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Water security and sustainability issues in Ghana's Pra River Basin: an introduction – projected usefulness of artificial intelligence

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Emmanuel Kwame Nti
West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, Tamale, Ghana and Department of Environment and Sustainability Sciences, Faculty of Natural Resources and Environment, University for Development Studies, Tamale, Ghana
Gordana Kranjac-Berisavljevic
West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, Tamale, Ghana and Department of Agricultural Mechanisation and Irrigation Technology, University for Development Studies (UDS), Tamale, Ghana, and
Dzigbodi Adzo Doke
West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies, Tamale, Ghana and Department of Environment and Sustainability Sciences, Faculty of Natural Resources and Environment, University for Development Studies, Tamale, Ghana

Abstract

Purpose – The aim of this paper is to determine whether the dominant integrated water resources management (IWRM) paradigm within which the Pra River Basin is managed holds the key to address the current water security and sustainability issues in Southwestern Ghana.

Design/methodology/approach – This study employed a literature review developed based on water security and sustainability studies as well as normative scenarios from the broad scenario planning methodology. The study builds on Wæver's Theory of Securitization and the Utilitarian theory to protect water bodies through the use of artificial intelligence (AI).

Findings – Insights on introducing innovative environmental sustainability technology are presented and propose the Pra-integrated smart water security management decision-making system that uses visual inspections, noise sensors, the potential of hydrogen (pH) probe sensor, real-time collection of hydrological data (streamflow) and wireless transmission of the data in real-time at the basin level. This serves as a robust tool for managing the basin's sustainable development ecosystem by using AI to protect water bodies against illegal mining.

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Originality/value – The proposed innovative environmental technology which is the first of its kind is meant to gain a better understanding of pollution incidents and respond quickly to them by integrating AI and Internet of Things (IoT) technologies with traditional IWRM practices. This addresses water security in the Pra Basin, supports policy development and innovation, strengthens the goal of the government to protect water resources against pollution and contributes to the African Water Vision and the United Nations' Agenda 2030 Sustainable Development Goals 3 and 6.

Keywords Water security, Integrated water resources management, Illegal mining, Artificial intelligence, Pra River Basin

Paper type Literature review

Introduction

Globally, micropollutants despite their low levels as synthetic chemicals found themselves in surface waters. Sources such as personal care items, household products, pharmaceuticals, pesticides, industrial discharge (Universität Wien, 2021) and illegal mining in waterbodies and water courses pose substantial risks to the environment, human health, aquatic ecosystems, water security and sustainability (Nti *et al.*, 2023b). This is due to the potent toxicity of micropollutants, endocrine-disrupting, carcinogenic, and mutagenic properties and their role in fostering antibiotic resistance (Universität Wien, 2021). As further noted by Universität Wien (2021), many of the environmental destructions, whether it involves wildlife in Asia, rainforests in South America or rivers in Europe, now impact the entire planet more quickly and significantly than ever before. A typical example is the transboundary river like the Danube which passes through at least ten countries. This suggests that any pollution in one or more of the ten countries (Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, Moldova and Ukraine) can quickly spread and affect water quality, aquatic life and the health of the ecosystems. Universität Wien (2021) reported that 66 tons of nickel were released from a factory into the Kokemäki River in Finland and went undetected for 30 h. In Poland, wastewater from Warsaw containing 300 tons of nitrogen and 30 tons of phosphorus was discharged into the Vistula River over the course of five days (Universität Wien, 2021). More importantly, an essential measure is to promptly identify the discharge points of micropollutants. The usefulness of this study across the globe is evident as numerous countries face similar threats to their water resources. However, the need for extraordinary measures to protect water bodies has now become a universal concern. As such, implementing international policies to address river pollution is crucial. It is therefore important to create early-warning systems using AI to detect river pollution (Hanak, 2024).

Recent studies exist on AI and IoT in advancing water management practices including González *et al.* (2024), Essamlali *et al.* (2024) and Singh and Ahmed (2021). These studies also demonstrate the effectiveness of AI and the Internet of Things (IoT) in water management through real-time monitoring and data analysis. For example, González *et al.* (2024) developed a monitoring system for water sources in the Tres Lagunas Andean high-altitude wetlands ecosystem in Ecuador that uses IoT technologies to transmit hydrological data. Essamlali *et al.* (2024) provided an in-depth overview of recent IoT wireless technologies and machine learning (ML) techniques. Singh and Ahmed (2021) also highlighted studies that have demonstrated the application of AI and IoT in water management including Pujar *et al.* (2020), Danh *et al.* (2020), Mukta *et al.* (2019) and Geetha and Gouthami (2016). For instance, the Krishna River was the subject of study by Pujar *et al.* (2020) who conducted real-time monitoring of water quality parameters, including the potential of hydrogen (pH), conductivity and dissolved oxygen. Similarly, in the Mekong Delta, Danh *et al.* (2020) developed the E-Sensor AQUA system that monitored water quality parameters such as dissolved oxygen, pH, temperature and salinity. The system utilized real-time data collection and cloud-based analysis. Mukta *et al.* (2019) study used ML algorithms to assess water quality and focused on continuous water quality monitoring. The study employed parameters such as temperature, pH, electrical conductivity and turbidity. More importantly, the novelty of the various studies on AI and IoT applications in water management with the successful implementations in the Mekong Delta and Krishna River regions are examples that demonstrate the effectiveness of these technologies.

The theories of securitization and utilitarianism provide a compelling rationale for the urgent protection of water bodies given the escalating threats of pollution, climate change and unsustainable practices that endanger water bodies globally. Wæver's (1995) Theory of Securitization explains that a politician declares water resources as a critical concern requiring exceptional measures for protection. However, once the declaration is accepted by the public, the securitization move is deemed successful (Bogardi *et al.*, 2016). According to Crowther and Hamdan (2024), utilitarianism emerged as an extension of liberalism. Utilitarianism addresses the need for societal regulation with each individual independently pursuing their own goals. In utilitarianism, the focus is on the government's role to mediate between individuals to ensure good outcomes. Thus, the consequence of actions rather than the actions themselves to determine their goodness or badness is critical (Crowther and Hamdan, 2024).

The practical application of securitization and utilitarianism theories can be seen in the ban on illegal mining, known as "Galamsey" initiated by the President of Ghana in 2017. The term "Galamsey" originally meant the traditional method of mining (the act of gathering and selling) practiced in Ghana prior to and during the colonial era (Baddianaah *et al.*, 2022; Nti *et al.*, 2023b). From a securitization perspective, the Government of Ghana identified "Galamsey" as a serious threat to water bodies and justified the need for extraordinary measures, such as the ban on "Galamsey" to protect Ghana's water resources for the present and future generations. Practically, the ban on illegal mining activities also reflected a utilitarian approach where it emphasized the overall wellbeing of society to protect public health, prevent environmental degradation and ensure sustainable benefits for the populace. From a utilitarian perspective, while "Galamsey" may provide immediate economic benefits to a small group, it jeopardizes the environment and natural resources needed for future generations. More importantly, the practical application of these theories is evident in the government's actions to regulate and ban illegal mining. Thus, the theories of securitization and utilitarianism provided a strong rationale for banning illegal mining to protect and promote the common good. Recently, because of digitization, some methods, resources and techniques that could usher in a new era of water management are progressively becoming available. Thus, technological innovation in every aspect of water management in response to major problems with water security to create a sustainable future is growing. Also, partnerships in knowledge co-creation and innovation could make a significant difference. This is to innovate something that is technically practical, economically viable, socially acceptable and locally adaptable solutions to the fundamental problems in the realm of water security (United Nations, 2023).

Water security has sorely been centered on water reliability, quality, quantity, safety, equitability as well as environmental provisioning of water supplies. This is equally important for human development and the environment. However, the deployment of artificial intelligence (AI) in other parts of the world has proven crucial particularly in the global north in improving decision-making, adaptation and mitigation capabilities.

Water security is defined in various ways in the literature. According to Marcal *et al.* (2021), it is regarded as managing too much, too little, too polluted and freshwater ecosystems degradation. As noted by Milutinović *et al.* (2016), the water security concept gained international prominence in the year 2000 during the Second World Water Forum. One major component of comprehensive water resource management is the need to assess water security status through research (Gerlak *et al.*, 2018). Following the City Blueprint indicator approach of urban water sustainability, water security was found to be among the eight broad important criteria to assess sustainability (Nti *et al.*, 2020; van Leeuwen *et al.*, 2011). A paradigm where water security and sustainability are rewarded and water profligacy from mining in water bodies causes a failure in water resource management for the future should be addressed (Bigas, 2012). It is important to safeguard water resources for both present and future generations. As governments increasingly recognize the value of water for their citizens, how quickly Ghana is able to move to a state where water security and sustainability are rewarded will also determine the interest of Ghana in water security management.

Illegal mining ("Galamsey") activities pose a danger to the development progress made over the past 2 decades. This may make it more difficult to meet the Sustainable Development Goals by 2030. "Galamsey" has been associated with the increase in artisanal small-scale mining (ASM) activities on the surface of water bodies causing pollution (Ofosu and Sarpong, 2022). In recent times, these small-scale miners have adopted the use of machinery like excavators in their mining and have entered into river courses. Due to their proliferation and a lack of permit to mine (illegal), it is very difficult to regularize their activities which are destroying the various water resources and the ecosystem at large. During the search, a series of water security issues were identified in the Pra River Basin and others situated in the Southwestern part of Ghana. These issues are evident to be hindering the progress of sustainable water management as far as the responsibilities of the Water Resources Commission and its affiliated bodies with both direct and oversight responsibilities are concerned. Already, integrated water resources management (IWRM) has been criticized as "too water-centric" in practice, when managing water resources (Giordano and Shah, 2014; United Nations, 2021). This critique arises because IWRM does not fully consider the important dimensions of social, economic and environmental linkages resulting in the emergence of different "nexus" complementary frameworks (Hoff, 2011; Roidt and Avellán, 2019; United Nations, 2021).

Existing studies primarily center on pollution and mining (Bessah *et al.*, 2021; Rajaee *et al.*, 2015), while giving limited attention to the crucial aspect of water security within the Pra Basin. This paper therefore extends its scope beyond the immediate issues of water pollution caused by illegal mining ("Galamsey") activities. The study encompasses broader concerns related to water security and the prevailing IWRM paradigm in the basin's management. This paper consequently bridges the gap in addressing the question, "does the dominant IWRM paradigm within which the Pra Basin is managed hold the key to address the current water security and sustainability issues?" Also, digital transformation and efficient utilization of AI in decision-making to protect water resources from detrimental heavy metal pollution are currently unavailable. Thus, currently, there is a technological gap in terms of monitoring mechanisms to protect Ghana's water resources against illegal mining ("Galamsey") activities. In addressing this gap, there is a need for more digital transformation mechanisms (Kapelan *et al.*, 2020). This is to help offer an alternative practical solution that has advantages over the illegal mining ("Galamsey") menace in waterbodies and water courses in Ghana. Among these, AI is the key technology in the digitalization move. Thus in order to close these gaps, a promising recent development is the introduction of digital transformation for water resource sustainability and the usefulness of environmental technologies in Ghana.

A synthesis of IWRM and water security paradigms in addressing water pollution in the Pra Basin is critical for the future of Ghana's water resources. Amongst the existing solutions in addressing water security concerns, after the government's awareness of the damages and risks from changes in water color and chemical contents placed a ban. The ban saw the launching of task forces and operations like "Operation GalamSTOP," "Vanguard" as well as the adoption and deployment of digital solutions in the form of drones to monitor the country's water resources against the mining menace. The results of using drones have not been much to address the problem. Also, little progress has been made with the complementary speedboats. Afterward, the ban was lifted, and the concept of community mining was implemented. However, the sustainability of water resources such as the Pra River Basin remains a threat (Nti *et al.*, 2023b). Arguably, the joint police and military operations have not been reliable enough to clamp down on the operations of illegal mining. This is partly due to poor transportation, monitoring and communication systems. They solely relied on "tip-off" from concerned citizens or informants.

It is important to state that bridging the identified gaps at the basin level is meant to support policy development and innovation in the field. It is therefore logical to assess in this paper, the usefulness of environmental technologies using AI and ML. This is meant to enhance successful water governance against the consequences of "Galamsey," especially in the Pra Basin in Ghana. The paper contributes in the following ways: first, to gain a better comprehension of pollution incidents and respond quickly to them using environmental technology. Second, improving the capability to predict the dissemination of pollution and implement more efficient measures to minimize its effects over an extended period. Third, to use data-driven AI that can learn and evolve over time. The rest of the paper is organized as follows: the methodology of the study, water security and IWRM in Ghana with a brief highlight on river systems in Ghana, IWRM and water security in the context of Ghana's Pra Basin, discussion and also highlights of the key components of complementing IWRM with water security plans and their interactions for future implementation particularly on AI, ML and water bodies caretakers. Section five concludes and makes policy recommendations.

Methodology

In this study, the methodology adopted consisted of a literature review developed based on studies on water security and normative scenario methodology. The methodological framework of the literature review adopted for the study was considered as the most reliable tool to summarize existing evidence as the primary data source. The justification therefore is that a literature review provides the foundational knowledge of a study and helps identify gaps in research, conflicts and inconsistencies in previous studies. In retrieving the papers with the intention of achieving high credibility, journals that were indexed by Scopus as well as papers written in English language for accurate interpretation were used. Methodologically, the steps below were followed:

(1) Databases identification of Scopus-indexed journals

(2) Selecting the appropriate keywords as well as the search criteria for the study

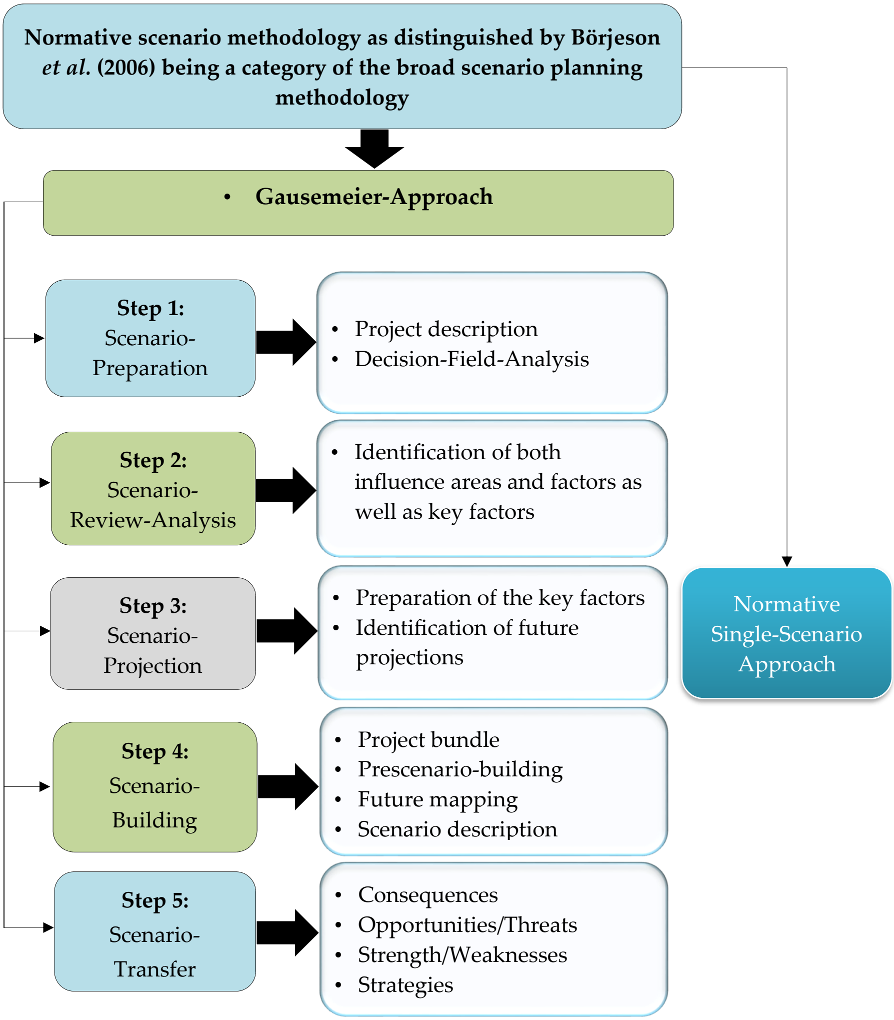
(3) Choosing and analyzing the papers

(4) Accepting and categorizing the papers into major themes

(5) Emphasizing gaps in accepted categorized papers

In this paper, keywords used in the search engine were "Water security," "Pra River Basin," "Southwestern river system," "Integrated water resources management" and "Water pollution." In choosing and analyzing papers, inclusion criteria were followed based on a screening process. This was done to identify suitable articles based on titles, abstracts and full texts of papers that focus on the Pra Basin. Papers that do not analyze water security issues were rejected solely on the basis of both abstracts and keywords. Some papers were found to be duplicated and such papers were deleted accordingly. Gray literature was also used in the review of water security issues in the context of the Pra Basin.

Normative scenario methodology as distinguished by Börjeson *et al.* (2006) being a category of the broad scenario planning methodology (Amer *et al.*, 2013; Sardesai *et al.*, 2021) was adopted for the study to project into the future of how digital transformation using AI and ML can be used in managing Ghana's water resources. In order to be prepared for various kinds of possible developments in the future, this methodology stimulates the creation of different scenarios. Scenario planning is sometimes referred to as "projections" (Sardesai *et al.*, 2021; Wilkinson and Eidinow, 2008). The scenario planning methodology incorporates various permutations of future states which sets it apart from other future research approaches like predictions and forecasts. Thus, scenario planning technique describes a future version that derives from the current stage of advances (Sardesai *et al.*, 2021). The generated scenarios assist in responding to change. The methodology also supports the creation and use of technology in order to comprehend and provide a sustainable future. Thus, the methodology helps organizations in the development of new innovative goods, technologies and ideas that better our environment (Amer *et al.*, 2013; Sardesai *et al.*, 2021). The methodology employs a robust approach to compress numerous future projections. This allows for the selection of a few scenarios for more detailed analysis (Gausemeier *et al.*, 1998; Sardesai *et al.*, 2021). The scenario planning methodology was applied to create an actionable solution for exploring and addressing the challenges of river pollution. The approach is divided into five distinct steps as illustrated in Figure 1.



Source(s): Adapted from Börjeson *et al.* (2006), with additional insights from Gausemeier *et al.* (1998) and Sardesai *et al.* (2021)

Figure 1.
Five distinct steps of scenario planning methodology modified in this study

This study refines the scenario narratives of developing multiple scenarios. It focuses on a single categorized subject matter based on the identified AI gap. Thus, in this paper, the normative scenario that addresses "how a specific goal can be achieved" (Amer *et al.*, 2013; Sardesai *et al.*, 2021) was used to answer this study's specific goal of "how digital transformation using AI and ML can be used in managing Ghana's water resources." Traditional scenario planning also involves developing a single outcome based on the identified gap. Thus mimicking the traditional methodology, this study is centered on the current technological advancements and how to use them to address water security and sustainability issues in Ghana's Pra River Basin. The normative single-scenario approach underscores the transformative potential of AI in enhancing water security management.

A case study demonstrating the proposed system's effectiveness is the Sustainable Watershed Management Through IoT-Driven Artificial Intelligence ("SWAIN") project in Europe. The "SWAIN" project is a pioneering initiative aimed at improving river pollution management through the deployment of smart sensors and advanced AI techniques. The focus of the project was on monitoring water quality in real-time. It also provided early-warning signals for micropollutants. This enabled quick identification of pollution sources and prevented environmental disasters (Hanak, 2024; Universität Wien, 2021). Thus in fighting river pollution, strategic locations along rivers were selected for sensor placement and the target was on high-risk pollution areas. Sensors were installed to measure various water quality parameters, including pH, turbidity, dissolved oxygen and specific micropollutants. The sensors collected and transmitted data wirelessly in real-time to a central database. The data were processed to provide a comprehensive view of water quality across the river. ML algorithms analyzed the data to identify patterns and anomalies indicating micropollutant presence. AI techniques such as regression analysis and neural networks were used to trace pollutants back to their sources. More importantly, an early-warning system was developed to generate real-time alerts when pollutant levels exceeded thresholds. Authorities were notified via SMS, email and a dedicated app with an interactive dashboard meant to visualize pollutant levels and sources on a map (Hanak, 2024; Universität Wien, 2021).

Water security and IWRM in Ghana

River systems in Ghana

In Ghana, per capita availability of water resources is declining (Yeleliere *et al.*, 2018). Internal renewable freshwater resources in Ghana in cubic meters were at 4,285 m^3/capita in 1962. The value was pegged at 1,113 m^3/capita in 2014 (Yeleliere *et al.*, 2018) showing a decrease of 3145 m^3 (1.41%) every ten years. Although ranked 127th in the world and 29th in Africa, Ghana is neither a rich nor poor country as related to water resources availability. Ghana's river systems are known to be three systems: the Volta (70%), the Southwestern (22%) and the Coastal River System (8%) (Yeleliere *et al.*, 2018). The annual runoff contributions of the river systems are 64.70%, 29.20% and 6.10% from Volta, Southwestern and Coastal River systems, respectively (MWRWH, 2007a, b). The Southwestern part of Ghana is highly polluted (Nti *et al.*, 2023b; Yeleliere *et al.*, 2018) with heavy metals (Duncan *et al.*, 2018a) due to illegal mining ("Galamsey") activities and accounts for 60% of critically polluted water bodies in Ghana (Ampomah, 2017; Nti *et al.*, 2023a).

According to the Water Resources Commission (2012), the prominent activity for most of the towns in the basin area is apparently mining. However, due to the inappropriate nature of the mining activities, most river systems in the Southwestern part of the country have been polluted. This affects agriculture and aquatic life currently, even though other factors may contribute to the pollution issues. Mantey (2017) and Ofosu and Sarpong (2022) reported that freshwater bodies in the Birim River in the Eastern Region have been polluted beyond treatment. The Ghana Water Company treatment plant was forced to shut down, and boreholes were constructed to serve the people of Kyebi with water (Ofosu and Sarpong, 2022). According to Mantey (2017), fishing activities around communities in the new Juaben and Koforidua areas have all been affected due to similar activities. In the Central Region, particularly Cape Coast, some water bodies have equally been polluted (Mantey, 2017). In the Ashanti Region, the Enu River that serves Konongo residents is polluted due to the same illegal mining (Galamsey) activities (Mantey, 2017; Ofosu and Sarpong, 2022). Figure 2 is a map of Ghana showing the Southwestern Pra River Basin and its coverage areas.

The Pra River Basin covers 23,256 km^2 (Awotwi *et al.*, 2018, 2021). The basin is home to the Offin River which is dammed at Barekese to serve treated water for urban settlement towns (Water Resources Commission, 2012). Thus, the Basin is home to Lake Bosomtwe, Ghana's sole noteworthy natural freshwater lake (Awotwi *et al.*, 2021). The prevailing climate is sub-equatorial wet in the Pra River Basin area. Rainfall seasons in the basin area are categorized into two rainy seasons: May–July is the main rainy season and the minor season begins in September–November (Awotwi *et al.*, 2021). The Pra River Basin area records 1,550 mm as annual average rainfall and toward the northern part, the rainfall distribution decreases spatiotemporally (Awotwi *et al.*, 2018). Throughout the year, temperatures are high in the basin area recording 23°C as an average minimum. This occurs particularly in August and between March and April, the basin area records an average maximum of 33°C (Awotwi *et al.*, 2021; Water Resources Commission, 2012). The basin and its major tributaries serve as water supply to most communities in the basin area.

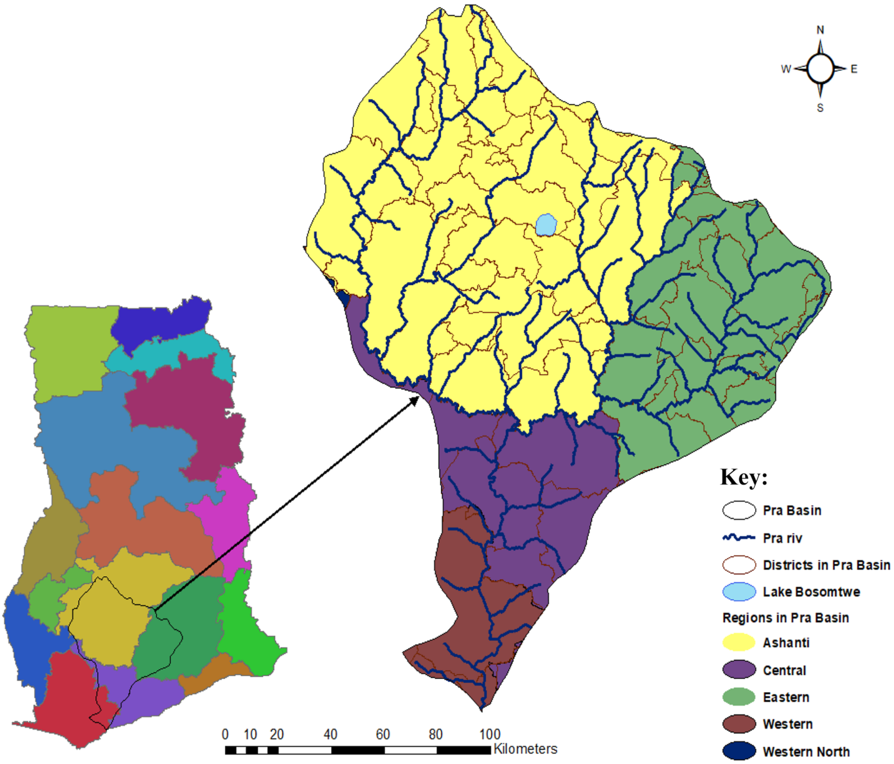


Figure 2.
Map of Ghana showing the Southwestern Pra Basin and the five of the regions it covers in Ghana

Source(s): Department of Geomatic Engineering, University of Mines and Technology, Tarkwa Ghana (Essikado Campus)

The alarming consequences of illegal mining (Galamsey) stimulate water security issues as an important topic for review. Ghana has been cautioned that, if illegal mining (Galamsey) is not properly checked, the country will soon have to import water from its neighboring states (Allotey, 2017) since the activity is posing a threat to the various water bodies like Tano, Ankobra, Pra rivers, etc. To avoid future catastrophes, there is a need to regulate mining activities and instigate water security measures to safeguard these water bodies (Baddianaah *et al.*, 2022).

Illegal mining and water security

Forkuor *et al.* (2020) stated that informal mining has continuous to grow rapidly, especially from 2003. This is because the illegal miners no longer extract or gather with simple tools, but rather depend on heavy excavators and hydraulic machines (Osei *et al.*, 2021). This means that "Galamsey" is an old extracting strategy revitalized with new technological resources. This illegal way of mining is now on a larger scale, where locals, politicians and even foreign nationals engage in it. This frightening activity is degrading arable lands, destroying forest reserves and polluting water bodies where the minerals are washed after extraction. Generally, this activity affects agriculture and aquatic life and poses water security problems in years to come. According to the United Nations (2021) to achieve water security, vulnerable water systems must be protected and that scientific knowledge should be applied to mitigate water hazards like illegal mining (Galamsey). This is to help manage Ghana's water resources toward recovery.

IWRM and water security in the context of Ghana's Pra Basin

Good water governance and management for water security occur across three different levels, unlike IWRM which is just a combination of "top-down" and "bottom-up" approaches. The first level takes place within each water use sector. It involves the management of supply and demand, and the strengthening of institutional capacities during the development of investment plans. The second level of management for water security incorporates every sectoral water user into the management process and water security plans. The third level sets water security as a government-level goal to be included in public and budgetary agendas (Nagabhatla, 2019a).

Similar to IWRM, the broad water security integrative framings across the scales of both local and global levels combine the concerns of both quality and quantity. This offers a paradigmatic approach in terms of water system analysis to show certain similarities. It is also important to note that the two concepts appear to be complementary. IWRM is recognized as the best approach to address the majority of the problems. It combines physical and social systems with transparent and participatory governance at many levels. However, to capture the complications of water-related issues in terms of management, neither IWRM nor the water security concept as the independent framework is broad enough to address water management challenges (Cook and Bakker, 2016). Thus, water security is related to IWRM and river basins (Bogardi *et al.*, 2016; Spring and Brauch, 2009). Combining IWRM with adaptive governance is a possible open management system for water security (Gupta *et al.*, 2016; Pahl-Wostl *et al.*, 2011). This is achieved through the use of principles. It allows good governance such as transparency, accountability, public participation, legitimate policy processes, equity and effectiveness that importantly aims at sustainable development (Brundtland, 1987; Gupta *et al.*, 2016).

However, following the importance of the basin's source of water supply and among others, the Water Resources Commission of Ghana (WRC) (Act 522 of 1996) established the Pra Basin Board. The Board is a decentralized management body constituting 17 members with the mandate to implement IWRM. According to Bakker and Morinville (2013), IWRM may be defined as "the unified or holistic management of water, land and other natural resources within the boundaries of entire river basins, watersheds or catchment areas." In the opinion of

McDonnell (2008), IWRM is a desirable framework that helps to bring about equity, efficiency and sustainability in the management of water resources (Cook and Bakker, 2012; McDonnell, 2008). Thus, IWRM is known to be an all-inclusive water management approach. The holistic nature of it has to do with the supply and demand management of water as well as water quality management (UNESCO and UNESCO i-WSSM, 2019). However, it is important to note that drawing an IWRM plan does not necessarily mean that IWRM is being implemented. In the case of Ghana's Pra Basin, the implementation of the IWRM plan started in the year 2011. Specific strategies were developed and implemented following IWRM objectives for the Pra Basin. This shows that the implementation of the IWRM plan was adhered to beginning from the year 2011 although some are still pending. For example, Duncan *et al.* (2019) confirmed the Pra River Basin IWRM plan implementation and reported that a significant obstacle to the plan lies in the buffer zone policy implementation.

However, to handle the foreseeable future environmental difficulties is critical for the Basin's management. The current IWRM strategies implemented in 2011 did not incorporate environmental technologies or digital transformation which restricts its ability to manage current pollution challenges. This is an important gap for the next sustainability of Ghana's Pra Basin emanating from the IWRM plans. The Pra Basin's IWRM should be updated by introducing digital transformation for sustainable water management to address the current water pollution challenges. Following the limitations in the existing IWRM plan, there is a need to integrate IoT technologies, AI and ML for Pra River Basin's technological intervention and innovation. Thus, leveraging this technological advancement is meant to enhance water management practices to mitigate pollution. This is to also promote environmental sustainability in Ghana where illegal mining (Galamsey) activities are ubiquitous.

Discussion

Ghana has gradually been able to address most of the water issues through the development of a robust institutional framework. However, most of Ghana's water resources are currently challenged by water pollution. IWRM has been adopted by several intergovernmental entities including the Water Resources Commission and its decentralized Pra (Offin) Basin Board in Ghana. There are certain challenges that exist and are to be addressed for proper coordination.

IWRM practices in the Pra (Offin) Basin Board are needed to make more water available for all purposes, including environmental, domestic, agricultural and industrial. This study focuses on managing polluted water, occurring as a result of the long history of discharge of waste as well as the massive forest clearance for mining activities and other infrastructural development. Settlements have increased pressure on the basin's water resources (Water Resources Commission, 2012). Duncan *et al.* (2019) noted that the IWRM plan was expected to bring benefits through achieving sustainable socioeconomic development, sound economy, environmental flows and more importantly to achieve water security. However, in most cases amongst the resultant benefits of IWRM, water security in water resources management has not yet materialized (Duncan *et al.*, 2019).

Separate basin plans were developed for the Dayi, Ankobra, White Volta and Densu River basins between 2007 and 2011. The fifth of the basin plans developed was the Pra IWRM plan. The Pra Basin IWRM plan mentioned water security without its working definition in the document while noting the following: "develop scenarios for extreme water availability, their impacts and develop corresponding strategies to adapt, cope and achieve water security." Again, it was "promoting increased resilience to climate change which will demand measures to ensure that policies on housing, energy, landscape, water services, agriculture and waste management are aligned and contributed to optimal use of water resources, and ultimately water security." Duncan *et al.* (2019) opined that IWRM is appropriate for managing the basins but the problem can be caused as a result of implementation gaps that contribute to the increased deterioration of water quality in the Pra River Basin.

As explained by Pahl-Wostl *et al.* (2016), water management problems are not solved when new concepts are introduced especially when the problem has to do with challenges in governance. Such problems in the opinion of Bogardi *et al.* (2016) are a result of the fact that there seems to be more attention on water, sanitation and hygiene (WASH) when it comes to the present political negotiations. Thus, there appears to be a missing integrated understanding of the water security perspective that also includes IWRM within complete water management and other benefits of ecosystem services, water quality and climate change. The IWRM framework has also been silent on illegal mining (Galamsey) activities despite Ghana's water policy developed in 2007.

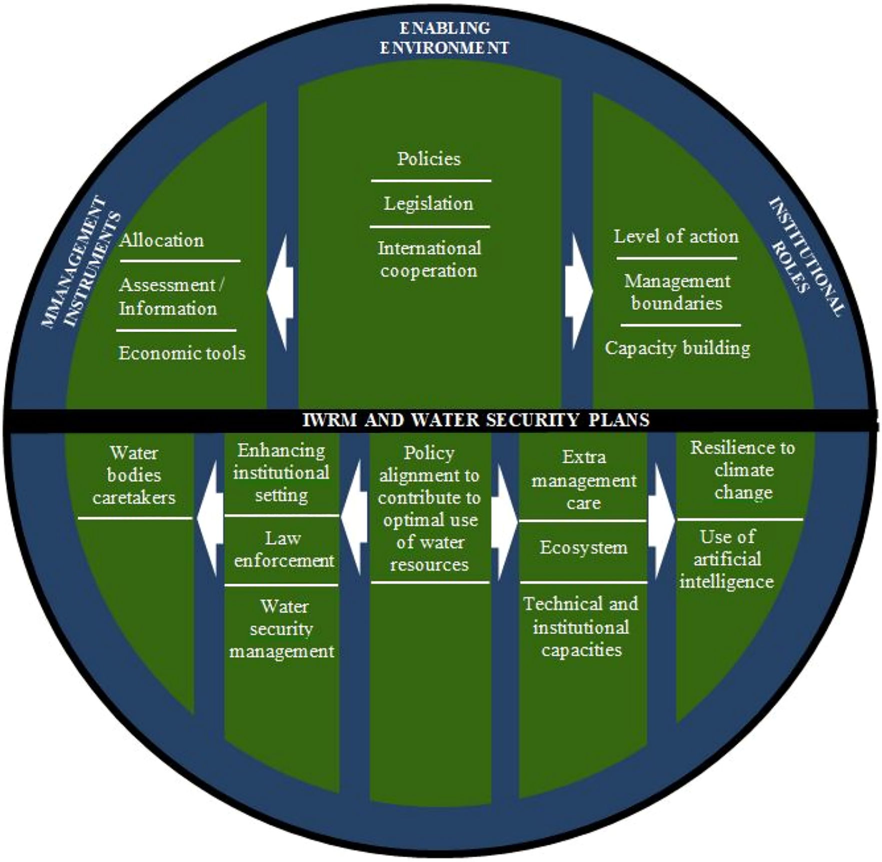
According to Bakker and Morinville (2013), water security perspectives place emphasis on the primacy of water protection. IWRM's comprehensive management approach is a tradeoff between the protection of ecosystems and economic development (Bakker and Morinville, 2013). The water security approach according to Rockström *et al.* (2009) usually places much strength for humanity on a "safe operating space." Nonetheless, the emphasis of IWRM perspectives particularly compromises on issues between social equity, ecological integrity and economic growth (Bakker and Morinville, 2013).

The water security concept could be used to develop a framework to address the current and future water needs of communities, particularly in preventing "Galamsey" activities on water bodies. This is to help form the basis to complement the national water policy based on sustainability (Cook and Bakker, 2016). Importantly, new strategies in terms of having multi-sector water resources planning strategies that support vertical and horizontal integration of different logic of argument are critical for the basin (Pahl-Wostl *et al.*, 2016). Figure 3 shows the summary of complementing IWRM with water security plans modified from the IWRM general framework (Nagabhatla, 2019b).

Addressing water pollution caused by illegal mining (Galamsey) activities should include law enforcement and policies. That is critical for the relevance of the IWRM for water security. Also, analyzing water problems with their associated environmental challenges using AI technologies to meet the Sustainable Development Goals (SDGs) is critical (Nti *et al.*, 2022). It is therefore necessary to strengthen both the technical and institutional capacities of the countries that already have IWRM plans, but their capacities are the main constraint to the adoption of water security approaches (Nagabhatla, 2019b). It is, therefore, logical to infer that complementing IWRM with water security plans as a management tool to strengthen the government-level goal of protecting water resources is critical in the management of water resources in Ghana. This has the prospect of improving the understanding of water security while protecting and valuing water for sustainability.

Key components of complementing IWRM with water security plan as well as environmental technological innovations and their interactions for future implementation

Artificial intelligence (AI). Kapelan *et al.* (2020) noted that there exist case studies in the water sector that employed AI applications. Crowther and Hamdan (2024) argued that AI will not replace humanity, but it could play a significant role in human efforts. These include detection and ML-based systems. Detection of pipe bursts using AI applications in water distribution pipe-point connections or networks also exists. With this technology, the system takes records and equally learns from past bursts and other events by estimating the likelihood of the event occurrence. The system raises corresponding alarms to predict future ones (Kapelan *et al.*, 2020). Smart alarms are used in another AI application in the water sector to predict and provide early warning of excessive water levels in sewers. This is for proactive wastewater network management. It equally allows for the monitoring of prospective pollution events and



Source(s): Modified from Nagabhatla (2019b)

Figure 3. Summary of complementing IWRM with water security plans modified from the general framework for IWRM planning

unusual levels that might be an indication of network obstructions. These examples show how AI has a significant global impact on water management (Kapelan *et al.*, 2020) although a significant research gap exists in the application of information technology for modeling and tracing the transport of micropollutants in rivers.

A more recent study on AI applications that addresses a similar problem of managing water pollution in river systems is the “SWAIN” project. In the “SWAIN” project, a pilot study was carried out in Turkey and Finland (Hanak, 2024; Universität Wien, 2021). The “SWAIN” system was validated in the Ergene River, one of Europe’s most polluted rivers in Turkey. The system successfully monitored pollution from industrial and agricultural sources and identified pollution sources in real-time to help prevent environmental damage. The system was also deployed in Finland in the Kokemäenjoki River to demonstrate its general robustness. In Kokemäenjoki River, Hanak (2024) reported that pollutants could reach the water intake site for the city of Turku within 20 min to 1–2 h. The system provided timely detection and prompted officials to prevent contamination of utility water (Hanak, 2024). These case studies highlight the effectiveness of AI in detecting and tracking micropollutants. They also offer actionable insights to mitigate pollution at its source. The integration of real-time data collection with advanced AI techniques provided a robust solution for safeguarding water quality in a similar context.

Following Ghana's pollution levels in the Pra Basin, it is a panacea to adapt and apply AI to address water pollution problems. However, the uptake of digitalization in addressing pollution incidents like illegal mining (Galamsey) activities in the Pra Basin is an evolving journey. It necessitates a shift in organizational culture in addition to the adoption of digital instruments. This is to help the water industry advance along the digital maturity curve. The projected usefulness of AI presented here aims at protecting water resources at the basin level and controlling the real-time monitoring of water resources. There are advantages of AI picking up and storing hydrological data. That data could be used as a basis for research and implementation of further digital technologies. Thus, a real-time monitoring, modeling and regulating system for river basin management to address illegal mining (Galamsey) activities to safeguard water resources and ensure water security is critical. This paper builds on the above critical examination of similar global initiatives and proposes the Pra-integrated smart water security management decision-making system. The main elements of this projected Pra-integrated smart water security management decision-making system are:

(1) Automatic monitoring of river basins through direct techniques that consist of visual inspections using high-powered closed-circuit television (CCTV) cameras across water resource areas declared as security zones. This will help protect water bodies against illegal mining (Galamsey) activities by strengthening water security. This also enhances incident management and source tracing.

(2) Noise sensors to detect engine-powered excavators, Chang-fan, water-pumping machines, etc. to allow the control center to monitor water resources remotely, with video analytics that send out automated alerts when riparian areas are at risk or encroached.

(3) pH probe sensor to measure the acidity or alkalinity of water including other traditional sensors that take precise readings of water quality characteristics like pH, turbidity and conductivity. This is to complement the cameras and noise sensors to detect any activity or pollution that may be going on to notify the guardians if the water quality is deemed abnormal.

(4) Real-time collection of hydrological data (streamflow) that can serve as a basis for research to strengthen IWRM and water security perspectives within the basin.

(5) Wireless real-time transfer of such data to a control center under the supervision of the Water Resources Commission's unit assigned to look after water bodies and other pertinent state and private institutions for analysis and follow-up action.

The proposed Pra system is meant to improve the monitoring and management of river pollution, especially in the context of illegal mining ("Galamsey") activities. The proposed system could help trace pollutants back through the river network to pinpoint the source or origin of the pollution. The primary novelty of the proposed Pra system is not only the ability to detect pollutants and their sources but also improves upon the existing methods and incorporates visual inspections and noise sensors. This demonstrates how the proposed Pra system improves upon the existing "SWAIN" system. Following the critical examination of similar initiatives globally, the proposed Pra system enhances traditional methods with innovative elements. It offers a more accurate, timely, and comprehensive approach to manage river pollution. Thus, it sets a new standard for sustainable environmental management. It also serves as a robust tool for managing the basin's sustainable development ecosystem particularly where illegal mining "Galamsey" activities are polluting water bodies.

The projected usefulness of AI using the integrated smart water security management decision-making system will result in a successful and sustainable operation against (Galamsey) activities. This will not be immune from a few identified key challenges. Such limitations of implementing the technology in the Pra River Basin are as follows.

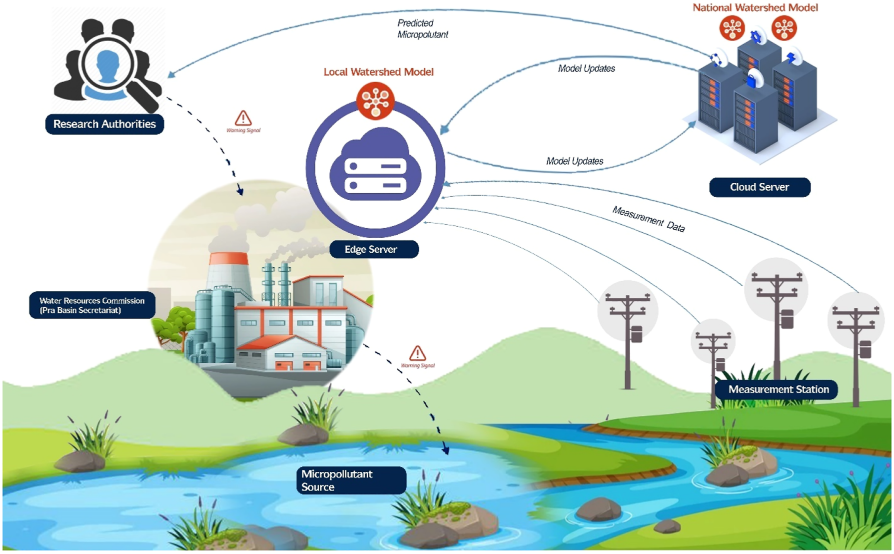
First, the technical standard of integrating multiple components like CCTV cameras, sensors, wireless communication, data storage, analytics tools as well as interoperability for the system would be a challenge coupled with poor Internet connectivity and network access. Thus, each of these components must not only function individually but also seamlessly interact with one another to ensure the system operates effectively. More importantly, achieving interoperability among the components is crucial but presents a significant challenge. This is so because different technologies and devices often use different protocols and standards. This further requires careful planning and the need to customize some of the solutions to ensure they can communicate and work together efficiently. Moreover, poor Internet connectivity and limited network access can severely hinder the real-time data transmission and communication essential for the system's operation. Thus, without robust connectivity, the effectiveness and reliability of the technological solutions intended for monitoring and managing activities in the basin may be compromised.

Second, CCTV cameras and real-time sensors generate massive amounts of data, which require more data space. High-resolution CCTV cameras generate large volumes of video data and continuous recording at multiple sites amplifies the data storage requirements. Thus, managing this enormous volume of data requires substantial data storage capacity. This necessitates not only adequate physical storage infrastructure but also robust data management systems to monitor and control illegal mining activities that pollute water bodies.

Third, job redesign to incorporate water bodies' caretakers for existing staff at the Water Resources Commission must be considered for the implementation of Pra-integrated smart water security management decision-making system. This will improve the knowledge and experiences of the existing workforce in the use of AI while addressing new challenges posed by the integrated system. It is important to note as emphasized by Crowther and Hamdan (2024) that AI has a place in our lives. However, it is meant to provide assistance to humans. Therefore, there is no need to be afraid of AI. This is because humans can adapt and make choices that go beyond their conditioning but AI systems are constrained by their programmed logic. Thus, it cannot truly innovate since its decisions and recommendations are based on typical values. Therefore, it all depends on humans and how they choose to use the technology (Crowther and Hamdan, 2024). Thus, caretakers can use data from the Pra system to implement proactive measures such as pollution control and preventive maintenance to ensure the long-term health of water bodies.

The last challenge or limitation would be on how the society would accept and embrace the use of technology to monitor and control illegal mining activities that pollute water bodies. Importantly, public communications must effectively address the concerns of miners who engage in illegality in and around water bodies. Thus, miners may worry about their livelihoods and public communication should address how sustainable mining practices can coexist with environmental protection and potentially improve long-term economic prospects. Figure 4 presents the visual aid of the Pra-integrated smart water security management decision-making system.

Machine learning (ML). ML is a type of AI that uses software applications to predict possible outcomes even without being programmed to do so. To implement AI, there is a need for the involvement of various learning processes of machines with statistical data (Nti *et al.*, 2022). ML as a domain of AI employs diverse mathematical techniques to create highly intelligent machines capable of enhancing and advancing technology through analysis. By utilizing these techniques, machines can process data and effectively carry out assigned



Source(s): Authors' design, based on "SWAIN" Project, Universität Wien (2021)

Figure 4. Visual aid of the Pra-integrated smart water security management decision-making system using AI, IoT technologies and ML

tasks to solve problems. The ML tool will use image processing patterns to predict the concentrations of particulate matter (PMs) or emissions like dirt, drops of mercury liquids, dust, human or vehicle locomotion for basin threats. In this context, a deep convolutional neural network (CNN) will be utilized. The CNN incorporates a suitable weighting factor that enables it to classify images accurately. This network will be constructed as a multilayer neural network, utilizing complex combinations, in order to predict the generation rates of PM.

According to Suh *et al.* (2022), PM concentrations can be predicted with various models like chemical transport models, statistical models and ML techniques. In such cases, based on long-term collected data, ML algorithms can discover previously unknown patterns. For example, Karayev *et al.* (2013) utilized a dataset comprising over 10,000 labeled photos with distinct visual styles to apply a ML method that utilized image processing to differentiate between different image styles. In this study, CCTV surveillance cameras will be manually fed with the data they need to know and the ability to predict objects. The cameras can be programmed for image data collection of features like humans, material objects and/or vehicle transportation around the Pra Basin. This is cost-friendly because it will capture and connect information of the CCTV around the basins, and serve as good indicators of pollution and their sources.

Water bodies caretakers. As a water security measure, "water bodies caretakers" would serve as the human forces that will safeguard the various water bodies. Similar to the Forestry Commission Forest Guards who patrol the various forest reserves from illegal lumberjacks and chainsaw operators in Ghana, these caretakers will serve as young security personnel under the Water Resources Commission who would *inter alia*, be tasked to station close and guard the various water bodies in Ghana with speed boats and other equipment's. They would rely mainly on AI, ML and sometimes human intelligence for any illegal activities happening in and around the water bodies. There is a need for these caretakers because one of the major challenges of the task force in the illegal mining (Galamsey) operations is stationing. There is no proper position where these guards are assigned; hence, they resort to traveling around the various mining sites. For instance, the government task forces rely solely on "tip-off" or "hearsay" of places where mining activities are said to be ongoing. Before their arrival, these illegal miners would have been informed and/or escaped. In order to strengthen the IWRM plans, there is a need for strict machinery that would tackle any water security threat. With the use of AI, the Basin Secretariat and the Water Resources Commission will monitor the country's water resources against illegal mining (Galamsey) activities with the proposed Smart Water Security Management System (as it is done in some places currently), and signals would be sent to "water bodies caretakers" who will rely on speed boats within the buffer zones. Thus, upon an alert, these water security personnel will hop on the speed boats to counter illegal mining (Galamsey) operators who are mining in and around the water bodies. The AI technology and "water bodies caretakers" would bridge the communication and transportation gap in the current task force.

Conclusions

The review was centered on whether the dominant IWRM paradigm within which the Pra Basin is managed holds the key to address the current water security issues following a technological gap in terms of a monitoring mechanism to protect Ghana's water resources against illegal mining (Galamsey) activities. The review brought to light that digital transformation and efficient utilization of AI and ML in decision-making to protect water resources from detrimental heavy metal pollution is currently unavailable. To enhance the basin's sustainability, the study proposed the use of new IoT technologies and advanced AI technologies to protect Ghana's water resources. However, as the proposed Smart Water Security Management System technologies are yet to develop and mature, further research, funding and testing are needed to realize the full benefits to ensure that the profligacy of mining in water bodies shifts to a paradigm where water resource management is strengthened with the integration of IWRM and water security. In the future, various institutions like the Water Resources Commission and the Environmental Protection Agency, among others, must be strengthened with AI technologies. This will serve as part of their direct and oversight responsibilities in terms of managing Ghana's water resources to ensure water security for the future. The successful monitoring of pollution from industrial and agricultural sources in Turkey, in the Ergene River, one of Europe's most polluted rivers using AI was able to identify pollution sources in real-time to prevent environmental damage. The AI system also provided timely detection and allowed officials to prevent contamination of utility water in Finland in the Kokemäenjoki River. This confirms that AI plays a significant role in human efforts and will not replace humanity but provides assistance to humans. Therefore, there is no need to be afraid of AI since it all depends on humans and how humans choose to use the technology as was done in Turkey in the Ergene River and in Finland in the Kokemäenjoki River to positively address pollution incidents, respectively. The study recommends the need to support vertical and horizontal integration of water security issues. This can be achieved through multi-sector water resource planning strategies with AI and ML. Furthermore, complementing IWRM with water security plans using the proposed environmental technologies while enhancing institutional setting with enforcement of laws is required to support the national water policy that is silent on illegal mining (Galamsey) activities and pollution. Policymakers should work to integrate the proposed Pra-integrated smart water security management decision-making system targeting illegal mining within the IWRM framework. This should include developing and implementing strategies for detecting and curbing "Galamsey" activities. Additionally, policymakers should prioritize enforcing existing regulations that mandate the creation and maintenance of buffer zones along water bodies. Policymakers should also coordinate with local authorities and communities to ensure compliance and effectively manage the implementation of the buffer zone policy. Researchers should collaborate with policymakers to provide insights necessary for integrating the proposed Pra-integrated smart water security management decision-making system against illegal mining within the IWRM framework. Researchers should also engage with local authorities and communities to help gather on-the-ground information and ensure that policies are evidence-based and contextually relevant to curb "Galamsey" activities. This would strengthen the government-level goal of protecting and valuing water resources for the future. To achieve water security with our water resources and sustainable environmental management and institutions in Ghana, it is important to note that water security is not a goal in itself but rather the collective responsibilities of individuals, households, communities, districts/municipals/metropolitans and national authorities who will access water in a sustainable manner that will support human wellbeing. Future research could focus on assessing the socioeconomic benefits of smart water security management systems using AI and policy frameworks for supporting smart water security management in Ghana.

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Corresponding author
Emmanuel Kwame Nti can be contacted at: kwame.nti@yahoo.com