UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF GROUNDWATER VULNERABILITY AND NITRATE CONTAMINATION RISK USING GIS-BASED DRASTIC MODEL WITH HYBRID STATISTICAL AND PROBABILISTIC TECHNIQUES

AMINREZA NESHAT

FK 2014 30

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By

AMINREZA NESHAT

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfillment of the Requirements for Degree of Doctor of Philosophy

AUGUST 2014

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To my father

and

To the spirit of my lovely mother

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of philosophy

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AMINREZA NESHAT

August 2014

Chairman: **Assoc. Prof. Biswajeet Pradhan, PhD**

Faculty: **Engineering**

Groundwater pollution is one of the most significant environmental problems today. It is caused by human activities, especially agricultural activities. Agricultural systems developed from traditional methods to modern applications, resulting in an overuse of chemical fertilizers that increase the amount of pollutants. Fertilizers such as nitrates play a significant role in water and soil pollution because of their special characteristics. Most of these fertilizers enter the groundwater through surplus water and create high-risk groundwater resources. Therefore, identifying and diagnosing the amount of pollutants using a groundwater risk map in the future can largely prevent more pollution in groundwater resources. Efficient preventive programs, such as risk management, should be implemented to reduce the risks of groundwater pollution.

In this research, the DRASTIC approach based on a geographic information system (GIS) was applied to evaluate groundwater vulnerability in Kerman Plain (Iran), an arid and semi-arid region that encounters intensive agricultural activities and over exploitation of land that has resulted in groundwater contamination. DRASTIC model includes seven parameters of depth to water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C) of the Kerman Plain. The original DRASTIC model was applied and integrated using original rates and weights. The generation of groundwater vulnerability map was performed by optimizing the rates and weights of DRASTIC model using GIS modeling techniques. The models used were analytical hierarchy process (AHP), single parameter sensitivity analysis (SPSA), frequency ratio (FR), and Wilcoxon non-parametric model. The optimized rates and weights were computed using each model. The Wilcoxon non-parametric test and FR analysis were applied to optimize the rates of DRASTIC model. AHP method was also used to optimize both the rates and the

weights of DRASTIC model, and sensitivity analysis was conducted to optimize only the weights of DRASTIC model. These methods were assigned to DRASTIC model and integrated to produce hybrid methods. So far, some of the generated hybrid methods using the abovementioned models have not been applied in other studies.

The most proper optimization of the vulnerability map was determined using Pearson's coefficient correlation. The Pearson's correlation value of each modified DRASTIC model used in this study was calculated. The regression coefficients showed the relationship between each vulnerability index and the nitrate concentration. The regression coefficient of DRASTIC model indicated a correlation of 0.37. The combination of Wilcoxon non-parametric test for rates and the sensitivity analysis for weights revealed the highest correlation of 0.87 among all applied hybrid models

The most appropriate groundwater vulnerability map with the highest validity and accuracy was selected and combined with the nitrate pollution map that indicates the amount of damage in the Kerman Plain. Then, Dempster–Shafer theory (DST) was applied to develop a new methodology for assessing pollution risk. DST method provides a major advantage by dealing with the varying levels of precision related to information and the more generalized form of probability theory. The combination of the damage map and the pollution occurrence probability map through DST method produces a novel method that can determine the groundwater risk map for the nitrate parameter.

The application of risk assessment method is recommended if the objective is to develop a risk map of areas that are vulnerable to pollution. Aside from nitrate, other pollutants can also be identified in other regions. Therefore, analyses are urged to search for other factors that lead to the pollution of groundwater resources.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN DAN AIR BAWAH TANAH KELEMAHAN NITRAT RISIKO PENCEMARAN MENGGUNAKAN GIS BERASASKAN MODEL HIBRID DRASTIK DENGAN TEKNIK STATISTIK DAN KEBARANGKALIAN

Oleh

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Ogos 2014

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Salah satu daripada kerosakan yang paling signifikasn terhadap alam sekitar pada masa kini adalah pencemaran air bawah tanah yang disebabkan oleh aktiviti manusia terutamanya aktiviti pertanian. Aktiviti pertanian telah dimajukan dari kaedah tradisional hingga ke kaedah moden; baja kimia yang berlebihan juga mengakibatkan peningkatan jumlah bahan pencemar. Malah, sesetengah baja yang mempunyai ciri-ciri yang unik seperti nitrat mengakibatkan pencemaran air dan tanah. Kebanyakan baja-baja ini memasuki air bawah tanah melalui air yang berlebihan dan ini mewujudkan risiko terhadap sumber air bawah tanah. Oleh itu, mengenal pasti dan diagnosis terhadap jumlah bahan pencemar yang terdapat di dalam air bawah tanah dengan peta tanah yang menunjukkan risiko boleh mengurangkan pencemaran sumber air bawah tanah. Oleh itu, program-program pencegahan yang cekap seperti pengurusan risiko perlu dilaksanakan untuk menandingi pencemaran air bawah tanah.

Dalam kajian ini, pendekatan DRASTIC yang berdasarkan sistem maklumat geografi (GIS) telah digunakan untuk menilai kelemahan air bawah tanah di dataran Kerman (Iran), yang merupakan sebuah kawasan gersang dan separa gersang yang menghadapi pencemaran air bawah tanah yang disebabkan aktiviti pertanian yang secara intensif serta pengeksploitasi tanah yang berlebihan. Model DRASTIC dijalankan di dataran Kerman merangkumi tujuh parameter iaitu kedalaman air (D), aliran masuk bersih (R), media akuifer (A), media tanah (S), topografi (T), kesan zon *vadose* (I) dan konduktiviti hidraulik (C). Model DRASTIC asal telah digunakan dan bersepadu dengan menggunakan kadar dan pem berat asal. Peta kelemahan generasi air bawah tanah juga dilakukan dengan mengoptimumkan kadar dan berat model DRASTIC dengan menggunakan teknik-teknik pemodelan GIS. Model-model yang digunakan ialah *Analytical Hierarchy Process (AHP), Single Parameter Sensitivity Analysis*

(SPSA), Frequency Ratio (FR) and Wilcoxon non-parametric model. Kadar optimum dan pem berat telah dikira dengan menggunakan setiap model masing-masing. Wilcoxon bukan parametrik dan kekerapan nisbah telah digunakan untuk mengoptimumkan kadar model DRASTIC. Kaedah AHP juga digunakan untuk mengoptimumkan kadar dan pem berat model DRASTIC. Analisis sensitiviti digunakan untuk mengoptimumkan hanya pem berat model DRASTIC. kaedah telah ditugaskan kepada model DRASTIC dan disepadukan untuk menghasilkan kaedah-kaedah hibrid. Sesetengah kaedah-kaedah hibrid yang digenerasikan dengan menggunakan model-model yang ternyata di atas masih belum diaplikasikan oleh kajian-kajian yang lain setakat ini.

Seterusnya, pengoptimuman yang paling baik terhadap peta kelemahan tanah ditentukan dengan menggunakan *Pearson's coefficient correlation*. Setiap nilai korelasi Pearson dari model DRASTIC yang telah diubahsuai dalam kajian ini telah dikira. Pekali regresi menunjukkan hubungan antara setiap indeks kelemahan dan kepekatan nitrat. Pekali regresi model DRASTIC menunjukkan korelasi 0.37 dan gabungan Wilcoxon bukan parametrik untuk kadar dan analisis kepekaan terhadap berat menunjukkan korelasi yang paling tinggi iaitu 0.87 di kalangan semua model hibrid yang digunakan.

Akhir sekali, peta kelemahan air bawah tanah yang paling sesuai dengan kesahan dan ketepatan yang paling tinggi telah dipilih dan digabungkan dengan peta pencemaran nitrat untuk menunjukkan jumlah kerosakan di dataran Kerman. Kemudian, teori Dempster-Shafer (DST) telah digunakan untuk membangunkan satu kaedah yang baru untuk menilai risiko pencemaran. Kaedah DST dapat berurusan dengan pelbagai peringkat ketepatan yang berkaitan dengan maklumat serta bentuk teori kebarangkalian yang lebih umum. Gabungan peta kerosakan dan peta kebarangkalian kejadian pencemaran dengan kaedah DST menghasilkan kaedah novel yang boleh menentukan peta risiko air bawah tanah bagi parameter nitrat.

Aplikasi kaedah penilaian risiko adalah disyorkan jika objektif kajian adalah untuk membangunkan peta berisiko di kawasan-kawasan yang terdedah kepada pencemaran. Tambahan pula, bahan pencemar yang lain juga boleh dikenal pasti di kawasan-kawasan lain selain daripada nitrat. Oleh itu, penganalisis digesa supaya mencari faktor-faktor lain yang membawa pencemaran kepada sumber air bawah tanah.

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I certify that a Thesis Examination Committee has met on (28 August 2014) to conduct the final examination of Aminreza Neshat on his thesis entitled " ASSESSMENT OF GROUNDWATER VULNERABILITY AND NITRATE CONTAMINATION RISK USING GIS-BASED DRASTIC MODEL WITH HYBRID STATISTICAL AND PROBABILISTIC TECHNIQUES " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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Declaration by graduate student

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