# *Optimization of Water Consumption Using Dynamic Quota based Smart Water Management System*

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**Abstract—Water is a vital resource for life and for the economy. Nowadays, one of the most serious challenges to solve is to manage water scarcity. As the importance of water usage optimization in monetary point of view is not that pronounced, we lack the incentive to invest in implementing technologically advanced systems for organized distribution of water. This paper describes the development of a meticulous water distribution system at a city level that will guarantee a continuous supply of water, overcoming some major issues like unaccounted supply to entities and Non-Revenue Water (NRW). A centralized control room equipped with a local computing machine and a Human Machine Interface (HMI) to monitor and control the city's water system is proposed. A smart tariff system should be exercised with an IoT-enabled mobile-friendly web portal developed for accessing various water usage statistics accompanied with an option of paying water bills online. In this volumetric, limit based model, the quota assigned to each entity is decided dynamically based on various supply and demand parameters including the availability of water with changing seasons. Adaptive learning through machine learning algorithms was used for the same. Unbilled, unauthorized consumption, apparent losses (water theft and metering inaccuracies) and transportation losses was curbed by monitoring from a remote location via IoT. Higher degree of theft and leakage was concluded using loss detection technique using the differential flow data. Here, a novel, cost-effective, real-time monitorable and controllable system is proposed with an analysis on a model simulation being performed for optimal water distribution.**

***Keywords—Smart water distribution, NRW, quota, IoT, Machine Learning***

## I. INTRODUCTION

Water is a precious natural resource with fixed quantum of availability. With continuous growth in our country's population, the per capita availability of utilizable water is going down. Rapid industrialization and urbanization have led to an improved standard of living which has increased the demand for fresh water.

However, unlike electricity and fuel, the importance of water usage optimization in the monetary point of view is not that pronounced. The fear that the cost of additional measurement, control, and automation of the related parameters may result in an exponential increase in water bills has acted as a major deterrent in the past years. The Per capita availability of fresh water in 2014 for the United States was 8,836 $m^3$. Whereas, for India, it was just 1,116 $m^3$ [1]. This number is decreasing every year which is evident as it was 1816 $m^3$ in 2001 and 1545 $m^3$ in 2011 [2].

We lack the incentive to invest in the installations and implementation of technologically advanced systems for the organized distribution of water. This vicious cycle has deeply impacted the water management system causing unrecorded and abysmal losses in water quantity.

This paper aims at developing a meticulous water management system at a city level that will guarantee measured, recorded and continuous supply of water with 24x7 supply of water, overcoming the major issues of unaccounted supply to entities and Non-Revenue Water (NRW) [3]. Instead of providing unregulated water for a limited period i.e. a time-based water system (currently deployed in many parts of India), a quota-based system is proposed wherein water will be provided all day. The quota assigned to each entity will be decided dynamically based on various supply and demand parameters.

## II. QUOTA DECIDING MECHANISM:

In most of the cities today, water is distributed on a timely basis, having no measure of the quantity being used. It is experimentally proven that storing water in locally installed tanks (present in every residence) for daily consumption results in more consumption of water than when provided with a continuous supply of water. Hence for better management and appropriate future planning, a system with 24x7 water supply is proposed. For conservation and preservation of water, an upper limit (quota) will be set on each consumer.

As per the Ministry of Urban Development, 150 liters [4] is considered to be a sufficient amount of water for a person residing in an urban area to live a comfortable life. Setting a quota on each entity (bungalow, flat, tenement, apartment, etc.) will ensure proper usage of water and curtail wastage.

Quota will be a dynamically changing parameter which will depend majorly on the following four parameters:

### *A. Number of residents:*

As the capacity of 150 liters is given to one person per day, the number of people living in a residence will define the usage limit for the house. As an example, for a house with four residents, the maximum quota will be $150 \times 4 = 600$ litres.

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### B. Present Dam water level:

The main water source for the city is generally a dam. The total stored water in its reservoir basically defines the water available for the city's usage. The volume of available water can be estimated by measuring the water level. Depending upon the time remaining for the next rains to start, the dam water level measurement can be used to manage water cuts, especially during summer seasons.

### C. Predicted consumption:

A major factor to consider in water management is the demand from the city. The water consumption of the city is ever increasing due to increase in the population and improvised standard of living of its residents. Hence the data of water usage collected in a certain year may not work for the next year. This can cause improper management of water leading to scarcity during summers.

A solution to this problem is predicting the water usage for the next year. Machine learning algorithm is applied to get the data for the next year. The consumption data (in MLD) of previous years is fed into the computer. The current data is sent in real time by using Internet of Things (IoT). The whole data is then analyzed and computed to get the predicted water consumption of the next year.

Multiple Linear regression technique [5] is used for the basic level. But as data increases and accuracy is to be maintained, more complex algorithms need to be implemented. The accuracy of predicted values would keep on increasing as more and more data is gathered by the computer.

### D. Estimated Rainfall

In case the water reserves are used completely, and the rainfall of next monsoon is not sufficient to fill them, it can create a scarcity condition.

To avoid such a situation, it is important to consider the estimated rainfall of the forthcoming year. This data can be taken from the meteorological department (MeT dept.) [6]. It would help in calculating the amount of water available for the next year.

## III. Quota Calculation

The quota is calculated based on two parts:

- *Current scenario*
- *Future Predictions*

The 'current dam water level' and 'total number of residents' considers the current scenario. These two parameters will be given more priority as these would have a strong effect on the society.

City/Sector's 'water consumption prediction' for the next year and 'estimated rainfall' gives the future estimation of water levels. These are important for future planning but may not affect society in near future. Hence these are given lesser priority in the quota decision mechanism.

The condition for what happens when the quota is exceeded depends on the current situation of the city at that time. Broadly, the cases are:

#### 1) Case I: Abundance of water

If the city's water source has ample of water available such that even with a little over-usage the water source will suffice the rest of the city, extra water will be given to the consumers, on their demand, at a higher tariff rate. This will ensure that people use water in limited quantities and the wastage gets controlled.

#### 2) Case II: Scarcity of water

Primarily during summers, the scarcity of water makes it very difficult for the government to provide water, even for the basic necessities. At such times, water will be cut-off at the building level to ensure equal water distribution for all. The water cut is controlled using a solenoid operated valve at the input of each building. The valve will reset the next day.

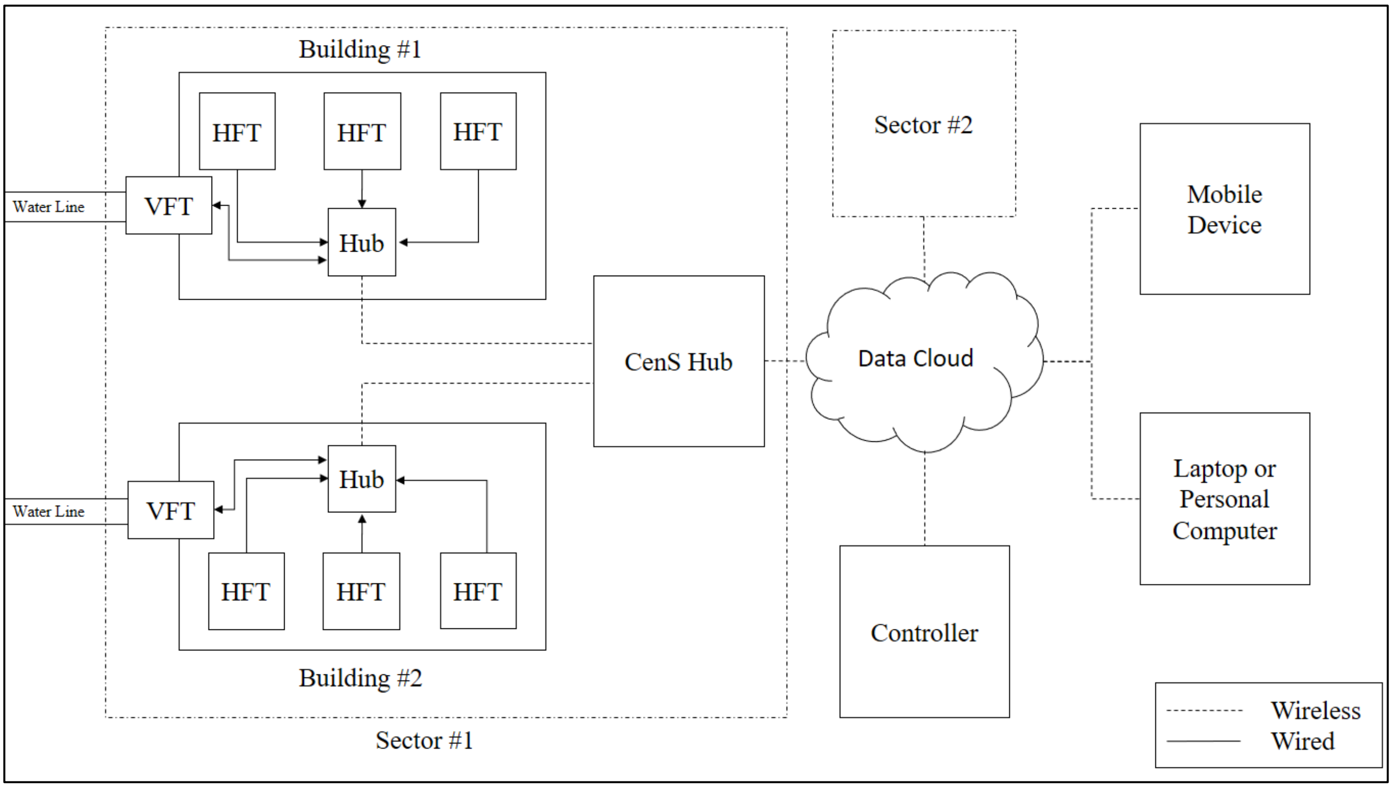
## IV. Internet of Things (IoT)

Implementation of IoT [7] will facilitate the feature to monitor the water usage and other water statistics with added option of paying water bills online conveniently from places where the Internet is accessible. A person can access his/her usage statistics from either his/her mobile device or any internet enabled device by providing the ID of his/her own society or house.

Internet connectivity in many areas is still not well established. So, for implementing this IoT-based system in a cost-effective manner, the city is divided into sectors (Refer Fig. 1). Every building of a particular sector will have a common hub (COM Hub) with wireless communication capability. The COM Hubs will communicate with a central sector hub (CenS Hub) of that sector on a private wireless network, not necessarily Internet (to reduce reliability over Internet connectivity of that sector). All the usage data from the COM Hubs will be collected by the CenS Hub, which will push the data to the cloud. Hence internet connectivity now must be maintained only at one point in that sector.

The size/radius of the sector will depend on the density of the area. Local wireless communication is highly hindered by obstacles. Hence high-density areas will have smaller sector sizes.

A controller will be monitoring all the usage statistics and control the input lines to each building. As soon as the quota for an entity is ended, the controller will know about it and signal the Solenoid controlled water flow transmitter (VFT). Also, it will calculate the tariff for each entity and send the data to the cloud. A web portal will access such similar data from the cloud and keep it on display for the residents. The system can be made transparent with the help of this web portal. For example, the water usage quota highly depends on the current dam water level. Citizens can see the current dam water level on these portals so that they do not feel cheated for a reduced usage quota.




*HFT – Home Flow Transmitters, VFT – Valve Flow Transmitters, CenS Hub – Central Sector Hub, Hub – Building COM Hub*

*Fig. 1: IoT Data Flow Diagram*

The implementation scope will include wireless IoT-enabled meters which will seamlessly send data to the cloud. The controller will collect data from the cloud, do the math and again feed the output to the cloud. The users will access this output via their internet enabled devices.

## V. 'NON-REVENUE WATER' REDUCTION

Over 70 percent water in Maharashtra is unaccounted for, i.e. not metered [8]. High levels of NRW are detrimental to the financial viability of water utilities, as well to the quality of the water itself. This majorly includes unbilled authorized consumption, water evaporating from open reservoirs, seepage in ground in reservoirs, apparent losses (water theft and metering inaccuracies), losses at storage tanks, distribution points and transportation losses. In the proposed system, flowmeters are to be installed at maximum distance of 2 km or at pipe junctions, whichever comes first in each pipeline. The instantaneous flow at the two points is different, hence integrated flow is taken into consideration. These flowmeters are to be continuously monitored and the totalizer data is to be sent to the control room wirelessly. On further processing of this data, the NRW is calculated e.g. the difference in the water meter at the outgoing of each pumping station and the flowmeter at the incoming pipeline of the water treatment plant. Also, in totality, the water let out to nature through the various sewage treatment plants as against the metered water given to the city through the dam would be the total water lost in transportation.

## VI. LEAKAGES, THEFTS AND PIPE BURSTS

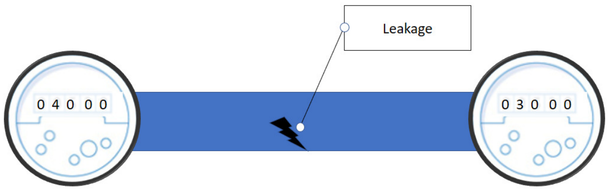



*Fig. 2: Leakage Detection*

Water is lost in transportation due to the mentioned reasons. The degree of theft and leakage is concluded using the loss detection algorithm. Various algorithms are present to detect water thefts and leakages [9,10]. In our algorithm, the degree of loss is calculated using the differential flow data. The unique name tags assigned to the flow sensors mapped with geographical locations all over the city allow the controller to pinpoint the exact source of water loss. There is an alarm activated instantaneously which also provides information regarding the degree of loss. The operator in control room, as well as the manager linked to the area, are immediately alerted. Even in an extreme case such as a pipe burst, which is the highest degree of loss, the time taken for rectification action reduces considerably. The alarm must be acknowledged; however, provision has been made in the algorithm that the alarm persists till the pipe has been repaired, acting as a constant reminder.

## VII. PREVENTIVE MAINTENANCE

The current system of water distribution is such that it introduces undue strain on the pipeline infrastructure. Water is distributed only in a time window of a duration of 2-3 hours per day. The taps are turned on by all users in the entire city to avail water. Thus, there is a sudden pressure on the main pipeline, increasing the probability of a burst. Along with this, the end user entities do not get enough pressure in their lines thus causing further issues of insufficient pressure for raising the water in overhead tanks. To tackle both these hardships singlehandedly, the quota based system has been introduced. The distribution of time slots of water in the entire day reduces pressure in the main pipeline as well as provides with sufficient pressure in the individual lines of the end users.

## VIII. IMPLEMENTATION ON MODEL

The concept of 'Virtual water' was introduced to encompass majority of the levels of water distribution in a city and an inclusive model was developed. In the virtual water model, the mapping of voltage to flow rate was used.

Mitsubishi's FX5U-32MT-ESS PLC was used as the controller for the model. A centralized control room has been developed with a master screen to monitor and control the city water management. GS2107 HMI has been employed for the same.

PLC as a controller was used majorly because of its higher number of I/O ports. Also, easier interfacing options for communication with different devices and simplicity in developing big algorithms with industrial standards and interlocks is an advantage. Ruggedness of PLC offers higher maintainability and sustainability of hardware.

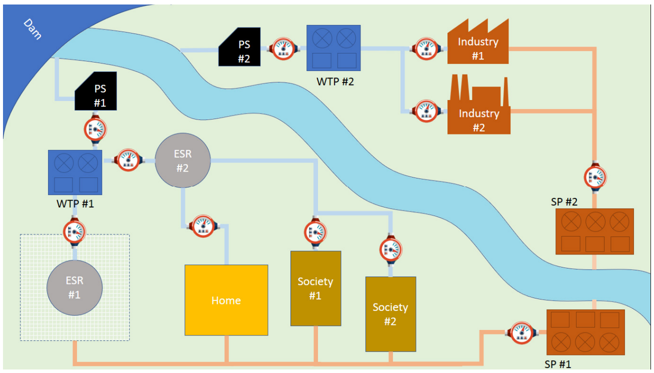
Machine learning is implemented as a parallel process in this transition to smart technology:

- For analysis and prediction of the future projection of water usage in existing scenario
- For the benchmarking in smart system

In the model, the dam water level can be controlled by changing the voltage using a potentiometer to simulate changing seasons e.g. low water level in summer and high water level in monsoon. The quotas allotted change consequently, thus the distribution of water right up to the last house will change accordingly. This usage data at each junction is collected by the controller.

The HMI displays the current usage trends and available water for usage at all instants with real-time changes. The modeled voltage was calibrated to flow. It is also possible to analyze the consequences if the individual units (houses, offices, etc.) consume more than the allotted limit of water or even less than the allotted amount, thus giving a comprehensive overview of all the possible combinations. This will help to verify whether the proposed solution is really near foolproof as is claimed.

Leakage, water theft and pipe burst can be detected. Locations of leakages and thefts are detected using the loss detection algorithm using the differences of water supply at two nodes, which is analogous to the difference in the readings of the water meters placed at two points in the path. Thus, the total amount water that is unaccounted for is deduced. This will result in the precise calculation of NRW. As a system response, apt alarms for leakage, water theft and pipe burst are separately built on HMI.




*PS – Pumping Station, ESR – Elevated Service Reservoir, WTP – Water Treatment Plant, SP – Sewage Plant,*

*Fig. 3: Block Diagram of the Model*

Smart tariff system is exercised at the back end, exploring the data processing power of the controller. The data usages per entity along with tariff is then sent to cloud. The special web portal and mobile-friendly platform has been developed and used for accessing the usage data and bill by individuals' login. It is also used for broad usages by any interested party under the Right to Information Act, 2005.

The analog input ports required surpassed by far the actual ports available on the controller. Thus, a data selector was introduced with the multiplexing ratio of 16:1.

The PLC is connected to the machine via Seamless Message Protocol (SLMP) [11]. PLC is also sharing data with HMI using Ethernet. Hence, an Ethernet hub is used for the connection of PLC, PC and HMI. (Refer Fig. 4)

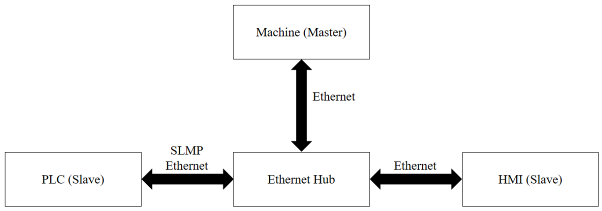



*Fig. 4: Block Diagram of Hardware Connections*

### A. Machine Learning:

Machine learning was used for the city's water usage prediction. Multiple Linear Regression algorithm was used for the calculations of each month. It was implemented on a machine (computer) which was connected to the controller through an Ethernet cable via a standard protocol. The machine learning algorithm was run on a local machine.

GNU Octave [12] was used as the coding platform for computing the predicted values. The present usage data was received from the field, by the controller. The controller then sent the data to the machine. A VBScript code was used to automate the transfer of data between the controller and the machine. On receiving the data, octave fetched the readings from the text file, and applied the algorithm on it. The output, i.e. the predicted value of the usage of the city, was being written in a separate text file. The data was then sent back to the controller, which sent it to the Human Machine Interface (HMI) for graphical visualization. The received data was also used to calculate quota of the citizens

### *B. Internet of Things*

Our implementation scope was to collect data from all water meters (voltmeters) with a wired connection to the controller's inputs. All analog voltage readings were stored in respective variables. To reduce cost, the local machine used for running machine learning algorithm, was also used for exchanging data on cloud; instead of attaching a Wi-Fi Module directly to the controller. A Master-Slave model of communication was established. The local machine (Master) commands the controller (Slave) to send all data via the Ethernet. This data is collectively sent in a hexadecimal coded character string to the local machine. It decoded this string, and sent some data sets to the machine learning algorithm (for improving its predictions) and all other data to the cloud in a text file. A web portal hosted on an FTP server accessed this data from the text file to display appropriate data on respective web pages. All processes involved here were automated by running scripts on the local machine.

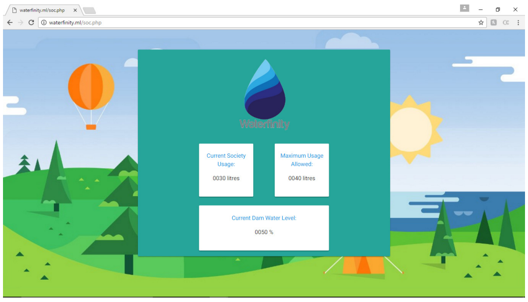



*Fig. 5: Web portal (*www.waterfinity.ml*)*

Our project scope covered implementation of the following IoT features (Refer fig.5):

- Monitoring of society's current water usage
- Check today's society's maximum water usage quota
- Check water bill for the current and the previous month of personal home

## IX. RESULT:

As soon as the consumption of a society or a housing entity exceeds the calculated quota, the water line (shown by LEDs) is turned off or starts blinking, depending upon the availability of water (refer Section III). The blinking shows that the quota is exceeded, but extra water can be used at a higher tariff.

A graph showing water usage of the city in the year of 2014 to 2016 (refer Fig. 6) is plotted. The three sets of data are used to predict the usage for the year of 2017; where the predicted output is shown by the red line.

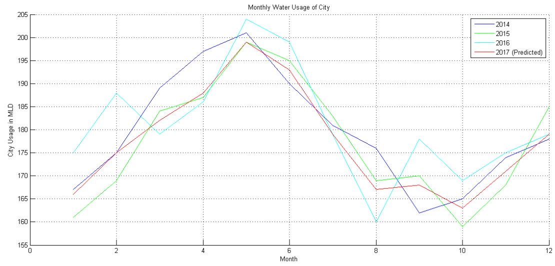



*Fig. 6: Machine Learning Graph*

## X. CONCLUSION

This is a low-cost practical solution suitable for many developing countries where proper management of this scarce resource is of paramount importance for social and economic development.

A novel, cost-effective system to overcome the basic water distribution problem with its salient features is presented in this paper with the added feature of incorporating IoT platforms for real-time monitoring. This should be an excellent contender in real-time monitoring solutions.

Future work can involve creating an application that will interface with the server so that the consumers can either demand for more water or monitor their water pipeline activities.

*"The need for innovation today is not to make a smart city but to make a city smart"*

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