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Geostatical Modelling For Ground Water Pollution in Salem by Using Gis

T. Subramani[1], P. Krishnamurthi[2]
[1]Professor & Dean, Department of Civil Engineering, VMKV Engg. College, Vinayaka Missions University, Salem, India
[2]PG Student of Environmental Engineering, Department of Civil Engineering, VMKV Engg. College, Vinayaka Missions University, Salem, India

ABSTRACT
Ground waters are the major resources to meet out the entire requirements. Pollution of air, water and land has an effect on the quality of the ground waters. The chemical characteristics of groundwater in Salem taluk of Salem district have been studied using Geostatistical modeling to evaluate the suitability of water for irrigation and domestic uses. The 32 water samples from PWD wells taken during the years 1999 to 2009 for post monsson and pre monsoon were tested for various chemical parameters like pH and TDS .The Geostatistical analyst of mean, mode, standard deviation, cluster & simple to study the spatial pattern of contamination movement for the years 1999 to 2009. Trend analysis was performed to identify trends in the input dataset. The concentrations of physical and chemical constituents in the water samples were compared with the World Health Organization (WHO) standard to know the suitability of water for drinking.
KEYWORDS: National Highway, Remote sensing, Alignment Using Gis, Shortest route

I. INTRODUCTION

Most parts of India are facing groundwater pollution. Such types of pollution are mainly enrichments of various chemical parameters such as nitrate, hardness, metallic trace elements and microbiological organisms. The Environmental Protection Agency, in the United States, has identified in 1993 more than 200 chemical compounds in groundwater, some of these are extremely hazardous to human health.

Most of drinking water sources has been contaminated by microbial or chemical contaminants potentially hazardous to human health on the part of intensive agriculture, unsewered sanitation in densely populated areas, or from point sources such as irrigation of land by sewage effluents (Suthar, et al., 2009) The over exploitation of groundwater in some parts of the project area induces water quality degradation.

This poses a problem of supply of hazard-free drinking water in the rural parts of the country. In the project area the Geostatistical analyst of ArcGIS was used to generate Voronoi maps like mean, mode, standard deviation, cluster & simple to project the spatial pattern for TDS and pH. Pollution of groundwater due to industrial effluents and municipal waste in water bodies is another major concern in many cities and industrial.

The concentrations of physical and chemical constituents in the water samples were compared with the World Health Organization (WHO) standard to know the suitability of water for drinking. In the project area Geostatistical analyst of ArcGIS was used to generate voronoi maps like mean, mode, standard deviation, cluster & simple to project the spatial pattern for TDS and pH.

Current pesticide concerns include their widespread usage, high toxicity, and environmental persistence. In Salem, pesticide applications have increased rapidly over the past decade. Imported pesticides increased from 5,537 metric tons in 1987 to 15,701 metric tons in 1996, or approximately double within ten years. More than 90% of the pesticides imported each year were herbicides, insecticides, and fungicides (DOA, 1996).

Usage of pesticides has greatly increased agricultural production. However, there has also been an increased potential for groundwater contamination. The more the pesticides are used, the higher the potential of groundwater contamination. This is due to the fact that pesticides applied to farmland can move downward with deep percolation from the root zone to underlying groundwater. The problem of groundwater quality deterioration in Salem caused by pesticide contamination is, therefore, taken into consideration in this project.

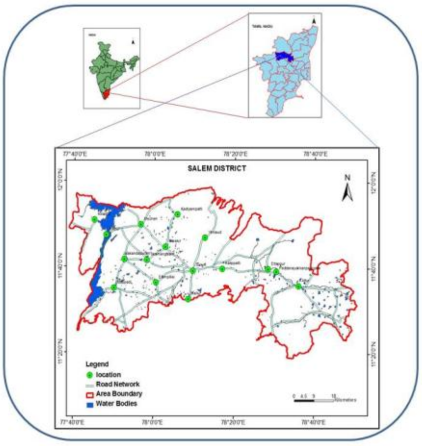
As pesticide applications increase in Salem, the need to protect groundwater becomes greater. Monitoring groundwater for pesticides is the first step toward protecting groundwater resources. However, it is impractical to monitor groundwater beneath all areas because of time and budget constraints. Therefore, a technique for assessing groundwater vulnerability to contamination by pesticides needs to be established. This technique would help identify areas where pesticides are likely to impact groundwater. Once the areas are identified, groundwater monitoring programs can be focused in such areas. Information derived from the monitoring programs would be helpful for protecting groundwater resources.

Several methods have been used to assess vulnerability of groundwater to contamination by organic contaminants. These include the DRASTIC model (Aller et al., 1987), pesticide root zone model (PRZM) (Carsel et al., 1985), vulnerability to pesticides model (VULPEST) (Villeneuve et al., 1990), leaching potential index (LPI) (Meeks and Dean, 1990), attenuation factor (AF) (Rao et al., 1985), and pesticide analytical model (PESTAN) (Enfield et al., 1982). However, this project proposes to use geographic information systems (GIS) technology to assess groundwater pollution potential by pesticides in central Salem. Specifically, the objectives of this research are:

(1) To produce maps of the project area showing relative vulnerability of groundwater to pesticide pollution
(2) To compare groundwater quality data derived from actual observations with the vulnerability maps
(3) To develop a model for predicting the degree of susceptibility of groundwater to contamination by pesticides
(4) To make recommendations for further studies involving the assessment of groundwater pollution potential by pesticides

1.1.PROJECT AREA

Salem is a city and municipal in Salem district in the Indian state of Tamil Nadu. Salem is located about 160 kilometers (99 mi) northeast of Coimbatore, 186 kilometres (116 mi) southeast of Bangalore and about 340 kilometres (211 mi) southwest of the state capital, Chennai. Salem is the fifth largest city in Tamil Nadu in terms of population after Chennai, Coimbatore, Madurai, and Tiruchirappalli respectively and fourth in terms of urbanisation. The area of the city is 100 km^2(39 sq mi). It is the fifth MunicipalCorporation and Urbanagglomeration commissioned in Tamil Nadu after Madras (year 1919), Coimbatore (1981), Madurai (1971) and Tiruchirappalli (1994) respectively. As of 2011, the city had a population of 829,267.



1.2Character of ground water

The Salem district, located in semi arid southeast India, is an important industrial and agricultural center. In recent years rapid development has created an increase in demand for groundwater. Detailed knowledge of water quality gives a brief insight on the hydrochemical system, promotiong sustainable development and effective management of groundwater resources. A hydrogeochemical investigation was conducted in the Salem district by collecting a total of 108 groundwater samples for Pre and Post monsoon seasons. The project reveal that pH in the area is neutral to alkaline ranging from 6.6 to 8.6 with an average of 8.0. The electrical conductivity and total dissolved solids (TDS) values was noted higher during both the seasons. The abundance of major ions in the groundwater is in the order of Na > Ca > Mg > K=Cl>HCO3>SO4>NO3. Hydrochemical facies demarcated was Ca-Mg-Cl, Na-Cl, Ca-HCO3, Ca-Na-HCO3 and Ca-Cl type. NO3, Cl, SO4 and F exceed the permissible limit during both the seasons. The quality of groundwater has been assessed by using SAR, Permeability Index and RSC values along with Wilcox and USSL diagrams. As per the classification of water for domestic and irrigation purposes, the influence of anthropogenic activities such as intense agricultural practices like application of fertilizers, irrigation practice,urban and industrial waste discharge influence the quality of groundwater in the project area.

II. GROUND WATER SCENARIO

2.1 Hydrogeology

Salem district is underlain entirely by Archaean Crystalline formations with Recent alluvial and Colluvial deposits of limited areal extents along the courses of major rivers and foothills respectively. Weathered and fractured crystalline rocks and the Recent Colluvial deposits constitute the important aquifer systems in the district. Colluvial deposits represent the porous formations in the district. These deposits comprise boulders, cobbles, gravels, sands and silts and are seen in the foothills of all the major hill ranges. The thickness of these aquifers ranges from a few meters to as much as 25 m. Ground water occurs under phreatic conditions and is developed by means of dug wells. They are important from ground water development point of view in the hilly terrain. Granite Gneiss, Charnockite, Granites and other associates represent the hard consolidated crystalline rocks. Ground water occurs under phreatic conditions in the weathered mantle and under semi-confined conditions in the fractured zones. These rocks are devoid of primary porosity but are rendered porous and permeable with the development of secondary openings by fracturing and their interconnection. The thickness of weathered zone in the district ranges from <1m to more than 25 m. The 8 depth of the dug wells tapping weathered residuum ranged from 10 to 38 m bgl. Dug wells have traditionally been the most common ground water abstraction structures used for irrigation in the district. The yields of the open wells are low in the hill areas about 500 lpm for a drawdown of 2 m for four hours pumping, where as the open wells in the plains varies from 200 to 1000 lpm. The yields of dug wells are improved at favorable locations by construction of extension bores, which are 50 to 75 m. deep. In recent years, the declining water levels and reduction in yields of wells are being observed due to increased extraction of ground water by a large number of bore wells for irrigation purposes. The Specific capacity of large diameter wells tested in crystalline rocks from 59 to 270 lpm / m. of drawdown

The yield of bore wells drilled down to a depth of 40 to 75 m, by various state agencies mainly for domestic purposes ranged from 20 to 500 lpm. The yield of successful bore wells drilled down to a depth of 300 m bgl during the ground water exploration programme of Central Ground Water Board ranged from <1 to 14.00 lps. The depth to water level in the district varied between 0.10 – 11.46 m bgl during premonsoon depth to water level (May 2006) and varied between 0.10 – 17.15 m bgl during post monsoon depth to water level (Jan 2007). The seasonal fluctuation shows a rise in water level, which ranges from 0.20 to 3.25 m bgl. The piezometric head varied between 3.00 to 18.00 m bgl (May 2006) during pre monsoon and 2.02 to 19.62 m bgl during post monsoon.

III. METHODOLOGY

3.1Application of GIS Methods

The purpose of this project is to use geographic information systems (GIS) technology for assessing groundwater pollution potential by pesticides in central Salem. This technology can help produce maps of the project area showing relative vulnerability of groundwater to pesticide pollution. The application of GIS methods for this project is described below:

3.2Identification of data layers

As mentioned in the previous chapter, this project focused on five variables affecting migration of pesticides to groundwater. Therefore, all of these variables including (1) soil texture, (2) percent slope, (3) primary land use, (4) well depth, and (5) rainfall were used for the GIS approach. In the case of rainfall, however, either average annual rainfall or monthly variance of rainfall, or both of them, could be involved. It was also noted earlier that the first three variables are GIS data in vector format, whereas the last two variables are not. Thus, both well depth and rainfall need to be converted into GIS format as well. In addition, each of soil texture and primary land use, which was originally derived as individual data for Kanchana Buri, Ratcha Buri, and Suphan Buri provinces, need to be combined into one area. Following are the GIS methods used for these purposes.

Add event theme Conversion of well depth and rainfall data into GIS format can be accomplished by the method called “Add event theme”. This method is used to add a new theme to a view of any GIS project using an event table. An event table contains geographic locations such as an address, latitude and longitude coordinates, or a route location (Hohl and Mayo, 1997). In this research, however, the geographic locations of wells and weather stations that provide well depth data and rainfall data are both in the Universal Transverse Mercator (UTM) coordinate system. The event table of wells is shown in Table 5 and the event table of weather stations is shown in Table 7. As a result of “Add event theme”, well depth was converted into GIS data in the form of a point feature theme. This theme contained 1,665 points representing depths of all wells used for this project (see Figure 7). In the same manner, rainfall was also converted into two different point feature themes. Each theme contained 50 points representing average annual rainfall (AAR) and monthly variance of rainfall (MVR) of all weather stations in the project area (see Figure 8). Conversion of both well depth and rainfall data into vector format was performed by ArcView version 3.2.

3.3Manipulation of data layers

All data layers or themes used to evaluate groundwater susceptibility to contamination by pesticides need to be manipulated by the following methods. First, it is necessary to convert polygon feature themes from vector to raster data. The reason behind this conversion is that many functions, especially those involving surfaces and overlay operations, are simpler to perform with raster than vector data structure. Moreover, raster data structures are relatively easy to conceptualize as a method of representing space (DeMers, 2000). Second, point feature themes need to be interpolated into continuous grid cells,which means that they are converted from vector to raster data as well. Third, each data layer needs to be reclassified into a certain group. This is to produce a consistent scheme among all layers or themes and to limit the number of classes to the level of detail in individual data layer.

3.4Converting polygon feature themes

The process of converting a polygon feature theme from vector to raster data structure is so called "Vector conversion" or "Rasterization" (Bernhardsen, 1999). Polygons are converted to cells, and each cell falling within a polygon is assigned a value equal to the polygon attribute value. The cells are usually in rectangular or, more often, square shape called "grid cells". All grid cells are the same size, and each occupies the same amount of geographic space as any other. Common cell size varies from 10 x 10 m, 100 x 100 m, 1 x 1 km, and 10 x 10km (Bernhardsen, 1999). The smaller the cell size and the greater the numbers of cells that represent an area, the more accurate the representation of that area. In this project, each cell had a square size of 100 x 100 m or 1 hectare. The size was chosen on the basis of spatial resolution of available data and computational considerations. Vector conversion of soil, slope, and land use/land cover themes were performed using ArcView spatial analyst.

3.5Interpolating point feature themes

This process, called "Interpolation", is a function used to generate a continuous surface from sampled point values. Interpolation predicts values for cells in a raster from a limited number of sample data points. It can be used to predict unknown values of any geographic point data such as elevation, rainfall, chemical concentrations, noise levels, and so on. The assumption that makes interpolation a useful technique is that spatially distributed objects are spatially correlated; in other words, things that are close together tend to have similar characteristics. By this assumption, the values of points close to sampled points are more likely to be similar than those that are further apart (McCoy and Johnston, 2001). There are three common methods of point interpolation, namely (1) Inverse Distance Weighted (IDW), (2) Spline, and (3) Kriging. No matter which method is selected, the more sample points and the greater their areal coverage, the more reliable the results (McCoy and Johnston, 2001). However, it is important to say that having more sample points does not always improve the accuracy or quality of the output. Indeed, it quite often increases the computation time and the data volume. In some cases, too much data tends to produce unusual results because clusters of points in areas where the data are easy to collect are likely to yield a surface representation that is unevenly generalized and therefore unevenly accurate (DeMers, 2000).

3.6Reclassifying data layers

Reclassifying simply means replacing input cell values with new output cell values. There are many reasons why data need to be reclassified; for example, it is needed to replace values based on new information, to group certain values together, and to reclassify values to a common scale (McCoy and Johnston, 2001). In this project, each data layer needs to be reclassified to a common scale showing its potential to cause contamination of groundwater by pesticides. This scale consists of five classes for each data layer with a value from 5 to 1, meaning high to low pollution potential. The reclassifications of all data layers were conducted by using ArcView spatial analyst 2.0 (ModelBuilder). - The soil data layer was reclassified by its texture, which is the most permanent of all soil characteristics. According to Olson (1981), soil texture can be categorized into five groups, including coarse textured (sand, loamy sand), moderately coarse textured (sandy loam), medium textured (very fine sandy loam, loam, silt loam, silt), moderately fine textured (clay loam, sandy clay loam, silty clay loam), and fine textured (sandy clay, silty clay, clay). The soil data layer was reclassified in accordance with the categories mentioned above. Table 16 shows the reclassification of soil texture into five classes. Because of this, each cell in this layer was assigned a value varying from 5 (coarse textured) to 1 (fine textured).

Table 3.1Reclassification of the soil data layer

Soil texture	Value	Reclassification
Stony Gravelly Sand (coarse, medium, fine, very fine) Loamy sand (coarse, medium, very fine)	5	Coarse textured
Sandy loam (coarse, medium, fine)	4	Moderately coarse textured
Very fine sandy loam Loam Silt loam Silt	3	Medium textured
Clay loam Sandy clay loam Silty clay loam	2	Moderately fine textured
Gravelly clay Sandy clay Silty clay Clay	1	Fine textured

3.7Analysis of data layers

The final step of GIS application in this project is to analyze all data layers through the process called "Overlay". Overlay is a spatial operation in which a thematic layer is superimposed onto another to form a new layer. In fact, this operation can be performed both in vector and raster data; however, raster overlay is often more efficient than vector overlay. This is because attribute values in raster data are not listed in tables as in vector data, but are represented by grid cells in thematic layers. Therefore, arithmetic operations and some other statistical operations can be performed directly during the overlay process.

That is, two or more thematic layers may be combined, subtracted, multiplied, etc., to create a new layer with new value for each grid cell (Bernhardsen, 1999).

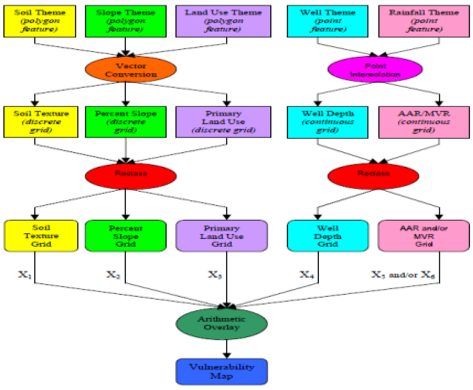


Figure 3.1 Flow chart of GIS methods used in this project

3.8Application of Statistical Method

Correlation was chosen as the statistical method in this project by two reasons. First, it helped identify weighting schemes for overlay analysis. By means of correlation, the relationship between each data layer and concentrations of pesticides in groundwater could be found. And correlation coefficients, both Pearson product-moment (r) and Spearman rank (rs), derived from this method were used as the criteria to determine the weight of each data layer. Second, correlation was used to compare the vulnerability scores derived from each map with groundwater quality data derived from actual observations. This is to test the relationship between a produced vulnerability map and the actual data. If correlation coefficient is close to 1, it means that the vulnerability map produced from a GIS is highly significantly correlated to the actual groundwater quality data, and vice versa.

In this project, correlation was conducted using a statistical software package called "Statistical Analysis System (SAS)". In fact, Pearson product-moment correlation is a parametric statistic, which is more powerful than Spearman rank (nonparametric) correlation. However, Pearson parametric correlation has stringent assumptions underlying its use, e.g., normal distribution of data and homogeneity of variances (Beitinger, 1999). Because of these requirements, many researches including this project are likely to use Spearman rank (nonparametric) correlation.

IV. RESULTS AND DISCUSSION

4.1 Vector Conversion

Three polygon feature themes (i.e., soil, slope, and land use/land cover) were converted from vector to raster data structure. The results derived from this process were three discrete grids representing soil texture, percent slope, and primary land use of the project area. Each of them contained a number of cells with the size of 100 x 100 m or 1 hectare. Figure 12 shows the map of soil texture grid, which is categorized into the following groups: clay, gravelly clay, clay loam, sandy clay loam, loam, silt loam, very fine sandy loam, sandy loam, sand, gravelly, stony, and others. The last group represents areas occupied by any categories rather than soil such as water bodies and rock land. It is evident that the lowland east and southeast of the project area is mainly occupied by clay together with other soil textures including loam, silt loam, sandy loam, sandy clay loam, and very fine sandy loam. Highland area in the west and southwest, on the other hand, are occupied mostly by stony with some clay and sand. Figure 13 is the map of percent slope grid that is divided into eight classes as follow: 0-5%, 5-10%, 10-15%, 15-20%, 20-25%, 25-30%, 30-35%, and greater than 35%. It shows that the flood plain lying from the eastern to southeastern parts has a slope ranging from 0-5%. And slope between 10% to greater than 35% can be found in the mountainous area especially in the northwest, west, and southwest of the project area. However, there are small valleys with 0-5 % slope located in between high mountains of this area. Figure 14 represents the primary land use grid, which is shown as the subgroups of major land use called "group land use". The group land use in this grid consists of paddy field, field crops, orchards, horticultures, evergreen and deciduous forests, natural water bodies, etc. Rice, which is a major crop of the project area, occupies most part of flood plain in the east, whereas other main crops such as sugarcane, corn, and cassava occupy the area in between paddy field in the eastern part and forest in the western and southwestern parts of the project area.

4.2 Point Interpolation

This process generates a continuous grid from sampled point values in vector data. The continuous grid contains a number of predicted values in which each of them represents an attribute value for a cell. Three methods (i.e., IDW, Spline, and Kriging) were applied for interpolating well and rainfall feature themes in this project. However, Spline interpolation was chosen for further operations for the following reasons. First, Spline is generally the better choice when dealing with unevenness in the distribution of sample points like well and rainfall data. Second, spline controls how tightly the surface conforms to the sample points and the smoothness or stiffness of the resulting surface. And third, it was found that Spline created more accurate results than the other two methods. This can be seen in Table 24 that compares the predicted values derived from each method with the actual values of well depth. It is apparent that all methods generated some of the predicted values that are not equal to the actual values. Among these, Spline interpolation generated more closely approximated observed data.

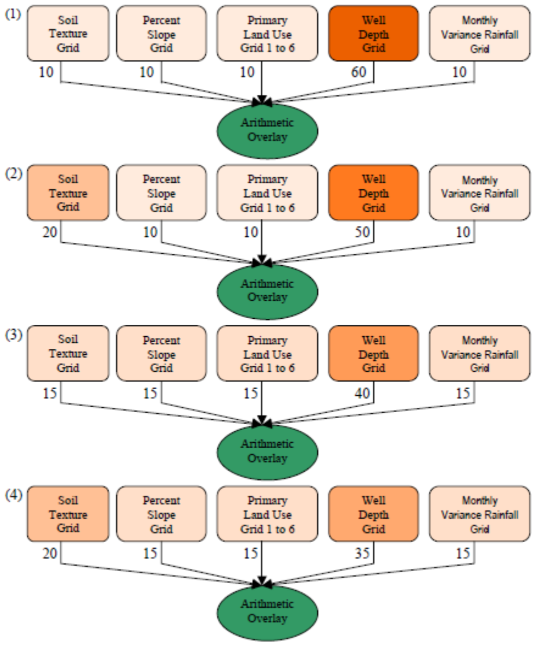


Figure 4.1 Flow chart of arithmetic overlays conducted by four weighting schemes

4.3 Comparison of Vulnerability Mapand Groundwater Quality Data

The purpose of comparing a vulnerability map and groundwater quality data is to test the relationship between vulnerability scores derived from a produced map and pesticide concentrations in groundwater derived from actual observations. Two data sets used for this purpose are shown in Table 32, which consisted of (1) concentrations of each pesticide found in groundwater from 90 wells in the project area and (2) vulnerability scores of the cells or mapping units where those wells are located.

From these data, a number of correlations were conducted in which each of them identified the relationship between concentrations of each pesticide and vulnerability scores of each map (see an example in Table 33). The results, in terms of Pearson product-moment and Spearman rank correlation coefficients (r and rs), are illustrated in Table 34. It is noted that only the correlation coefficients whose probabilities are less than or equal to 0.05 (Pr and/or Prs $\leq$ 0.05) were taken into consideration for comparing the vulnerability maps with the actual groundwater quality data.

4.4 Vulnerability Model

In general terms, a model is a representation of reality. It helps describe or predict how things work in the real world. According to McCoy and Johnston (2001), models can be divided into two main types: (1) representation models that represent the objects in the landscape, and (2) process models that attempt to simulate processes in the landscape.The process models are used to describe processes and also to predict what will happen if some action occurs. There are many types of process models to solve a wide variety of problems, i.e., suitability model, distance model, hydrologic model, and surface model. The surface model is relevant to this project because it can be used to predict the pollution level for various locations in a certain area.

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This project focused on using geographic information systems (GIS) technology to assess groundwater pollution potential by pesticides in central Salem. Specifically, the main objectives of the project were: (1) to produce maps of the project area showing relative vulnerability of groundwater to pesticide pollution, (2) to compare actual groundwater quality data with the vulnerability maps, and (3) to develop a model for predicting the degree of susceptibility of groundwater to contamination by pesticides. To achieve this goal, a variety of data were collected from many relevant agencies of the royal Thai government.

These included soil texture, percent slope, primary land use, well depth, rainfall, and groundwater quality data of the project area. A number of GIS methods were used to manipulate the data mentioned above. Soil texture, percent slope, and primary land use were converted from polygon features to discrete grids by "vector conversion". At the same time, well depth and rainfall were converted from point features to continuous grids by "point interpolation". These five data layers, which affect migration of pesticides to groundwater, were then reclassified to a common scale showing the potential to cause contamination of groundwater by pesticides. This scale consisted of five classes for each data layer with a value from 5 to 1, meaning high to low pollution potential. Finally, all of the reclassified data layers were superimposed by the process called "Arithmetic overlay" to yield a composite vulnerability map. This was the map showing relative vulnerability of groundwater to contamination by pesticides in the project area. It is noted that four weighting schemes (i.e., 60:10:10:10:10, 50:20:10:10:10, 40:15:15:15:15, and 35:20:15:15:15) were applied during the overlay operation. These schemes were designed by conducting correlations between two data sets as follows: (1) pesticide concentrations found in groundwater from 90 wells in the project area, and (2) values or classes assigned to the cells of each data layer placed at the same location with those wells. The schemes represented the weights or influence factors for well depth, soil texture, monthly variance of rainfall, primary land use, and percent slope, respectively.

Well depth played the most important role and was assigned the highest weight. There were a number of arithmetic overlays operated by these four weighting schemes. And these operations were performed separately for each pesticide (i.e., 2,4-D, atrazine, carbofuran, dicofol, endosulfan, and the group of banned pesticides). The results derived from all operations were maps showing relative vulnerability of groundwater to contamination by these pesticides in the project area. Vulnerability maps produced from the GIS technique were compared to groundwater quality data of the project area. This is to test the relationships between those maps and available data derived from actual observations.

By this reason, it is concluded that the first weighting scheme would be the better choice than the others for producing a vulnerability map of the project area. Three final maps of the project area were produced using the first option of weighting schemes. Each of them represents the degree of susceptibility of groundwater to contamination by endosulfan, atrazine, and total BHC and heptachlor & heptachlor epoxide. The maps show that about 83 to 88% of the entire project area is occupied by medium susceptibility, 7 to 8% by high susceptibility, and 4.9 to 8.7% by low susceptibility. Among these, the lowland especially in the eastern and southeastern parts tends to have lower susceptibility of groundwater contamination than other parts in the project area. These maps are therefore helpful for policy makers or administrators of government agencies to prioritize areas vulnerable to pesticide pollution. Once the areas are prioritized, groundwater monitoring programs and protective measures can be focused particularly on the areas with high susceptibility to contamination by pesticides.

5.2 Recommendations

Following are a list of recommendations for further studies involving the assessment of vulnerability of groundwater to contamination by pesticides:

(1) In this project, well depth was chosen as one of the data layers used to evaluate the vulnerability of groundwater to pesticide pollution. This type of data indicates how far a pesticide will be carried through soil media from land surface to groundwater level. However, well depth does not represent the actual distance between land and groundwater level. This is because wells are drilled below first encountered groundwater levels. The greater the depth of a well below groundwater, the more protection it has against contamination. To avoid this problem, it is recommended to use depth of aquifer as another alternative. This type of data is better than well depth because it represents the actual distance between land surface and an aquifer.

There is another reason why depth of aquifer should be used instead of well depth. That is, well depth is a kind of irregularly distributed data. A cluster of wells is usually found in some areas like domestic or agricultural land, whereas only a few of them can be found in forested areas. Because of this, the result of interpolating well feature theme may not be accurate in areas having a few sample points.

(2) Primary land use was the only anthropogenic factor involved in the project. It is therefore recommended that not only primary land use but also other anthropogenic factors should be taken into account. The amount of water used in irrigation is an example of another anthropogenic factor. This type of data can be used in the assessment because it affects the movement of pesticides into groundwater. The more the water used in irrigation, the greater the opportunity of pesticides reaching groundwater. It is anticipated that taking anthropogenic factors into the assessment process may yield more accurate results.

(3) Physical properties of pesticides are important in assessing groundwater vulnerability because they are associated with leaching and persistence. Therefore, it is recommended for future studies to take this factor into consideration. Solubility in water is an example of those physical properties. Basically, pesticides with high solubility in water have greater opportunity to leach to groundwater than those with low solubility. Atrazine, for example, is highly soluble in water when compared to DDT and dieldrin. Because of this, it tends to contaminate groundwater more than the other two chlorinated hydrocarbon insecticides. Another example of physical properties of pesticides is Octanol-water partition coefficient (Kow).

It is the ratio of a pesticide's concentration in the octanol phase to its concentration in the aqueous phase. This property is generally indicative of a pesticide's ability to accumulate in fatty tissues rather than remain in water. The higher the value of Kow, the greater the tendency of a pesticide to adsorb to soil containing organic carbon or to accumulate in biota. Therefore, pesticides with high Kow (e.g., DDT and dieldrin) have lesser opportunity to leach to groundwater than those with low Kow such as atrazine.

Table 7.1 compiles a list of ten pesticides used in this project with their physical properties relating to potential for groundwater contamination. In addition, the scores showing physical property hazard of these pesticides have been proposed. In fact, this is only a guideline to develop a physical property hazard scheme for future studies. In this project pesticide concentrations in groundwater was the data used to

identify weighting schemes for overlay operations and for the model, and to compare with vulnerability maps produced from the GIS. If this type of data is not available, however, both purposes can be accomplished using data derived from actual observations of pesticide concentrations in the vadose zone. It is obvious that pesticides in the vadose zone have a chance of moving downward to groundwater if they are highly soluble in water and not adsorbed by soil particles or soil organic matters. Therefore, the higher the pesticide concentrations in this zone, the higher the chance of groundwater to be polluted.
It is recommended that more observations of pesticide concentrations in the vadose zone should be designed in order to obtain more accurate results when using this data to achieve the purposes mentioned above.

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