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Application of Blockchain Technology in Agricultural Water Rights Trade Management

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Abstract: Water is a basic and essential natural resource, and its rational allocation plays a key role in environmental and economic sustainable development. Agriculture consumes a large share of water resources, but the allocation of water rights often deviates from water use in reality. Therefore, an appropriate management method for agricultural water rights trading is needed. In this paper, blockchain technology is applied to address the agricultural water rights trading issue. Firstly, an alliance chain and the practical Byzantine fault tolerance (PBFT) consensus mechanism are adopted to support a smart contract and application. Then, a trading platform based on blockchain for agricultural water rights trading is proposed. Finally, the role and function of a decentralized autonomous organization (DAO) in a self-financing irrigation drainage district (SIDD) are clarified. This study provides a secure and stable platform which can reduce the trading confirmation time and support numerous users. The trading process of agricultural water rights is updated to minimize the cost of water rights' transactions and improve the system's efficiency.

Keywords: smart water conservancy; blockchain; water rights; management platform; decentralized autonomous organization

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1. Introduction

Water is a basic natural resource, a strategic economic resource, and a controlling element of the ecological environment, necessary for human survival and social development. Among the various industries, agriculture consumes the most water resources [1]. According to the literature, agriculture consumes over 70% of the fresh water used in the world [2,3]. With water usage on the rise around the world, the better management of water resources is urgent. However, agricultural water rights management is usually ignored. With scientific management, water rights trading can drive the optimal allocation of water resources [4]. Therefore, to achieve sustainable water resource utilization, water rights management in agriculture is necessary.

The term water rights is derived from the concept of property rights and related theories, i.e., having the property right to a water resource. Its essence is commoditizing water resources and allowing them to be traded. The study of water rights trading first originated in the USA, Australia, and other developed countries [5]. In recent years, Chile, China, and other countries have rapidly developed water rights trading [6]. Based on the differences in national conditions, social systems, culture, etc., there are different principles of water allocation rights. In China, the law states that water resources are owned by the state. Water rights trading mainly refers to the right to use, allocate, and trade water resources.

A water rights trading platform was established in China in 2016. The platform allows for large regional water rights and small agricultural water rights trade. Regarding the trade in regional water rights, rational allocation is most important [7]. Compared to regional water rights trading, agricultural water rights are traded more frequently, and there is a greater need for regular updates.

Blockchain technology consists of cryptography and a distributed system and adopts the Hash function, asymmetric encryption, digital signature, and a digital certificate in cryptography to ensure that the parties involved in the transaction are trusted in the network and that the transaction information is immutable, safe, and reliable [8,9]. The distributed system ensures that transaction data are decentralized in a multicenter system, and data are stored securely and consistently, making it difficult to tamper with data [10,11]. Combined with the IoT (Internet of Things) and the cloud, blockchain has a role in advancing initiatives pertaining to environmental sustainability [12,13]. The block structure is shown in Figure 1. The block consists of two parts, the block header and the block body, which generate and record the information of the transactions. The block header is responsible for connecting to the next block through the main chain, and the block body is responsible for storing data information. When the blocks are connected to form a chain, the system automatically generates a timestamp to be stamped on the data information, which is a major innovation of blockchain.

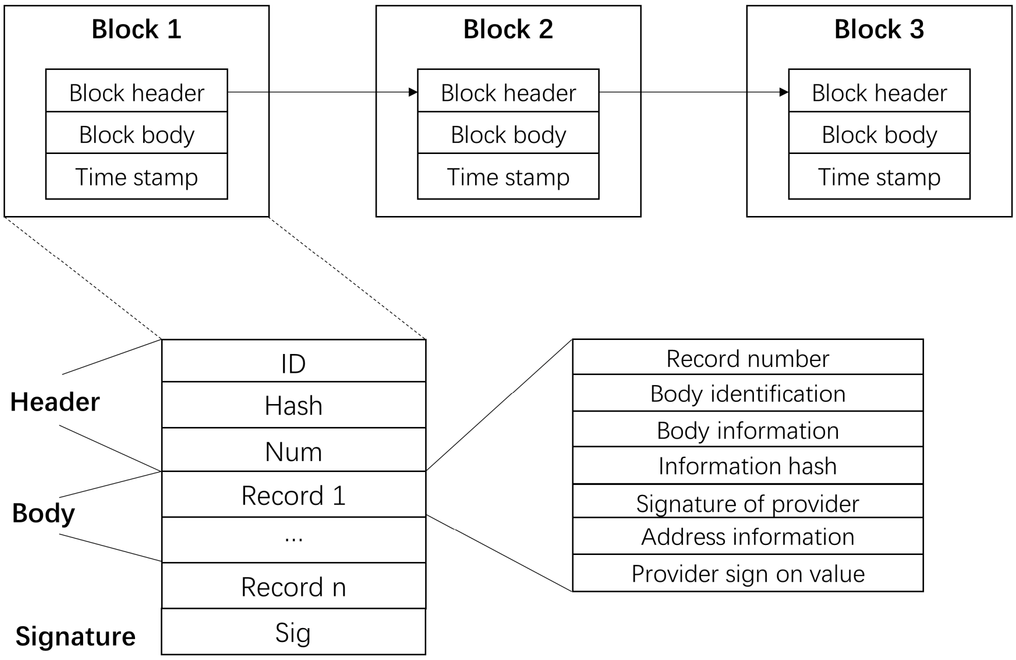

Figure 1. The block structure and function.

As the origin and the most popular example of blockchain technology, Bitcoin emerged in 2009 [14]. After this, blockchain technology developed rapidly [15]. A number of new forms, such as Ethereum and Hyperledger Fabric, have emerged and are being used in many areas. For example, based on Hyperledger Fabric, it is possible to apply serious games to urban water management from the perspective of mobile crowdsensing. Blockchain has a wide range of applications in smart water conservancy [16] and can be used to build a smart water conservancy platform. It has injected new vitality into the modernization of agricultural water resources [17–23]. Combined with the IoT, a smart water management system in agriculture was designed in [24]. Enescu, Bizon [25] offered a solution implementing blockchain technology in irrigation systems. However, there is very little research on blockchain in water rights trading. This paper aims to use blockchain technology to improve the water rights trading system.

Blockchain has more applications in management due to its verifiable and immutable nature, which is important for improving the security and efficiency of transactions. If a local energy market is updated with blockchain, a home energy management system can be established to optimize energy consumption and minimize electricity costs [26].

Based on the blockchain, schemes for transactions can be more secure [27]. Blockchain technology is an effective support for bilateral trade management [28]. In trade demand-side management, a blockchain-based model is used [29]. However, for the application in the management of agricultural water rights trading, it is still almost nonexistent. In this paper, blockchain technology is used to simplify the transaction process, reduce transaction costs, and promote the further expansion of agricultural water rights trading.

2. Methodology

2.1. Water Production Function and Water Allocation

Water rights trading is actually the redistribution of the initial water rights of water resources in order to achieve the sustainable development of water resources through the market. In China, agricultural water rights trading should reasonably regulate the relationship between allocation and demand. The optimization of water resources among agricultural water users in irrigation areas is mainly based on the water production function of crops. The suitable allocation of water resources requires determination of the economic irrigation quotas for different crops. Water requirements differ between crops. The initial water rights allocation based on the principle of equity is not necessarily the optimal method for water resource utilization, which means that there may be differences between the water requirements for crop irrigation and the actual amount of water allocated. In order to determine the optimal water amount for each user and the allocation method that maximizes the overall benefits of the irrigation area, the mathematical relationship between crop yield and water should be calculated. The Water Production Function is calculated as follows:

$$Y_i = f(X_i) \tag{1}$$

$$V_i = k_i \times Y_i \tag{2}$$

$$V = \sum V_i \times A_i \tag{3}$$

where Y_i is the yield of crop *i*; X_i is the irrigation quota of crop *i*; V_i is the output value of crop *i*; k_i is the unit yield coefficient of crop *i*; V is the total net production value of the whole irrigation area; and A_i is the planted area of crop *i*.

Based on the above mathematical relationship between water and crops in an irrigation district, a suitable model will follow the principle of maximizing the overall economic benefits of the irrigation district. Therefore, we have the objective function

$$Max\left(\sum V_i\right) \tag{4}$$

$$\frac{d(\sum V_i)}{dX_i} = 0 \tag{5}$$

and the constraint condition

$$W = \sum (X_i \times A_i) \tag{6}$$

where W is the total amount of irrigation water.

According to the objective function, the marginal benefits of various crops are required to be equal. Based on the economic irrigation quota and the area of the crop, the optimal allocation of water for each crop can then be calculated. This optimal allocation of water tends to differ significantly from the initial water right allocation, so there is a greater demand for agricultural water rights trading.

2.2. Blockchain Technology

Blockchains include three types: a public chain, an alliance chain, and a private chain. Public chains have no node access restrictions. Anyone can read data, send transactions, and have them validly confirmed: for example, Bitcoin and Ethereum. Private chains are usually used within an entity, and the permissions on the chain depend on the entity rules. Alliance chains are an intermediate form between public and private chains, where only authorized nodes are allowed to join. A comparison of the attributes of the three is shown in Table 1.

Table 1. Comparison among blockchain types.

Type	Public	Alliance	Private
Nodes	Any	Authorized users	In an organization
Centralization extent	Decentralized	Polycentric	Centralized
Consensus mechanism	POW, POS, DPOS	Raft	Solo
Incentive necessity	Yes	Optional	No
Openness	Complete	Partially	Not
Speed	Slow	Faster	Fastest
Application	Bitcoin	Hyperledger	Ant Financial

Compared with public chains, the openness degree of an alliance chain is limited. However, it retains a certain degree of decentralization and is more efficient and targeted. In agricultural water rights trading, a high consensus cost occurs among irrigation water users. It needs to be balanced with decentralization when blockchain technology is applied. An alliance chain can ensure data privacy, which is of significance in public resource trading. Taking the maturity of the current blockchain technology into account, the alliance chain is selected for the agricultural water rights trading system.

3. Blockchain Technology in Agricultural Water Rights Trading

3.1. Architecture of Trading System Based on Blockchain

The architecture of the trading system for agricultural water rights is shown in Figure 2. It includes six layers.

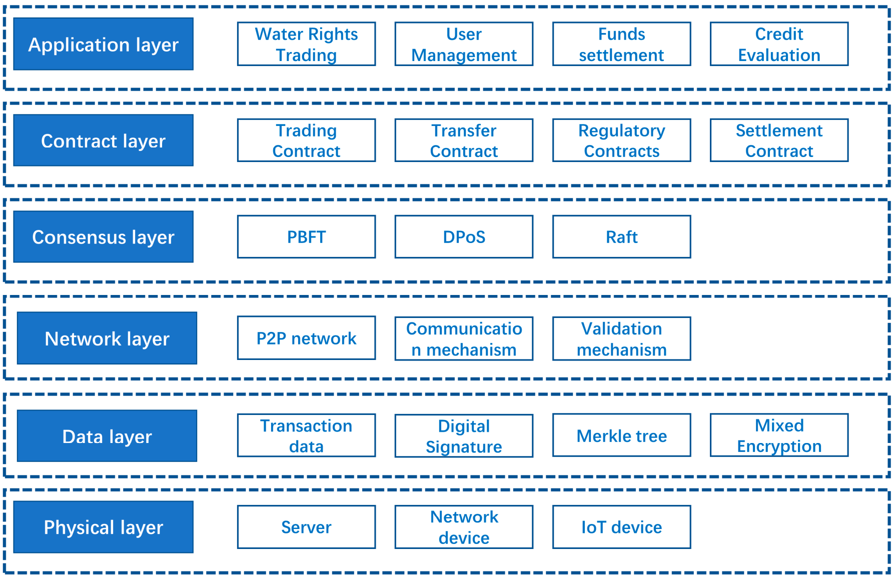

Figure 2. The architecture of the blockchain for agricultural water rights trading.

The physical layer includes the basic hardware and software facilities required for the water rights trading system based on the alliance chain technology, which provides the physical environment support.

The data layer is used to store transaction data, user data, and settlement data in the water rights trading system. These data are stored on the alliance chain of the water rights trading system in time-stamped blocks. The blocks are constructed using a hashing algorithm.

The network layer uses a P2P network with a data validation mechanism, and the nodes in the alliance chain in the trading system achieve information transmission and service realization through a peer-to-peer network.

The consensus mechanism in the consensus layer is one of the most critical technologies of the blockchain system, which is responsible for the coordination to ensure the consistency of the data records of all nodes in the network. This model uses the Practical Byzantine Fault Tolerance (PBFT) consensus mechanism, which is optimal for alliance chains.

The contract layer encapsulates the scripts, codes, algorithmic mechanism, and smart contracts. Water rights trading system users achieve water resources trading, settlement, and supervision through smart contracts. The water rights trading process involves a variety of contracts between the two sides of the transaction. Smart contracts are automatically executed by the script code and algorithm when the predetermined corresponding conditions are triggered.

The application layer is responsible for running the various applications involved in the agricultural water rights trading.

3.2. Trading Platform Design Based on Consensus Algorithms

The platform for agricultural water rights trading must adapt an appropriate consensus algorithm. The consensus algorithms are one of the blockchain core technologies and have different features (Table 2). Proof of Work (PoW) requires members of a network to expend effort solving an arbitrary mathematical puzzle to obtain the rights to modify the ledger. It is the most decentralized of all algorithms. Proof of Stake (PoS) requires one to stake coins or set them aside to be randomly selected as a validator. It is centralized to some degree due to the coin factor used to determine the next set of counterfeiters. With PBFT, each node knows every other node. Thus, although there is less centralization, the number of connections on each node is very high. The Delegated Proof of Stake (DPoS) algorithm has a further degree of centralization compared to the traditional PoS, whereby users of the network vote and elect delegates to validate the next block. The elected delegates become the central authority for the next block. The Proof of Elapsed Time (PoET) algorithm generates a random wait time for each node in the blockchain network; the node with the shortest wait time will wake up first and, thus, be allowed to commit a new block to the blockchain. It has no degree of centralization, as the next miner is chosen based on a random timer.

Table 2. Consensus algorithms' features.

Consensus Algorithms	PoW	PoS	DPoS	PBFT	PoET
Decentralization	Complete	High	Normal	Low	Complete
Efficiency	Slow	Medium	Medium	Fast	Medium
Energy consumption	Very high	Normal	Low	Very low	Low
Security	High	Relatively high	Relatively high	Medium	Relatively high

In the process of agricultural water rights trading, the core nodes of the chain correspond to the government and other important organizations. They have the highest access level. All nodes are operated and maintained by themselves. The entire agriculture water rights trading platform is organized with institutional alliances as a unit. After an organization or an individual obtains permission, they can link to the platform to join the chain and achieve relevant information. After comparing the consensus algorithms, the PBFT algorithm has the best effect on guaranteeing the strong consistency of the system nodes. Therefore, it is the most suitable for the agricultural water rights trading platform.

4. Management of Water Rights Trading Based on Blockchain

Agricultural productivity is highly dependent on water resource management. To drive the sustainable development of water, it is critical to address the water scarcity problem.

Therefore, implementation of blockchain technology would allow more irrigators to participate in a platform that entitles and allocates water securely and transparently, further boosting the overall efficiency of water resources.

4.1. Management of the Platform

The blockchain-based water rights trade management is centered on building a trading platform (Figure 3). With the support of this platform, the management agency acts as a third-party member to develop smart contract rules based on historical data. The recording of transaction information can then be conducted automatically by the smart contract. Because of blockchain technology, distributed bookkeeping and storage can be achieved. Any node on the blockchain can publish its own demand information and achieve automatic recording of transaction behavior and results. In addition, transaction information cannot be tampered with and will be kept intact in the distributed database. Therefore, when combined with blockchain technology, due to the network-wide synchronization feature of the blockchain ledger, it can reduce the cost of data backup and water rights transactions.

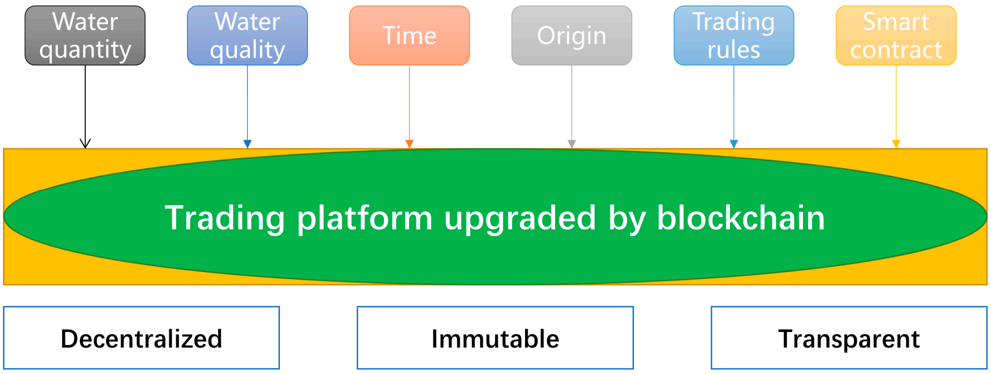

Figure 3. Trading platform based on blockchain.

Based on the platform, the following functions can be achieved: (1) The blockchain ledger is synchronized across the network due to its nature. Therefore, blockchain can enable a group of independent users who compete for scarce resources to trust the system and the other community members [30]. (2) When encountering similar contract scenarios, the system automatically executes the corresponding processes. (3) It can break the information asymmetry and protect privacy security. (4) A social supervision feedback mechanism can be established due to the information traceability blockchain introduced.

4.2. Blockchain-Based Business Process Transformation

In order to apply blockchain technology for authentication, the whole system must contain different types of nodes and a suitable mechanism for internode communication. The logic diagram is shown in Figure 4. The nodes are of four types: general nodes are used to synchronize all information about transactions on the chain, where each node has a complete ledger of transactions; core nodes are composed of representatives from government departments and organizations with good computing performance; validation nodes are for the management of water rights trading, with high credit; and arranging nodes require good stability and computing power.

The information transmission on blockchain proceeds via the following steps.

Step 1: A water user submits an application for water rights trading to a validation node. The validation node validates the transaction information according to the contract, performs the calculation of the transaction data, and returns the result of the water right transaction to the water user.

Step 2: The water user receives sufficient validation and submits a water right transaction to an arranging node. The arranging node performs the sorting of the water right transaction data and sends the sorted information to a core node.

Step 3: The core node receives the water rights transaction information, and general nodes continuously synchronize the data.

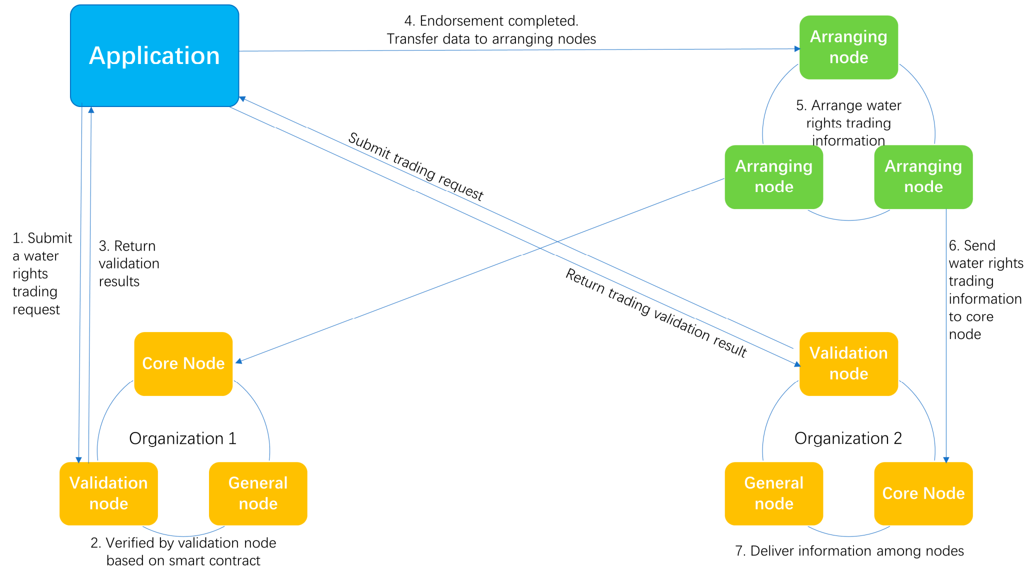

Figure 4. Node interactions and information transmission on blockchain.

With blockchain technology applied, the water rights trading process can be simplified by reducing manual examination. The flowchart is shown in Figure 5. The blockchain-based water rights trading process has the following advantages: (1) The initiated water rights trading application can be automatically reviewed through smart contracts. (2) Relying on the reliability of the blockchain system, the two sides of the water rights trading can negotiate and match on their own. Manual matching by management is no longer required. (3) Because the water rights transaction data in the blockchain network are immutable and traceable, the contract of a water rights transaction no longer needs a third party to review.

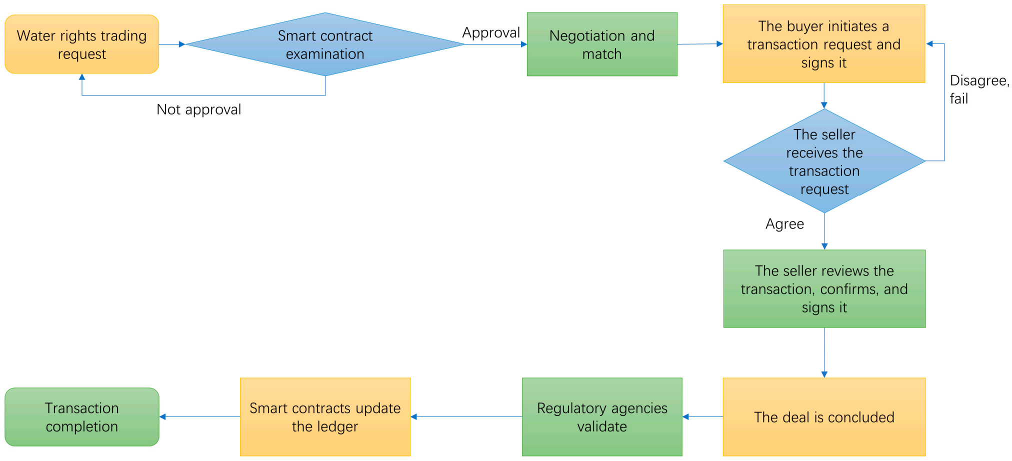

Figure 5. The processes of agricultural water rights trading based on blockchain.

4.3. "DAO" in Agricultural Water Rights Trading

A decentralized autonomous organization (DAO) is an organization represented by rules encoded as a computer program that is transparent, controlled by the organization members, and not influenced by a central government. A DAO launched on a blockchain and governed by a smart contract promises to bring self-organization to a new technological level [31]. DAOs have many unique features, which are described in Table 3. The management model is updated in a DAO. A DAO is a blockchain-based system that enables people to coordinate and self-manage mediated by self-executing rules deployed on a blockchain [32]. In a DAO, the management and operational rules are all encoded on the blockchain, so it allows a participant to autonomously operate [33]. According to the research, a DAO can reduce transaction costs by providing a more efficient management model [34].

Table 3. Detailed features of DAOs.

Features	Description
Decentralization	Since blockchain operates in a decentralized mode with every node in the network, a DAO allows autonomous execution according to the predefined provisions by a smart contract. Hence, the system decentralization maintains ceaseless service availability by eliminating the single point of failure, decreases data usage and latency, and ensures accountability.
Forgery Resistance	Smart contracts preserve the integrity of the distributed ledger, and computational logic is verified with digital signatures. In a DAO, the transaction and related operation once implemented cannot be changed even by their owner.
Transparency	The transaction and other data can be accessed by authenticated users all the time.
Self-execution	Business affairs between the entities within the network execute once the predefined conditions are met, without any need for a third party.
Openness	Traditional organizations tend to have a manager or central department, with a strict hierarchy to ensure the enforcement of rules. The DAO breaks the pyramidal management hierarchy of traditional organizations. In such an organization, each individual can issue proposals and make decisions through voting.
Incentives	DAO projects can issue tokens. The circulation of tokens on the blockchain can allow different rights holders to obtain the benefits by the realization of rights. In this way, it can optimize resource allocation within the organization and achieve large-scale cooperation.

Self-financing irrigation districts (SSID) are a widespread form of organization that has reformed the irrigation management system and operating mechanism by changing the irrigation district management unit from an institution to a water supply company and water using association. Water users participate in management and decision making. The water supply company undertakes the construction, operation, and maintenance of the project. The main feature is that it is part of the market economy, including independent operation, independent accounting, and economic self-sufficiency. An SSID is suitable to act as an example of a DAO in many aspects. In an SSID, contracts are signed according to water use plans, and charges are made according to the amount of water used. The information will be immutable and can be dynamically changed in real time with relative rules and system updates to the DAO. In addition, information can be shared by all members, so it is conducive to creating a good trading ecological environment. At the same time, because of the dynamic real-time information broadcast and full access to the network, the water rights demand and supply sides can reach cooperation to create a convenient way to effectively overcome the information asymmetry.

5. Conclusions

Currently, water rights play a key role in water resource utilization. The scientific management of water rights trading is critical to environmental and economic sustainability. Although its application is slightly immature, blockchain is a development trend of advanced technology in the new era. In this paper, agricultural water rights trading was upgraded by blockchain to achieve more efficient management.

The alliance chain type PBFT consensus mechanism can balance decentralization and efficiency. With its adoption, a blockchain-based trading platform for agricultural water rights could be established. The date, water quantity, water quality, time, and trading rules could be made immutable and transparent on the platform. With the help of blockchain technology, the system would be trustworthy and automatic and make information accessible.

The water rights trading process could be upgraded by a smart contract. First, the automatic review of smart contracts takes the place of manual examination. Moreover, the two trading sides can negotiate independently and match on their own. Last but not least, the water rights transaction data will be kept on a chain automatically and traceably, which makes the data more secure and accessible. Because of the reduction in the amount of manual processing needed, the cost will decrease, and the efficiency will improve.

DAO and SSID naturally fit well together. Once the irrigation districts become economically independent, they can form a DAO. In a DAO, the data are open, real-time synchronized, and built by multiple parties working together. Therefore, the information asymmetry that hinders agricultural water rights trading development will be eliminated. DAOs have a high economic flexibility and can provide an appropriate incentive model with which to enhance participants' level of activity. More active members achieving benefits will greatly promote labor productivity.

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