UNIVERSITI PUTRA MALAYSIA

PREDICTION OF NITRATE –NITROGEN LEACHING IN PADDY SOIL USING MULTIVARIATE ANALYSIS AND ARTIFICIAL NEURAL NETWORK

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By

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DEDICATION

This thesis is dedicated to my beloved family,
in memory of my departed father.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman: **Associate Professor Mohd Kamil Yusoff, PhD**

Faculty: **Environmental Studies**

Nitrate-nitrogen leaching from agricultural areas is a major cause for groundwater pollution. Polluted groundwater with high levels of nitrate is hazardous and causes adverse health effects. This research aims to study nitrate–nitrogen leaching into groundwater in paddy soils at Ladang Merdeka Ismail Mulong in Kelantan, Malaysia. The assessment of soil physical properties and groundwater quality, effect of fertilizer on the groundwater nitrate-nitrogen concentrations, identification of contributory factors and prediction of nitrate-nitrogen leaching using computer modeling were the specific objectives of this study.

A total of twelve observation wells and sixteen privately-owned wells were selected for groundwater quality monitoring. Their physical properties were measured by ASTM method while the concentrations of nitrate-nitrogen, phosphate and potassium were analyzed according to US-EPA 300.0, 365.2 and 200.2 procedures, respectively. Groundwater nitrate-nitrogen concentration ranged from 0.0 to 3.85 mg NO_3^--N/l in the obervation wells and 0.0 to 5.08 mg NO_3^--N/l in the private-owned wells. These values fall below the permissible limit of 10 mg/l nitrate-nitrogen. However, the increasing trends of nitrate-nitrogen concentrations in the wells are of concern because it might accumulate over time and pollute the groundwater.

The phosphate concentrations in 54.2% of observation wells and 36.7% of private-owned wells exceeded the permissible standard of 0.2 mg/l. The high values of phosphate could create problems related to the taste and odor of the water. The soil texture was classified as clay based on the United States Department of Agriculture (USDA) soil textural classification system. The results of soil bulk density (1.38 g/cm^3), porosity (38.8%) and soil penetration resistance (1.48 MPascal) confirmed the existence of a hard pan within the soil profile; (1) topsoil (0-30cm), (2) hard pan (30-60 cm) and (3) subsoil (below 60 cm).

Nitrate leaching at different soil depths (20, 30 and 40 cm) was monitored using soil suction samplers for two consecutive seasons. The concentrations varied from 1.10-11.70 mg NO_3^--N /l and 1.20-3.78 mg NO_3^--N/l in the first and second season, respectively. The results showed that nitrate-nitrogen concentration in the soil increased with soil depth and higher fertilizer application indicating that fertilizer

application influences the leaching process which leads to the accumulation of nitrate-nitrogen in the soil. The total nitrogen loss was 0.93% to 1.30% of the applied nitrogen with the highest leaching rate at the 40 cm soil layer (0.35 kg NO_3^--N/ha/d) indicating soil contamination and causes nitrate build-up in the groundwater above permissible limit, thus rendering it unsuitable for human consumption.

The complex data matrix (128 x 16) of nitrate-nitrogen parameters was subjected to multivariate analysis mainly principal component analysis (PCA) and discriminant analysis (DA). PCA extracted four principal components from this data set which explained 86.4% of the total variance. Analysis using Alyuda Forecaster software confirmed that the most important contributors were soil physical properties (R^2 = 0.98). Discriminant analysis was used to evaluate the temporal variation in soil nitrate-nitrogen on leaching process. Discriminant analysis gave four parameters (hydraulic head, evapotranspiration, rainfall and temperature) contributing more than 98% correct assignments in temporal analysis. DA allowed reduction in dimensionality of the large data set which defines the four operating parameters most efficient and economical to be monitored for temporal variations.

Four different data sets were used to develop predictive nitrate-nitrogen models in an Artificial Neural Network (ANN) environment. The results showed good agreement between predicted and observed nitrate-nitrogen leaching rate for TD-ANN model with coefficient correlations of R = 0.98 in the testing step. Based on the principal component analysis scores, ANN generated two models, PCS-ANN1and PCS-ANN2, which gave good predictions with R = 0.97 and 0.94 in their respective testing steps. An inspection of the results showed that ANN gave reliable predictive

models with acceptable accuracies. The results of this study indicate that ANN can be reliably used as a tool to predict nitrate-nitrogen leaching rates in paddy soils based on the selected sixteen parameters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falfasah

RAMALAN PENGURASAN NITRAT-NITROGEN DI DALAM TANAH PADI MENGGUNAKAN ANALISIS MULTIVARIAT DAN RANGKAIAN NEURAL TIRUAN

Oleh

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April 2012

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Pengurasan nitrat-nitrogen dari kawasan pertanian adalah punca utama bagi pencemaran air bawah tanah. Air bawah tanah yang tercemar dengan tahap nitrat yang tinggi adalah berbahaya dan menyebabkan kesan mudarat ke atas kesihatan. Kajian ini bertujuan untuk mengkaji pengurasan nitrat-nitrogen ke dalam air bawah tanah di tanah padi di Ladang Merdeka Ismail Mulong di Kelantan, Malaysia. Penilaian sifat fizikal tanah dan kualiti air bawah tanah, kesan baja ke atas kepekatan nitrat-nitrogen air bawah tanah, mengenalpasti faktor-faktor penyumbang dan ramalan pengurasan nitrat–nitrogen menggunakan pemodelan komputer adalah objektif khusus kajian ini.

Sebanyak dua belas telaga pemerhatian dan enam belas telaga milik persendirian telah dipilih untuk pemantauan kualiti air bawah tanah. Sifat fizikal air bawah tanah telah diukur dengan kaedah ASTM manakala kepekatan nitrat-nitrogen , fosfat dan kalium dianalisis mengikut prosedur US-EPA 300.0, 365.2 dan 200.2 masing-masing. Kepekatan nitrat- nitrogen dalam air bawah tanah adalah 0.0-3.85 mg NO_3^--N / l untuk telaga pemerhatian dan 0.0 hingga 5.08 mg NO_3^--N / l dalam telaga milik persendirian. Nilai ini rendah daripada had yang dibenarkan sebanyak 10 mg / l nitrat-nitrogen. Walau bagaimanapun, trend peningkatan kepekatan nitrat-nitrogen dalam telaga membimbangkan kerana ia mungkin terkumpul dari masa ke semasa dan mencemarkan air bawah tanah. Keputusan bagi kepekatan fosfat menunjukkan bahawa 54.2% daripada telaga pemerhatian dan 36.7% daripada telaga persendirian melebihi standard dibenarkan iaitu 0.2 mg / l. Nilai-nilai fosfat yang tinggi boleh menimbulkan masalah yang berkaitan dengan rasa dan bau air tersebut. Tekstur tanah telah dikelaskan sebagai tanah liat yang berdasarkan sistem klasifikasi tekstur tanah Jabatan Pertanian Amerika Syarikat (USDA). Keputusan ketumpatan pukal tanah (1.38 g/cm^3), keliangan (38.8%) dan rintangan penembusan tanah (1.48 MPascal) mengesahkan kewujudan lapisan kematu dalam profil tanah; (1) tanah atas (0-30cm), (2) lapisan kematu (30-60 cm) dan (3) subtanah (di bawah 60 cm).

Pengurasan nitrat pada kedalaman tanah yang berlainan (20, 30 dan 40 sm) telah dipantau dengan menggunakan alat penyedut air tanah (“soil suction samplers”) untuk dua musim berturut-turut. Variasi kepekatan adalah dari 1.10-11.70 mg NO_3^--N / l dan 1.20-3.78 mg NO_3^--N/l dalam musim pertama dan kedua, masing-masing. Hasil kajian

menunjukkan bahawa kepekatan nitrat-nitrogen di dalam tanah meningkat dengan kedalaman tanah dan penggunaan baja yang lebih tinggi membuktikan bahawa penggunaan baja mempengaruhi proses pengurasan yang membawa kepada pengumpulan nitrat-nitrogen di dalam tanah. Jumlah keseluruhan kehilangan nitrogen adalah 0.93% hingga 1.30% daripada baja nitrogen yang digunakan dengan kadar resapan yang tinggi di lapisan tanah 40 sm (0.35 kg NO_3^--N/ha/h) menunjukkan pencemaran tanah dan menyebabkan pengumpulannya dalam air bawah tanah melebihi had yang dibenarkan, dan ini menjadikannya tidak sesuai untuk kegunaan manusia.

Matriks data parameter nitrat-nitrogen yang kompleks (128 x 16) telah dianalisa dengan multivariat terutamanya analisis komponen utama (PCA) dan analisis diskriminan (DA). PCA mengekstrak empat komponen utama daripada set data ini yang menjelaskan 86.4% daripada jumlah varians. Analisis menggunakan perisian Peramal Alyuda telah mengesahkan penyumbang yang paling penting adalah sifat fizikal tanah (R^2 = 0.98). Analisis diskriminan digunakan untuk menilai variasi masa proses pengurasan nitrat-nitrogen dalam tanah. Analisis diskriminan memberikan empat parameter (tekanan hidraulik, evapotranspirasi, hujan dan suhu) menyumbang lebih daripada 98% ramalan yang betul dalam analisis masa. DA membenarkan pengurangan dalam dimensi set data yang besar yang mentakrifkan empat parameter operasi yang paling cekap dan ekonomi untuk dipantau bagi variasi masa.

Empat set data yang berbeza telah digunakan untuk membangunkan model ramalan nitrat-nitrogen dalam persekitaran Rangkaian Neural Tiruan (ANN). Keputusan

menunjukkan korelasi kadar resapan nitrat -nitrogen yang baik antara diramalkan dan diperhatikan untuk model TD-ANN dengan korelasi pekali R = 0.98 dalam peringkat ujian. Berdasarkan analisis skor komponen utama, ANN menjana dua model, PCS-ANN1 dan PCS-ANN2, yang memberikan ramalan yang baik dengan R = 0.97 dan 0.94 dalam peringkat ujian masing-masing. Pemeriksaan keputusan menunjukkan bahawa ANN memberikan model ramalan yang dipercayai dengan ketepatan yang boleh diterima. Keputusan kajian ini menunjukkan bahawa ANN sesuai digunakan sebagai alat untuk meramal kadar pengurasan nitrat-nitrogen dalam tanah padi berdasarkan enam belas parameter yang dipilih.

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I certify that a Thesis Examination Committee has met on 17 April 2012 to conduct the final examination of Hazilia binti Hussain on her thesis entitled "Prediction of Nitrate-Nitrogen Leaching in Paddy Soil Using Multivariate Analysis and Artificial Neural Network" 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 Degree Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or any other institution.

_____

HAZILIA BINTI HUSSAIN

Date: 17 April 2012.

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