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Optimal Allocation of Water and Soil Resources in Irrigation Area

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Abstract: The optimal allocation of water and soil resources is of great significance to irrigation schemes and sustainable management. This paper introduces the concept and application of optimal allocation of water and soil resources, and studies the methods and models of optimal allocation of water and soil resources in irrigation schemes, which provides decision-making basis for irrigation scheme planning in irrigated areas.

Keywords: Water and Soil Resources; Optimal Allocation; Irrigation Area; Model.

1. Introduction

Water and land resources are important components of the physical geography system. They are interrelated and mutually restricted. In irrigation planning, especially in large water systems, the optimal allocation of water and soil resources for different crops is a complicated process because of the different soil and environment. China is a water-poor country, especially in the arid area of northwest, the water resource bottleneck is especially prominent. Therefore, in irrigated areas with limited water resources, it is of scientific guiding significance to explore fair and effective research methods for optimal allocation of water and soil resources, and formulate irrigation schemes that improve productivity and protect ecology.

2. Concept and Application of Optimal Allocation of Water and Soil Resources

The optimal allocation of water and soil resources refers to the arrangement, design, combination and layout of regional limited water and land resources in time and space in order to achieve the harmonization of economic, social and ecological benefits under certain conditions. According to the characteristics and system principles of water and soil resources, so as to improve the utilization efficiency of water and soil resources, maintain the relative balance of land ecosystem, and realize the sustainable utilization of water and soil resources [1]. There have been many studies on optimal allocation of water and soil resources aiming at agricultural irrigation water planning. Gorantiwar [2], Li et al. [3], Zhang et al. [4] and Lei et al. [5] took irrigated areas in different regions, analyzed the internal structure according to the characteristics of water and soil resources and requirements for water and soil resources in irrigated area planning, and established the optimal models of main crops in different irrigated areas. Currently, most irrigation water management models only consider crop water demand or economic factors [6], but in many cases, ecological water demand also needs to be considered.

3. Research Methods of Optimal Allocation of Water and Soil Resources in Irrigated Areas

There are two kinds of research methods for optimal allocation of water and soil resources in irrigated areas. One is based on systems engineering theory. The main models include linear programming model, dynamic programming model and multi-objective programming model, which are widely used. The other method is based on system dynamics theory, including system dynamics model [7]. Most of the models are based on building mathematical models to solve the relatively optimal allocation of resource supply and demand. From the perspective of model application purpose, they are mainly aimed at improving irrigation efficiency.

3.1. Linear Programming (LP) Model

Linear programming mathematical model is the earliest and more widely used in the optimal allocation of water and soil resources, but it is mostly used in the static analysis of a single stage and has limitations, so it is often combined with other planning methods to solve the optimal allocation of water and soil resources. For example, Reca et al. [8] considered three independent optimization problems of crop system, irrigation area and whole basin, and established an economic optimization model for hydrological planning of water-scarce irrigation system according to the principle of maximizing marginal benefit of water. Das et al. [9] developed software for optimal land and water allocation using a linear programming model for a multifunctional irrigation project on the Mahanadi River in eastern India. Bai et al. [10] established an optimal planning model for regional water-saving irrigation projects on the basis of considering the available water amount of regional agricultural irrigation, the current situation of water-saving irrigation projects, the adaptability of various water-saving irrigation technologies, comprehensive irrigation quota and mu investment, etc. Sun et al. [11] combined land, water, fertilizer and crop planting patterns in the study area and proposed a multi-objective fuzzy linear programming model for the purpose of optimizing economic benefits, crop yield and labor force, so

as to reasonably allocate water and soil resources and improve water resource utilization, crop yield and net benefits.

3.2. Dynamic Programming (DP) Model

Dynamic programming model is a mathematical method to solve the problem of multi-stage optimal allocation. It is often used to determine the optimal irrigation system of single crop or multiple crops. For example, under the condition of severe water shortage, Shangguan et al. [12] proposed a recursive control model aiming at the overall maximum efficiency of regional optimal allocation of irrigation water resources, which is composed of three levels and can be applied to arid and semi-arid regions. Cui [13] based on the objective of maximizing the total efficiency of the irrigation area, established a two-layer decomposition and coordination model (DP-SDP iterative method) for rice irrigated areas according to the irrigation characteristics, which were used to solve the optimal irrigation system under the condition of inadequate irrigation of a single crop and the optimal distribution of limited water and soil resources among various crops. Yu [14] improved the dynamic programming method and used accelerated genetic algorithm (RAGA) to calculate the model. The model not only optimized the operation of the reservoir, but also considered the optimal allocation of water resources in the irrigated area, which could effectively improve the irrigation efficiency of the irrigated area (especially in dry years).

3.3. Multi-objective Programming Model

Multi-objective programming is a method developed on the basis of linear programming to solve complex problems of optimal decision-making of multiple objectives in resource management [15]. The optimal allocation of water and soil resources usually takes into account several factors such as economic development, ecological protection, and social benefits. In order to achieve the optimization of comprehensive benefits, it is necessary to adopt the multi-objective programming model for water and soil resource allocation. For example, in order to solve the inefficiency and inequity of water resources allocation in the Sierra region of Ecuador, Evans et al. [16] took land, water resources, labor force, population, crops and livestock as constraints to establish a multi-objective comprehensive measurement model that takes into account both efficiency and equity to provide a scheme for optimal allocation of irrigation water resources. In China, Wang et al. [17] fully considered the agricultural available water amount, water source type, crop planting area, irrigation project and other conditions, established the optimal regional agricultural water conservation planning model. Under the condition of guaranteeing the irrigation water consumption of various crops, the development area of various water-saving irrigation technologies with minimum total investment was obtained, so as to achieve the optimal allocation of water and soil resources. From the perspective of water-energy-food nexus, Chen et al. [18] studied and constructed a multi- objective optimal allocation model approach for water and soil resources in irrigation areas, which provides a decision reference for decision making for further comparison and selection of multi-group optimal allocation schemes and quantification of comprehensive benefits.

3.4. System Dynamics (SD) Model

System dynamics is a computer simulation technology that simulates the dynamic behavior of social economy and ecosystem. The research and application of dynamic model is relatively late, but due to its combination of qualitative and quantitative methods, system, analysis, synthesis and reasoning integration, it has gradually become an effective tool for modern scientific decision-making and prediction, so it is widely used in the analysis and dynamic optimization of resource carrying capacity, especially in the evaluation and optimization of resource optimal allocation schemes [7]. The system dynamics model can simulate the dynamic process of the system and solve nonlinear and complex time-varying system problems. For example, Ren [19] established the SD model of coordinated development of regional water and soil resources, and obtained the scale of land development, the corresponding water consumption structure and crop planting structure of Hami City under certain water resource utilization conditions. Tong et al. [20] established the basic tree model of system dynamic flow rate for optimal allocation of regional water and soil resources, and coupled relevant factors such as water demand, water supply, land demand and supply, and ecological environment impact with social, economic and environmental systems into a complex water resource-land resources-social economy-ecological simulation system. The implementation plan of joint allocation and sustainable utilization of water and soil resources in the hilly area of southern Jiangsu is formulated.

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