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A Survey on Legionnaires Disease and Benefits of Using IoT and Artificial Intelligence for Control Measures

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Abstract

In this paper, we summarized Legionella, its outbreaks, detection techniques, compliance, and traditional control measures. We proposed the benefits of using a Remote temperature monitoring and tap flushing system that can be implemented with the help of Internet of Things (IOT) and Artificial Intelligence (AI). Legionella bacteria is usually found in all types of water systems and soil. Humans are affected by breathing Aerosols from the infected sources. Figure 2 shows the major sources of Legionella and its routes to human exposure. It is asymptomatic in most individuals but can cause Pontiac fever, Legionnaires disease and can lead to severe Pneumonia. People with weak immune systems, the old aged and smokers are most susceptible to legionaries' disease. There are no distinct symptoms for legionnaires disease, so it is unnoticed or neglected most of the time. Legionellaceae family consists of more than 50 species of which Legionella Pneumophila is the most common serogroup which causes Legionnaires disease. Temperature between 20°C to 50°C is most suitable for its growth. Artificial water systems like water tanks, Domestic water distribution systems, Spa pools, Cooling towers are some of the major sources of legionella. Legionella bacteria grows on Biofilms and stagnant water in supply pipes and water systems. There is detailed guidance and legislation to maintain these systems to prevent legionella outbreaks. A remote temperature monitoring and a remote outlet flushing solution can help the legionella organizations to keep the water systems compliant and safe from Legionella. A sensor network for remote monitoring of water temperatures and initiating outlet flushes can help reduce the manual efforts.

Keywords: Automatic Tap flushing; Artificial Intelligence for Legionella; Legionnaires disease; Internet-of-things; Legionella, Machine Learning; Remote temperature monitoring.

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1. Introduction

A mysterious outbreak of pneumonia at the American legion convention held in Philadelphia in 1976 affected more than 200 people. 34 out of 221 cases were fatal and the cause of it was not recognized until 6 months later. After many laboratory Investigations, an etiologic agent which is a fastidious gram-negative bacillus was discovered and the disease was named Legionnaires' [1]. Several outbreaks that were unsolved in the 1950s and 1960s were confirmed to be legionnaires' disease after antibody tests from Pneumonia [1]. Another kind of illness called Pontiac fever which is non pneumonic and milder was infecting people in Pontiac, Michigan in 1968. This illness occurred in a health facility in Pontiac, Michigan and affected more than 144 people (95 percent of the employees in the building). The source of this Pontiac fever was assumed to be from a faulty air conditioning system. People affected were suffering from fever, headache, Malaise, and myalgia lasting from two to five days. It is assumed to be airborne due to no secondary persons like family or friends were affected [2]. An Isolate discovered in 1947 known as "Rickettsa-like" organism was later identified to be of Legionnaires species that was isolated during Philadelphia outbreak [3]. Legionellae bacteria is found in freshwater and is a gram-negative bacterium found in natural and artificial aquatic environments however it grows rapidly in human made reservoirs [4].Some major sources of Legionella and its route to affect humans is shown in Figure 2. Modern equipment that makes use of stored water like air conditioning systems, Taps, Showers, Cooling towers, fountains, spa pools, Spray machines, dental appliances etc., can spread contaminated aerosols that affect humans [5]. Incubation period for legionnaires' disease is assumed to be anywhere between 2 and 14 days and it can become a pneumonia or severe infection [6].Legionella occurs as part of Biofilms or planktonic forms. L.Pneumophila has an ability to sustain harsh conditions by entering a sustainable but non -culturable state (VBNC- Viable but non-culturable cells) [7] . In a notable number of cases, Legionella was diagnosed in water samples between 30°C and 40°C [8]. Figure 1 shows the presence of legionella in different parts of a pipe. The bacteria causing legionnaires' disease is not easy to detect and Legionella is rarely diagnosed due to a lack of awareness [9]. Legionnaires' disease can be described as infections caused by Legionellaceae Family [10]. Legionellaceae family consists of more than 50 species and 70 serogroups. Legionella pneumophila serogroup is the most common and accounts for 80% of reported cases [10]. Characteristics of Legionella Pneumophila are depicted in Table 1.

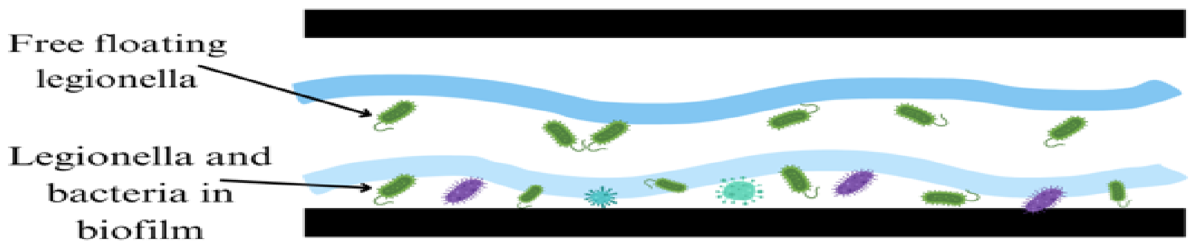

Figure 1: Legionella Inside a Water Pipe [11]

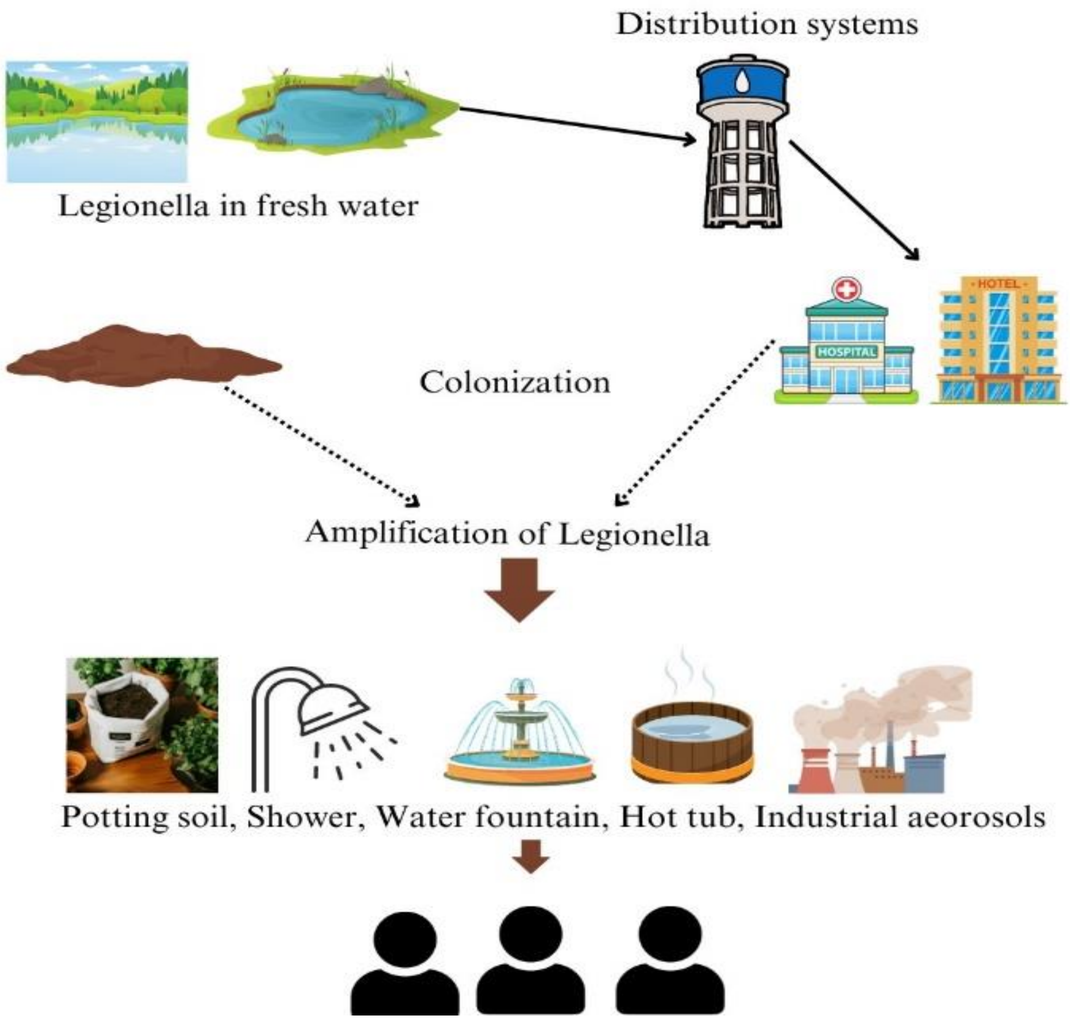

Figure 2: Legionella Route from different sources to humans, causing Legionnaires disease [12]

Table 1: Characteristics of Legionella Pneumophila [11]

Characteristics	**Legionella Pneumophila**
Family	Legionellaceae
Form	Bacillus
Colouring per gram	Gram (-)
Metabolism	Aerobic
pH	5 - 8.5
Habitat	Aquatic habitats (biofilm, within multicellular organisms)
Nutrients	Amino acids (L-cysteine), iron
Survival Temperature	0-63°C
Reproductive Temperature	25-37°C
Sensitivity	Drying, Chlorine, UV radiation

2. Legionella Outbreaks and Statistics

Recognizing legionella is hard and it is only found out after an outbreak in most cases. A brief description of some major outbreaks around the world are discussed below:

In April 1985, an outbreak occurred in Stafford General Hospital. 68 confirmed cases and 22 fatalities were reported during this outbreak. Samples from a cooling water system of an air conditioning system had legionella pneumophila, serogroup 1. An investigation suggested that a chiller unit could have been contaminated [13].

In February 1999, a Legionella outbreak was reported at a flower show in Bovenkarspel, Netherlands. 188 people became ill after visiting a Whirlpool spa during the flower show. Samples from two whirlpool spas and a sprinkler in the flower resulted in positive legionella. At the time of the outbreak, there were no guidelines regarding the use and maintenance of Whirlpool spas. Strict regulations for the use of whirlpool spas are necessary to avoid Legionella [14]

In April 2000, a Legionella outbreak was reported in a newly constructed aquarium in Melbourne, Australia. 125 cases were confirmed out of which 110 people visited the aquarium and 15 other people who were in 500 meters of vicinity. Microbiological tests confirm that outbreak was caused due to contaminated cooling towers. Automatic biocide dosing pumps installed with the cooling towers were assumed to be the root cause. Samples taken on 27 April,2000 from cooling towers indicated the presence of legionella with no detectable biocide. Faulty biocide dosing pump contaminated the tank with legionella organisms and presence of drift eliminators could not stop the spread of aerosols around the aquarium and people inhaled legionella. Lack of proper control measures and routines inspections caused this outbreak [15].

In July 2001, a massive outbreak of legionella occurred in Murcia, Spain. 449 out of 800 suspected cases were confirmed with Legionella. The source of outbreak was unknown until an epidemiologic investigation revealed the cooling tower at a hospital [16]

In July 2002, a legionnaires disease outbreak occurred in Barrow-in-Furness, England. A total of 179 cases were confirmed with legionnaires disease. The Source of the outbreak was a cooling tower related to a wet air conditioning unit [17].

In May 2005, a legionella outbreak occurred due to an air scrubber in Sarpsborg, Norway. Industrial air scrubbers are used to clean the polluted air by spraying water. After Investigating surviving patients, they analyzed that the risk ratio was directly proportional to the distance from the air scrubber. Until this discovery, the maximum distance of transmission for legionella was assumed to be around 3 km. 8 patients in this case had not been to a radius of 10 km from the source. This study suggests that air scrubbers are more likely to transmit more distance than Cooling towers [18].

In December 2008, 2 people were diagnosed with legionnaires' disease in Denmark. The source of the infection was a newly built block of flats. Comparison of samples from the patients and water systems suggested that hot water supply system was the most probable source. Stagnancy of water in the newly constructed building pipe work and low temperature were reported as major problems [19].

In February 2010, an outbreak occurred in a hospital at Wisconsin due to a decorative water wall fountain. 8 patients were diagnosed with legionella who were in the same hospital 10 days before the outbreak. Regular cleaning and maintenance of the fountain didn't eliminate the risk of legionella. Legionella pneumophila serogroup 1 was found in high counts in the foam material found in the fountain [20].

In July 2012, 21 cases of legionnaires disease were confirmed in Stoke on Trent, England. An investigation suggested that all 21 patients visited a common source. A spa pool displayed in the indoors of a retail premises was declared the source of outbreak [21].

As per the above case studies, the source of a legionella outbreak is through contaminated water in a water system. Artificially stored water for various reasons got contaminated and the aerosolization of the water caused the outbreaks in most cases. Table 2 shows the information related to cooling tower associated legionella outbreaks. These outbreaks were detected because the size and capacity of these systems was very big and most of them were nearby public places. Many systems in similar condition may not be identified as the number of people visiting it can be minimum and the affected person may not be recommended to take a legionella test.

Table 2: Legionella Outbreaks Associated with Cooling Towers [17]

Location of Outbreak	**Year**	**Cases (deaths)**	**Case Vs fatality rate (%)**	**No of patients Hospitalized**	**No of cases in Intensive care/mechanical ventilation**
Stafford Hospital	1985	68 (22)	32·0	68	—
Glasgow Royal Infirmary	1985	16 (5)	31·3	16	4
Gloucester	1986	18 (3)	16·6	12	—
BBC	1988	79 (3)	3·8	—	11
Nottingham	1988	14 (2)	14·0	12	1
Piccadilly Circus	1989	33 (5)	15·0	—	—
Netherlands	1999	188(17)	9·0	163	34
Melbourne	2000	125 (4)	3·2	95	—
Barrow-in-Furness	2002	179 (7)	3·9	134	18
Catalonia	2002	113 (2)	1·8	83	—
Hereford	2003	28 (2)	7·1	23	—
Murcia	2003	449 (5)	1·0	332	—
Pas-de-Calais	2003/04	86 (18)	21·0	84	—
Sarpsborg	2005	56 (10)	17·9	—	—
Pamplona	2006	146 (0)	0·0	76	7
Edinburgh	2012	61 (4)	6·5	49	22

In most cases, symptoms of legionella are fever or headache which can easily be ignored by the patient. To detect the legionella clusters and outbreaks, we need a legionella database. Many countries maintain official databases to maintain the information of suspected and confirmed cases of Legionella. Data accumulated by Public Health England (PHE) provided some insightful information regarding Legionella. The data collected by PHE includes confirmed cases of legionella tested positive based on a culture-based test, urinary antigen test or nucleic acid detection. Some data analysed by PHE based on various factors is depicted below in Table 3 and Figures 3,4,5,6.

Below chart depicts the number of cases according to month of symptom onset. From below information, we can see that there is a spike in the number of cases between June and October. Ambient temperatures of the water systems in these months are usually higher compared to winters. Increase in the ambient temperature can help legionella to grow in water systems as it is dormant below 20°C and active above 20°C and 45°C [22].

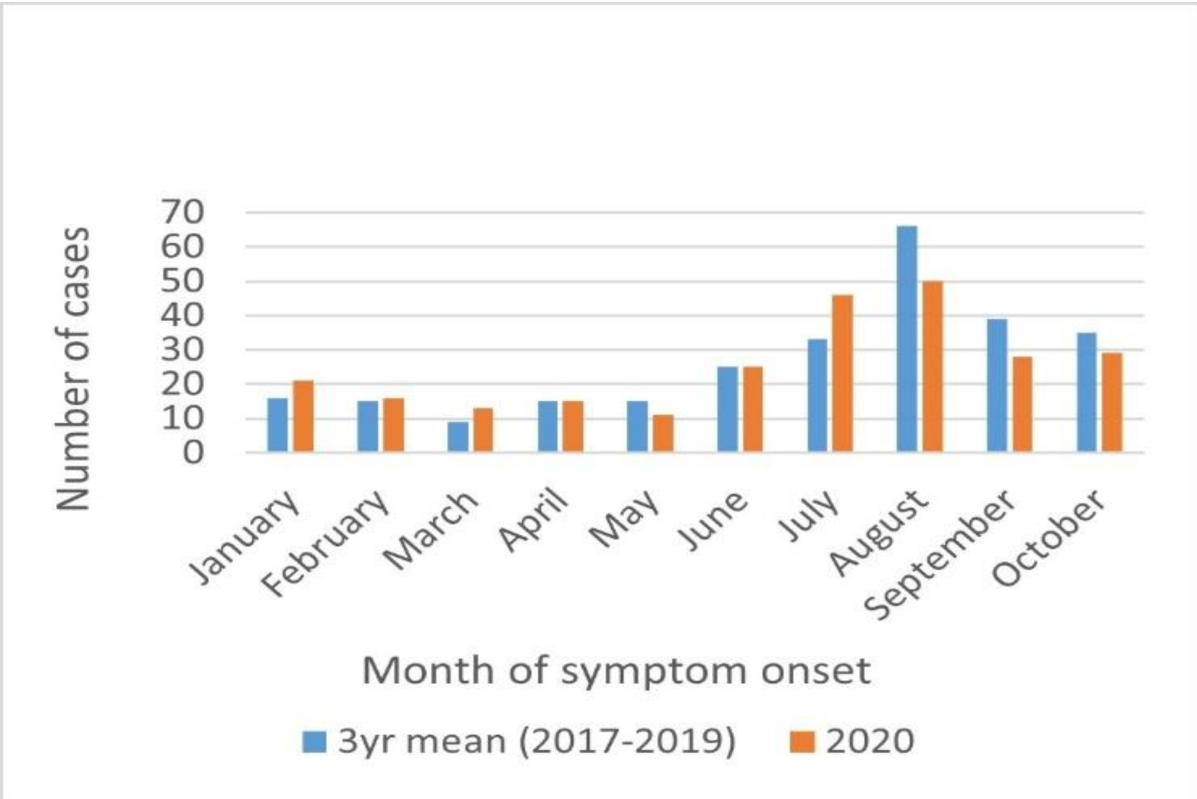

Figure 3: Number of cases by month of onset [23]

Table 3 describes the confirmed cases based on the region of residence in United Kingdom. From this table we can analyse that the northeast part had least cases whereas all others were comparative with London, southeast and west Midlands showing some increased numbers. This can be because northeastern part of the UK is very cold, and the water systems are either under 20°C or above 45°C when heated for domestic use.

Table 3: Region of residence by symptom onset from 2017 till October 2020 [23]

Region	**2017 - 2019 (3-year mean)**	**2020**
London	46	33
West Midlands	36	36
East Midlands	32	30
Southeast	30	45
Southwest	28	19
East of England	24	31
Northwest	24	25
Yorkshire and Humber	22	22
Wales	20	9
Northeast	3	4
Total	**266**	**254**

Figure 4 and 5 describes the number of cases according to the age group and medical conditions respectively. According to Figure 4, number of cases are increasing directly proportional to the age group. Figure 5 shows the medical conditions of positive cases and at least 70 percent of cases were suffering from one medical condition.

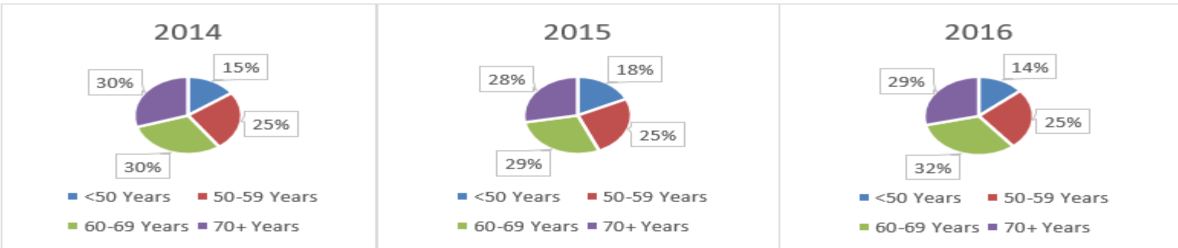

Figure 4: Number of cases based on the age group [23]

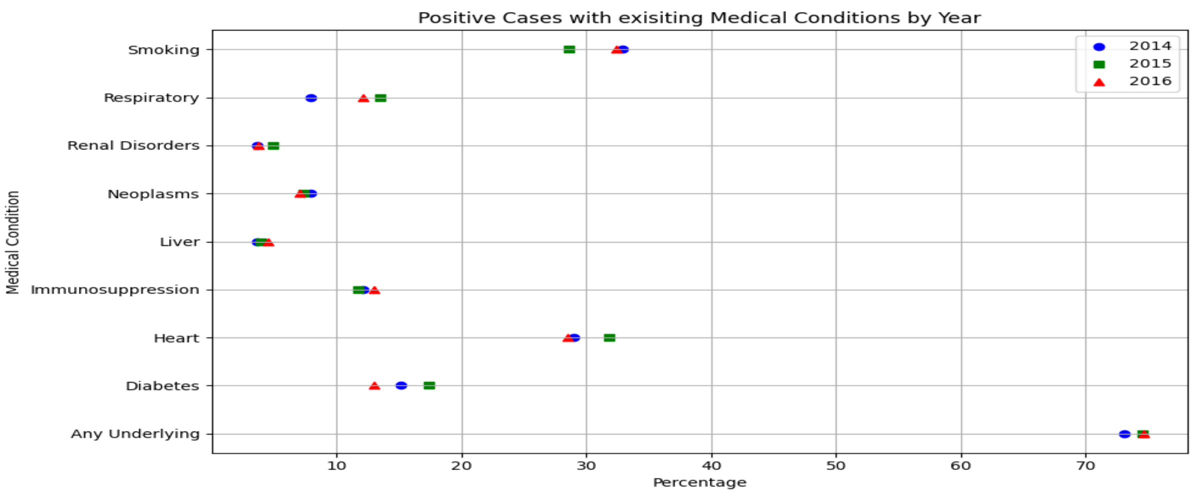

Figure 5: Number of cases based on medical conditions [23]

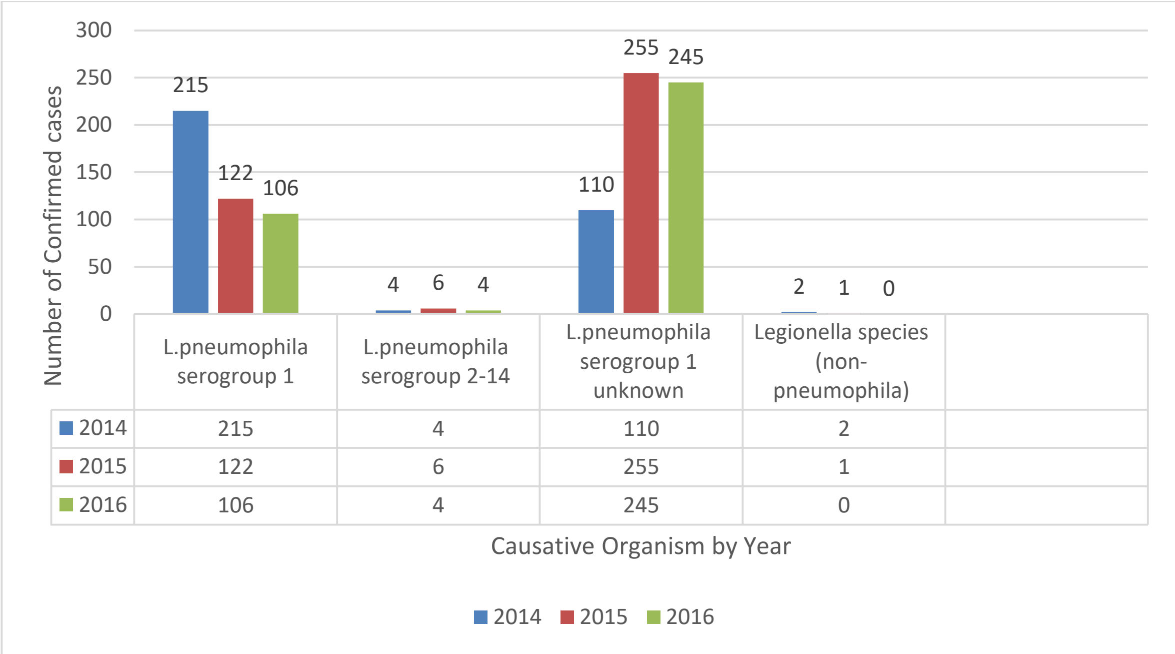

Figure 6: Confirmed cases according to causative organism [23]

According to Figure 6, L. pneumophila serogroup 1 is the causative agent in maximum number of cases.

It is surprising to know that most of the outbreaks were recognised only after the outbreak has occurred. Each of them needed to be investigated further to know the root cause of the Outbreak. In most cases, samples from artificial water systems which are not maintained properly resulted legionella positive. Data from PHE reveals many patterns based on different scenarios like Climate/Seasons, Region of residence, Age group, medical conditions, and legionella serogroup. It shows us a spike in number of cases in the months of July to October. This can be because of the ambient temperature in summer season in the United Kingdom. When compared with other regions, Northeastern parts of the UK show lowest number of cases. This can be because of the cold temperatures below 20°C throughout the year or because of the low density of population. People aged above 50 years comprises of more than 80% of all positive cases. 70% of positive cases were already suffering from some kind of medical conditions. Around 30% of cases were either smoking or suffering from a heart related medical condition. It is challenging to detect and diagnose legionella in early stages as the symptoms are very common like fever, headache, and other flu like symptoms. Doctors may not be able to predict and prescribe for a legionella test in all cases due to no distinct symptom. There are multiple types of diagnostic techniques to test legionella in humans and some of them are discussed in the next section. It can be cured without treatment in some cases but can be fatal sometimes.

3. Diagnostic Methods Used for Detection of Legionella in Humans

Antibody-based methods with a very limited set of culture were used for investigations in the early days. For example, a direct fluorescent antibody (DFA) assay. Legionella UAT (Urine antigen tests) was adopted widely until the introduction of PCR and DNA sequencing techniques (Nuclear acid molecular techniques) in 1980s [12]. Legionnaires’ disease cases classification depends on different factors including symptoms, supporting epidemiological information, and positive laboratory results. Case classification and assignments differ slightly between European Union and United states as EU allows a single high antibody titer for disease assessment [12].

3.1. Microbiological culture

Legionella detection through isolation and culture remains as the gold standard for LD [9]. Sputum, pleural fluid, bronchial alveolar lavage fluid and bronchial aspirates from lower respiratory tract are acceptable culture [24]. Sensitivity of detection using specimens ranges from less than 10% to 80% depending on various factors including sample type, experience, and proficiency of laboratory [25]. Lack of expertise to isolate legionella in the laboratory was a major reason for the drop in the culture-based detection. A survey conducted by college of American pathologists confirmed that one third of laboratories could not grow pure legionella culture [26]

3.2. Urinary Antigen Test (UAT)

UATs are popular for easy procedure, relatively low cost, speed of diagnosis (15 minutes), commercial availability [12]. The urinary antigens are detectable in majority cases 2-3 days after the occurrence of symptoms. Antigens can be detectable for more than 10 months and even during treatment in some cases [27]. UAT tests are available in two different forms in the market. A rapid immunochromatographic test (ICT), which is basically a card or strip based and ELISA or EIA (which is a 96 well plate-based enzyme immunoassay) [12]. UAT manufacturers suggest that if initial UAT results are not positive, but the index of suspicion is high, clinicians do multiple tests over a longer period and try alternative test like PCR [28].

3.3. Serological testing

This testing procedure is a valuable epidemiological tool but is not useful for clinical testing's due to delay in getting the results. A major limitation of serological testing is that it takes several weeks for seroconversion. Another limitation of serological testing is that it can't detect all the serogroups and legionella species. Seroconversion of Legionella pneumophila serogroup 1 is believed to be highly predicted with this test but there is no proper evidence for other serogroups [25].

3.4. Direct Fluorescent Antibody (DFA) Staining

DFA staining can provide a result within 2-4hrs. Respiratory secretions and tissue samples can be used for this technique. This method requires experienced laboratory personnel. Results from this technique are less sensitive compared to culture results. Due to problems in specificity and sensitivity, usage of DFA is limited and a positive result is not accepted without any other supporting evidence [25].

3.5. Nucleic Acid Amplification

DNA detection techniques promised rapid diagnosis of Legionella. PCR technique can amplify very little amounts of legionella DNA and can detect infections caused by all legionella species [29]. PCR has been tested successfully on different samples. Samples collected from lower respiratory tract showed sensitivity greater than or equal to culture [29]

4. Guidance and Regulations to prevent Legionella growth.

Legionella can grow in all places where there is a water system. As water systems are common in commercial and domestic places, government agencies all over the world provides guidance and regulations to prevent and control legionnaires disease. We summarized the guidance and regulations released by the agencies of United Kingdom and United states in this paper.

4.1. Compliance and Health and Safety Legionella Guidance in United Kingdom

Health and Safety Executive (HSE) is a government agency that regulates guidance for workplace health and safety in the United Kingdom. The HSE publishes many documents to provide guidance for the control of Legionnaires' disease.

As per Legionnaires diseases technical guidance HSG274 and HSG282 guidance, any water system can be a potential source for Legionella bacterial growth and legionella risk if [30]:

- Water is recirculated or stored in a water system.
- Water Temperature The water temperature is between 20- and 45 °C in any part of the system.
- Residual waste or deposits such as organic matter, rust, scale, sludge that can support bacterial growth.
- Any possibility of producing water droplets from the system.
- Any possibility of employees, visitors, contractors etc. could be exposed to water droplets.

The Approved Code of Practice (ACOP L8) describes the guidance from the Health & Safety at Work Act 1974, health and safety law that applies to the control of Legionella bacteria in water systems. Management of Health & Safety at Work Regulations (MH & SAWR), The Notification of Cooling Towers and Evaporative Condensers Regulations, the control of substances hazardous to health regulations 2002(COSHH) describes a framework to prevent, control and assess risks from hazardous substances which includes legionella [30].

4.1.1 Risk Assessment

As per health and safety law and many other legislations, an employer needs to maintain a Legionella risk assessment following all the guidelines to control and prevent legionella.

- Duty holders or employers need to carry out a legionella risk assessment and maintain it up to date. Competent persons should be appointed as responsible to manage the control scheme. The competent person needs to understand the water systems, its parts and equipment's associated. If no qualified person is available, an external person should be appointed [30].
- The risk assessment should include a survey of all the waters systems on site considering other health and safety aspects (Example: Using Ladders, confined spaces, work permits etc.). It should include a list of

management responsibilities, schematic diagram, Risk evaluation, operating procedures, control measures, results, limitations [30].

- BS 8580-1 2019 water quality, risk assessments for legionella control, Code of practice and The Water management society's guide to risk assessment for water services are useful resources for guidance regarding Legionella risk assessment [30].
- Regular review of the risk assessment and particularly when there is a susception of validity. Review should be done in all cases where there is a change in water systems, change in use of a building, updated risk available, where control measures are no longer effective, change in management, positive legionella detected/associated with the site [30].
- Controlling exposure if prevention or substitution is not possible.
- Testing of control measures
- Maintaining and examining of control measures.
- Providing information, method statements and training for employees.
- Surveillance of employee health when an exposure may cause severe health effects.

4.1.2. Prevention of exposure by using a less hazardous substance or substituting a method or process.

Some precautions for doing this include Preventing and controlling the aerosolization of water, Eliminating/Avoiding the conditions that help the growth of Legionella and microorganisms, Ensuring movement of water in all systems on a regular basis, Ensuring pipe lengths are as short as possible and removing dead legs and redundant pipework, Using materials that are approved by Water regulations advisory scheme, Maintaining clean water and systems, Following water treatment methods to control the growth of legionella [30].

Notification of cooling towers and evaporative condensers regulations 1992 states that eemployer's should write to local authorities if they operate a cooling tower or an evaporative condenser. They need to include details of about the device like its location etc. They also need to inform the authorities if such devices are not in use [30].

Reporting of injuries, Disease, and dangerous occurrences regulations 2013 (RIDDOR) states that eemployer's are required to inform HSE about any accidents or some diseases caused at work or out of work. Legionnaires' cases can be reported under RIDDOR if employees current job involves working with cooling towers, water systems or if a medical practitioner notifies the employer [30].

Health and Safety (Consultation with Employees) Regulations 1996 and The Safety Representatives and Safety Committees Regulations 1977 states that safety representatives at Trade unions, employee representatives or employees are required to be consulted by employers regarding the changes at work that may affect health and safety, risk, and controls information, arranging for getting competent help and health and safety training plan [30].

As per HSG 274 part 2, An employer with 5 or more employees must record the risk assessment. The records need to be retained for at least two years after they are invalid. Monitoring and inspection documents should be retained for a minimum of 5 years. Records should contain the accurate information including dates, signatures, and names wherever necessary [30].

Water used for domestic purposes are supplied from Hot and cold-water systems. Water systems in health cares, residential homes and care homes need special care. Some of the risk areas associated with the hot and cold-water systems include:

- Dead legs, dead ends, infrequently used outlets and poorly circulated areas.
- Base of a water heater / storage vessel.
- Incoming cold temperatures above 20°C which causes cold water systems to gain heat and support legionella growth.

Design of Hot water systems can vary based on the requirements and size of the building. Smaller systems include instant water heaters and combination boilers. In some systems, the hot water can enter cold water and according to regulations, the allowed cold water storage temperature is 25°C and 38°C when it is serving hot vessel (The Water Supply (Water Fittings) Regulations 1999, 15 the Scottish Water Byelaws 2004,16 and BS 3198 Specification for copper hot water storage combination units for domestic purposes). Risk assessment should include this type of systems and control measures need to be suggested so that no microbial growth happens in this type of systems [30].

Gravity fed water systems are used in relatively medium and large-sized buildings/commercial places. These cold water from the mains are stored in water storage tanks or directly fed to the calorifiers/boilers. The heated water from calorifiers is either recirculated or only circulated when required. The heated water is allowed to become cool in the pipes in a non-recirculating system. Vent pipes in these types of systems need to be drained separately into a safe and visible point. Connection of the vent pipe into cold water storage is not allowed as it increases risk of microbial growth because of warm storages temperatures [30].

The design of a calorifier where there is a large gap/area below the coil needs to be considered carefully as stratification may occur. Installing a shunt pipe with timer control should be considered to recirculate water inside large calorifiers. Shunt pipe operations need to be scheduled in a such way that they shouldn't be done before cleaning/descaling routines to avoid disturbance of sediments at the bottom of calorifier [30]

Expansion vessels help the pressurized systems to maintain the correct level of pressure in the systems. Internal bladders of expansion vessels may support microbial growth as they are made up of synthetic rubber. Expansion vessels that comply with BS6920 are recommended [30].

4.2. Guidance in United States

United States centers for disease control and prevention (CDC) regulates the guidance and legislation for Legionella control in the United States. As per CDCs (Centers for Disease Control) water management program to prevent and control legionella, seven key elements as mentioned below need to be included in a water management program [31].

4.2.1 Establish a team for water management program

4.2.2 Use flow diagrams and text to describe the water systems in a building

4.2.3 Identify the areas of building where legionella can grow and spread

4.2.4 Agree and decide the places to monitor and control measures to be implemented

4.2.5 Make ways to intervene when control limits are not met

- If biofilm growth is detected in the weekly checks of a decorative Foutain, it should be shut off as per water management program rules, disinfected and checked again before getting it back to use [31].
- Another example of a different control measure includes unoccupied building or parts of a building. If for some reason a building is unoccupied, relevant control measure like measuring temperature and chlorine needs to be implemented more frequently [31] .
- Debris found in a cooling tower during an inspection will need to be addressed with a relevant control measure of cleaning and disinfection [31].
- Contingency response is required to initiate some customized actions for some unexpected problems. For instance, biofilm growth in a fountain even after regular clean and disinfection will need to be investigated further to find out the root cause of the growth of biofilm and necessary action need to be taken [31].

Another example is when water main break can cause infiltration of dirt into water system. A one-off action needs to be taken to repair and get back the water system into normal condition.

Another example in hot tubs is if levels of chlorine in a Hot tub are not within limits, necessary action needs to be taken. A broken chlorinator in a hot tub needs to be actioned immediately with relevant actions as per water management program [31].

4.2.6 Verify and validate that the program is conducted as designed and effective as planned

4.2.7 Communicate and document every activity

As per CDC, an effective water management must include:

- Always maintaining and supplying water outside the ideal temperature range of legionella growth.
- Avoiding stagnation of water.
- Ensuring disinfection of water systems when necessary.
- Regular maintenance of all the equipment's in the system to avoid corrosion, biofilm, scale, and sediment.

CDC states that water management programs should be tailored to the conditions of each building. Several factors like age of the building, location, size of building, use of building and areas of risk for legionella growth need to be considered while designing a program. The requirement of a program depends on the type of building. A water management program is required for each building in some cases whereas a program to just cover the equipment that aerosolizes water is sufficient [31].

5. Review of Remote Monitoring using different technologies

These remote monitoring solutions can be implemented based on existing research. In reference [32], they proposed a remote water temperature monitoring and control system using ZigBee. They used ESP826 Chip, RS485 BUS, CC2530 chip and DS18B20 temperature and humidity sensors for the implementation. They used CC2530F256 as the core control chip and Zigbee for data transmission. Fig.4 shows the implementation of the solution. This type of a solution can be used for temperature control routines. Sensors can be installed at different locations in a building and temperature can be broadcasted to the cloud server. The broadcasted data can be stored on the cloud and used to make the reports.

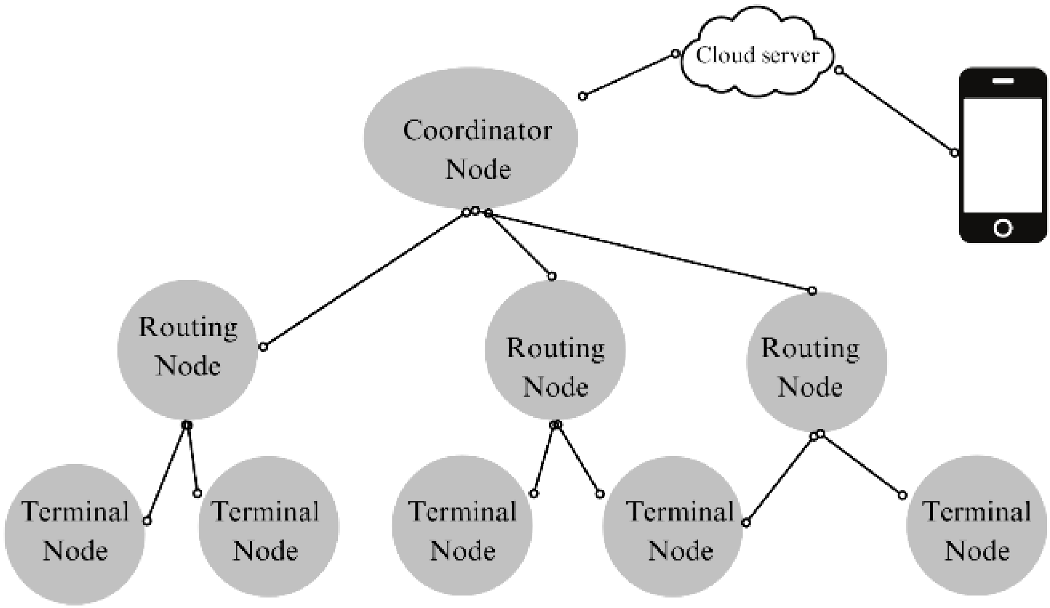

Figure 7: Remote monitoring using Zigbee protocol [32]

In reference [33] they designed a water monitoring system based on wireless sensor networks. They used temperature and pH sensors to monitor water quality in outdoor environments. They used data monitoring nodes, database stations and monitoring centre for processing data from various locations. They used Zigbee and GPRS to transfer data between database stations and remote monitoring stations. They made clusters which included data monitoring nodes and a database station. This solution is also similar to the previous solution, A similar setup can be made to monitor water system temperatures. Zigbee protocol can be used in places where low power consumption is required. Realtime transfer of data cannot be possible in some scenarios, this kind of a solution can store the collected temperature information at the database stations. The stored data can be either transferred to cloud database in regular intervals or on ad hoc basis.

Reference [34], describes the methodology for implementing a monitoring solution for controlling the Taps. They developed an android app to control and monitor the water taps. They used Arduino uno, water flow sensor and a solenoid valve to achieve this. Flow sensor was used to collect the information of water flow in a tap.

Solenoid valve is used to control the water flow. They collected data on a database and used the same to display in the app. This kind of a solution can be modified according to the requirements of a legionella flushing regime. The microcontrollers can be programmed to flush the taps when the flow is not detected for a certain period.

In reference [35] they implemented an automatic irrigation system. They used Arduino board including ATMega328 microcontroller, moisture sensors, water level sensors and water pump to implement this project. They programmed the microcontroller to switch ON/OFF the water pump. The soil moisture sensor values were used as inputs to calculate the thresholds and initiate the water pump. This kind of a solution can also be used to implement legionella flushing regime. Temperature sensors can be used instead of soil moisture sensors and water pump, or a solenoid valve can be used to control the water tap.

Emerging technologies like Machine learning and Artificial Intelligence can be used to predict Legionella in a water system. Algorithms can be used for many applications in Legionella industry, one of the basic examples is to use supervised machine learning for legionella classification. Similar examples in different applications is a twitter user classification based on machine learning approach has been conducted in reference [36], they described a machine learning framework for twitter user classification based on user profile, tweeting behaviour, linguistic content, social network. In reference [37], they proposed a new heart disease diagnosis based on fast condition mutual information method and Support vector machine. They used Cleveland heart disease dataset for the experimentation and used different feature selection methods like Least absolute shrinkage selection operator (LASSO), Relief and Local learning-based features selection (LLBS). They addressed the problem of proper feature selection by using above techniques and trained the classifiers to get good accuracy.

6. Discussion: Remote Monitoring for Implementing Legionella Control Measures

Temperature control and regular outlet flushing are the two common control measures to minimize the risk of legionella proliferating in water systems. In this section we will discuss in detail about how we can use IOT and Machine Learning for Legionella control measures and prediction.

Temperature control is the traditional control measure to reduce the risk of legionella in water systems. As per HSG274 cold water systems should be maintained at a temperature below 20°C and within two minutes at the outlet. Hot water should be stored at 60°C and circulated to reach a minimum temperature of 50°C (55°C in healthcare premises) within one minute at the outlets [30]. There is limited risk of scalding for most people at 50°C but a risk assessment should be considered where there are elderly and young children who are at risk.

Apart from temperature control, different techniques are encouraged to enable regular movement of water systems. Legionella bacteria grows in water systems with residual deposits. So, it is important to maintain clean systems. In the hard water areas, softening of cold-water supply to water systems needs to be considered to avoid deposits of scale from hot water systems. A regular flushing regime of little used outlets can help preventing the growth of legionella.

As per our previous section, there are different control measures that should be followed to prevent Legionella. All the control measures require manual efforts. A temperature monitoring or flushing routine in a big multi storey building can take hours/days. A large amount of water is wasted during the temperature monitoring and flushing regime. Monitoring or checking hot water in a water system also requires unnecessary heating of water and accounts to energy waste. These routines are often conducted by qualified and competent personnel. There is a chance of delay or risk of non-compliance when the routines are missed due to unavailability of a competent person. Unavailability of a qualified and competent person on site can force the company to outsource the person. The contracted person in this case may need to travel to site which again adds to the fuel costs, manual costs.

There is also a risk in cases of no access to certain areas on a site for conducting the control measures. A remote monitoring solution for measuring temperature of outlets and flow in them will be useful to reduce the wastage of water and energy resources. It will decrease the unnecessary wastage of water for testing and routines. A qualified person will be able to monitor the temperature and flow of an outlet remotely. This can help responsible persons to concentrate more on the irregularities rather than conducting routines.

Remote monitoring devices can be configured to collect temperature readings as frequently as every second. We can also identify water movement inside pipes with the help of rapid temperature changes.

Table 4: Factors affecting two scenarios [38]

	Manual Temperature Monitoring	**Remote Temperatures Monitoring**
Cost	Human errors	Admin costs
	Time spent for taking temperatures and travel to sites	Installation costs
	Cost of no access and repetitive visits, No compliance risk.	IT server, storage, and maintenance.
	Lack of qualified and competent persons	IT admin legionella competence.
Environmental	Carbon emissions (Travel to remote sites)	Use of Microcontrollers and signals etc.
	Water wastage: Unnecessary flushing, heating.	E waste
Health and safety	Lack of access causing no compliance, Human error, Cross contamination, scalding etc.	Short-circuit
Traceability	Loss of documentation/ proof of monitoring	No access to device/system due to network issues.

Some key benefits of using remote monitoring systems include:

- Real time monitoring of water systems.
- Remote monitoring of restricted areas, difficult to access areas.
- Identification of low used outlets or places of stagnant water.

- Identification of a leak or open outlets for an extended period.
- Confirmation of flushing the outlets with recorded Logs.
- Reduces the cost of employing individuals for routine monitoring.
- Frees up the qualified individual to monitor the work remotely and act upon irregularities.
- Reduces risk of non-compliance due to human errors or non-completion of routine works.
- Reduces the wastage of water and electricity during monitoring.
- Easy and improved documentation for proof of monitoring.

The study mainly focuses on using new technologies for preventing and controlling legionella, but no practical implementation is conducted during this research. Although the study aimed to include legionella outbreaks all over the world, it is limited to only some parts of world due to time constraints and lack of information. It will be interesting to research more about legionella in tropical and hot climate countries as the ambient temperature in these regions is ideal for the growth of Legionella. The guidance of legionella control reviewed in the paper is limited to United Kingdom and United states of America. All the remote monitoring techniques discussed in the paper are not developed specifically for legionella control and only some aspects of each process are relevant to Legionella. Combination of techniques from different studies can help us achieve a remote monitoring solution for Legionella control.

7. Conclusion

Based on the review of Legionella outbreaks, we understood that Legionella proliferates in stagnant water and can go into a dormant stage when the environment is not suitable. Most identified outbreaks occurred due to Cooling towers but there are many other different sources like Whirlpool spas (Bovenkarspel, Netherlands, February 1999) , Aquarium (Melbourne, Australia, April 2000), Industrial Air scrubbers (Sarpsborg, Norway, May 2005), Hot water system in a newly built flats(Denmark, December 2008), Decorative water wall fountain (Wisconsin, February, 2010), Spa pool (stoke on trent, England, July 2012). As per the available previous data, People with low immunity and old aged are more susceptible to Legionnaires disease. As the symptoms are too common like fever and headache, Legionella tests are often not prescribed. Preventing legionella growth in health care premises is essential to avoid any outbreaks.

Most of the identified outbreaks are due to growth of Legionella in stagnant water in an artificial water system. There is no significant evidence of its transmission from human to human, but it is caused due to breathing of contaminated droplets of water (Aerosols). As Legionella is found naturally in many water sources, prevention is the only way to control its growth and spread.

Preventive measures to avoid the growth of Legionella can take a lot of effort. A qualified and competent person is required to comply with the regulations and to keep the water systems safe from legionella. It also requires a lot of manual work like collecting temperatures from many locations on a site to analyze water systems. In cases of flushing, a person needs to manually conduct the flushing on unused/little used outlets. A qualified person might not be available every time and some human errors in these activities can increase the risk of legionella.

A system/device that can track the temperature of water systems remotely will help with the temperature check and control measure routine whereas use of remote-controlled taps can eliminate the intervention of humans. Using this kind of device can reduce the cost of legionella control measures. A competent person can analyze and manage multiple sites remotely. This will reduce the costs of employment or consultancy, Travel costs, Water usage etc. Data stored can be used as proof of control measures and can help reducing manual efforts in documenting and storing information.

The remote monitoring and automatic flushing solutions can track the water systems and their irregularities. It can help responsible persons to conduct remedial actions on sites where the temperatures are not met, or water is stagnant for long periods. As with the temperature monitoring the automatic flushing will reduce the costs of employment/consultancy, travel costs, water usage etc.

Internet of things can be used to solve this problem. A microcontroller with temperature sensor probes can be installed in required places on site. The microcontroller can be programmed to collect temperatures frequently. The collected temperatures can be stored and sent to cloud where the data can be analyzed Legionella responsible persons. Solenoid valves and an IR sensor Taps can be programmed to flush automatically when triggered by an event. This kind of solution can solve the automatic flushing of stagnant water in the systems.

Furthermore, Remote monitoring and data collected on cloud can be used to build machine learning models. Predictive analytical models can help predict the risk of legionella based on selected features in a water system. A list of important features like temperature information, positive sampling results, building size, no of outlets and number of flushes can be used as main features to train the machine learning model. A live dataset of legionella positive cases and related metadata can be used to train classifier. The developed machine learning model can be used for predicting the risk of Legionella in a water system.

We propose the use of technology to prevent and control Legionella and Legionnaires disease. Improper maintenance and control of artificial water systems can lead to severe outbreaks of Legionnaires disease. Regular implementation of control measures and maintenance are important to prevent Legionella and comply to the health and safety laws. Combination of technologies like Internet of Things, Machine Learning and Artificial Intelligence can help building remote monitoring networks. Remote monitoring and controls can assist the organizations and Individuals adhere to the rules of regulatory bodies/government authorities while being safe, decreasing efforts and costs.

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