Agricultural Contamination in Soil and Groundwater from Irrigated Farmland in Thailand: Risk Implications for Sustainable Agriculture and Food Safety

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1. Abstract

Groundwater is an important source of freshwater supply in Thailand, particularly in dry season for non-irrigated area. Unfortunately, our groundwater supply has generally not been adequately protected from natural and anthropogenic contaminants. Assessments of the vulnerability of groundwater to contamination range in scope and complexity from simple, qualitative, and relatively inexpensive approaches to rigorous, quantitative, and costly assessments. This paper presents a stochastic framework for the assessment of groundwater vulnerability using GIS-based geostatistical models accounted for aquifer heterogeneity and temporally averaged rainfall-runoff data. The studying area is located in Suphanburi province of Thailand. This area has been identified with nitrate contamination in groundwater aquifer underneath. Attempts to spatially estimate nitrate concentration profile in soil and groundwater by employing deterministic recharge rate from an empirical relationship between infiltration rate and precipitation intensity, result in overestimating of nitrate concentration profile in groundwater. Prediction of nitrate plume from MODFLOW based on this initial concentration thus lead to an over-prediction of plume travel distance and perhaps concentrations at specific location. We are currently employing a geostatistical approach to account for aquifer heterogeneities. MODFLOW will be employed with the equally probable aquifer realizations generated from real bore log information at the study area.

2. Introduction

Groundwater in Thailand plays a vital role in supplying water for agricultural and industrial needs. Reduction and/or unreliability of surface water due to drought, global climate change, and increasing demand from population growth may further increase the national's reliance on groundwater resources. Nitrate is a chemical compound of one part nitrogen and three parts oxygen that is designated the symbol NO_3^-. It is the common form of nitrogen found in water, besides others such as nitrite and ammonia. Nitrate in groundwater originates from natural sources, organic sources (i.e., decaying plant materials, human/animal waste discharge in septic systems, animal yards, manure storage lagoons, and wastewater treatment plant discharge), atmospheric deposition, and inorganic fertilizer.

Table 1 *Commercial Nitrogen*

Name	Chemical Formula
Anhydrous Ammonia	NH_3
Aqua Ammonia	NH_4OH
Ammonium Nitrate	NH_4NO_3
Ammonium Nitrate-Lime	$NH_4NO_3+CaCO_3$
Ammonium Sulphate	$(NH_4)_2SO_4$
Calcium Nitrate	$5Ca(NO_3)_2\ NH_4NO_3\ 10H_2O$
Nitrate of Soda	$NaNO_3$
Urea	$CO(NH_2)_2$
Ammonium Nitrate Solution (sol)	$NH_4NO_3+H_2O$
Urea Ammonium Nitrate (UAN) (sol)	$NH_4NO_3 + CO(NH_2)_2 + H_2O$
Calcium Ammonium Nitrate (sol)	$5Ca(NO_3)_2\ NH_4NO_3\ 10H_2O + H_2O$

Nitrogen fertilizer consumption in Asia has dramatically increased approximately 17 fold in the last 40 years (Tirado 2007). In Thailand, nitrate accumulation in surface water and shallow groundwater, perhaps originating from fertilizers, has been reported in Suphanburi and Kanchanaburi provinces. Based on 21 groundwater samples collected from both provinces, 6 samples from asparagus farms were reported with maximum concentration level (MCL) higher than WHO drinking water standard of 50 mg/L for nitrate (Tirado 2007). Asanachinda (1996) also reported high concentrations of nitrate, up to 290 mg/L, in groundwater collected from agricultural areas of Chiang Mai province in northern Thailand. Suphanburi not only hosts intense agricultural activities, but leaky sewage systems can also influence the increase in nitrate concentration detected in groundwater. In fact, there is no proper sewage collection facility in the study area and individual pipelines from each household directly discharge into the nearby canals with no prior treatment.

3. Objectives

- Spatially generate NO_3-N fertilization pattern in the study area via GIS-based map
- Deterministic recharge rate calculation from a published empirical relation between infiltration rate and precipitation intensity
- Spatially estimate nitrate concentration profile in soil and groundwater
- Estimating of nitrate concentration profile in groundwater
- Construct 3D geostatistic aquifer realizations from observed lithological bore logs and generate 2D layers of equally probable aquifer realizations accounting for aquifer heterogeneities

4. Methodology

Table 2 *Hydrological Conditions of Suphanburi Province (Source: Thai Meteorological Department, 2009)*

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Fab	Mar
Rainfall (mm.)	48.1	114.0	94.7	101.8	117.2	230.1	189.0	45.8	6.0	3.7	6.9	18.7

Hydrological conditions of the study area can be represented by the data in the table below illustrated the 30-yr (1980-2009) monthly average rainfall distribution. From Table 2, the reported 30-yr annual average rainfall in the study area is estimated to be 976 mm.

The distribution of groundwater recharge rate (R) in the study area located in Thailand has been previously investigated (Siriputthichaikul 2002) and may later be estimated based on available soil types, soil properties, annual rainfall (P) and infiltration rate (I) as shown in Equation 1:

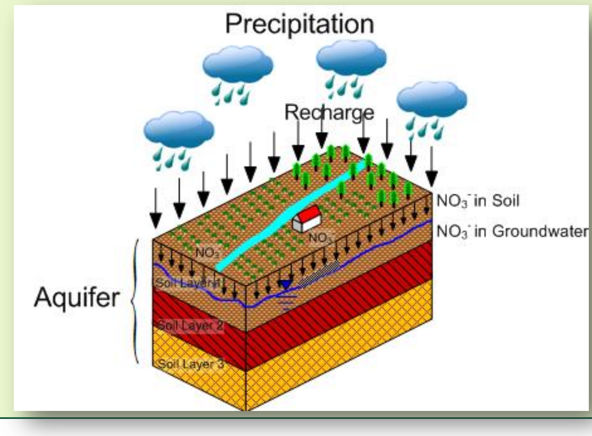
$$R = P \times I \qquad (1)$$

The spatial average rainfall (P) is estimated using Thiessen Polygon. For this, the 30-yr annual average rainfall data from 4 raingauge stations in the study area are employed. The highest rainfall is in the northern part of Suphanburi province, while the middle of the study area receives the least amount of rainfall. Infiltration rate (I) can be estimated from the distribution of soil in the study area.

Siriputthichaikul (2002) reported a relationship between infiltration rate (I: % of annual average rainfall in cm/hr) and hydraulic conductivity (K; cm/hr) as follows:

$$I = 9.24K + 3.2 \qquad (2)$$

Figure 1 *Conceptual Methodology*



5.Results

Figure 2 *Suphanburi Land-use Map (Source: Land Development Department,2005)*

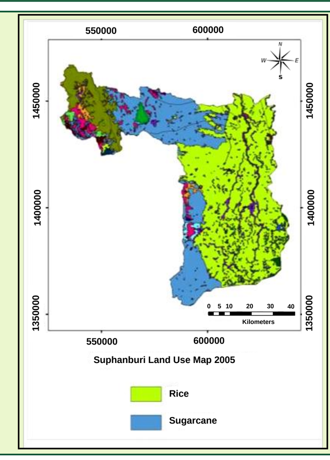


Figure 3 *(A) Spatial Distribution of Infiltration I (% of Annual Average Rainfall); and (B) Spatial Distribution of Groundwater Recharge Rate R*

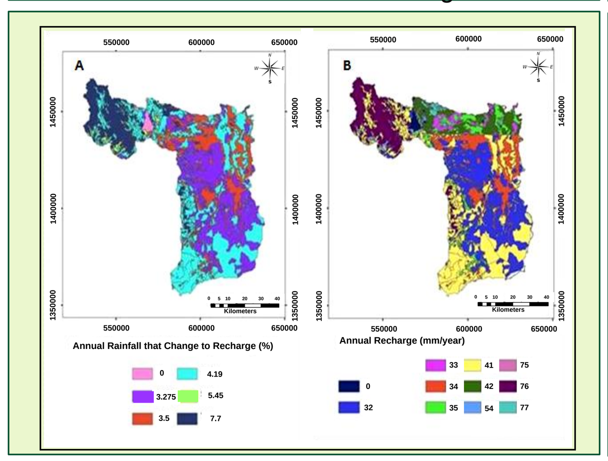


Figure 4 *(A) Spatial Distribution of Leftover Nitrate Concentration in Soil from Overfertilization; (B)Spatial Distribution of Nitrate Concentration in Recharge Water Hydrological model*

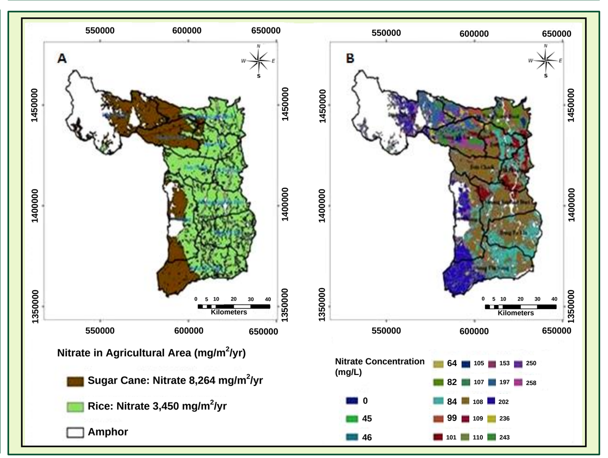


Figure 5 *Spatial Distribution of Estimated Nitrate Concentration in Groundwater*

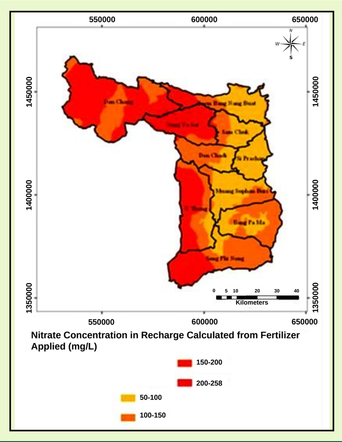


Figure 6 *Correlation of Nitrate (Left-Hand Side) and Potassium (Right-Hand Side) in Groundwater Samples Collected from the Study Area*

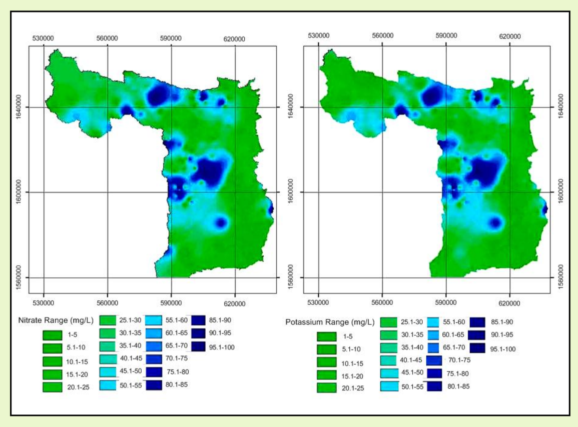


Figure 7 *Borehole Data (Source: Department of Groundwater Resources)*

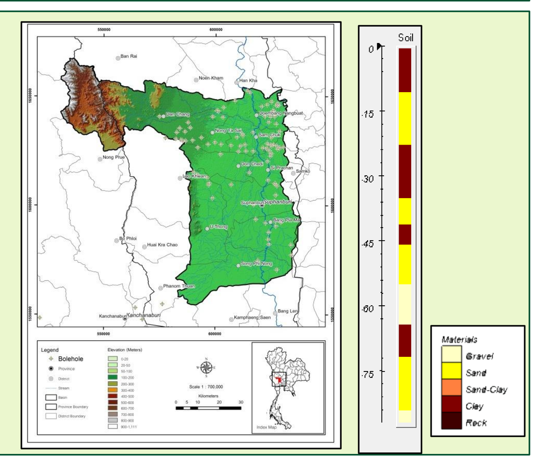


Figure 8 *Material set on 3D grid*

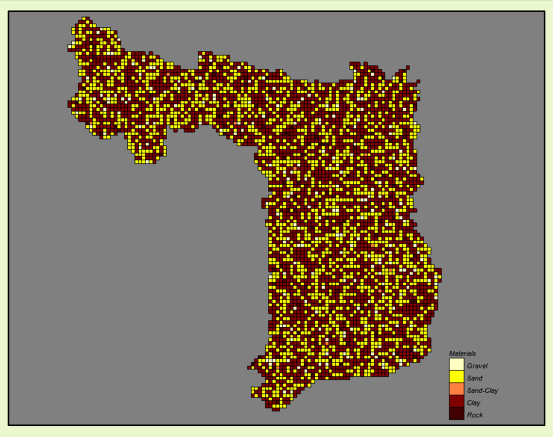
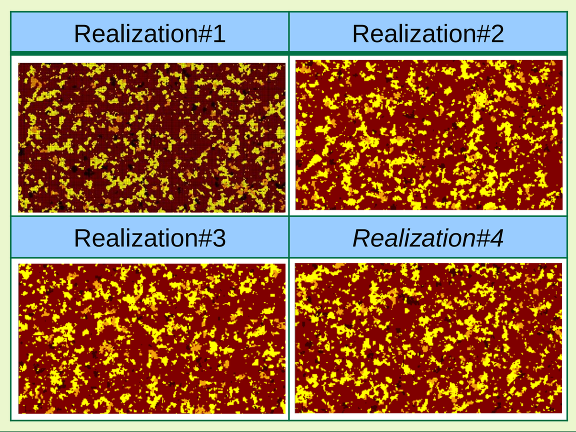


Figure 9 *Realization of the aquifer heterogeneity*



6. Conclusions

Nitrate contamination in groundwater is a rising concern that has been facing through agricultural practices of N fertilizers present in Thailand. Potential effects of nitrate on the quality of surface water and groundwater as well as implications of such effects on human health (especially children), pose issues of international concern that require science-based assessment and response. Identification of nitrate origin, therefore, is imperative for assessing groundwater vulnerability to agricultural contamination and for subsequently deploying monitoring resources to areas where they are needed.

Suphanburi is our study area owing to the previous report on surface and subsurface nitrate contamination. Based on annual average rainfall of more than 900 mm and spatially distributed soil types, estimated groundwater recharge ranged between 33 and 77 mm/year. The highest groundwater recharge rates are near the mountainous area in the north of Suphanburi. Nitrate concentration in groundwater recharge that potentially turned into source of groundwater contamination with nitrate was calculated based on the leftover nitrate fertilizer in soil. Rice and sugarcane fertilization patterns are studied. Diammonium phosphate [DAP; $(NH_4)_2HPO_4$] 18-46-0 and ammonium nitrate (NH_4NO_3) 33-0-0 were the original forms of nitrogen in the fertilizers used to calculate the spatial leftover nitrate in soil and recharge. The maximum leftover nitrate concentration in recharge water is up to 250 mg/L. Areas that are subjected to the most severe contamination are U-Thong (central part of Suphanburi) and Song-PeeNong (southern part of Suphanburi). Nitrate and K trends reveal strong positive correlations at several locations where observed nitrate concentrations were high in groundwater, indicating the possibility that nitrate contaminant in groundwater in the study area was originated from agricultural activities rather than from sewage systems in the vicinity.

Attempts to spatially estimate nitrate concentration profile in soil and groundwater by employing deterministic recharge rate from an empirical relationship between infiltration rate and precipitation intensity, result in overestimating of nitrate concentration profile in groundwater. Prediction of nitrate plume from MODFLOW based on this initial concentration thus lead to an over-prediction of plume travel distance and perhaps concentrations at specific location. We are currently employing a geostatistical approach to account for aquifer heterogeneities. MODFLOW will be employed with the equally probable aquifer realizations generated from real bore log information at the study area.

7. References

Putthividhya, A., and Pipitsombat R., GIS-based and laboratory-scaled leaching assessment of agricultural contamination in heavily cultivated area of Thailand, Environmental Earth Sciences, 2015; 73:3975–3986.

8. Acknowledgment

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