

# Assessment of potential risk of nitrate leaching on agriculture region using Arc-NLEAP model

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## Abstract

In recent years, fertilizer applied is continuing to increase and overuse of chemical fertilizers raises the risk of nitrate pollution of groundwater in the North China Plain. To preserve the groundwater and reduce the economic losses, an efficient and quick assessment of nitrate leaching risk on regional farmland is crucial. It is extremely hard to quantify the environmental impacts of unconscionable nutrient management, since rural areas have an extremely distinct spatial heterogeneity. In this research, based on principles of the NLEAP model, we developed the Arc-NLEAP toolbar for ArcMap with the help of ESRI's ArcObjects(AO)and MS-VB. Arc-NLEAP integrated calculation process of nitrogen leaching assessment model and the GIS platform for spatial analysis, and achieve regional farmland assessment of nitrogen leaching by computing grid. In this study, we applied the model in the North China Plain by combining the statistical and Remote Sensing data to prepare the spatial layers for model. The output parameters of the model and N hazard class we defined both serve to evaluate the nitrate leaching risk.

## Key Words

Nitrate, Leaching, NLEAP, Model, GIS

## Introduction

Hebei Plain is the main crop rotation area with winter wheat and summer corn, and Hebei economic statistic data manifest that output value of agriculture accounts a large amount of gross output value. Compared with 2006, the yield of grain increased 3.7% in 2007; simultaneously the rate of applied fertilizer increased 6%. It is certain that application of nitrogen fertilizer can ensure crop yield in an agricultural ecosystem. However, the input of fertilizer nitrogen exceeds the amount a crop needs, and the excess nitrogen will be converted into nitrate, accumulate in the root zone and be subject to leaching into deeper layer, with the irrigation and rainfall, and contaminate the surface water and threaten groundwater eventually. The amount of fertilizer application rose rapidly to meet increase of population and food demand in recent decades in China. Numerous researches proved that overuse of fertilizes polluted the ground water, and many sites detected nitrate contents exceeding the permitted range in north China (Liu Hongbin *et al.* 2006; Guo Zhanling *et al.* 2008). So serious nitrate leaching occurred in some areas of agriculture. The mechanism of nitrate leaching is complex and to quantify the amount of nitrate leached is extraordinarily difficult. Thus the mathematical model simulation is one of the best technical methods to analyze the amount of nitrate leached, and one of the main purposes of many soil-nitrogen cycle models is to quantify the impact of nitrate leaching on the environment. Because the mathematical model can simulation different inputs easily, such as speed, time step, and the impact of different field management practices (Mahesh *et al.* 2000). In this study, we based on the principal of NLEAP (Pierce *et al.* 1991; Shaffer *et al.* 1991), combined with AO and VB to develop Arc-NLEAP Toolbar for ArcGIS Desktop environment. The intent of the current research is to integrate GIS technology with a nitrate leaching model to propose a new model to assess the nitrate leaching risk in the agricultural region and apply this new model to the southern plains of Hebei province in 2007-2008.

## Study sites and methods

### Study area

Study area is located in the southern plains region of Hebei Province(Figure 1), extending northward from 36°2'45"N to 39°37'25"N and east-west between approximately 114°16'4"E and 117°51'31"E, including a total of 102 counties, and covers an area of 6 223 940 ha. The average elevation in the study area is 28 m, and the main soil type is alluvial soil. This area is the main grain production region in Hebei Province, with Winter wheat-summer corn as the dominant double cropping system, in addition to cotton, soybeans, fruit trees and other crops. The average annual production of wheat and corn are 4.9 t/ha and 5.0 t/ha, respectively. According to the statistic data, the average applied fertilize rate is 500kg/ha in 2007.



**Figure 1. The location of study area in Hebei Province, China**

### *NLEAP Model description*

Nitrogen Leach and Economic Analysis Package (NLEAP) is a computer application model developed for use by farmers, extension personnel and action agency who required rapid site-specific estimates of nitrate-N ( $\text{NO}_3\text{-N}$ ) leaching potential under agricultural crops, and potential impacts of  $\text{NO}_3\text{-N}$  leaching into groundwater (Shaffer *et al.* 1991). The program translates the information of soil, climate, crop and field management into projected N budgets to estimate leaching index, including nitrate available for leaching (NAL), amount of nitrate leached (NL), movement risk index (MRI). NLEAP has been widely used in the United States to simulate N management scenarios. Delgado (2008) pointed out the NLEAP had been widely tested across several sites in the USA and internationally by independent user group (Delgado *et al.* 2001; Helena Rimski-Korsakov *et al.* 2004). Furthermore, Shaffer (1995) proposed to combine the NLEAP model with GIS technology to calculate the long term potential mass of nitrate leaching on vast geographical region. Delgado (2008) developed Nitrogen Trading Tool (NTT) based on NLEAP and De Paz JM (2009) used GIS NIT-1 to assess spatial and temporal N losses to the environment on the Mediterranean coast of Spain with quantitative and qualitative ranking. Nevertheless, all these models are not shared and cannot be used in China for several reasons.

### *Integrated Arc-NLEAP model*

The Arc-NLEAP model was integrated with NLEAP model and GIS using VB and AO. The quantitative N index approach is similar to Pierce (1991) and Shaffer (1991), but some essential changes were made to fit the study area. Utilizing GIS spatial analysis capabilities, qualitative ranking that can be quickly detected from very low to high attributing to various field managements.

An easy-to-navigate Arc-NLEAP toolbar consists of different tools available in a menu, including input data, run model and display the results. The popup dialogue frame allow input data of spatial data layers, including crop information, soil properties, precipitation and some parameters of text. The user can set the output path for results before running the model. The spatial layers required by the Arc-NLEAP were 14 in total.

### **Spatial layers for Arc-NLEAP**

The main source of farmland nitrogen is applied nitrogen fertilizer and the total input nitrogen are absorbed by crop grain and straw mainly. Taking winter wheat as an example, nitrogen fertilizer account for about 70% of total nitrogen applied, while nitrogen absorbed by crop grain accounts for 80% of total nitrogen output. Thus it is extremely necessary to determine the amount of chemical fertilizer and nitrogen absorbed by crop grain.

Taking the obvious spatial heterogeneity owing to various field management practices into account. We use a decision tree by utilizing the NDVI time series derived by MODIS data to map land use land cover of the study area. Based on diverse crop, we use the greenness index and NDVI derived from remote sensing data to obtain the fertilizer status and crop information layers to manifest the difference of geographical location, soil quality and various field management practices. Besides, we have the digital soil map of Hebei Province to access the variety of soil properties layers for the model.

## Model run results

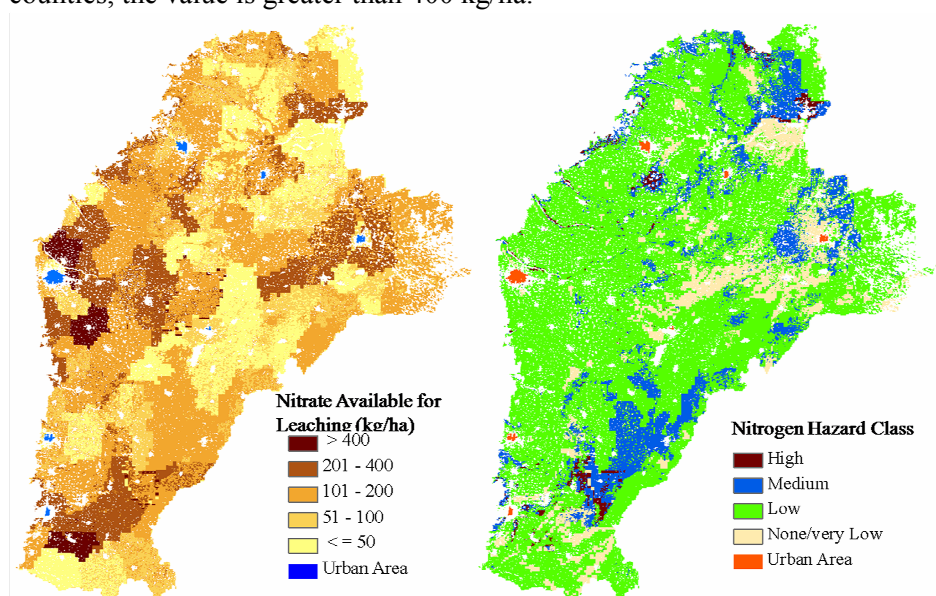
The simulation result of the management scenario of the study area in 2007-2008 can be displayed and analyzed under ArcMap environment. In study area winter wheat-summer corn, cotton, fruit trees occupy an area of 3404618 ha, 1504725 ha, 412462 ha, respectively. The results for applied fertilizer in the study area, show average nitrogen application rate for winter wheat-summer corn rotation zone is 390 kg/ha, 70% of which are applied during the winter wheat season. In cotton and fruit growing areas, with an overall lower level, the average nitrogen application rate is 187 kg/ha and 101 kg/ha.

The risk of moving nitrate below a soil profile given soil, climate and management combination, but without taking the concentration of nitrate being leached into account can be estimated using (Shaffer *et al.* 1991):

$$\text{MRI} = 1 - \exp [(-K)(\text{WAL})/(\text{POR1} + \text{POR2})] \quad (1)$$

Where K is the leaching efficiency (unitless), POR1 is the porosity of the top 25 cm, POR2 is the porosity of the lower horizon (cm), WAL is water available for leaching from the bottom of the soil profile (cm). The simulated value of MRI ranges from 0 to 1, which is primarily a measure of water management and climate impacts on general leaching. The simulation MRI has the average value 0.45 and the spatial pattern also depicts that most of region (77%) labelled with a medium value.

The input nitrogen was absorbed by grain principally, besides, straw absorption, ammonia volatilization and denitrification lost some nitrogen. However, as a result of irrational field management practices, much nitrogen has not been utilized effectively and has accumulated in the root zone in the form of nitrate, indicating that significant amounts of nitrogen became available for leaching along with precipitation and irrigation water, threatening aquifers (Michael *et al.* 2009). The spatial pattern of nitrogen available for leaching (NAL) is depicted in Figure 2 (Left) has an average value of 117 kg/ha. In counties near Shijiazhuang, this winter wheat-summer corn rotation zone has a higher NAL values, for instance, in some counties, the value is greater than 400 kg/ha.



**Figure 2.** The simulated amount of Nitrate Available for Leaching (Left) and Nitrate Leaching Hazard (Right) of the study area.

**Table 1.** The definition of N hazard class.

N INDEX	Very Low (0)	Low (2)	Medium (4)	High (6)	Very High (8)
Water Leaching Index	≥ 0 & < 1	≥ 1 & ≤ 2	> 2 & ≤ 10	> 10 & < 16	> 16
Nitrate Available to leach Potential (kg N/ha)	≥ 0 & < 25	≥ 25 & ≤ 50	> 50 & ≤ 100	> 100 & ≤ 150	> 150
Estimated Nitrate leaching (kg N/ha)	≥ 0 & < 25	≥ 25 & ≤ 50	> 50 & ≤ 100	> 100 & ≤ 150	> 150
NH <sub>3</sub> Volatilization (kg N/ha)	≥ 0 & < 10	≥ 10 & ≤ 20	> 20 & ≤ 30	> 30 & ≤ 400	> 40
Denitrification (kg N/ha)	≥ 0 & < 5	≥ 5 & ≤ 10	> 10 & ≤ 20	> 20 & ≤ 300	> 30
Total Nitrate Leaching	≥ 0 & < 8	≥ 8 & < 17	≥ 17 & < 25	≥ 25 & < 33	≥ 33 & < 40
N hazard Class	None/Very Low	Low	Medium	High	Very High

To assess the potential nitrogen leaching risk, according to Delgado's (2006) research, we take water leaching index, nitrogen available for leaching, amount of nitrate leached, ammonia volatilization and denitrification into consideration, and define the different levels of these factors as a specific weight value, the sum of all factors (Total Nitrate Leaching) is divided into five classes to evaluate the nitrogen leaching risk of study area, the definition of the hazard class is listed in the Table 1 and the spatial pattern of result is showed in Figure 2 (Right). As can be seen from the chart, the study area is marked as a Low label in green, which account for 74%, in spite of this, continued excessive amounts of nitrogen fertilizer application will lead to much more nitrogen leached below the root zone. The none or very-low hazard region, occupying 11% of the study area, is mainly distributed in the middle of the study area. Medium risk hazard accounts for 14 %, and is located in southern of cotton area and north-east of the study area, where input and output of nitrogen is not very high, however, the potential leaching risk is high, and more leaching will occur associated with increasing fertilizer applied.

## Conclusion

This study proposed an integrated model by combining GIS capabilities and the existing model of nitrogen index simulation and calculation function to assess fertilizer management and quantitatively rank the potential risk to the environment effectively. This paper presents a case study on the application of this integrated spatially model to quantitatively evaluate nitrate losses to the environment across an agriculture region of the North China Plain using remote sensing data. The Arc-NLEAP model has the potential to assess the effect of various management scenarios on larger agricultural scale and can be used to reduce nitrate losses to the environment supporting effective N management in the changing world. In future studies the leaching index annual leaching risk potential (ALRP) will be considered to quantify potential nitrate leaching below the root zone associated with various management practices.

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## References

- De Paz JM, Delgado J A, Carlos Ramos, Shaffer MJ (2009) Use of a new GIS nitrogen index assessment tool for evaluation of nitrate leaching across a Mediterranean region. *Journal of Hydrology* **365**, 183-194.
- Delgado JA, Marvin Shaffer, Chengensu Hu (2006) A decade of change in nutrient management: a new nitrogen index. *Journal of soil and water conservation* **61**, 66-74.
- Delgado JA, Ronald R Riggensbach (2001) Evaluation of Nitrate-Nitrogen Transport in a Potato-Barley Rotation. *Soil. Sci. Soc. Am. J.* **65**, 878-883.
- Delgado JA, Shaffer MJ, Lal H (2008) Assessment of nitrogen losses to the environment with a Nitrogen Trading Tool(NTT). *Computers and electronics in agriculture* **63**, 196-206.
- Guo Zhanling, Shen alin, Kou Changlin (2008) Investigation and monitoring of nitrate pollution in ground water in Hennan province. *Monitoring* **5**, 25-127
- Helena Rimski-Korsakov, Gerardo Rubio (2004) Potential nitrate losses under different agricultural practices in the pampas region. *Argentina.Agricultural Water Management* **65**, 83-94.
- Liu Hongbin, Li Zhihong, Zhang Yungui (2006) Nitrate contamination of groundwater and its affecting factors in rural areas of Beijing Plain. *Acta pedologica sinica* **43**, 405-413.
- Mahesh N R, David AW, Mitchell L N (2000) A GIS-based modelling approach for implementation of sustainable farm management practices. *Environmental Modelling & Software* **15**, 745-753.
- Michael GJ, R. Willem Vervoort, Julie Cattle (2009) Nutrient losses under simulated rainfall from pasture plots in the Great Lake District, New South Wales. *Australian Journal of soil research* **47**, 555-564
- Pierce FJ, Shaffer MJ, Halvorson AD (1991) Screening procedure for estimating potentially leachable nitrate-nitrogen below the root zone. In 'Managing nitrogen for Groundwater Quality and Farm Profitability'. (Eds Follet RF, Keeney DR, Cruse RM), pp. 259-283. (Soil Science Society of America: Madison, Wisconsin).
- Shaffer, MJ, Havorson AD, Pierce FJ (1991) Nitrate leaching and economic analysis package (NLEAP): model description and application. In 'Managing nitrogen for Groundwater Quality and Farm Profitability'. (Eds Follet RF, Keeney DR, Cruse RM), pp. 285-322. (Soil Science Society of America: Madison, Wisconsin).