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GEOGRAPHICAL INFORMATION SYSTEM (GIS) AS A TOOL FOR MONITORING AND ANALYSING PESTICIDE POLLUTION AND ITS IMPACT ON PUBLIC HEALTH

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Abstract: Geographical Information System (GIS) combines information from cartography sources (i.e. maps), earthbound surveys, remote sensing (i.e. aerial and satellite imagery) and creates overlapping layers that can be accessed, transformed, and manipulated interactively in one spatial structure. Thanks to the great flexibility of GIS, its possible applications are countless. For example, dynamic databases created by GIS can manage information from various sources and make spatial correlations with epidemiological data about temporal distribution of environmentally-related diseases. GIS has also been increasingly used to monitor, analyse and model pesticide migration in the environment. GIS analysis has proved to be a valuable tool in environmental and public health studies yielding important results that may ultimately help prevent excessive or uncontrolled exposure to xenobiotics, including pesticides. Despite its obvious advantages GIS technology is still not commonly used for such studies, particularly in the developing countries where the knowledge about GIS technology and its accessibility is limited. The presented review briefly explains the basic features of GIS and discusses exemplary studies where this technology has been successfully used for monitoring and analysing pesticide pollution and its impact on public health.

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INTRODUCTION

Geographical Information System (GIS) was first considered as a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data from the real world for a particular set of purposes [3]. These data can be accessed, transformed, and manipulated interactively in one spatial system, and can serve as a test bed for studying various environmental processes. Also, GIS is used for analysing the trends and environmental impacts caused by human activity, and as an aid in the prediction of possible results and planning at different governmental levels. The data in the GIS database model of the real world can be implemented in many ways for environmental investigations. Numerous GIS applications include analysis of pesticide distribution and endurance in the environment, as well as their impact on public health [2, 8, 11, 15, 20].

GIS has its origin in the need to combine information from cartographic sources, earthbound survey and remote sensing. The location on the surface defined by a coordinate system was a key issue in creating GIS. The first computer assisted mapping and map analysis (a direct predecessor of GIS) was used in the 1960s and

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1970s for resource assessment, land evaluation, and planning [3]. The realization that the different components of the earth's surface, including human activity, did not function independently from one other made people to evaluate them in an integrated, multidisciplinary way. This was the moment when GIS started to play a significant role. One way to evaluate environmental features is an approach of natural units in which a recognizable, unique, and independent combination of the environmental characteristics of landform, geology, soil, vegetation, and water create an ecological complex. Every complex creates a unique, natural set of conditions for accumulation and transportation of chemicals, including pesticides [14].

Current GIS technology provides capabilities to combine multiple data sources such as ground survey data, vectorized maps, satellite and airborne images (Fig. 1) of different types (vector, raster) and resolution in a complex way that allows for the better answering of questions asked by researchers. In pesticide research, such questions may concern changes in spatial distribution of pesticides types, their quantity and association with pesticides inputs – current and past. The data stored and processed in a GIS database allows for answering the questions about spatial distribution and locations and thus provide a better understanding of pesticide impact on environment and human health. The present review shows examples of GIS applications in pesticide research at different spatial levels.

The main advantages of GIS in pesticide research can be summarized as follows:

- it helps to create needed data layers about the environment, land cover, pesticide inputs (i.e. depth of aquifers, soil texture and type, settlement, road network, etc.);
- allows for recording changes in time with regard to spatial extent;
- enables to compute buffer zones and perform spatial analysis in order to define exposure levels at the desired points, lines, polygons (e.g. residence unit, water creek, vegetable field);
- facilitates the way of adding new data layers (i.e. remote sensing information from different sources, air borne and satellite borne platforms), and updating current layers.

COMPONENTS OF GIS

There are 3 main components of GIS – data inputs, database transformation (including data query and data analysis), and data output (Fig. 1).

Information from traditional maps is commonly used as a source of input. Input includes points of data, linear features and aerial polygons (i.e. soil pits locations, networks of roads or forest areas, respectively). There are also other sources of information – such as location from ground survey registered by Global Positioning System (GPS, a satellite-based navigation system), aerial photographs, satellite images or other; provided they are giving information about location in space. Input data usually have either a raster or vector format [3, 10].

New maps in digital or analog form, with information derived from GIS database, create output. Besides these, the user is often interested in tabular information and reports giving records about the output results and steps taken during the database analysis.

The main strength of GIS comes from its core component - the possibility of database transformation and analysis. These include transformation of the coordinate system of input data layers, raster to vector conversion, data extraction and overlaying, data management and others [3, 10]. One of these procedures is neighbourhood analysis, for example, creating buffer zones around the pesticides inputs (Fig. 1) and combining them with land cover information derived form aerial or satellite images. This analysis, in the research conducted by Brody *et al.* [2] or Ward *et al.* [20], helped in defining the residential exposure to pesticide application. Targeted areas of exposure (based on cutting-off distance from pesticide affected areas to residential areas) can be used for further scrutiny with regard to temporal changes in pesticide concentration.

GIS has great flexibility in mapping methods. The conventional mapping methods yield sharp boundaries, thereby ignoring the continuous features of nature. One of the techniques of handling uncertainty in geographical processing is fuzzy logic. This method has been used recently for analysis of mutually related environmental components [4, 12]. In pesticide research, it may help for better understanding of pesticides distribution and movements across the environment.

GIS AS A TOOL FOR MONITORING AND MODELING PESTICIDE CONTAMINATION OF WATER ENVIRONMENTS

Groundwater is one the main carriers of pesticides in the environment. Pesticides contaminate groundwater by leaching from agricultural and industrial applications. Groundwater is also the primary source of drinking water for large populations. As such, its contamination by pesticides may have great impact on human health [1]. It was mentioned before that GIS technology seems to be very useful in the modelling, predicting and monitoring of pesticides migration in aquatic ecosystems. Surprisingly, however, there are relatively few studies that utilized this dynamic and comprehensive approach. One of the few examples is a recent work of Dabrowski *et al.* [8]. The authors predicted relative runoff-induced pesticide loss from sub-catchments of the Lourens River (South Africa) using a GIS model. Runoff is the main cause of pesticide leaching to surface waters in rural areas and GIS proves to be an efficient tool for modelling it. Pesticide contaminated runoff is dependent on the physicochemical properties of a given pesticide such as water solubility and half-life. Other important factors include soil

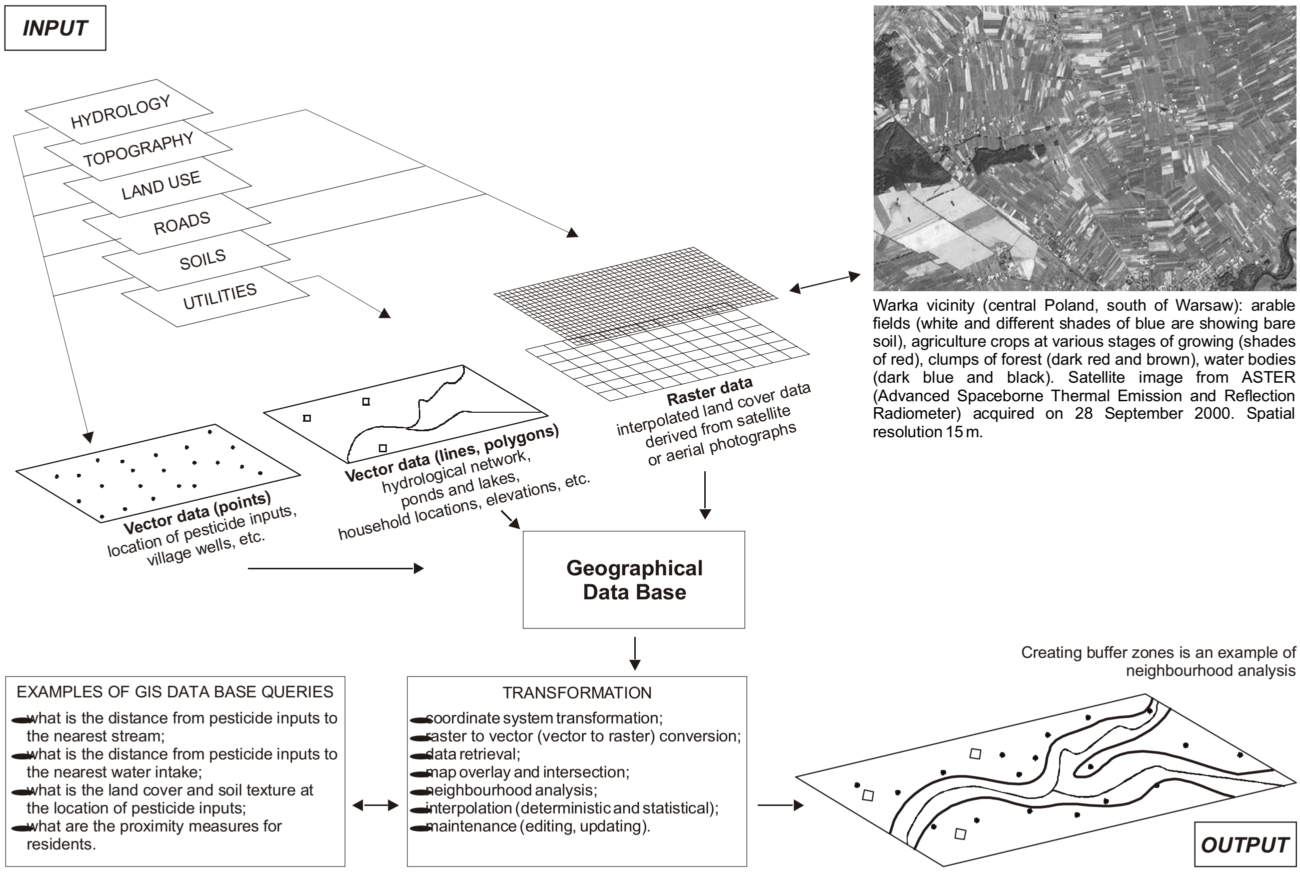

Figure 1. Components of Geographical Information System (GIS) and its application to pesticide analysis (see text for detailed description).

properties, presence of erosion, slope angle, crop type and density or presence of buffer zones. All these factors can be entered into GIS software, and reciprocal relations between them may be analyzed [8].

Another interesting study evaluated the vulnerability of groundwater to pesticide pollution [15]. Using GIS analysis, the authors tried to establish, the impact of several factors - soil texture, slope, land use, well depth and rainfall - on the levels of pesticides in groundwater collected from 3 provinces in Thailand. GIS turned out to be a very useful tool for computing indices of groundwater vulnerability in large areas. With the help of GIS, the authors generated vulnerability maps which showed pockets of high liability to pesticide contamination. These targeted areas may be easily adjusted or modified should the pattern of pesticide distribution change.

GIS AS AN INDISPENSABLE TOOL FOR ANALYSIS OF PESTICIDE EXPOSURE AND SPATIAL DISTRIBUTION OF PESTICIDE-RELATED DISEASES

GIS rapidly becomes an indispensable instrument of essential importance in revealing associations between environmental exposures to hazardous substances and their impact on human health. Dynamic databases created by GIS applications can manage information from various sources and make spatial correlations with epidemiological data about temporal distribution of particular disease. For example, it is possible to correlate the data about pesticide use, proximity to agricultural fields, contamination of soil/water, biomarkers of pesticide exposure with the occurrence of certain forms of cancer or birth defects. Despite the obvious advantages of GIS technology, only a few researches have utilized this method for large-scale epidemiological studies.

A landmark study performed by Ward *et al.* [20] assessed the feasibility of identifying populations exposed to pesticides by analysis of crop patterns using GIS and remote sensing technology. By means of satellite imagery combined with historical data from agricultural agencies, the authors reconstructed specific crop patterns in parts of the state of Nebraska, USA. Then, average application rates of pesticides and herbicides specific for these crops were estimated. Finally, residential addresses obtained from a population-based epidemiologic study of non-Hodgkin lymphoma were mapped with GIS software, and compared with previously reconstructed crop/pesticide application maps. GIS analysis of these combined data revealed that 22% of households where patients participating in a non-Hodgkin lymphoma study lived had at least one of the crop types within 500 m of their residence [20]. Residents of these households were likely exposed to pesticides since pesticide drift from spraying operations ranges can reach as far as 1,000 m [5, 6, 9,]. This may have accounted for the high incidence of lymphoma in the area. Moreover, application of pesticides in close proximity to residential areas may lead to increased dermal exposure as well as contamination of drinking water. It is well established that both of these routes of pesticide exposure are relevant for their toxicity [1, 16, 17, 18, 19].

The study of Ward *et al.* [20] suggested that GIS and remote sensing technology may allow the identification of populations with potentially higher exposures to crop pesticides. In consequence, this technology could become a useful tool for studies evaluating health effects of exposures to agricultural pesticides. In fact, similar conclusions were obtained in a more recent report by Brody *et al.* [2]. These authors gathered historical data about pesticide application in Cape Cod, Massachusetts that spanned almost 50 years. The historical data was incorporated into GIS and linked with a representative set of 4,000 residential addresses from that region, which allowed the identification of areas with the highest likelihood of pesticide exposure [2]. This area was subsequently targeted by the same group of researchers in a large-scale epidemiological study of breast cancer [11]. The research revealed increased breast cancer incidence among women who had lived in the affected area for 5 or more years [11]. The above-mentioned studies clearly exemplify the great value of GIS in the management of large-scale public health studies.

REMOTE SENSING APPLICATIONS IN PESTICIDE INVESTIGATION

Satellite imagery is currently one of the most critical inputs into the GIS database. In pesticide applications such images can deliver information about land cover. Land cover types (vegetation, bare land, water, urban areas, etc.) and various types of crops differ from each other in terms of their reflectance and spectral characteristics (Fig. 1). These differences vary throughout the seasons of the year. Thus, the image can be classified into separate land cover/land use types based on land use unique spectral features. In the field, each crop type is treated with a different, specific type of pesticide. Knowledge about land use and its changes (e.g. crop rotation types) over the years can be used to identify source areas of potential exposure to agriculture pesticides [20]. GIS allows for updating the information layers in an easy, efficient way; thus, land cover information, based on remotely sensed data, can be updated every season. Both GIS and remote sensing have become very powerful tools in monitoring pesticide spatial distribution and their evaluation [2, 20].

CONCLUSIONS

GIS technology, as outlined above, emerges as an invaluable tool in large-scale environmental and epidemiological studies. Geospatial and epidemiological data integration, analysis and visualization performed by GIS technology rapidly gains importance and becomes a standard tool in the management of public health and risk assessment throughout the world [7, 13]. GIS technology has been increasingly used in many environmental studies analyzing distribution of pesticides and their impact on public health. Although GIS is still not fully implemented in this type of research, the examples given above are proving the usefulness of GIS in pesticide investigations. Hopefully, more researchers dealing with pesticide use and management will use GIS in the near future.

REFERENCES

1. Badach H, Nazimek T, Kamiński R, Turski W: Organochlorine pesticides concentration in the drinking water from regions of extensive agriculture in Poland. *Ann Agric Environ Med* 2000, **7**, 25-28.
2. Brody JG, Vorhees DJ, Melly SJ, Swedis SR, Drivas PJ, Rudel RA: Using GIS and historical records to reconstruct residential exposure to large-scale pesticide application. *J Expo Anal Environ Epidemiol* 2002, **12**, 64-80.
3. Burrough PA, McDonnell RA: *Principles of Geographical Information Systems*. Oxford University Press, Oxford 1998.
4. Burrough PA: Fuzzy mathematical methods for soil survey and land evaluation. *J Soil Sci* 1989, **40**, 477-492.
5. Byass JB, Lake JR: Spray drift from tractor powered field sprayer. *Pestic Sci* 1977, **8**, 117-126.
6. Chester G, Ward RJ: Occupational exposure and drift hazard during aerial application of paraquat to cotton. *Environ Contamin Toxicol* 1984, **13**, 551-563.
7. Croner CM: Public health, GIS, and the internet. *Annu Rev Public Health* 2003, **24**, 57-82.
8. Dabrowski JM, Peall SK, Van Niekerk A, Reinecke AJ, Day JA, Schulz R: Predicting runoff-induced pesticide input in agricultural sub-catchment surface waters: linking catchment variables and contamination. *Water Res* 2002, **36**, 4975-4984.
9. Frost KR, Ware RJ: Pesticide drift from aerial and ground applications. *Agric Eng* 1970, **51**, 460-467.
10. Heywood I, Cornelius S, Carver S: *An Introduction to Geographical Information Systems*. Prentice Hall 1998.
11. McKelvey W, Brody JG, Aschengrau A, Swartz CH: Association between residence on Cape Cod, Massachusetts, and breast cancer. *Ann Epidemiol* 2004, **14**, 89-94.
12. Oldak A: Biotic potential determination using Geographical Information Systems, fuzzy logic and classical approaches. *Die Erde* 2001, **132**, 421–436.
13. Ricketts TC: Geographic information systems and public health. *Annu Rev Public Health* 2003, **24**, 1-6.
14. Salski A: Fuzzy-knowledge based models in ecological research. *Ecological Modeling* 1992, **63**, 103-112.
15. Thapinta A, Hudak PF: Use of geographic information systems for assessing groundwater pollution potential by pesticides in Central Thailand. *Environ Int* 2003, **29**, 87-93.
16. Toś-Luty S, Obuchowska-Przebirowska D, Latuszyńska J, Tokarska-Rodak M, Haratym-Maj A: Dermal and oral toxicity of malathion in rats. *Ann Agric Environ Med* 2003, **10**, 101-106.
17. Toś-Luty S, Przebirowska D, Latuszyńska J, Tokarska-Rodak M: Histological and ultrastructural studies of rats exposed to carbaryl. *Ann Agric Environ Med* 2001, **8**, 137-144.
18. Toś-Luty S, Tokarska-Rodak M, Latuszyńska J, Przebirowska D: Dermal absorption and distribution of (14)C carbaryl in Wistar rats. *Ann Agric Environ Med* 2001, **8**, 47-50.
19. Toś-Luty S, Tokarska-Rodak M, Latuszyńska J, Przebirowska D: Distribution of dermally absorbed 14C DDT in the organs of Wistar rats. *Ann Agric Environ Med* 2002, **9**, 215-223.
20. Ward MH, Nuckols JR, Weigel SJ, Maxwell SK, Cantor KP, Miller RS: Identifying populations potentially exposed to agricultural pesticides using remote sensing and a Geographic Information System. *Environ Health Perspect* 2000, **108**, 5-12.