**Project: IoT-Based Water Quality Monitoring System for Urban/Rural Water Distribution**

**Introduction**

Water is a fundamental necessity in daily human activities. The United Nations defines the human right to water as the entitlement of everyone, without discrimination, to sufficient, safe, acceptable, physically accessible, and affordable water for personal and domestic use [*insert reference*].” As part of the 6th Sustainable Development Goal (SDG), the UN aims to improve water availability, promote sustainable water management, and enhance sanitation for the entire population. To achieve this goal, most countries have established water supply network/system to manage resources from various sources—such as rivers, lakes, and underground wells—through treatment plants to the final point of consumption, whether for residential, industrial, commercial, or firefighting use.

The structure of a water supply system typically involves two key phases:

1. **A screenshot of a computer

   Description automatically generatedWater sources – Treatment Plant (Water supply):** In this phase, water is sourced from rivers, lakes, bore wells, etc., and transported to a treatment plant, where it undergoes filtration, aeration, and disinfection to make it suitable for human consumption.

Figure 1: Water supply network

1. **Water Distribution network (WDN)**: Once treated, the water is stored in a Clearwell for distribution. This phase involves the transportation of water from centralized storage to the end users through a network of pipes, valves, pumps, and storage tanks, which is influenced by city topography and demand.

This project focuses on the **second phase: the Water Distribution network (WDN)**

After treatment, water is stored and distributed through a complex system of infrastructure. During distribution, it is crucial to monitor water quality to ensure it meets regulatory standards, such as those outlined in the European Union Water Framework Directive, the U.S. Clean Water Act, and WHO drinking water quality guidelines.

However, water quality monitoring is not the only challenge in WDNs. Issues such as pipe cracks, bursts, and leaks can lead to water contamination or service disruptions. Traditional management techniques struggle to effectively handle these challenges due to the spatial complexity of WDNs. According to [1], WDN management consists of nine distinct components. While this project will not cover leak detection, pressure control, demand prediction, or other aspects of WDN management, it will address one critical component: **Water Quality Monitoring using IoT technology**.

**Project Description**

The quality of water distributed for human consumption must meet specific standards defined by governing bodies. These standards typically classify water quality metrics into three categories: physical, chemical, and biological. Physical parameters include colour, temperature, and odour, while chemical metrics focus on substances like pH, hardness, and the presence of metals (iron, aluminium, zinc) or ions (carbonate, sulphates, nitrates). Biological factors might include contaminants like pathogens or microorganisms. These measurements must be conducted at various stages throughout the water distribution network (WDN) to ensure that water quality is maintained.

**Water Distribution Network (WDN):**

The WDN comprises two key components involved in transporting treated water from storage to consumers:

1. **Regional Storage Tanks**: After treatment, water is moved from the Clearwell to large-capacity regional storage tanks positioned at elevated altitudes to supply water to different zones.
2. **Distribution Pipes**: These pipes transport water from the storage tanks to the consumers, following various network configurations depending on the city's topography and demand.

**Project Scope**:

This project focuses on real-time monitoring of water quality at two critical points in the WDN: regional storage tanks and distribution pipes. The goal is to develop a system that continuously monitors key water quality parameters, provides alerts when thresholds are breached, and activates actuators to mitigate potential issues based on the detected anomalies.

**Objective**:

* Develop and deploy an IoT-enabled system for real-time monitoring of water quality across the city's water distribution network, ensuring the safety and reliability of water supplied to households.

**Project Deliverables**:

* Installation of IoT sensors at key points in the city's water distribution network to monitor parameters such as pH, turbidity, temperature, conductivity, and contamination levels.
* Real-time data collection, storage, and analysis.
* Automated alerts for abnormal water quality readings or contamination risks.
* A user-friendly dashboard for water authorities and households to monitor water quality trends.

**Exclusions**:

* Maintenance of water distribution infrastructure (e.g., pipelines, tanks).
* Monitoring of non-potable water sources (e.g., industrial effluents or untreated water bodies).

**System Description**

The proposed **IoT-based Water Quality Monitoring System** is designed to ensure and maintain the quality of water within a Water Distribution Network (WDN). It comprises six main components, each playing a critical role in monitoring, managing, and responding to water quality parameters. The components interact seamlessly to create a robust and responsive system.

**Components of the System**

1. **Sensors**:

The system will employ **seven types of sensors** to measure critical water quality parameters across the WDN. These sensors provide real-time data for analysis and action.

|  |  |  |
| --- | --- | --- |
| **Sensor** | **Function** | **Application Stage** |
| **ORP Sensor** | Measures overall water quality based on voltage between electrodes (oxidative/reductive capacity). | Storage Tanks |
| **pH Sensor** | Monitors hydrogen ion concentration, indicating acidity or alkalinity (ideal range: 6-8.5). | Storage Tanks, Distribution Pipes |
| **Salinity Sensor** | Detects salt levels by measuring water conductivity (acceptable: 0–600 mg/L). | Storage Tanks, Distribution Pipes |
| **Ultrasonic Level Sensor** | Monitors water levels in storage tanks, aiding in distribution planning. | Storage Tanks |
| **Turbidity Sensor** | Detects cloudiness/haziness in water caused by suspended solids (ideal: <1 NTU). | Storage Tanks |
| **Temperature Sensor** | Measures water temperature, which impacts chemical reactions and solubility. | Storage Tanks |
| **Flow Sensor** | Tracks the flow rate of water in pipes and tanks. | Distribution Pipes |

1. **Actuators**

Actuators respond to sensor readings to control or mitigate issues detected in the WDN.

|  |  |
| --- | --- |
| **Actuator** | **Function** |
| **Solenoid Water Valve** | Controls water flow, enabling redirection to filters or stopping flow during contamination. |
| **Chemical Dosing Pumps** | Dispenses chemicals to treat water (e.g., chlorine, pH balancers) when quality issues arise. |
| **Backflow Preventers** | Prevents contaminated water from flowing back into the clean supply system. |
| **Automatic Flushing Systems** | Periodically flushes pipes to remove sediment or biofilm. |
| **Cooling Systems** | Regulates water temperature in scenarios where temperature sensors indicate deviation. |

1. **Middleware**

The middleware acts as the central processing hub, receiving sensor data, analyzing it, and initiating appropriate actions.

* **Data Processing**:
  + Receives data from sensors and compares it to predefined acceptable ranges.
  + Analyzes metrics such as pH, turbidity, salinity, and temperature to determine water quality.
  + Detects anomalies or threshold breaches.
* **Control Signals**:
  + Sends commands to actuators (e.g., close valves, activate dosing pumps) when conditions warrant action.
* **Data Forwarding**:
  + Forwards sensor data to the database for historical storage.
  + Provides real-time data to dashboards for visualization.

1. **Database**

The system includes two key types of databases for managing data:

1. **Sensor Data Store**:
   1. A **time-series database** stores real-time sensor data, enabling trend analysis and anomaly detection.
   2. Ensures data is organized for quick retrieval and long-term analysis.
2. **User Data Store**:
   1. Stores user information and system access data.
   2. Manages roles and permissions for stakeholders, ensuring secure and structured access.
3. **Alerting System**

Alerts are triggered when sensor readings fall outside acceptable ranges, as defined in the **Metrics Description Table**.

**Functions**:

* 1. Notifies system managers about critical conditions, such as contamination or equipment failures.
  2. Triggers actuators to take corrective action (e.g., closing valves, started flushing).
  3. Send notifications via multiple channels (email, SMS, app alerts).

1. **Dashboard and Visualization**

A **user-friendly dashboard** provides visualization of real-time and historical data, enabling quick decision-making and system management.

**Features**:

* + Real-time metrics for each sensor (e.g., pH, turbidity, salinity).
  + Graphical trends and historical data for long-term analysis.
  + Predictive insights into potential risks.
  + Alerts and event logs for system monitoring.

**Users**:

* + Water distribution authorities for operational oversight.
  + Maintenance teams for identifying and resolving system issues.
  + Regulatory bodies for compliance and reporting.

**Metrics Description Table**

The table below summarizes the acceptable and unacceptable ranges for key water quality parameters.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S/N** | **Sensor** | **Measurement Range** | **Acceptable Value** | **Stage Needed** |
| 1 | **ORP Sensor** | -100 to 1000 mV | 650–700 mV | Storage Tanks |
| 2 | **pH Sensor** | 0–14 | 6–8.5 | Storage Tanks, Distribution Pipes |
| 3 | **Salinity Sensor** | 0–50,000 mg/L | Ideal: 0- 600  Fair: 600 -900  Poor: 900 – 1000  unacceptable: >1000 | Storage Tanks, Distribution Pipes |
| 4 | **Ultrasonic Level Sensor** | 0–8 meters | >0 | Storage Tanks |
| 5 | **Turbidity Sensor** | 0–50 NTU | 0–5 (<1 best) | Storage Tanks |
| 6 | **Temperature Sensor** | -55°C to 150°C | 25–30°C | Storage Tanks |
| 7 | **Flow Sensor** | >3–10 feet per second | Variable by pipe size | Distribution Pipes |

**Applicable Domain**

**Urban Utilities and Smart Cities**: The system is designed for water supply authorities, urban households, and municipal governance, particularly in cities looking to improve the efficiency and safety of their water distribution systems.

**Functional Requirements**

1. Data Collection: IoT sensors continuously monitor water quality parameters (e.g., pH, turbidity, temperature, etc.).
2. Data Transmission: Sensor data is wirelessly transmitted to the cloud using IoT communication protocols (e.g.MQTT).
3. Data Processing: Real-time analysis of the data using a middleware to detect anomalies such as contamination.
4. Notifications: Automated alerts sent to city authorities and affected households if water quality falls below acceptable standards.
5. Visualization: A dashboard that displays real-time and historical water quality data, including predictive insights.
6. Reporting: Automated reports for stakeholders to track water quality trends and compliance with regulations.
7. Configurable thresholds and targets: the system allows for the configuration of custom water quality thresholds and targets for different parameters (e.g., pH, turbidity, temperature).

**Non-Functional Requirements**

1. Performance: The system must provide real-time monitoring with minimal latency (<5 seconds) for critical alerts.
2. Scalability: It should support deployments in cities of various sizes, accommodating hundreds or thousands of sensors.
3. Reliability: Ensure 99.9% system uptime with redundancy for data storage and failover mechanisms.
4. Security: Implement strong encryption and access control to prevent unauthorized access or tampering.
5. Energy Efficiency: Use low-power IoT devices to ensure long-term operation without frequent battery replacements.
6. Compliance: Adhere to local and international water quality standards and regulations. Use of low-power IoT devices to ensure long-term deployment without frequent battery replacements.

**References**

1. N. K. Velayudhan, P. Pradeep, S. N. Rao, A. R. Devidas and M. V. Ramesh, "IoT-Enabled Water Distribution Systems—A Comparative Technological Review," in IEEE Access, vol. 10, pp. 101042-101070, 2022, doi: 10.1109/ACCESS.2022.3208142.
2. <https://mrccc.org.au/wp-content/uploads/2013/10/Water-Quality-Salinity-Standards.pdf>
3. <https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/public+health/water+quality/salinity+and+drinking+water>
4. <https://cdn.cyfoethnaturiol.cymru/media/694218/information-note-turbidity.pdf>
5. <https://www.dypcn.com/news/how-to-monitor-the-water-level-of-the-pipe-network-what-sensor-is-used-to-monitor-the-water-level-of-the-drainage-pipe-network/>
6. <https://eur-lex.europa.eu/eli/dir/2020/2184/oj>
7. <https://ieeexplore.ieee.org/abstract/document/9895399>
8. <https://ieeexplore.ieee.org/document/7960032>
9. <https://ieeexplore.ieee.org/document/8016224>
10. <https://eur-lex.europa.eu/EN/legal-content/summary/drinking-water-essential-quality-standards.html>
11. To Read
12. <https://evogov.s3.amazonaws.com/media/60/media/17107.pdf>
13. <https://mimoza.marmara.edu.tr/~orhan.gokyay/enve311/ch8.pdf>