Optimization strategy integrity for watershed agricultural non-point source pollution control based on Monte Carlo simulation

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Abstract. This study has established a set of methodological systems by simulating loads and analyzing optimization strategy integrity for the optimization of watershed non-point source pollution control. First, the source of watershed agricultural non-point source pollution is divided into four aspects, including agricultural land, natural land, livestock breeding, and rural residential land. Secondly, different pollution control measures at the source, midway and ending stages are chosen. Thirdly, the optimization effect of pollution load control in three stages are simulated, based on the Monte Carlo simulation. The method described above is applied to the Ashi River watershed in Heilongjiang Province of China. Case study results indicate that the combined three types of control measures can be implemented only if the government promotes the optimized plan and gradually improves implementation efficiency. This method for the optimization strategy integrity for watershed non-point source pollution control has significant reference value.

1. Introduction
Agricultural non-point source pollution refers to the surface and groundwater environmental pollution caused when sediment, nutrients, pesticides and other pollutants in farmland are integrated into water through surface runoff, interflow, farmland drainage and underground seepage during the precipitation or irrigation processes[1]. These pollutants are derived primarily from farmland fertilization, pesticides, livestock, aquaculture and rural residents. With the acceleration of modernization in rural areas, farm production and lifestyles have changed gradually, and the contaminant components of waste have become increasingly complex. Agricultural non-point source pollution is the most significant and most widely-distributed non-point source pollution, and is becoming one of the primary causes of the deterioration of the ecological environment in rural areas[2]. This has severely restricted the sustainable development of agriculture and the rural economic environment[3]. In order to promote the stable and rapid development of the rural economy and realize harmonious development between man and nature, an integrated study of agricultural non-point source pollution is therefore immediately necessary[4]. Implementing the optimization strategy integrity for pollution control can improve governance efficiency[5]. Additionally, it has significant value in both theoretical and practical applications[6].
2. Research method
Based on actual conditions, a field study was conducted in the northeast area of China. The survey primarily included the basic conditions of agricultural land such as position, topography, range, elevation, soil type, planting type and area, etc. A survey of nitrogen and phosphorus loss was also conducted. Based on the characteristics of the area including concentrated rainfall, high soil nutrient content, strong soil freezing and thawing and serious loss of nitrogen and phosphorus, the Ashi River watershed was chosen as a case study, and various proposed measures for the governance of agricultural non-point source pollution were investigated. A software model was then constructed to simulate the optimization scheme.

The general idea is as follows: First, the source of watershed agricultural non-point source pollution is divided into four aspects, including agricultural land, natural land, livestock breeding and rural residential land. Secondly, different pollution control measures at the source, midway and ending stages are chosen. Thirdly, the optimization effects of pollution load control in three stages are determined based on Monte Carlo simulation.

The overall technical route is shown in figure 1. The research procedures are as follows. In figure 1, different “X” values indicate different scenarios. Rlb and Rub indicate the upper and lower bounds of reduction rates.

- Collate each optimized measure of control efficiency as the input parameters of the software model.
- Select six optimization measures according to specific geographic, topographic and climatic conditions of the case study area.
- Simulate the corresponding optimization results of each scenario with MATLAB software based on Monte Carlo simulation and adjust the scenario model input parameters. Obtain the corresponding output parameters of each optimization scheme.
- Integrate output parameters. Finally, select the best optimization schemes by comparison to provide technical support for the formulation of watershed agricultural non-point source pollution control measures.

The primary collected control measures are as follows; each measure has upper and lower bounds of the rate of nitrogen reduction:

- Source control measures. These primarily include N\textsubscript{11} centralized treatment of rural sewage, N\textsubscript{12} centralized treatment of rural life garbage, N\textsubscript{13} scale of livestock and poultry, N\textsubscript{14} grain for green, N\textsubscript{15} soil improvement technology, N\textsubscript{16} reasonable application of livestock manure, N\textsubscript{17} testing soil for formulated fertilization, N\textsubscript{18} water-saving irrigation farmland, and N\textsubscript{19} agricultural structure optimization.
- Path control measures. These primarily include N\textsubscript{21} technique of artificial pond, N\textsubscript{22} oxidation pond technology, N\textsubscript{23} artificial wetlands technology, and N\textsubscript{24} vegetation buffer.
- River bank control measures. This primarily include N\textsubscript{31} water shore buffer.

A simulation of an optimization scheme of total nitrogen pollution was chosen as an example. The reduction plan for total nitrogen includes the following six scenarios.

- Choose common optimization measures and build optimization scenario 1——TN_SA1: N\textsubscript{13} + N\textsubscript{15} + N\textsubscript{17} + N\textsubscript{23} + N\textsubscript{31};
- Choose policy guidance optimization measures and build optimization scenario 2 — — TN_SA2: N\textsubscript{13} + N\textsubscript{14} + N\textsubscript{16} + N\textsubscript{23} + N\textsubscript{24} + N\textsubscript{31};
- Choose optimization measures in which farmers can actively participate and build optimization scenario 3——TN_SA3: N\textsubscript{12} + N\textsubscript{16} + N\textsubscript{18} + N\textsubscript{21};
- Choose more scientific optimization measures and build optimization scenario 4——TN_SA4: N\textsubscript{13} + N\textsubscript{16} + N\textsubscript{19} + N\textsubscript{22} + N\textsubscript{23} + N\textsubscript{31};
- Choose efficient cutting optimization measures and build optimization scenario 5 — — TN_SA5: N\textsubscript{12} + N\textsubscript{15} + N\textsubscript{23} + N\textsubscript{31};
3. Results and discussion

The optimization results of total nitrogen pollution were respectively simulated based on Monte Carlo simulation. The probability distribution is shown in figure 2 and the optimization effect of the distribution box is shown in figure 3. The optimization effects of the total nitrogen pollution situations are respectively distributed as numbers 1 through 6 in 67, 58, 65, 68, 52, and 68 which can be seen in figure 2 and figure 3. The optimization effects of Scenario 2 and Scenario 5 are relatively good. The optimization effects of Scenario 6 are relatively poor. The optimization effects of scenarios 1, 3 and 4 are similar and fall in the middle of the observed efficacies.

The optimization effects of efficiency and policy-oriented optimization schemes are relatively good. The optimization effect of source control optimization is relatively poor. Due to the existence of a certain reading error, errors exist between the average value displayed in the box diagram and the normal distribution, but overall optimization results similar.

Figure 1. Research diagram for agricultural non-point source pollution control.
Figure 2. Normal distribution of the optimization effect of watershed agricultural non-point source total nitrogen pollution.

Figure 3. Box figure of optimization effect of watershed agricultural non-point source total nitrogen pollution.
The optimization results of each nitrogen pollution condition was respectively simulated based on Monte Carlo simulation. The computed optimization effect of each total nitrogen pollution scenario is shown in Figure 4. Results indicate average optimization reduction. The optimization effects of scenarios 1 through 6 are 66.47, 51.45, 67.46, 68.54, 50.78 and 88.55, respectively. The results are similar to analytical results presented in the normal distributions, box figures and histograms.

Analysis of Figure 2, Figure 3 and Figure 4 indicates that the order of optimization effects induced by the six scenarios is as follows: S2, S5>S1, S3, S4>S6. In scenario 2 and scenario 5, source control measures, path control measures and riverbank control measures combined. Therefore, in the governance process of watershed agricultural non-point source pollution, three types of control measures should be combined. Source control measures require relatively low cost; however, it is difficult to control the agricultural non-point source pollution in watersheds with source control measures alone. Scenario 3 indicates that farmers are actively involved in the optimization measures, source control measures and path control measures combined. The execution rate of this scenario is relatively high but each optimization measure is not sufficient and lacks scientific and policy guidance. Scenario 1 and scenario 4 represent the combination of three types of control measures. Scenario 1 represents a common optimization measure, and lacks scientific and policy guidance. Scenario 4 provides a more scientific optimization measure, but the execution rate of this scenario is relatively low and cannot be widely used across a large area.

4. Conclusion
Based on the analysis of optimization scenarios regarding total nitrogen pollution, the governance of watershed agricultural non-point source pollution requires policy guidance and more efficient optimization measures. The proposed plan can be implemented only if the government promotes the optimized plan gradually improves implementation efficiency. This simulation scheme is feasible and has significant reference value.

Figure 4. Histogram of optimization effect of watershed agricultural non-point source total nitrogen pollution.
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