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EXPERT SYSTEM FOR PREDICTING GROUNDWATER POLLUTION POTENTIAL FROM THE IMPACT OF AGRICULTURAL ACTIVITIES

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Abstract

Degradation of groundwater quality due to the application of nitrogen fertilizers and pesticides in intensive farming, can take place over large areas from diffused sources such as deep percolation from intensively farmed fields into the underground environment. Though inconspicuous and out of sight, groundwater forms a very important part of the environment. Special care must now be exercised to protect it against possible pollution for the benefit of present and future generations. An expert system for predicting the impact of intensive agriculture on groundwater pollution potential was established by using CLIPS (NASA's Jonson Space Centre). In the case of groundwater environmental impact assessment, knowledge base could be extracted from Ministry of Agricultural and Rural Development Malaysia, Food and Agriculture Organization, Environmental Impact Assessment reports, established literature and domain experts for preparing an expert system skeleton. The expert system could predict the groundwater pollution potential under several conditions of agricultural activities and existing environments, therefore, the appropriate mitigation and protection measures can be applied efficiently. Using a sample of special care intensive farms, a policy scheme combining the control of pesticide and nitrogen use can be assessed.

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INTRODUCTION

In Thailand and Malaysia groundwater is often the best and sometimes the only source of cheep potable water. It supplies over 50% and 25 % of drinking of the water requirements in the nation[1]. It is attractive as a supply option because it is often conveniently available close to where the water is required, it has excellent natural quality, which is generally adequate for potable supply with little or no treatment, and the capital costs of development are relatively low.

The extent of land devoted to agricultural production, the unusual pricing system in place, the intensity and efficiency of modern farming, ranching, and other animal production systems all contribute to the complexity and diversity of the system. This intensification of agricultural production can lead to serious deterioration in groundwater quality in some pedological, geological and climatic conditions. Agriculture production has a great potential to adversely affect the environment, most particularly from nonpoint sources, hazardaus waste disposal, habitat destruction and inlocalized areas, nuisanceodours. Nonpoint source pollution of groundwater by agricultural chemicals is an increasing environmental problem. According to the congressional research service [2] agricultural activities are the most pervasive contributors to nonpoint source pollution of groundwater. The sources of nonpoint pollution is more ambiguous and, by definition ,can not be related to a specific point. A major example of this type of pollutant introduction is the application of pesticides and fertilizers to agricultural fields. A comprehensive list of nonpoint sources of groundwater pollution would be extensive, with many pollutants of local or regional significance. The two most commonly determined pollutants are nitrates and pesticides, probably because of their adverse effects on human health, together with increasing salinity in the more arid environments[3]. This has impacts in terms of the continued used of aquifers for human water supply in neighboring towns and in the rural areas themselves. Under some condition, it can affect the sustainability of agricultural irrigation itself. The information on expected pollutants and release modes from a given source will aid in planning the initial responses to the release (e.g., data collection, sampling, site characterization). In addition, this information will be valuable when considering groundwater protection strategies for a potential source.

The objective of this study was to predict potential groundwater quality problems resulting from the application of nitrogen fertilizers and pesticide to crops by combining information on the availability of the potential pollutant with the assessment of the pollution vulnerability of study area by using an expert system.

The outcome of this study is a production of an expert system (new software) which can be used for groundwater pollution impact assessment to aid in predicting the impacts due to agricultural activities.

METHODOLOGY

A study was carried out from several sources of established literature and domain expert to get knowledge base and rule base for expert system construction. The detail of methodology are following : An expert system for predicting the impact of intensive agriculture on groundwater pollution potential, was developed by using CLIPS (C Language Integrated Production Systems.), a computer software developed by NASA/Lyndon B. Johnson Space Centre. To predict groundwater pollution potential, groundwater vulnerability methodology was combined with information on cropping areas, recommended nitrogen fertilizer, and pesticide application rates, which were incorporated into this expert system. To minimize and compensate groundwater pollution impacts, proposed mitigating measures will be introduced by using the knowledge bases from Ministry of Agricultural and Rural Development Malaysia, Food and Agriculture Organization, Environmental Impact Assessment (EIA) reports submitted to Department of Environmental (DOE), established literature and domain experts.

EXPERT SYSTEM APPROACH

Expert systems are typically classified according to the type of problem to which they are applied. Categories of expert systems include interpretation, diagnostic, prediction, design, planning, control, repair, debugging, monitoring, and instruction. The three most common applications of expert systems in groundwater contamination studies are interpretation, diagnostic and prediction [4]. Regarding this study, a groundwater pollution potential index, produced by using groundwater vulnerability methodology was combined with information on cropped areas, recommended nitrogen fertilizer and pesticide application rates in the Peninsula Malaysia, these processes were applied by groundwater pollution expert system (figure 1).

APPLIED MODEL FOR RULE BASE OF EXPERT SYSTEM

1. Existing groundwater environment

Extensively used, parametric procedures are based on a very limited set of independent means of different evaluation schemes, i.e. matrix, rating, point counting, etc. Weight or multipliers are sometimes used to increase the relevance of some aspects or parameters in relation to specific types or forms of pollution. Factor identification, assignment of weights, establishing scaling functions, development of numerical indices or classification schemes are all largely subjective operations where sound professional judgment is needed to reach meaningful results. There are several types of models to predict groundwater pollution potential presently, there is no the best model for using in general because suitability of any models depends on existing environments of study area [5]. In case of this study groundwater vulnerability method which has been being very well known in evaluating impacts of groundwater environment [6,7], was selected. A very common empirical procedure is the numerical rating scheme called DRASTIC [8], acronym standing' for the factors used in vulnerability evaluation :

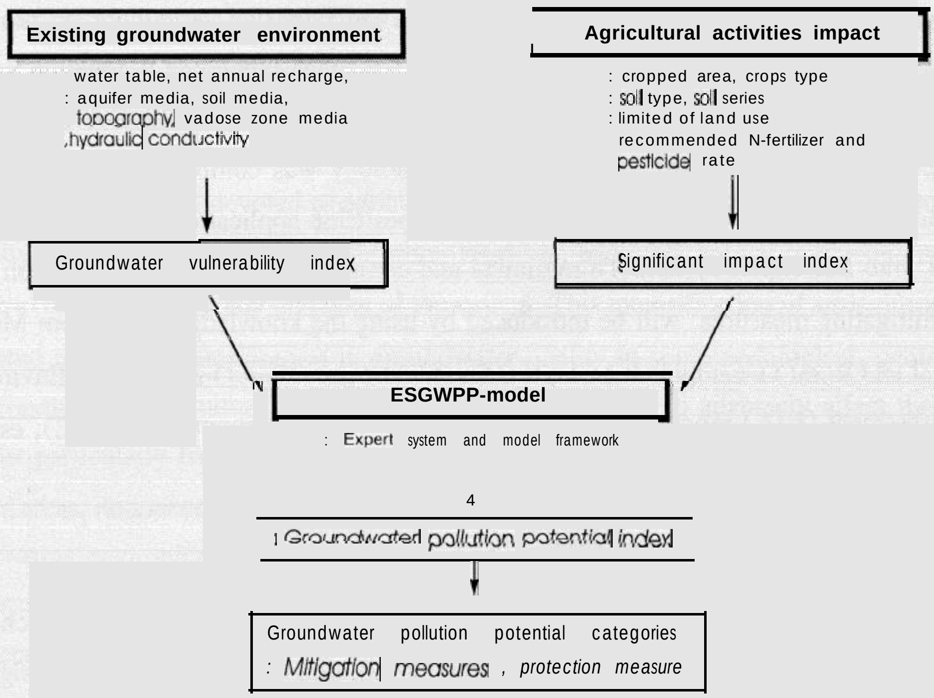

Figure 1 Flow chart of groundwater pollution expert system for evaluating groundwater quality problem.

depth to water table (D), recharge rate (R), textural properties of the aquifer (A), soil properties (S), surfaces topography (T), impact on vadose zone (I), and hydraulic conductivity of the aquifer (C). The procedure consists of the computation of a ranking index from quantitative factors which have been weighted and summed. Each factor has been divided into ranges or significant types. The latter have been assigned a typical or variable rating for each factor.

The general additive model for determining groundwater vulnerability potential (GVP) is

$$GVP = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \quad (1)$$

where subscripts R and W stand for rating and weight, respectively.

The weights assigned to groundwater vulnerability factors are indicated. In the agricultural case, the most prevalent role played by soil media and topography and the lower importance assigned to hydraulic conductivity of aquifer should be noted. The groundwater vulnerability procedure is a representative example of how relevant factors pertinent to the different aspects of potential migration processes may be associated to produce evaluations of vulnerability. In this hydrogeologically based method, great attention is paid to flow condition, both in the unsaturated and saturated zones, and to other physical factors controlling potential movement of contaminants. The soil zone, although included, is not directly considered for its attenuation role.

2. Agricultural activity impact

The information on cropping areas, recommended nitrogen fertilizer, and pesticide application rates in the study area , which will be predicted were summed to give the total rai of planted crop land within the study area. The total amount of nitrogen fertilizer and pesticide applied to a specific crop within a study area was computed as :

$$Ni = Ci \times Fi \qquad (2)$$

$$Pi = Ci \times Ei \qquad (3)$$

Ni, Pi are the nitrogen fertilizer and pesticide applied to crop (i) in study area = kg, liter

Ci is the area of crop (i) planted in the study area = rai

Fi , Ei are the recommended nitrogen fertilizer application and pesticide rate for crop (i) in agricultural district or in the study area = kg/rai, liter/rai

The results were summed to give the estimated total nitrogen fertilizer (kg) and pesticide (liter) applied to the study area in existing environment of the study area. This estimate for the study area was divided by the total rai planted in that study area to yield the estimate average nitrogen fertilizer and pesticide application rate (N and P) for the study area in kg/planted rai and liter/planted rai. This estimate of nitrogen fertilizer application rate represents an average for the study area and dose account for spatial variability in cropping patterns within individual study area. The resulting data represent the estimated average nitrogen fertilizer and pesticide application rate of the study area. The knowledge base about nitrogen and pesticide application rate derived from the Soil and Analytical Service Brach Division of Agriculture, Ministry of Agricultural and Rural Development Malaysia, and Food and Agriculture Organization [9,10]. Nevertheless, nitrogen fertilizer and pesticide application rate of each plant are evaluated by using the potential maximum of adverse impact on groundwater quality. This mean that it is the highest rate of nitrogen fertilizer applied for each plant types and each plant varieties, those can be grown on each of study area. In addition, there has been a consideration on the highest possibility of each plant type which can be planted in the maximum of the same study area during the year or cropping system. The general addition model for determining significant agricultural impact potential index (S) was incorporated in the expert system, as show in equation 4.

$$S = N_W N + P_W P \qquad (4)$$

It consist of nitrogen fertilizer and pesticide application rate. Both factor related to significant impact for groundwater pollution potential, where sub script $_w$ standard for weight, N (estimate average nitrogen fertilizer application rate) and P (estimate average pesticide application rate).

EXPERT SYSTEM COMPONENT

Basically, an expert system for predicting groundwater pollution potential is made up of three main components, namely the *knowledge* base which is a store house information, organized in the some usable fashion, an inference engine which is a set of strategies for using the knowledge in the knowledge base, and the user interface which is a collection of methods by which the program will interact with the end user. Reasoning will be replaced by the inference engine and the knowledge base section is identical to expert's knowledge as well. The two basic elements in the main structure of the expert system, i.e. the inference engine and the knowledge base were combined with the working memory, facts about the problem were entered by the user during the consultation. Enhancement of the system can be done by connecting all the elements in the structure with a user interface[11]. This interface interprets the user and the advice, consultation or modification of facts entries through the working memory.

RESULTS AND DISCUSSION

GROUNDWATER POLLUTION EXPERT SYSTEM SKELETON

In this expert system developed structure with using CLIPS, CLIPS is an OPS-like forward chaining production system written in ANCI C. The CLIPS inference engine includes truth maintenance, dynamic rule addition, and customizable conflict resolution called COOL (CLIPS Object Oriented Language) which is directly integrated with the inference engine. This expert system will be developed using a modular programming technique and window capabilities "Toolbox" facilities will be use extensively especially for the input output operations. CLIPS provide a cohesive tool for handling a wide variety of knowledge which support for three different programming paradigms: Rule based programming ,Object oriented programming and The procedural programming[12]. The skeleton of the expert system for groundwater is divided into five main parts : 1 Introduction, 2 Concept, 3 Model, 4 Mitigation and 5 Monitoring (figure 2). Both the introduction and concept parts will help the EIA proponents to produce existing groundwater introduction and to fill-in the groundwater parts of matrix. The last three main parts; i.e. model, mitigation and monitoring will be incorporated into the expert system to predict the future situation of groundwater and to propose the possible mitigation measures, so that the proposed adverse impacts to groundwater can be minimized appropriately.

EXPERT SYSTEM RULES

The results of several sources of established literature and domain expert are then translated in to rules, being incorporate in the expert system. The expert rules will be presented in the form of "IF-THEN". The example of the set of rules are shown in the appendixes.

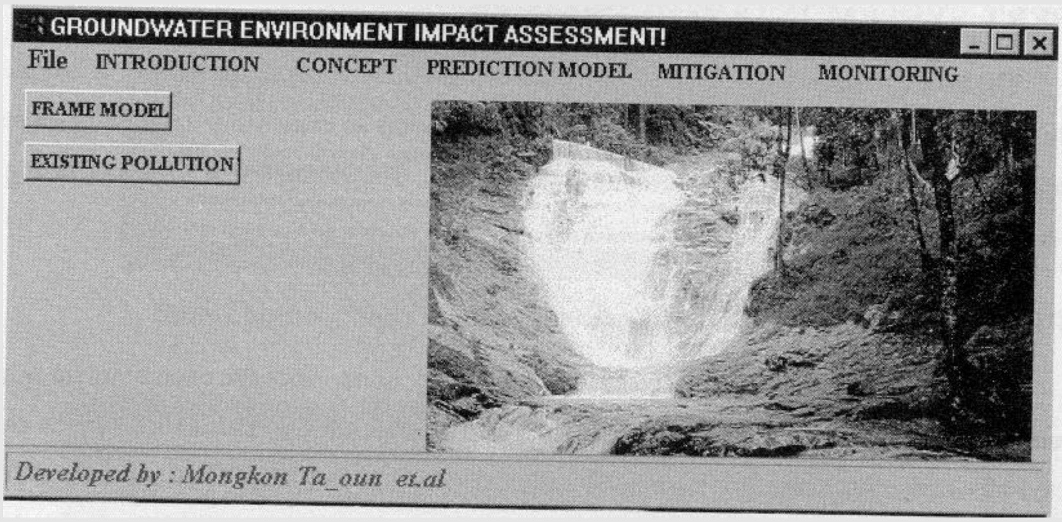

Figure 2 The main of an groundwater pollution expert system skeleton.

Expert system identification

Numerically, A groundwater pollution potential index was the result of the multiplication of the groundwater vulnerability index by the recommended nitrogen fertilizer and pesticide applied or significant impact index (S), these processes are applied by groundwater pollution expert system.

Groundwater pollution potential *index* = $((D_w D_s + R_w R_s + A_w A_s + S_w S_s + T_w T_s + I_w I_s + C_w C_s))(S)$

= (Pollution vulnerability potential) x (Average N-fertilizer and pesticide application rate for the study area)

= (Groundwater vulnerability index) x (Significant impact index)

The groundwater pollution potential index composes of combination with numerical values the zero value indicated the study area where no cropping. The high values indicated a higher potential for groundwater pollution from nitrogen fertilizer and pesticide. These values were grouped into 4 pollution potential categories for agricultural activities impact (nitrogen fertilizer and pesticide) :

(1) very low/negligible groundwater pollution potential,

(2) low groundwater pollution potential,

(3) moderate groundwater pollution potential, and

(4) high groundwater pollution potential.

Using the groundwater pollution expert system, this approach was modified [13] and 14]. The very low category represents the study areas where no cropping. The remaining three categories were subdivided on the basis of 10%, 60% and 30% distribution of the low, moderate, and high pollution potentials, respectively.

EXPERT SYSTEM INTERFACING

The user interface of an expert system goes beyond traditional user interfaces. It is typically highly interactive, usually with the "help" facility, and contains an explanation facility for illustrating or depicting the inference or reasoning process used. The examples of user interfacing are shown in the appendixes.

EXPERT SYSTEM PRODUCT

Developed expert system can be used easily by any users, since the expert system is setup for running in windows, and structure frame of expert system consisted of choices which can be selected by users, telling user by loading data files, calculating data base, thus, user can get more information of groundwater pollution impacts by project activities, mitigation measure , groundwater data base, groundwater standard ,and general information of groundwater evaluation. The outcome of expert system will display on monitor, file output, pictures, graphics, sound and printed out details. Using expert system for predicting groundwater pollution potential, there will be the questions and possible answers to choose. Just key in the answer number of derived question as shown in figure 3 completely, then the expert system will evaluate the data by the combination of these question. Thus, the results of the evaluation will be shown in the figure 4 and mitigation measures and management control will be shown in figure 5 where the evaluation of groundwater pollution potential is high risk.

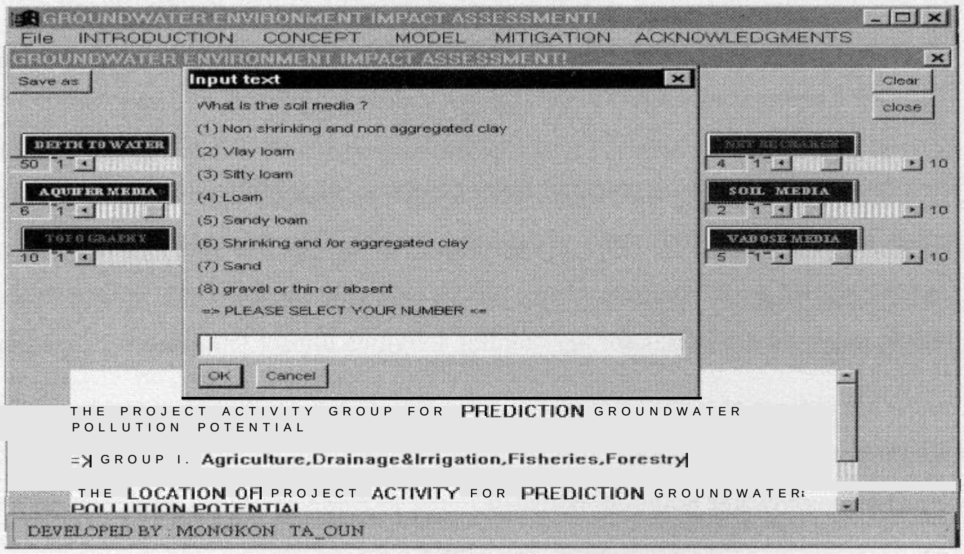

Figure 3 An Example question in groundwater vulnerability model: What is soil media tending to affect on groundwater pollution potential? (possible answers are shown as choices on screen)

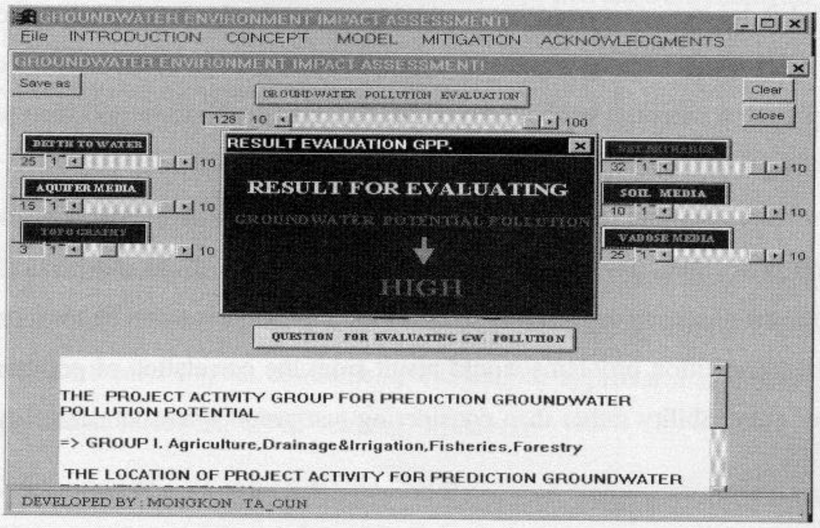

Figure 4 Example of results of evaluating groundwater pollution potential.(High)

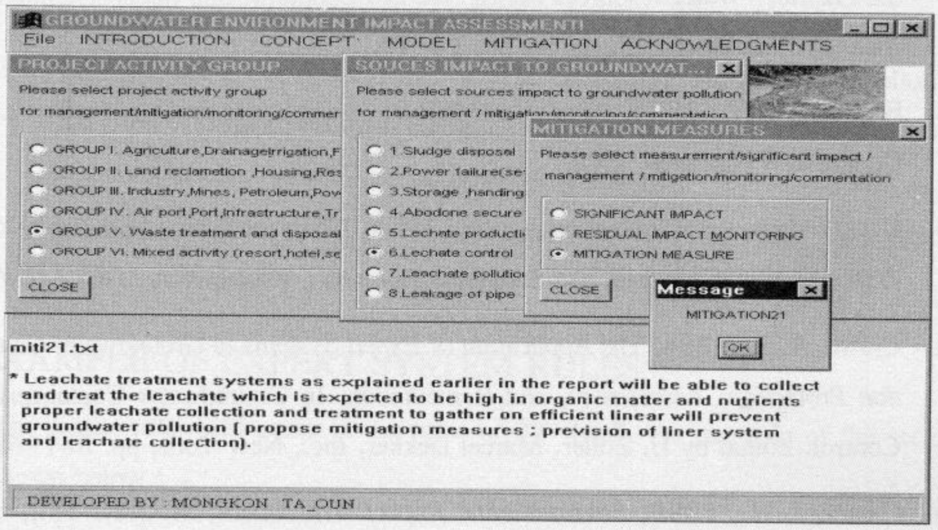

Figure 5 An example of mitigation measure for minimizing groundwater pollution

CONCLUSION

The skeleton of an expert system for predicting the impact of nitrogen fertilizer and pesticide from agricultural activities on groundwater pollution potential, is divided into five main parts. Both introduction and concept parts will help to produce existing groundwater introduction. The last three main parts; i.e. model, mitigation and monitoring will be incorporated into the expert system to predict the future situation of groundwater and to propose the possible mitigation measures. The expert rules will come in the form of “if-then”. Knowledge bases extracted from Food and Agriculture Organization ,Ministry of Agriculture and Rural Development Malaysia ,EIA reports, several sources of established literature and domain experts were used preparing the expert system skeleton. The groundwater pollution expert system was used to assess the groundwater pollution potential from nitrogen fertilizer and pesticide applied to cropped area. The groundwater pollution potential index was generated by combining groundwater vulnerability index (the vulnerability of on study area) with the significant agricultural impact potential index. Four categories of groundwater pollution potential were identified base on the groundwater pollution potential index as follow very low, low, moderate and high. The results of prediction, generally, indicate that groundwater is most vulnerable to nitrate and pesticide leaching where : the soil and unsaturated zone are thin and permeable, several crops a year are grown, fertilizer and pesticide inputs are high. The basis for the approach used in this study was the hypothesis that a better screening tool for identifying potential pollution problems would result from the correlation of pollutant availability with groundwater vulnerability rather than considering just groundwater vulnerability.

REFERENCES

1. Das Gupta, A., 1991, "Study on Groundwater Quality and Monitoring in Asia and the Pacific," Water resources *Series* No. 70, Economic and Social Commission for Asia and The Pasific, Bangkok, pp. 13-9 9.
2. Feliciano, D.V., 1986, Agricultural Effects on *Groundwater Quality*, The Library of Congress,Washington, DC.
3. U.S. Environmental Protection Agency, 1984, Nonpoint *Source Pollution in the U.S.*, Office of Water ,Criteria and Standards Division , Washington , DC.
4. Crowe. A. S., 1994, The Application *of Expert Systems* to Groundwater Contamination Protection, Assessment, and Remediation, In Groundwater Contamination and Control. Edited by U. Zoller, Marcel Dekker, Inc., New York, pp. 567-584.
5. Canter, L.W., 1996, Environmental Impact Assessment, McGraw-Hill, Inc. New York.
6. Rosen, L., 1994,"A Study of the DRASTIC Methodology with Emphasis on Swedish Conditions," Groundwater, Vol. 32, No. 2, pp. 278-285.
7. Rundquist,D.C., Rodekohr,D. A., Peters, A.J., Ehrman, R.L., and Murray, G. 199 1. "Statewide Groundwater-Vulnerability Assessment in Nebraska Using the DRASTIC/GIS model," Geocarto-International, Vol. 6, No. 2, pp. 51-58.
8. Aller, L., Bennet, T., Lehr, J.H., Petty, R.L., and Hackett, G. 1985, DRASTIC : *a* Standardized *System for* Evaluating Groundwater Pollution Potential *Using Hydrogeologic* Setting, EPA (Environmental Protection Agency) Report 00 /2 - 8 7 /0 3 5.
9. FAO., 198 3, Fertilizer Use Under *Multiple* Cropping Systems, FAO fertilizer and plant nutrition bulletin 5, Food and Agriculture Organization of the United Nations.

10. Kanapathy, K. 1976, Guide to Fertilizer Use *in Peninsula Malaysia,* Soil and Analytical, Service Brach Division of Agriculture, Ministry of agriculture and rural development Malaysia.

11. Giarrantano, J., and Riley, G. *1994, Expert system : Principles and Programming,* PWS Publishing Co., Boston.

12. Daud, M., Omar, H., and Aziz, A.A., 1996, "EIA Reports:CLISP for Expert System," *Proceeding of the first seminar on a comprehensive expert systems for environmental impact assessment, evaluation, approval and monitoring,* University Pertanian Malaysia, UPM serdang, Malaysia.

13. Alexander, W.J., Liddle S.K., Mason R.E., and Yeager, W.B., *1986, Groundwater Vulnerability Assessment in Support of the First Stage of the National Pesticide* Survey, Research Triangle Park, Research Triangle Instute, Contract No.EPA 68-01 -6646, U.S.Environmental Protection Agency, Wasingtao, D.C.

14. Halliday, S.L., and Wolfe, M.L., 1991, "Assessing Ground Water Pollution Potential from Nitrogen Fertilizer Using a Geographic Information System," *Water Resources Bulletin,* Vol. 27 ,No.2, pp. 237-245.

APPENDIXES

THE EXAMPLE OF EXPERT SYSTEM RULES

The expert rules will come in the form of "if-then". An example of the set of rules is shown below :

(defrule read-input

(initial-fact) =>

(printout t "What is the depth to groundwater /the water table depth? (1) level (A) < 3 meter [choose] "crlf) (bind ?ans (read)) (if (eq ?ans 1) then (bind ?d 50))

(printout t "What is the net annual recharge ? (1) level (A) > 2 50 mm/y [choose] " crlf) (bind ?ans (read)) (if (eq ?ans 1) then (bind ?r 36))

(printout t "What is the aquifer media ? (1) Basalt or sand and gravel [choose] "crlf) (bind ?ans (read)) (if (eq ?ans 1) then (bind ?a 30))

(printout t "What is the soil media ? (1) gravel or thin or absent [choose] "crlf) (bind ?ans (read)) (if (eq ?ans 1) then (bind ?s 20))

(printout t "What is the topography / the slope and slope variability of the land surface ? (1) level (A) < 2% [choose] "crlf) (bind ?ans (read)) (if (eq ?ans 1) then (bind ?t 10)) (printout t “What is the impact of the vadose zone media factor? (1) Sand and gravel [choose]“ crlf) (bind ?ans (read)) (if (eq?ans 1) then (bind ?i 45))

(printout t “What is the hydraulic conductivity of the aquifer? (1) level(A) > 100 m/d [choose] “crlf) (bind?ans (read)) (if (eq?ans 1) then (bind?c 30))

(printout t “How much N-fertilizer application rate(estimate average kg/rai) for the study area are there? (bind? N (read)) = 100))

(printout t “How much pesticide application rate (estimate average liter/rai) for the study area are there? (bind ? P (read)) = 50))

(bind ?sum ((+ ?d ?r ?a ?s ?t ?i ?c)) (+?n ?p))

(if (>= ?sum 2030) then

(printout t “GW pollution potential = Very high “crlf))

Translation :

IF Data are read from facts

THEN 1. The depth to groundwater/the water table depth < 3 meter

2. The net annual recharge >250 mm/y

3. The aquifer media = basalt or sand and gravel

4. The soil media = gravel or thin or absent

5. The topography or the slope and slope variability of the land surface < 2%

6. The impact of the vadose zone media factor = san and gravel

7. The hydraulic conductivity of the aquifer >100 m/d

8. The estimate average of N-fertilizer application rate = 100 kgN/rai

9. The estimate average of pesticide application rate = 50 liter/rai

RESULT : The groundwater pollution potential index = 2 2 10

RESULT TO PREDICT

IF The groundwater pollution potential index = 2030

THEN The agricultural activity of this study area is risk to high Groundwater pollution potential, Please go to mitigation 3.

These rules will eventually be detailed out when the knowledge from all the three sources (domain experts, established literature, and field research) are made to complement each other. The skeleton will have some details that write out in its memory related existing groundwater conditions in different situation. The expert system will also be constructed to accommodate modules that could model groundwater situation in the near future.

THE EXAMPLE OF EXPERT SYSTEM INTERFACING

The users can use the screen and the keyboard to interface with the system. The expert system will ask the user with the questions and display the set of possible answers to be selected as shown in the list below :

Question 1.

What is the depth to groundwater /the water table depth ?

Possible answer :

1. The depth to groundwater/the water table depth < 3 meter
2. The depth to groundwater/the water table depth 3-5 meter
3. The depth to groundwater/the water table depth 5-10 meter
4. The depth to groundwater/the water table depth 10-15 meter
5. The depth to groundwater/the water table depth 15-25 meter
6. The depth to groundwater/the water table depth 25-35 meter
7. The depth to groundwater/the water table depth > 35 meter

Question 2 : *What is the net annual recharge ?*

Possible answer :

1. Net annual recharge < 50 mm/y
2. Net annual recharge 50-100 mm/y
3. Net annual recharge 100-150 mm/y
4. Net annual recharge 150-250 mm/y
5. Net annual recharge > 250 mm/y

Question 3 : *What is the aquifer media ?*

Possible answer :

1. Massive shale
2. Metamorphic/Igneous/Weathered metamorphic/ Igneous
3. Glacial till
4. Massive sandstone or Limestone Bedded sandstone, limestone, and sequences
5. Basalt or Sand and grave
6. Karst limestone

Question 4 : ***What is the soil media ?***

Possible answer :

1. Non shrinking and non aggregated clay
2. Clay loam
3. Silt loam
4. Loam
5. Sandy loam
6. Shrinking and/or aggregated clay
7. Sand
8. Gravel or Thin or absent

Question 5 : What ***is the topography/the slope and slope variability of the land surface ?***

Possible answer :

1. Slope variability of the land surface < 2 %
2. Slope variability of the land surface 2 - 6 %
3. Slope variability of the land surface 6 - 12 %
4. Slope variability of the land surface 12 - 18 %
5. Slope variability of the land surface > 18 %

Question 6 ***: What is the impact of the vadose zone media factor ?***

Possible answer :

1. Confing layer
2. Silt clay or Shale
3. Limestone orMetamorphic / Igneous
4. Sandstone or Bedded Limestone ,Sandstone, and Shale or Basalt or Sand and grave / with significant silt clay
5. Sand and gravel
6. Karst limestone

Question 7 : ***What is the hydraulic conductivity of the aquifer?***

Possible answer :

1. Hydraulic conductivity < 1 m/d
2. Hydraulic conductivity 1 - 5 m/d
3. Hydraulic conductivity 5-20 m/d

4. Hydraulic conductivity 20-50 m/d
5. Hydraulic conductivity 50-100 m/d
6. Hydraulic conductivity >100 m/d

Question 8 : How much nitrogen fertilizer application rate (estimate average kg/ planted *rai) are there in the study area?*

Answer : *The possible answers are the independent numerical number. User just in put numerical* data via keyboard.

Question 9 : *How much pesticide application rate (estimate average liter/ planted rai) are there in the study area?*

Answer : *The possible answers are the independent variables. User can in put numerical data via keyboard.*