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RESEARCH ARTICLE

APPLICATION OF ARTIFICIAL INTELLIGENCE IN SUSTAINABLE MANAGEMENT OF RIVERS FLOW

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ABSTRACT

The precision of river flow management decisions depends on the applied techniques and decision support systems. In recent decades, Artificial Intelligence (AI) has emerged as a pivotal technology in decision-making. Determining the correct trends for using these applications based on a solid knowledge base requires a review of these applications and an assessment of their effectiveness in regions suffering from water scarcity and struggling with managing River's flow, such as Iraq. This paper critically discussed the AI applications in the modeling and management of river flow with focusing on the Tigris River in Iraq as a case study. The review surveyed global and local literature on the use of AI in river systems, covering hydrology, hydraulics, river modeling, decision-making, water quality, water resources management, focus areas, and challenges, as well as, AI methods like ANNs, SVMs, and deep learning, which emphasize optimization, modeling, forecasting, and flood prediction. The findings indicated that the main challenges include data availability and quality (28%), model interpretability (22%) and system integration (20%). AI applications prioritize decision support systems (30%) and hydrological forecasting (25%), while irrigation efficiency (10%) is less emphasized. In river flow management, data availability (30%) and climate change (25%) are key issues, with flood forecasting (30%) and water quality monitoring (25%) being the most critical. The results showed that AI significantly enhances predictive capabilities, optimizes water distribution, and minimizes wastage, with critical applications in flood forecasting and water quality monitoring. The deployment of AI in Iraq needs a localized approach through improving data infrastructure enhancements. The Tigris River benefits from AI for sustainable river management even though the implementation poses various challenges to support climate change adaptation. The research shows AI has significant potential as a water resource solution for nations facing development challenges.

KEYWORDS

Artificial Intelligence, River Flow Modeling, Tigris River, flood management, Decision Support Systems, Sustainable Water Management.

1. INTRODUCTION

River management efficiency stands essential for combating water scarcity together with climate change impacts in arid and semi-ared regions suffering from flooding and drought events. Major river flow management procedures use various theories alongside implementation methods and established techniques. River flow patterns are understood using the rational method together with the unit hydrograph theory in hydrological frameworks which aid in flow prediction (Maidment, 1993; Singh, 2013; Chow et al., 1988). Numeric modeling platforms consisting of Computational Fluid Dynamics (CFD) together with HEC-RAS, SWMM, MIKE 11, HEC-HMS, INFO WORKS ICM, TUFLOW, and SOBEK help researchers analyze river flow dynamics while evaluating potential scenario outcomes (Chaudhry, 2007; Kueh and Samad, 2011; Ab Ghani, and Duan, 2011). Remote sensing tools involving satellite imagery and LiDAR data analysis generate valuable data about river morphologies and hydrological systems (Kuenzer and Dech, 2013; Carabajal and Harding, 2005; Sharma et al., 2013; Hossain and Aryal, 2017).

Sustainable river basin management depends heavily upon applying advanced modeling approaches alongside decision support frameworks as its fundamental enabling components. The latest valuable and efficient Artificial Inelegance (AI) techniques currently serve river management efficiently as per research in (Chang et al., 2023; Mahardhika, and Putriani, 2023).

The combination of future condition prediction alongside massive dataset analysis helps AI systems optimize resource distributions in water resources management and river systems. The applications of AI technologize flood management while tracking water quality and preserving ecosystems and maintaining infrastructure. Predictive models driven by AI-based systems boost outbreak preparedness before such events by providing decision-making support systems to policy makers. Through scenario projection and adaptive strategy development it enables adaptation to climate change (Hsu et al., 2012; Abrahart, and See, 2019; Bandaragoda et al., 2019).

The sustainability of water resource management has become an immediate worldwide priority due to the combination of water deficits in

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arid and semi-arid areas with severe climate effects. Water scarcity worsens because climate change simultaneously creates damaging effects to hydrological systems. The incorrect assessment of river management by traditional hydrological modeling occurs because such systems lack capacity to address numerous river management factors.

AI technology offers a future-driven solution which drives modern water resource management into transformative improvements. Hydrological prediction systems achieve enhanced performance through the fusion of Machine Learning (ML) and Deep Learning (DL) artificial intelligence systems which enable accurate probabilistic forecasts and water resource management functions. Through AI-based integration within river flow management predictive capabilities increase while adaptation planning improves and inclusive solutions emerge to solve environmental along with socio-economic demands.

AI integration offers substantial benefits for water systems' efficiency, sustainability, and resilience, ensuring better management of these vital resources (Ahmed et al., 2022; Al-Husseini et al., 2023).

Sustainable water resource management aims to preserve the ecological, economic, and hydrological integrity of the present society and its potential for the future. Highlighted the widespread use of AI approaches in urban water resource planning, citing their significant potential for reasoning, adaptation, modeling, and forecasting water demand and capacity. The scholars and authors underscored the importance of water resources for both social and economic development (Ali, R., Kuriqi, A., Abubaker, S., and Kisi, O., 2019).

In arid and semi-arid regions with complex and interconnected water resource systems with large temporal and spatial variations in abundance and lost demand, including Iraq, water scarcity and drought problems have become a real threat to the sustainability of life in these regions. Iraq depends mainly on the Tigris and Euphrates rivers, which form a complex system with significant water shortages and significant impacts from climate change, so a comprehensive and close understanding of the applications of AI in this country is of utmost importance.

There is an urgent need to develop advanced methodologies employing AI techniques for improved understanding and management of river flow dynamics, specifically addressing challenges associated with the Tigris River, Figure 1, a vital water source for millions, supporting agriculture, drinking water, and industry. Its management is crucial due to challenges like pollution, climate change, and regional conflicts. Studying the Tigris River provides insights into sustainable practices applicable to other rivers facing similar issues globally. Previous studies, such as (Al Aboodi et al.,2009; Al-Mukhtar, M., 2018 ; Ewaid et al., 2018; Ewaid et al., 2018; Al-Ani, 2020; Al-Obaidi et al., 2020; Nama et al., 2022 ; Walekhwa et al., 2022; Yaseen et al., 2016). have predominantly relied on traditional hydrological models, which struggle to accurately capture the complex behaviors of river systems.

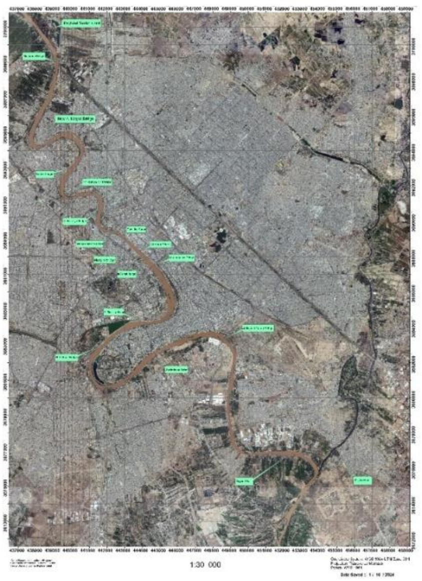

Figure 1: Layout of Tigris River in Baghdad.

Worldwide most of the AI review paper focused on the hydrological events, such as (Kingston et al., 2008; Alaghaet al., 2012; Murat and Serhat, 2018; Damian, 2019; Khosravi et al., 2022). Others deals with hydraulic parameters such as (Ibrahim and Mishra, 2020; Kumar et al., 2023; Ng and Santamarina, 2023; Zhaoet al., 2024).

The magnitude of water-related problems is most evident in arid and semi-arid regions. This exacerbates the need to expand the application of advanced modelling, forecasting, assessment and decision-making techniques, most notably the AI.As Iraq extended within a very complex arid and semi-arid hydrological regions and it is one of most impacted countries by the water scarcity, then applying the AI for water resources management is evidently very valuable. Therefore, investigation the expansion of knowledge and application scope and specifying the strengthen and weakness as well as the knowledge gaps can be of valuable contribution in developing the sustainable management of water resources in such arid and semi-arid regions.

However, up to the best of the researcher's knowledge, there is no review on the use of AI in water resources modeling and/or management in Iraq. The Tigris River's discharge capacity in Baghdad has significantly declined over the past three decades due to neglect and sediment buildup, increasing flood risks. The river's management faces challenges such as water scarcity, ineffective flood control, environmental degradation, and inefficient water resource practices.

This paper aims to conduct a comprehensive review of research on the application of AI for river modeling and management, focusing on the AI applications in worldwide Rivers and with focusing on the Tigris River, Iraq. It seeks to identify innovations, assess technical gaps, and explore practical applications to advance sustainable river flow operations and management in the region, in addition to hydraulically analyze the Rivers's characteristics, evaluate current management challenges, and explore AI-based strategies for sustainable flow management to address water scarcity, optimize resource allocation, and mitigate flood risks.

This review paper will hence seek to provide a global and local review of AI applications needed for the modeling, monitoring, and management of the Tigris River. To recognize potential areas of application and new knowledge in this field, as well as to find out what further research is required to create a strategic working plan for this extent of the Tigris River. Therefore, as an attempt to synthesize the findings from previous studies, this paper aims to give an overall picture of the contribution of AI. It discusses how AI algorithms like ML and DL can generate good models that should depict the relations of these hydrological factors.

The research provides a comprehensive critique of AI applications for river management systems through its investigation of hydrological, hydraulic and water quality frameworks. Adopting the Tigris River in Iraq as a case study of the water scarcity regions, this paper connects fragmented knowledge while identifying potential opportunities which produce implementable guidelines to advance sustainable water management in Iraq and similar global locations.

2. Materials And Methods

AI adds value by providing the means for coming up with novel solutions to difficult issues and improving decision-making. Potential areas of AI in water resources include information systems, flood forecasting and control, water quality assessment, water supply network, drought identification and mitigation, and reservoir regulation and scheduling (Hsu et al., 2012; Abrahart and See, 2019; Bandaragoda et al., 2019).

Comparative analysis is built based on the comprehensive review of the literature on the application of AI in water resources management from all over the world. Include local and global studies to ensure that it present information on various uses and developments of AI methods in the subject area.

These areas include water resources management and general, investigations and monitoring of water hydrological process, hydraulic structures and Observed water flowing and behavior in channels and pipes, river modeling techniques, systems that in decision making in water resource management and water quality assessment. In addition, it includes various statistics to provide a comprehensive understanding of the field. These statistics encompass the percentage of papers for each topic, reflecting their prominence in water resources management literature. Additionally, the review highlights the annual development of the use of these AI applications globally and locally.

Also, it covers the types of AI technologies employed, the sections of the Tigris River included in studies, and the expected outcomes from applying AI methodologies in river management. The anticipated results include improved predictive capabilities, enhanced decision support, a deeper understanding of complex systems, increased resilience to environmental challenges, and optimized resource allocation. These outcomes contribute to bridging scientific gaps in our understanding of river dynamics and enable more effective and sustainable management practices.

The Tigris River is included in the study area in Iraq, Figure 1. The Tigris River flows for approximately 1,850 kilometers from its source in the eastern highlands of Turkey, entering Iraqi territory at Zako, which is a town in the Dohuk Governorate in the Kurdish region of northern Iraq, flows through Iraq a distance of about 400 to 450 km to the Euphrates River confluence there at Al-Qurnah Town, forming the River Shatt al-Arab. This interdisciplinary investigation aims to advance the understanding and management of river systems, specifically the Tigris River in Baghdad, through the integration of AI techniques and comprehensive data analysis. The anticipated benefits consist of increased efficiency of forecasting, supported decision-making, improved understanding of the system, better coping with environmental pressures and resource utilization.

3. Results And Discussion

3.1 AI Applications Review

The management of water resources is very essential for the welfare of communities. Relevant aspects of hydrology research, hydraulic modeling, water quality analysis, river modeling, and decision support systems are indispensable for the proper analysis and efficient distribution of water resources.

Worldwide various review papers were published concerns the AI applications in various issues of water resources. Most of these review papers focused on the hydrological events.

The researcher presented a review series of two parts on AI techniques in hydrology (Kingston et al., 2008). However, the first part reviewed AI methods. It focused on AI-based optimization techniques for hydrological prediction and simulation, and compared AI optimization. It highlights that the AI optimization methods apply very well in complicated hydrology modeling and management problems because of aspects like the possibility of dealing with various and non-continuous objectives and constraints, and flexibility that is synonymous with the ability to work in parallel. The review evaluates different optimization techniques with respect to their characteristics such as strengths, weaknesses, and applicability in hydrology with a view to providing a guideline that can be used when one is choosing among these methods each time a problem arises. reviewed the application of AI techniques in hydrological modeling using ANN and SVM, in addition to solving problems of conventional physical hydrological models, like data demands, both in terms of quantity and quality, and variability effects. Thus, AI techniques have appeared as efficient substitutes for overcoming the limitations presented above. In this paper, the authors give brief descriptions of the mainstream ANNs and SVMs, their theories in hydrological application, and their advantages. It also highlights successful case studies where ANNs and SVMs have been used to model various hydrological processes reviewed the extensive use of AI in various fields, including economics, business, translation, computer science, robotics, engineering, medical, and psychology (Murat and Serhat, 2018). Highlighted that research studies applying AI to modeling methodologies produced results for solving non-linear, linear, and other systems that closely replicated real data. The paper assessed the state of the art at the moment and new developments in AI modeling regarding water components, including rainfall runoff, evapotranspiration additionally evaporation, sediment, streamflow, water quality elements, in addition, variations in lake or dam water levels. Also, the work offered directions for further investigation and modeling of these water parameters. As a study reviewed the application of AI models in forecasting hydrological events, addressing their effectiveness compared to traditional methods (Damian, 2019). It discusses the challenges in hydrological forecasting, such as complex variable interrelationships, data availability issues, and missing data, which hinder the performance of numerical models. To overcome these limitations, AI techniques like ANNs, Fuzzy Logic (FL), and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) have been employed. The article reviews thirty studies from the past eleven years that applied these AI models to various hydrological processes, including streamflow, rainfall-runoff, groundwater modeling, water quality, and sediment load prediction. The findings suggest that AI models generally outperform conventional numerical models, demonstrating their enhanced reliability in describing and forecasting hydrological events. This analysis presented the first application of an optimized deep-learning algorithm, CNN-BAT (Convolutional Neural Network with BAT metaheuristic), for predicting daily streamflow (Khosravi et al., 2022). It compares CNN-BAT with four other algorithms—MLP-BAT, ANFIS-BAT, SVR-BAT, and RF-BAT—using 15 years of data from the Korkorsar catchment. The study finds CNN-BAT superior in prediction accuracy based on various evaluation metrics and statistical tests.

Others deals with hydraulic parameters such as (Ibrahim et al., 2022; Kumar et al., 2023; Ng et al., 2023; Zhao et al., 2024). As a study discussed the growing interest and advancements in applying AI and optimization techniques to river hydraulics (Ibrahim et al., 2022). The paper highlights the innovative use of nature-inspired algorithms for improving forecasting and reservoir management amidst climate change. The review categorizes AI and optimization methods, summarizes their advantages and limitations, and provides future recommendations based on high-impact research from 2009 to 2020.

The research reviewed the use of DL for flood forecasting and management, highlighting its ability to handle large datasets and improve prediction accuracy. The review covers data sources, DL models, and evaluation metrics, and critically assesses current methods' strengths and weaknesses. The review also addresses challenges like data access, model interpretability, and ethical concerns, and suggests future research directions such as incorporating uncertainty estimates, integrating diverse data sources, and developing hybrid models. This review aims to enhance flood prediction and control, benefiting both researchers and practitioners (Kumar et al., 2023).

Zhao et al (2024) published a review focused on the application of DL and hybrid DL models in streamflow forecasting. The paper outlines DL model characteristics, hybrid model configurations, and optimization methods for input and hyper-parameters. The review also addresses limitations and suggests future research directions. It is an update of the Cochrane Database published between 2017 and 2023 and is designed to support the development of enhanced streamflow forecasting and enhanced water resources management (Zhao et al., 2024).

Chau (2006) addressed the limitations of traditional numerical models for coastal flow and water quality processes, which lack heuristic knowledge integration and are difficult to interpret, by analyzing how AI techniques—such as knowledge-based systems, genetic algorithms, artificial neural networks, and fuzzy inference systems—can enhance model usability, calibration, and problem-solving capabilities while identifying future directions for integrating AI into water quality modeling (Chau, 2006).

Nourani et al (2014) reviewed the advancements in hydrologic modeling and emphasize the critical role of accurate and efficient models for sustainable watershed management, highlighting the potential of hybrid wavelet-AI models due to their ability to handle multiresolution analysis, de-noising, and optimization; the study explores the history, benefits, and future opportunities of such models in hydrology to better understand and predict complex hydrological processes (Nourani et al., 2014).

Ay and Özyıldırım (2018) explored the most modern advancements in AI modeling for water-related variables, including surface water processes (rainfall-runoff, evaporation, and evapotranspiration), streamflow, sediment transport, water quality parameters, and reservoir or lake water levels, highlighting AI's ability to provide near-accurate solutions for linear, non-linear, and complex systems while proposing future research directions to further enhance AI applications in water resource modeling (Ay and Özyıldırım, 2018).

Elkiran (2019) evaluated three single AI-based models—BPNN, ANFIS, and SVM—alongside the linear ARIMA model for single and multi-step ahead modeling of dissolved oxygen (DO) in the Yamuna River, India, using water quality parameters, such as BOD, COD, Q, pH, NH_3, and WT from three stations (SL1: Hathnikund, SL2: Nizamuddin, SL3: Udi). Additionally, three ensemble techniques: Simple Average Ensemble (SAE), Weighted Average Ensemble (WAE), and Neural Network Ensemble (NNE) were applied. Model accuracy was assessed using Determination Coefficient and Root Mean Square Error. Results indicate that the ANFIS model outperformed other single models, improving accuracy by 7% and 19% for SL1 and SL2, while SVM achieved a 16% improvement for SL3. Among ensemble techniques, NNE provided a 14% average improvement across stations during the verification phase, demonstrating its robustness and reliability for multi-step ahead DO modeling in nonlinear systems (Elkiran et al., 2019).

Rajaee et al (2020) reviewed the application of AI methods for forecasting river water quality, focusing on single AI models (e.g., ANN, GP, FL, SVM) and hybrid models (e.g., Hybrid NF, ANN-ARIMA, GA-NN, and wavelet-based models like WANN, WNF, WSVR, WLGP). Researchers analyzed 51 scholarly papers published during 2000–2016 by investigating their predictive choices and data standardization, training/test separation protocols along with modeling method selection and time prediction duration and evaluation techniques. Out of the researched papers fifty-seven percent came out during the past five years before reaching 1716 citations by February 2016. WANN models held the second rank after ANN models for applied techniques with 17 papers whereas WANNs were utilized in seven publications. The study shows how combining various modeling methods enhances individual prediction accuracy while delivering essential knowledge about AI systems capable of predicting multiple parameters across river environments (Rajaee et al., 2020).

Tung and Yaseen (2020) analyzed river pollution originating from climate change and human activities while recognizing the complex character of water quality data that includes nonlinearity along with nonstationarity and ambiguity. The unprecedented success of AI models now surpasses traditional methods of river water quality monitoring through their combination of precision and dependability alongside affordable solutions and fast implementation. The study examined more than 200 research articles published from 2000 to 2020 to catalog AI models adapted for water quality simulations together with their system configurations and variable inputs and performance metrics as well as regional application capabilities. The research underscores urgent requirements for AI advancements focused on addressing the problems of incomplete data and intricate time-series patterns together with automated early warning system development. Survey results provide vital information about AI model developments in surface water quality modeling but also present research prospects to strengthen river water quality tracking methods (Tung and Yaseen, 2020).

Moraru et al (2020) worked to develop an AI-based system for designing sewage transport networks which would exhibit resistance against water hammer effects. The water pumping system synthesis started from determining the intake location based on maximum discharge constraints and sediment conditions. The Hytran model estimated peak pressure at a 96.59-meter distance during water hammer prediction (WHP). Water pressure shock control included features in rough UPVC pipes proved to be the best design choice for the system. Researchers deployed ANFIS alongside a PSO algorithm enhancement and conducted tests against regular ANFIS techniques. Analysis established ANFIS delivered higher performance for WHP estimation in UPVC pipes but ANFIS-PSO exhibited better results for metal pipes due to its material versatility (Moraru et al., 2020).

Krajewski et al (2021) proposed a set of basic metrics for assessing data-driven models for nowcasting daily streamflow, including those developed with advanced AI techniques. These benchmarks are data-based and provide a foundation for evaluating performance improvements from more complex methods. Metrics include temporal and spatial continuity, continuity adjusted by base flow and streamflow, and distance-weighted runoff from space-time rainfall. Derived benchmarks utilize principles such as flow accumulation, scale invariance in basin response, flow separation (quick and slow), water residence time, and rainfall averaging by basin breadth. Using data from 140 streamflow gauges in Iowa, spanning 17 years and scales of 7–37,000 km^2, results show benchmarks' validity: annual mean streamflow predictions achieve efficiencies >0.6 at over 60% of locations, and >0.8 in 20% of cases for one-day-ahead forecasts. The benchmarks are straightforward to apply and beneficial for developers of data- or physics-driven hydrologic models and real-time data assimilation strategies (Krajewski et al., 2021).

Kim et al (2021) compared data-driven ML models (DMLs) and process-based hydrologic models (PHMs) to assess whether DMLs can enhance the simulation accuracy of classical PHMs or vice versa. The study compares five hydrologic models across four diverse watersheds in the Continental US (CONUS), considering different input, climate, and regional conditions. The models include two classical lumped models (SAC-SMA and XAJ), one modern distributed model (CREST), and two DMLs (ANN and LSTM). Results show that DMLs, particularly ANN, outperformed the other models in high-flow regimes and when rainfall dominated the runoff relationship, achieving high simulation accuracy with delayed input scenarios. However, DMLs showed bias with baseline inputs. PHMs performed better in low-flow regimes. The study concludes that both DMLs and PHMs have potential for streamflow simulation and should be further developed independently, with more investigations needed on DMLs' scalability and transferability for large-scale experiments like the Distributed Model Intercomparison Projects 1&2 (Kim et al., 2021).

Lowe et al (2022) reviewed the application of ML and AI in enhancing water-based applications, including chlorination, adsorption, membrane filtration, water quality monitoring, river level monitoring, and aquaponics/hydroponics automation. AI/ML models, coupled with IoT, sensors, and smart technologies, have shown success in control, optimization, and modeling across various water and wastewater applications, offering potential for reduced capital expenditures (CAPEX). However, challenges such as poor data management, low explainability, lack of model reproducibility and standardization, and insufficient academic rigor hinder progress. To address these issues, the review suggests enhancing model explainability, improving data organization, and establishing model causality to ensure the effective and sustainable use of these technologies in water-based applications (Lowe et al., 2022).

Bentivoglio et al (2022) reviewed recent advances in DL approaches for flood modeling, specifically enhancing traditional flood mapping techniques by utilizing rapid yet less accurate numerical models. A total of 58 articles are analyzed to examine the state of the art, research directions, and gaps in the field. The DL models are categorized based on their type, flood mapping applications, flood types, spatial scale, and the data used. Results show that models utilizing block layers are more precise due to their ability to better translate spatial features of floods, while fully connected layers perform well when combined with other statistical models. DL models have proven more accurate and faster than traditional numerical methods for fixed point problems. However, further research is needed to explore DL's application in flood warning systems, flood risk measurement, and the ability to generalize to new case studies. Additionally, the deterministic nature of current models poses a limitation, and incorporating randomness or probabilistic estimates can enhance model accuracy. The authors suggest leveraging advances in DL , physics-based models, and probabilistic methods like deep Gaussian processes or Bayesian neural networks to address these gaps and improve flood risk management (Bentivoglio et al.,2022).

Hamitouche and Molina (2022) reviewed AI approaches for predicting high-flow extremes, particularly in the context of assessing climate change impacts on water levels and flow rates. It begins with an overview of current AI techniques and demonstrates their applications before conducting a SWOT analysis to evaluate their forecasting capabilities using various parameters. The paper identifies 14 AI methods, with Artificial Neural Networks (ANNs), Support Vector Machines (SVMs), wavelets, and Bayesian methods emerging as the best performers due to their low computational cost, robustness, and ability to handle hydrological uncertainty and causal relationships. The study emphasizes the need for further research into the forecasting potential of decision trees, ensemble methods, Convolutional Neural Networks (CNNs), MARS, Genetic Programming (GP), and agent-based models for predicting high-flow extremes (Hamitouche and Molina, 2022).

Ibrahim et al (2022) evaluated the rapid growth of AI applications in hydrology to enhance water resource management and forecasting under changing rainfall conditions due to climate change. The analysis reveals how AI technology and advanced optimization methods combine to enhance streamflow prediction accuracy while optimizing reservoir operational performance. The review divides ML strategies into three distinct categories by exploring their use in combination with optimization methods to manage uncertain hydrological events. The research tackles different fields applying AI models to hydrology while presenting the identified limitations and benefits together with recommendations for future growth. This research draws from high-impact scientific publications published from 2009 to 2020 to analyze how AI advances hydrological practices for improved water resource management (Ibrahim et al., 2022).

Muñoz et al (2023) reviewed the growing integration of AI and ML in hydrology, a traditionally stable field that is now facing complex challenges due to large data volumes from remote sensing and IoT systems. While AI/ML applications have advanced hydrological research, often rely on black-box approaches that lack physical explanations, raising concerns about transparency and interpretability.

establishes four types of hydrological problems through analyzing spatial and temporal bounds to evaluate current tools before discussing existing challenges. AI/ML technology shows promise for hydrology through improved data acquisition along with enhanced analytical abilities and knowledge discovery systems and model development procedures. Hydrological knowledge gaps require new solutions thanks to AI/ML techniques which merge structured and unstructured data frameworks while delivering insights about hydrological processes and productively improving system management. The paper advocates that hydrologic AI effectiveness requires sustained research through learning methods combined with decision analytics capabilities and action rule development. The paper advocates the growth of self-operating technologies through cycles of learning and suggests that governments must back this development through combined public-private cooperation to handle water resource strain stemming from climate shifts (Muñoz-Carpena et al., 2023).

Zekrifa et al (2023) described the intricate processes of studying and modeling Earth's water cycle that operates via transpiration, evaporation, condensation, precipitation, runoff and infiltration. Hydrological modeling faces multiple performance obstacles resulting from scarce observational data and procedural variability coupled with data obscurity and human-induced disturbances to natural water operations. The water resource industry depends heavily on Artificial Intelligence (AI) and Machine Learning (ML) for both improved management approaches and risk reduction. Modern hydrologic technologies enhance major analysis zones including streamflow modeling and rainfall prediction and river flood risk estimation and forecast. This paper demonstrates practical hydrological applications through detailed analyses of real implementations which tap into ML and AI technologies to handle data quality issues while addressing interpretability and scalability challenges. The present study highlights ongoing research requirements for emerging hydrological modeling trends but centers the analysis on optimizing technology advancement for increased accuracy and efficiency (Zekrifa et al., 2023).

Kambarbekov and Baimaganbetov (2024) discussed how AI/ML applications have entered hydrology which was historically considered stable but now needs solutions because of massive data datasets from IoT systems and remote sensing platforms.s. Hydrological research has advanced through AI/ML applications but these techniques present a transparency and interoperability concern due to their black-box operational methods which lack clear physical justifications. The article emphasized how hydrological modeling advances water resource management by tackling expanding water shortage problems across arid and semi-arid areas. The development of Artificial Intelligence (AI) technology during recent years has brought about substantial transformations in hydrological modeling approaches. Researchers have reviewed recent studies about applying AI techniques to hydrological models which demonstrate AI's benefits in strengthening both efficiency and sustainability and accuracy of water resource management. Hydrological models supported by AI demonstrate the power to transform current water resource management approaches by delivering efficient solutions which conserve and manage water supplies effectively. Final discussions note that more research is essential to build and improve hydrological systems based on AI modeling because they hold significant promise to support future water management sustainability (Kambarbekov and Baimaganbetov, 2024).

3.1.1 Summary of AI Application

Based on the presented review papers, the considered Issue and main focusing of the AI application in water resources on global level can be summarized as shown in Table 1.

Table 1: Issue and main focusing of the AI application in water resources on global level.

Author	Date	Issue	main focusing
Chau,	2006	AI in water quality modeling	Examines AI techniques like ANNs and genetic algorithms in water quality modeling.
Kingston et al	(2008)	AI techniques in hydrology	AI-based optimization techniques
Alagha et al	(2012)	AI in hydrological modeling	Application of ANNs and SVMs to overcome limitations of physical models in hydrology.
Nourani et al	2014	AI techniques in hydrology	Reviews wavelet-AI models for hydrology.
Murat and Serhat	(2018)	AI in water modeling	Use of AI in modeling water components such as streamflow, sediment, and water quality.
Ay and Özyıldırım	2018	AI applications in water modeling	Reviews AI in various water-related modeling applications.
Elkiran et al	2019	AI in water modeling	Compares AI models for predicting DO in the Yamuna River.
Damian	(2019)	AI in hydrological forecasting	AI models (e.g., ANNs, Fuzzy Logic, ANFIS) for predicting hydrological processes.
Rajaee et al	2020	AI in water modeling	Reviews AI models for river water quality simulation.
Tung and Yaseen	2020	AI in water modeling	Reviews AI for river WQ simulation and policy suggestions.
Moraru et al	2020	AI in water modeling	Uses AI to optimize sewage transfer systems for water hammer pressure.
Krajewski et al	2021	AI techniques in hydrology	Proposes metrics for evaluating AI-based streamflow models.
Kim et al	2021	AI in hydrological modeling	Compares DMLs and PHMs for streamflow simulation.
Lowe et al	2022	AI in water modeling	Reviews AI/ML in water management and challenges like data organization.
Bentivoglio et al	2022	DL in flood control	Analyzes DL in flood modeling and identifies research gaps.
Hamitouche and Molina	2022	AI techniques in hydrology	Reviews AI methods for predicting high-flow extremes.
Khosravi et al	(2022)	DL in hydrology	Introduces CNN-BAT for daily streamflow prediction.
Ibrahim et al	(2022)	AI in river hydraulics	Use of nature-inspired algorithms for forecasting and reservoir management in river hydraulics.
Ibrahim et al	2022	AI techniques in hydrology	Reviews AI for streamflow prediction and reservoir operation.
Muñoz et al	2023	AI in hydrological modeling	Reviews AI/ML in hydrology for data acquisition and modeling.

Table 1(Cont.): Issue and main focusing of the AI application in water resources on global level.			
Kumar et al	(2023)	DL in flood control	Application of DL models to improve flood prediction accuracy and management.
Ng et al	(2023)	AI in hydraulic parameters	AI techniques for optimizing hydraulic parameter modeling and water flow management.
Kambarbekov,and Baimaganbetov	(2024)	AI in hydrological modeling	
	Explores AI's role in hydrological modeling for arid regions.		
Zhao et al	(2024)	DL in streamflow	Review of DL and hybrid models for improved streamflow forecasting.

The table provides an overview of key studies highlighting the application of AI in hydrology and water resource management from (2008 to 2024). It captures advancements in AI techniques, including optimization algorithms, machine learning, and DL models, showcasing their impact on improving hydrological forecasting, water quality modeling, and flood control.

In addition, scrutinize the review papers shows the main considered issues and their percentages were as listed in Table 2. This summary illustrated the must considered issue is the data availability and quality. However, the less considered is the computational requirements. Furthermore, the main focusing of the considered issues were as shown in Table 3. Decision support systems and optimization stand as the primary consideration point while water quality remains in the background of attention.

Table 2: Main considered issues of the AI application in water resources.

Issue	Percentage (%)
Computational Requirements	12
Scalability and Adaptability	18
Integration with Existing Systems	20
Model Interpretability and Transparency	22
Data Availability and Quality	28

Table 3: Main focusing area of the AI application in water resources.

Main area	Percentage (%)
Water Quality Monitoring and Management	20
Irrigation and Water Use Efficiency	10
Hydrological Modeling and Forecasting	25
Flood Forecasting and Risk evaluation	15
Decision Support Systems and Optimization	30

The utilized AI techniques and methodologies the reviewed papers were as shown in Figure 2.

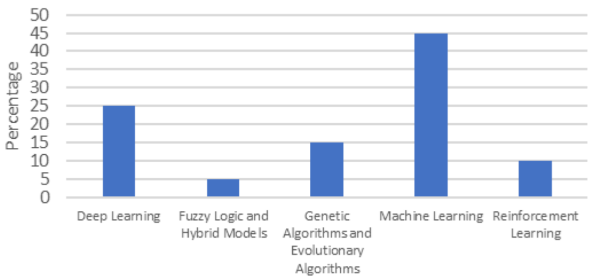

Figure 2: AI techniques and methodologies

The figure illustrates the distribution of AI techniques and methodologies used in hydrology and water resource management. ML has the highest percentage, indicating its dominance due to its adaptability and efficiency in modeling complex hydrological systems. In contrast, fuzzy logic and reinforcement learning have the lowest percentages, suggesting their limited application, possibly due to the complexity of implementation or narrower suitability for specific tasks in this field.learning have the lowest percentages, suggesting their limited application, possibly due to the complexity of implementation or narrower suitability for specific tasks in this field.

The percentage of adopting the AI in water resources management in developed countries (60%) is greater than this in the developing countries (40%).

The main limitations and challenges specified in the reviewed papers were as shown in Figure 3.

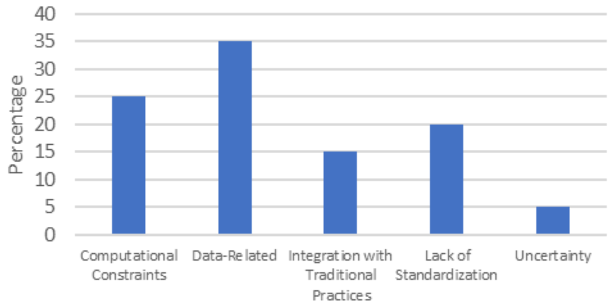

Figure 3: Limitation and Challenges

This figure illustrates the key challenges in implementing AI applications in water resource management, with percentages representing their relative impact. Data-related issues hold the highest percentage, indicating that inadequate data quality and availability are the most significant barriers to AI implementation. This underscores the critical need for robust data collection, management, and sharing frameworks to improve AI effectiveness.

This visual display depicts implementation barriers within the field of AI water resource management while expressing their force through percentage representation. The majority of barriers to implementing AI stem from data-related problems suggesting data quality deficiencies and insufficient access represent the biggest obstacles. Building effective data frameworks becomes essential for AI solutions to function better.

Analysis demonstrates that uncertainties form the least critical factor despite its minimal presence in these statistics. The effectiveness of AI models for predictive purposes remains a challenge despite these findings in diverse hydrological and environmental conditions.

Improving data infrastructure standards along with solving computational integration problems represents a critical requirement for accelerating the implementation of AI-based solutions in sustainable water management practices.

3.1.2 AI Applications in Global Scale

As part of their research Muratoglu and Yuce (2016) utilized a rainfall-runoff model to evaluate annual river flow patterns at undisclosed points along the Tigris River Basin. A total of eleven ML techniques were used to examine five datasets containing drainage area and average long-term discharge from 34 flow monitoring stations (FMS). Standard multiple regression analysis produced results with an R^2 of 0.96. The best-fit came from linear regression analysis used to establish a drainage-area-to-discharge relationship map. The findings suggested the potential to forecast the mean annual flow rate for any sub-basin of the Tigris River (Muratoglu and Yuce, 2016).

Peng (2017) conducted a comprehensive analysis of hydraulic system fault diagnosis technologies to address poor working conditions, difficult parameter acquisition, and multiple, uncertain faults. A fault diagnosis model based on an ANN Expert System (ANNES) has been constructed. The system components' structure and design were discussed, and the ANNES-based diagnosis for an excavator's hydraulic system was realized.

Simulation results had proven the system's feasibility, fully realizing expected functions and demonstrating strong intelligent behaviors (Peng, 2017)

Khidirov et al (2021) proposed an operational implementation for multi-section drainage facilities using maneuvering moving barriers. These barriers have been intended for control of water from the upper to the lower part, the design, and functional modes of the drainage system. The maneuvering mode ensured the proper sequencing, phasing, and level of barrier openings. Effective control of the hydraulic regime managed kinetic energy, flow reversal, and deformation processes. The system had been adapted for integration with hydropower plants, water intakes, sluices, and flow control systems (Khidirov et al., 2021).

Zhou and Lei (2021) developed a fault diagnosis method for mechanical hydraulic systems based on AI dynamic monitoring. Combined functional principal component analysis (FPCA) with BP neural networks for feature extraction and applied it to diagnose faults in coordinator hydraulic systems. The study analyzed the system's structure, failure modes, and common faults, establishing a failure mode and effects analysis (FMEA). A joint simulation model was created using ADAMS, AMESim, and MATLAB, and the fault detection signals were compared with experimental data to validate the model. The method had better diagnostic accuracy reaching 0.9848 and 0.9927 much improved reliability and decreased uncertainty (Zhou and Lei , 2021)

Samadi et al (2021) examined the possibility of predicting dynamic pressure distribution in flip buckets to enhance the design and functioning of hydraulic structures. Based on experimental studies, examined five soft computing methods: ANN, GEP, CART, M5MT, and MARS. However, according to M5MT and MARS analysis, CART and formulations from GEP yielded simpler calculations than ANN. However, the GEP presented the closest estimations, regarding RMSE of 0.095, SI of 13%, and the MAE of 0.073 (Samadi et al., 2021).

Kumar et al (2024) addressed the challenge of predicting flow velocity in vegetated river channels, which is notoriously difficult. The study serves as the first examination of hybrid and standalone M) model performances. The experiments include four individual algorithms: Kstar and M5P along with reduced error pruning tree (REPT) and random forest (RF) and eight hybrid models based on Additive Regression (AR) and Bagging (BA) approaches. Research demonstrates vegetation height shows the strongest relationship with flow velocity and ML models achieve superior results than empirical equations. The hybrid AR-M5P model demonstrated outstanding performance in the test group of models according to the results (Kumar et al., 2024).

Saliba et al (2020) studied the rising problems from heavy rainfall storms attributed to climate change and economic development which now requires essential stormwater drainage system improvements. Standard passive systems targeted for retrofitting with controllable valves and pumps offer promise under real-time control software systems called RTC. Reinforcement Learning applications serve stormwater management optimization through the combination of real-time flooding data and predicted rainfall. Real-time Cyber-physical systems apply the Deep Deterministic Policy Gradient (DDPG) algorithm to process data containing uncertainties and noise. Three cases were studied: perfect data, imperfect rainfall forecasts, and imperfect water level/forecast data. The experiments using 85 training instances followed by 15 test cases demonstrated that DDPG eliminated flooding events by 70.5% which proved its effectiveness for real-world conditions with noisy input data (Saliba et al., 2020).

Munawar et al (2021) reviewed the role of modern technologies in enhancing flood management, including prediction, detection, mapping, evacuation, and relief efforts. These technologies are critical for reducing fatalities, minimizing environmental impacts, and mitigating economic losses. In the literature, various techniques from remote sensing, machine learning, image processing, and data analysis have been explored. This research introduces a framework to classify recent advancements in flood management, addressing key research questions: (1) What are the major techniques used in flood management? and (2) What problems do flood management systems aim to solve? It identifies significant gaps, particularly the lack of hybrid models combining image processing and machine learning, and the limited use of ML in post-disaster situations. Future work should integrate disaster management knowledge with these technologies for more comprehensive flood management across all phases (Munawar et al., 2021).

Xue et al (2022) analyzed flood control optimization strategies in the context of China's evolving water conservancy industry, which increasingly focuses on leveraging existing engineering measures for river basin flood management. Coordinating flood control in large rivers requires evaluating meteorological and hydrological factors, historical flood records, engineering requirements of multiple reservoirs, and various flood control objectives, making it a complex decision-making problem. In this study, the Luanhe River Basin is examined, where constraints such as wastewater discharge, reservoir storage capacity, and water release decisions are considered to build a flood control optimization model. The objective function aims to minimize the square of the sum of reservoir discharge and interval flood discharge. The study applies genetic algorithm, particle swarm optimization, spider swarm optimization, and grey wolf optimization (GWO) to solve this issue. Results show that GWO outperforms genetic and particle swarm algorithms in terms of optimization capability, convergence performance, and stability. It also shows better results than spider swarm optimization. The GWO has a broader application scope for solving long-sequence problems and offers faster computation times, making it ideal for the flood control optimization of the Panjiakou Reservoir Group (Xue et al., 2022).

Zhang and Wang (2023) addressed the global concern of flood management, with increasing flood incidences driven by climate change and extreme weather patterns. Flood studies are essential for risk reduction and are extensively documented in scientific literature. This paper aims to extract flood control information from the literature using DL approaches. A dataset of 4,742 flood-related academic papers from the past two decades was collected, and ML methods were applied to preprocess the documents. A total of 347 sample data were gathered, from which approximately 61,000 sentences were manually annotated. The study utilized both traditional ML models (NB, LR, SVM, RF) and DL models (ANN, Bert, Bert-CNN, Bert-RNN, ERNIE) for model training and sentence-level knowledge extraction. Results showed that deeper models achieved better accuracy but required significantly more training time compared to simpler models like ANN. The DL methods were ranked based on their feature extraction capabilities and computational efficiency: ERNIE > Bert-CNN > Bert > Bert-RNN. Calibration of Bert with a benchmark model revealed that deformation models had useful characteristics, and ERNIE exhibited enhanced performance with its masking mechanism. Additionally, 124,196 usage method sentences and 8,935 quotation method sentences were generated, showing an increasing trend in the publication of method-related content over the past 20 years. This study lays the foundation for future knowledge extraction in flood management (Zhang and Wang, 2023).

Nowak et al (2022) investigated the administrative processes of diagnostics of the technical state of small hydraulic structures in Poland. Just research on the case of Oświecim Weir on the Prosna River has shown the looseness of the concrete structure of the water control bastion, such as the crackling and the forming of the cavities. The study pointed out that different remodeling activities as well as costs were attributed to environmental aspects especially the water flows to warrant stabilization of water conditions in the area. In the context of climate change, the proper maintenance of hydraulic structures through diligent monitoring has been essential for mitigating these challenges (Nowak et al., 2022).

Mehedi et al (2022) investigated urban flooding, particularly in the context of increasing global urbanization and the sensitivity of urban fluvial systems to various interacting factors. Many methods have been proposed to reconstruct hydraulic models for urban flooding, but high spatial resolution and refined discretization remain challenging due to the computational cost of solving numerical physical equations. These challenges hinder the full potential of data-driven approaches. This study applies artificial intelligence, specifically ML and DL, to estimate urban flooding volume in the lower part of Darby Creek, PA, USA. The dataset includes geographic and hydraulic data such as topographic height, water depth, impermeable area, discharge, and more. ML classifiers including logistic regression (LR), decision tree (DT), support vector machine (SVM), and K-nearest neighbors (KNN) were used to identify flooded locations. A DNN-based regression model quantified water depth. Evaluation results show satisfactory performance, with F-1 scores of 0.975, 0.991, 0.892, and 0.855 for the classifiers and a root mean squared error of 0.027 for the DNN model. Blocked K-fold cross-validation showed an overall accuracy of 0.899 for detecting flooded locations. This work demonstrates the potential of highly efficient ML methods for addressing urban flooding, leveraging large multi-dimensional datasets (Mehedi et al., 2022).

Zhu and Tang (2023) investigated the damage mechanism affecting large hydraulic concrete structures like dams throughout alternating load cycles and aging-related deterioration. Structural monitoring emerges as crucial because cracks degraded both the structural integrity and impermeability and durability of these buildings. Research suggested an automatic system which combines artificial intelligence with computer vision to perform damage diagnosis and detection tasks. A novel Xception backbone network with adaptive attention mechanism image segmentation method from Deeplab V3+ architecture was proposed to enhance crack feature extraction capability. Experimental findings demonstrated highly precise crack identification performance with IOU at 90.537% and Precision at 91.227% while obtaining a combination of Recall at 91.301% and F1-score at 91.264%. Recent applicability tests conducted this method on actual hydraulic concrete structures with different types of cracks (Zhu and Tang, 2023).

3.3 AI Applications in Tigris River, Iraq

This review paper attempts to provide the missing piece in the development of AI applications in conventional River Flow Control measures. It develops bespoke AI models to enhance data integrity, estimate effectiveness of the climate change solutions, and analyze socio-economic outcomes. To combat the water crisis and the impact of climate change in Iraq and the entire global population, our initiative aims to find the use of AI in the water resource sector.

There are various applications of AI in the different water resources issues in Iraq. As this paper focus on Tigris River, below is a review for the must studies concerning the AI application in modeling and management of Tigris River water resources.

3.3.1 Hydrological Studies

Al Aboodi et al (2009) developed three artificial neural network (ANN) models using a backpropagation algorithm to forecast real-time water levels of the Tigris River in Qurna City, Basrah, southern Iraq, for short-term staging. The results indicated that the ANNs with backpropagation provided nearly accurate 1-week forecasts of the river stages, demonstrating their effectiveness in predicting river levels over short time horizons. This approach highlights the potential of neural network models in enhancing flood prediction and water level management in the region (Al Aboodi et al., 2009).

Al Aboodi (2014) employed three heuristic regression methods known as M5 Model Tree (M5-Tree), multivariate adaptive regression splines (MARS), and least square support vector regression (LSSVR) for forecasting and predicting the monthly streamflow. Used data from, Hit and Baghdad hydrological stations in Iraq, and Besiri, and Malabadi in Turkey. The used Evaluation technique was cross-validation. To identify each station’s one-month ahead streamflow forecast, initially, the analyses performed multiple linear regression (MLR) and heuristic regression models. More specifically, in the second step, the models were compared and assessed by analyzing data from other stations of the networks. The study has also applied the periodicity component or the month of the year to the long-term streamflow modeling. The comparative results showed that during both phases, the performance of the LSSVR model was higher than the MARS, M5-Tree, and MLR models. Also, it was demonstrated that augmenting the periodicity feature as an input significantly enhances the forecasting performance of the models for monthly streamflows in both stages of the study (Al Aboodi, 2014).

Yaseen et al (2016) emphasized the importance of monthly streamflow forecasting for various hydrological applications such as water resource system designs for both rural and urban development, water resource operation and pricing, water usage efficiency estimation, water quality assessment, and agricultural and/or irrigation management. It is important to note that the continuous enhancement of improved forecast models is still a major consideration in hydrology. In this study, the possibility of the still comparatively little explored data-driven technique, the extreme learning machine (ELM) method, was examined for the prediction of the monthly stream flow discharge of the Tigris river in Iraq. The ELM algorithm is an SLFN as it randomly defines the input weights and the hidden layer biases and output weights of the SLFNs are mathematically computed. Five input combinations with lagged streamflow values were selected with the help of partial autocorrelation functions of historical streamflow data for the development of the optimal model for streamflow forecasting. The research analyzed ELM model performance relative to other data-driven methodologies by comparing it against SVR and GRNN models. Different assessments evaluated the results from the forecasting model using the correlation coefficient of determination (r) together with Nash-Sutcliffe efficiency (ENS) and Willmott's Index (WI) and Root Mean Square Error (RMSE) along with Mean Absolute Error (MAE). These assessments were derived from observed and predicted stream flow data. Accordingly, the result analysis revealed that for all the statistical measures, the ELM model achieved a higher and significant success rate than the SVR and GRNN models. Particularly, the ELM model gave a better performance with ENS of 0.578, 0.378, 0.144, r of 0.799, 0.761, 0.468, and WI of 0.853, 0.802, 0.689 as compared with other models. Moreover, the ELM model was able to save almost 21.3 percent RMSE reduction in comparison with SVR and 44.7 percent in comparison with GRNN. Further research on the implemented ELM model for the contours of hydrological forecasting is suggested (Yaseen et al., 2016).

Yaseen et al (2016) investigated monthly streamflow forecasting using three regression heuristics techniques: MARS, LSSVR, and M5-Tree, with data from stations in Turkey and Iraq. LSSVR outperformed MARS, M5-Tree, and MLR in both predicting for a month in front and predicting streamflow at one station using data from nearby stations. Including periodicity as an input significantly improved model accuracy (Yaseen et al., 2016).

3.3.2 Hydraulic Studies

The literature indicates persistent requirements for reliable expert systems with accurate real-time streamflow prediction functionality despite recent enhancements in hydrological modeling methods Yaseen et al (2018) presented a wavelet extreme learning machine (WA-ELM) as a novel complementary data intelligence model dedicated to river flow prediction in semi-arid river basins. Model calibration and validation used monthly river flow data from 1991 to 2010 and the proposed model utilized antecedent flow data for prediction. A comparison of predictive performance took place between WS-ELM and ELM models by using statistical measures and visual evaluation methods for model assessment. The application of wavelet-based data pre-processing techniques with ELM models produced substantial improvements in river flow prediction accuracy. The WA-ELM model delivered 65% RMSE and 67% MAE reduction compared to independent execution of the ELM model. The WA-ELM simulated river flow displayed consistent distribution patterns with observed flow data according to Violin plot analysis and established a very tight correspondence to observed data based on Taylor diagram results compared to the standalone ELM model. The wavelet decomposition method enhanced the ELM model's ability to identify critical information used for modeling chaotic river flow regimes that display both non-stationarity and stochastic patterns. Research findings demonstrated that WA-ELM establishes itself as a dependable algorithm for water flow prediction in arid areas throughout different hydrological conditions from low to medium to high flow scenarios (Yaseen et al., 2018).

The forecasting accuracy of extreme learning machine (ELM) was enhanced through Yaseen et al (2020) by introducing the Salp Swarm Algorithm (SSA). The integration of the Salp Swarm Algorithm into Extreme Learning Machines resulted in enhanced performance using Baghdad Tigris River data with a 13.1% reduction in MAE and an 8.4% improvement in RMSE over standard models (Yaseen et al., 2020).

Al-Mukhtar et al conducted a study during (2020) to examine how water scarcity in Abu-Ziriq Marsh affected both ecological conditions and biodiversity features in the southern Iraqi region. This paper used three different forms of AI models: Models ANFIS and ANN together with MLR evaluated the drain patterns at Abu-Ziriq Marsh while predicting future flows based on Al-Badaa regulator outputs. Studies employed 725 samples of daily discharge data which included Al-Badaa regulator (QB) output measurements and Abu-Ziriq Marsh (Qz) intake observations collected during 2017 through 2018. Each data set was separated randomly to create train data consisting of 29.5 % while test data occupied 70.5 % of the distribution. Each model performance was evaluated through observations of the R^2 value together with RMSE observations and NSE measurement. The ANFIS model validated through calibration presented statistical results of RMSE=4.11 (4.17) together with R^2 = 0.87 (0.83) and NSE = 0.76 (0.70). The analyzed data provided evidence that the ANFIS model exhibited superior performance compared to other evaluated models. The analysis demonstrates that ANFIS technology can effectively compute Qz values for Iraqi Marshes and supports hydrological research as an additional investigative method (Al-Mukhtar et al., 2020).

3.3.3 River Modeling And Decision-Making Systems Studies

Allawi et al (2021) executed monthly flow data stream prediction research to optimize reservoir management at Haditha Dam on the Iraqi Euphrates River. A co-active neuro-fuzzy inference system (CANFIS) served as the research framework because its purpose was to boost forecasting accuracy. Comparing CANFIS, three AI-based models: ANN and adaptive neuro-fuzzy inference systems (ANFIS) with four kinds of training methods. The study measured temperature prediction accuracy by assessing Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Relative Error at or below 15% along with R^2 coefficients calculating forecast agreement with actual measurement results. During the second stage of the training processes, the given results showed that the proposed CANFIS model has a higher performance than ANN and ANFIS models. Consequently, the CANFIS model was able to estimate a low MAE of 69.66 m^3/s, RMSE of 78.10 m^3/s, and high R^2 = 0. 97 of monthly inflow for efficient reservoir management. In general, the study illuminated a better model of CANFIS for forecasting reservoir inflows for better water management at Haditha Dam and potentially possible application in other regions (Allawi et al., 2021).

Mohammed et al (2022) established a new data forecast model integrating ANN and Marine Predators Algorithm to predict the Tigris River water level in Al-Kut, Iraq for a month. When applied to 2011-2020 historical data, MPA-ANN data yielded better results compared to other algorithms such as CPSOCGSA-ANN and SMA-ANN with scatter index (SI) of 0.0009 and R^2 = 0.98. Similarly, singular spectrum analysis was also useful for removing noise from the time series data (Mohammed et al., 2022).

Alqahtani et al (2023) explored the use of ML techniques for predicting rainfall. Because the input data–output conditions dependency is non-linear, rainfall prediction is challenging, so DNN models act as approximations for expensive, sophisticated systems. Simple and cost-effective models can be developed with a huge deep neural network, especially for rainfall prediction. On the other hand, water levels are commonly determined by the level of rainfall. The effect of climate change may result in unpredicted rainfall that may lead to floods or drought. The majority of the people including farmers depend on the forecasts of rain. In our work, are interested in the wetlands in the southern region of Iraq are iconic geographical areas found all over the world, This is the point at which the Shatt al-Arab discharges into the Arabic Gulf and at which the Tigris and Euphrates rivers were birthed in the Mesopotamian plain. It was not until the early 1980s that the wetlands, referred to as "the marshes," encountered dry seasonal periods. Upon entering the 21st century, a large portion of the 'marshes' had shifted to 'terrestrial' and non-living systems, whilst 'Sabkha' transformed to an area of zero biodiversity, as they were densely populated with water. In addition, certain parts of these areas have gone through notable hydrological and climatic changes. The focus area of this research is the Marshes of southern Iraq trying to formulate rainfall predictive models. Hence, the augmentation of monthly rainfall forecasting is achieved through the LSTM and hybrid DL optimization. To verify the accuracy of the forecasts, the predicted precipitation is compared statistically with the measured data and the quality and validity of the models are evaluated. The hybrid convolutional stacked bidirectional long-short-term memory outperformed all other models for the first time (CNN-BDLSTMs) (Ahmed et al., 2023)

Using the case Euphrates–Tigris Basin in Turkey, Guzey and Önöz (2023) worked at and compared two hydrological models. The first model is the linear regression using hydroclimatic data and stream flow data concerning the cluster analysis. The second one is the HBV semi-distributed model which provides process-based hydro. Logical modeling. HBV model yielded superior to the regression model inflow forecasting, although the regression model offered credible results (NSE=0.752). The paper also discusses the advantages of the regression model in combination with the physically based model, and the favorable future of the HBV model when it comes to accurate estimation of stream flow that is very essential for determining the hydropower energy potential of any region (Alqahtani et al., 2023)

3.3.4 Water Quality Studies

Water quality modeling in particular is one of the essential frameworks in natural science and engineering disciplines. This makes it easy for stakeholders to comprehend many water systems, anticipate the results of certain factors on the quality of water, and also formulate effective mechanisms to prevent decay and misuse of water. Water quality models enabling the linkage of data, scientific principles, and computational methods are useful tools in management and policy development to address water-related issues.

Omar's (2017) developed a Feedforward Neural Network (FFNN) model, supported by the back-propagation learning algorithm, to predict the dissolved oxygen (DO) content in the Tigris River, Baghdad, Iraq, based on Biological Oxygen Demand (BOD) and water temperature, for five days. The Artificial Neural Networks model was established for the Baghdad water treatment facility in 2008. The ANN models were first introduced with large elements derived from water quality indicators – as shown by a comparative analysis of dependent variables and dissolved oxygen. The performance of the ANN models was evaluated with the coined Nash-Sutcliffe (NS) efficiency coefficient, the Coefficient of determination (R^2), Mean Squared Error (MSE), and Mean Absolute Error (MAE). The results indicated that low values of MSE were obtained with the temperature and biological oxygen demand-based FFNNs with back-propagation learning; MSE 1.133, MAE 0.369, high correlation coefficient 0.885, and efficiency coefficient 0.782. The findings established that artificial neural networks, under the FFNN paradigm, could estimate DO very accurately suggesting application in the management of the Tigris River in Baghdad (Omar, 2017).

Ewald et al (2018) analyzed monthly averaged water quality data for 10 different locations on the Tigris River, Baghdad, in 2016 had previously established a water quality model (WQM) with water quality index (WQI) as the dependent variable and independent variables identified through stepwise MLR analysis. Taking into consideration the assigned weights, eleven significant criteria were adopted in the construction of WQI. Out of 2760 values of physiochemical water quality parameters, the WQM analyzed 23 parameters (Ewaid et al., 2018)

Ewaid et al (2018) AI and fuzzy logic were adopted to create a new water quality index for daily water quality assessment of river water for human consumption. Had included TD, TH, FC, and BOD as indexes since were important to Iraqi water systems. The project created a fuzzy logic inference system through Matlab by implementing predetermined Mamdani Max-Min fuzzy logic rules. Researchers evaluated the FWQI by analyzing Tigray River data from 2017 and used Iraqi DWQ standards to measure the new FWQI performance. The fuzzy inference system resulted in a simple yet realistic method for assessing water quality suitability in Iraqi rivers for drinking purposes. During the research period the FWQI successfully assessed the water quality condition of the Tigris River (Ewaid et al.,2018).

Ay and Özyıldırım (2018) assessed the vital position of AI in water management by demonstrating its capability to handle complicated water system models and conduct complex water process solutions. Research documented AI development in water modeling that includes surface water systems such as rainfall-runoff and streamflow procedures alongside evaporation and evapotranspiration processing and water quality measures and reservoir and lake water level predictions. This analysis demonstrated AI as a tool which handles linear and non-linear systems alongside dynamic and complex water management tasks. The study presented potential research pathways to enhance AI-based modeling techniques for water while accelerating the development and operational efficiency of AI in water management (Ay and Özyıldırım, 2018).

Al-Rubaie and Al-Musawi (2019) used ANN and GIS models to analyze the water quality of the Diyala River using the WQI. Considering fourteen characteristics of seven stations during the years 2011-2016 the river water quality appeared to be between good and very polluting. In the study, ANN was proven effective in achieving a high level of prediction accuracy with the help of GIS which yielded a good graphic display of water quality (Al-Rubaie and Al-Musawi, 2019).

Ibrahim and Mishra (2020) showed that water could sometimes pose a risk to people and their belongings. Even though this is one of the most vital components of life on earth. This article highlights the phenomenon of Tigris river pollution, which developed water pollution sensors in Baghdad city. The goal of this study was to evaluate and map the water environment. It is an effort to use modern scientific approaches IoT and ML to predict pollution and avoid potential problems. This could be used as one of the beneficial strategies of the E-governments to their people. Above listed are the portals of: Internet of Things; E-government; water pollution prediction; Tigris river; artificial neural network (Ibrahim and Mishra, 2020).

Al-Obaidi (2020) carried out research to assess the sodium adsorption ratio(SAR) to among other factors, standard the suitability of water for irrigation. Based on those objectives, the research concerned numerous physicochemical features, in addition to the weekly, monthly, and yearly flow discharge (Q) of the Tigris River. Surface water samples were taken from three important sites of the river namely the Samarra (above), Baghdad (mid-stream), and Kut (below) from 2016 to 2018. Customer and self-generated data collected, however, revealed that Tigris River water quality was within WHO-recommended standards of drinking water except for sulfate content. The Sodium Adsorption Ratio (SAR) was determined, and Artificial Neural Network (ANN) models for other sites were also established. The results were estimated using the squared error function, and the coefficient of determination (R^2) was calculated as well. The Analyzed ANN models exhibited fair forecast performance, with the coefficient of determination R^2 equal to 0.992 for Samarra, 0.986 for Baghdad, and 0.955 for Kut. Further, the study also found that salt concentrations influenced SAR prediction results at all three stations. In general, the ANN model was proven to be an efficient technique to determine SAR and evaluate the usability of the water of the Tigris River for irrigation intent (Al-Obaidi et al., 2020).

Khaleefa and Kamel (2021) evaluated and quantified the quality of drinking water of the Euphrates River in Hit, Iraq through the WQI obtained from ten physical and chemical characteristics. The medium was found to be very poor according to the WQI average of 110.156 due to high TDS and magnesium mainly from human activities of the river (Khaleefa and Kamel, 2021).

Alrufaye et al (2022) used the Tigris River neural network algorithm to approximate the oxygen concentration like water quality requirement for usage by people. In this study, an attempt was made to forecast COD, BOD, and DO levels with a neural network model. The neural network system was developed with different input parameters that contain factors affecting the water quality. These factors were then employed to derive optimal weights of COD, BOD, and DO in the output layer. An application interface was designed and used to compare the efficacy of the system with those of the previous methods by computing parameters like Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), and Correlation Coefficient (R2). In general, the study emphasizes the importance of using the neural network algorithm in the calculations of the water quality parameters and especially in evaluating the oxygen content of the Tigris River which is a useful application in the assessment. And management of water qualities efficiently (Alrufaye et al., 2021).

Jaafer and Al-Mukhtar (2024) assessed Five AI model techniques such as AdaBoost, Tree, KNN, Random Forest, and Gradient Boosting were evaluated on their effectiveness on the predictions of the water quality parameters like BOD and DO of the river. Each technique's performance was evaluated on the datasets from the Al Muthanna Bridge and the Aammah Bridge spanning the Tigris River in Baghdad city. The data was divided randomly into two parts: In the presented work, the authors split their data into the training dataset (70%) and the testing dataset (30%). Applying the Principal Component Analysis (PCA), it was examined what of those input variables could be taken into account for modeling DO and BOD. For the comparative analysis of the generated models, four performance criteria were used, namely R2, RMSE, MAE, and MSE.

It showed that the predicting power of AdaBoost and Gradient Boosting is superior to the other models in predicting DO and BOD. For Gradient Boosting (which also uses AdaBoost) at Al Muthanna Bridge and Al Aammah Bridge, the R2 values were 0.994 (0.992) and 0.994 (0.991) respectively for DO prediction, while for BOD prediction, the correlation coefficients R2 of Gradient Boosting (with AdaBoost) were 0.992 (0.982) and 0.989 (0.990) respectively. To sum up, the outcome of this study highlighted the fact that much more sophisticated ML algorithms such as gradient boosting and AdaBoost should be employed for describing water quality indices. Could also be useful for the future prognostication and handling of other water quality parameters of other water supply systems in water-related communities where artificial intelligence technology is still under active exploration (Jaafer and Al-Mukhtar, 2024).

Modeling Rivers and Decision-Making Systems; sediment transport; river morphology uses mathematical computation to simulate the Rivers and systems. These models assist in the assessment of river conditions, the formulation of future conditions, as well as in management decisions relating to the river. These models are incorporated with data and analytic tools in decision-making systems to plan and manage riverine systems.

Al-Mukhtar (2018) used the Adaptive Neuro-Fuzzy Inference System (ANFIS) alongside two types of Artificial Neural Networks (ANNs)—feed-forward and radial basis networks—to model the Suspended Sediment Load (SSL) in the Tigris River in Baghdad. The study utilized streamflow discharge and SSL data from the Sarai station in Baghdad, covering the years 1962 to 1981. 70 percent of the data had been used to train the networks, and 30 percent of the data had been used to test the networks. The degree of similarity between measured and predicted data was assessed using NSE, RMSE, and coefficient of determination R^2. The ANFIS model gave better prediction results for all the methods where during calibration R^2 0.58, RMSE 75617 and NSE 0.58 and during validation R^2 0.72, RMSE 27944 and NSE 0.59. Estimates from the ANFIS method provide strong potential for river suspended sediment load measurements (Al-Mukhtar, 2018).

Researchers at Thakur and Manekar (2022) Investigated hydrologic modeling through an analysis of how spatial changes in model parameters influence prediction results. The study explored Gene Expression Programming (GEP) for classifying Land Use Land Cover (LULC) and compared its performance with five other AI techniques: Support Vector Machine (SVM) together with Adaptive Neuro-Fuzzy Inference System (ANFIS) and M5 Model Tree, Multivariate Adaptive Regression Splines (MARS) along with GEP formed the key artificial intelligence methods examined during the study. The analysis incorporated error and accuracy metrics using omission and commission errors in combination with overall tests and the Kappa coefficient measurements. Results from the study revealed GEP to show comparable effectiveness to SVM and ANFIS by attaining Kappa coefficients above 0.85 which establishes GEP as a top tool to generate mathematical functions for LULC classification tasks. The results favor GEP as the recommended methodology for this specific application mainly because of its outstanding performance (Thakur and Manekar, 2022).

Mohammadi et al (2021) analyzed the operational capabilities of two waterfall-based rainfall-runoff models named HBV and NRECA coupled with seven artificial intelligence-derived hybrid models comprising Adaptive Neuro-Fuzzy Inference System (ANFIS) and Support Vector Machine (SVM) and Generalized Method of Data Handling (GMDH). The modeling used precipitation data that was shifted by 1 month before training. AI hybrid models demonstrated superior performance compared to HBV and NRECA in model predictions, and GMDH generated the smallest RMSE measurements at Cipero, Kedungdowo, Notog, and Sukowati stations. GMDH produced the most precise peak value predictions at both Sukowati and Cipero monitoring sites. When provided appropriate input data AI-based modeling techniques prove to be successful substitutes for conventional hydrologic models while working best in areas with minimal hydrologic data (Mohammadi et al., 2021).

Boloorani et al (2022) developed an advanced dust source susceptibility mapping method through D-S theory integration with five ML classifiers comprising Support Vector Machine, Random Forest, Naïve Bayes, Logistic Regression and Artificial Neural Network. The study utilized MODIS-Terra/Aqua imagery and environmental drivers to identify 411 active dust sources throughout the Tigris-Euphrates basin. D-S theory integrated with five ML classifiers achieved 87.7 percent accurate predictions for dust sources classified as susceptible and 86.3 percent accurate predictions for non-susceptible classes. Wind erosion thresholds were applied to assess susceptibility (Boloorani et al., 2022).

The reviewed studies also cover various aspects of water resources management, including evaporation forecasting, reservoir inflow prediction, and water quality monitoring.

Hmoud and Waselallah (2021) explored the use of automated AI techniques to reduce costs in water supply and sanitation system development while ensuring compliance with water quality standards. It proposes an Adaptive Neuro-Fuzzy Inference System (ANFIS) for predicting the Water Quality Index (WQI) and compares it with Feed-Forward Neural Network (FFNN) and K-Nearest Neighbor (KNN) algorithms for water quality classification. Using a dataset with eight key variables, results show that ANFIS provides reliable WQI predictions, while FFNN excels with 100% accuracy in classifying water quality categories, outperforming ANFIS in classification tasks (Hmoud Al-Adhaileh et al., 2021).

3.3.5 Water Resources In General

Hesam et al (2023) investigated the importance of water management in the development and preservation of the environment. Traditional WRM approaches have been marred by several challenges including data acquisition timely, adequate and timely data processing, and above all, effective decision-making. As a result, new groundbreaking approaches have had to be put into practice. AI and Big Data Analytics (BDA) hold the promise to transform WRM and identify its future trajectory. Current practices of using only AI and BDA in WRM were analyzed in the work and revealed possibilities of these tools in overcoming current issues. Further, the study examined how BDA supports water resource management using other sources of information such as social media, IoT, and remote sensing (Kamyab et al., 2023).

Abbas (2024) proposed a pipeline to transport potable water from Mosul Dam Lake to Basra Governorate, addressing water shortages and improving urban water quality. Crossing reservoirs in central and southern governorates, it supports the Shatt al-Arab via the Tigris and Euphrates Rivers. The route is optimized using spatial data and natural inclines for efficient flow, while its interior routing reduces risks from terrorism and evaporation. The pipeline also serves as an emergency backup for dam failures. Artificial intelligence enhances project management, ensuring cost efficiency and addressing critical health, environmental, and security challenges in regional water resource management (Abbas, 2024)

Ethaib et al (2022) evaluated water scarcity in Thi-Qar Governorate, Iraq, using GIS estimation, environmental data, climate change effects, and marshland changes over the last three decades (1991–2021). The methodology involved analyzing water quality indicators, surface water quantity, climatic data, and Landsat images obtained from the USGS. Hydrological analyses were conducted using ArcGIS 10.4.1. Results revealed Iraq's annual water availability per person (1,390.95 m^3/cap/year) falls below the water scarcity threshold (1,700 m^3/cap/year). Thi-Qar's average daily potable water supply (284 L/cap/day) is lower than Iraq's average (340 L/cap/day), with 6% of months (1998–2018) failing to meet demand. Water quality tests showed biological pollution in 55% of annual samples. Landsat imagery highlighted significant marshland variation, with the highest area (1,548.21 km^2) in 1991 and the lowest (65.45 km^2) in 1999. The findings emphasize severe water scarcity impacts on local populations and offer actionable insights for mitigating and managing the crisis (Ethaib et al., 2022)

This review paper intentionally focuses more on the hydraulic aspects of the Tigris River applying AI techniques to provide a stronger foundation for its better, sustainable, and efficient hydraulic management through prediction, monitoring, allocation and assessment, and policy intervention to improve effective management of available resources, control of pollution from various Riparian upstream countries and more so, flood management. Even a rough segregation of the topics that the AI application of the Tigris River, Figure 4 represented, revealed that more than half, approximately 50% of it, was inclined towards water resources management and hydrological studies. However, less attention is given to the decision-makingsystems and water quality, where both do not exceed 25%.

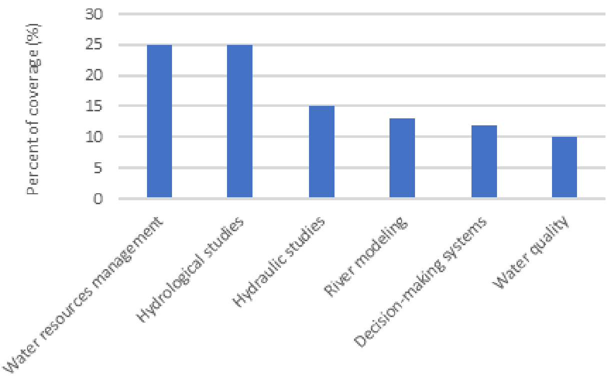

Figure 4: Percentage of Topics coverage

Table 4: Key Issues Affecting River Flow Management and Their Relative Impact (%)

Issue	Percentage (%)
Data Availability and Quality	30
Climate Change and Water Scarcity	25
Political and Geopolitical Issues	20
Integration with Existing Infrastructure	15
Uncertainty	10

Table 5: Main Areas of Focus in River Flow Management and Their Relative Importance (%)

Main area	Percentage (%)
Flood Forecasting and Risk evaluation	30
Hydrological Modeling and Forecasting	20
Reservoir and Dam Management	10
Water Allocation and Irrigation Optimization	15
Water Quality Monitoring and Management	25

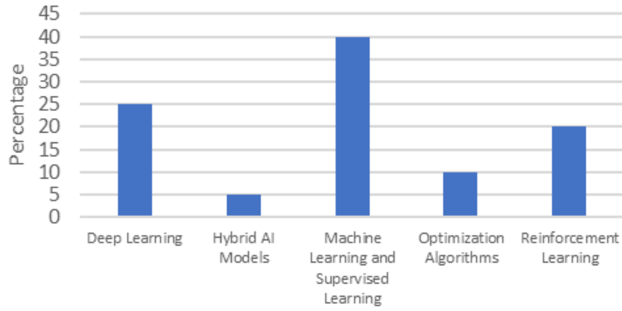

Figure 5: AI Techniques and Methodologies

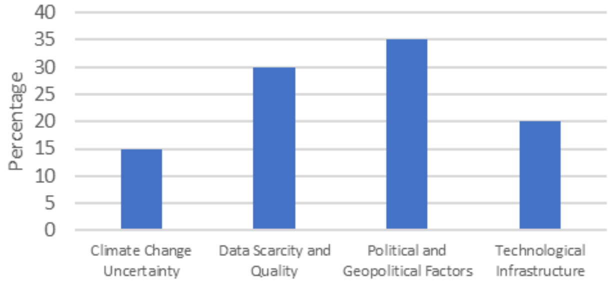

Figure 6: Limitation and Challenges

This review shows how AI models predict floods and help in disaster prevention, and ML in predicting the river flow rate to facilitate water resource management. Moreover, AI allows for monitoring water quality and pollutant detection in real-time, in addition to considering the remote sensing data for water conditions, It is potentially powerful for modeling and efficient management of efficient water resource systems. Similarly, by applying AI models of climate change impacts, 'adaptation plans' are in place and it also assists in proper rationing of water provision in agriculture, industries, and households. AI makes decisions, reduces the cost of operations in organizations, and makes accurate decisions.

An annual progression of AI applications for water resources development throughout the world reveals an upward trend due to technological progression, enhanced data availability, and awareness about the usage of AI to address water issues. By reviewing the publications activities concerning the Ai application in water resources in global web sites for the period 2015-2024, it can be noted that the global interest in adopting topics related to AI has grown by about 20-30%. However, AI applications in water resources locally are developed every year differently based on the presence of government programs, grants and appropriations, and technological support. Local advancements are particularly monitored through academic institutions, government reports, and local partnerships.

The interest in AI applications in water resources has remained weak in Iraq, with a slight increase during the last two years, not exceeding 15% of research interests. regulatory frameworks to support AI in river management is essential, though challenges exist in implementing AI within existing policies. The economic benefits of AI must be weighed against its costs, requiring financial investments and potential funding sources to be identified. Data collection presents challenges, including issues with standardization and gaps that need to be addressed.

This paper concludes that the participation of communities in AI in river management is essential, including incorporation into conventional water usage and indigenous wisdom. Moreover, it is crucial to build strategic regulations for AI in river management despite the barriers to integrating AI with policies. AI, being an economic enabler, has a relative cost, which means that to embark on implementing AI, one must be able to estimate costs, including the financial resources needed to finance its implementation. Data collection remains a problem since there are some problems such as standardization issues and gaps to be filled with solutions. National water practices and Indigenous knowledge. Additionally, developing

In addition, qualifications such as infrastructural requisites and technical know-how are required for AI systems to work. Sustainability must also be taken into account, both in the long-term, and in the completeness of the system including AI costs, and sustainability such as energy requirements. There is also a need to fine-tune the algorithms used in the ML models sometimes and also put in place a system of having several sensors to make thorough monitoring. AI can play a significant role in protecting ecosystems, biodiversity, and habitat quality, while strategies for detecting and mitigating river pollution should also be developed.

The social impacts on local communities and stakeholders must be considered, as well as ethical issues related to data privacy, bias, and ensuring equitable benefits. Interdisciplinary collaboration is essential, as is the integration of AI with other management tools for a holistic approach to river management.

The reviewed studies present various innovative methods and findings related to hydrological modeling, water quality assessment, sediment analysis, and environmental changes in the Tigris River and surrounding regions. However, several key areas were not adequately covered. Integration of climate change projections with hydrological and water quality models to anticipate long-term changes in river behavior and water resources was limited. The socio-economic impacts of river management decisions, water quality, and sediment load changes on local communities, agriculture, and industry were not sufficiently emphasized.

Potential frameworks or strategies for improving transboundary water management among riparian countries, which are critical for sustainable management of shared water resources like the Tigris River, were not explored. The studies primarily focused on specific aspects such as water quality, sediment load, or flow prediction but lacked a more integrated approach that combines these aspects into a comprehensive river basin management plan, considering both natural and human-induced factors. Although AI techniques were applied in several studies, there is room for further exploration of advanced AI models, such as DL , for real-time monitoring, prediction, and decision-making support systems in river management. The role of public awareness, stakeholder engagement, and policy development in implementing AI-driven river management solutions was not addressed, highlighting a need for research on how these technologies can be effectively communicated and integrated into public policy. The studies did not sufficiently discuss strategies for dealing with data scarcity and uncertainty, particularly in regions with limited monitoring infrastructure, which could include the use of remote sensing or crowd-sourced data to complement traditional data sources. There is a paucity of long-term, extensive records of natural river flow, water quality, and sediment yield that span several decades of a river system for assessment and development of the measures for the future.

Consequently, this review paper seeks to fill the existing scientific literature niche of incorporating AI with the conventional approach to river flow management in Baghdad's Tigris River. It aims to create specialized models and applications of Artificial Intelligence to improve the quality of the data in terms of its collection, to make the necessary forecasts concerning further shifts in climate, and to assess the socio-economic consequences that might be caused by these shifts. This offers a new way for sustainable and adaptive river management in challenging geographic spaces. It arises from the recognized need to manage water resource sustenance, flood control, and environmental conservation, particularly in expanding urban future cities such as Baghdad that are likely to suffer impacts from climatic variations and growth impulses. This paper is novel to previous research in the evaluation of numerous studies to understand the details of applying Artificial Intelligence in the management of the Tigris River in Baghdad as well as in the integration of AI algorithms like ML and neural network algorithms in developing more precise and perfect and sophisticated models for estimating the relations among numerous factors that control the behavior of Tigris River. This approach can be conceptualized as being markedly different from traditional processes and methodologies and has the potential to expand the existing understanding of how one might improve the predictive profiling and decision-making concerning river flow as it pertains to the utilization of water sustainably in urban centers.

In sum, these papers show that advanced modeling, remote sensing, and interdisciplinary have been used systematically to tackle a wide array of water resource problems. Hydrological modeling is greatly enhanced with AI and ML, along with remote sensing to provide advanced structures for water resource management and decision-making.

The result of this paper aims at building efficient and sustainable strategies in river management for conservation and socio-economic development in Iraq.

4. Conclusions

This paper focused on investigating the use of AI techniques on the river flow modeling and management, with focusing to Tigris River in Iraq as a case study of water scarcity regions. Based on a review of hydrological theories, numerical modeling, remote sensing, and AI algorithms such as ML and DL. The study aims to overcome the problems often found in conventional hydrology models which is likely to contribute to improving predictive accuracy for sustainable water resource management. Based on the obtained results of this review, the main conclusions can be summarized by:

- ✓ Integrating AI with traditional hydrological models has significantly improved river dynamics prediction, data quality, and hydrological insights. These advancements enhance flood management, water distribution, and water quality monitoring, particularly for water scarcity regions like Iraq. AI plays a critical role in bolstering resilience against water shortages and climate change, offering precise tools for addressing complex water resource challenges.

- ✓ AI has shown remarkable potential for improving the management of the Tigris River by increasing resilience to climate change and environmental threats. Tailoring AI applications to local conditions and integrating them with remote sensing data enables detailed analysis of river morphology and hydrological processes. However, successful implementation requires high-quality datasets, improved data collection systems, and a focus on the region's unique socio-economic and environmental conditions.

- ✓ While AI surpasses traditional methods in accuracy and efficiency, its application faces significant challenges. These include insufficient high-quality data, the need for model interpretability and transparency to build stakeholder trust, and technical issues like scalability and computational complexity for large-scale systems. AI deployment requires successful merging with traditional water management systems to remove operational challenges for achieving maximum organizational results.

- ✓ Current AI applications in water resource management focus heavily on flood forecasting, risk evaluation, and hydrological modeling. The expansion potential exists in unexamined water resource control domains including reservoir management and dam operation and water distribution systems. AI applications in water management spaces help maximize water resource usage and build stronger decision tools while sustaining long-term sustainable water strategies.

- ✓ To achieve sustainability alongside climate change resilience it must invest into advanced AI technologies together with solid data collection frameworks and multidisciplinary scientific research. Through these improvements AI will evolve from its basic optimization origins to provide integrated systems which tackle complicated water management problems including hydrological modeling and streamflow prediction and water quality control.

- ✓ Rapid development in AI requires permanent review to understand modern industry trends as well as scientific advancements. Global research has primarily focused on improving AI applications in hydrological modeling, streamflow forecasting, and water resource management, emphasizing flood prediction, water allocation, and climate change resilience. However, the landscape of AI in water management is evolving quickly, requiring ongoing assessments to integrate the latest advancements and refine existing models. Regular review papers are essential for keeping up with these developments, ensuring that AI applications remain effective, relevant, and tailored to the complex challenges of water resource management in diverse regions like Iraq.

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