Study on Coupling Mechanism of Carbon-Water Symbiosis System and Regulation and Control of Water Resources in the Context of Regional Collaborative Development

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Abstract. In the aspect of theoretical research, the regional carbon-water coupling mechanism has not yet formed a complete conceptual framework, so there is an urgent need to build an academic system of the carbon-water coupling under a unified physical device. Therefore, based on the overall identification of the coupling mechanism of the water cycle and carbon balance, this paper systematically analyses the characteristics of carbon capture and release in the process of water resources and energy development, puts forward the connotation, symptoms and overall tasks of water resources development and allocation model based on low-carbon development theory, constructs a technical framework supported by regional carbon-water coupling simulation and water resources allocation. The technical critical issues such as water resources allocation, model construction process, countermeasures and safeguard measures based on the low-carbon model. The safety early warning model of water quality and quantity in regional carbon-water symbiosis system is put forward, which provides a method reference for the regulation and control of local water resources.

1. Introduction
Climate change has a profound impact on the multi-process of the water cycle and its multi-feedback mechanism. At the same time, the continuous occupation of environmental land and organic water aggravates the process of climate change. Innovating the traditional model of development, utilization and protection of water resources, mitigating and adapting to climate change has become a significant frontier and hot issue in the field of resources and environment. Rational allocation model of water resources summarizes the socio-economic system as regional carbon generation, ecological environment system as regional carbon collection, water shortage rate and net carbon discharge as constraint targets. It sets water balance, carbon balance, groundwater level, minimum water supply rate, eco-environmental water use and emergency water sources and other constraints [1]. Through the allocation of water resources and net carbon emissions at the macro and micro levels, the degree of protection of water use can be improved.

At present, scholars at home and abroad mainly study the mechanism of the water cycle and carbon cycle through prototype observation methods and numerical simulation methods [2-6]. Most of the carbon-water coupling models are developed in large-scale regions. The simulation accuracy of carbon-water cycle in hour-space scale and the artificial environment is insufficient. The regulation methods of sophisticated water resources in the regional context need further study. Therefore, from the perspective of carbon-water balance and reduction of carbon emissions, this paper takes a regional carbon-water coupling system, identification of action mechanism and rational allocation of water...
resources as research objects [7]. In order to improve the lack of coordination ability of carbon emission and carbon capture under the existing water resources regulation mechanism, this paper provides direct theoretical support for the related research of water resources regulation and management based on low-carbon development model [8].

2. Regional carbon-water coupling system

2.1. Coupling relationship between the water cycle and carbon balance
Water balance is a crucial factor affecting vegetation distribution and productivity. The amount of water retained by the canopy in the water cycle affects the photosynthesis and respiration rate of plants, the soil water content directly affects the vegetation evapotranspiration and soil evaporation process, thereby affecting the physiological and ecological evolution of regional vegetation, and thus changing the carbon emissions and capture of the ecosystem capacity and regional carbon emissions. Accordingly, the composition and distribution of vegetation affect the regional surface energy process, evapotranspiration, surface roughness and maximum depression storage depth, and affect the surface runoff production and confluence process. Besides, the changes in plant roots change the physical and chemical properties of the soil, which leads to changes in the process of runoff production and confluence in the region. For example, Bosch and Hewlett’s studies have shown that the decrease in forest cover will increase regional evapotranspiration and lead to a reduction in runoff [9].

2.2. The basic framework of a regional carbon-water coupling system
In the carbon-water cycle system usually defined, the carbon theme characterized by the increase of carbon dioxide concentration in the atmosphere and the water problem described by the shortage of water resources is the focus of the current basic theory of carbon cycle and water cycle. Due to the influence of human activities and the increase of carbon emissions, water resources decrease, water quality pollution intensifies, and the balance of the water cycle is changed. According to the characteristics of regional carbon-water cycle and key ecological water resources security issues, this paper constructs a regional carbon-water coupling framework under a unified physical mechanism, including three aspects: driving mechanism, interaction mechanism and early warning mechanism of the regional carbon-water cycle.

![Figure 1. The framework of regional carbon water coupling system.](image-url)
3. Rational allocation model of water resources based on the low-carbon model

3.1. General thinking
The study area is divided into land-use units based on functional vegetation types, and according to the carbon conversion relationship between surface water, groundwater and carbon pools, the carbon-water coupling model is used to simulate the primary data such as precipitation, evapotranspiration, runoff, confluence, carbon flux and capture at different temporal and spatial scales. Calculate the total amount and available amount of water resources, the amount and the available amount of passenger water resources, and the carbon flux and capture of the natural-artificial system.

3.2. The Objective function and constraint conditions
Objective function construction. According to the goal and principle of rational allocation of water resources based on low-carbon development model, the minimum water shortage and net carbon emission within and between the allocation units of regional carbon-water coupling system under certain water supply conditions are selected as the key objective factors to construct the objective function. $f_1(x)$ is a function of unit water shortage. $f_2(x)$ is the net emission function of unit carbon. To embody the principle of fairness, $f_3(x)$ and $f_4(x)$ respectively represent the difference between the net carbon emission of adjacent units and the difference of water shortage.

- $f = \{f_1(x)\} = \{f_1(x), f_2(x), f_3(x), f_4(x)\}$
- $f_1(x) = \min \sum_{t=1}^{T} \sum_{m=1}^{M} W(t, m, x); f_2(x) = \max \sum_{t=1}^{T} \sum_{m=1}^{M} C_{net}(t, m, x)$
- $f_3(x) = \min |\Delta C_{net}| = \min |C_{net}(t, m + 1, x) - C_{net}(t, m, x)|$
- $f_4(x) = \min |\Delta W| = \min |W(t, m + 1, x) - W(t, m, x)|$

In the formula: $W(t, m, x)$ is the water shortage under the water supply for the first calculation unit in the first period. $\Delta W$ is the difference of the water shortage under the period of the water supply of the adjacent allocation unit. $C_{net}(t, m, x)$ is the net carbon emissions under the water supply of the first calculation unit in the first period of time. $\Delta C_{net}$ is the difference between the net carbon emissions under the water supply of two adjacent calculation units in the first period of time.

3.2.1. Constraint construction.
- Total regional water consumption constraint: $\sum w_{con}(t) \leq w_{avail}(p)$
- Unit water balance constraint:

$$W(t, m, x) = \sum_{n=1}^{N} k_1(n) \{w_{demand}(t, m, x) - w_{river}(t, m, x) - w_{reservoirs}(t, m, x) - w_{undergr}(t, m, x) - w_{reuses}(t, m, x)\}$$

- Carbon balance constraint: $C_{net}(t, m, x) = C_{release}(t, m, x) - C_{capture}(t, m, x)$
- Carbon-water relationship index constraint: $NRW(t, m, x) = RW(t, m, x) - CW(t, m, x)$

3.3. Model operation
The year with complete essential data is selected as the base year, and the historical series values such as regional surface water, groundwater, evapotranspiration, industrial water consumption, water quality monitoring data of typical nodes and ecosystem carbon reserves are used as a reference. Reasonable adjustment of parameters such as precipitation infiltration recharge coefficient, river infiltration recharge coefficient, canal leakage recharge coefficient, reservoir leakage recharge coefficient, relationship threshold between carbon emission and available water and carbon capture weight of various ecosystems, improve the linear correlation coefficient between the output results and the real historical series, reduce the error coefficient, and improve the simulation accuracy of the model.
Table 1. Primary data of the base year model of a river area.

|                        | S1   | S2   | S3   | S4   | Carbon reduction |
|------------------------|------|------|------|------|-----------------|
| Surface water          | 0.099| -0.091| -0.102| 0.341| 0.36            |
| Groundwater            | -0.767| 0.135| 0.249| 0.042| -0.42           |
| Evapotranspiration     | 0.035| -0.164| -0.141| -0.079| 0.19           |
| Water Consumption      | -0.231| -0.211| -0.027| -0.092| -2.16          |
| Precipitation infiltration | 0.205| 0.610| -0.103| -0.038| 0.07           |
| Water supply           | -0.011| -0.139| -0.070| -0.071| 3.24           |
| carbon emission        | 0.712| -0.083| 0.303| -0.023| 2.15           |
| Carbon capture         | -0.042| -0.057| -0.109| -0.080| 1.67           |

3.4. Model solving
As two kinds of objective functions of carbon and water flux are involved, the multi-objective programming method based on ideal point and genetic algorithm are selected to solve the problem. The specific process is as follows: First of all, the genetic algorithm is used to address the objective function $f_i(x)$ respectively. A non-inferior solution is obtained, and the optimal value $f_i^*$ of each objective function is obtained, which is taken as the ideal point of approximation of the corresponding objective function, and the single objective function $\text{min}_\varphi [f(x)] = \sqrt{\sum_{i=1}^{4} [f_i(x) - f_i^*]^2}$ with the shortest distance from the perfect spot is obtained. Then a non-inferior solution of multi-objective decision-making is achieved by using a genetic algorithm as a satisfactory solution, and the target value of the multi-objective function is obtained respectively.

4. Safety early warning method of water quality and quantity system in the regional carbon-water symbiosis coupling system
Comprehensively considering the changing development trend of the operation process of water resources circulation system in the selected study area affected by rain, underlying surface, drainage and other factors, a model based on raw water quality pollution simulation and water demand prediction is constructed. A carbon-water coupling alarm simulation system based on carbon emission exceeding the standard constraint mechanism is developed as an early warning model. At the same time, the dangerous situation assumption conditions of a sudden rainstorm, underlying surface conditions, underground drainage network, reservoir and flood control facilities in the unit area are set to generate a warning data set based on raw water quality pollution simulation and water demand prediction data.

A radial basis function network model (RBFNN model) of hierarchical correlation degree between disaster factors and early warning based on historical data is established. By searching the historical water quality database, the set of risk factors of water quality is screened, the association rules between risk factors and early warning indicators are found through mathematical statistics, and the early warning index system of urban water quality and quantity is established. At the same time, the fitting calculation is carried out to obtain the correlation function between the disaster risk factors and the warning index. The classification type of disaster and the controllable degree parameter of early warning is determined, and the threshold of critical early warning index is determined by using historical disaster data. Establish a diagnosis model to track and compare the evaluation value of the key early warning index with the threshold of the early warning index, and send a signal once the limit of the early warning index is exceeded. As shown in the following figure, the diagnosis model is analyzed, and the event disposal decision variable is generated.
5. Conclusion and prospect
Low-carbon development model has become one of the fundamental means for countries to deal with global climate change. Therefore, with the goal of low-carbon emission rate, the evolution law of regional eco-hydrological process is identified by prototype observation and digital simulation. Thus, based on the low-carbon and carbon water balance model, this paper constructs a reasonable allocation model of water resources, puts forward the mathematical model construction and numerical analysis of regional water resources fair allocation, limiting local carbon emissions and improving carbon capture capacity. This will provide a model reference for future environmental problems such as climate change, carbon emission reduction and greenhouse effect mitigation. At the same time, this paper also puts forward the components and mutual influence factors of regional water resources system, and analyses the interaction and transformation relationship between the components. According to the characteristics, structure analyses and water pollution of the regional surface water system, the main influencing factors and uncertainty characteristics of the water resources security system are determined. According to the collection of the critical factors of the regional water resources security, the early warning model of regional water quality and quantity in the context of carbon water coupling based on the water circulation system is established to improve the safety of the urban water supply and water environment.

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