Blockchains in Water Management & Trading

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Abstract. In 2021, the potential for *blockchain technology* in water markets were recognized by the World Economic Forum and identified by UNCTAD as one of 11 frontier technologies in Sustainable development. The use of AI techniques combined with *Internet of Things IoT*s sensors in Smart Water Management Systems, *SMWS*, emerged from nearly 2 decades; the integration of blockchains to those systems provides decentralization, immutability, traceability, verifiability, and real-time automation of the employed SWM using smart contracts. Since 2017, extensive research efforts from academics and water international organization were dedicated to study possible uses of blockchains in water management systems; a lot of pilot studies are there, and a few real-world projects have started in many countries too. This paper is a systemization of knowledge on the use of blockchains in water management systems. We introduce an exhaustive literature survey of research papers on that direction, cover software projects, and we also gather and discuss available material on practical true cases of blockchain usages in water managements around the world. This paper aims to provide researchers and investors examining such approach with an organized version of all existing material.
Keywords: Blockchain, token, IoTs, Water management, Water Trading, Leakage detection, consensus, smart contracts.

1 Introduction

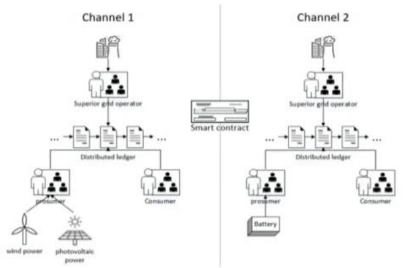
A simple search on Google scholar and known scientific sites on the words "water" & "blockchain" leads to hundreds of papers[1], in addition to case studies in many countries, commercial software blockchain solutions companies that offer their software, and finally international water and/or UN organizations that reports on the existing countries experiments and study the possibility for other countries. In this paper, we try to collect and organize this scattered material, along with the necessary background on blockchain technology and on water management problems; we found 12 papers in *sciencedirect*, 33 in *IEEE*, 2 in *ACM*, 19 in *MDPI*, and more than 10 other papers in *Researchgate.* One of *MDPI* papers [1] provide a comprehensive review of 104 academic papers, 14 white papers, 24 hackathon projects, and some other web documents up till 15 Oct 2022; yet the authors acknowledge the potential

[1] All those numbers increase dramatically if we included papers discussing the use of Blockchain & IoTs in sustainability in general. In fact, part of the material covered in this paper could be applicable in those areas too due to the similarities in the main architecture.

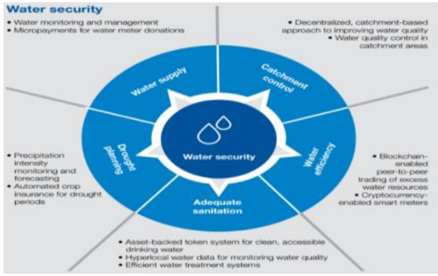
of research appeared in the years after that they were not able to cover, and there are also some sub areas we aim to shed light on.

The main theme in blockchain water management (or energy management in that context, see Fig.1-a) solutions whether in research or practice is a distributed network of ***IoTs*** (*Internet of Things*) sensors to measure certain data metrics, then the data is recorded and ***SWM*** (*Smart Water Management*) techniques is integrated and now coded with more flexibility into (***smart contracts***) on the blockchain to provide an automated online decision making; sometimes, ***Data Mining*** techniques are used to process the massively *big data* collected from the sensors [2].

Designs vary on the kind of data gathered by the *sensors* and the kind of *AI* processing done on the gathered data according to the many possible applications; (Fig.1-b) is taken from [3]. They also vary on whether they use a special purpose blockchain, *HyperLedger Fabric* [4] is a commonly used opensource software to connect it to IoTs, or are developed as an application on top of one of the famous existing blockchains like *AquaSave* project on Solana [5]; some designs use both by making the local blockchain a backup *digital twin*, like *Ganache* in [6]. Data storage is also a design decision, where *DDS* (*Distributed Data Storage*) like *IPFS* (*Interplanetary File System*)[2] with *Filecoin* as its tradable token is sometimes used instead of centralized clouds or servers [6,7].



Fig(1-a) energy trading using blockchains[3]



Fig(1-b) possible water management applications

In addition to automated online actions, ***blockchains*** provide many other advantages; the *tampered proof* record keeping and the duplicate *data redundancy* at each node to avoid single point of failure in centralized designs; the *decentralization* feature facilitates the cooperation between different entities according to any desired governance rules without the need to a trusted third party; *cryptographic verification* of each transaction provides a defense line against recently increasing cyberattacks [8]; blockchain literature already have solutions to *provide confidential transactions*, [9] adopted *bloom filters* in their proposed water distribution system, and [7] used *FHE (Fully Homomorphic Encryption)* in their flood detection system.

In this paper we are going to span real countries experiments and/or pilot studies like South Africa, Australia, South Korea and some states in USA; also international

[2] IPFS has a blockchain architecture itself, and is used for NFT storage in many cases, where the price of its token is considered as an incentive for nodes to store the data (https://medium.com/0xcode/using-ipfs-for-distributed-file-storage-systems-61226e07a6f/)

[3] Taken from (https//link.springer.com/chapter/10.1007/978-3-031-31420-9_4)

organizations reports like *International Water Association* [10][4], *World Economic Forum* [11] , *Observer Research Foundation* on G20 countries [12] , and funded studies evaluating the possible use of blockchains in different water scarcity areas, especially on transboundary water sources where the decentralized nature of blockchains is beneficial [13]; in addition, we are going to cover in some detail the new evolving use of AI in consensus protocols to better suit water systems like [14] as an example. Our aim is to give a starting point and a consolidation of all possible material to researchers from both sides in such an interdisciplinary area; the paper should be helpful too to governments and/or private sectors trying to assess the risks and benefits of those projects.

The rest of the paper is organized as follows: section 2 gives the necessary background on blockchain technology; section 3 presents an exhaustive list of most water management applications where blockchain deployment would be beneficial; section 4 covers different research directions, software companies and emerging projects working in blockchain water management solutions, and case studies from different countries. Finally, section 5 concludes the paper.

2 Blockchain Technology

This section gives the necessary background on the blockchain architecture, their different kinds, smart contracts, and the problems endorsed in applying them.

2.1 Blockchain Architecture

Blockchains as an append only distributed ledger, sometimes referred to as ***DLT*** (Distributed ledger Technology), was first introduced in 2008 by S. Nakamoto as a data structure to hold Bitcoin transactions [15]. As shown in Fig.2, a blockchain could be viewed as linked list of ***Blocks***; each block contains a number of cryptographically signed transactions as its data, and some authenticating data in the *block header* including the *Merkle root* of all contained transactions and the hash of the previous block. A block gets appended to the chain only if it is validated, including every transaction inside it, by a (>50%) majority of the participating P2P nodes according to a predetermined ***consensus protocol***. For Bitcoin, and the first generation of cryptocurrencies that followed it, the consensus protocol was *POW* (*Proof Of Work*)[5]

[4] We included part-1 as a reference, the reader can find the links for parts 2&3 navigating through the site.

[5] To be accurate, the idea of *POW* first appeared as a spam protection scheme in emails (performing enough computation that outweighs the spam profit) and failed, then it was widely adopted as a consensus approach in cryptocurrencies because it requires only a majority above 50% honest nodes to guarantee integrity as opposed to the traditional ***BFT*** (*Byzantine Fault Tolerance*) protocol that requires >2/3 the participating nodes to be honest. With the emergence of more cryptocurrencies and blockchain types, many other consensus approaches kept flooding to meet the specific needs of the target application or system (including water management systems as we will see through the paper)

where consensus can be achieved with (>50%) majority; this way no trusted third party is needed, and data is duplicated in each node preventing single point of failure problems in centralized approaches. And any device with enough hash power can participate as a node and be part of the consensus; what is called ***public permissionless blockchains***. Many applications started to take advantage from the *public Bulletin Board* feature of this kind to use it as an authentic record for documentation purposes; one can find university exam results[6] published on Bitcoin or Ethereum, and also cryptographic checksums that need to be verified or agreed upon by different entities[7].

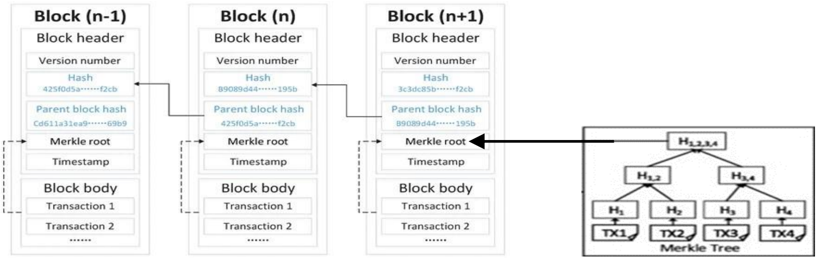


Fig.2: Blockchain structure (the Merkle tree is not stored, it's calculated with each validation)

2.2 Smart Contracts

A major breakthrough was the development of Ethereum in 2015 with an ***EVM*** (*Ethereum Virtual Machine*) [16][8], Fig.3, that enabled writing programming code (***smart contracts***) inside transactions, as opposed to script-only transactions of Bitcoin; at the beginning Ethereum smart contracts was written in *Solidity* language, nowadays most cryptocurrency blockchains allow smart contracts to be written in many other languages including Rust, C++, Go-Lang, …etc.

Fig. 3: The Ethereum virtual machine and how it works, adopted from [16]

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[6] NFTs are usually used for such purpose, however some university courses still use non-standard UTXOs to publish exam results as Bitcoin transactions; in both cases they choose times when transaction fees are low to publish a whole class result. This type of result publishing became more suitable as a certified proof for online remote students.

[7] Examples include CBDC designs and some research suggestions for e-voting; even if the internal design of each participating entity does not follow the DLT approach, the cryptographic values are still readable for them.

[8] The figures in the Ethereum foundation site (https://ethereum.org/en/developers/docs/evm/) are adopted from [6] (Ethereum EVM illustrated) as an indication it is a simplified tutorial; the yellow and a beta beige papers are available in GitHub (https://github.com/ethereum/wiki/wiki/White-Paper) for the more sophisticated reader

Smart contracts opened the door for enormous number of applications to be coded inside a blockchain transactions. Applications or DAOs (Decentralized Autonomous Organizations) were developed on top of a blockchain issuing their own ***token***[9] and each token has a price that fluctuates according to its market; the theme was to "*tokenize everything"*. ***Tokenomics***[10] refer to the cost benefit analysis of a start-up project to decide whether to issue their own token or not [17]; not just Decentralized Finance applications, there are game tokens, data storage tokens like *Filecoin* mentioned above, and physical infrastructure tokens including water tokens like *$AQC* of [5] which is part of *DePIN* (*Decentralized Physical Infrastructure Networks*) over Solana (a ranked #5 cryptocurrency blockchain). The idea of tokenizing water using blockchains started to emerge in 2017 [18], and now there are several water trading tokens whether governmental or by the private sector [19].

2.3 Different Kinds of Blockchains

Other kinds of blockchains emerged with time, for example ***POS*** (*Proof of Stake*) cryptocurrencies are considered ***public permissioned blockchains*** since permission access is assigned according to prespecified rules (stakes in POS) and after registration. ***Private permissioned blockchains*** are sometimes used as the backbone of information systems where secrecy of user's transactions is also a target like banks or private companies. When such blockchains are governed by a group of authorities rather than just a single entity[11] they are usually referred to as ***consortium blockchains***; this suitable for multi organizational systems and are commonly used in sustainable development applications like water or energy management.

IOTA[12] is also a distributed ledger design of IoTs sensors; however, instead of the linked list approach of blockchains nodes are arranged in a *DAG* (*Directed Acyclic Graph*). Although *IOTA* is mainly designed for sustainability solutions [20], we haven't reported any water applications using IOTA in the literature, and since it's not

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[9] The term token is adopted from systems programming, the struct that hold the current item being parsed; here it was first used by Ethereum EVM and could be viewed as a C struct or object. The first standard was ERC-20 to hold Ethereum tokens then ERC-721 was the next standard to represent NFTs, other cryptocurrencies use the same terminology; like programming language libraries could define new data types a lot of token standards have been proposed (https://github.com/PhABC/ethereu-token-standards-list). On the other hand, DAO tokens are on a top layer in the blockchain layers hierarchy (https://www.gemini.com/cryptopedia/what-is-tokenization-definition-crypto-token); those and most other cryptocurrencies tokens follow the Ethereum ERC-20 standard.

[10] See (https://en.m.wikipedia.org/wiki/Tokenomics)

[11] A private permissioned IoT Blockchain could be less than 10 home smart devices (https://arxiv.org/abs/2107.08970), while larger sustainability solutions with various institutions and organizations use a consortium Blockchain; Fig.(1-a) is a consortium design, and HyperLedger Fabric assumes consortium as a general case.

[12] see (https://github.com/iotaledger/iota-wiki) for more details.

a blockchain design anyway, we consider it out of the scope of this paper and suffice with a clarifying figure, Fig.4, taken from [20].

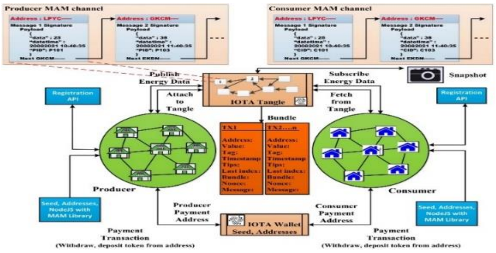

Fig.4: an IOTA energy trading system, [20]; *MAM =Masked Authentication Managing* protocol

2.4 Overhead Complexities

As [10-13,21] discussed for water applications, and even in cryptocurrencies and financial applications [17], deploying Distributed Ledger Technology (*DLT*) introduces some extra costs and needs some pre-requirements:

- ***Energy consumption and carbon footprints*** are persisting problems in all POW blockchains, and even when a private blockchain is used the energy consumption of the IoT sensors remains a problem; the only mitigation is to use clean energy resources and green IoT [13].
- ***Physical & Digital Infrastructure:*** naturally building such distributed networks of sensors and blockchain nodes involves the establishment of the needed physical and digital infrastructure; this is seen from the fact that all successful running systems are in developed countries, and the rest is still in the research phase. However, if the infrastructure is only missing in one of several covered areas, can still benefit from blockchain through decentralization [13]. The integration with current old systems is also a consideration to minimize the cost.
- ***Public awareness & digital knowledge:*** water applications involve the whole population with all its sectors, and agriculture applications involve farmers. Hence, using such technologies should be preceded by increasing public awareness and the necessary needed training; a reported threat in is increasing the gap between "those who know and those who don't know" which may induce public rejection.
- ***Cyber Attacks:*** whenever there is a digitization, cyberattacks become a threat [2] and the necessary security defenses must be deployed.
- ***Regulatory Framework:*** any use of trading tokens involves establishing the necessary laws and regulations to handle them; there were endless debates on the DeFi communities on whether to treat tokens as a commodity or as a security or make a different new model[13]. IoTs also need regulations; new

[13] A security in USA means a tradable object, and different countries may have different views; see (https://youtu.be/eVg8zAJoCxc) for an enlightening discussion between academics on how tokens are legally treated in USA, England, and European countries.

technology paradigms introduce new crimes, like for example cybercrimes penalties; whether it would be integrated in old laws or new laws are added is another decision.

3 Water Management Areas Blockchains Could be used in

In this section we try to cover all possible water applications in which blockchain usage were suggested or are actually in use in existing systems [1,2,22,23].

1. ***Water Trading***
   A blockchain water market provides a publicly accessible immutable register of all trades, and the automated decentralized process provides cheaper faster (up to 90% time saving is reported in [11]) transactions. The token price represents the price of the water unit; hence, the water consumption quantity could be measured, and price controlled accordingly. Any desired policy could be programmed in the smart contract and executed online, for example rewarding incentives could applied for water saving. South Africa established and developed the water network which launched the first world water utility crypto token[14], ***H2O*** [24]; $H2O price as of today 1/4/2024 is $0.2574. Examples of private sector water tokens include ***$AQC*** [5], ***$WTR*** (worth 2 Swiss Francs) [25] from Hypercube tokenizes the production of existing water reuse facilities and sells it for companies as voluntary water credits to fund new water projects[15], ***$LAK3*** is the token of a web3 project in Switzerland [26], and there are a lot more. Non-Commercial examples include *water 150* [27] a long-term project by *longhouse foundation* (started 2020, smart contracts written and white paper released 2022, with plans till 2026) that aims to "democratize" water access globally with impact wells done in Tanzania and Ghana; *the water token* is a master thesis project form Twente University California [28].
2. ***Water Utilization and Governance***
   The same systems used for water trading could also be used for water governance since they measure water consumption. *Civic Ledger* is an example company in Australia [29], IBM in California[16] [30,31], South Korea and Japan experiments are discussed in the G20 report [12], and there is also a proposed blockchain solution for water governance by Colorado's governor office of information technology [32]. Existing water consumption data can be helpful in many aspects of governmental planning [33]; for

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[14] When searching for water management tokens, please do not mistake NFT water donation tokens or game NFTs that involve the word "water" for some reason.

[15] There are 3 existing projects (https://www.hypercube.eco/token/1) : water reuse systems, green desalination, and rainwater harvesting.

[16] The start of California project in 2019 was to track the groundwater level, but since the purpose was to govern farmers usage of it, we preferred to discuss it under water access rights applications.

example, before building a new city or inhabiting a new district that will depend on certain water resources, studies should be made on current and expected new water consumption. A simpler yet useful application suggested by [22] is to classify the online measured difference between actual and planned water use into (red, yellow, and blue) to provide an early warning system, analyze water consumption to implement water-saving measures accordingly. Another important usage that benefits from traceability and smart contracts code is introduced in [34] where management of agricultural water access rights could be strictly controlled to ensure the appropriate allocation of water for each use; i.e., agricultural water use would be significantly affected if an irrigation district originally applied for a water permit for agricultural irrigation and then used the water for industrial use, since each case imply different water quality standards and different wastewater management.

3. ***Monitoring Water Quality***

The same network could be used to measure water quality in addition; the automated trustless water quality monitoring increases the ***credibility*** of the published metrics; the royal bank of *Canada* started with other organizations a freshwater quality monitoring project using Ethereum [35], where anyone can view automated water quality monitoring online [36]; in 2018 [37] suggested the use of blockchains to improve the quality of drinking water (by monitoring it) in Puerto Rico, while [38] claims to be the first to suggest such usage in 2017.

In addition, the decentralized nature provides more ***traceability***; when water quality is measured at each node, the type of pollutant, its source, and the responsible person or malfunctioning can be accurately and automatically traced without tampering or denial; see [2] for a true story of pollution denial, Fig.5, before deploying blockchains. Also, [39] discussed the use of blockchains to detect pollutant in agriculture irrigation water.

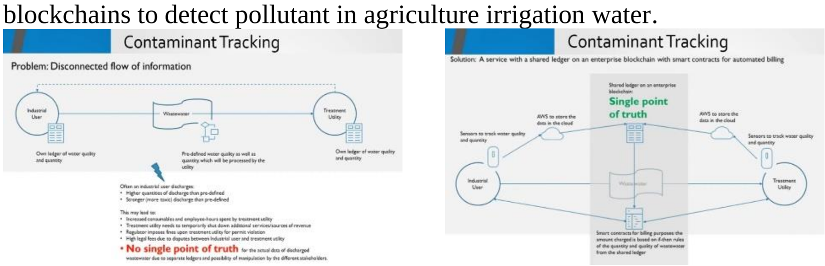

Fig.5: pollution source detection before and after blockchains from [2][17]

4. ***Managing Water Resources***

When there is *more than one water resource* is used to supply water to a district, water quantity and quality can be monitored for each resource. Then, the data can be used to manage the performance of each resource kind and act accordingly. Vice versa, the decentralized nature of blockchains could be

[17] recall that cloud storage is not the only storage option as we mentioned in section1

beneficial in managing a *transboundary water resource* shared by more than one country; [13] studied the pros and cons of using blockchains in managing many case studies of transboundary shared resources including Jordan Basin and Lake Victoria, while [1] mentioned it as a possible future work. Another water resource management problem is how multi-scale irregular water resource spatial distribution escalates under climate change conditions; [40] deploys AI techniques on blockchain smart contracts to accelerate the capturing of complex patterns on the shifting (due to climate change) water distribution.

5. ***Managing Water Supply Systems***

   A recent 2023 paper [41] discussed how the use of Blockchains can improve the functionality of water supply systems in Bulgaria; [22] studied the problem in general and divided it to managing *waterworks* and *water pipes*.

   - Waterworks: Smart contracts are used to compare the monitoring data of water withdrawal with the amount in the water abstraction permits to determine whether the permit is exceeded. In addition, water quantity and quality of the source water will also affect the water supply dispatching scheme and thus needed as input data. The authors in [9] proposed a smart meter *data aggregation* mechanism for water supply systems in 2019; then introduced a complete toolbox in 2021 [42] by linking real-time monitoring data of water quantity and water quality of reservoirs to ensure that water supply plans can be adjusted scientifically and quickly.
   - Water Pipe: in addition to monitoring the water quality in each pipe, ***pipe leakage***[18] rate could be monitored and compared to standard values to identify faulty pipes; [22] suggested establishing a hydraulic model based on real-time measured water pressure in the pipeline to locate leakage points in the pipe network and diagnose faults in the water supply network. However, the authors in [43] reported the complex execution of their modular API for flow control and water leakage detection; they used Go programming language to write a smart contract for a Hyperledger Fabric network. Pipe freezing naturally happens due to cold weather, and we will encounter in 7 another side effect of bad weather conditions on the accuracy of visual data.

6. ***Wastewater and Sewage Management Systems***

   Different wastewater kinds go into different recycling processes; similar strategies can be applied to manage wastewater by measuring amount and quality of reused wastewater, then developing the necessary code for data analysis and decision making [44,45]. Water quality indicators at the

[18] According to (https://www.bmscat.com/blog/preventing-frozen-pipe-damage/) an average of over 250,000 homes each year will suffer damage from frozen and burst pipes; the damage is estimated to be in the $400-500 million each year. A major incident happened in USA 2008 (https://inspectioneering.com/journal/2008-07-01/217/united-states-csb-determines-m)

drainage system can be compared to known standards; also, the sewage volume and quality is monitored at the water inlet & outlet of sewage treatment plants and fed to the decision-making code at the smart contract. A very promising project is formed between *BWT* (*Botanical Water Technologies*) from Australia and Fujitsu to develop ***$BWX*** (*Botanical Water Exchange*) on Hyperledger Fabric, Fig.6 from [46]; the project is estimated to recover 3 trillion liters of pure drinkable water annually from juice, alcohol, and alike products if making facilities were equipped with *BWT*'s equipment.

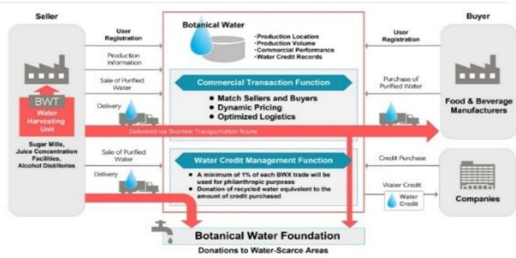

Fig.6: the Botanical Water eXchange project

7. ***Flood & Drought Dam Controls***
   Such systems use data analysis and visualization to classify the flood risk, provide early warning, and implement emergency response measures, like sluice control and pump station scheduling; values measured through sensors could include precipitation, water inflow, reservoir or dam level, water flow in drainage networks, and a lot more. In Nov 2022 Saudi Arabia suffered from a flood and heavy rains incidence that caused many losses; in 2023 [7] suggested the use of *drones* (since other kinds of image capturing devices have low quality during bad weather conditions), *IPFS* distributed data storage (for the larger size of visual stored data), and *Paillier Fully Homomorphic Encryption* to protect data privacy in their blockchains design.
8. ***Groundwater Management***
   Governments usually deploy techniques to forecast groundwater availability which include collecting and gathering groundwater data from different sites. The authors in [6] introduced a system for groundwater management in USA states using Ethereum, *IPFS*, and another local blockchain; the California IBM project [30] measures groundwater levels to tackle drought problems.
9. ***Water Transportation***
   A somehow different application was introduced by [47] in 2023; the authors evaluated the deployment of blockchains in water transportation systems. According to the authors, its information sharing score was 93; its data storage and management score was 96.1; its smart contract score was 97.4; its fund management score was 97.1; its IoT technology score was 96.5.

4 Research Directions, Software, and Case Studies

In this section we summarize main research directions in Blockchain usage in water management, emerging software projects in the field, and case studies research or evaluation reports; all mentioned research threads are expected to continue for the near future and are considered promising future research opportunities.

4.1 Research Directions

The use of blockchains in water systems only started in 2017, so there is still room for research *mapping traditional water management applications* and old techniques to the blockchain architecture; for example, the techniques introduced in [48] for measuring water quality and storm effects in nursery containers could be encoded in an automated smart contract. Another direction is to address *the challenges introduced in blockchain water systems*; [49] tackles energy consumption problem by integrating green energy trading and water trading in one system that is suitable for small farmers associations; security challenges and existing solutions were surveyed in [50], while [51] is an earlier paper that suggested a 3-fold objective attack model along with introducing an irrigation precision system using blockchains; regulatory framework for groundwater is discussed in [52] as an example.

Then, there is the infinite possibilities of *introducing innovations or enhancements in one of the system main three modules*. We could include using drones to address the quality of gathered data, [7], and the use of distributed data storage systems versus clouds to handle big data under the first phase; the possible variety of AI techniques employed belong to the informative decision making phase [9,39-45], and also refining all smart water management research like those mentioned in [22] to their smart contract version; while the innovation of performing meaningful AI techniques instead of regular block mining computations in POW consensus [14, 34], or research testing the deployment of certain blockchain or software like HyperLedger sponsored research [2,33,46] belong to the blockchain design.

An interesting 2024 paper, [53], design a blockchain-driven incentive mechanism for water saving using tripartite evolutionary *game theory* model; the 3 players are the *government*, the *farmers*, and water saving *service companies*. The study investigates the relevant factors affecting the players choices (like the added cost of deploying blockchain technology and the incentive to save water), and then scrutinizes the “multi-directional” influence exerted by various stakeholders in the game. Building game models is a common research approach to study the behavior of countries sharing transboundary water resources[19], and in analyzing cyberattacks incentives[20]

[19] The interested reader may refer to a long history of different game models for the Nile Basin (2006: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2005WR004238, 2011: https://www.academia.edu/15471274/A_Game_Theory_Approach_to_Understanding_the_Nile_River_Basin_Conflict, 2020: https://blogs.cornell.edu/info2040/2020/10/01/the-dangerous-game-theory-behind-the-grand-ethiopian-renaissance-dam/); also (https://www.researchgate.net/publication/359685621_Basin-

like [51]; however, using it to study and incentivize the involved parties in water management systems is an innovation that could start a whole research thread that suggests different game models for different water applications.

4.2 Software & Projects

It is true that most large-scale water government solutions are sponsored by government; however, the trading nature of tokens originally belongs to the private sector and entrepreneur projects like [25-28]. Other innovations include ***water coin***, [54], which is a sustainable Bitcoin mining project in Austria that claims to utilize the available funds to acquire fresh water sources and manage them sustainably.
Then, there is software projects that try to introduce supportive software to blockchain water management systems; examples include ***Aleo*** that provides *ZK* (Zero Knowledge) layer1 solutions for sustainability applications [55], ***DePIN*** group of projects over Solana [5], and the major opensource software ***HyperLedger Fabric*** that added more flexibility to previous *SCADA* (Supervisory Control and Data Acquisition) dashboard in handling the IoT data [2].

4.3 Case Studies

Due to the nature of sustainability problems, there will always be research and governmental reports discussing the feasibility of integrating blockchains in the existing water systems and investigating cost-benefit analysis; [12,13] provide comparative summaries of many countries experiments and pilot studies along with all their original references. More research belonging to this category include [31] on California, [41] Bulgaria, [21] comparing Los Anglos (USA) and Bengaluru (India), [56] Duch, [57] Netherland, [58] Spain, [35,36] Canada, and [7,43] Saudi Arabia.

5 Summary & Conclusions

The use of blockchain technology in water systems has been an emerging research and software development topic in the last decade; the interdisciplinary area contain contributions in all water trading & management problems from one side, and AI, IoTs, Big data gathering & storage, consensus protocols, cyber security, and all blockchain related topics from the other side. In this paper, we attempted to systemize the existing research and status quo knowledge on real experiments and different possible applications, after introducing the necessary background on blockchains and

Wide_Water_Resources_Management_Strategies_Improve_Cooperation_Effectiveness_and_Benefits) is a more general and recent, 2022, paper

[20] Most consensus protocols study the attacker incentives by weighting the attack computation cost against the expected attack profit, see (https://arxiv.org/abs/1902.10865) for an 2019 survey on applications of Game Theory in Blockchains.

the challenges involved in using them. The paper then closed by outlining the main broad lines for current and possible future research and development directions.

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