IoT and Cloud Computing based Smart Water Metering System

Aritra Ray
A. K. C. School of Information Technology
University of Calcutta
Kolkata, India
aritra98.ray@gmail.com

Shreemoyee Goswami
A. K. C. School of Information Technology
University of Calcutta
Kolkata, India
shreemgoswami@gmail.com

***Abstract*—This paper focuses on the developmental and implementation methodology of smart water meter based on Internet of Things (IoT) and Cloud computing equipped with machine learning algorithms, to differentiate between normal and excessive water usage at industrial, domestic and all other sectors having an abundance of water usage, both for Indian and worldwide context. Recognizing that intelligent metering of water has the potential to alter customer engagement of water usage in urban and rural water supplies, this paper fosters for sustainable water management, a need of the present. With shrinking reserves of clean water resources worldwide, it is becoming cumbersome to cater for this resource to masses in the coming years on a consistent basis. Using our smart water meter, water resources can be managed efficiently and an optimum use could save water for the future generations. Sensors will provide for real time monitoring of hydraulic data, automated control and alarming from Cloud platform in case of events such as water leakages, excessive usage, etc. Analysis of the same will help in taking meaningful actions. Thus we do propose for a smart water metering technology that can be utilized by Indian citizens, and worldwide, to curb wastage of water. With an ease of monitoring and visualization of the data through the Cloud platform combined with machine learning based tools to detect excess water consumption, the server-less architecture we propose can be easily adopted and implemented in a large scale.**

Keywords—Cloud computing, IoT, Machine learning, Server-less architecture, Revenue generation.

I. Introduction

The 2018 edition of the United Nations World Water Development Report stated that nearly 6 billion peoples will suffer from clean water scarcity by 2050 [1]. The present scenario across India shows that we use about 27% of water for bathing and toilet use [2]. Approximately, a leaking faucet can waste 4,000 drops of water, which is equal to a liter of water within a very limited period of time. Thus in a larger context, such leaks can lead to the wastage of thousands of gallons of water. On an average one person wastes about 45 liters of water per day. To understand it better, it is almost 30% of water requirement per person per day [3]. In Indian cities, the piped water supply is owned by the state or central governments and managed by different public authorities (State water board, or Municipal water supply department) [4]. Seventeen percent of the world's human population is in India. Yet, the country has to manage with just four percent of freshwater available globally. According to the National Commission for Irrigated Water Resource Development of India, the water shortage problem we face is not due to lack of it but due to excessive waste [5].

India's water crisis is often attributed to lack of government planning, increased corporate privatization, industrial and human wastage. In addition, water scarcity in India is expected to worsen as the overall population is expected to increase to 1.6 billion by year 2050. By that time, global water scarcity is expected to become a leading cause of national political conflict in the future, and the prognosis for India will be no different [6]. Table I shows the acute water crisis that West Bengal, a major state of India is facing in particular with the rise in population [7].

TABLE I. Depicts the growth of population and declining per capita water for West Bengal

Year	Population (in Crores)	Per capita water consumption
1951	2.63	2574
1961	3.49	1940
1971	4.43	1528
1981	5.46	1240
1991	6.80	966
2001	8.02	844
2011	9.40	720

The common problems that rise in such a populated country are uneven supply of water, poor demand management practices, lack of metering, and water loss due to leakages. Table II shows domestic water consumption per household and per capita per day as collected from field reports [8].

TABLE II. Domestic water consumption per household per capita per day, as per field survey

Cities	Per Household (in liters)		Per Capita (in liters)	
	Mean	Standard Deviation	Mean	Standard Deviation
Delhi	377.7	256.8	78.0	49.9
Mumbai	406.8	158.6	90.4	32.6
Kolkata	443.2	233.6	115.6	64.9
Hyderabad	391.8	172.0	96.2	43.8
Kanpur	383.7	286.2	77.1	58.2
Ahmedabad	410.9	224.1	95.0	54.6
Madurai	363.1	182.1	88.2	44.4
Total	398.3	220.20	91.56	51.51

We would like to introduce smart water meters because they help detect leaks and major faults in water pipeline distribution system as well as alert and notify all concerned users about excessive water usages. This would encourage users to use water judiciously thereby also allowing this utility system to easily monitor the volume of water usage in every water pipe it would be fitted in through a Cloud platform. In turn by monitoring the amount of water used, the government can levy penalty for excessive usage or generate revenues as some parts of India already have a

978-1-7281-6575-2/20/$31.00 ©2020 IEEE

water taxation system in place in proportion to the amount of water used.

II. Related Works

Smart water meters previously developed [9] [10] have been for the same purpose but the entire processing is done in the data acquisition unit without the feature of Cloud computing, which would thereby make the system prone to single point of failure, that is, if the data acquisition unit fails, no more data is recorded and no knowledge is there to the user that the unit has failed until its checked physically, making it difficult to maintain in large scale implementation. In another study [11], there is a concept of the android based smartphone application to visualize the water consumption for water pipes wherein the data from the acquisition units are directly transmitted to the smartphones. In other recent studies [12] [13], they have used the Cloud platform yet the data acquisition module is designed using Raspberry Pi or Arduino UNO micro-controllers, compared to ours NodeMCU, which would make their system far costly than ours. However, our architecture involves the use of Cloud computing which have several other benefits like it can ensure server-less architecture, ease of scalability, visualization of many users at one go through mobile computing devices, implementation of machine learning techniques, efficient centralized data storage among others.

III. Proposed Methodology

Our system was designed to collect data from the water pipes, of any diameter, whose water flow rate is to be monitored. In real time, the data would be pushed from the data acquisition units at regular intervals into the cloud platform for processing. The predictive analytics would be processed on the collected data using machine learning tools and be easily be visible to the user. If excess water flow occurs, the measure of what is excess for one pipe will be different for another, and thus will be decided through efficient machine learning techniques as discussed in our paper, or if there is a continuous abnormal usage of water through a water pipe, in both cases the system generated alerts would be sent be sent to the concerned users. We have also kept in mind of the fact that whenever this gets implemented, alongside the help from governmental authorities as water is a public resource and maintained by the government, a database of water consumption would also be created and the government if willing can take measures based on the database records to curb the wastage of water in the future. The architecture we present, and has been tested out, is a server-less architecture wherein it is a way to build and run applications and services without having to manage the infrastructure. Fig. 1 depicts our proposed system architecture.

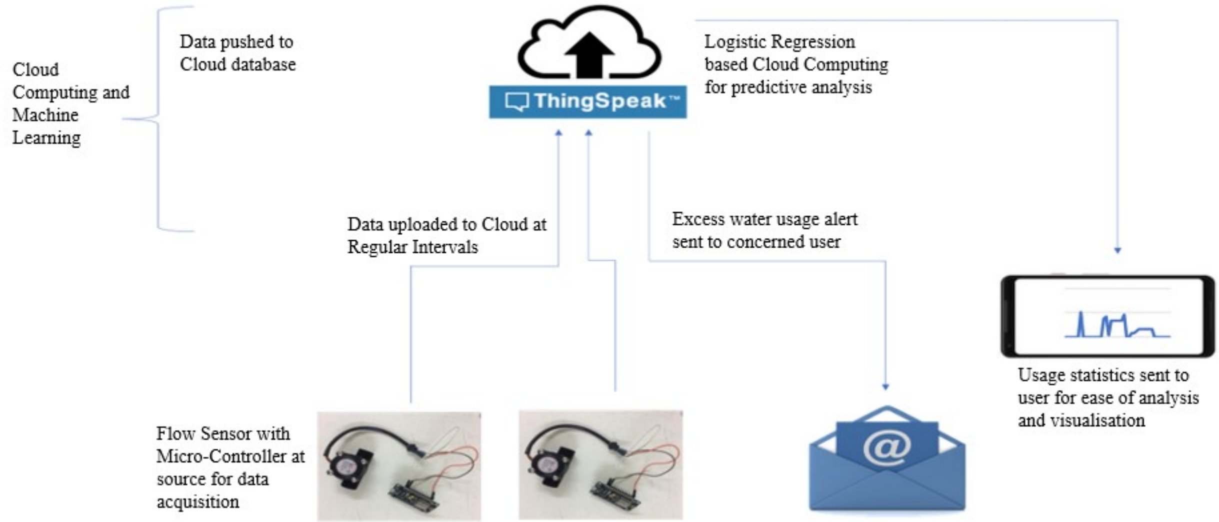


Fig. 1. Proposed Solution Architecture

A. Data Acquisition

The data acquisition unit is controlled by NodeMCU which is an open source Internet of Things (IoT) platform. [14][15] It includes a firmware which runs on the ESP8266 Wi-Fi system on chip (SoC) from Espressif Systems and hardware based on the ESP-12 module. [16][17] The term NodeMCU by default refers to the firmware rather than the development kits. The firmware uses the Lua scripting language. It is based on the eLua project and built on the Espressif Non-OS SDK for ESP8266. We interfaced the NodeMCU unit with YF-S201 water flow sensor which sits in line with the water line, whose water flow is to be monitored. It contains a pinwheel sensor to measure how much water has moved through it. There is an integrated magnetic hall-effect sensor in it that outputs an electrical pulse with every revolution. Herein we have preferred the use of NodeMCU for designing the data acquisition unit because this part of the architecture doesn't deal with any sort of data processing and just to acquire the data periodically and transmit them in real-time data to the Cloud server, designing the system using NodeMCU also curtailed costs by almost 56% compared to using micro-controllers like Atmega 328 which is popularly implemented in Arduino. Keeping in mind the fact that we designed the system to be self-sufficient, that is, to ensure the system can work independently without any external power source, we harnessed solar energy through solar panels and the supply voltage was provided using solar cells. The operating voltage of the NodeMCU being at 3.3V makes it optimum for our architectural design to be a success. We have also thought of implementing a small memory unit to that of the NodeMCU wherein if in case the internet connection is put off for some time, as it can happen in real life scenarios, the data acquired can be stored and be sent all at once into the Cloud platform once internet connectivity sets in. The data acquisition unit that we developed is depicted as in fig. 2.

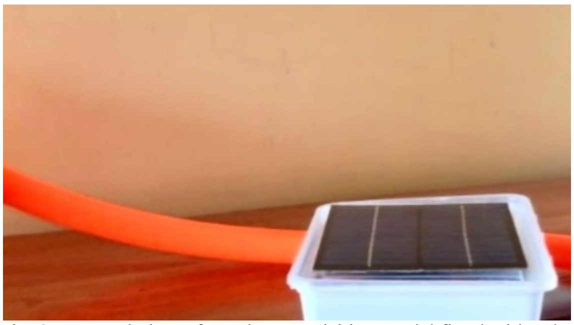


Fig. 2. External view of our data acquisition model fitted with solar panel.

B. *Connectivity with Cloud platform*

The data collected at the water pipe line unit was transmitted in real time to ThingSpeak Cloud platform. ThingSpeak Cloud platform allows us to aggregate, visualize and analyze live data streams in the cloud. Some of the key capabilities of ThingSpeak Cloud platform include its ability to easily configure devices to send data to ThingSpeak Cloud platform using popular IoT protocols and visualizing the sensor data in real-time. A channel, with a unique identification key, access controls either as public or private, read write API keys among other features, is allocated for every unit or channel that collects data and thus recordings of each water pipeline can be monitored and access controls of what will be made visible to specific users can be regulated as per requirement ensuring data abstraction.

C. *Graphical visualization*

Data received on the Cloud platform gets automatically G.M.T time stamped and visualizations can be easily done though mobile computing devices by the concerned user a single click of a button. The concerned user for the specific water pipe can visualize the water usage he has used for a specific interval of time and the concerned regulatory authorities like for instance the government can keep track of the usage patterns of all concerned users as access controls would be defined accordingly for the users.

D. *Volume of water consumed*

The total volume of water consumed though a particular water pipe can be measured for a particular period of time, as deemed necessary very easily though the click of a button in the Cloud dashboard. The underlying functionality we designed was by using the trapz function and defining the window size for which we wanted to calculate the total water consumed. This was used to calculate the historical data of total water usage for a particular meter and thus interpret it as normal or excessive flow.

E. *Applications of Machine Learning Tools*

We used machine learning to identify and differentiate flow patterns as normal, excessive or continuous flow. The underlying principle does indicate that what maybe excess flow for one water pipe may not be so for another one as the diameter of the water pipes vary, the usage of the water consumed through the water pipe like for instance it can be used for commercial or industrial or domestic purposes vary and many other factors determine it. Thus we developed a tool to differentiate between excess and normal consumption for water, wherein the model can specifically train itself for every water pipe.

We performed linear regression on the historical data that we acquired and tested it for unknown flow rates. However, the result was erratic as the water flow patterns in real life are not linear in nature. Thus we moved on with logistic regression model as a tool to differentiate between normal and excessive flow. This performed much better on average compared to the prior. Since logistic regression model requires a classifier set to train initially, we had to design a classifier model that could be used to train our model about what is normal and what is excessive flow using historical data. We have tested a few machine learning models on some sample data and the linear support vector model has given the most accurate results in terms of classifying the data into two classes. Hence, we have used the linear SVM model to generate a classifier to be used by the logistic regression technique.

F. *System generated alerts*

Once excess water flow was detected in any one of the water pipe lines, system generated alerts were triggered to all concerned users through email notifications. Multiple users can easily be notified as per need, as well as to the concerned authorities. Herein, we deploy the WebHooks services with IFTTT platform to alert the concerned group of users. The Webhooks service allowed us to integrate services on IFTTT with our project via simple web requests. If This Then That, also known as IFTTT, is a free web-based service to create chains of simple conditional statements, called applets. An applet is triggered by changes that occur within other web services like email services that we used here.

G. *Integration of all the designed modules*

Execution and ordering of all these modules for analysis and visualization can easily be controlled by the 'Time Control' feature of the ThingSpeak Cloud platform which allows to trigger each program on the data that is acquired continuously as per the desired prefixed time intervals. This way we can monitor the water flow in each pipes and run the machine learning algorithms to classify it as normal and excess flow and alert the concerned users through emails in case of the later. The visualization of the same can be done at the will of the concerned users by logging into their account and opening up the visualizations in their ThingSpeak Cloud platform dashboard.

H. *Harnessing Solar Power to make system self-sufficient*

We affixed a solar panel, as shown in fig. 2 to charge up a solar cell in the data acquisition unit to provide for the running voltage for the water meter. This would make our meter self-sufficient.

I. Proposed Revenue Model

As water in particular is under the jurisdiction of the governmental authorities in India, the large scale scarcity is a serious issue in the coming years, only in few parts of southern India, water taxes are levied, keeping a large part void, both across India and worldwide in many countries. Based on a literature survey of how the taxation process works in Tamil Nadu, a state in India, we have implementation of the proposed water meters can only be done under governmental guidance. Though the water given some representational figures in Table III [18] of the revenues that the governmental bodies and other concerned agencies can generate once the proposed concept of water meter could be implemented in a large scale process. KL in Table III indicates kilo-liters.

TABLE III. A POSSIBLE REVENUE MODEL THAT CAN BE IMPLEMENTED

Category	Quantity of Water	Rate/KL (in Rupees) or quantity consumed	Minimum Rate Chargeable (in Rupees)	Frequency of Billing
A. Domestic				
Flats or houses in a block of flats or line of houses respectively and used specifically for residential purposes. (Total consumption divided by no. of flats.)	Up to 10 KL	4.00	Rs.80/- per month per dwelling unit	Monthly
		11 to 15KL	16.00	
		16 to 25 KL	24.00	
		Above 25 KL	40.00	
B. Commercial				
	Private Hospital – up to 500 KL.		Rs.1694/-* (Water Intensive)	Monthly
	All others up to - 500 KL		Rs.787/- (Non Water Intensive)	Monthly
	Private Hospitals - above 500 KL		Rs.1694/- *(Water Intensive)	Monthly
	All others - above 500 KL		Rs.1452/- *(Water intensive)	Monthly
	Industry Up to – 500 KL		Rs.787 /-* (Water intensive)	Monthly
	Industry – above 500 KL		Rs.145/KL for entire quantity	Monthly
C. Institutional				
	Private Educational Institutions	85.00/K.L. entire quantity	Rs.787.00	Monthly
	Government Hospitals	43/K.L. entire quantity	Rs.424.00	Monthly
	All others	61.00/K.L. entire quantity	Rs.605.00	Monthly
D. Municipal Bulk supply				
	Entire consumption	7.00 /KL (wherever local bodies meet the cost of infrastructure)	-	Monthly
	* Water intensive means premises used fully or partly as Theatres, Hotels, Boarding Houses, Lodges, Clubs, Private Hospitals, Private Hostels, Clinic with patient facility, Swimming baths Places for keeping animals, Vehicle Service Stations, Nurseries.			
E.	Hydrant and Public Supply (per fountain per month including maintenance charges)		Rs.1200/-	Monthly
F.	Mobile Water Supply to Slums		Rs.39/- per 1000 litres for entire quantity supplied. + Hire charges	Monthly

IV. RESULTS

A. Data Acquisition and real time transmission

The flow sensor reading was noted by the NodeMCU and transmitted at regular intervals to the ThingSpeak Cloud platform once internet connectivity set in. Fig. 3 shows the real time transmission of the data collected from the flow sensor to the ThingSpeak Cloud server platform.

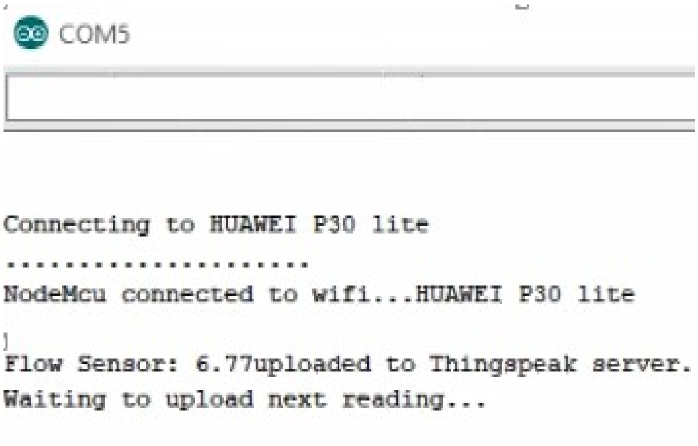


Fig. 3 . Data being uploaded from the NodeMCU to the ThingSpeak Cloud server platform as shown in the serial monitor of the NodeMCU programming IDE.

B. *Data Visualization*

The data is stored in the Cloud platform with their respective G.M.T. timestamps as shown in fig. 4. The graphical plot is simply generated from these data points through a piece of code, trapz function specifically, that specifies the time duration or the window size for the plot as given in fig. 5.

Timestamps	FlowMeter
02-Nov-2019 13:40:20	0.32
02-Nov-2019 13:41:08	0.32
02-Nov-2019 13:44:30	0.32
02-Nov-2019 13:49:22	0.97
02-Nov-2019 13:49:38	0.97
02-Nov-2019 13:51:13	0.32
02-Nov-2019 13:51:40	5.81
02-Nov-2019 13:55:07	0.32
02-Nov-2019 13:55:38	0.97
02-Nov-2019 13:56:09	1.29
02-Nov-2019 13:56:55	1.61
02-Nov-2019 13:57:26	0.97
02-Nov-2019 14:00:51	0.65
02-Nov-2019 14:01:08	0.32
02-Nov-2019 14:08:07	0
02-Nov-2019 14:13:18	4.84
02-Nov-2019 14:13:50	5.16
02-Nov-2019 14:16:12	2.26
02-Nov-2019 14:20:57	4.52
02-Nov-2019 14:21:13	4.52
02-Nov-2019 14:22:16	4.52
02-Nov-2019 14:23:51	4.52
02-Nov-2019 14:24:07	4.52
02-Nov-2019 14:25:42	5.48
02-Nov-2019 14:26:46	1.61
02-Nov-2019 14:27:02	1.61
02-Nov-2019 14:27:33	2.58
02-Nov-2019 14:29:08	2.58
02-Nov-2019 14:31:16	2.9
02-Nov-2019 14:32:51	3.23
02-Nov-2019 14:33:54	3.23
02-Nov-2019 14:34:10	3.23
02-Nov-2019 14:37:36	3.23
02-Nov-2019 14:38:38	3.23
02-Nov-2019 14:38:53	3.23
02-Nov-2019 14:41:40	0.97
02-Nov-2019 14:42:10	0.65
02-Nov-2019 14:42:25	0.97
02-Nov-2019 14:42:41	0.97
02-Nov-2019 14:43:27	0.97
02-Nov-2019 14:44:13	0.65
02-Nov-2019 14:44:43	0.65

Fig. 4. The data as received in the Cloud platform.

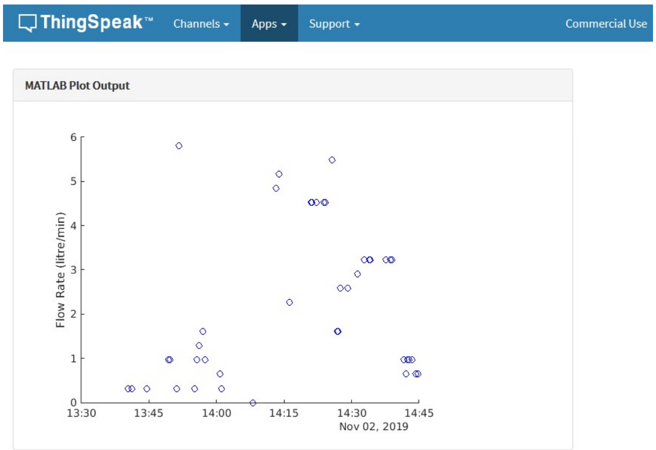


Fig. 5. Data represented graphically, for a defined window size, for ease of understanding

C. *Machine Learning models*

The two machine learning models as described in the proposed methodology section were tried out in regard to the sample data, alongside the linear support vector classifier and the graphical representation of how they featured are as shown in fig. 6 and fig. 7.

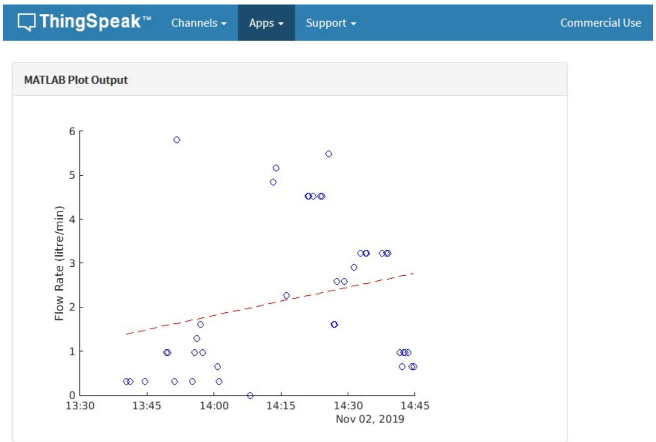
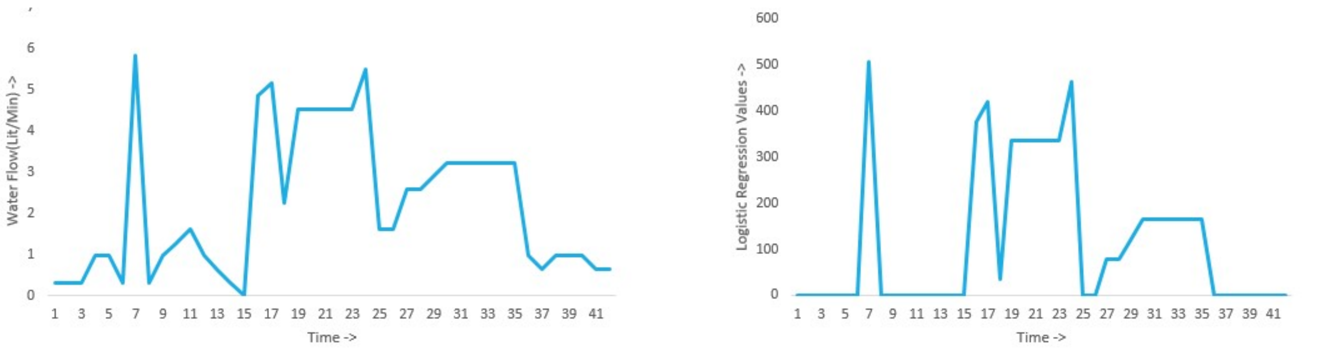


Fig. 6. Linear Regression model used on the historical data to learn flow rates, which is specific for each water meter.

V. *Implementation Risk and Mitigation Issues*

- At times, the water pipelines may be buried deep inside the architectural design of the building, then it may get difficult in connecting the water meter there. For such an event, we may need to monitor through some other pipes, like the ones coming out of the storage tanks, etc. wherein at times, we may require more meters than just one for net monitoring of an industrial set-up or residential complex or likewise.



Line graph from actual flow, as recorded by sensor

Logistic Regression model used on the same historical data to learn flow rates, which is specific to each flow meter

Fig. 7. Logistic regression models used to analyse flow rates.

- Failure to get internet (network) connectivity, for which the data may not be pushed up into the cloud. Thus we need to have a local storage of the flow rates in the acquisition unit and push it back to the cloud once internet connectivity gets restored.
- There may be intentional or environmental disconnection of the internet connectivity or damage inflicted to the meter. Thus it may be required to deploy some individuals to investigate such occurrences or send alerts to the concerned users that no meter readings are sent into the cloud for a specific period of time.

VI. Discussion

Our smart water meter has low infrastructural cost, as only NodeMCU and the water flow sensor was used in recording, visualizing and analyzing the water flow patterns. For a large scale implementation, it would encumber a cost of accessing the Cloud facilities. We have proposed a server less architecture that would ensure reliability of the data once recorded in the cloud. We deploy the use of Cloud Computing for recording, visualizing and analyzing flow patterns, analysis specific to each water pipe made possible through a single machine learning model trained specifically for every water meter, and generation of alerts. Reliability and accountability of visualization and analysis of the data is also very high as Cloud Computing is used. Ease of access is also very high as we deploy the entire processing of data in Cloud Computing domain, which allows users to visualize data from any corner of the world at any time. It is secured, as only authorized users can login and only view that portion of the data they are authorized to view. ThingSpeak, a platform designed by MathWorks is quite prompt in this domain. Cost of Cloud Computing is also not very high as ThingSpeak Cloud platform is relatively cheap compared to others in the race and it will allow enormous amount of data to be processed at low cost. Excessive water flow is notified on immediate historical data and that could prevent wastage of water and ensure proper water resource management. It is a self-sustainable model as we do make use of solar panels to run the data acquisition unit and transmit the data to the Cloud platform in real time.

References

[1] Boretti, A., Rosa, L. Reassessing the projections of the World Water Development Report. npj Clean Water 2, 15 (2019).

[2] Gupta, Aditya & Mishra, S. & Bokde, Neeraj & Kulat, K.D.. (2016). Need of smart water systems in India. 11. 2216-2223.

[3] https://indiaeducationdiary.in/every-indian-wastes-45-litres-water-per-day/

[4] A. Amiraly and A. Kanniganti, The impact of a pilot water metering project in an Indian city on users' perception of the public water supply, The Journal of Field Actions, Vol 5, 2011.

[5] https://www.livpure.com/blog/10-shocking-facts-about-water-wastage-in-india-you-should-know

[6] https://thewaterproject.org/water-crisis/water-in-crisis-india

[7] The Status of Water Resources in West Bengal, Kalyan Rudra, Posted Date : Wed, 2009-08-12 12:58 hrs, Water India Portal

[8] Abdul Shaban, R N Sharma, Water Consumption Patterns in Domestic Households in Major Cities, Economic and Political Weekly June 9, 2007.

[9] D.Anandhavalli, K.S. Sangeetha, V. Priya Dharshini, B. Lukshana Fathima, Smart Meter for Water Utilization using IoT, International Research Journal of Engineering and Technology (IRJET), Volume: 05 Issue: 04, Apr-2018.

[10] M. J. Mudumbe and A. M. Abu-Mahfouz, "Smart water meter system for user-centric consumption measurement," *2015 IEEE 13th International Conference on Industrial Informatics (INDIN)*, Cambridge, 2015, pp. 993-998.

[11] M. Suresh, U. Muthukumar and J. Chandapillai, "A novel smart water-meter based on IoT and smartphone app for city distribution management," *2017 IEEE Region 10 Symposium (TENSYMP)*, Cochin, 2017, pp. 1-5.

[12] Maruthi H V, Lakshmi Priya, Lavanya A R, Meda Manideep, "AN IOT-BASED WATER SUPPLY MONITORING AND CONTROLLING SYSTEM", International Journal of Advanced Research in Computer Science (ISSN: 0976-5697) CONFERENCE PAPER Available Online, Conference Paper: Third National Conference on "Advances in Computing and Information Technology", Volume 9, Special Issue No. 3, May 2018.

[13] G. M. Tamilselvan, V. Ashishkumar, S. Jothi Prasath, S. Mohammed Yusuff, "IoT Based Automated Water Distribution System with Water Theft Control and Water Purchasing System", International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-7 Issue-4S, November 2018

[14] Zeroday, "A lua based firmware for wifi-soc esp8266" Github. Retrieved 2 April 2015

[15] Hari Wignua. "NodeMCU LUA Firmware". Hackday. Retreived 2 April 2015.

[16] Systems, Espressif. "Espressif Systems". Espressif-WikiDevi. Retrieved 3 June 2017

[17] Brian Benchoff. "A DEV BOARD FOR THE ESP LUA INTERPRETER". Hackaday. Retrieved 2 April 2015.

[18] https://chennaimetrowater.tn.gov.in/tariff.html