METHODS

The water testing site data were downloaded from the USGS website, which were used to make a geocoded shapefile. Separate tables for each year (1988-2003) were then created, as well as a table for an aggregated 5 year period (eg., 1993-1998). A total of 9171 records were retrieved, spanning the time period from February 1982 to March 2004 These new tables were summarized by watershed (HUC code) to calculate the maximum, average, sum and the standard deviation of measurements within that watershed for that year. These tables were then respectively linked to a shapefile of the watersheds (HUC_8 subregions) and a separate shapefile was created for each year. This allowed examination of average values of Atrazine and/or Metolachlor within each watershed.

Cancer incidences, totaling almost 400,000 records, in the state of Iowa were downloaded from the Surveillance, Epidemiology and End Result (SEER) Registry of the National Cancer Institute, which were available for the years 1973 through 2002 (http://seer.cancer.gov/). Within the registry, individual patient data were found in relation to sex, year of diagnosis, age at diagnosis, primary tumor site, and patient demographics by county.

Cancer incidence in Iowa was analyzed spatially using county-level data, as data on the zip code level could not be acquired. Previous studies have shown that county-level data may, in fact, be preferable. Wang (2004) states that a few occurrences of a rare disease such as cancer may create insignificant clusters when spatially analyzed over a small population, such as a zip code. Using county-level data helps to stabilize the rate of increase or decrease of cancer incidence (Wang, 2004).

A basic county by county map of Iowa was taken from the Iowa State University Public GIS server (ftp://ftp.gis.iastate.edu) and served as a base map. In addition, the HUC watersheds were downloaded from the public server and also were used throughout the study.

RESULTS AND DISCUSSION

Watershed Analysis

Average Atrazine and Metolachlor values measured in each watershed for a given year were mapped to provide an understanding of patterns and variations across the state. Not all watersheds were measured every year and some watersheds were measured in greater spatio-temporal detail than others. Almost half of the measurements were taken in the Lower Cedar (1321), Middle Cedar (1040), Turkey (777) and Middle Iowa (747) watersheds. The greatest number of watersheds sampled in one year took place in 1991 with 1061 samples being taken in 50 watersheds.

During 1991, 582 samples were obtained during the agricultural season (April, May, June and July). This represents only 20 of the 65 watersheds in Iowa. The agricultural season is of interest since it represents the periods of application and runoff and watersheds likely will have elevated values during this period. However, the reduced sampling volume and area does not lend itself to a significant analysis. We compared average values for the entire year with average values measured during the agricultural season and found no significant difference. Therefore, in order to utilize the larger dataset, the annual average for each watershed was used.

Prior to 1988, only a few watersheds were being sampled for Atrazine and Metolachlor, so that subsequent analyses only consider watershed data 1988 and beyond. In addition, since there is a likely lag time between exposure to a chemical in the water supply and the diagnosis of cancer, we considered only the data up to 1998, creating a 5 year lag time to the most current cancer incidence data.

Examining the watershed averaged values over time, it is clear that variations are inherent in the data, but trends are noticeable. Maps were generated for every year, with two samples shown (Figure 1). The eastern watersheds tend to have higher values, especially the lower watersheds in eastern Iowa. Among these, the South Skunk, North Skunk, Skunk, Middle and Lower Iowa as well as the

Cedar River stand out, along with the Upper Wapsipinicon and Turkey in northeastern Iowa. In western Iowa, a region of higher Atrazine and Metolachlor values is defined by the Little Sioux, Maple and Boyer watersheds, along with the North Raccoon River.

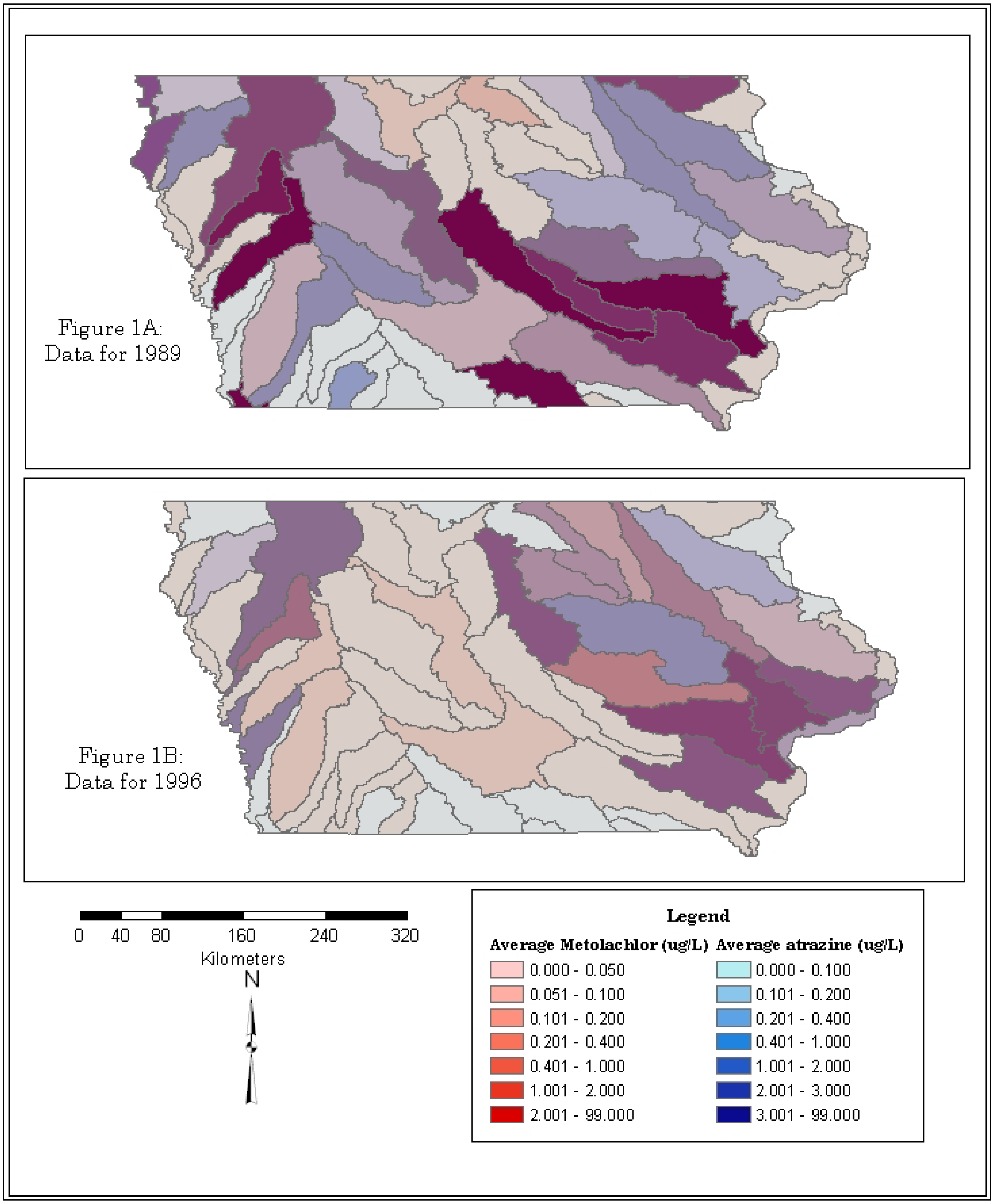


Figure 1: Average Atrazine and Metolachlor measurements summarized for each watershed in Iowa for the years 1989 (Figure 1a) and 1996 (Figure 1b)

From these maps, we created a summary map that showed watersheds ranked by the number of years in which the average Atrazine and the average Metolachlor measured within the watershed increased (Figure 2). The watershed that consistently showed an increase in average Atrazine values was the North Raccoon River, which ends in the Saylorville Dam, just north of Des Moines.

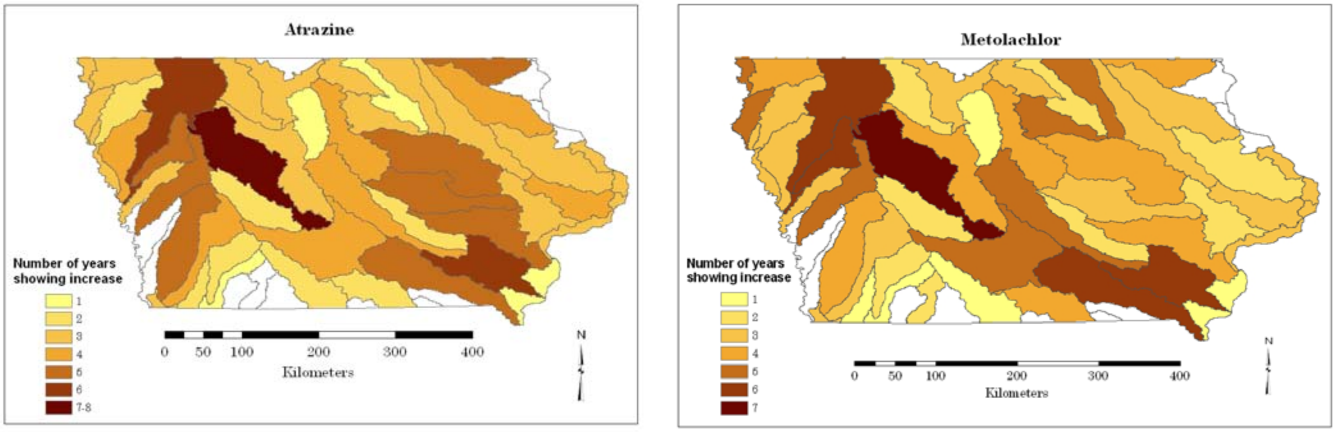


Figure 2: Number of times average Atrazine (on left) and Metolachlor (on right) measurements within a watershed increased over a one year period, within the measurement record of 1988 to 1998

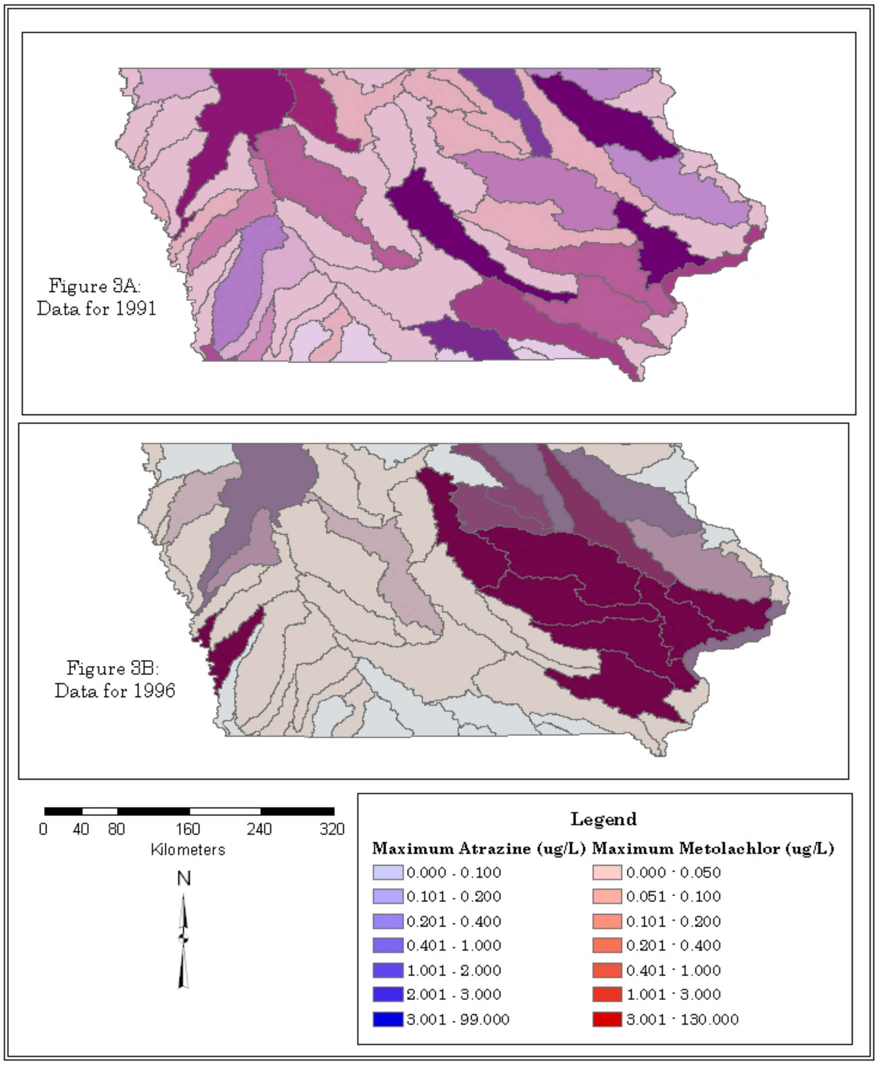
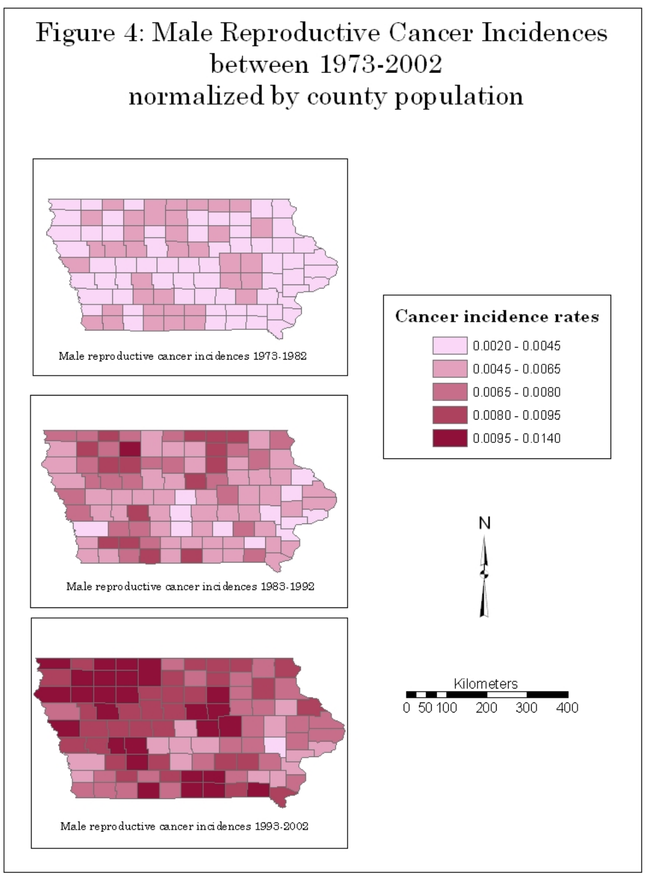


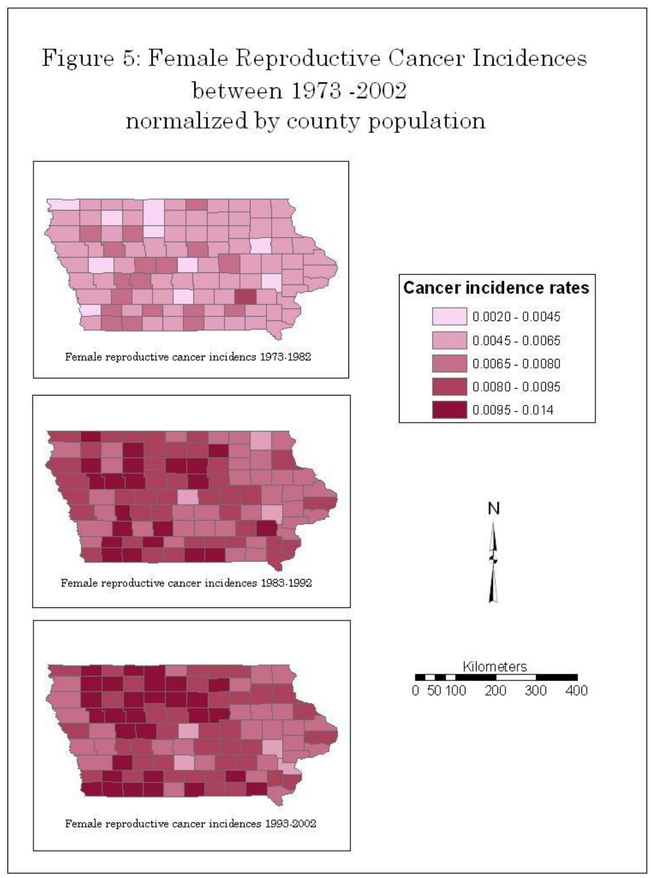
Figure 3: Maximum concentrations of Atrazine and Metolachlor measured in Iowa watersheds in 1991 (Figure 3a) and 1996 (figure 3b)

Since the average value for a watershed represents an average over time, and can be taken as a measure of chronic exposure, we felt it also prudent to examine maximum values measured within the watersheds for each given year, two of which are shown in Figure 3. While average values often fall under the recommended EPA value of 3 ppm, maximum values more frequently exceed this. Maximum Atrazine values for the years 1991 and 1996 confirm the same general trends seen in average values. Eastern Iowa watersheds contain higher levels of these herbicides. It may be that, due to the varied topography and shallower soil depth in northeastern Iowa, these chemicals may run-off into the watersheds more quickly.

Cancer Analysis

Figure 4 shows male reproductive cancer incidences in 10-year increments from 1973-2002. The number of reproductive cancer recorded in Iowa counties in 1973-1982 is low. All of the counties in the first map are lightly shaded, indicating low cancer rates. However, the incidences in 1983-1992 rise dramatically, especially in the northwest corner of the state. In the next ten years, 1993-2002, this portion of the state becomes even darker, symbolizing a higher reproductive cancer rate. Figure 5, showing female reproductive cancers, follows the same trend of increasing cancer over time throughout the state and especially between the periods of 1973-1982 and 1983-1992. However compared to Figure 4, the 1983-1992 increase in cancer in females seems more dramatic, not only in





the northwest but throughout the state.

Figures 4 and 5: Male and female reproductive cancer incidences over time in Iowa in ten year increments, normalized by population for each decade. Cancer incidences are reported for residence at time of diagnosis

The trend shown in the sequential cancer maps throughout the study time period shows an increase in cancer, of all types, over time. One explanation for this increase may be the improved cancer detection during the study period. This may account for some but not all of the increases. Something else that might be causing the increased cancer rate may be the combined effects of atrazine and metolachlor exposure, beginning in 1976. This analysis can only indicate patterns and trends in the data.

To better analyze if Atrazine and Metolachlor are potentially affecting cancer rates, maps were created which looked specifically at 1993-2002 male cancer rates overlain onto Atrazine and Metolachlor rates in Iowa watersheds. All of the cancer data were normalized for county population and symbolized by standard deviation. Figure 6 shows male cancer incidences (1993-2002) and the average Atrazine and Metolachlor values in 1991. Male cancers mainly fall into the average standard deviation, symbolized by yellow circles. Areas with large, red circles indicate an above average incidence of cancer in the state, with a greater than two standard deviations from the mean. In this map, there seems to be little correlation between watersheds high herbicides and cancer incidences. However, this may be due to the use of averaging the herbicides in a watershed. The average values were taken as representative over the whole watershed and do not represent specific areas of high concentrations of Atrazine and Metolachlor. Also, the average is over the whole year, and may be offsetting the data because it includes months where Atrazine and Metolachlor values are inherently low. Average values may indicate chronic exposure, which can increase the likelihood of cancer development.

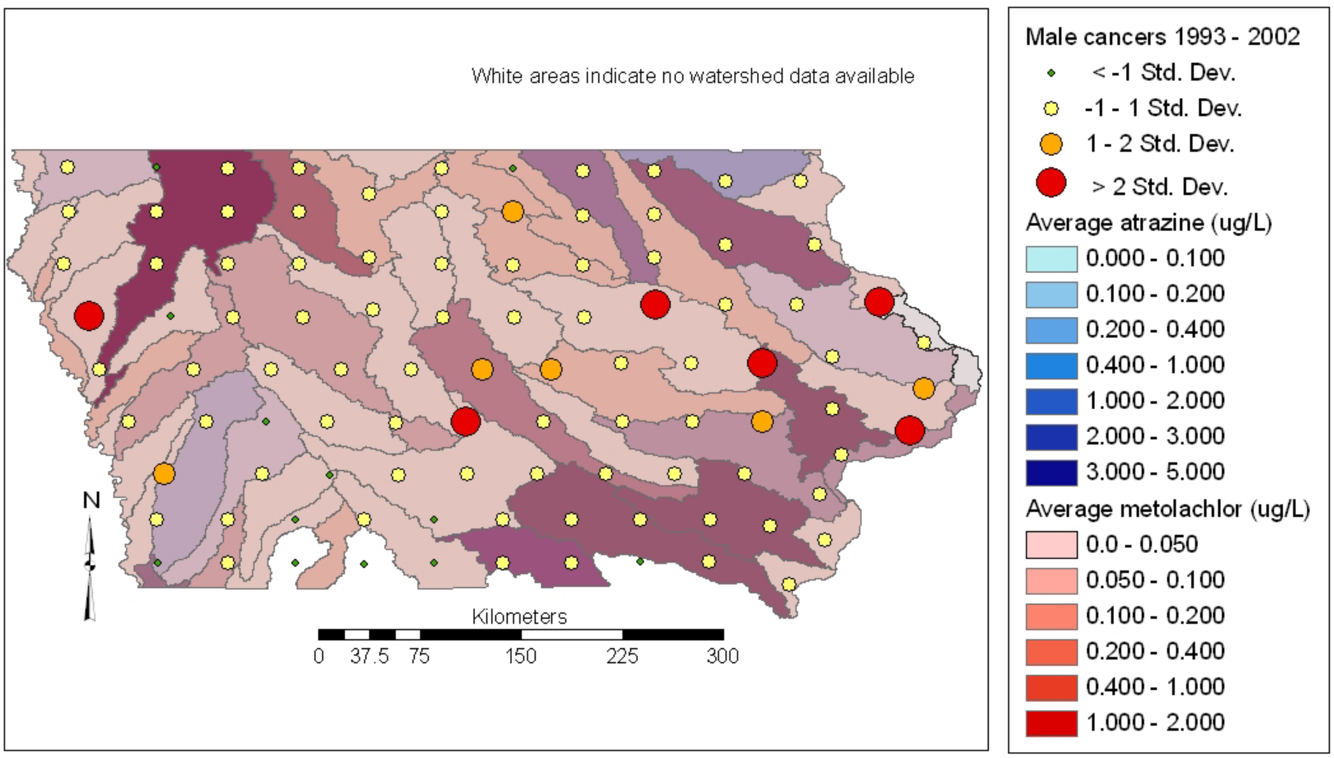


Figure 6: Male cancer incidences (normalized by population) from 1993 to 2002 overlain on measured average Atrazine and Metolachlor values for 1991

The best correlation between cancer and Atrazine and Metolachlor rates was seen in male cancers from 1993-2002, overlain onto the water chemistry for 1996 watersheds (Figure 7). Here the chronic exposure does correlate to the above average (greater than two standard deviations) cancer incidence. This can be seen in the eastern portion of the state where watersheds have high Atrazine and Metolachlor values as well as cancer rates. This same trend is also seen in male reproductive cancers between 1993-2002 in both average and maximum Atrazine and Metolachlor data. Figure 7 shows the high values of Atrazine and Metolachlor in watersheds for the eastern portion of the state as well as the three predominant areas of above average cancer rates of the region. Not every watershed was measured every year and thus regions that are not colored in a shade of purple indicate a lack of data.

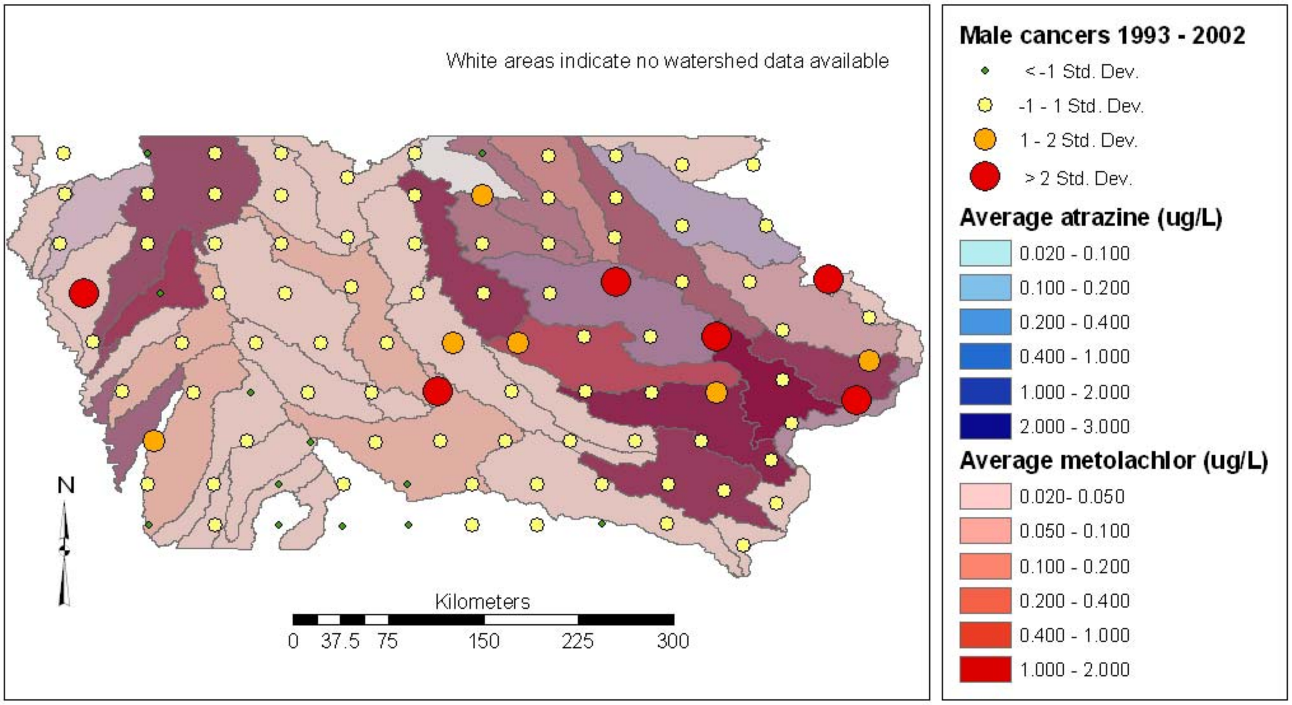


Figure 7: Male cancer incidences (normalized by population) for 1993 to 2002 overlain on average Atrazine and Metolachlor measurements in 1996.

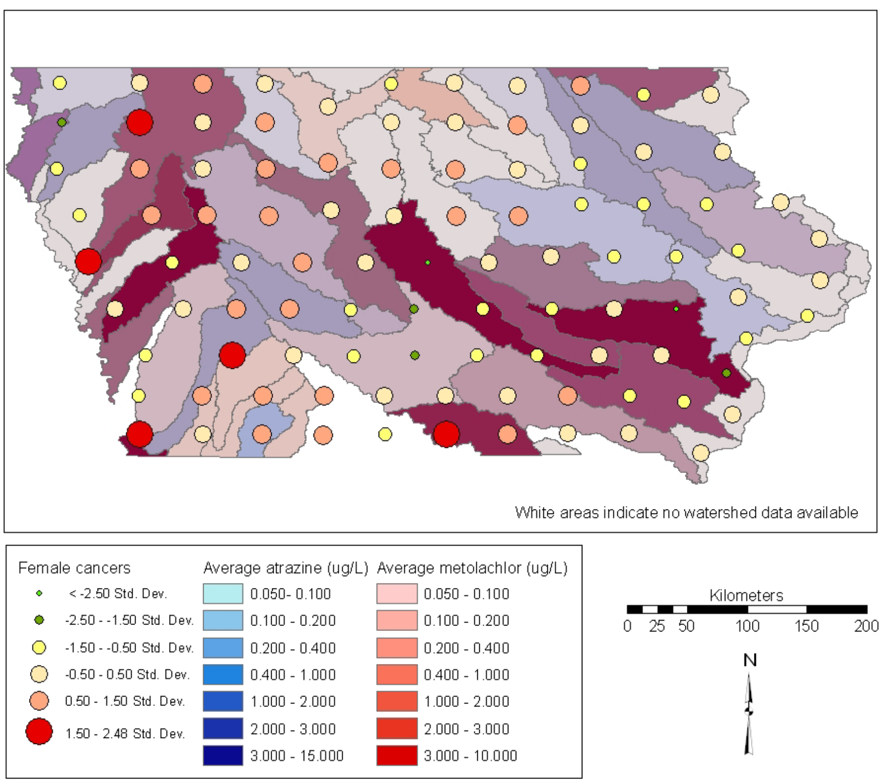


Figure 8: Female cancer incidences (normalized by population) from 1993 to 2002 overlain on average Atrazine and Metolchlor measurements in 1989

Figure 8 show female cancer incidences for the time period 1993-2002, displayed as graduated symbols indicating the standard deviation of total incidences per county. The watersheds underlay the county-based cancer data, with measured Atrazine and Metolachlor values overlain on each other. The patterns apparent in maps showing male cancers, overlain with Atrazine and Metolachlor, are not seen in female cancer rates (Figure 7). A correlation between high levels of Atrazine and Metolachlor and female reproductive cancers is not shown. We suspect that this may be that since Atrazine and Metolachlor, known or suspected environmental estrogens, may be more detrimental in combination on the male reproductive system.

CONCLUSION

While definite conclusions about the correlation between cancer incidence and exposure to Atrazine and Metolachlor can not be drawn, some patterns were evident in the study. Cancer incidences have increased consistently over a thirty year period and appear to have taken a jump following the commercial introduction of Metolachlor in 1976. Male reproductive cancer rates appear to be increasing at a faster rate than female reproductive cancers in the last 10-year period. Incidences of all reproductive cancer seem to occur more frequently in the northwestern portion of the state. This could show that perhaps the effects are a result of not a high level of one or the other, but the combined effects of both chemicals.

FUTURE WORK

Data collected during this research include comparison of childhood cancers and birth defect rates to the presence of Metolachlor and Atrazine in watersheds. An analysis of birth defects year by year, in comparison to watershed data may provide a better understanding of the influence of exposure to these chemicals. Analyses of these data are forthcoming. Future work could also entail using the individual sampling sites within each watershed to allocate portions of the watershed to that sampling site via Thiessen polygons, to give greater definition on the ranges and values of Atrazine and Metolachlor measured in the watershed, rather than averaging sampling values over the entire watershed. In addition, future work should attempt to determine pesticide use and run-off to water by taking into account loading factors.

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