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Auditing of Filtered Municipal Water Quality Using Deep Learning - A comprehensive IoT based Neural Network Model

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***Abstract*— The paramount problem faced by living beings regarding the universal solvent is its salinity and other dissolved solvents. Also being the requisite for the existence of life, its characteristics and composition is to be made favourable for the well being of living beings. To purify the water from the water resources which is not potable, efficient filtration technologies have been developed. The quality of the purified water is monitored through the IOT module in the respective plants. This data is then fed to a Neural Network Model which then predicts the quality of filtration of the particular plant with respect to the quality of the water derived from it. These technologies are equipped to combat the issues in filtration plants and quality in municipal water distributed to homes. Water purification and Quality monitoring and prediction is still is a major concern in research as more efficient water purification techniques are evolving to combat the shortcomings of existing techniques.**

Keywords* : *Water Quality Monitoring , IOT, Recurrent Neural Network, Osmosis, Electrolysis, Ultrafiltration, UltraViolet radiation.

I. INTRODUCTION

Water, predominantly is a molecule composed of one oxygen atom and two hydrogen atoms affixed by covalent

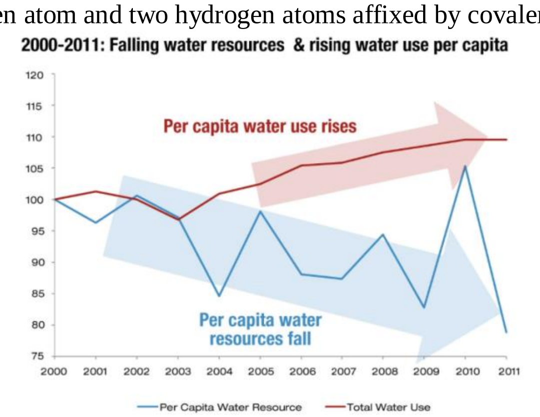


Figure 1.a

bond. This hydrogen chalcogenide is a polar molecule with an electric dipole moment. Due to its polarity, a molecule of water in the liquid or solid state can form up to four hydrogen bonds with neighbouring molecules, Thus termed the "Universal Solvent". Water accounts to 71% of Earth's composition, 96.5% of it accounts to seas and oceans. Freshwater accounts to 2.5%, of which 98.8% is in its solid state and 0.3% occurs in rivers and lakes, which is considered as good water [8] . Despite technologies having risen the quality of life for humans by providing ease of access to potable water, One billion people still lack access to clean drinking water. Research estimate that by the end of the upcoming decade, half the world's population will face grievous water crisis, the demand for water is to exceed supply by 50%. To combat this upcoming catastrophe, technologies are being developed to avail potable water needs by means of water purification techniques [7] . It is also efficient to analyse the quality of water in the filtration plants before distribution and thus can help in the analysis of the quality of the water and the plant itself. The *figure 1.a* denotes the falling water resources and increasing demand.

II. CHARACTERISTICS OF WATER

At standard pressure of 1 atm, water is at its solid phase at 0°C and vapour phase at above 100 °C, increasing the pressure lowers the melting and boiling point for upto 220 atm. At very low pressure(below 0.006 atm), sublimation occurs. At very high pressures (above 221 atm), a state called supercritical steam occurs, where the liquid and gas states are no longer distinguishable. The density of water decreases on phase transition from gaseous to solid state. The maximum density possessed by water in its liquid phase (at 1 atm) is 1,000 kg/m3. The refractive index of liquid water is 1.333 at 20 °C, which is much higher than that of air (1.0), thus supports marine life by facilitating sunlight penetration.

The viscosity of water is about 0.001 Pas or 0.01 poise at 20 °C, the speed of sound in liquid water ranges between 1400 and 1540 m/s depending on temperature. Thus, sound travels long distances in water with little attenuation, especially at low frequencies which avails the usage of SONAR. It has high specific heat capacity of about 4.2 J/g/K, heat of fusion is about 333 J/g , heat of vaporization is 2257 J/g , and thermal conductivity is between 0.561 and 0.679 W/m/K, which makes it appropriate to moderate Earth's climate.

Biologically, water possesses discrete properties that is obligatory for escalation of life. Water influences the metabolism of all living beings by playing a crucial role in its anabolic and catabolic processes. Being the universal solvent, water dissolves many ionic compounds and polar compounds such as ammonia.Oxygen-saturated supercritical water combusts organic pollutants efficiently, so supercritical water is the recent trend in the field of research.

III. CONTAMINATION OF WATER

Issues with water are expected to grow worse in the coming decades, with water scarcity occurring globally, even in regions currently considered water-rich. Water well is primarily, a structure built by drilling the ground to access underground aquifers.Shallow wells often yield water at a much lower cost. However, impurities from the surface easily reach shallow sources, which leads to a greater risk of contamination for these wells compared to deeper wells. Incase of bore wells, the hazardous contaminants food in the underground get mixed with the water causing threats to human health. The contaminants include metals, minerals, microorganisms and gases. The *Table 1.a* states the pathogens and other contaminants, its sources and hazards caused respectively.

Table : 1.a

S.No.	Pathogenic Contaminant	Example
1.	Bacteria	*E. coli, Salmonella, Shigella*, and *Campylobacter jejuni*.
2.	Viruses	*norovirus, sapovirus, rotavirus*, enteroviruses, and hepatitis A
3.	Parasites	*Giardia lamblia, Cryptosporidium, Cyclospora cayetanensis*, and microsporidia

IV. CHARACTERISTICS OF POTABLE WATER

The crucial parameters for determining the standard of potable water are pH, energy potential, molecular structure, dissolved oxygen and purity. Researches reveal that potable water consists of a pH of 7 or above, an electron activity in the negative millivolts (mV), a redox of 22 or less, water that is less than 5 molecules per cluster and ideally monomolecular, and in its pure state, free from organic matter. Fresh water consists less than 0.1% of salt , mostly comprising of the river and lake water, which is made potable after distillation [6] .

IoT modules are installed in the filtration plants to monitor the pH, Turbidity, Dissolved oxygen, Ammonia and conductivity of the water. This is used to calibrate the efficiency of the filtration techniques and the filtration plant.

V. CONVERSION TO POTABLE WATER

As the crisis heads its peak, advanced technologies are evolving to purify the water efficiently at lower cost, with minimal use of chemicals and energy consumption and imposing least possible impact on the environment. To combat the crisis, new technologies are getting equipped in water distillation, to increase the quality of potable water.

There are various technologies for purification of water, mostly distinguished by the process involved. Some of the technologies are as follows:

A. Gravity based water purification
B. Reverse Osmosis
C. UV Radiation based purification
D. Ultrafiltration
E. Carbon based purification
F. Candle filter purification
G. Solar disinfection
H. Life Straw
I. Nanofiltration
J. Biosand Filter

A. *Gravity based water purification*

Gravity based water purification systems do not use electricity. These type of water purifiers usually contain carbon filters and sediment filters that remove physical impurities and chlorine from the drinking water. gravity water purifier is mostly used if the TDS level of the water is low.Its efficiency is low compared to other techniques

Advantages: Does not use electricity

Disadvantages: Lower efficiency.

B. *Reverse Osmosis*

Reverse osmosis is the most suitable and advanced water purification process. In this process, a semipermeable membrane is used in which water is allowed to pass through it. Because of the very small pore size of the semi-permeable membrane, only pure water can pass through it leaving behind all the rest impurities. It is the only process that can remove heavy metals and dissolved salts from the drinking water. The presence of heavy metals in water can cause drastic effects on human body. The water purification process is required in the water supply contains high TDS level Multiple-Effect distillation performs through a series of steps termed 'effects'[1] .The inlet is heated by steam in tubes, some of the water vapour and the steam moves into the next effect, heating and evaporating more water, efficiently reusing the energy from the previous state.

Principle : SODIS-Solar Disinfection Sunlight can be used to disinfect water, the UV radiation and heat from the sun will kill bacteria and viruses [5] .

The figure 5.a describes the operation of MED.

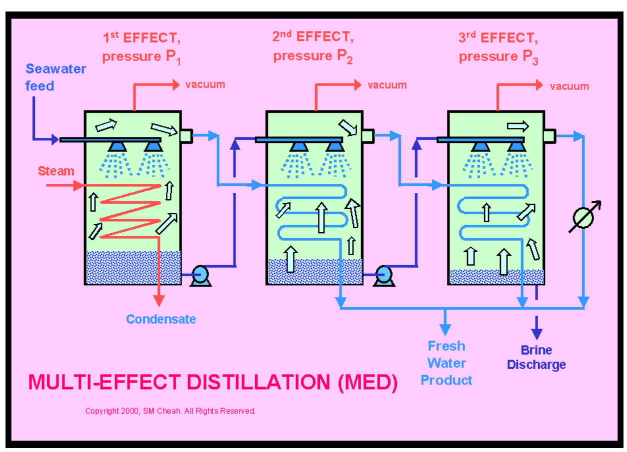


Figure 5.a

Advantages : Operates at low temperatures, small to medium-sized plant sizes, reduced scaling risk, low thermal energy consumption, reduced operating costs.

Disadvantages : incompatible with higher temperature heat sources due to scaling issues during spray evaporation.

C. Vapour Compression

This technique involves a mechanical compressor or a jet stream to compress the vapour above the liquid.[4] The compressed vapour is then employed to provide the heat required for the vaporisation of the remaining sea water.

The *figure 5.b* below represents the mechanism of vapour compression .

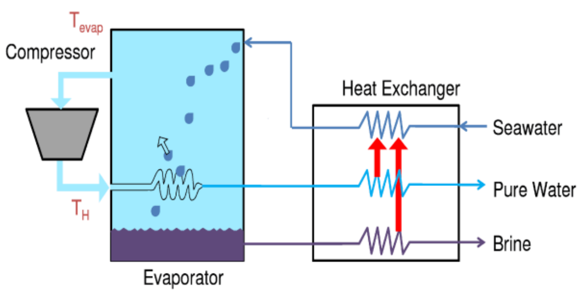


Figure 5.b

Advantages : Doesn't require water as coolant, complicated and cost-intensive feed installations are not mandatory, reduced corrosion risk, minimised scaling risk, process stability, External thermal energy is not required.

D. Electrodialysis Reversal

It is the exchange of ions between electrodes in an electrolytic solution, based on the property of conductance possessed by saline water.It is a water desalination process in practice since 1960.

Principle : An electric potential applied to saline water, helps migrate dissolved salt ions through an electrodialysis sack packed with alternating layers of cationic and anionic exchange membranes. Systematically, the direction of ion flow is reversed by reversing the polarity of the applied electric potential.

Due to its polarity reversal design, EDR has a self-cleaning mechanism.It achieves high water recovery for water scarce areas. EDR reclaim about 20 million gallons per day (75,000 cubic meter/day)[2] of wastewater for other uses.

The figure below represents the mechanism of Electrodialysis Reversal.

Advantages : Separation occurs without phase change, limited pretreatment is satisfactory, Osmotic pressure being a factor of no significance, the pressure can be used for concentrating salt solutions to 20% or higher.

Disadvantages : Organic matter, colloids and Silicon dioxide aren't removed, Proper selection of materials for membranes and stack construction is vital to ensure compatibility with the feed stream.

B. Reverse Osmosis

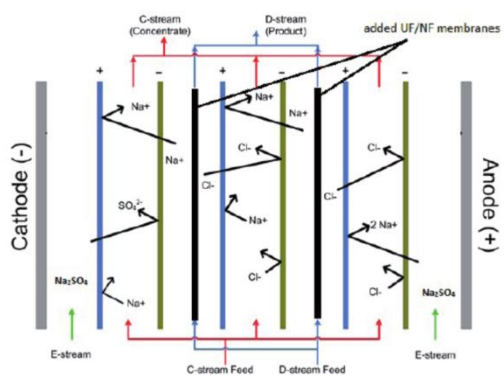
Osmosis is a natural process, which involves a semi-permeable membrane through which liquid flows from medium of lower concentration to higher concentration . Reverse Osmosis is a water purification technology that employs a semi permeable membrane to discard ions, molecules and other colloids

Principle : Reverse Osmosis is the process of forcing the flow from high concentration to low concentration on application of high pressure to overcome the osmotic pressure, a colligative property driven by the chemical potential differences of the solvent, a thermodynamic parameter.

Construction : The setup consists of wells or pipe like structures for water intake. It has pre filtration and post filtration areas,storage tank, outlet pipes for filtered impurities and potable water. It also consists of semi-permeable membrane, flow restrictor,shut off valve and also carbon filtration tank.

Operation : Water enters through the Valve that fits onto the cold water supply line. The valve has a tube that attaches to the inlet side of the RO pre filter. This is the water source for the RO system.
Water from the cold water supply line enters the Reverse Osmosis Pre Filter first. There may be more than one pre-filter used in a Reverse Osmosis system, the most common being sediment and carbon filters. These pre-filters are used to project the RO membranes by removing sand silt, dirt, and other sediment that could clog the system. Additionally, carbon filters may be used to remove chlorine, which can damage the RO membranes.The Reverse Osmosis Membrane is the heart of the system. The semipermeable RO membrane is designed to remove a wide variety of both aesthetic and health-related contaminants. After passing through the membrane, the water goes into a pressurized storage tank where treated water is stored. After the water leaves the RO storage tank, but before going to the RO faucet, the treated water goes through a final “post filter”. The post filter is usually a carbon filter. Any remaining tastes or odors are removed from the product water by post filtration “polishing” filter.To conserve water, the RO system has an automatic shut off valve. When the storage tank is full, the automatic shut off valve closes to stop any more water from entering the membrane and blocks flow to the drain. Once water is drawn

from the RO faucet, the pressure in the tank drops; the shut off valve then opens to send the drinking water through the membrane while the contaminated wastewater is diverted down the drain.A check valve is located in the outlet end of the RO membrane housing. The check valve prevents the backward flow of treated water from the RO storage tank. A backward flow could rupture the RO membrane. Water flowing through the RO membrane is regulated by a flow restrictor. There are many different styles of flow controls, but their common purpose is to maintain the flow rate required to obtain the highest quality drinking water (based on the gallon capacity of the membrane). The flow restrictor also helps maintain pressure on the inlet side of the membrane. Without the additional pressure from the flow control, very little drinking water would be produced because all the incoming water would take the path of least resistance and simply flow down the drain line. The flow control is most often located in the RO drain line tubing. The standard RO storage tank holds from 2 - 4 gallons of water. A bladder inside the tank keeps water pressurized in the tank when it is full. The typical under counter Reverse Osmosis tank is 12 inches in diameter and 15 inches tall. The RO unit uses its own faucet, which is usually installed on the kitchen sink. Some areas have plumbing regulations requiring an air gap faucet, but non-air gap models are more common The outlet is used to dispose of the wastewater containing the impurities and contaminants that have been filtered out by the reverse osmosis membrane. The figure represents the working of the reverse osmosis technique.



Advantages : Effective sanitizing treatment and Oxidation of organic compounds (185 nm and 254 nm) upto 5 ppb TOC

Disadvantages : Decreases resistivity.
Will not remove particles, colloids, or ions

F. Nano filteration

Nano filtration is a recent trend in membrane filtration process, employed to discard totally dissolved solids of much smaller size.It is employed for demineralisation. The membranes employed in this process have pores sized in a range of 1-10 nanometers. Nano-filtration has evolved to be the most used technique in desalination and distillation of water.

G. Membrane Distillation

Membrane distillation employs membranes of different grades to distill water by expelling out the impurities.Since it employs mechanical pressure for the flow of water through the membrane for mass transfer.Membrane technology covers all engineering approaches for the transport of substances between two fractions by consuming least energy. Thus membrane distillation has revolutionised the process of desalination and distillation of saline water to a greater extent.

This process allows symbiotic power and water generation. It also photocopies the water cycle by involving the membranes as a medium for both evaporation and condensation at different stages of the process.
The figure represents the membrane distillation technique.

H. Forward Osmosis

Forward osmosis is yet another technique, which is merely an osmotic process, like reverse osmosis employees a semi-permeable membrane. Unlike reverse osmosis less pressure and energy is consumed since here water flows from a region of lower concentration to higher concentration to effect separation of water from dissolved solutes. It has a drawback that the rate of purification is relatively less, since low pressure is employed. Ultra pure water could not be achieved by employing the technique of forward osmosis.

I. Freezing Desalination

Freezing desalination is based on the principle that ice crystals are made of essentially pure water. During freezing desalination, the temperature of the saline water is lowered, such that pure water passes into its solid state faster that the brine. The fresh water which is turned into ice is distilled further to obtain potable water. Freezing desalination requires minimal amount of energy.

The other desalination technologies replicate nature's water cycle by a series of elope ration and condensed involving various sources of energy to provide the necessary temperature for evaporation to occur, Thus employing various structural and technical advancements.

VI. WATER QUALITY MONITORING - ELECTRONIC SYSTEM

With the above mentioned techniques of municipal water filtration, irrespective of the filtration methodology used the water outlet of each filtration plant will have an IoT Module attached to it, to monitor the quality of the filtered water. The system monitors the pH level, Turbidity, Temperature, Ammonia, Dissolved Oxygen and connectivity of the filtered water. The data is processed in the NodeMCU module, which using its inbuilt WiFi module, pushes the sensor data to the cloud. The data from the cloud is then used for further analysis. The pH and turbidity levels are displayed in an LCD module for the awareness of the quality of the water outlet. The figure below is the schematic of the electronic module.

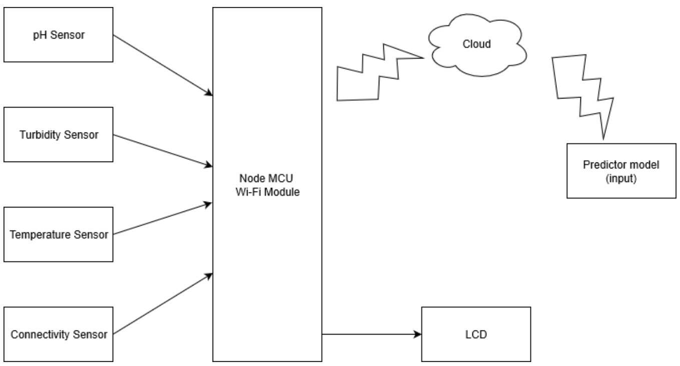


Figure 6.a

VII. NEURAL NETWORK MODEL.

A neural network is a comprehensible model of the procedure in which the human brain processes information. It executes by initiating a huge number of interconnected processing units that resemble conceptual versions of neurons. The processing units are leveraged in layers. There are typically three parts in a neural network: an input layer, with units representing the input fields; one or more hidden layers; and an output layer, with a unit or units representing the target output field. The units are connected with varying connection weights. Input data are presented to the first layer, and values are propagated from each neuron to every neuron in the next layer. Eventually, a result is delivered from the output layer. The network learns by analysing individual records, generating a prediction for each record, and making adjustments to the weights whenever it makes an incorrect prediction. This process is repeated with a high frequency, and the network continues to improve its predictions until one or more of the stopping criteria have been met.

The water parameter data from the cloud is preprocessed and fed into the input layer of the Neural Network. The data is normalised and fed into the network of recurrent neural network and after learning, the output predicted data is denormalized and then the test data set is used for analysis of the accuracy of the model. This predicted value is used for the analysis of the quality of the filtration process and the water outlet. The figure below shows the process flow of the Recurrent Neural Network used in the analysis of water filtration process quality.

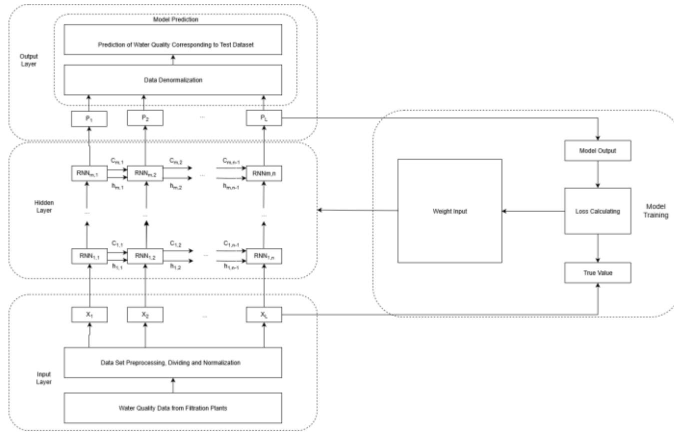


Figure 7.a

VIII. OBSERVATION AND RESULTS - IOT MODULE

The data obtained using the IoT module from various plants, with various filtration techniques as discussed previously in this paper, in a modern water filtration industry is plotted in the *figure 8.a* below. This data can be used to analysis the efficiency of water outlet from various filtration techniques.

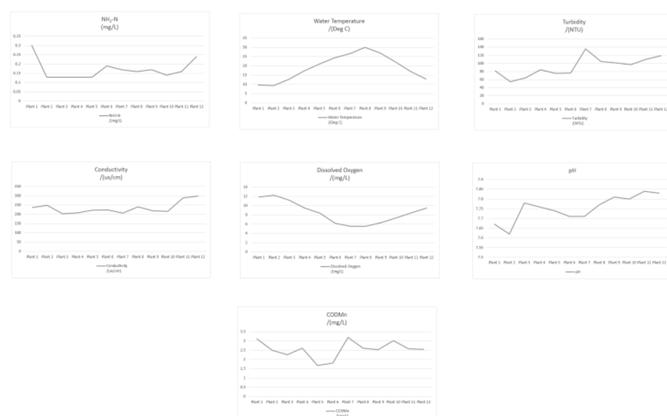


Figure 8.a

IX. OBSERVATION AND RESULTS -RECURRENT NEURAL NETWORK

The data obtained using the IoT module from various plants, with various filtration techniques is pushed to the cloud, after being inputted into the Recurrent Neural Network Model, the ideal parameters of the water quality of the respected plant is predicted prior filtration for any session of filtration. This is then compared with the actual values of the respective session, if any anomalies occur, the fault in quality filtration is alerted. This helps in the monitoring of filtration plant quality as well as filtered water quality prior distribution. The actual and predicted values of the water quality of a particular session for various plants with various filtration mechanisms is plotted in the *figure 9.a* below.

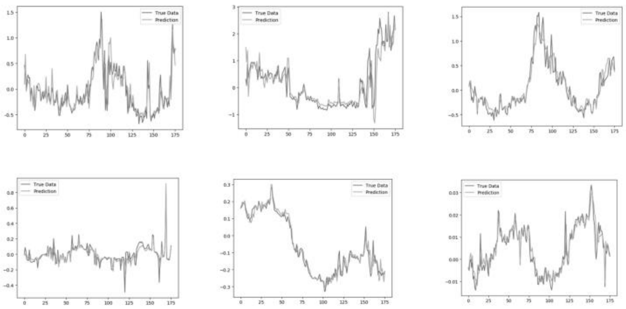


Figure 9.a

X. RECENT ADVANCEMENTS IN FILTRATION MECHANISMS

The recent advancement in desalination technologies involve Cryo Desalination, Biomimesis(uses Biomimetic membranes for filtration), employing ElectroKinetic Shocks and Integrated biotectural systems.

A. Cryo Desalination

On freezing, pure water in form of ice floats on saline water. There is always some unrest in isolating the ice from saline water. To overcome this discord a fluid which floats between ice and saline water is introduced in cry desalination. The salt crystals in contact with ice turns into slush on introducing the intermediate fluid.Thus cry desalination is prefaced to overcome the shortcomings of freezing Desalination [9] .

B. Electro Kinetic Shocks

It employs electrokinetic shocks waves for membrane-less desalination at ambient temperature and pressure. In this process, anions and cations in salt water are exchanged for carbonate anions and calcium cations, respectively as a result of electrokinetic shockwaves. Thus reacting to form calcium carbonate which precipitates leaving fresh water. The theoretical energy efficiency of this method is on par with electrodialysis and reverse osmosis [11].

C. Integrated biotectural system

A new approach to saline water desalination, which provides to be eco friendly is the integrated biotectural system. It works like a solar still, but on scale on industrial elope ration ponds. It can be considered as full desalination, since it converts the entire saline water intake to distilled water, while producing sea salt as a by product.Its technology is not to be confused with the common greenhouse as it desalinates in a eco friendly manner. It is termed ‘integrated’ as it is a combination of farming and living in one building, featured with desalination of sea water, or brackish groundwater. the IBTS requires less energy, since it is the establishment of closed water cycles. It is most suitable in arid and semi- arid regions as it requires high solar energy. It is a revolution in desalination techniques as it consumes conventional energy sources and is pollution free.

XI. CONCLUSION

Health ailments due to contaminated water being the major catastrophe to be faced in the upcoming decades, water filtration is the need of the hour for healthy living. With advancement in technology potable water can be efficiently obtained. With this technology of water quality monitoring using an IoT system and then prediction of the quality parameters for each filtration plant, adopting a particular filtration mechanism using Recurrent Neural Networks, proves efficient by helping analysis the filtered water quality, filtration plant quality and the efficiency of a particular filtration process prior water distribution to the locales. Water purification being the quick fix to water borne ailments, more competent technologies are evolving as research contrive.

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