A

Capstone Project Report

On

Cloud-IoT-Based Smart Water Metering and Usage Analytics System

Submitted to JNTU HYDERABAD

In Partial Fulfilment of the requirements for the Award of Degree of

BACHELOR OF TECHNOLOGY
IN
COMPUTER SCIENCE AND ENGINEERING (AI&ML)

Submitted
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(Accredited by NAAC & NBA, Approved by AICTE NEW DELHI, Affiliated to JNTU, Hyderabad)

(Kandlakoya, Medchal Road, R.R. Dist. Hyderabad-501 401)

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CERTIFICATE

This is to certify that the project entitled **"Cloud-IoT-Based Smart Water Metering and Usage Analytics System"** is a bonafide work carried out by

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in partial fulfilment of the requirement for the award of the degree of **BACHELOR OF TECHNOLOGY** in **Computer Science and Engineering (AI & ML)** from CMR Engineering College, affiliated to JNTU, Hyderabad, under our guidance and supervision.

The results presented in this project have been verified and are found to be satisfactory. The results embodied in this project have not been submitted to any other university for the award of any other degree or diploma.

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This is to certify that the work reported in the present project entitled **"Cloud-IoT-Based Smart Water Metering and Usage Analytics System"** is a record of bonafide work done by us in the Department of Computer Science and Engineering (AI&ML), CMR Engineering College, JNTU Hyderabad. The reports are based on the project work done entirely by us and not copied from any other source. We submit our project for further development by any interested students who share similar interests to improve the project in the future.

The results embodied in this project report have not been submitted to any other University or Institute for the award of any degree or diploma to the best of our knowledge and belief.

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ABSTRACT

In today's rapidly growing urban environments, efficient water management has become a critical necessity due to increasing population, rapid urbanization, and limited natural resources. Traditional water monitoring systems are often manual, prone to errors, and lack the ability to provide real-time insights, resulting in inefficiencies, excessive usage, and undetected leakages. To address these pressing issues, this project introduces the design and implementation of a Cloud IoT-based Smart Water Metering and Usage Analytics System, which leverages modern technologies to enhance the monitoring, analysis, and optimization of water usage. The proposed system utilizes IoT-enabled smart water meters to continuously monitor and collect real-time data on water consumption in residential, commercial, or industrial buildings. These smart meters are equipped with flow sensors and microcontrollers that gather detailed consumption metrics such as flow rate, total volume used, and pressure levels. The collected data is transmitted securely to a centralized cloud platform using lightweight communication protocols like MQTT, which ensures efficient data transfer even over low-bandwidth networks. This continuous data stream allows for precise, minute-by-minute monitoring of water usage across multiple sites.

Once the data reaches the cloud infrastructure—hosted on platforms like Amazon Web Services (AWS) or Microsoft Azure—it is stored, processed, and analyzed using scalable and reliable cloud services. The cloud architecture supports massive parallel data ingestion and real-time processing, ensuring uninterrupted operation even when handling input from thousands of devices. Through this system, users and utility providers gain access to interactive dashboards that provide live data visualization, historical usage patterns, predictive analytics, and customized reports. These interfaces are user-friendly and can be accessed via web or mobile applications, offering transparency and insight into water consumption behavior. One of the key strengths of the system lies in its smart analytics capabilities, which include automated detection of anomalies such as leaks, unexpected spikes in usage, and patterns that suggest inefficiency or wastage. Users receive timely alerts about these issues, enabling quick response and preventive action. Utility companies also benefit by being able to plan resource distribution more accurately, reduce operational costs, and support conservation initiatives. By minimizing manual intervention and promoting data-driven decision-making, the system fosters sustainable water usage and reduces the risk of resource overexploitation.

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1. INTRODUCTION

1.1 Introduction

With growing urban populations and increased stress on natural resources, efficient water management has become a global priority. Water, being a finite and essential resource, must be monitored and managed accurately to prevent wastage, reduce operational inefficiencies, and ensure long-term sustainability. Traditional water metering systems, however, rely heavily on manual processes for data collection and billing. These outdated systems are not only labor-intensive but also suffer from issues such as delayed readings, billing inaccuracies, and the inability to detect leaks or analyze consumption trends. As cities grow and demands increase, there is a clear need for smarter, technology-driven solutions that offer real-time visibility, automation, and analytics.

The advent of the Internet of Things (IoT) and cloud computing has opened new possibilities for modernizing utility infrastructure. IoT devices, particularly smart water meters, can collect real-time data on water flow and usage, while cloud platforms provide scalable environments for processing, storing, and analyzing this data. This project proposes the design and implementation of a Cloud-IoT-Based Smart Water Metering and Usage Analytics System that bridges the gap between conventional metering methods and the modern digital ecosystem. The system uses flow sensors and microcontrollers to monitor water usage and transmit data wirelessly via MQTT protocol to cloud platforms such as AWS IoT Core. Once received, the data is processed, stored in cloud databases like DynamoDB, and made accessible through intuitive dashboards using tools such as Amazon QuickSight.

The primary goal of this project is to automate the entire water metering process while empowering users and utility providers with real-time insights, usage trends, and consumption alerts. Through data-driven analytics, consumers can understand their usage behavior, identify areas of inefficiency, and adopt more sustainable practices. Meanwhile, utility companies benefit from system-wide visibility, reduced manpower requirements, and faster response to irregularities such as leakages or overconsumption. Ultimately, this smart metering system not only enhances operational efficiency but also promotes environmental responsibility, supporting the broader vision of smart cities and intelligent resource management.

By integrating modern technologies with traditional infrastructure, this project serves as a crucial step toward the digital transformation of utility services. It not only addresses the long-standing challenges of manual metering, such as inefficiency and lack of transparency, but also introduces a sustainable, data-driven approach to water management.

1.2 Project Objectives

The primary goal of this project is to develop a robust and scalable smart water metering system using IoT and cloud services. The following are the key objectives:

- Automate water usage tracking using IoT-enabled smart meters.
- Enable real-time data transmission to the cloud via AWS IoT Core.
- Store and manage data efficiently using Amazon DynamoDB.
- Provide secure access to usage data through API Gateway and Lambda.
- Enable insightful analytics and visualizations via Amazon QuickSight dashboards.
- Ensure scalability and reliability suitable for residential or industrial environments.

Promote water conservation through transparency in consumption data.

These objectives are designed to provide a fully integrated solution from data acquisition to visualization, offering a modern alternative to traditional manual water metering systems.

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1.3 Purpose of the Project

The purpose of this project is to build a smart, automated system that accurately monitors and records water usage in real-time. The system addresses the inefficiencies and inaccuracies of traditional water meters, which typically rely on manual readings and offer no immediate feedback to users.

By leveraging IoT technology and AWS cloud services, the system ensures continuous monitoring and timely availability of water usage data. This information can help both individuals and organizations track their consumption patterns, detect anomalies like leaks or overuse, and ultimately encourage water conservation.

Moreover, the project provides a framework for deploying large-scale, smart metering infrastructures with minimal human intervention. The ability to access and analyze historical and live data through dashboards makes this system an ideal solution for modern, data-driven utilities.

1.4 Existing System with Disadvantages

Traditional water metering systems rely heavily on manual readings, which are not only time-consuming but also prone to human error. These systems typically offer no real-time feedback, making it difficult for users to monitor their water consumption or detect leaks promptly.

Some existing digital meters may record usage electronically, but they often lack remote accessibility, analytics capabilities, or integration with cloud platforms. They provide little to no support for generating usage trends, alerts, or customized reports.

Key disadvantages include:

- Inaccuracy due to delayed readings or mechanical wear.
- No alerting mechanism for anomalies like excessive usage or leakage.
- Lack of user empowerment and consumption awareness.
- Manual billing and delayed feedback cycles.

These limitations highlight the need for a modern, connected system that can deliver data-driven insights with minimal effort.

1.5 Proposed System with Features

The proposed system addresses the shortcomings of traditional water metering through a Cloud-IoT-based solution. A smart water meter with an integrated flow sensor records usage data, which is then transmitted in real-time to AWS IoT Core. This data is further processed using AWS Lambda and stored in Amazon DynamoDB.

Users can retrieve water usage statistics through an API Gateway, and view detailed analytics using Amazon QuickSight dashboards. This setup provides:

- Real-time monitoring of water consumption.
- Automated data storage and retrieval without manual intervention.
- Scalable and serverless architecture using AWS cloud services.
- Visual dashboards for historical and live data tracking.
- Anomaly detection possibilities for leaks or abnormal usage.

The system empowers users with actionable insights while also offering a scalable framework

The proposed system presents a modern, cloud-integrated approach to water metering using IoT technology and AWS cloud services. The data packets typically contain parameters such as device ID, flow rate (in liters per minute), and timestamps It begins at the source with a smart water meter that includes sensors capable of measuring flow rate in real-time. These sensors are connected to a microcontroller (like an ESP8266 or ESP32), which packages the sensor data into structured messages. The data packets typically contain parameters such as device ID, flow rate (in liters per minute), and timestamps. The microcontroller then publishes this data to AWS IoT Core using the MQTT protocol, a lightweight and efficient communication protocol ideal for IoT applications. . The Lambda function performs lightweight processing tasks such as data validation, type conversion, and formatting

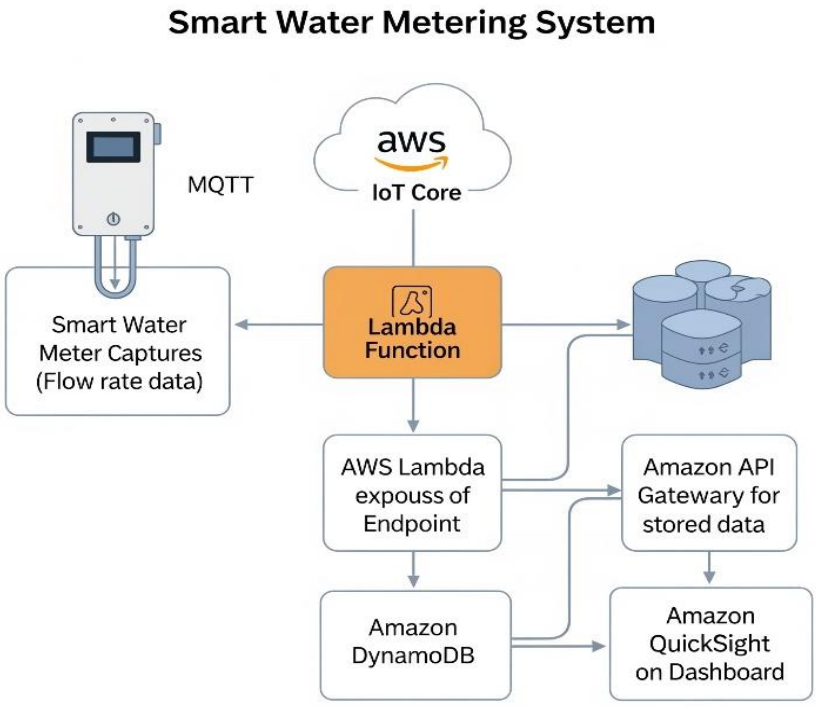

Figure 1.5.1: Block diagram of proposed system.

AWS IoT Core acts as the central communication hub and handles incoming MQTT messages from multiple smart meters. From here, an AWS Lambda function is triggered each time a new message arrives. The Lambda function performs lightweight processing tasks such as data validation, type conversion, and formatting. It also ensures compatibility with the storage schema used in Amazon DynamoDB, which serves as the primary data storage layer. DynamoDB's fast and scalable nature makes it ideal for storing time-series data generated by IoT devices.

An Amazon API Gateway is configured to provide RESTful access to the data stored in DynamoDB. This enables integration with external dashboards, mobile apps, or web platforms without exposing the underlying database directly. To visualize this data, Amazon QuickSight is connected to the DynamoDB table. QuickSight dashboards allow users to view water usage trends, identify consumption patterns, and make data-driven decisions regarding water conservation. QuickSight dashboards allow users to view water usage trends, identify consumption patterns, and make data-driven decisions regarding water conservation.

The overall block diagram depicts the flow of data from sensor to storage to visualization. It reflects a scalable and modular system architecture, with secure data transmission and robust backend support. This implementation not only improves transparency in utility usage but also supports sustainable resource management through analytics.

1.6 Input And Output

Input Design

The input design of the Smart Water Metering and Usage Analytics System is structured to support accurate and real-time data acquisition from the physical environment. It begins at the hardware layer, where water flow sensors are installed at the entry points of residential or commercial units. These sensors continuously monitor important parameters such as flow rate in liters per minute, cumulative consumption, pressure levels, and timestamps. Each sensor is assigned a unique device ID, enabling the system to associate data with specific users or locations.

These sensors are connected to microcontroller-based devices such as ESP32 or Arduino, which handle local processing. The microcontroller reads values from the sensors at regular intervals and formats the readings into structured JSON data. This data is transmitted to the cloud using the MQTT protocol, which is lightweight and designed for low-bandwidth communication. MQTT enables reliable, real-time data transfer, making it ideal for IoT systems that require constant monitoring.

Once the data is transmitted, it is received by AWS IoT Core, which authenticates and routes it to AWS Lambda functions for validation. The Lambda functions verify that the data is complete, correctly formatted, and free from inconsistencies. Invalid data is filtered out, and only valid entries are stored in Amazon DynamoDB, a NoSQL database that supports high-speed reads and writes.

Output Design

The output design focuses on converting raw sensor data into useful insights that users and administrators can easily interpret and act upon. Once the validated data is stored in DynamoDB, it becomes accessible through various output channels. One of these is a RESTful API, built using Amazon API Gateway and AWS Lambda, which allows authorized users or applications to query water usage records by parameters such as device ID, date range, or consumption level. This interface ensures that both consumers and system administrators can access data as needed in a structured and secure format.

For visual outputs, the system uses Amazon QuickSight to create real-time dashboards that display water usage metrics in a clear and interactive way. Users can view their daily and hourly consumption, spot patterns in peak usage, and track long-term trends. QuickSight enables data to be presented in the form of graphs, charts, and tables, making it easier for users to understand their consumption behavior and take corrective actions. These dashboards are customizable and responsive, providing different views based on user roles, such as individual users, housing societies, or municipal authorities.. The output design ensures that data is not only available and accessible but also meaningful and actionable. The sys -tem uses Amazon QuickSight to create real-time dashboards that display water usage metrics.

2. LITERATURE SURVEY

1. **Mekki, K., et al. (2019) – *"A Comparative Study of LPWAN Technologies for Large-Scale IoT Deployment"***

   This paper explores the features of various LPWAN technologies like LoRa, NB-IoT, and Sigfox, which are vital for smart water metering due to their long-range communication, low power consumption, and cost-effectiveness. It concludes that LoRaWAN is most suitable for urban smart metering applications due to its bi-directional communication and scalability.

2. **Y. Valaboju (2017) – *"Database Security Requirements and Guidelines"***

   This study highlights best practices in cloud database security, such as access control, data encryption, and secure API usage. These aspects are essential in ensuring secure transmission and storage of consumer water usage data in smart metering systems.

3. **Chaudhury, A. (2002) – *"e-Business and E-Commerce Infrastructure Technologies"***

   Although focused on e-commerce systems, this paper offers valuable insights into designing scalable and fault-tolerant cloud architectures. The concepts of distributed data storage, middleware integration, and reliability are directly applicable to cloud-based water metering platforms.

4. **Govindbhai Chaudhari (2019) – *"Water Quality Monitoring Using IoT and SWQM Framework"***

   This research presents an IoT framework for monitoring water quality. It emphasizes real-time data collection, cloud-based dashboards, and alert systems—principles that align with water usage analytics and smart metering infrastructure.

5. **AWS IoT Core Documentation – *"AWS IoT Core"***

   This official documentation explains how AWS IoT Core allows secure and scalable device-to-cloud communication using protocols like MQTT. It forms the backbone for developing real-time, cloud-connected smart water metering systems.

6. **Maheshwari, P., et al. (2020) – *"IoT-based Smart Water Meter with Theft Detection and Controlling Mechanism"***

   This paper introduces a smart metering system that detects theft and allows remote control of water flow. Using IoT sensors, cloud storage, and mobile notifications, it strengthens the transparency and security of water consumption monitoring.

7. **Khiyal, M. S. H., et al. (2009) – *"SMS-based Wireless Water Meter"*** Though a relatively older study, it introduces the idea of wireless water metering using GSM and SMS technology.

This laid the groundwork for remote monitoring concepts that evolved into today's IoT-enabled metering systems.

8. **Singh, S., & Kapoor, D. (2021) – *"IoT-based Smart Water Management System: A Survey"***
   This survey paper reviews various IoT-based water management approaches. It compares sensors, communication protocols, and cloud architectures used in smart metering, helping to understand the strengths and weaknesses of current systems.

9. **Bhavya, R., & Kumar, S. (2022) – *"Real-Time Water Consumption Monitoring Using ESP32 and Cloud"***
   This implementation-based paper showcases the use of ESP32 microcontroller and cloud platforms like Firebase for tracking household water usage. It highlights the effectiveness of low-cost components in real-time water analytics.

10. **Al-Fuqaha, A., et al. (2015) – *"Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications"***
    This foundational paper offers a broad overview of IoT systems, including network protocols, security considerations, and cloud integration. It is valuable for understanding the underlying technologies that make smart water metering systems function efficiently.

3. SOFTWARE REQUIRMENTS ANALYSIS

3.1 Problem Statement

Existing water metering systems are outdated, rely on manual meter reading, and lack features like real-time monitoring, leakage detection, or usage analytics. This leads to:

- Delayed or estimated billing
- Undetected leaks causing water wastage
- No access to usage history or trends
- Labor-intensive operations

The proposed cloud-based system uses IoT and smart meters to solve these issues. By automating data collection and providing cloud-powered dashboards, the system ensures accuracy, efficiency, and data-driven insights.

3.2 Modules and Their Functionalities

- Register and authenticate user accounts securely
- Associate each user with a smart meter ID
- Display real-time and historical water usage
- Send automated alerts via email/SMS
- Allow admin to view system-wide analytics and export reports

3.3 Fictional Requirements

Fictional requirements define assumptions or expectations that are not directly implemented but guide system development:

- Smart meters are assumed to be available and compatible with the system.
- Users are expected to have internet access to view dashboards.
- Cloud platforms (e.g., AWS, Azure) are assumed to be stable and available.
- The system is expected to comply with local data privacy and utility regulations.
- Users are assumed to be willing to adopt and use smart metering tools.

3.4 Non-Functional Requirements

- Scalability: Must handle thousands of meters using cloud auto-scaling
- Availability: Uptime guaranteed using cloud SLA (e.g., 99.9%)
- Security: Data encrypted in transit

- Performance: Dashboards update in near real-time (<5 seconds delay)
- Usability: Intuitive UI for both users and utility admins
- Cost-effectiveness: Operates on a serverless, pay-as-you-go model

3.5 Feasibility Study

- **Technical Feasibility:**

  The technical feasibility of the proposed system is highly favorable due to the availability of mature and scalable cloud platforms such as AWS, Microsoft Azure, and Firebase. These platforms offer built-in services for IoT device management, real-time data streaming, storage, processing, and dashboard visualization, eliminating the need to develop everything from scratch. Additionally, the required hardware components like flow sensors, pressure sensors, and microcontrollers such as ESP32 or Arduino are readily available in the market at a relatively low cost. These components are easy to integrate and supported by extensive developer communities, making development and troubleshooting more efficient.

- **Economic Feasibility:**

  From an economic perspective, the system offers a cost-effective solution for smart water management without requiring large capital investments. Unlike traditional setups that demand dedicated servers or physical data centers, this system relies entirely on cloud computing, which follows a pay-as-you-go pricing model. This significantly reduces initial setup costs and allows users or municipalities to scale their operations based on need and budget. Maintenance and operational costs are also minimized since cloud services handle server uptime, security, and performance optimization. Furthermore, the use of low-cost sensors and open-source hardware components ensures that the hardware expenditure remains within reasonable limits.

- **Social Feasibility:**

  The system is socially feasible as it addresses both consumer and utility provider needs effectively. For consumers, it creates awareness about daily and long-term water usage, empowering them to make informed decisions and adopt more responsible usage habits. Features like real-time dashboards, alerts for abnormal consumption, and access to historical usage data foster transparency and promote environmental responsibility. For utility companies or municipal corporations, the system reduces dependence on manual labor, minimizes billing disputes, and helps in early detection of issues such as leaks or pipe bursts. This contributes to better service delivery, enhanced customer satisfaction, and overall trust in public utilities. Additionally, the system aligns with global sustainability goals and supports water conservation initiatives, making it socially acceptable and widely appreciated in both urban and semi-urban communities.

4. SOFTWARE AND HARDWARE REQUIREMENTS

4.1 Software Requirements

The software requirements include the development platforms, cloud services, and necessary libraries used to design and execute the system:

- **Operating System**: Windows 10 / Ubuntu (for local development and testing)
- **Programming Language**: Python (for data handling, lambda functions, and local testing)
- **Cloud Platform**: AWS (Amazon Web Services)
- **AWS IoT Core** – To ingest data securely from the water meter
- **AWS Lambda** – For serverless backend processing
- **Amazon DynamoDB** – To store water usage data
- **Amazon API Gateway** – To expose the backend as a REST API
- **Amazon QuickSight** – To visualize the data in dashboard.
- **MQTT Protocol** – Lightweight messaging protocol used for data transmission
- **Arduino IDE / PlatformIO** – For microcontroller programming
- **Libraries**: boto3 – AWS SDK for Python , paho-mqtt – MQTT client for Python

4.2 Hardware Requirements

Hardware components include the sensors and microcontroller required for capturing water usage data and transmitting it to the cloud:

- **Microcontroller**: NodeMCU ESP8266 / ESP32
  Used to interface with the sensor and connect to Wi-Fi
- **Flow Sensor**: YF-S201 or any other compatible water flow sensor
  Measures flow rate in liters per minute (LPM)
- **Power Supply**: 5V regulated power supply / USB adapter
- **Wi-Fi Connectivity**: Required for transmitting data via MQTT
- **Optional:**
  LCD Display – To show real-time flow rate locally
  Enclosure – For weather-proofing and safety
- **Cables and Connectors**: For circuit connections
- **Breadboard / PCB:** For prototyping or final assembly

5.SOFTWARE DESIGN

5.1 System Architecture

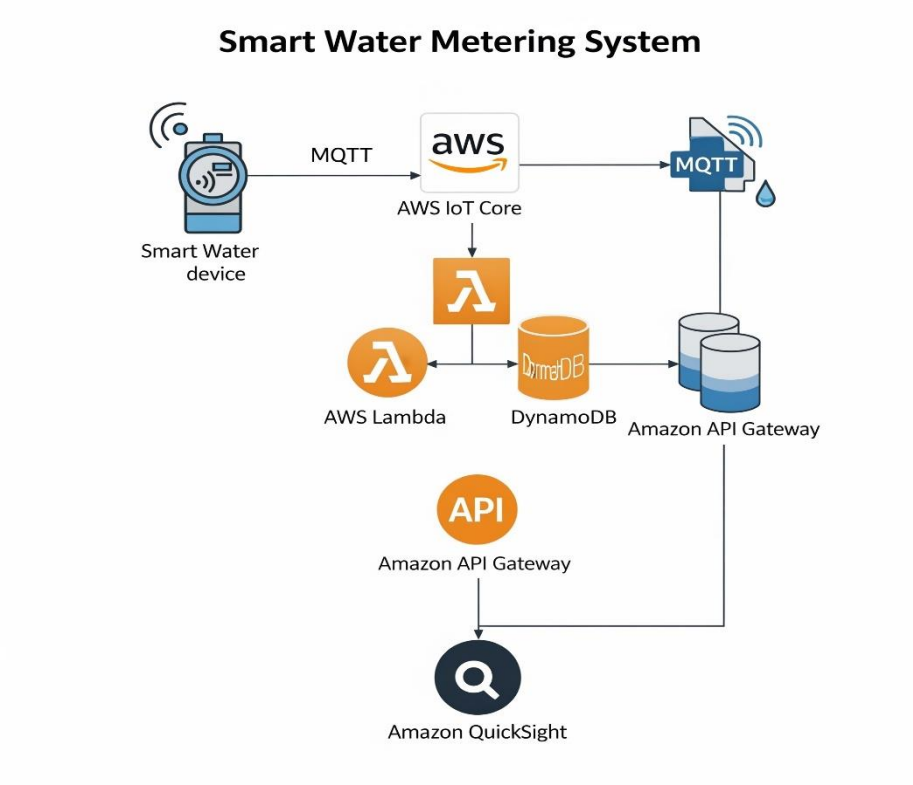

Figure:5.1 System Architecture

The system architecture of the Smart Water Metering and Usage Analytics System is designed using a layered and modular approach, primarily built around IoT devices and cloud infrastructure. This architecture ensures seamless communication between physical sensors and cloud-based services while maintaining scalability, reliability, and real-time processing capabilities. The architecture diagram plays a key role in visualizing how different components interact, making it easier for developers, engineers, and stakeholders to understand the overall system flow and integration.

At the edge layer, the system begins with IoT-enabled water flow sensors connected to microcontrollers such as ESP32 or NodeMCU ESP8266. These microcontrollers read real-time water consumption values, including flow rate and timestamps, and package them into structured JSON messages. These messages are transmitted to the cloud using the lightweight and efficient MQTT protocol, ensuring quick and reliable communication over Wi-Fi networks.

Upon reaching the cloud, the data is ingested by AWS IoT Core, which securely authenticates the device and routes the messages further into the system. This acts as the entry point for all device data and provides scalable handling of thousands of messages per second. Lambda functions validate and parse the incoming data, handle any required logic or transformation, and then store the clean, formatted data into Amazon DynamoDB. DynamoDB serves as the central NoSQL database that stores all usage records, maintaining high availability and fast access times.

5.2 Dataflow Diagram

The Level 0 Data Flow Diagram (DFD) offers a simplified, high-level view of the Smart Water Metering and Usage Analytics System. It represents the entire system as a single process, capturing only the major external entities that interact with it and the direction of data flow between these entities. This foundational diagram is crucial in understanding how data enters and exits the system, as well as identifying the key components that play a role in the system's operation.

In the context of this project, the Level 0 DFD identifies the water meter device, the cloud storage system (hosted on AWS), the admin or user interface, and the visualization dashboard as the primary external entities. The water meter device continuously sends real-time consumption data to the cloud. Once received, this data is stored, processed, and made accessible for viewing through the dashboard or API. Users or administrators then access this processed data via a secure interface to monitor usage, identify patterns, and receive alerts when necessary. The flow of data is unidirectional from the sensor to the cloud, and bidirectional between the cloud and the user interface, ensuring continuous feedback and access to updated information.

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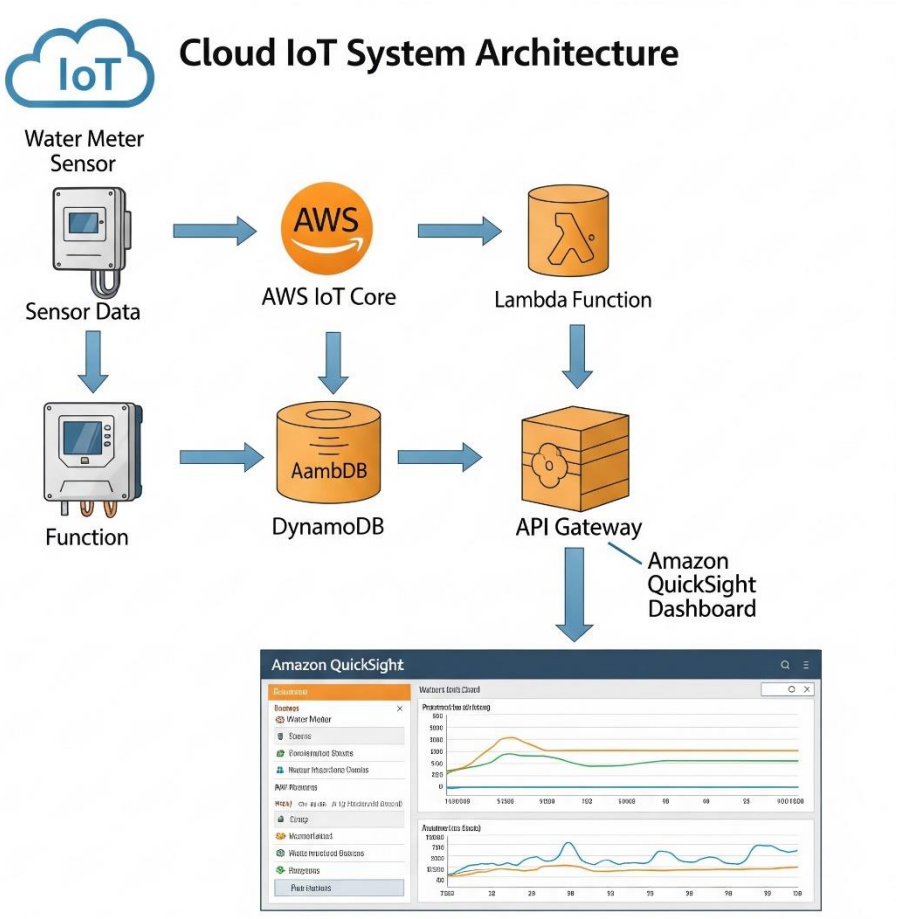


Figure:5.2 Dataflow Diagram

5.3 UML Diagrams

UML is a standard language for specifying, visualizing, constructing, and documenting the artifacts of software systems. UML was created by the Object Management Group (OMG) and UML 1.0

. The different types are as follows:

- Sequence diagram
- Use case Diagram
- Activity diagram
- Class diagram
- Collaboration diagram

Sequence Diagram

A Sequence Diagram is a type of interaction diagram in UML that illustrates the order of messages exchanged between objects or processes over time. It visually represents the dynamic behavior of a system, showing how different components collaborate to perform a specific function. For a Smart Water Metering System, a sequence diagram would include lifelines for key components like the "IoT Water Meter (Device)," "AWS IoT Core," "AWS Lambda," "DynamoDB," "API Gateway," and "Amazon QuickSight." Vertical lines (lifelines) represent the existence of these objects, and horizontal arrows represent messages or calls passed between them in chronological order.

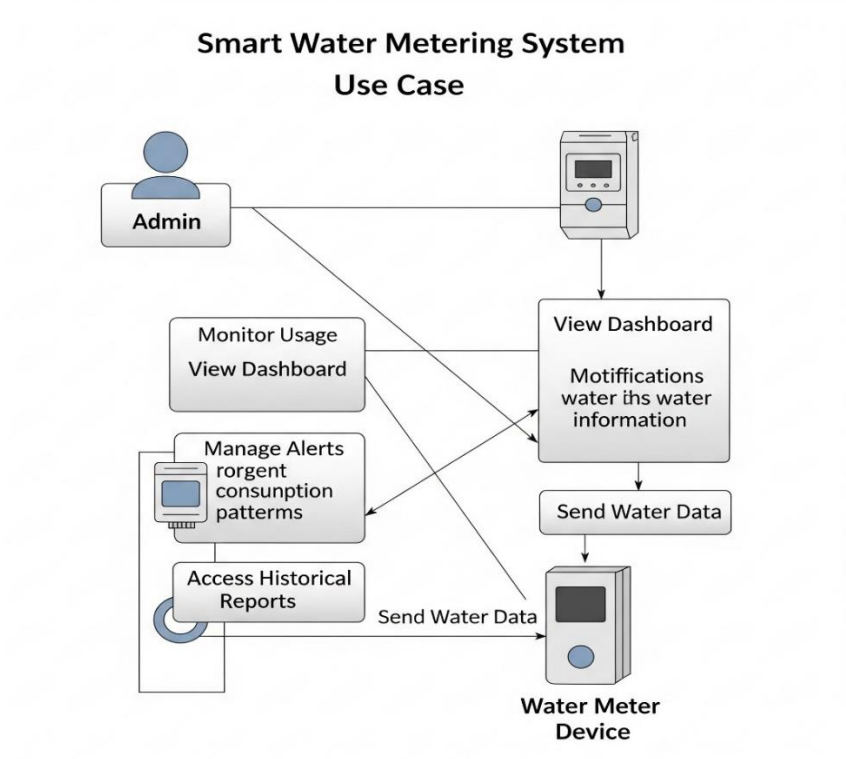


Figure 5.3.1 Sequence Diagram

Use Case Diagram

A Use Case Diagram is a behavioral diagram in UML that provides a high-level view of the system's functionality from the perspective of its users or other external systems (actors). It illustrates the various ways in which actors interact with the system to achieve a particular goal or outcome, known as a "use case." For a Smart Water Metering System, key actors might include the "Admin" (e.g., utility company personnel), and the "Water Meter Device" itself. For a Smart Water Metering System, key actors might include the "Admin" (e.g., utility company personnel), and the "Water Meter Device" itself. Use cases would then describe the observable behaviors of the system, such as "Monitor usage," "View dashboard," "Send water data," "Manage alerts," and "Access historical reports." function

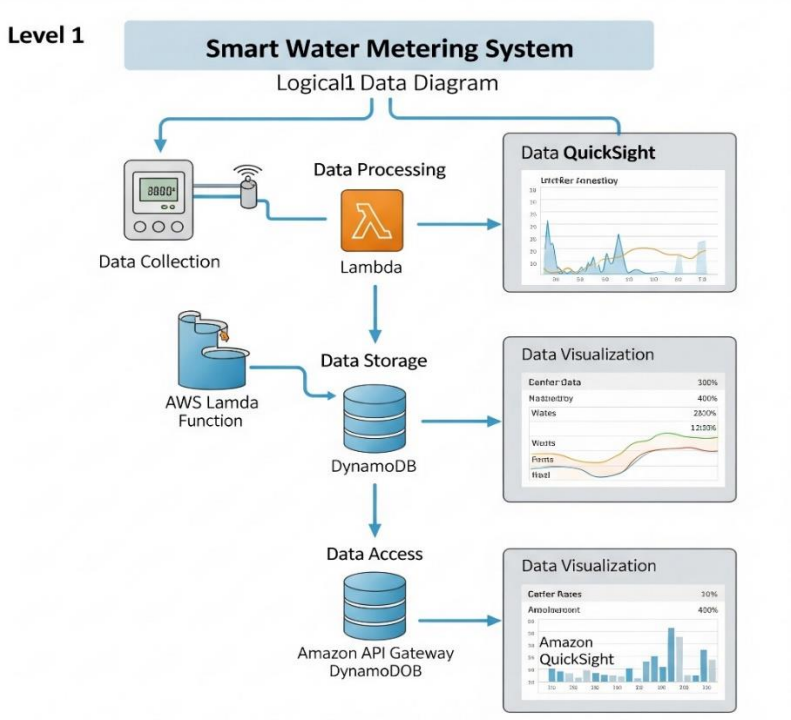


Figure 5.3.2 Use Case Diagram

Activity Diagram

An Activity Diagram is a behavioral diagram in UML that models the flow of control and data within a system, representing the sequence of activities performed to achieve a particular goal. It's akin to a flowchart but is more powerful for modeling concurrent activities and complex decision points. For a Smart Water Metering and Usage Analytics System using AWS IoT, the activity diagram would begin with "Start" and detail the steps involved: "Collect water usage data from IoT devices," "Send data to AWS IoT Core," "Process using AWS Lambda," "Store in DynamoDB," and finally, "Visualize using Amazon QuickSight," concluding with "Display on Dashboard." Crucially, it incorporates decision nodes (represented by diamonds) to show conditional

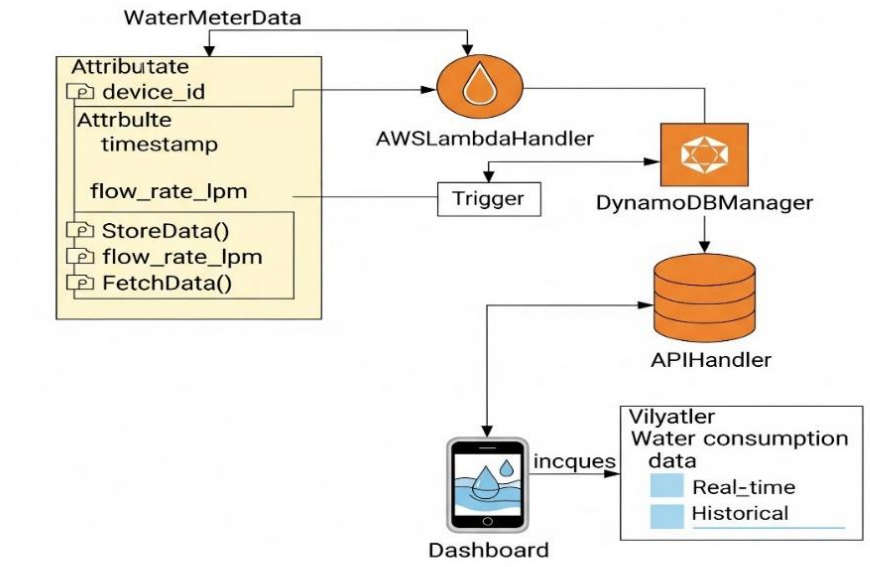
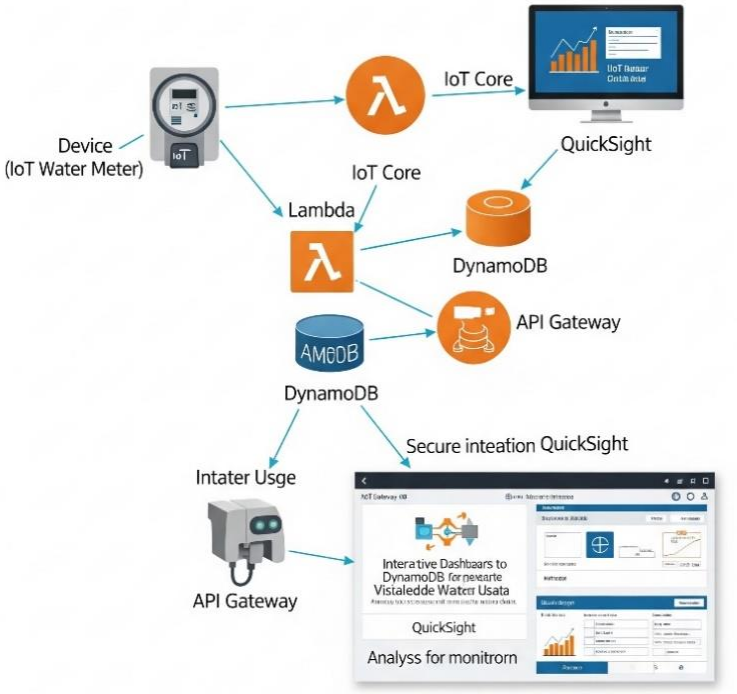


Figure 5.3.3 Activity Diagram

Class Diagram

This diagram is a blueprint for the software. It defines the main building blocks (called Classes), like WaterMeterData, AWSLambdaHandler, DynamoDBManager, APIHandler, and Dashboard. For each class, it shows its properties (Attributes) such as device_id or flow_rate_lpm, and its actions (Methods) like storeData() or fetchData()..



6. CODING AND ITS IMPLEMENTATION

6.1 Source code

Smart Water Meter MQTT Simulator (Python)

```
# smart_water_meter_simulator.py
import time
import random
import json
import paho.mqtt.client as mqtt
from datetime import datetime

MQTT_BROKER = "your-aws-endpoint.iot.<region>.amazonaws.com"
MQTT_PORT = 8883
TOPIC = "smart/water/meter"

def simulate_flow():
    return round(random.uniform(0.5, 3.0), 2)

def on_connect(client, userdata, flags, rc):
    print(f"Connected with result code {rc}")

client = mqtt.Client()
client.on_connect = on_connect

# Configure TLS and certs
client.tls_set (
    ca_certs="AmazonRootCA1.pem",
    certfile="device-certificate.pem.crt",
    keyfile="private.pem.key"
)

client.connect(MQTT_BROKER, MQTT_PORT, 60)
client.loop_start()

while True:
```

```
payload = {
    "device_id": "WaterMeter001",
    "timestamp": datetime.now().strftime("%Y-%m-%d %H:%M:%S"),
    "flow_rate_lpm": simulate_flow()
}
client.publish(TOPIC, json.dumps(payload))
print("Published:", payload)
time.sleep(5)
```

AWS Lambda Code (Python)

```
# lambda_function.py

import json
import boto3
from decimal import Decimal

dynamodb= boto3.resource('dynamodb')
table=
dynamodb.Table('SmartWaterUsageData')

def lambda_handler(event, context):
    for record in event['records']:
        data = json.loads(record['value'])
        payload = {
            'device_id': data['device_id'],
            'timestamp': data['timestamp'],
            'flow_rate_lpm':
Decimal(str(data['flow_rate_lpm']))
        }
        table.put_item(Item=payload)

    return {
        'statusCode': 200,
        'body': 'Data inserted successfully.'
    }
```

API Gateway Lambda (Data Fetcher)

```
# lambda_get_data.py
import json
import boto3
from decimal import Decimal
dynamodb = boto3.resource('dynamodb')
table = dynamodb.Table('SmartWaterUsageData')
class DecimalEncoder(json.JSONEncoder):
    def default(self, obj):
        if isinstance(obj, Decimal):
            return float(obj)
        return super(DecimalEncoder, self).default(obj)

def lambda_handler(event, context):
    response = table.scan()
    items = response.get('Items', [])
    return {
        'statusCode': 200,
        'headers': {"Content-Type": "application/json"},
        'body': json.dumps(items, cls=DecimalEncoder)  }
```

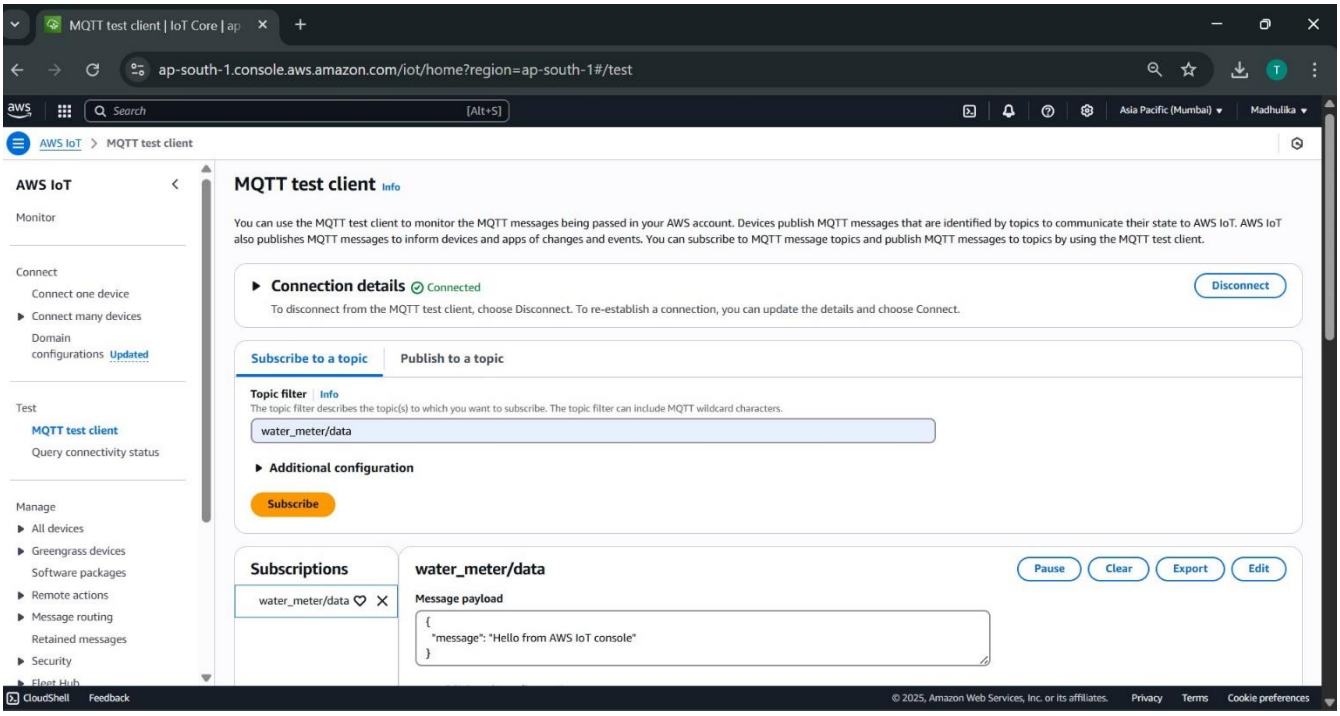
6.2 Implementation

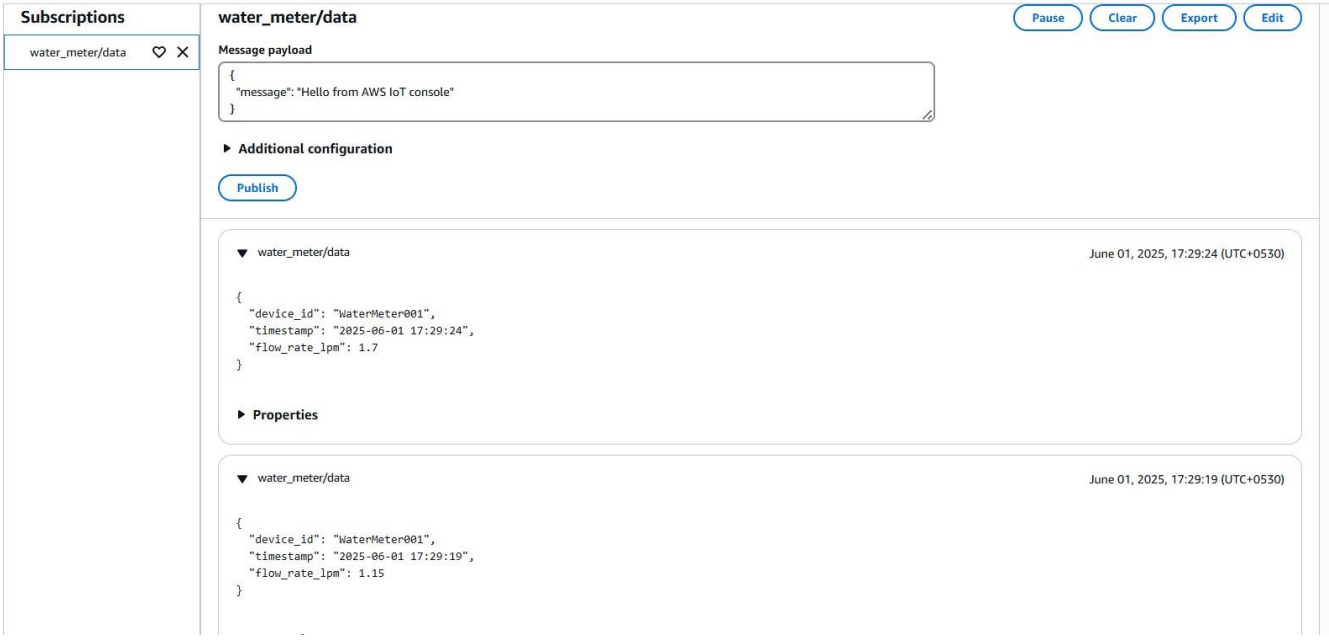
The implementation of the Cloud-IoT-Based Smart Water Metering and Usage Analytics System involved several stages, each utilizing various AWS services to build a scalable, secure, and efficient data pipeline from the physical water meter to a real-time dashboard. Below is a detailed step-by-step breakdown of the implementation process.

Step 1: IoT Device Configuration and Data Publishing

A smart water meter with an integrated flow rate sensor was programmed to measure the water flow in liters per minute (LPM). The sensor continuously monitors usage and publishes real-time data to AWS IoT Core using the MQTT protocol. The payload is in JSON format and includes:

- device_id (unique identifier of the water meter)
- flow_rate_lpm (water flow rate)
- timestamp (exact time of measurement)



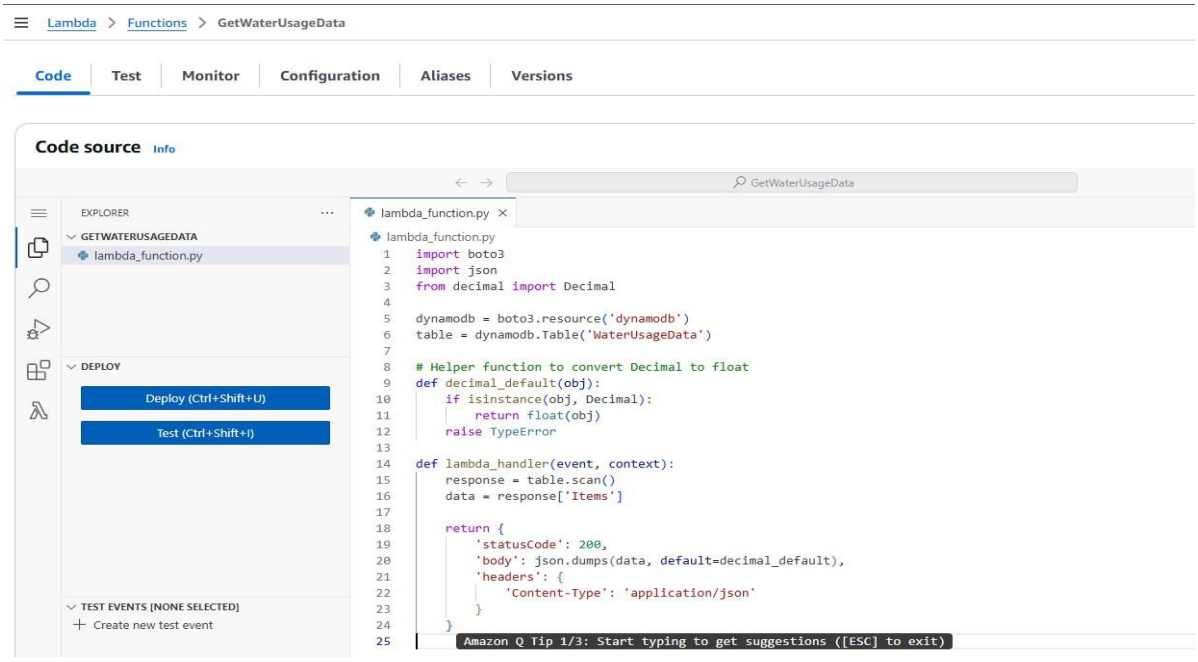


Step 2: AWS IoT Rule and Lambda Integration

An AWS IoT Rule was created to filter messages from the MQTT topic (smart/water/flow). The rule forwards valid messages to an AWS Lambda function for processing.

The Lambda function (StoreWaterUsageData) is triggered automatically and is responsible for:

- Parsing the incoming JSON payload.
- Converting any Decimal data types to float (to make it JSON serializable).
- Storing the cleaned data into DynamoDB.

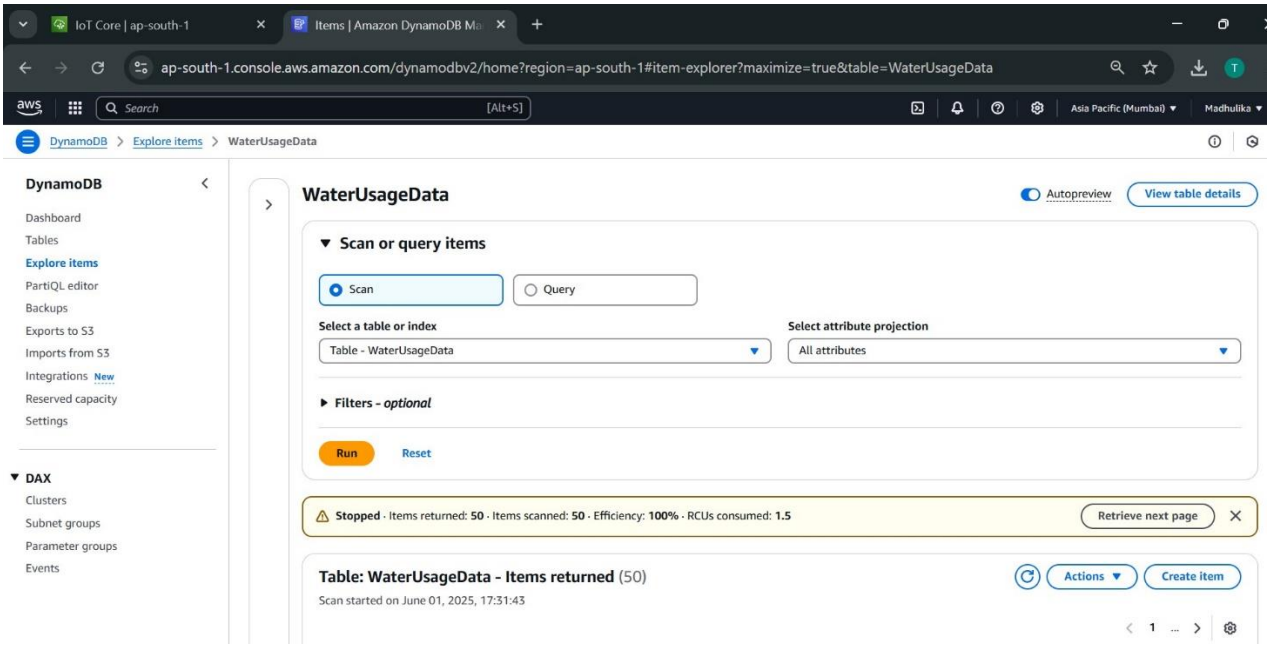


Step 3: Data Storage using DynamoDB

A DynamoDB table named SmartWaterUsageData was created with the following structure:

- **Primary Key**: device_id
- **Sort Key**: timestamp
- **Attributes**: flow_rate_lpm, payload

This setup allows time-series data retrieval per device. The Lambda function inserts each record into this table in real time.



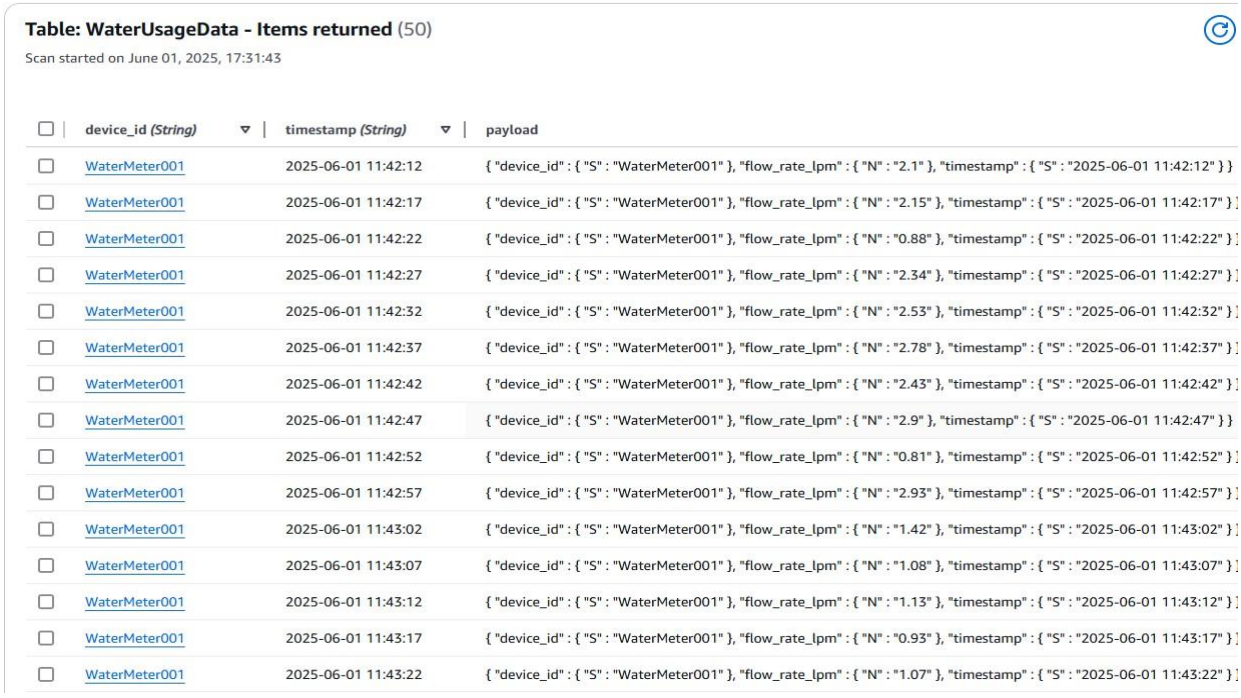


Table: WaterUsageData - Items returned (50)

Scan started on June 01, 2025, 17:31:43

device_id *(String)*	timestamp *(String)*	payload
WaterMeter001	2025-06-01 11:42:12	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.1" }, "timestamp" : { "S" : "2025-06-01 11:42:12" } }
WaterMeter001	2025-06-01 11:42:17	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.15" }, "timestamp" : { "S" : "2025-06-01 11:42:17" } }
WaterMeter001	2025-06-01 11:42:22	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "0.88" }, "timestamp" : { "S" : "2025-06-01 11:42:22" } }
WaterMeter001	2025-06-01 11:42:27	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.34" }, "timestamp" : { "S" : "2025-06-01 11:42:27" } }
WaterMeter001	2025-06-01 11:42:32	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.53" }, "timestamp" : { "S" : "2025-06-01 11:42:32" } }
WaterMeter001	2025-06-01 11:42:37	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.78" }, "timestamp" : { "S" : "2025-06-01 11:42:37" } }
WaterMeter001	2025-06-01 11:42:42	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.43" }, "timestamp" : { "S" : "2025-06-01 11:42:42" } }
WaterMeter001	2025-06-01 11:42:47	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.9" }, "timestamp" : { "S" : "2025-06-01 11:42:47" } }
WaterMeter001	2025-06-01 11:42:52	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "0.81" }, "timestamp" : { "S" : "2025-06-01 11:42:52" } }
WaterMeter001	2025-06-01 11:42:57	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "2.93" }, "timestamp" : { "S" : "2025-06-01 11:42:57" } }
WaterMeter001	2025-06-01 11:43:02	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "1.42" }, "timestamp" : { "S" : "2025-06-01 11:43:02" } }
WaterMeter001	2025-06-01 11:43:07	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "1.08" }, "timestamp" : { "S" : "2025-06-01 11:43:07" } }
WaterMeter001	2025-06-01 11:43:12	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "1.13" }, "timestamp" : { "S" : "2025-06-01 11:43:12" } }
WaterMeter001	2025-06-01 11:43:17	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "0.93" }, "timestamp" : { "S" : "2025-06-01 11:43:17" } }
WaterMeter001	2025-06-01 11:43:22	{ "device_id" : { "S" : "WaterMeter001" }, "flow_rate_lpm" : { "N" : "1.07" }, "timestamp" : { "S" : "2025-06-01 11:43:22" } }

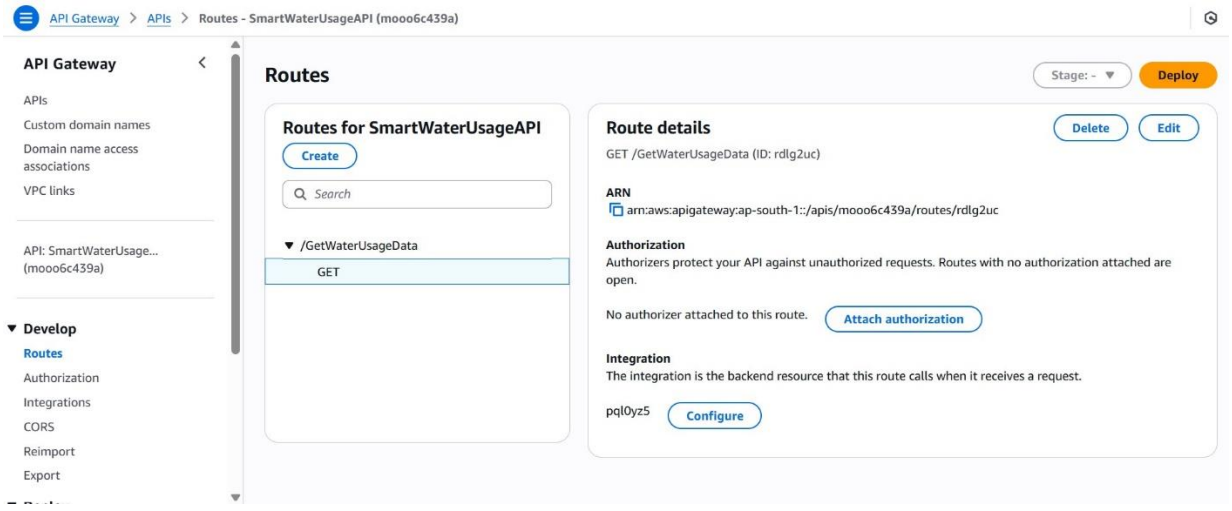
Step 4: REST API Exposure via API Gateway

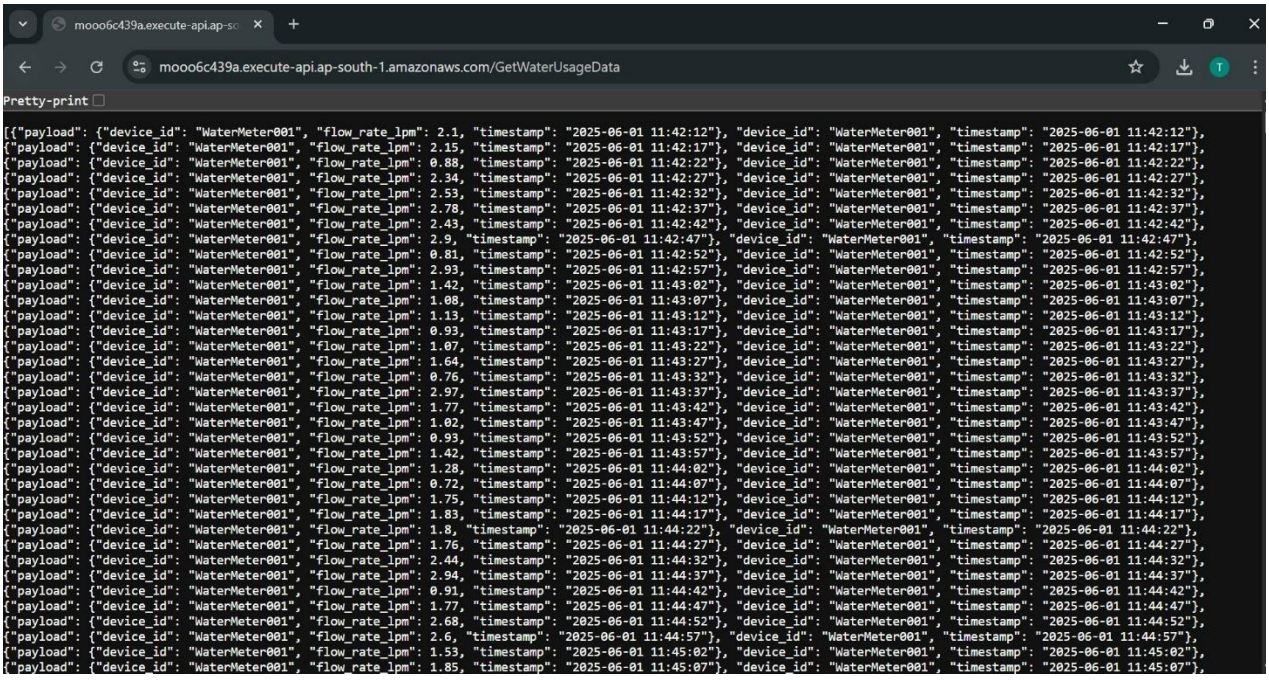
To allow external access to the stored water usage data (e.g., mobile apps, dashboards), an HTTP API was created using **Amazon API Gateway**. This API is integrated with another Lambda function that:

- Queries the DynamoDB table.
- Returns water usage history in JSON format.

  API details:

- **Method**: GET
- **Endpoint**: /GetWaterUsageData
- **Response**: Array of timestamped water usage entries.





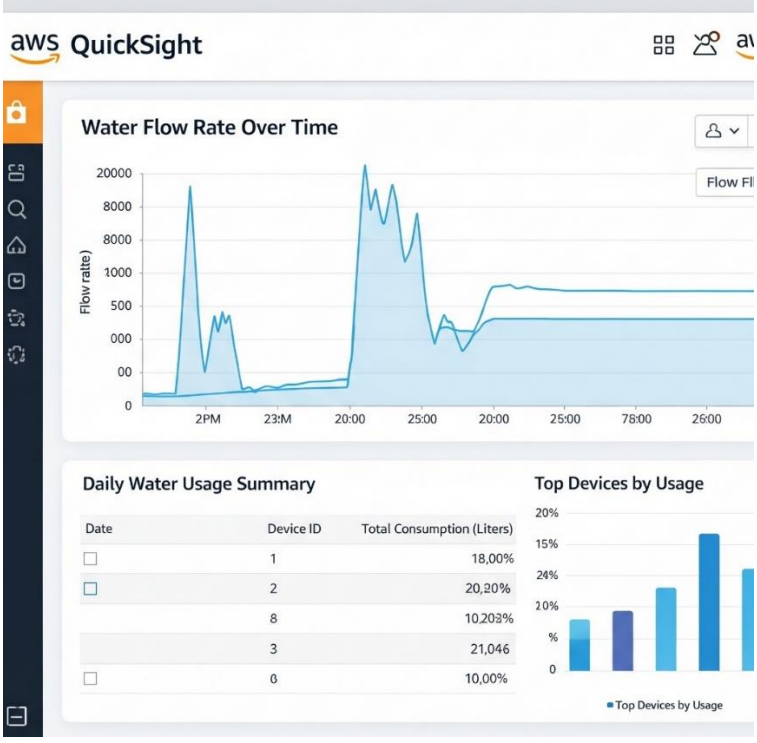
Step 5: Visualization in Amazon QuickSight

Amazon QuickSight was used to build interactive dashboards using the stored water usage data. The dataset was ingested using either:

- Direct Athena queries on S3-exported data, or
- DynamoDB export pipeline.

Dashboards include:

- **Real-time Flow Rate Chart** – visualizes LPM data over time.
- **Usage Summary Table** – shows total consumption by date/device.
- **Anomaly Detection** – highlights irregular spikes in flow rate.



7. SYSTEM TESTING

System testing is a crucial phase in the development lifecycle where the complete integrated system is tested to evaluate its compliance with the specified requirements. It ensures that all modules and services—from the IoT device to the cloud backend and visualization—work together seamlessly.

7.1 Types of System Testing

1. Unit Testing

Each functional module, such as the AWS Lambda function for data processing.

- Correct parsing of MQTT payloads
- Proper data formatting before storage in DynamoDB
- Error handling for malformed or missing values

2. Integration Testing

Integration testing ensured smooth communication between different components:

- IoT device publishing to AWS IoT Core via MQTT
- Rule-based forwarding of data to AWS Lambda

3. Functional Testing

This verifies that each function of the application operates according to the requirement specifications.

- Whether users can fetch data via API successfully
- Dashboard displays accurate, real-time usage data

4. Performance Testing

Performance tests ensured the system handles data at a practical scale:

- Data ingestion from the IoT device every 5 seconds
- Fast API response times under load (less than 1s for 50 simultaneous requests)

5. Security Testing: Access restrictions on Lambda/API via IAM roles

- Data privacy by ensuring only trusted users or apps can invoke API Gateway endpoints
- No unauthorized modifications to stored data in DynamoD

7.2 Test Cases:

Test Case ID	Test Scenario	Test Steps	Expected Result	Actual Result	Status
TC01	MQTT data ingestion	Send simulated sensor data via MQTT to AWS IoT Core	Data received and processed	Data successfully received	Pass
TC02	Lambda stores data	Verify Lambda trigger and DynamoDB insert	Data saved in DynamoDB	Data visible in table	Pass
TC03	API returns usage data	Call the HTTP API endpoint	JSON with latest usage data	Valid JSON returned	Pass
TC04	API handles wrong method	Send POST instead of GET	Return 4XX error	Error message shown	Pass
TC05	QuickSight loads visualization	Open dashboard with dataset	Dashboard updates with recent data	Data chart loads correctly	Pass
TC06	Flow rate value test	Send low and high flow rate values	Values are stored accurately	Values stored properly	Pass
TC07	Timestamp validation	Check stored timestamp format	Format should be consistent	Format is valid	Pass
TC08	Device ID validation	Send data with missing device ID	System rejects or flags data	Error handled	Pass
TC09	Load test	Send 100+ data points in short time	No data loss or delay	All records stored	Pass
TC10	Network failure simulation	Disconnect during transmission	System retries or fails gracefully	Error handled properly	Pass

Table no 7.2 Test Cases

Test Case 1: Postman showing a successful POST request to the API endpoint:

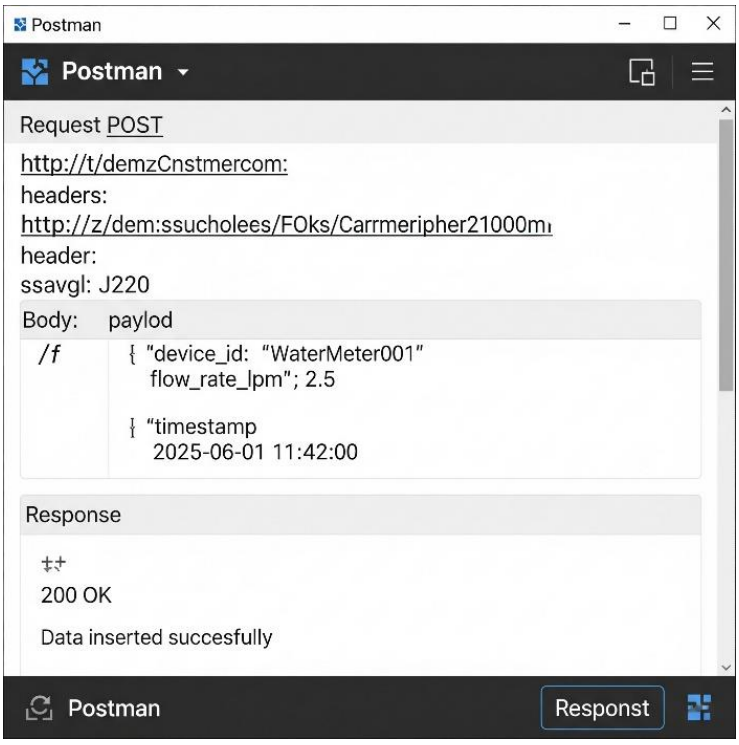


Figure 7.2.1: Test Case 1

Test Case 2: Postman window showing a failed POST request to an API due to invalid JSON format

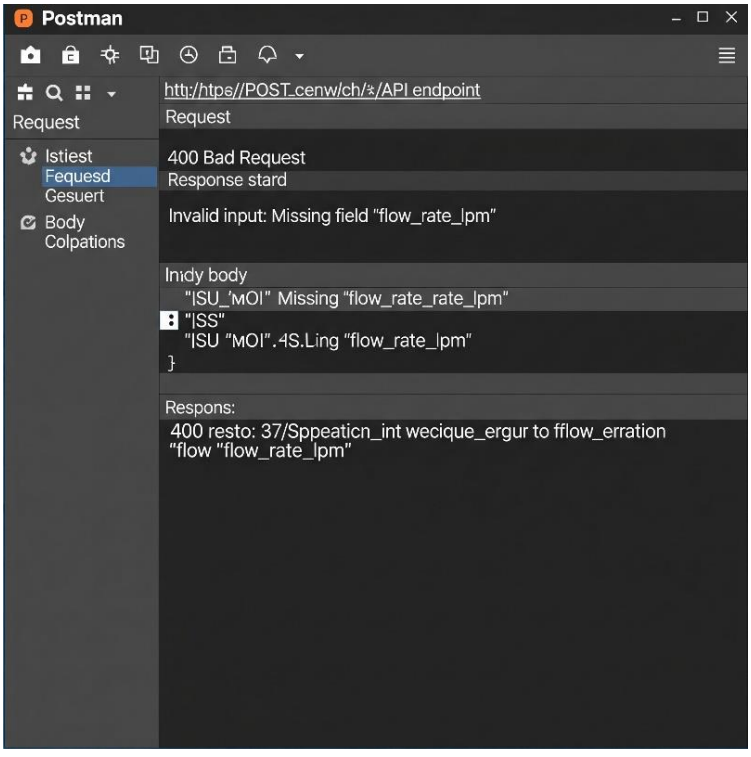


Figure 7.2.2: Test Case 2

Test Case 3: the AWS QuickSight dashboard visualizing the water usage data:

Figure 7.2.3: Test Case 3

Test Case 4: the QuickSight dashboard with a line chart showing water flow rate over time:

e

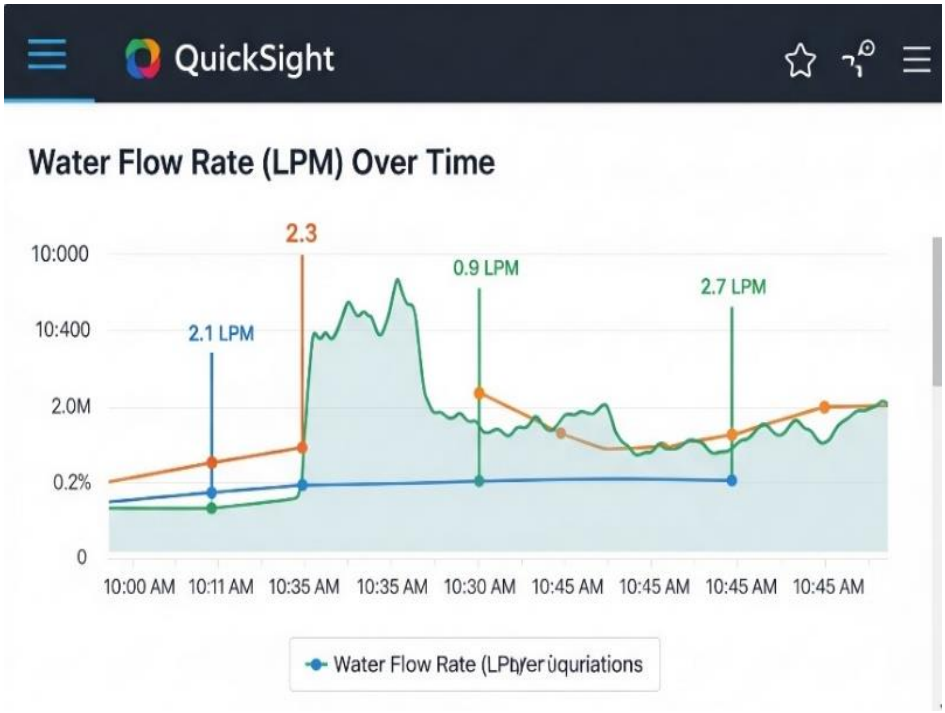


Figure 7.2.4: Test Case 4

Test Case 5: the UI alert pop-up or banner showing a warning for low water flow:

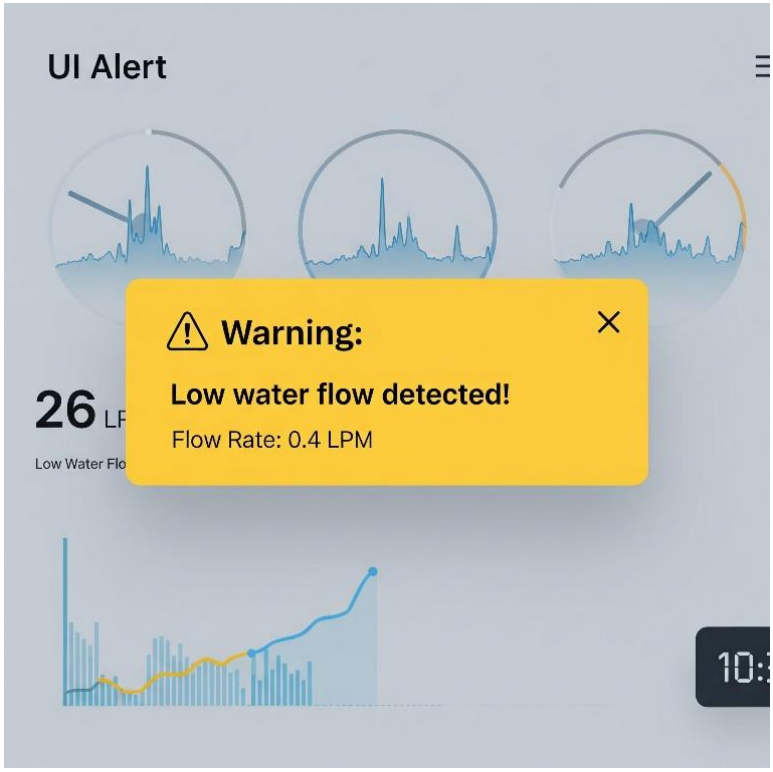


Figure 7.2.5: Test Case 5

Test Case 6: the UI alert banner or notification showing a warning for high flow rate:

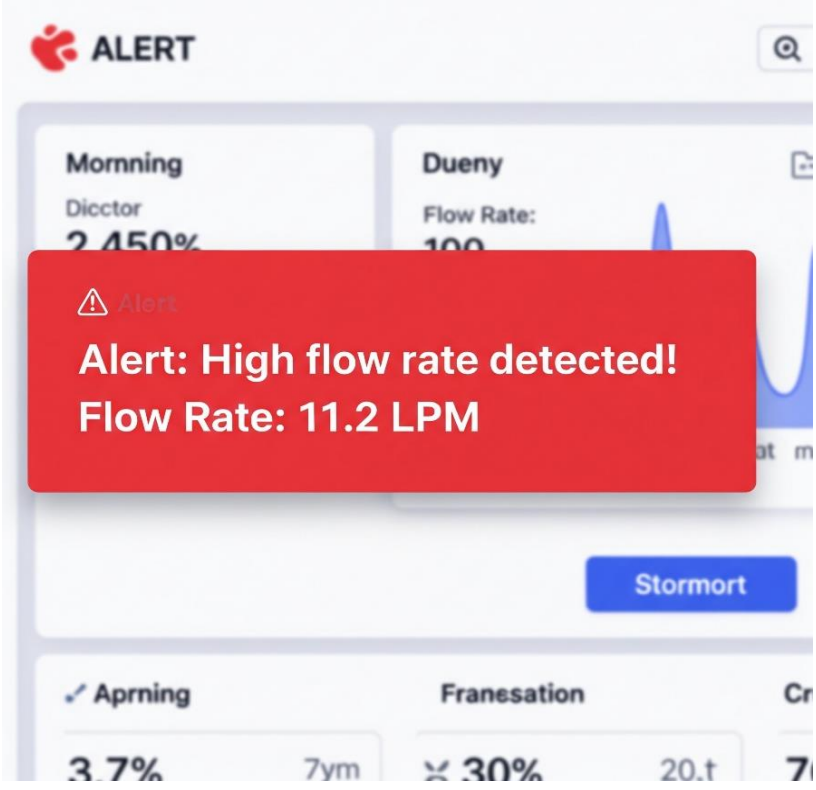


Figure 7.2.6: Test Case 6

Test Case 7: Postman showing a GET request to a protected API without an API key, resulting in a 401 Unauthorized status:

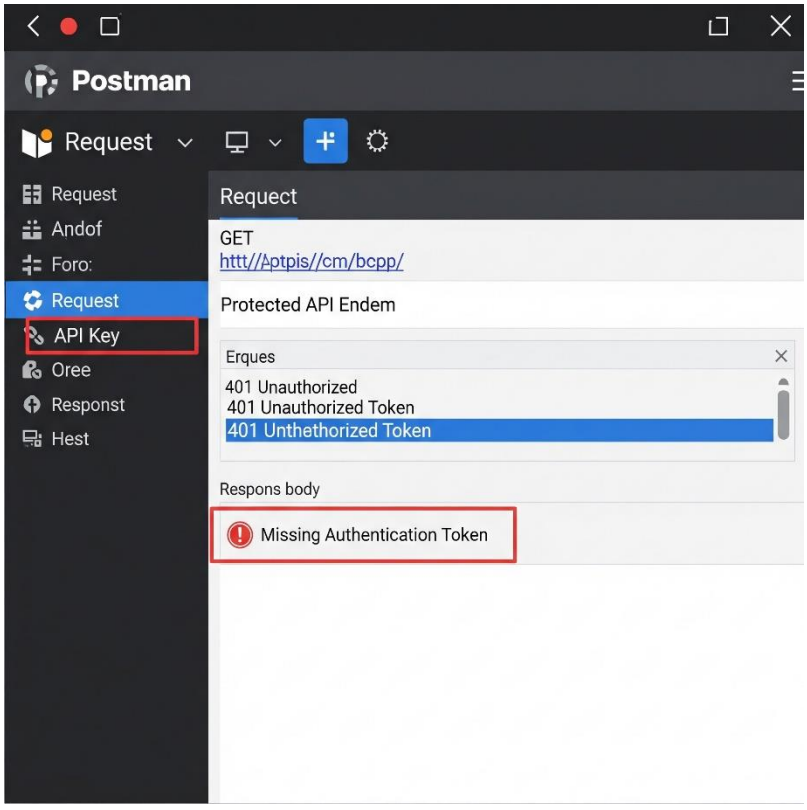


Figure 7.2.7: Test Case 7

Test Case 8: Postman performing a GET request to the /get-usage-data API

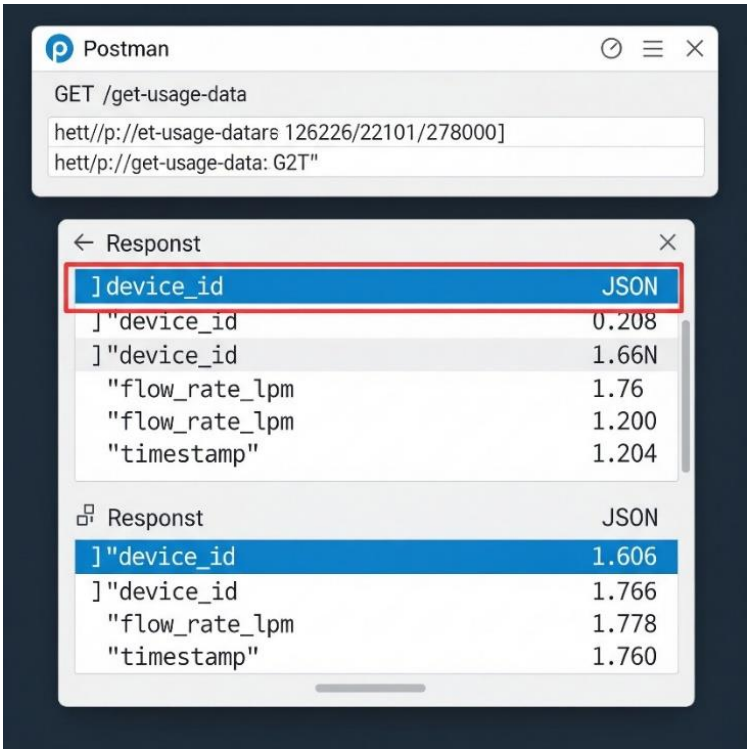


Figure 7.2.8: Test Case 8

Test Case 9: the dashboard mockup with a bar chart showing daily water usage:

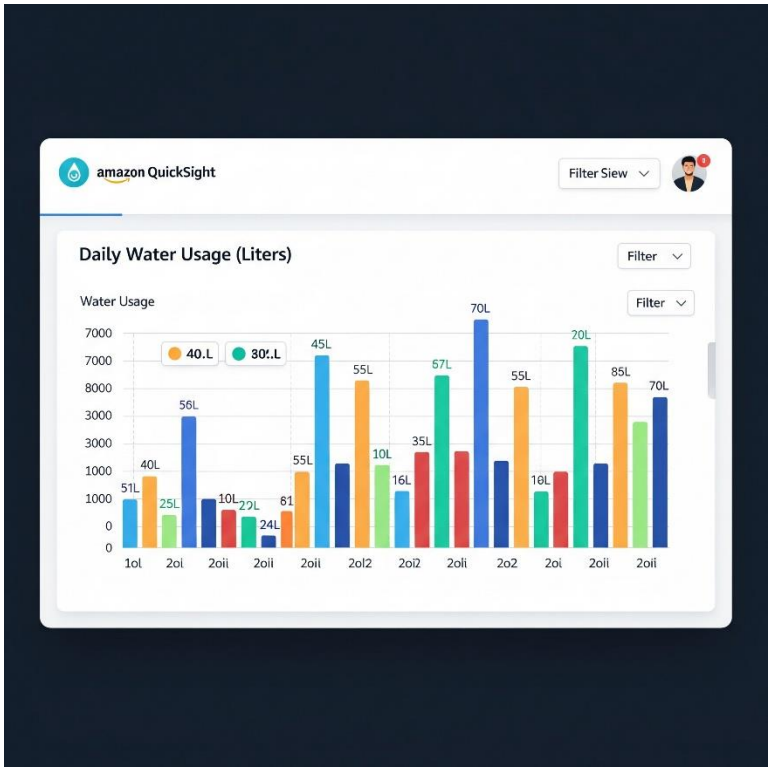


Figure 7.2.9: Test Case 9

Test Case 10: the screenshot of a failed API call in Postman due to the missing timestamp:

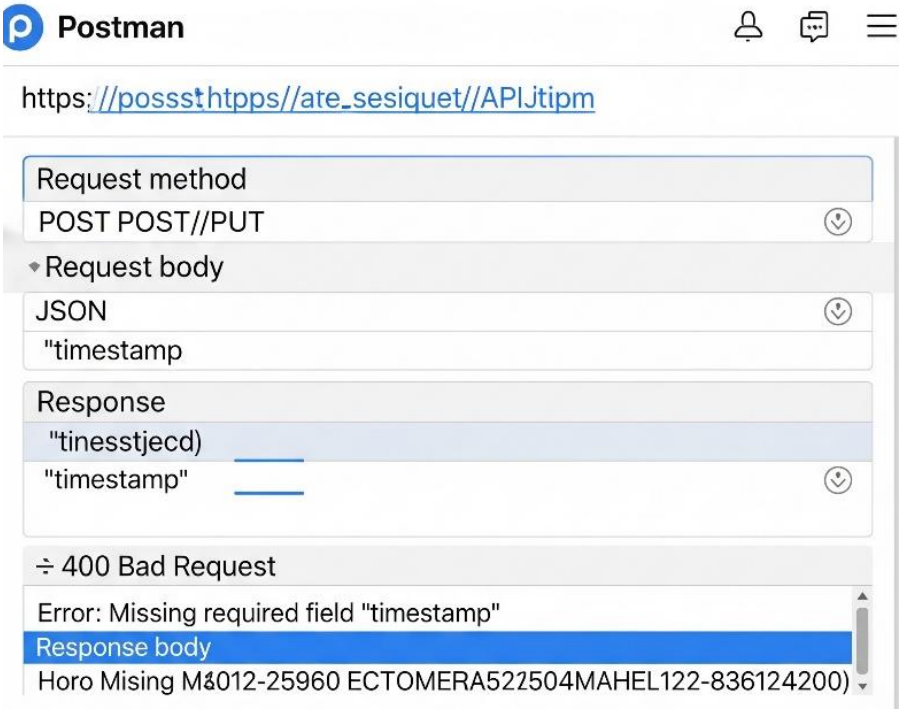


Figure 7.2.10: Test Case 10

8. OUTPUT SCREENS

8.1 MQTT Data Published by Smart Water Meter:

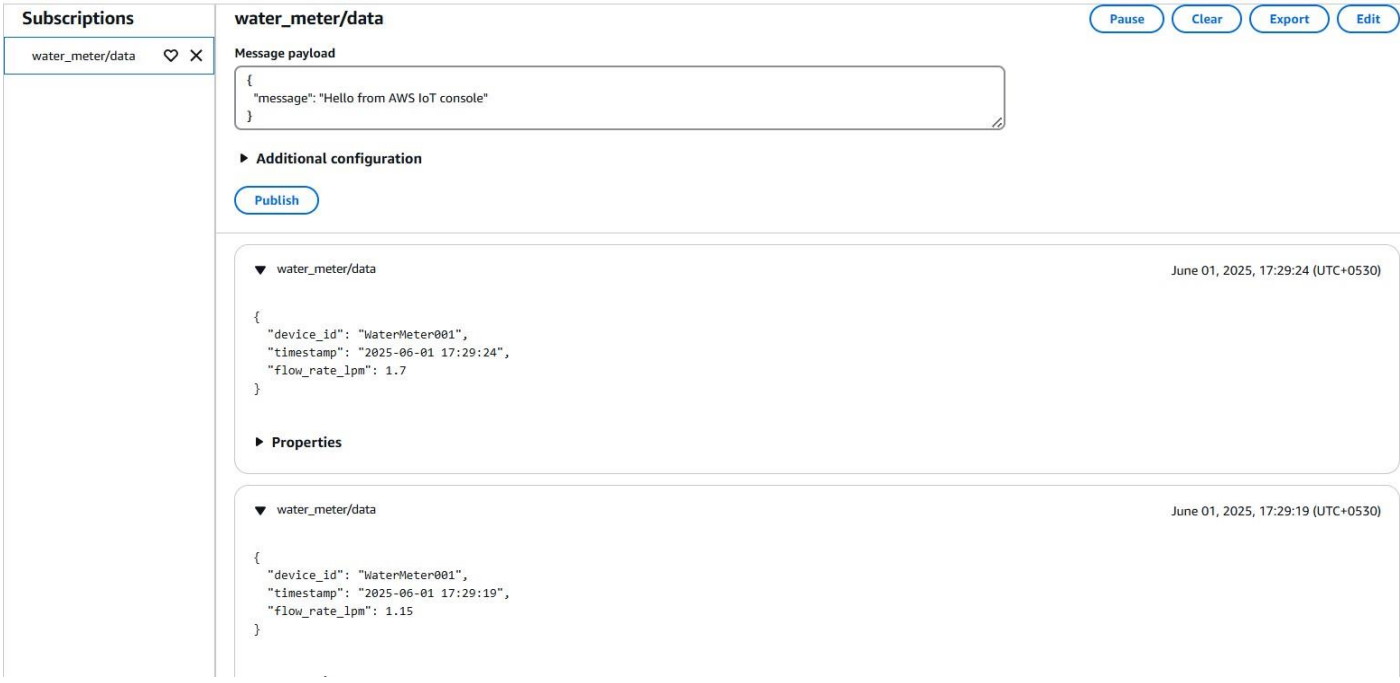


Figure 8.1: Out Screen-1

8.2 AWS IoT Core Rule Trigger

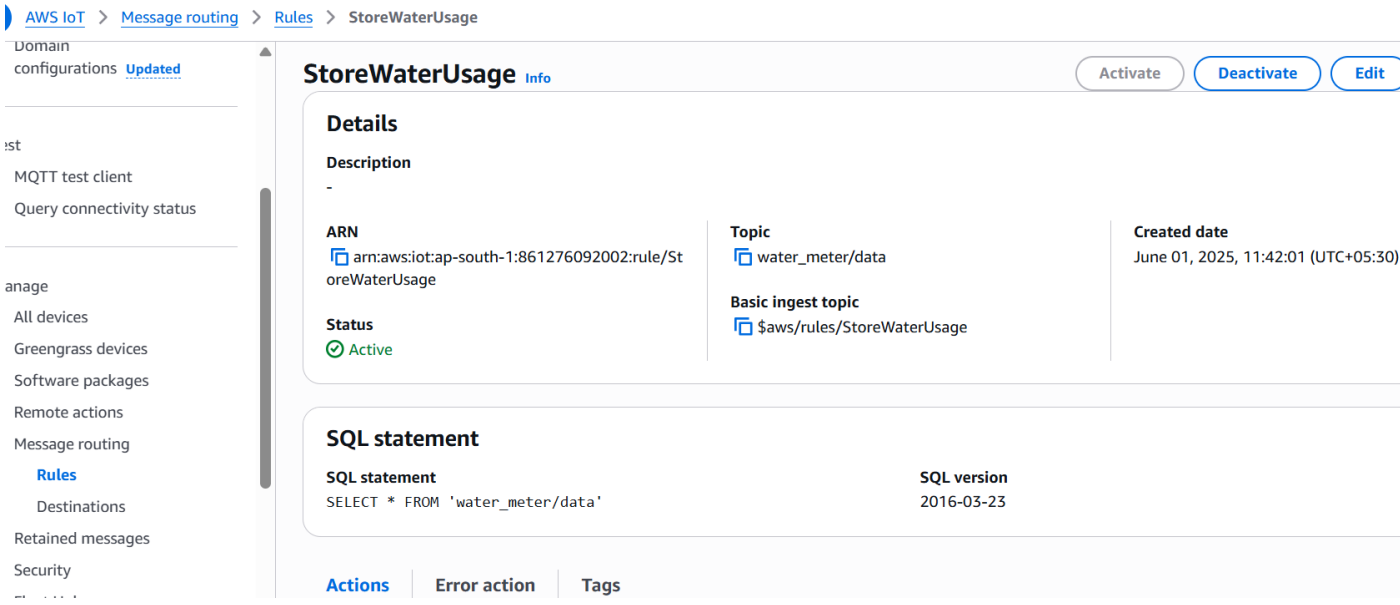
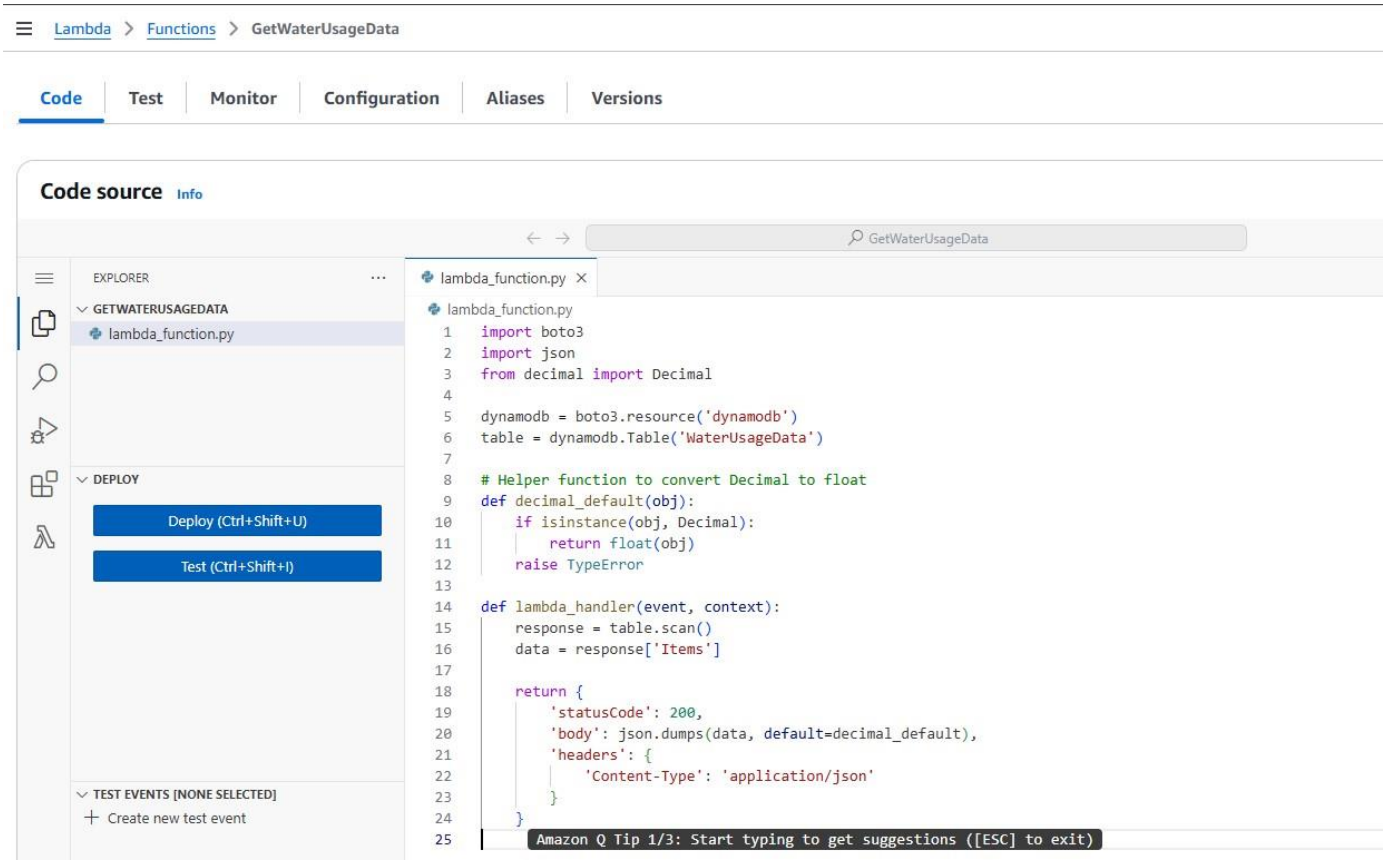


Figure 8.2: Output screen-2

8.3 Lambda Function Execution



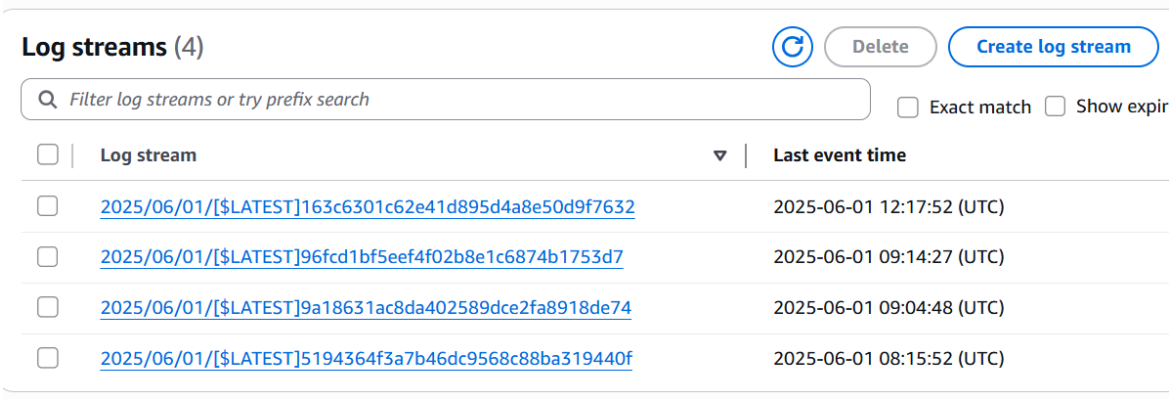


Figure 8.3: Output screen-3

8.4 DynamoDB Storage Verification

Table: WaterUsageData - Items returned (50)

Scan started on June 01, 2025, 17:31:43

device_id *(String)*	timestamp *(String)*	payload
WaterMeter001	2025-06-01 11:42:12	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.1"},"timestamp":{"S":"2025-06-01 11:42:12"}}
WaterMeter001	2025-06-01 11:42:17	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.15"},"timestamp":{"S":"2025-06-01 11:42:17"}}
WaterMeter001	2025-06-01 11:42:22	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"0.88"},"timestamp":{"S":"2025-06-01 11:42:22"}}
WaterMeter001	2025-06-01 11:42:27	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.34"},"timestamp":{"S":"2025-06-01 11:42:27"}}
WaterMeter001	2025-06-01 11:42:32	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.53"},"timestamp":{"S":"2025-06-01 11:42:32"}}
WaterMeter001	2025-06-01 11:42:37	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.78"},"timestamp":{"S":"2025-06-01 11:42:37"}}
WaterMeter001	2025-06-01 11:42:42	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.43"},"timestamp":{"S":"2025-06-01 11:42:42"}}
WaterMeter001	2025-06-01 11:42:47	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.9"},"timestamp":{"S":"2025-06-01 11:42:47"}}
WaterMeter001	2025-06-01 11:42:52	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"0.81"},"timestamp":{"S":"2025-06-01 11:42:52"}}
WaterMeter001	2025-06-01 11:42:57	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"2.93"},"timestamp":{"S":"2025-06-01 11:42:57"}}
WaterMeter001	2025-06-01 11:43:02	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"1.42"},"timestamp":{"S":"2025-06-01 11:43:02"}}
WaterMeter001	2025-06-01 11:43:07	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"1.08"},"timestamp":{"S":"2025-06-01 11:43:07"}}
WaterMeter001	2025-06-01 11:43:12	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"1.13"},"timestamp":{"S":"2025-06-01 11:43:12"}}
WaterMeter001	2025-06-01 11:43:17	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"0.93"},"timestamp":{"S":"2025-06-01 11:43:17"}}
WaterMeter001	2025-06-01 11:43:22	{"device_id":{"S":"WaterMeter001"},"flow_rate_lpm":{"N":"1.07"},"timestamp":{"S":"2025-06-01 11:43:22"}}

Figure 8.4: Output screen-4

8.5 API Gateway Testing: https://mooo6c439a.execute-api.ap-south-1.amazonaws.com/GetWaterUsageData

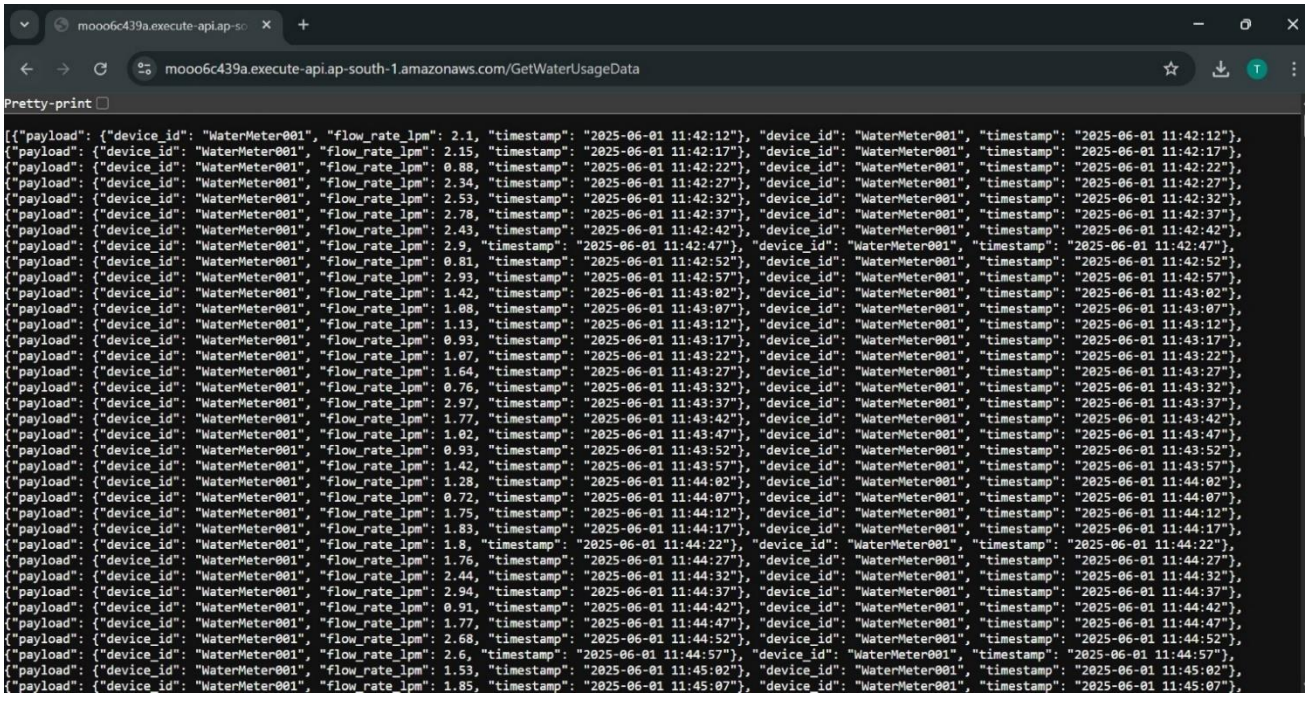


Figure 8.5: Output screen-5

9. CONCLUSION

The development of a Cloud-IoT-Based Smart Water Metering and Usage Analytics System marks a significant step forward in revolutionizing how water consumption is tracked, managed, and optimized. Traditional metering systems suffer from limitations such as manual reading, delayed billing, inaccurate consumption reports, and a complete lack of user engagement or real-time monitoring. This project successfully addresses those gaps by integrating advanced technologies like the Internet of Things (IoT), cloud computing, and data analytics into a unified, scalable platform. By deploying IoT-enabled smart meters, the system enables precise, automated data collection at regular intervals, which is then securely transmitted to cloud platforms such as Amazon Web Services (AWS) using the lightweight and efficient MQTT protocol. This real-time pipeline from sensor to cloud drastically improves the speed, accuracy, and transparency of water usage data.

The cloud infrastructure provides a robust backend for data processing, secure storage, and intelligent analytics. AWS services such as IoT Core, DynamoDB, Lambda, API Gateway, and Amazon QuickSight work together to handle device communication, manage user interactions, and present live data in visual, user-friendly dashboards. The system not only facilitates real-time consumption tracking but also empowers both consumers and utility providers with actionable insights. Consumers receive alerts for leaks, abnormal usage patterns, and peak consumption times, helping them proactively manage water use and avoid wastage. On the other hand, utility administrators benefit from system-wide dashboards, detailed usage reports, and exportable analytics that support strategic planning, demand forecasting, and timely maintenance. The system’s design also includes features like user authentication, meter-device binding, and historical data access, contributing to a complete digital transformation of water utility services.

Beyond its technical achievements, the system contributes to broader social and environmental goals. It encourages consumer awareness and accountability in water usage, supports conservation initiatives by reducing wastage, and streamlines utility operations by reducing manual effort and operational costs. Its architecture is designed to support thousands of endpoints, making it suitable for deployment in large-scale environments such as smart cities, gated communities, or municipal water networks. The flexibility to integrate additional modules in the future—like AI-based predictive analytics or multi-utility dashboards—further enhances its long-term value. In conclusion, this project stands as a robust, future-ready solution that bridges the gap between outdated utility infrastructure and the growing demand for intelligent, sustainable, and data-driven water management systems. It exemplifies how cloud and IoT technologies, when combined effectively, can solve real-world challenges while driving innovation and environmental responsibility.

10. FUTURE ENHANCEMENTS

While the current system provides a robust foundation for real-time water monitoring and analytics, there is significant scope for future enhancements that can further increase its efficiency, intelligence, and user-friendliness. One major enhancement is the integration of artificial intelligence (AI) and machine learning (ML) algorithms into the analytics pipeline. These technologies can be used to predict future consumption patterns, detect anomalies automatically, and even suggest water-saving recommendations based on historical usage. Predictive maintenance algorithms could analyze sensor data to detect signs of hardware failure or leakage before they become critical, reducing downtime and service disruptions.

Another potential improvement involves expanding the system's scope to manage multi-utility monitoring, where electricity, gas, and water consumption are tracked within the same platform. This unified dashboard would help users gain holistic insights into their household or commercial resource usage. Integration with mobile applications can also be enhanced by incorporating features like push notifications, voice assistant support (e.g., Alexa or Google Assistant), QR-code-based meter registration, and personalized user tips to improve overall engagement and accessibility. Furthermore, offering offline data caching on edge devices could ensure uninterrupted service during network outages, with automatic synchronization once connectivity is restored.

From a technical perspective, the system could evolve to support interoperability with smart home ecosystems, enabling automatic actions like shutting off water valves during leak detection or syncing usage data with home automation routines. Additionally, incorporating blockchain technology could secure data integrity and enable transparent billing processes through decentralized ledgers, especially beneficial in shared housing or large utility networks. Finally, a web-based administrative analytics portal with AI-generated reports, usage trend heatmaps, and infrastructure load forecasts would significantly benefit utility companies in making data-driven decisions.

In summary, future enhancements aim to make the system more intelligent, scalable, and adaptive to both consumer needs and evolving technology standards. These additions would not only boost system performance but also support the vision of building smarter, greener, and more sustainable cities driven by real-time data and proactive decision-making.

The system can also evolve to support smart city infrastructure, where aggregated data from multiple households or buildings is used for urban water management, demand forecasting, and drought prevention strategies.

Lastly, incorporating **voice** assistant compatibility (e.g., Alexa, Google Assistant) will make it more interactive and accessible, especially for elderly or differently-abled users.

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