IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⸾ Peer-reviewed & Refereed journal ⸾ Vol. 15, Issue 8, August 2026

DOI: 10.17148/IJARCCE.2026.15832

A COMPREHENSIVE SURVEY OF AN AQUA CYCLE INTELLIGENCE: AI BASED SYSTEM FOR RO REJECT WATER OPTIMIZATION AND SUSTAINABILITY

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Abstract: Reverse Osmosis (RO) water purifiers are widely used in households, industries, educational institutions, and commercial buildings for obtaining clean drinking water. However, one of the major disadvantages of RO purification systems is the excessive generation of reject water. Approximately 50–75% of the input water is discharged as reject water during the purification process, leading to significant water wastage and environmental concerns. In most cases, reject water is directly discarded without analyzing its quality or exploring its potential for secondary usage. Existing systems mainly focus on water purification and fail to provide intelligent monitoring, optimization, and sustainability-driven reuse mechanisms. This paper proposes AQUA CYCLE INTELLIGENCE, an Artificial Intelligence-based system designed to optimize the utilization of RO reject water through smart monitoring, analysis, and recommendation techniques. The proposed system integrates IoT sensors, Artificial Intelligence algorithms, cloud computing, and real-time dashboards to monitor parameters such as Total Dissolved Solids (TDS), pH level, temperature, turbidity, and water flow rate. Using AI and Machine Learning techniques, the system predicts the quality and usability of reject water and recommends suitable secondary applications such as floor cleaning, gardening, flushing, cooling systems, and washing purposes. The proposed framework also enables real-time monitoring through web and mobile dashboards, tracks water savings and environmental impact, and generates analytical reports for users and authorities. By intelligently managing RO reject water, the system promotes water conservation, reduces unnecessary wastage, supports sustainable development goals, and encourages efficient resource utilization. The integration of AI, IoT, and cloud technologies transforms RO reject water from a discarded byproduct into a valuable reusable resource.

I. INTRODUCTION

Water scarcity has become one of the biggest global challenges due to rapid urbanization, population growth, industrial expansion, and climate change. Freshwater resources are continuously decreasing, while water demand is increasing significantly in households, industries, and agriculture. Reverse

Osmosis (RO) systems are commonly used for water purification because they effectively remove impurities and provide safe drinking water.

Although RO systems improve water quality, they also generate a large quantity of reject water during the purification process.

RO reject water contains higher concentrations of dissolved salts and minerals, but in many cases, it is still suitable for non-drinking purposes such as cleaning, flushing, gardening, and cooling applications. Unfortunately, most households and organizations discharge this water directly into drains without any intelligent analysis or reuse strategy. This leads to enormous water wastage and negatively affects environmental sustainability.

Traditional RO systems mainly focus on purification efficiency and do not include mechanisms for reject water optimization. Existing water management approaches also lack intelligent monitoring, predictive analytics, automated recommendations, and centralized tracking systems. Manual analysis of water quality is time-consuming, expensive, and impractical for everyday users. Therefore, there is a strong need for a smart, automated, and intelligent system that can continuously monitor RO reject water quality and suggest suitable reuse methods.

The proposed system, AQUA CYCLE INTELLIGENCE, addresses this issue using Artificial Intelligence, Internet of Things (IoT), and cloud computing technologies. The system continuously collects real-time data using IoT sensors and applies AI algorithms to analyze water quality and predict the most appropriate reuse applications. The framework also provides real-time alerts, cloud-based reporting, sustainability tracking, and dashboards for users and administrators.

By transforming reject water into a reusable resource, the proposed system supports water conservation initiatives, reduces environmental impact, and promotes sustainable water management practices. The system also contributes

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toward Sustainable Development Goal 6 (Clean Water and Sanitation) by encouraging efficient utilization of water resources.

Additionally, the increasing dependency on RO purifiers in urban households, apartments, offices, and commercial establishments has significantly increased the volume of reject water generated every day. Studies show that a standard domestic RO purifier may waste nearly three liters of water for every one liter of purified water produced. Despite this large quantity of wastewater, there is very little awareness regarding its reuse potential and sustainability benefits. In many cases, users are unaware of the quality of reject water and whether it can be safely utilized for secondary purposes. As a result, potentially reusable water is discarded unnecessarily. With advancements in Artificial Intelligence, IoT, and smart monitoring technologies, it has become possible to build intelligent systems that can analyze water quality in real-time and automate decision-making processes.

II. RELATED WORK

Patil et al. [1] proposed an IoT-based water quality monitoring system for domestic water applications. Their framework used sensors to measure water parameters such as pH, turbidity, and temperature in real-time. Although the system provided efficient monitoring capabilities, it lacked AI-based optimization and water reuse recommendation mechanisms.

Sharma and Jain [2] developed a machine learning-based water quality prediction system that used historical sensor data to predict water contamination levels. Their work improved water quality assessment accuracy but did not focus on reuse optimization or sustainability-based applications.

Kumar et al. [3] discussed the potential reuse applications of RO reject water for household and industrial activities. Their study highlighted that reject water can be effectively utilized for cleaning, gardening, and flushing purposes. However, the proposed approach was manual and lacked automated monitoring and intelligent recommendations.

Zhang et al. [4] implemented an AI-driven smart water management framework that integrated cloud computing and IoT technologies for sustainable resource management. Their system improved data collection and analytics but did not specifically address RO reject water utilization.

Prasad et al. [5] proposed a sustainable water conservation model for residential buildings using sensor-based monitoring systems. Their research emphasized reducing water wastage but lacked predictive analytics and cloud-based reporting mechanisms.

George et al. [6] developed a cloud-enabled smart environmental monitoring system for real-time data analysis and sustainability tracking. Their framework demonstrated the effectiveness of IoT and cloud technologies in environmental monitoring applications.

Ramesh et al. [7] proposed a smart IoT-based water conservation framework for residential buildings using automated sensors and cloud analytics. Their system monitored daily water consumption patterns and generated alerts for excessive water usage. However, the framework did not include AI-based prediction or reject water reuse optimization mechanisms.

Ahmed and Khan [8] developed a sensor-based greywater monitoring system for sustainable household water management. The system analyzed water quality parameters and suggested limited reuse applications. Although effective for monitoring, the system lacked intelligent decision-making and centralized cloud reporting.

Li et al. [9] introduced a deep learning-based water quality prediction model using neural networks and historical environmental datasets. Their framework improved prediction accuracy for water contamination levels but did not focus on RO reject water reuse or sustainability tracking.

Fernandez et al. [10] proposed a cloud-enabled smart water analytics platform for industrial water management. The system collected real-time water usage data and generated optimization reports for industries. However, the solution mainly targeted industrial environments and lacked household-level sustainability features.

Mehta et al. [11] designed an AI-powered environmental monitoring system using IoT devices and machine learning algorithms. Their system provided predictive analytics and real-time alerts for environmental safety. Although efficient, the framework did not address water reuse optimization or reject water management.

Wang et al. [12] implemented a smart resource management system integrating IoT and cloud technologies for sustainable smart city applications. Their work demonstrated the importance of intelligent monitoring and centralized analytics for resource optimization but did not include specific reuse recommendation engines for water conservation.

Srinivas and Rao [13] proposed a sustainable wastewater reuse framework for domestic applications using automated quality assessment techniques. Their system focused on reducing freshwater dependency through wastewater reuse practices. However, the framework lacked AI-driven adaptive learning, predictive recommendations, and user-friendly dashboard interfaces which are provided in the proposed AQUA CYCLE INTELLIGENCE system.

Although existing studies provide solutions for water monitoring and quality analysis, most systems fail to integrate AI-driven optimization, real-time recommendations, sustainability tracking, and centralized cloud-based reuse management.

ISSN (O) 2278-1021, ISSN (P) 2319-5940

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To overcome these limitations, the proposed AQUA CYCLE INTELLIGENCE framework integrates IoT sensors, AI algorithms, cloud storage, and real-time dashboards to provide intelligent reuse recommendations and efficient reject water optimization.

III. PROPOSED SYSTEM

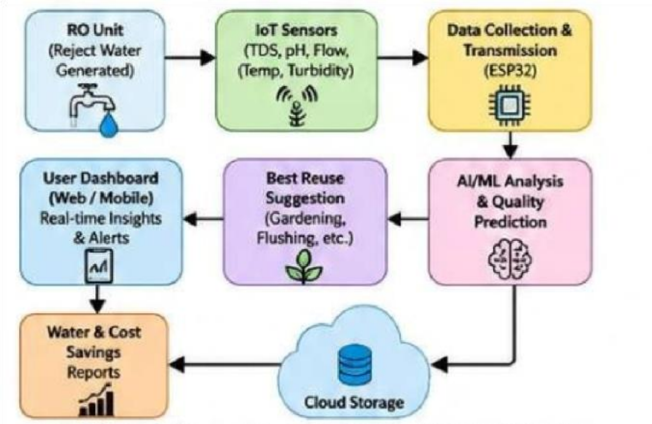

Fig. 1 Proposed System Flow – AQUA CYCLE INTELLIGENCE

The proposed system, AQUA CYCLE INTELLIGENCE, is an AIpowered smart framework developed to optimize the utilization of RO reject water and promote sustainable water management practices. The system combines IoT devices, Artificial Intelligence algorithms, cloud computing, and real-time dashboards to analyze reject water quality and recommend suitable reuse applications.

The framework continuously collects water quality parameters such as TDS, pH level, turbidity, temperature, and flow rate using IoT sensors connected to the RO system. The collected data is transmitted to a cloud server where AI and Machine Learning algorithms analyze the water quality and determine the most suitable reuse options.

• loT Monitoring: Sensors collect real-time parameters (TDS, pH, Turbidity, Flow Rate, Temperature) from RO reject water.
• Al-based Analysis: Machine Learning models predict reject water quality and classify its suitability.
• Smart Recommendations: System suggests best reuse applications (gardening, flushing, cleaning, cooling).
• User Dashboard: Web and mobile app provide real- time monitoring, alerts, and usage reports.
• Sustainability Tracking: Calculates water saved, cost saved, and environmental impact.
• Cloud Integration: All data is stored securely for analysis and future insights.

IV. FLOW DIAGRAM

• The flow diagram of the proposed AQUA CYCLE INTELLIGENCE system illustrates the complete process of intelligent RO reject water optimization and sustainability management. The process begins with IoT sensors that continuously monitor important water quality parameters such as TDS, pH, turbidity, flow rate, and temperature from the RO reject water. The collected sensor data is then transmitted through an ESP32 communication module to the centralized cloud platform for further processing and storage.

• Once the data is stored in the cloud database, AI and Machine Learning algorithms analyze the water quality and predict the suitability of the reject water for various secondary applications. Based on the analysis results, the system provides smart reuse recommendations such as gardening, floor cleaning, flushing, and cooling applications.

• The processed information is then displayed on the user dashboard, where users can access real-time insights, alerts, and monitoring reports through web and mobile applications. Simultaneously, the framework tracks water savings, cost reduction, and environmental impact reports to measure sustainability benefits. The continuous feedback loop in the system ensures real-time monitoring, intelligent decision-making, and efficient utilization of RO reject water, thereby reducing water wastage and promoting sustainable resource management.

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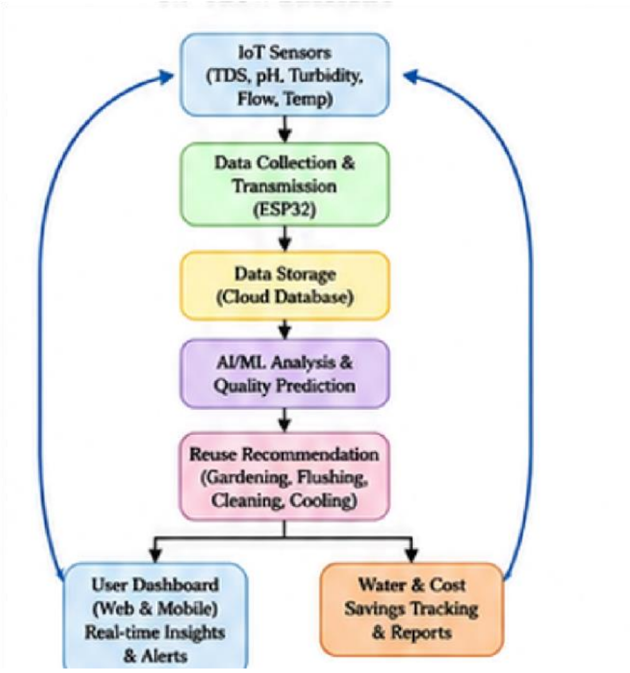

V. COMPARATIVE STUDY OF EXISTING

SYSTEMS TO OUR SYSTE

Existing Systems

• Traditional RO Purifiers mainly focus on water purification andsafe drinking water production. These systems do not provide any mechanism for monitoring or reusing reject water. As a result, large amounts of reject water are directly discharged into drains, leading to significant water wastage and environmental impact.

• IoT-Based Water Monitoring Systems are capable of collectingreal-time water quality data using sensors. These systems improve monitoring efficiency and provide live parameter tracking, but they generally lack intelligent AI-based decision-making and automated reuse recommendations for reject water optimization.

• AI-Based Water Quality Prediction Systems use machine learningalgorithms to analyze water quality and predict contamination levels. Although these systems improve analytical accuracy, most of them are limited to prediction tasks and do not provide practical sustainability solutions, cloud-based tracking, or water reuse suggestions.

• Smart Sustainability Platforms focus on environmental monitoring, water conservation analytics, and sustainability reporting. These systems provide dashboards and basic reporting mechanisms but lack specialized reject water optimization, intelligent recommendations, and automated reuse management.

• Greywater Management Systems support the reuse of wastewaterfor secondary applications such as gardening and flushing. However, most existing systems require manual analysis and lack real-time IoT integration, AI-based prediction, and centralized cloud reporting.

• Cloud-Based Environmental Monitoring Systems providecentralized storage, analytics, and remote access to environmental data. These platforms improve scalability and reporting capabilities but are not specifically designed for RO reject water optimization and sustainable reuse applications.

• Industrial Water Optimization Systems are mainly developed forlarge-scale industries to monitor water usage and reduce operational wastage. Although effective in industrial environments, these systems are often expensive, complex, and not suitable for domestic or small-scale applications.

Proposed System: AQUA CYCLE INTELLIGENCE

The proposed AQUA CYCLE INTELLIGENCE system combines the strengths of IoT, Artificial Intelligence, Machine Learning, and cloud computing into a single intelligent framework for sustainable RO reject water management. The system continuously monitors water quality parameters, analyzes usability using AI algorithms, and recommends suitable reuse applications in real-time. Unlike existing systems, the proposed framework provides automated optimization, cloud-based sustainability tracking, user-friendly dashboards, and environmental impact analysis.

Key Advantages of the Proposed System

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• Real-time monitoring of RO reject water quality using IoT sensors
• AI and Machine Learning-based quality prediction and optimization
• Smart reuse recommendations for household and industrial applications
• Cloud-based centralized storage and reporting
• Water savings and cost reduction tracking
• Real-time dashboard and alert system
• Sustainability and environmental impact analysis
• Scalable, affordable, and user-friendly implementation

VI. METHODOLOGY

The AQUA CYCLE INTELLIGENCE framework follows a structured methodology integrating IoT, Artificial Intelligence, Machine Learning, and cloud computing technologies for efficient RO reject water optimization and sustainability management. The methodology ensures continuous monitoring, intelligent analysis, and efficient reuse recommendations for minimizing water wastage.

Step 1: Sensor Installation and Data Collection

IoT sensors are installed near the RO system to continuously collect water quality parameters such as TDS, pH, temperature, turbidity, flow rate, and reject water quantity.

Step 2: Data Transmission and Cloud Integration

The collected sensor data is transmitted using ESP32 communication modules to the centralized cloud database for secure storage, real-time access, and analysis.

Step 3: AI and Machine Learning Analysis

AI and Machine Learning algorithms analyze the sensor data and classify the usability of reject water based on predefined quality thresholds and historical datasets.

Step 4: Reuse Recommendation System

The framework recommends suitable reuse applications such as gardening, floor cleaning, toilet flushing, cooling systems, and vehicle washing based on water quality analysis.

Step 5: Dashboard Monitoring and Alerts

Users can monitor live water quality data, recommendations, sustainability reports, and alerts through web and mobile dashboards in real-time.

Step 6: Sustainability and Cost Analysis

The system calculates total water saved, reduction in freshwater consumption, environmental impact, and cost savings achieved through reject water reuse.

Step 7: Continuous Learning and Optimization

The AI model continuously improves prediction accuracy using historical data, user feedback, and adaptive learning mechanisms for long-term optimization.

Step 8: Notification System

The framework automatically sends notifications and alerts when water quality exceeds safe limits or when maintenance is required for sensors and monitoring devices.

Step 9: Report Generation and Analytics

The system generates daily, weekly, and monthly analytical reports related to water conservation, sustainability performance, and reuse efficiency for users and administrators.

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