

Engineering Water Pollution Control System Design Based on Robust Optimization Strategy

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Abstract: Environmental and health problems caused by engineering water pollution have become an important factor restricting the sustainable development of our country's engineering. Our country's engineering water pollution control has the characteristics of diverse structure, multiple objectives, related elements and great uncertainty, which brings challenges to the reasonable and effective development of engineering water pollution control planning. The structural design and technical selection method of engineering water pollution control established in this paper includes two parts: multi-objective robust optimization model and robust analysis framework. Among them, the multi-objective robust optimization model uses Latin hypercube sampling to improve the non-dominated sequencing genetic algorithm to provide an optimal scheme set that takes robustness into consideration for the planning of the engineering water pollution control system. A multi-attribute evaluation index system is constructed in the framework of robustness analysis. Through evaluation and selection of the optimal scheme set, subjectivity of system optimization scheme selection is reduced, and the scientific and quantitative level of scheme evaluation is improved. Based on the uncertainty analysis, key factors and sensitive areas affecting the robustness of the system are identified, which further improves the interpretation and application capabilities of the multi-objective robust optimization model.

1. Introduction

Generally speaking, a system is defined as a whole made up of several components or elements that are interrelated and interact with the environment in which they are located. The collection of subsystems covering the source control, collection and transportation, and end treatment of domestic sewage and rainwater runoff in the engineering water system is defined as the engineering water pollution control system, which mainly includes the engineering sewage and rainwater runoff collection and transportation subsystem, the sewage treatment subsystem to realize centralized sewage treatment, the rainwater runoff control subsystem, and the reclaimed water treatment and transportation subsystem [1]. The above subsystems are the constituent elements of the engineering water pollution control system. In order to deepen our understanding of the concept of the engineering water pollution control system, we can understand the complexity characteristics of the engineering water pollution control system from three aspects: diversity of structure and composition, multiplicity of targets, and correlation between upstream and downstream:

The structure of the engineering water pollution control system can be expressed as: a certain structure or order is formed inside and outside the system through certain material transmission, technical connection, management system and other related relations, thus giving full play to the overall functions of the engineering water pollution control system in the aspects of environment, economy and resources [2]. Each specific subsystem has specific components and structures and embodies different properties, characteristics and functions. At the same time, various sub-systems of



pollution control facilities are continuously innovating and developing their optional technologies, which also makes the engineering water pollution control system have a variety of structures and compositions and is in a long-term dynamic process of construction, development and change [3].

The overall functions and objectives of the engineering water pollution control system are embodied in many aspects such as environment, economy, resources, technology and society, which is a multi-level and multi-functional system. The most basic functional objective is to ensure the quality of the water environment of the project and control the water pollution load. In addition, and it is also necessary to take into consideration the feasibility of cost, the recycling of water resources and nutrients, the reliability and adaptability of technological choices, and the acceptability of the public. At the same time, with the deepening of the cognition of the system uncertainty, in addition to the system's static nominal performance, new demands are put forward on whether the system can stably realize the system's environmental and economic performance under the influence of the uncertain environment and parameters, that is, the stability, robustness and reliability of the system's performance under the uncertainty [4]. To sum up, the planning and construction of engineering water pollution control system is a multi-criteria decision-making process of continuous coordination among multiple conflicting or complementary targets.

The internal upstream and downstream subsystems and internal technical units of the engineering water pollution control system are interrelated and interact with each other. Although each subsystem and technical unit has different characteristics, and can display different organizational structures, system characteristic association relations and overall functions from different angles and levels, the overall functions of the system are obtained through mutual influence and coordination combination among these system elements, and the performance of local performance affects but does not determine the realization of the overall functions of the system [5]. In the decision-making and planning based on the overall function of the engineering water pollution control system, it is necessary to take into consideration the overall and local aspects and integrate the point source and non-point source pollution control of the engineering. Considering the relationship and information transmission among subsystems, the system structure design and technology screening are carried out in coordination, thus ensuring the integrity and reliability of the system structure design and technology screening for engineering water pollution control system.

2. Engineering Water Pollution Control System

The engineering water pollution control system consists of different subsystems, each of which is a series of facilities combination adopting different technologies to realize the overall multiple functions of the system under the joint action [6]. Different subsystem combinations, different facility units and technical combinations jointly determine the overall structure of the system, thus affecting the specific functional performance of the system. The structure of engineering water pollution control system refers to the way or order in which the components (subsystems, supporting facilities, control technology, etc.) of the system are interrelated and interact with each other, that is, the specific form in which the components are arranged and combined within the system.

More specifically, different water facilities are matched under different system structures to guide different water activities and produce different material flows and environmental impacts under different water pollution control technologies [7]. For example, the most primitive direct drainage combined drainage system is to arrange a drainage pipe network according to the principle of nearby slope to the water body, and rainwater and sewage are mixed and discharged directly into the water body without treatment and utilization. In this system, there is no removal of pollutants and no reuse of water resources and nutrients, which has the greatest impact on the water environment of the project. As another example, the structural model of "traditional drainage system rainwater source treatment sewage reuse" can reduce the risk of waterlogging caused by rainfall runoff on the basis of controlling the pollution load entering the water environment, reduce the impact of engineering runoff pollution on the water environment, and reuse deeply treated sewage at the same time, thus reducing the demand of engineering systems for natural raw water.

The importance attached to the recycling of sewage, the research and application of new drainage systems, and the intensified demand for control of non-point source pollution in the project affect the flow direction and intensity of water and substances in the water environment system of the whole project, and further affect the structure, layout and treatment capacity of the whole system. Therefore, this study generalizes the engineering water pollution control system into four subsystems: rain and sewage collection and transportation subsystem, rain and runoff control subsystem, sewage treatment subsystem, reclaimed water treatment and transportation subsystem, as shown in Figure 1.

The existing research has accumulated a lot of achievements in the planning and technical screening of the engineering water pollution control system, but there is still a certain gap between these achievements and the demand of this research. First of all, the system boundary and research objects are more concentrated in the sewage and reclaimed water treatment subsystem, and there is little comprehensive consideration of the engineering rainwater runoff pollution control technology a-

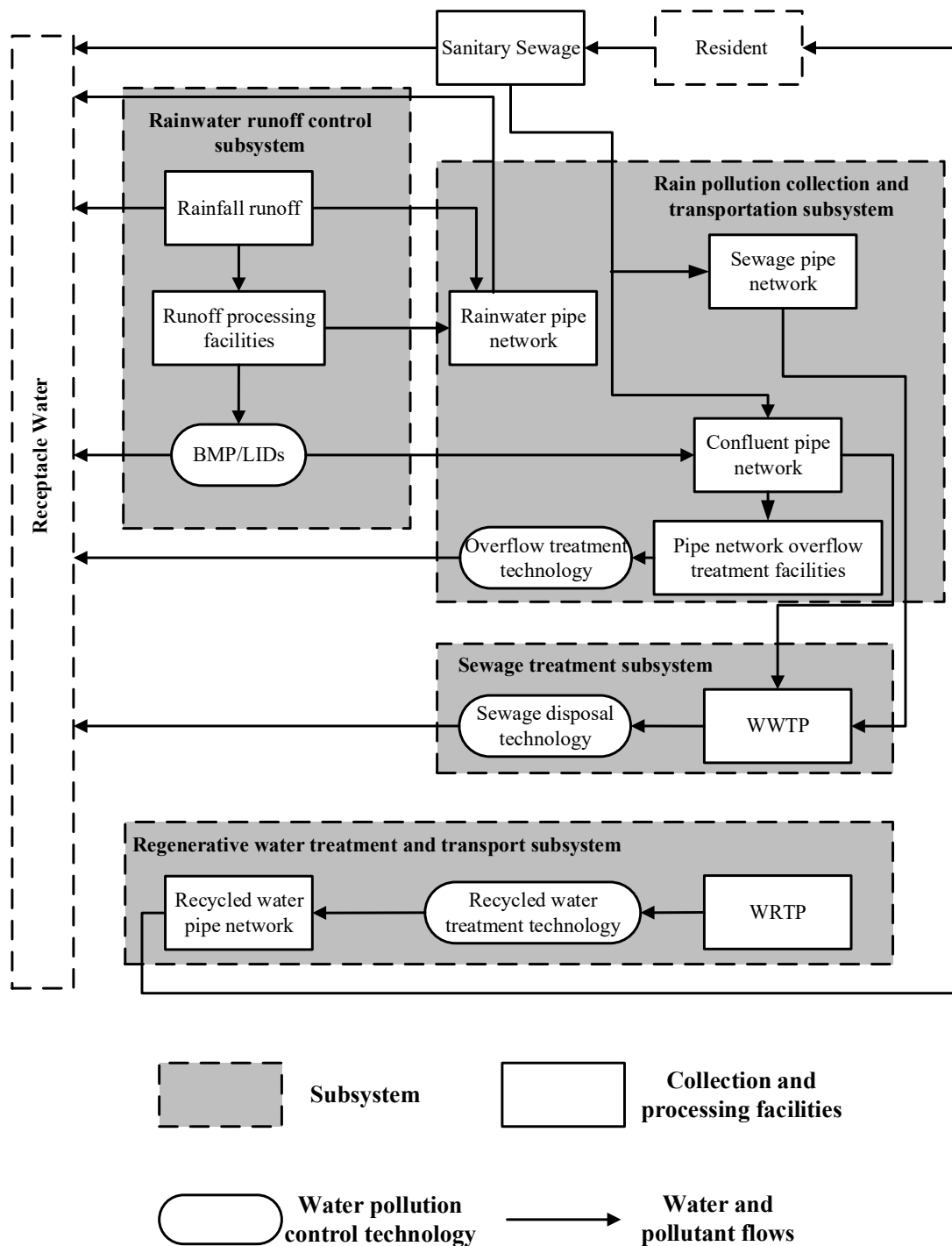


Fig.1 Generalization of Engineering Water Pollution Control System

and the confluence pipe network overflow pollution control technology, which undermines the integrity of the engineering water pollution control system. On the one hand, it is difficult to realize the coordination and coordination between various planning objectives and design indexes among subsystems, on the other hand, it is difficult to obtain the overall optimal plan under the planning objectives. Secondly, the screening of engineering water pollution control technology is mostly carried out under the condition that the system structure is established, and it is difficult to answer the problems of diversity and matching of system structure and technical screening. Finally, facing the

uncertainty of system structure and parameters, there is a lack of optimization methods to ensure the system's static nominal performance and robustness, stability and reliability. Therefore, in the stage of rapid urbanization in our country, the engineering water pollution control system is an important foundation for the engineering water safety guarantee and the healthy development of the project. It is urgent to build an optimized decision method based on the existing results to deal with the complexity and uncertainty of the engineering water pollution control system.

3. Structural Design and Technical Selection Method of Engineering Water Pollution Control System

Based on the demand for tools and the nature of scientific problems in the structural design and technical screening of the engineering water pollution control system, this chapter establishes the structural design and technical selection method framework of the engineering water pollution control system, and provides tool support for various parts of the method framework. Based on the bottom-up technology model and technology database, a multi-objective robust optimization model of engineering water pollution control system is constructed to provide a robust optimization scheme set for the structural design and technology screening of engineering water pollution control system. Based on multi-attribute comprehensive evaluation and uncertainty analysis, a robust analysis framework is constructed to guide the scheme to screen and identify sensitive parameters.

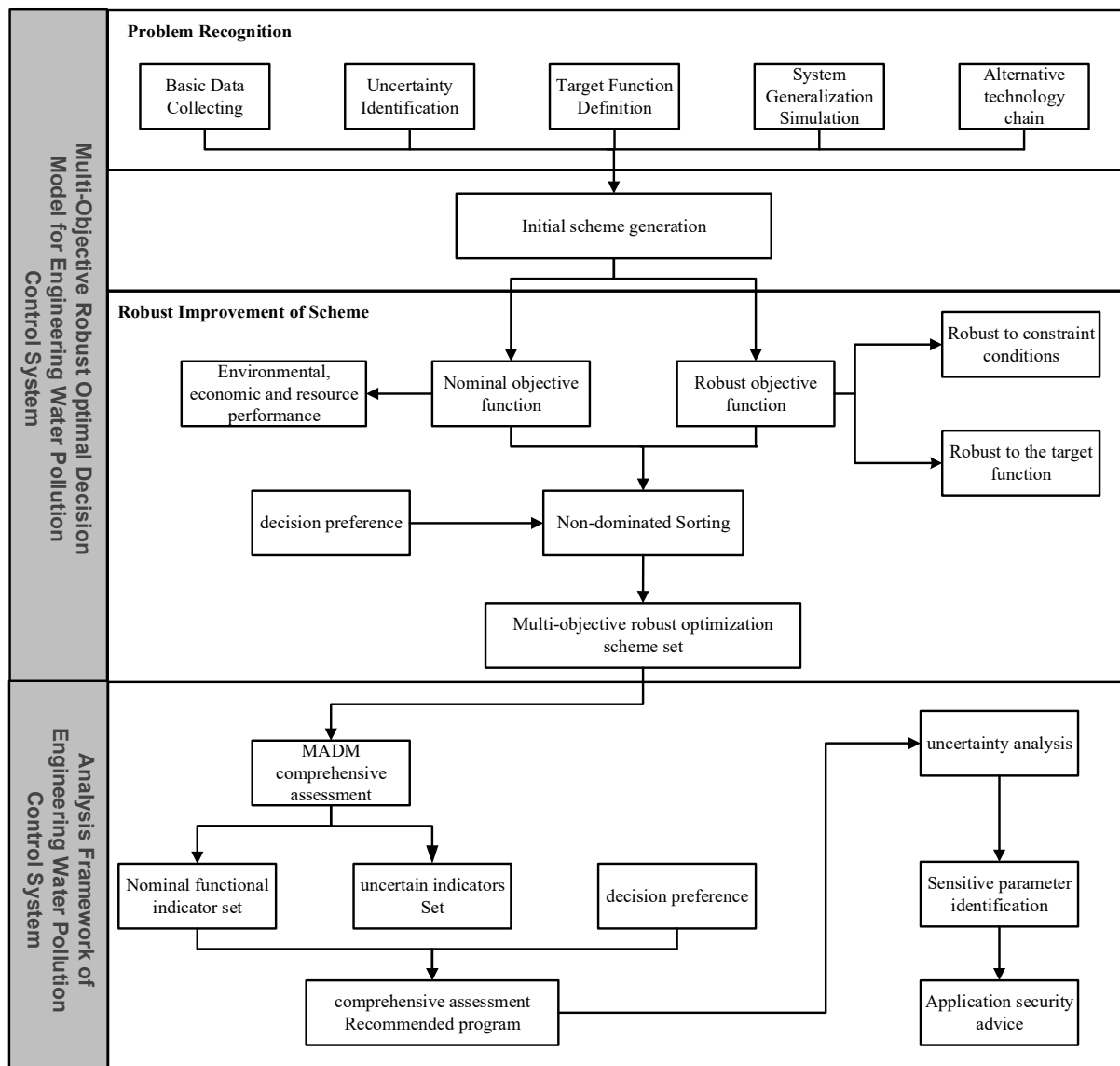


Fig.2 Structural Design and Technical Selection Framework of Engineering Water Pollution Control System

In order to solve the planning complexity problem of engineering water pollution control system caused by the diversity and uncertainty of engineering water pollution control system structure and technology, this section constructs the framework of engineering water pollution control system structure design and technology selection method based on Monte Carlo simulation and uncertainty analysis, as shown in Figure 2.

This method mainly includes two parts: multi-objective robust optimization model and robustness analysis framework. The multi-objective robust optimization model combines with the alternative technology chain generated by the technical database of the engineering water pollution control system to carry out structural design and technical selection on the engineering water pollution control system to generate a robust optimal frontier solution set. The robustness analysis framework includes the construction of a comprehensive index system and uncertainty analysis, carries out a comprehensive evaluation of the optimal scheme set, carries out scheme selection in combination with decision preferences, and further provides decision information and application guarantee through robust feature identification.

4. Multi-Objective Robust Optimization of Optimization Scheme for Engineering Water Pollution Control System

Based on the structural design and technical screening methods of the engineering water pollution control system based on robust optimization constructed in Section 2, this section introduces the application of multi-objective robust optimization model tools for standard projects constructed based on the national average engineering conditions. At the same time, it compares and analyzes the collaborative coupling relationships among environment, economy, resources and robustness of the engineering water pollution control system under different degrees of uncertainty and different levels of constraints, so as to provide corresponding recommendation scheme and decision information for the planning of the water pollution control system of standard case projects.

The water quality and quantity information mainly includes the production amount and pollutant concentration of engineering domestic sewage and engineering rainwater runoff. According to the engineering divisions and consumption levels, the reference coefficient manual measures the per capita daily domestic sewage production and the per capita daily pollution load of the standard engineering, and calculates the distribution of the characteristic pollutant concentration of domestic sewage in all engineering divisions and grade combinations as shown in Figure 3.

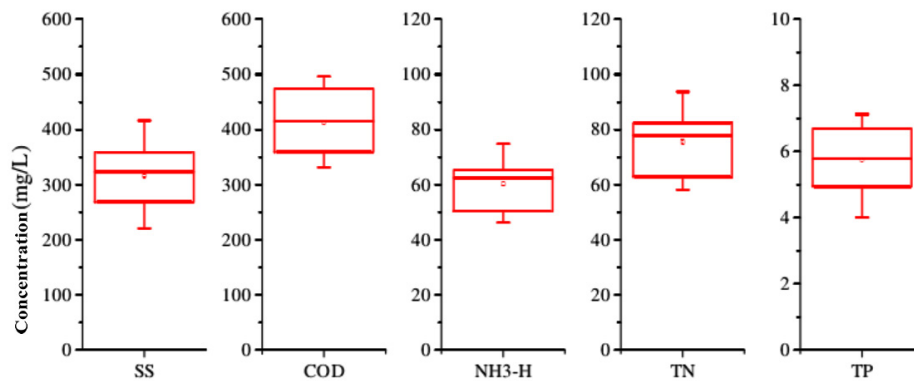


Fig.3 Water Quality and Quantity Information of Engineering Domestic Sewage

Based on the quantitative model input information mentioned above, by invoking the engineering water pollution control technology database and the multi-objective robust optimization module, six sets of optimal scheme sets are generated under three different degrees of disturbance ($k = 5$, $k = 10$, $k = 20$) respectively. Each scheme set contains 100 Pareto optimal schemes.

The distribution of the three objective functions of the 6 groups of robust optimal scheme sets generated by the model is shown in Figure 4, wherein each point respectively represents the system structure and technical combination optimization scheme under the three-level disturbance degree. In addition to intuitively reflecting the system's overall pollution load emission equivalent, the system's total life cycle cost and the system's overall robustness performance distribution, it also includes the structure and scale of each subsystem in the system, the technical combination and technical effect of water pollution control facilities, and the system's robustness response relationship and influence degree to uncertain disturbances, which help to further understand the non-intuitive internal information of complex system coupling optimization under uncertain environment.

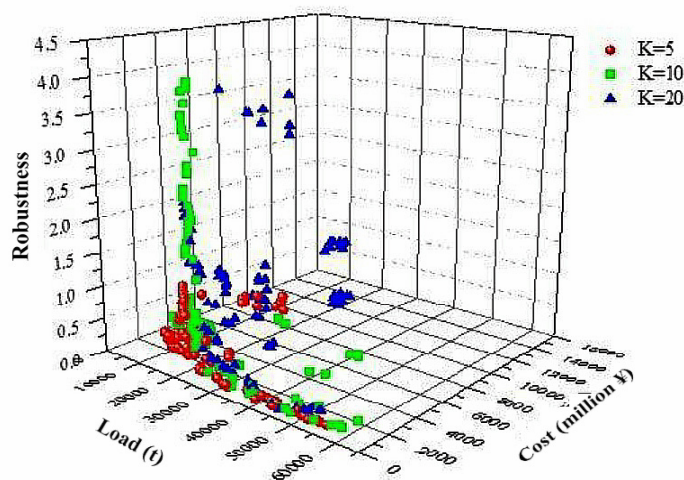


Fig.4 Optimal Scheme Set for Multi-Objective Robustness Optimization

As can be seen from the performance distribution range of the scheme in Fig. 4, the difference between the upper and lower limits of the system load emission equivalent value of the optimization scheme is small in the face of different degrees of uncertainty disturbance, while the life cycle cost range distribution of the optimization scheme is quite different. In order to maintain the robustness of the system, the life cycle cost of the system under the same constraint also increases with the increase of the degree of uncertainty disturbance. From Fig. 4, it can be seen that when the degree of disturbance increases from $k = 10$ to $k = 20$, it needs to increase the life cycle cost of the system to maintain the robustness of the system to a certain extent.

5. System Performance Analysis

The optimal scheme set output by the model provides a system structure optimization and technical combination optimization scheme for factories with a population of 10,000 under different environmental, economic and robustness target requirements. It can be used by decision makers to make choices based on different investment budgets for water pollution control in projects, different control targets for water environmental pollution discharge in projects, and different requirements for the environmental and economic performance of the system such as anti-interference capability, and reliability capability of effluent quality of sewage and reclaimed water treatment facilities. After rearranging all schemes according to the total cost of life cycle, comparing and analyzing the contribution and change trend of each subsystem to the overall economic, environmental and robustness performance of the system can also provide key influence and restriction factors to the development and change of the comprehensive performance of the project in different stages.

Figure 5 reflects the trend of the cost contribution of the four sub-systems in each scheme as the total cost of the life cycle increases. When the uncertain disturbance is small, the increased cost at the later stage of the cost allocation turning point is mainly due to the increase in the scale of water pollution collection and treatment facilities. The increase in cost is due to the increase in the rain and sewage collection rate, the expansion of the scale of the rain and sewage collection and transportation network, and the increase in the scale of sewage and reclaimed water treatment facilities. With the increase of uncertainty disturbance k , the life cycle of the system increases greatly, which also shows that in order to maintain the robustness of the system, it is necessary to adjust the resource allocation in the engineering water pollution control system and put forward higher requirements for investment.

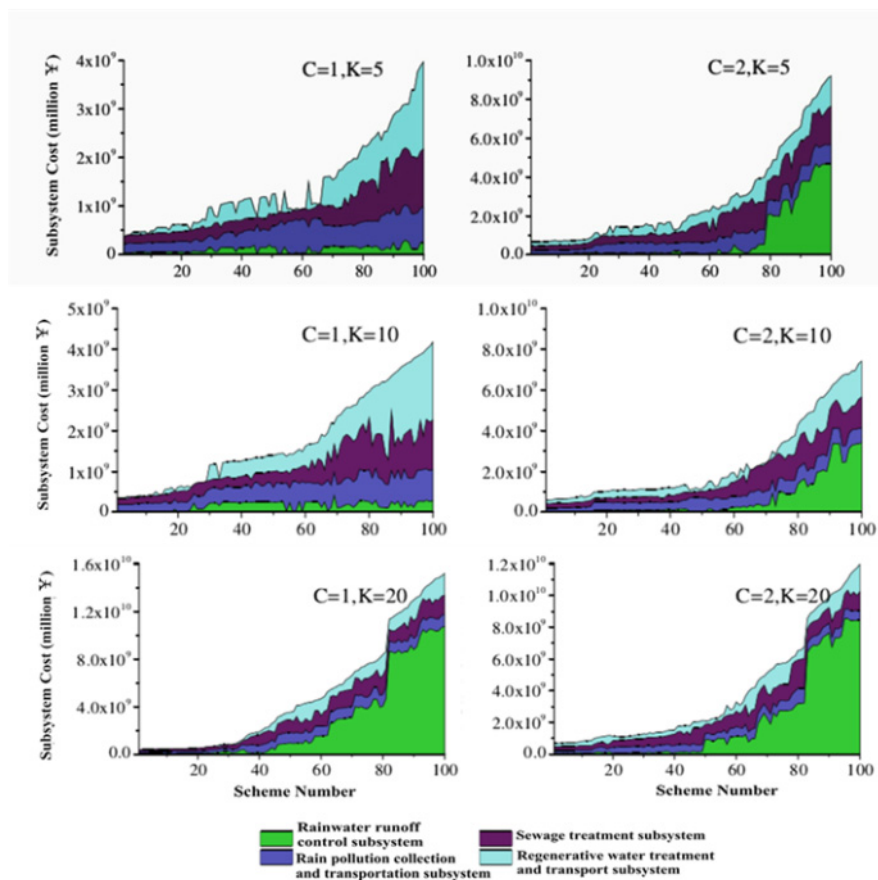


Fig.5 Subsystem Cost Contribution of Engineering Water Pollution Control System

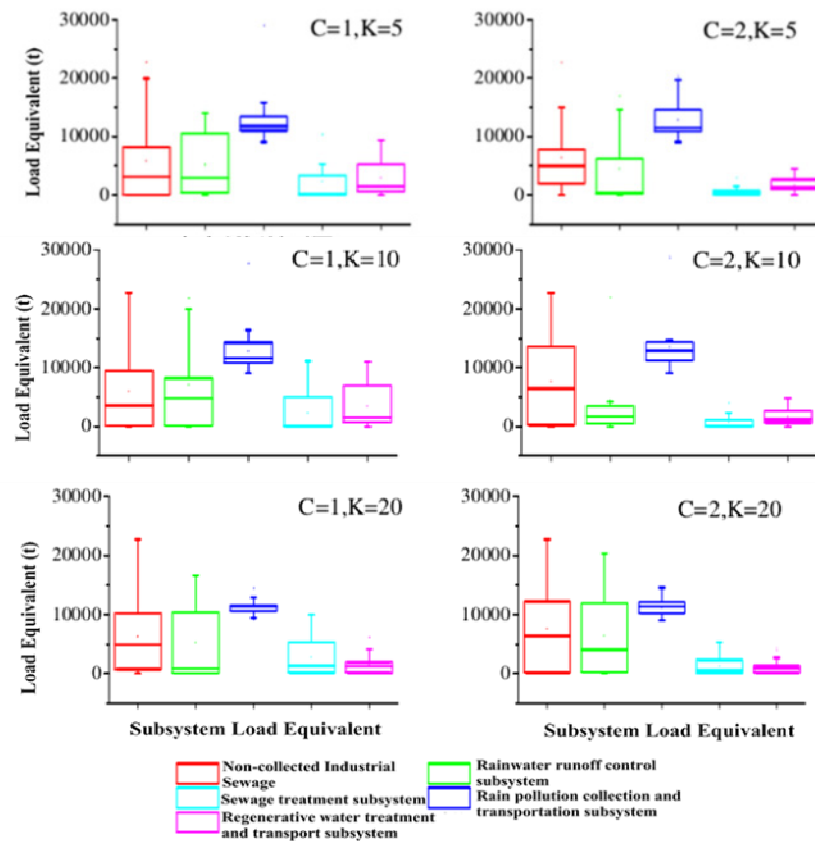


Fig.6 Subsystem Load Contribution of Engineering Water Pollution Control System

The optimal plans of each group are centralized, and the distribution of pollutant load emission equivalent in each subsystem is shown in Figure 6. The high contribution of the rain and sewage collection and transportation subsystem is mainly caused by pipe network leakage. The load discharge of the sewage treatment subsystem is limited and relatively concentrated, while the load contribution caused by the failure to collect domestic sewage, rainwater runoff pollution and pipe network leakage is relatively scattered.

6. Conclusion

Aiming at the complexity problems caused by various system structures, multiple decision objectives and interrelated elements in the planning of engineering water pollution control system under uncertain environment, based on the theory of multi-objective robust control, this paper uses the improved genetic algorithm based on Latin hypercube sampling and combines the methods and analysis tools of material flow analysis, engineering economics, multi-attribute index analysis, uncertainty analysis, etc. to construct a robust optimization method for structural design and technical selection of engineering water pollution control system with multi - objective, multi-constraint and multi-uncertain variables, which improves the robustness, scientificity and rationality of the optimization decision of complex system under uncertainty. Under the framework of this method, a robust optimization model of engineering water pollution control system including a technology combination module and a multi-objective robust optimization module is constructed, and the model is applied to standard projects representing the average level of national engineering infrastructure construction.

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