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A decision-support system for cropland irrigation water management and agricultural nonpoint sources pollution control

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ABSTRACT

In this paper, an agricultural water and nonpoint sources pollution management decision support system (AWPM) was developed in Tongzhou district and Daxing district, Beijing, China, where is relatively developed in economical but has severe water-lacking and water quality problems. The AWPM provided a dynamic decision to managers on irrigation water management, and a decision scheme system on agricultural nonpoint sources pollution control from different perspective based on hydrological models and geographic information system in the study areas. The AWPM was designed a user-friendly interface, and the results adopted from AWPM can help managers make sound decision in the suburb of Beijing and similar areas.

Keywords: Decision-support system; Irrigation water management; Agricultural nonpoint sources pollution; Sustainable development

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1. Introduction

The problem of the deterioration of water quality and the shortage of water quantity is urgent in different parts of the world [1]. Agriculture plays a major part to this problem, whose activities are the main sources of water pollution to surface water and groundwater in rural areas [2–5]. It is important for the manager to realize the relationship of clear production and agricultural sustainable development. Traditionally, farmers preferred to use excessive application of fertilizers and water to gain higher yields, which resulted in nutrient contamination of water and soil bodies, as well as waste of water. How to reasonably schedule the irrigation water amount and fertilizer needs to be researched. Improving irrigation management is important not only for enhancing agricultural efficiency, but also for an efficient and environmental water use through integrated water management practices [6]. Moreover, the agricultural nonpoint pollution risk control is also need to be researched. Considering for the comprehensive

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planning of socioeconomic development and eco-environment protection, the decision support system (DSS) for sustainable development is desired which are capable of supporting complex decision making and of solving semistructured or unstructured problems through an accessible computer interface that presents results in a readily understandable form [7,8].

China is a large scale of agricultural and irrigation nation, where agricultural water accounts for about 62% of the national total water consumption. However, the shortage of water resources has become a serious restriction of economy development and sustainable development in China. Therefore, the issue of how to allocate water resources efficiently becomes more and more critical in China [9]. Moreover, the spatial and temporal variations exist in agricultural water management systems. For the consideration of both precipitation variation and sustainable development, the optimized agricultural water irrigation schedule needs to be defined in intensive irrigation areas. Especially, how to obtain the maximum economic benefits with limited water resources is an urgent problem to be solved. In China, agricultural nonpoint pollution is one of the important factors that cause the current water environment pollution. Main environmental problems are in this respect of eutrophication caused by high loads of phosphorus and/or nitrogen [10]. Extensive soil disturbance and application of fertilizer and manure in agriculture cause nonpoint sources (NPS) losses of soil and nutrients such as nitrogen and phosphorus. These nutrients can lead to eutrophication or nuisance algal growths due to their high concentrations, causing the increased turbidity and taste and odor problems in the receiving water bodies [11]. In addition, many kinds of pollutants, such as nitrogenous pollutants, especially those in the form of very soluble nitrate (i.e. NO^3-N, NO^2-N, and NH^3-N) are accumulated on the surface of roadways and are swept into nearby waterways when rain falls, which can contaminate water and make it unsafe for drinking [12–14]. Because of the growing demand for water of both sufficient quantity and satisfied quality, irrigation water resources optimization allocation management and agricultural nonpoint sources pollution research in intensive irrigation area are at the forefront in formulating sustainable development policies for many countries [15,16].

DSS has become an important technical mean of researching the irrigation water management and controlling agricultural nonpoint sources pollution. A DSS, which can be defined as computer-based tool used to support complex decision-making and problem solving [8], is integrated, usually consisting of various coupled models, databases, and assessment tools embedded in a user-friendly interface [8,17,18]. DSSs have been applied in many cases, and the previous studies have seen the advances in DSS supporting for the water management and nonpoint sources pollution control [19–28]. However, among the previous researches about water management DSS, few researches have irrigation water optimization model designed in intensive irrigation area, especially for the dynamic irrigation optimal model. And the researches on the agricultural nonpoint sources pollution are few. The decision-making processes associated with the utilization of irrigation water resources and agricultural nonpoint sources pollution control are complex, requiring thorough consideration and analysis. The consequences of water policy decisions are of interest both to specialists involved in design, construction, and operation of irrigation water resources systems and agricultural nonpoint sources pollution control system and, more importantly, to those affected by such decisions [20]. So it has great significance to develop a DSS combining irrigation water dynamic optimization management and agricultural nonpoint sources pollution control for agricultural managers and database maintenance administrators within an intensive irrigation area.

In this study, we aim to develop a DSS (an agricultural water and nonpoint sources pollution management decision support system [AWPM])-integrated irrigation water management and agricultural nonpoint sources pollution control, and the developed AWPM was applied in Tongzhou and Daxing districts, Beijing, China. The study entailed several elements. First, we presented a dynamic irrigation water management nonlinear programming model and the algorithms in the AWPM, and the AWPM can show optimal management measures of irrigation water dynamically only need to input basic parameters when login as the identity of the managers; second, we constructed a large agricultural nonpoint sources pollution control system based on Geographic Information System (GIS) and hydrological models in the study areas; third, we designed a user-friendly interface that allowed ordinary users to obtain designated information and effective assistance in the AWPM; fourth, the DSS presented in this work had been tested by solving a real-life problem. The AWPM can also help managers make sound decision in similar areas.

2. Overview of the study area

The study areas are Tongzhou (116°32′–116°56′E, 39°36′–40°02′N) and Daxing districts (116°13′–116°43′E, 39°26′–39°51′N) as Fig. 1 shows, which located in the

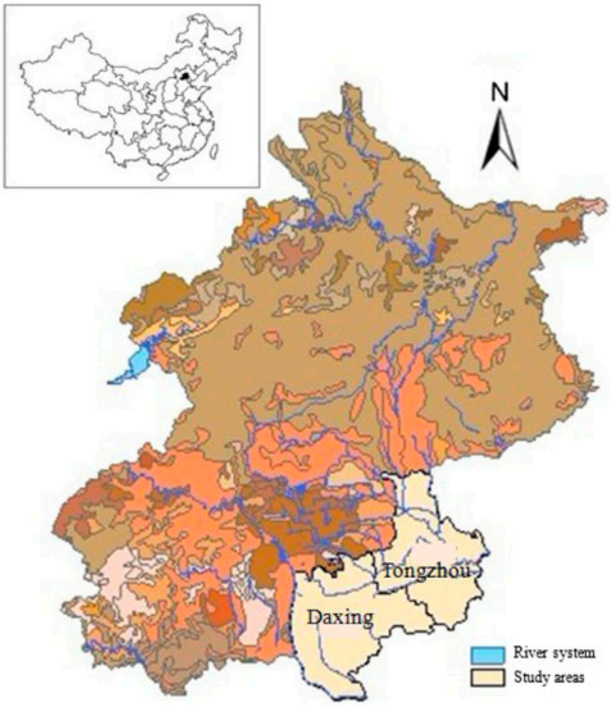


Fig. 1. The study area.

southeast of Beijing, the capital of China. Tongzhou and Daxing districts are low-lying, with many rivers converging together. In the two districts, the quaternary soil is widely distributed with large thickness, and the aquifer is better. The major soil texture types of the two districts are light loam, sandy loam, and sandy soil. The average annual precipitation rainfall capacity and evapotranspiration capacity are 591.3 and 1164.4 mm, respectively. Tonghou and Daxing districts' food, eggs, and meat are the main supply base to Beijing. However, the two districts' water resources shortage is severe. How to obtain the agricultural biggest economic benefits with limited irrigation water supply is the problem to be solved. Agricultural nonpoint sources pollution is one of the important reasons that influence the water quality of Tongzhou and Daxing districts. For many years, the sewage of Hui River and Liangshui River flowing through Tongzhou and Daxing makes the two districts' surface water polluted, and then, most groundwater in the districts would be polluted if using the polluted surface water to irrigate crops. A large number of untreated urban sewage coupled with excessive amounts of pesticides and fertilizers are discharged into river and soak away, which leads to the districts' water environmental capacity lack, the drinking water sources is seriously polluted, and the shallow groundwater has been polluted to varying degrees. It seriously restricts the healthy development of the social economy of the two districts. The main factors that limit the development of Tongzhou and Daxing districts are the shortage of water resources, the pollution of surface water and the groundwater levels' drawdown. So it is of great significance to develop a DSS that can optimally deal with irrigation water management of typical crops and agricultural nonpoint sources pollution issues comprehensively and visually in Tongzhou and Daxing districts.

3. Method

There are three parts in this section: data collection, irrigation water management, and agricultural nonpoint sources pollution control. Based on basic data and their analysis, the decisions for irrigation water optimal allocation schemes will be obtained through solving the nonlinear dynamic programming model, and the solutions from some hydrological models for agricultural nonpoint sources pollution control were obtained, and most of them were shown in the form of GIS. The content of this part is the basis for the decision schemes of irrigation water optimal management and agricultural nonpoint sources pollution control, as well as the data and theory basis of AWPM.

3.1. Data collection

AWPM's needing data include the following: meteorological data (temperature, wind speed, radiation, precipitation, evapotranspiration, relative humidity, etc.), hydrogeology data (aquifer hydrogeology data, terrain and river network information, the level, land use situation, etc.), soil data (soil type and granulometric composition data, organic matter content, planting structure, etc.), water quantity and quality data (irrigation and fertilization information, quality of surface water and groundwater), agriculture, breeding industry, industry wastewater information and so on. The data mentioned previously were collected by investigating the study areas, referring to statistical yearbooks, measuring the field experiments from year 2005–2010, which is the most important way to obtain data and construct database. Fig. 2 shows the soil sampling points of Tongzhou district and Daxing district. From these soil sampling points, we can get many basic data about soil that contribute to the development of AWPM, including soil particle composition, soil bulk density, saturated hydraulic conductivity, characteristic curve of soil moisture, the

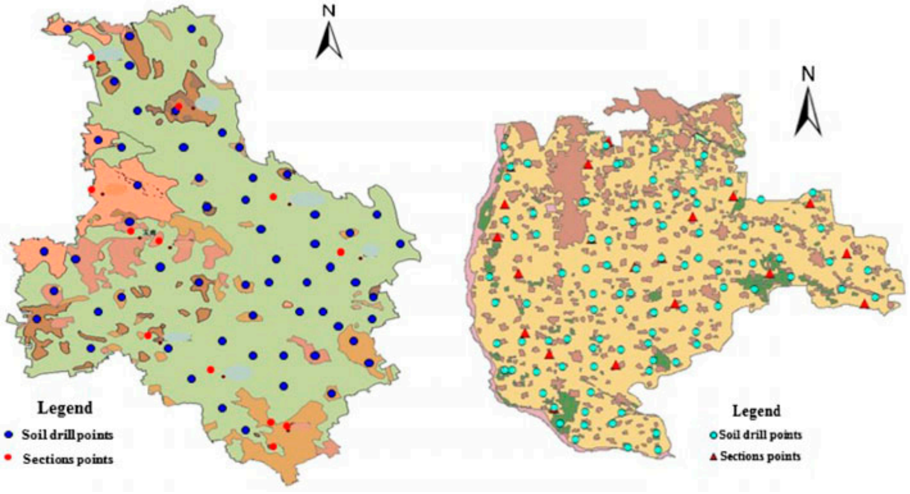


Fig. 2. Soil sampling points of Tongzhou (left) district and Daxing (right) district.

content of total nitrogen, total phosphorus, organic matter, nitrate nitrogen, and ammonium nitrogen.

3.2. Irrigation water management

Irrigation water management is one of the main parts of AWPM, and a nonlinear dynamic programming model about crop optimal irrigation system was developed. The objective of this model is to maximize the total economic benefits by allocating the limited irrigation water to crop's different planting stages. In this study, winter wheat was chosen as our study crop that has three growth stages (sowing—reviving, reviving—heading, and heading—harvest). Field experiments were conducted from 2005 to 2008 on winter wheat in Tongzhou district, from which, some related data were collected, including rainfall data, evapotranspiration data and corresponding yield data, deep seepage and recharge quantity, soil data, such as the soil density in different soil depth, field capacity, wilting point and so on.

Crop Sensitivity Index, varying from different growth stages and different years, is one of the important factors in crop optimal irrigation system. However, many previous studies adopted settled Crop Sensitivity Index to manage irrigation water in different years because of the lack of basic data or to simplify the solution process of irrigation models, which results in inaccuracy irrigation schedule of crops. The acquisition of Crop Sensitivity Index is based on crop water production function and can be obtained through multiple linear regression method based on field experiments from years 2005–2008.

In this paper, Jensen multiplication dynamic model was chosen as crop water production function and the main expression can be described as follows:

$$\frac{Y_a}{Y_m} = \Pi_{i=1}^{n}\left(\frac{ET_{ai}}{ET_{\max i}}\right)^{\lambda_i} \tag{1}$$

where i is the crop growth numbers; Y_a is the crop actual production on unit area, kg/hm^2; Y_m is the crop maximum production on unit area, kg/hm^2; ET_{ai} is the actual evapotranspiration of crop *i*, *mm*; ET_{mi} is the maximum evapotranspiration of crop *i*, *mm*; λ_i is the sensitivity index of crop *i*.

The crop optimal irrigation schedule model in this part is a dynamic model, and the main mathematical expressions are as follows:

(1) Stage variable: different growth stages, $i = 1, 2, 3\ldots$;
(2) Decision variable: the actual irrigation water m_i of different growth stages;
(3) State variable: the water that can be distributed in the early growth stage (q_i) and the total effective water in the crop plan wetting layer (h_i), h_i is the function of soil moisture.

$$h_i = 1000\gamma H(\theta_i - \theta_w) \tag{2}$$

where h_i is the total effective water in the crop plan wetting layer (*mm*); γ is the soil dry density (*g*/*cm*^{3}); H is the depth of plan wetting layer (*m*); θ_i is the average soil moisture; θ_w is the lower bound of soil moisture.

(4) Target function:

$$F^* = max\prod_{i=1}^{n}\left(\frac{h_i - h_{i+1} + m_i + P_i + F_i - K_i}{ET_{maxi}}\right)^{\lambda_i}\cdot Y_m\cdot T \tag{3}$$

where T is crop average price, RMB/kg; h_{i+1}, h_i are the available water in the early stage of $i+1$ and i (mm); P_i is the effective rainfall in the growth stage i, (mm); F_i is the supply of the groundwater in the growth stage i (mm); K_i is the seepage water in the growth stage i (mm).

(5) Constraint conditions:

$$\text{Water amount constraint}\quad 0 \le m_i \le q_i \quad (i = 1, 2, \ldots, n) \tag{4}$$

$$\text{Evapotranspiration constraint}\quad ET_{\min i} \le ET_i \le ET_{\max i} \tag{5}$$

$$\text{Soil moisture constraint}\quad \theta_w \le \theta_i \le \theta_f \tag{6}$$

where j is the type of crop; m_i is the irrigation amount in the growth stage i mm; q_i is the available water supply in the growth stage i (mm); Q is the total water supply (mm); θ_i is soil moisture in the growth stage i.

(6) Starting conditions:

We assume that the soil moisture at the time of sowing is known, i.e. $\theta_1 = \theta_0$, so when $i = 1$, the available soil water amount can be described as:

$$h_1 = 1000H\gamma(\theta_0 - \theta_w) \tag{7}$$

At the first growth stage, the limited irrigation quota constraint can be described as:

$$q_1 \le Q_0 \tag{8}$$

(7) State transition equation:

A: Water distribution equation:

$$q_{i+1} = q_i - m_i + R_i - L_i \tag{9}$$

where q_{i+1}, q_i are the available water distributed in the growth stage $i+1, i$ (mm); R_i, L_i are the increase amount of distributed water and extra water amount (mm).

B: Water balance equation in the soil plan wetting layer:

$$h_{i+1} = h_i + m_i + P_i + F_i - ET_{ai} - K_i \tag{10}$$

"Sequential decision, inverted order recurrence" dynamic programming was used to solve the above model. The recurrence equation is:

$$\begin{aligned} F_i^*(q_i, h_i) &= \max_{m_i}\{(ET_a/ET_m)_i^{\lambda_i}\cdot F_{i+1}^*(q_{i+1}, h_{i+1})\} \\ i &= 1, 2, \cdots, n-1 \end{aligned} \tag{11}$$

$$F_n^*(q_n, h_n) = \max_{m_i}\,(ET_a/ET_m)_n^{\lambda_n} \tag{12}$$

where $F_{i+1}^*(q_{i+1}, h_{i+1})$ is the rest stage's desired value.

3.3. Agricultural nonpoint sources pollution control

Besides irrigation water management, agricultural non-point sources pollution control is another main part of AWPM. The main content of this part is to simulate the pollutants transportation and transformation rule of surface water, soil water, and groundwater based on field experiment and nonpoint sources pollution survey. Fig. 3 shows the overall frame diagram of agricultural nonpoint sources pollution control. Many typical hydrological models and their improvement forms are contained in this part, including SWAT and AGNPS model for simulating surface

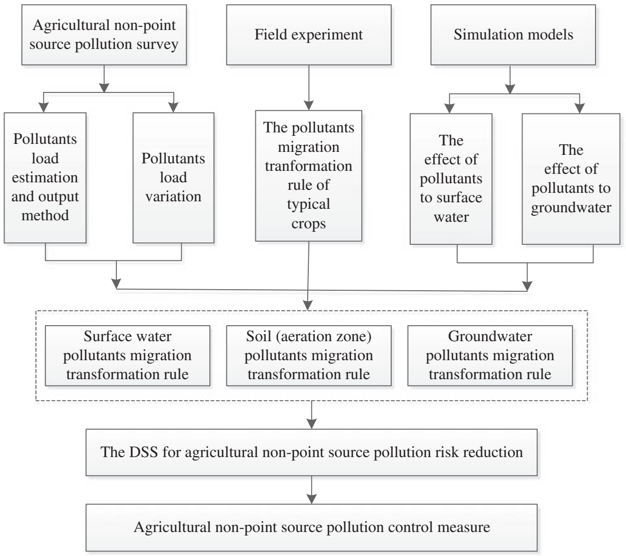


Fig. 3. The overall frame diagram of agricultural nonpoint sources pollution control.

water cycle's hydrological process; SWNTM model (including soil water movement equation, soil thermal motion equation, nitrogen transformation process model, soil solute transport equation, crop growth process model, Penman–Monteith formula, etc.) and RZWQM-CERES (R-C) model for simulating the process of soil water and nitrogen migration and transformation; Modflow model, MT3D model, and DRASTIC model for simulating the process of groundwater and evaluating groundwater vulnerability and risk and so on. Besides hydrological models, there are many methods, for example, entropy weight fuzzy optimization method and analytic hierarchy process are used to evaluate groundwater vulnerability and assess groundwater risk, respectively.

4. Development of the DSS

4.1. Structure

The AWPM was developed based on the above data collection, methods, models, and optimization efforts. AWPM is a highly intuitive, visually based, and user-friendly system. All interfaces are normal Windows style. Most operations can be activated by using a mouse or keyboard to select various buttons, menus, or terms. Fig. 4 shows the basic structure of AWPM. It generally consists of three components: (1) graphical user interfaces that interact with users in a friendly manner and are deliberately developed for multiple levels of end-users such as decision maker, database maintenance administrator; (2) inference engine that drives the knowledge base through reasoning processes; (3) knowledge base, the primary component of the developed AWPM, contains data base, method base, model base, logic base, and water standard base that are used to store data, knowledge, information, and rules. As for the knowledge base, basic information from literature, experts, and empirical observations are transformed and then represented in the knowledge base through knowledge acquisition [29]. Knowledge acquisition, which is always a difficult and time-consuming process, is commonly recognized as a bottleneck in the development of an expert system [30], and effective methods and models of knowledge acquisition are critical in building a DSS. In this study, the models and methods for irrigation water management and agricultural nonpoint pollution control introduced in Section 3 as well as some standards and rules are utilized for establishment of the knowledge base.

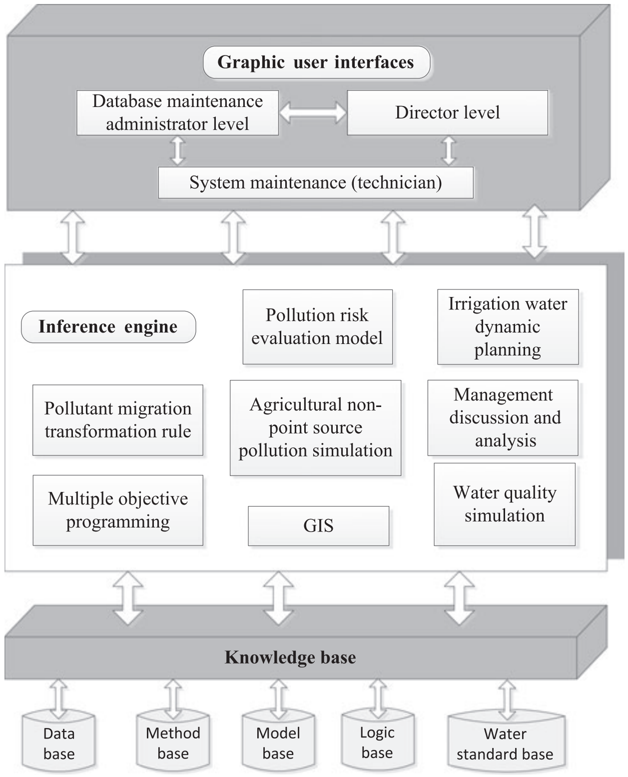


Fig. 4. Basic structure of the DSS.

4.2. DSS operation

Using the AWPM is a simple process. By double-clicking the shortcut to DSS AWPM, the user interface could be seen, click user login. You can login as the identity of the managers or database maintenance administrators, and the user name and password must match. After login, the main subject interface is presented. The total subject includes five contents: research objectives, research contents, research framework, simulation model and DSS. Each content has its child content (Fig. 5, taking simulation model as example). By double-clicking the function module text or the corresponding icon, we can get the corresponding document. For example, if we click "Simulation Model," three child content will be presented in front of us, including the simulation technical road map of surface water, soil water, and groundwater. Fig. 6 shows the main menu of the AWPM, and there are 9 issues and a best management practices in the main menu. If login as the identity of managers, you can operate all the issues, while, if login as the identity of database maintenance administrators, you can modificate all the issues. By double-clicking one issue in the main menu, the users can choose any subissue he/her wants. The right part of the subissue is its introduction, in the form

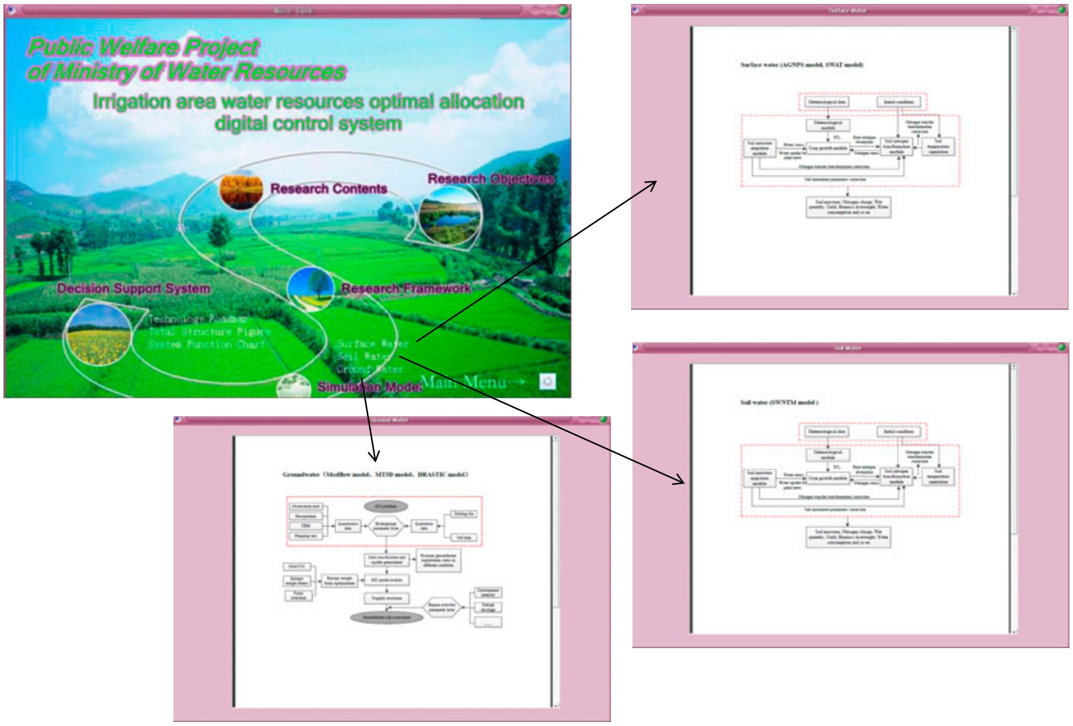


Fig. 5. The main subject inference.

of technology roadmap, integrating words and/or figures, and the left part is the main research content of the subissue. By clicking the pull-down menu, you can choose any subissue you want to get the detailed research content, corresponding results, their analysis and suggestions.

4.3. Decision analysis of AWPM

In this study, a DSS (AWPM) that addresses the planning needs of regional managers was designed. Among the structure of AWPM, two main sections were developed. The first section is irrigation water management, which can optimally develop irrigation

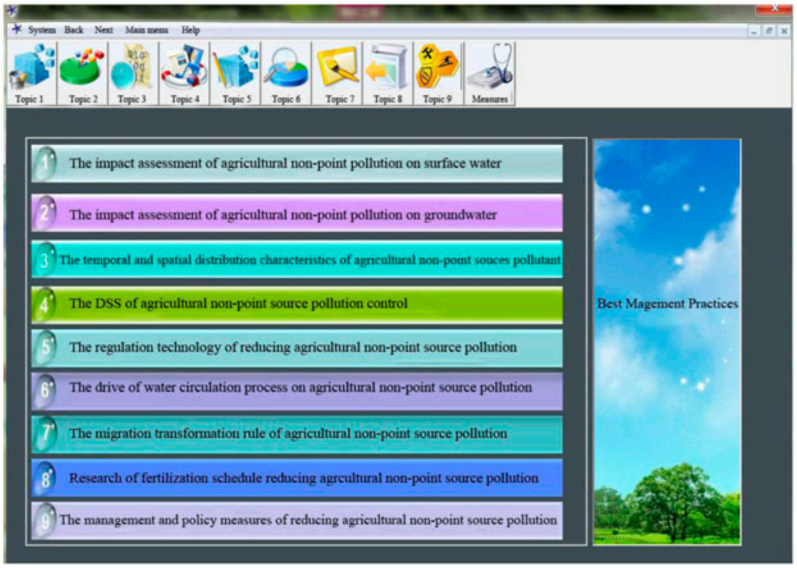


Fig. 6. The main menu.

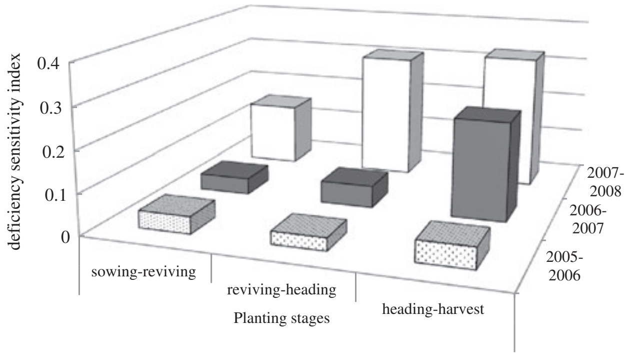
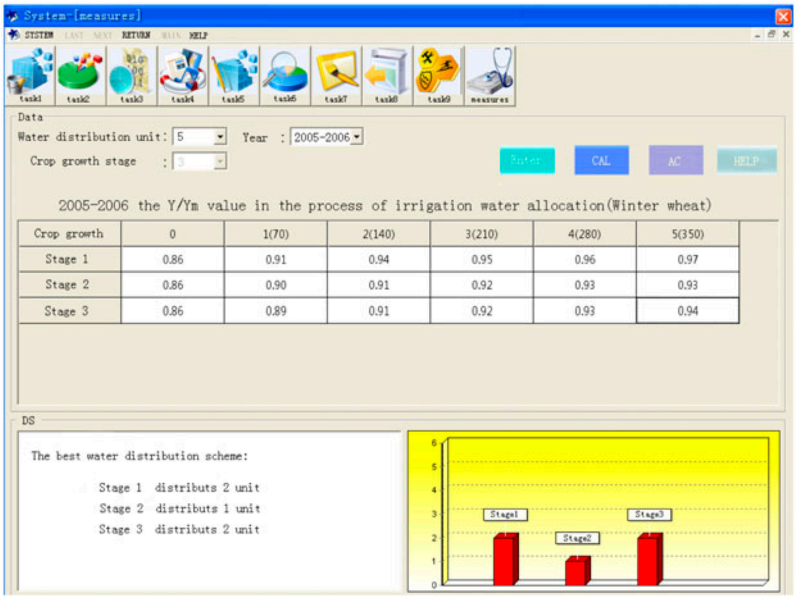


Fig. 7. The deficiency sensitivity index of winter wheat.

water allocation planning strategies with maximum economic benefits. Based on basic data and the corresponding models, the deficiency sensitivity indexes of winter wheat during its different growth stages and different study years were obtained as Fig. 7 shows. From the Figure, we can get that the most water deficiency sensitive period is between heading—harvest (i.e. economic loss in this period is the most serious if water supply to winter wheat is not enough), the second sensitive period is between reviving—heading, and the last is sowing—reviving in the three study years. The deficiency sensitivity index in period 2007–2008 > in period 2006–2007 > in period 2005–2006. The deficiency sensitivity index influence winter wheat's optimal irrigation schedule in Tongzhou district. Table 1 shows winter wheat optimal irrigation schedule from year 2005 to 2008 in Tongzhou district. Besides Crop Deficiency Sensitivity Index, the results are related to meteorological conditions (e.g. precipitation), water resources conditions (e.g. water supply), soil conditions (e.g. soil moisture content, planned moisture layer, etc.) and so on. The decision makers can obtain optimized planning strategies for the study area in different years dynamically according to local condition, tailoring these to his or her perceptions and preferences. Taking period 2005–2006 as example, Fig. 8 gives the dynamic decision process through inputting related basic parameters as Figure shows.

The second section is agricultural nonpoint sources pollution control, which can help decision makers look up the results and strategies that we have made in the specific study area. Although there are nine issues about agricultural nonpoint sources pollution control in the main menu of AWPM, two main parts were contained in summary, including agricultural nonpoint sources risk evaluation and groundwater vulnerability evaluation, the spatial and temporal distribution, transportation and transformation rule of agricultural nonpoint sources pollutants in surface water, soil water, and groundwater. In this study, GIS was widely used in the acquisition, operation, treatment and displaying images of spatial data and geographic data. Therefore, the results in the AWPM can be displayed in front of users more quantificationally and vividly. Fig. 9 shows the main results of agricultural nonpoint sources pollution control. We list some main results of the two parts content only. Fig. 9(a) shows the simulated results of nitrate nitrogen concentration of different soil depth. From the Figure, we can get that the changed trend of simulated values



Water distribution unit: 5
Year : 2005-2006
Crop growth stage : 3

2005-2006 the Y/Ym value in the process of irrigation water allocation(Winter wheat)

Crop growth	0	1(70)	2(140)	3(210)	4(280)	5(350)
Stage 1	0.86	0.91	0.94	0.95	0.96	0.97
Stage 2	0.86	0.90	0.91	0.92	0.93	0.93
Stage 3	0.86	0.89	0.91	0.92	0.93	0.94

The best water distribution scheme:

Stage 1 distributs 2 unit
Stage 2 distributs 1 unit
Stage 3 distributs 2 unit

Fig. 8. The optimal measures of irrigation water.

Table 1
The winter wheat optimization irrigation system from 2005 to 2008 in Tongzhou district

Year	Irrigation number	Irrigation water allocation in different growth stages (mm)			Irrigation quote (mm)	Benefits (RMB/hm^2)	Y/Y_m	Y_m	Y
		a	*b*	*c*					
2005–2006	0	0	0	0	0	9123.25	0.863	5034.07	4344.40
	1	0	70	0	70	9465.76	0.8954		4507.51
	2	0	70	70	140	9759.65	0.9232		4647.45
	3	140	70	0	210	10032.40	0.9490		4777.33
	4	140	70	70	280	10027.11	0.9485		4774.82
	5	140	70	140	350	10476.40	0.9970		4988.76
2006–2007	0	0	0	0	0	8345.46	0.5585	9115.54	3974.03
	1	0	0	80	80	10186.39	0.6817		4850.66
	2	0	80	80	160	11458.01	0.7668		5456.20
	3	0	80	160	240	12756.53	0.8537		6074.54
	4	0	80	240	320	13735.27	0.9192		6540.60
	5	80	90	240	400	14533.21	0.9726		6920.57
2007–2008	0	0	0	0	0	9198.80	0.6507	6731.8	4380.38
	1	0	0	70	70	10642.17	0.7528		5067.70
	2	70	0	70	140	11729.29	0.8297		5585.37
	3	70	0	140	210	14136.78	1.0000		6731.80

Notes: The market price of winter wheat is 2.1 RMB/kg.

a, *b*, *c* in Table 1 represent sowing—reviving, reviving—heading, heading—harvest, respectively.

The irrigating water quota is 70 mm in period 2005–2006 and 2007–2008, and 80 mm in period 2006–2007.

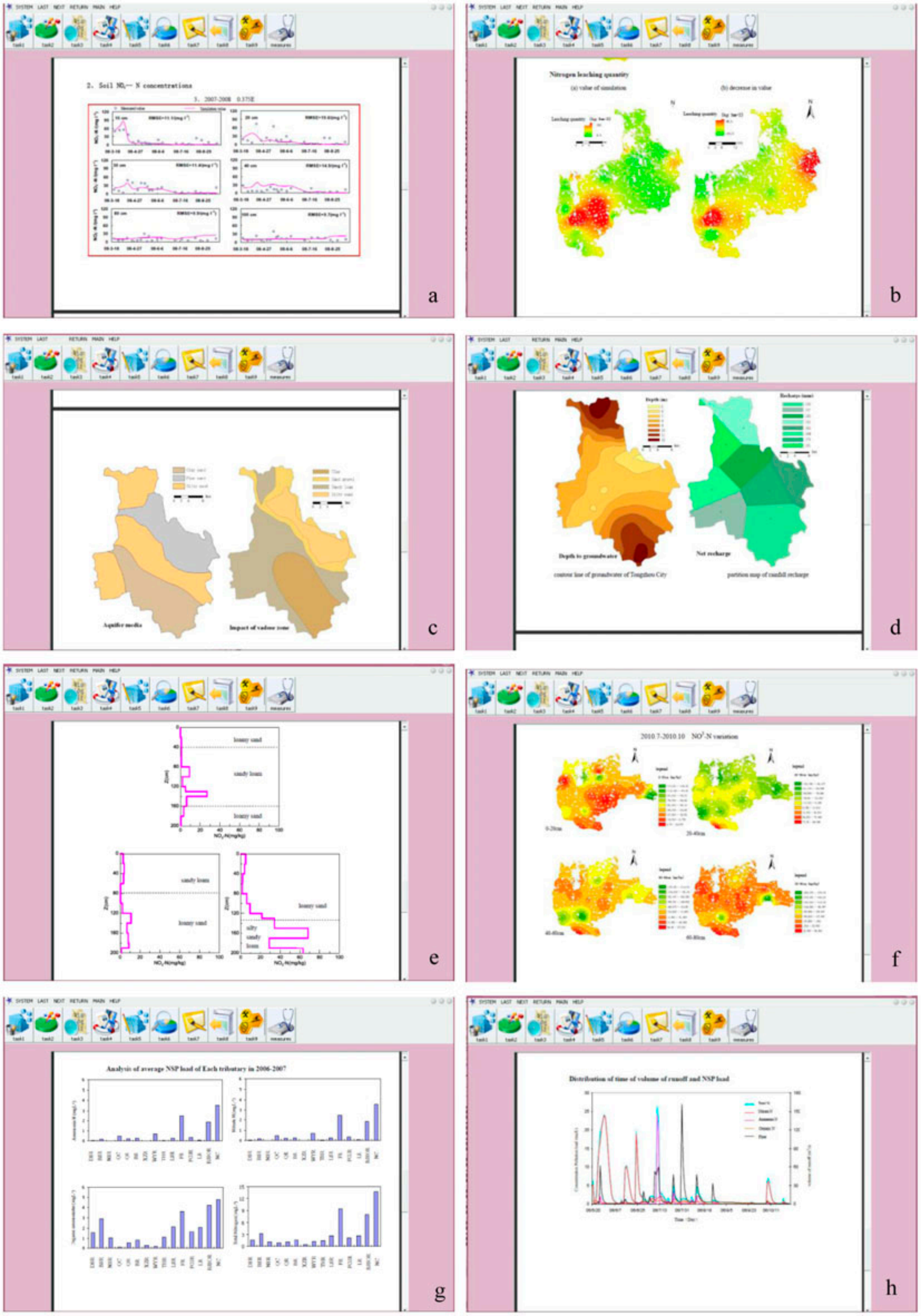


Fig. 9. The main results of agricultural nonpoint sources pollution control.

and measured values is the same, and the simulating effects of each soil depth is preferable except 80 cm soil type, because the concentration of nitrate nitrogen has cumulative phenomenon in this soil type. Fig. 9(a) is the validation of the field experiment data and the method we choose and is the basic study to further

Table 2
Yield, nitrogen uptake and leached amount under different fertilizer conditions for summer corn and winter wheat

Fertilizer conditions	Yield (kg/hm^2)		Nitrogen uptake (kg N /hm^2)		Nitrogen leached amount (kg N /hm^2)	
	Wheat	Corn	Wheat	Corn	Wheat	Corn
N0	2,510	3,420	30.2	52.3	−12.6	2.3
N50	3,530	5,730	59.3	78.4	−5.3	5.6
N100	3,930	6,950	115.5	102.3	−1.0	12.9
N150	4,820	7,570	142.6	167.9	3.2	23.6
N250	5,040	7,810	208.3	183.4	18.3	40.9

Notes: N0, N50, N100, N150, and N250 represent the crops are fertilized with 0, 50, 100, 150, and 250 kg N/hm^2.
There are two fertilizer time: before planting and in their each growth stage.

study of agricultural nonpoint sources pollution control. Fig. 9(b) is the comparison simulation results between optimal and traditional water and nitrogen management of main crops in Tongzhou and Daxing districts and was displayed in the form of nitrogen leached amount. The two pictures present a vivid result that the region with the nitrogen leached amount less than 40 kg/hm^2 accounts for 60.5% of the total region, while, the nitrogen leached amount more than 80 kg/hm^2 accounts for 11.6%, and nearly 28% between 40 and 80 kg/hm^2. The Figure also shows that the nitrogen leached amount can be reduced 1609t compared with traditional water and nitrogen management. Table 2 is the influence of different fertilization schedules on crops' yield nitrogen uptake and leached amount under settled irrigation schedule and the 150 kg N /hm^2 fertilizer rate for winter wheat and 100–150 kg N /hm^2 fertilizer rate for summer corn are regarded as their optimal fertilization schedules, respectively. Fig. 9(c) and (d) are some parameters analysis of model DRASTIC based on GIS for groundwater vulnerability evaluation, including depth to groundwater, net recharge, aquifer media, impact of the vadose zone media. Together with topography, soil media and hydraulic conductivity of the aquifer analysis, the groundwater vulnerability can be obtained based on DRASTIC model. High-risk, middle-risk, and low-risk vulnerable regions account for 14.6%, 58.8%, and 26.6% of the total study region in Tongzhou district. This result can be found in AWPM when choosing corresponding issues. Fig. 9(e) and (f) show the nitrate nitrogen leached amount and their variations in different texture soils and different soil depth. The NO^3–N in upper layer of soil (less than 40 cm) decreases as soil depth increases, while the NO^3–N in lower layer of soil (more than 40 cm) increases as soil depth increases. Fig. 9(g) represents the nonpoint sources pollutant load's spatial distribution of different rivers in the study areas. Nonpoint sources pollutant load mainly occurs in Feng river (FR) and drainage river of Beijing. Taking FR as example, the analysis between pollutants load concentration and runoff was made according to time series method as Fig. 9(h) shows. The loss of nitrogen in farm mainly occurs in flood season, and different forms of nitrogen leached amount are accordant with runoff. So deferring fertilizer time and decreasing fertilizer amount can reduce the burden on environment that caused by nitrogen loss, as well as guarantee crops growth. Among Fig. 9(g) and (h) can reflect the migration and transformation rule of agricultural nonpoint sources pollution in surface water, while (a), (b), (e), and (f) are in soil water, and (c), (d) are in groundwater.

The decision makers can make a further decision depends on the results and strategies in the study areas or similar areas. All the data from the two sections are fully connected in practical use, and this can help decision makers to make more accurate decisions. In the future, we will use new versions of the AWPM that incorporate updates of hardware and relevant modules, which will make the section of agricultural nonpoint sources pollution dynamic. That is to say, new dynamic procedure will be introduced in the second section and the corresponding results and strategies in any similar study area and any year will be show in front of the decision makers if inputting related basic parameters. It is usually necessary to have experienced users involved in using the AWPM to ensure that sensible output is being generated, to understand why certain solutions are selected as optimal, and to implement marginally suboptimal solutions that may actually be preferable [8].

5. Conclusions

In this research, a DSS for cropland irrigation water management and agricultural nonpoint sources pollution control (AWPM) was developed and applied in Tongzhou and Daxing districts, Beijing, China. The AWPM considers multiple sectors within a general decision-support framework. In the AWPM, a nonlinear dynamic irrigation water optimal model and many hydrological models based on GIS were established. The managers can make dynamic decision on irrigation water management and look up any decision information and effective solutions to the designed problems, where we have made on agricultural nonpoint sources pollution control in intensive irrigation area. The results from the AWPM can help to support sustainable management practices in similar areas. Further programming adjustments in the tool will be made more dynamic not only in irrigation water optimization but also in agricultural nonpoint sources pollution control.

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