Non-Point Source Pollution Characteristics of Agriculture-Derived Nitrogen in Groundwater in Suburban Area of Shanghai Based on Models

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Abstract. This paper analyzes the characteristics of the NPS nitrogen pollution of the groundwater in Guoyuan Village, Pudong District, Shanghai. And the associated effects on the surface and groundwater around the study area are discussed in detail based on the successive observed data, DNDC and L-THIA model. The results show that both of the surface and groundwater are polluted so seriously that they are not suitable to drink. The average content of total nitrogen in surface water is 6.3 mg/L and 16.85 mg/L in the groundwater, and both of them attribute to Grade Ⅴ surface water standard (≤2.0 mg/L) according to the national standard(GB 3838-2002). It is concluded that the nitrogen pollution comes mainly from the fertilizer of the peach orchard based on the further modeling analysis. Therefore, reasonable adjustment of fertilization measures and project may be an effective and practical approach to control the nitrogen pollution around the peach orchard.

Keywords: DNDC model; L-THIA model; nitrogen content; NPS pollution; peach orchard

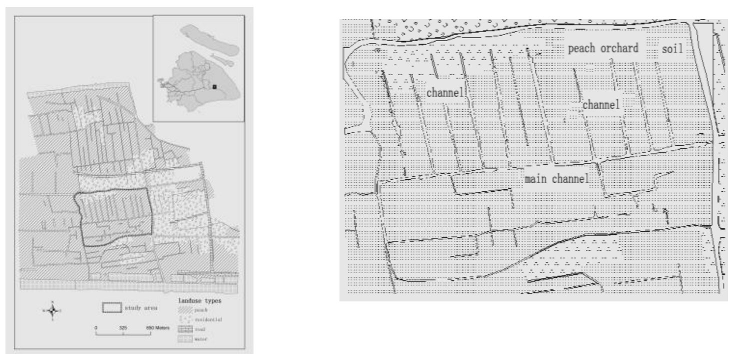
1 Introduction

Non-point source (NPS) pollution is the main factor of surface and groundwater pollution as point source pollution is becoming under control. Among all the non-point pollution, the agriculture-derived nitrate NPS pollution of groundwater has become an environmental issue which may cause algal bloom and eutrophication in aquifers, and even produce potential hazards to human health though the link is still disputable [1]. The heavy use of nitrogen (N) fertilization for intensive farming and cropping system with low N use efficiency is often responsible for nitrate overloading into groundwater. The role of agricultural NPS in water quality degradation is the most prominent [2-3], especially in the suburbs of Shanghai where ecological agriculture is predominant. In 2001, the application of N in fields was up to 612.75 kg/hm^2, which is 59.6% higher than the average level in China, and with 1.3×10^6 kg N•a^{-1} flowing to the aquifers [4]. Characteristics of agriculture-derived NPS nitrogen pollution and the load estimation are the important part for regional water quality control. Concerning studies on the pollution load include many aspects, such as estimation of the relationship between total precipitation and pollution load, estimating NPS pollution load of the long-term average output by using the model (L-THIA) [5], farmland runoff pollution load model [6], the use of NPS Watershed SWAT model system for different scenarios of watershed management [7] and agricultural NPS pollution load. There are some studies on the characteristics of agricultural NPS pollution focusing on analyzing the factors such as the land use types, topography and its associated impacts on the NPS pollution. The spatial and temporal variability of agriculture-derived NPS pollution is the subject of intensive research recently.

In this study, the characteristics of the agriculture-derived NPS nitrogen pollution of groundwater is analyzed based on the biogeochemical process model DNDC, the L-THIA model and the simultaneous observation data in soil, surface and groundwater. Guoyuan Village, Xinchang Town of Pudong District, located in the southern Shanghai, China, traditionally a high-yield area for growing peaches, is selected as the study area. We aim at exploring the optimum efficiencies of water and fertilizer usage in peach orchard by analyzing the relationship between agricultural management measures and agriculture-derived NPS nitrogen pollution. Results are discussed in terms of the multi-objective management for peach orchard in order to reduce or avoid the nitrogen pollution in groundwater.

2 Study area

The research is conducted in the peach orchard of Guoyuan Village (31°03'N, 121°39'E), located in Xinchang Town of Pudong District on the east of Huangpu River in Shanghai, China (Fig.1(a)). The site situates in a subtropical monsoon zone with 4 m altitude. The average annual temperature is 15.7 ℃ and 1100 mm of the average annual rainfall, ranging from 300 to 1300 mm with most falling during the period from July to September[8]. There has been a long history of peach planting in this area since 1621. The planting area reached 5336 hm^2 in 2005 and peach became the symbol of this district [9]. The study area, which is in roughly rectangular shape with the area of about 33.35 hm^2, is adjacent to living area of Guoyuan Village (Fig.1(b)). Peach trees are planted at a density of an amount of 900 per hectare. The peach orchard is surrounded by river and some ditches distribute regularly inside. A main ditch from east to west divides the peach orchard into northern and southern parts. The north of the main ditch is segmented vertically by 11 ditches with equal space while several ditches distribute irregularly on the other side (Fig.1(b)). The sources of the water pollution are mainly from the peach orchard and residential area because there are no other land use types in the district. The compound planting mode that green vegetables are planted under the peach trees when the peach is ripe (from June to August) is employed in the peach orchard. 70% of the peach orchard is interplant one-season vegetables, others of two-season vegetables [10]. This compound planting and management mode in study area increases soil nitrogen content and associates with the surface and groundwater pollution.



(a) (b)

Fig. 1. The location of Guoyuan Village & ditches in peach orchard

3 Material and method

3.1 Data Collection

Measurements of N in surface, groundwater and soil have been carried out since June, 2009. The monitoring locations in soil, surface and groundwater were chosen respectively according to their different features. GPS was used to fix the monitoring location. It is worthy of mentioning that the monitoring locations of surface and groundwater were collected precisely according to the topography and the flowing direction of the ditches to make sure that monitoring locations can present the spread of nitrogen in the soil runoff as much as possible (Fig.2).

- Sixteen soil samples were collected from different depth (0 ~ 15 cm, 15 ~ 30 cm, 30 ~ 45 cm) in June, 2009. Total nitrogen in soil was analyzed by conventional method and nitrate (in terms of nitrogen) by Bremner method.
- Fifty-three water samples were collected from Oct.2009 to Dec.2009, Jan.2010 and from Mar.2010 to Aug.2010. Twenty-five samples were from surface water, and

twenty-eight samples from groundwater. Total nitrogen in the water was analyzed by alkaline potassium persulfate ultraviolet spectro-photometric method and nitrate (in terms of nitrogen) by Zinc cadmium reduction method.

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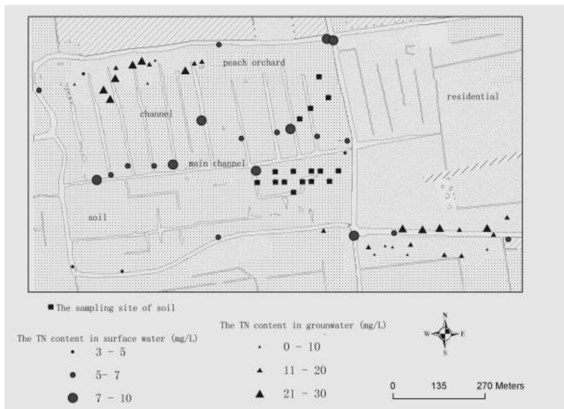

Fig. 2. The distribution map of monitoring locations

3.2 Model Parameters

Field management including fertilizer application and tillage system can influence soil fertility directly through fertilizer inputs and nitrogen circulation in agro-ecological process. Models can simulate the processes responsible for production, consumption and transport of N_2O in both long and short terms, and also allow spatial simulation [11]. Simulation mechanistic models consider all factors affecting N_2O circulation in the agriculture ecosystem. In this study, these factors include the planting mode, fertilizer application, irrigation strategy and the tillage measures of peach orchard in recent ten years (Tab.1), which were acquired through field survey, visiting local farmers and references [8].

Table 1. The management measures of the peach orchard

Month	Management
1	Fertilizer (compound fertilizer 750 kg/hm^2, organic fertilizer 1.5×10^4 kg/hm^2), deep tillage
3	Fertilizer (compound fertilizer 600 kg/hm^2)
5	Fertilizer (compound fertilizer 600 kg/hm^2), shallow tillage
9~11	Interplanting green vegetable
10	Irrigation, deep tillage
11	Fertilizer (compound fertilizer 545 kg/hm^2)

(The N concentration of the compound fertilizer is 15%, the organic material content in the organic fertilizer is 25%, and the N concentration is 0.45%.)

In addition, the spatial data such as the land use maps of different years, soil type maps of Guoyuan village are necessary, which are used to calculate the pollution load in agricultural runoff based on hydrologic impact assessment model. These data were provided by local village committee or obtained through remote sensing image interpretation. Meteorological data such as the temperature, rainfall data of recent thirty years were provided by the weather station of Pudong district.

3.3 Study approach

The study area is a relatively independent agro-ecosystem. The compound management mode and agricultural management practices directly impact on the soil-water NPS nitrogen pollution in the area around peach orchard. Modeling allows the complex links among soil physical, chemical and microbial processes that underpin nitrification, de-nitrification and decomposition to be examined. Therefore, this paper quantitatively calculates and analyzes the mechanism of nitrogen circulation in soil based on DNDC model, and estimates the nitrogen content in soil runoff by using NPS pollution load model L-THIA. The measure values of monitoring locations are compared with the simulating values in order to analyze in detail the mechanism of nitrogen dynamic change in agro-ecosystem and the relationship between the compound management model and the pollution characteristics of the surface and groundwater.

3.3.1 Biogeochemical model The DNDC model is a mechanism model, which is used to simulate and assess the emission of N_2O, NO, N_2 and CO_2 from agro-ecosystem [10-13]. Although this model was initially created according to the growing conditions of America, it has been verified in many agro-ecosystems such as grassland, farmland and forest ecosystem in many countries such as America, Canada, India, European, China and New Zealand and so on. DNDC model, which is considered as one of the best biogeochemical models [14], is able to simulate the emission of a fixed point and also can assess the emission of a region. The model has reasonable data requirement and is suitable for simulation at appropriate temporal and spatial scales. Tab.2 shows the parameters and associated values required by DNDC model in this study.

Table 2. The parameters and partial values in DNDC model

	Parameter	Value
Climate information	Temperature & precipitation	Daily data (omission)
	N content in rainfall (mg N/L)	2.53
	NH3 content in the air (ug N/m^3)	0.06
	CO_2 content (ppm)	350
Soil background	Bulk density (g/cm^3)	1.33
	Texture	clay

information	SOC (kg C/kg)	0.022
	PH	6.8
Crop information	Crop	Peach, green vegetable
	Rotate mechanism	Interplanting
	Growth parameter	Each organ (omission)
Management information	Times of tillage	3 times a year
	Fertilizer amount (kg N/(hm^2•a))	Compound fertilizer:374 Organic fertilizer:150.62
	Times of irrigation	Once a year
	Portion of straw returning	Peach 100% Green vegetable 0%

DNDC model can simulate the biogeochemical process under a certain management of production and learn about soil nitrogen pollution and the nitrogen flux during the process. It also can analyze the effects of different management measures such as fertilization and tillage on soil organic carbon content [15]. This provides the basis for further quantitative analysis of nitrogen load in agricultural runoff.

3.3.2 NPS pollution load model Agricultural runoff is the key factor to quantify and simulate agricultural NPS pollution. The concentration of output pollutants in runoff and the pollution load per unit area are related with the regional climatic conditions [16]. Long-term hydrologic impact assessment model (L-THIA), which is integrated with GIS, can estimate the average annual runoff and NPS pollution load based on land use type, soil type and daily rainfall for at least thirty consecutive years [17].

The adjacent western and southern areas of the study area are also peach orchards, and the northern and the eastern areas are residential areas. Survey and experimental data show that the soil nitrogen is carried over by rainfall and irrigation water to enter the river via surface runoff, resulting in different levels of water eutrophication. The nitrogen content in the runoff is analyzed via simulating by L-THIA model. The migration of nitrogen is estimated comprehensively and quantitatively by using DNDC model. The results are tested and compared with the measured values to explore the mechanism of the nitrogen circulation in agro-ecosystem, and learn about the nitrogen pollution load in surface and groundwater under current field management practices and local climate conditions.

4 Results and Discussion

4.1 The analysis of Water samples

The total nitrogen and nitrate nitrogen contents measured in water of the peach orchard are showed in Fig.3. Obviously, the nitrogen content is widely different between surface and groundwater. The nitrogen content in groundwater is about 1 to 2 times higher than that in surface water. The standard error of nitrogen content in surface water is smaller than that in groundwater, which represents that the nitrogen content in surface water changed little among all the samples. In particular, as shown in Fig.3, total nitrogen in surface water measured in May 2010 (14.57 mg/L) is significantly higher than that in other times, which is probably due to large amount of fertilizer application in May. Besides, the rainfall of the day when we sampled reached 45.5 mm (22nd May). However, the variance of nitrogen content in groundwater is very distinct: the total nitrogen content ranges from 0.24 to 49.23 mg/L; the nitrate content from 0.18 to 45.41 mg/L.

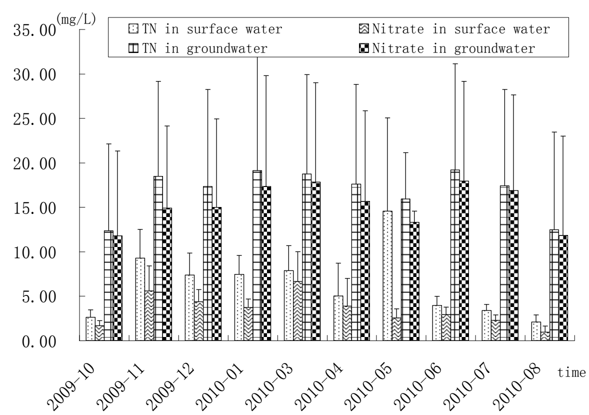

Fig. 3. Nitrogen content in water of the peach orchard

Furthermore, we learn about the spatial variation features of nitrogen content in water body reference to Fig.2 and Fig.3. The nitrogen content in surface water samples around the orchard is relatively low, while those near the main ditch are higher. This distribution pattern of nitrogen content indicates that fertilization probably is the main cause resulting in superfluous nitrogen in water. As for groundwater, the nitrogen content is lower in residential area and higher in the orchard. These characteristics are in accordance with that agricultural production activities contribute to NPS nitrogen pollution in water body.

The measured results state that monthly average total nitrogen content of surface water reaches 6.3 mg/L, higher than the value of surface water Grade Ⅴ (≤ 2.0 mg/L) according to Chinese surface water quality standard (GB 3838-2002) (in terms of total nitrogen), which means the surface water in study area is polluted seriously and belongs to surface water Grade Ⅴ based on the current water quality assessment method in China [18]. For groundwater, 16.85 mg/L of monthly average total nitrogen is also much higher than that of the surface water Grade Ⅴ(≤ 2.0 mg/L). The monthly average nitrate nitrogen in groundwater is 15.24 mg/L which falls in to groundwater Grade Ⅲ (≤ 20 mg/L) according to Chinese groundwater quality standard (GB/T14848-93) (in terms of nitrate). However, 20% of groundwater samples belong to water Grade Ⅴ (> 30 mg/L) in terms of nitrate nitrogen content. It is summarized that groundwater in the district belongs to groundwater GradeⅤ, far lower than surface water GradeⅤ. The water pollution in this area is serious, which is consistent with the conclusion by Huang Hongyan [8].

4.2 Characteristics of NPS soil nitrogen pollution

To explore the characteristics of NPS nitrogen pollution in the peach orchard, DNDC and L-THIA model are employed to simulate C, N circulation in this agro-ecosystem. Climate, management measures such as fertilization application and soil input variables for DNDC are listed in Tab.2. Field data used for all of the variables are listed except for clay fraction and depth of the soil water retention layer. Here default values are used. In this study, the nitrogen input that come mainly from the organic fertilizer, fertilizer, nitrogen sedimentation in rainfall, totalizes to 548.53 kg N/(hm^2•a) according to DNDC. The output nitrogen is 339.48 kg N/(hm^2•a) in this agro-ecosystem including crop absorption, the volatilization of NH_3, N_2O, NO, N_2. So, it is calculated that the yearly nitrogen flux change or the net increased nitrogen in soil is about 209.05 kg N/ (hm^2•a) based on simulation.

In addition, the simulated results of DNDC model show that average total nitrogen content from different soil depths is 1887.2 kg/hm^2, while the field measured value in June 2010 is 1728.7 kg/hm^2. The fitness of the two parts is up to 91.6%, which suggests that the simulated results of the C, N circulation in peach orchard by DNDC is credible and valuable for quantificational C, N monitoring.

L-THIA model is used to simulate the runoff depth, total nitrogen & nitrate nitrogen load based mainly on the local climate and land use type data. Fig.4 displays the runoff depth map, total nitrogen & nitrate nitrogen load maps of the peach orchard derived from L-THIA.

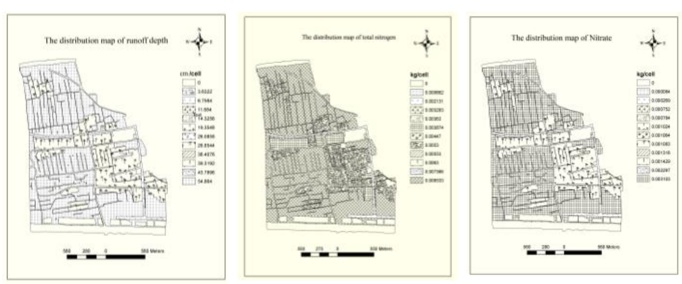

Fig. 4 The distribution maps of runoff depth, TN & NO_3^-N

Simulations show that the average annual runoff depth of the peach orchard is 190 mm. As it shows in Fig.4, the maximum nitrogen pollution load is in orchard when compared with other land use types, where the output of total nitrogen is 0.0085 kg/cell (each cell is 3 m * 3 m), or 9.44 kg/hm^2, and the output of nitrate nitrogen is 0.0031 kg/cell, or 3.44 kg/hm^2.

The estimated values from L-THIA model represent the average nitrogen output in a region for a long time, reflecting the average nitrogen pollution level. While the measured values of nitrogen in surface water depend on the crop growing stages, farm management practices and climatic conditions. Comparing the measured values with the simulation results from L-THIA model, the results indicate that simulated total nitrogen content in runoff accounts for 78.08% of measured values in surface water, and nitrate nitrogen covers 52.28% of measured values. Hence, it may be reasonable that there are other nitrogen sources affecting the surface water pollution besides the soil we have known. In addition, the compound management mode of interplanting vegetables in peach orchard promotes the soil nitrogen circulation and increases nitrogen content to some extent. However, the mode is not considered in L-THIA model, which may result in the simulated values littler than it is.

Shanghai, situated in the Yangtze River Delta region, owns a plentiful water source and its soil is with higher nitrogen content, all of which cause serious NPS nitrogen pollution [26]. The average annual rainfall is 1100 mm with most falling from July to September in Shanghai and nitrate could descend 1 cm in soil with about per 2 ~ 3 mm precipitation [19]. According to this rule, 209.05 kg N/(hm^2•a) of the net increased nitrogen content in the peach orchard soil would go down 330 ~ 550 cm at differently speed. In this study, the samples in groundwater are from the wells whose depth is 4 m. Therefore, the descending nitrogen in soil from agricultural activities might be one of the main reasons resulting in the higher nitrogen concentration in groundwater. Furthermore, taking 11% as the soil seepage and runoff nitrogen loss occupying total nitrogen input [10], the detailed analysis based on L-THIA model and DNDC simulation shows that 1.7% of annual net increased nitrogen goes to the surface water via the soil runoff, 5.8% to the groundwater via soil leaching loss. Thus, 3.5% is cumulative in the soil leachate. In this case, here about 19.2 kg N/(hm^2•a) would enrich nitrogen in groundwater so much as resulting in pollution.

5 Conclusion and Discussion

The NPS nitrogen pollution in surface and groundwater is quantitatively analyzed in detail in this paper based on the monitoring location measured data, DNDC and L-THIA.The surface water falls into Grade Ⅴ in terms of nitrogen content and the groundwater quality belongs to Grade Ⅴ surface water standard, while the nitrate content in groundwater belongs to Grade Ⅴ groundwater standard according to national associated standard,

The fertilizer application in agricultural production is the main pollution source of surface and groundwater in the study area. The mechanism of migration and output of nitrogen in the process is directly related to NPS pollution of the groundwater where nitrogen content variation is wide. It cannot but mention that, there is the same agro-ecological environment around the study area with the same peach orchards and residential areas. The study area is a relatively independent region for the river separates it from the surrounding environment. This study analyzes the nitrogen characteristics of NPS pollution by taking the agro-ecosystem of peach orchard as the case. It is difficult to absolutely divide the boundary between the study area and the conjoint area because of the complexity of the environment of agricultural soil and water, which may affect the accuracy of results. Meanwhile, the same agro-ecosystems surrounding the peach orchard suggests that the results of this study can reflect the status of NPS nitrogen pollution for such agro-ecosystem. In particular, the simulated values, the measured values and the speculated or predicted values of soil nitrogen leakage should include or cover the NPS pollution from some possible fuzzy boundaries. In addition, soil drainage changing with rainfall intensity and duration is one of the main reasons to cause groundwater contamination although the critical cause of nitrogen pollution is heavy fertilizer application. Therefore, to improve fertilization strategy is an effective means to reduce nitrogen pollution. Some measures such as adjusting the fertilization structure, the ratio between compound fertilizer and organic fertilizer, the proportion of nitrogen, phosphorus and potassium in fertilizer and so on should be done to control and stable the amount of nitrogen fertilizer.

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