Water Quality Detection using Wireless Sensor Network

Project Report

submitted in partial fulfillment of the requirements for the award of degree of

Bachelor of Technology

by

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under the guidance of

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Certificate

I hereby certify that the work which is being presented in this project report entitled "**Water Quality Detection using Wireless Sensor Network**", in partial fulfillment of the requirement for the award of degree of "Bachelor of Technology" submitted in Department of Computer Science Engineering and Information Technology of Jaypee University of Information Technology, Waknaghat, is an authentic record of my own work carried out under the supervision of Mrs. Monika B. Jindal. The work has referred research work of others which are duly listed in the reference section.

The matter presented in this project report has not been submitted for the award of any other degree or to any other university.

(**Akash Sharma**)
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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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Acknowledgement

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Waknaghat

May, 2019 (Akash Sharma)

Abstract

Water, being an essential component for survival of flora and fauna and covers almost 71.4% area on the Earth. It undergoes various chemical, thermal and physical changes due to man-made and natural hazard which deteriorate the water quality. In order to monitor the quality of water with respect to its physical parameters such as Electrical Conductivity, pH, Temperature, Chloride and Dissolved Oxygen, a consistent monitoring methodology is required. For the purpose, the different sampling techniques were suggested earlier that focused on evaluating underwater quality through sample collection manually from various locations. These samples are further sent for laboratory testing which is time consuming process. The techniques face various challenges like manpower, continuous monitoring, high cost and complex installation. To address the challenges, Underwater Sensor Network *(UWSN)* came into existence that targets to gather data through the sensors as a wired or wireless network. It consists of variable number of sensors and autonomous vehicles, to perform collaborative monitoring tasks over targeted area. These network captures physical parameters and images using different kind of sensors and forward them to surface station through acoustical signals. Therefore, in this project work, a Multi-Parametric Sensor *(MPS)* is proposed. The *MPS* is an integration of different parametric sensors fabricated on Arduino board. It is used to measure physical parameters in river water.

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Chapter 1

Introduction

With the advancement in the communication technology and deployment strategies, Wireless Sensor Network (*WSN*) has emerged as a promising domain. *WSN* is composed of spatially distributed autonomous devices, *i.e.*, intelligent sensors, to measure physical or environmental conditions. A sensor has various components such as a radio transceiver with an internal antenna, micro-controller and electronic circuit(s) (Orumwense et al. (2016)). With the advances in *WSN* and their pervasive deployment for information gathering, various networks on land, underground, underwater and multimedia have been described.

1.1 Wireless Sensor Network

The sensor is a physical device that may vary in sizes, property and functionality in accordance to the application (Climent et al. (2012); Fonseca et al. (2015)). For example, temperature and ultrasonic sensors are used for measuring room temperature and finding obstacles, respectively. The basic structure of a sensor is shown in Figure 1.1. Each sensor has main controller unit, *i.e.*, *CPU* which is inter-linked with sensor interface circuitry and on-board storage for storing the sensed data. This data is further transmitted to the surface station *via* waves like Radio Frequency (*RF*), ultrasonic and sonar. Each sensor is protected with Poly Vinyl Chloride (*PVC*) housing (Sozer et al. (2000)) and is equipped with battery operable components before it is deployed in the hostile environment (Fiorelli et al. (2006); Proakis et al. (2001)). It is due to the battery dissipation issue that affects the lifetime of the sensor

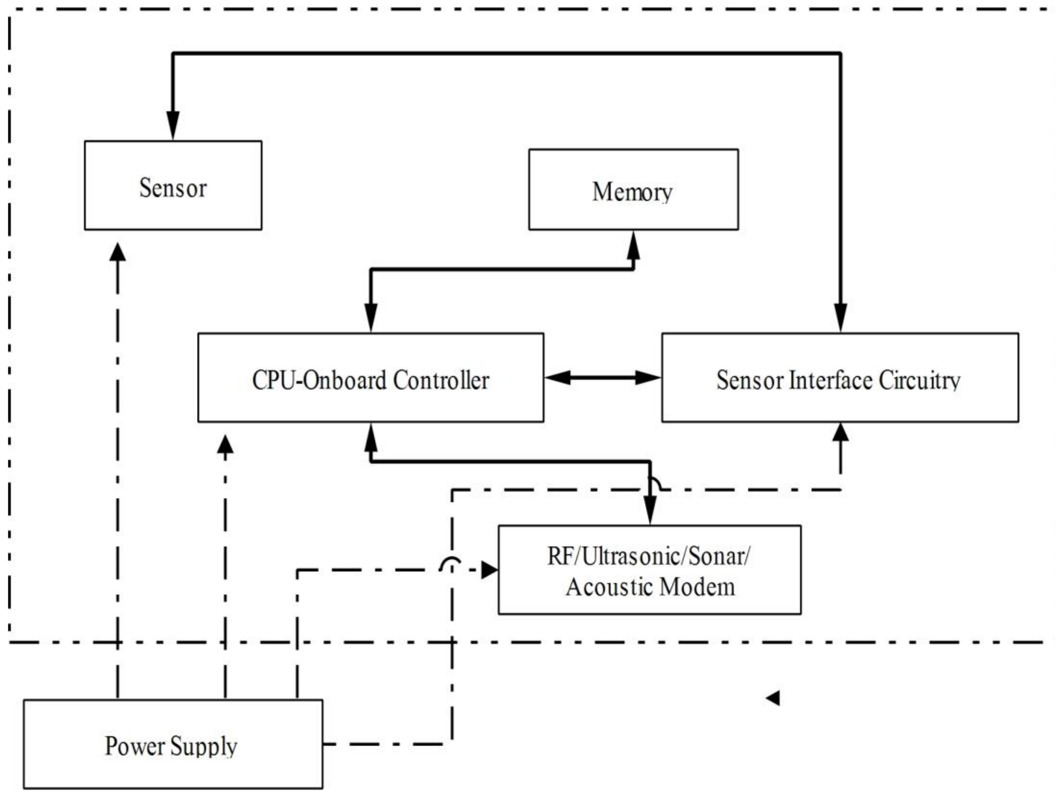

Figure 1.1: Sensor Architecture

while processing sensed data. To meet the issue, various scheduling techniques like sleep or wakeup, Time Division Multiple Access *(TDMA)*, Collision Detection Multiple Access *(CDMA)* schemes, *etc.*, are suggested (Lloret (2013)). These techniques enable sensors to transmit data to the surface station efficiently.

WSN is a collection of sensors deployed over some geographical area for sensing and monitoring the physical activities like climate, humidity, fluctuations, *etc*. A typical architecture of *WSN* is shown in Figure 1.2 (Lloret (2013)). It is capable of interacting with the environment by processing the sensed data. The sensors collaboratively interact among each other to send the buffered data as it is not possible for single sensor to process the data.

1.1.1 Types of *WSN*

On the basis of deployment, *WSN* is categorized into following types (Climent et al. (2012)).

i. **Terrestrial *WSN*:** It is created with hundreds to thousands of inexpensive wireless sensors deployed in a given area *via* an ad-hoc or a pre-planned manner. Another

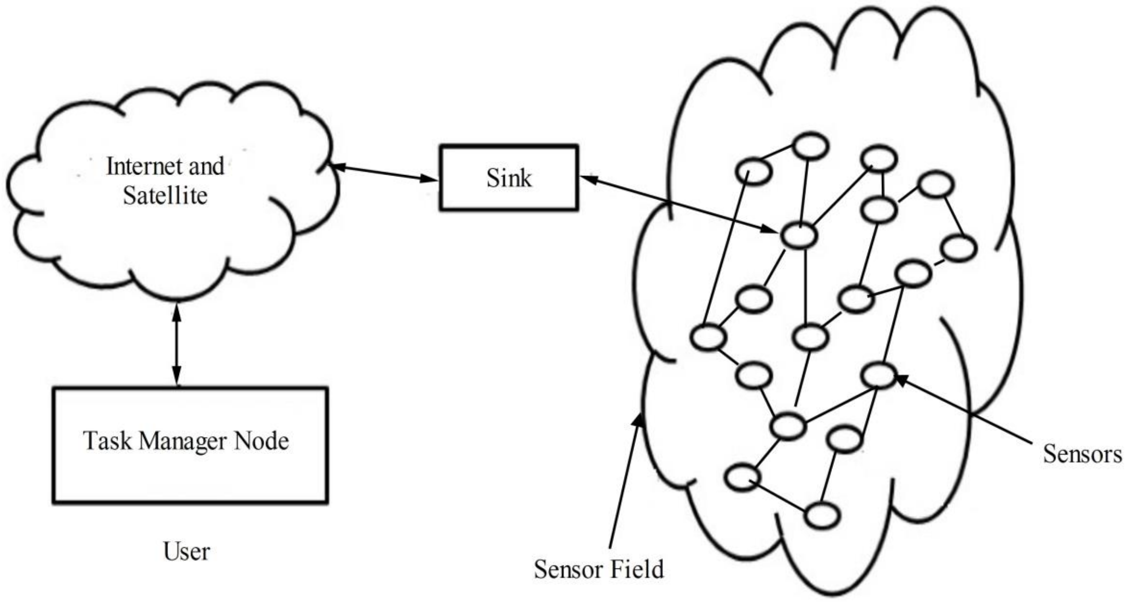

Figure 1.2: Sensor Network scattered in a Field

important consideration is the reliable communication in a dense environment where each sensor must be able to effectively communicate data back to the base station.

ii. **Underground *WSN*:** To monitor underground conditions, a network composed of number of sensors are buried underground or in a cave, mine. Sink nodes are located above ground to relay information from the sensors to the surface station. An underground *WSN* is more expensive than a terrestrial *WSN* with respect to equipment, deployment and maintenance.

iii. **Multimedia *WSN*:** It is used for monitoring and tracking of events like audio, moving text, video, *etc*. The network consists of a number of low cost sensors equipped with cameras, microphones and interconnects among each other over a wireless connection for data retrieval.

iv. **Underwater *WSN*:** In this type of network, sensors are deployed underwater along with autonomous underwater vehicles to gather data for exploration. In comparison to terrestrial *WSN*, a sparse deployment of sensors is positioned underwater and underwater wireless communications are performed using ultrasonic, sonar and acoustic waves.

1.1.2 Communication Methodology

The communication methodology for sensors is through optical, radio, electromagnetic and acoustics waves. The electromagnetic waves are used at very low level as they propagate to short distances. The acoustics waves are used to provide high speed communication among the sensors and to carry digital data through the channel which in turn provide better communication. Optical and radio waves are used when there is a wire communication whereas heavy cables are used for wired construction. The communication in air and underwater is done through single hoping and multiple hoping (Catipovic (1990); Akyildiz et al. (2002)).

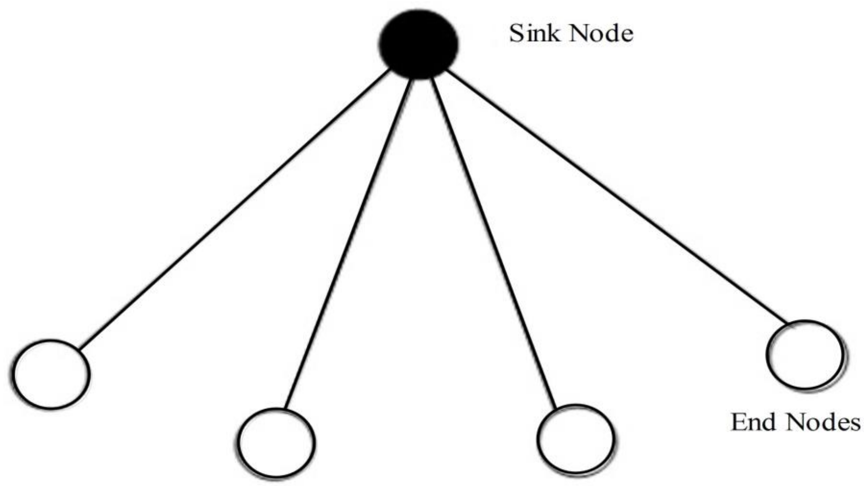

Figure 1.3: Single Hoping

In former, there is only one hop between destination and host. In latter, there are multiple hops or nodes between the host and destination which are used for underwater communication.

1.1.3 Factors Affecting Communication in Underwater *WSN*

The factors like path loss, noise, multi-path, Doppler spread, propagation delay affect acoustic communication with changing physical parameters' variability of the channel. They bound the available bandwidth of the acoustic channel where bandwidth relies on both range and frequency. Long-range systems with bandwidth upto few *KHz* run over several tens of kilometers (*km*) whereas a short-range system have more than a hundred *KHz* bandwidth

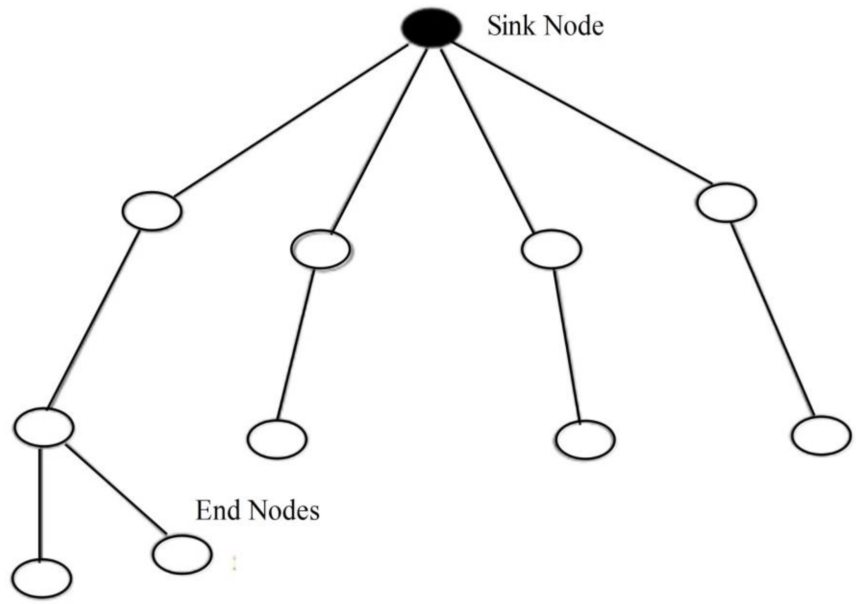

Figure 1.4: Multiple Hoping

working over tens of meters and has low bit rates. The acoustic communication links are categorized on the basis of their range and direction in which sound waves travel as vertical and horizontal. With respect to time dissipation, multi-path delay spreads, delay variance and their propagation characteristics differ consistently (Proakis et al. (2001); Freitag et al. (2001); Brekhovskikh and Lysanov (2003)). These factors are described below.

i. **Path loss:** The transfer of acoustic energy into heat results into path loss or attenuation that increases with distance and frequency. Path loss is determined by the depth of water. It gets affected by dispersion, refraction, and diffraction.

ii. **Geometric Spreading:** The expansion of the wavefronts results in to scattering of energy produced by sound and is affected with the propagation distance but is independent of frequency. The two types of geometric spreading are sphere-shaped and cylinder-shaped.

iii. **Noise:** The noise is produced by different sources at different frequencies that affects the communication. It is classified into two types, *i.e.*, *man-made* and *ambient noise*. The former is caused by machine and shipping activities whereas the latter is related to hydraulics, unstable and natural phenomena.

iv. **Multi-path:** The degradation of the acoustic communication is due to multi-path extension. The link configuration is generated by multi-path geometry where vertical channels are distinguished by little time dispersion and horizontal channels have extreme long multi-path spreads, whose value rely on the water depth.

v. **High delay and delay variance:** The propagation speed is the amount of time taken to transmit data from source to destination. It depends on the medium of communication. It is five orders of magnitude lower than in radio channel in *UWASN*. This results into large propagation delay which is a measured by ratio of distance of communication medium to propagation speed. Hence, this large propagation delay can reduce the system's throughput.

vi. **Doppler spread:** Doppler spread causes a degradation in the performance of digital communications, *i.e.*, transmissions at a high data rate cause many adjacent symbols to interfere at surface station. It generates two effects *i.e.*, a simple frequency translation and a continuous spreading of frequencies, which constitutes a non-shifted acoustic signal. While the former is easily compensated at surface station, the effect of the latter is harder to compensate.

1.2 Problem Formulation

With the exhaustive survey on *WSN*, it has been found that *WSN* is promising field of research and definitely will be a major step forward towards monitoring, surveillance applications. The main focus for deploying sensors in *WSN* is to know its hostile environment with its vital assets like natural resources, minerals, gas, petroleum, *etc*. These assets promote economy of most countries, therefore, it is required to maintain and protect them. The protection of these assets from unknown hindrances, *i.e.*, intentional and non-intentional attacks, needs special consideration. Moreover, with the deployment of sensors, the monitored data should be sent to surface station in an efficient manner to take timely preventive measurements.

But, the energy efficient transmission in *WSN* is still a key challenge as the sensors are adhered with water constraints like Doppler effect, path loss, noise, propagation delay, *etc*.

The dynamic deployment of sensors need to be implemented to mitigate the effects of water and to sustain the deployment for longer periods. Further, these sensors need to be equipped with storage capacity in order to retain data for some time and must have capability to communicate sensed data to either smartphone or *PC via* blue-tooth in short time interval. This strategy will not hamper in computation of gathered data at surface station.

1.3 Objectives

The objectives of this work are-

i. To study and analyze the existing techniques for data communication.

ii. To procreate energy efficient method for data transmission to the surface station.

1.4 Organization

The thesis has been organized as per following chapters.

Chapter 1: Introduction

This chapter discusses the basics related to *WSN*, its communication methodologies and emerging key challenges that influence acoustic communications.

Chapter 2: Literature Review

The comprehensive survey of work done in the area of *WSN* is carried out in this chapter; highlighting the various protocols, techniques for communication.

Chapter 3: System Development

The chapter highlights the proposed framework and methodology for water quality measurement.

Chapter 4: Result and Analysis

The performed testbeds and analysis of proposed framework is discussed in this chapter. It includes the practical implementation with the perspective of measuring water's quality.

Chapter 5: Conclusion and Future Scope

The chapter concludes the project's outcome and provides an insight into the future scope of the work.

Chapter 2

Literature Review

2.1 Introduction

The chapter highlights the most comprehensive contributions in the field of *WSN* with respect to underwater data communication. Data communication includes deployment strategies and protocols. A general, comprehensive and structured overview of existing techniques are described.

2.2 Data Transmission Techniques

Due to hostile environment, human reach is quite difficult. Therefore, sensors are deployed to help sensing and transmitting data to surface station for further processing. For the purpose, the prior requirement is to understand distinct deployment strategies and protocols for sensors. This will help to ease in communication and computation processes. This section has provided a structured literature survey of the existing research contributions with respect to communication techniques, systems, models, algorithms based on real time simulations, test beds, and implementations of protocols on sensors.

2.2.1 Deployment Strategies

The deployment strategies for data transmission are broadly classified in to methodologies, *namely*, mobile sink gateway, clustering, distributed sink and network topologies. These are discussed.

i. **Mobile Sink Gateway based Techniques:** In mobile sink gateway based techniques, a mobile sensor act as an interface to transmit data among various surface stations and helps to preserve the energy of the idle sensors deployed at the bottom surface. For example, a network system for detecting pipeline leakage has been designed by Tu and Chen (1999). The system helps in taking suitable actions against pipeline leakages. The system has its limitations that it detects limited portion of pipeline. To this improvement, Wu et al. (2007), have presented a modular *WSN* design that provide access to host for detecting leakages in wide area networks. The design allows the gateway to be deployed in heterogeneous network environment and enables remote upgrading. It faces few limitations that the continuous updating of design slows the process of deployment and measurement. To improve the techniques of measurement and prolonging the lifetime of *WSN*, three schemes have been postulated by Basagni et al. (2008). These schemes exploit the mobility of the network sink. For determining sink movements, *firstly*, Mixed Integer Linear Programming *(MILP)* analytical model is described. It helps in maximizing network's lifetime. The *second* scheme *namely*, Greedy Maximum Residual Energy *(GMRE)* controls distributed and localized sink movements and heuristically moves the sink from its current location to a new site. The *third* scheme, *i.e.*, Random Movement *(RM)* moves the uncontrolled sink randomly throughout the network. These schemes are compared using *NS-2* simulations and is observed that moving the sink increases network's lifetime. In order to implement these schemes on real environment, it is improved with a technique based on continuous phase distributions and Kronecker algebra (Bruneo et al. (2010)). It helps in reducing power consumption of sensors. The technique provide effectiveness in figuring wider network context with complex topology, redundant nodes, and unreliable links. To analyze sensor's failure, a mobile gateway is designed that supports Zigbee and blue-tooth (Angove et al. (2011)). It facilitates interaction with conventional mobile devices using wireless communication.

   This mobile gateway is further extended for monitoring river water using a satellite *namely*, EnviSat RA-2. The satellite helps in analyzing echoes over inland water (Berry et al. (2012)). This satellite provides successful measurement of smaller water surfaces at 1800 *Hz*. It enables monitoring of smaller river systems. The satellite has its disadvantages that it provide delayed monitoring during rainfall.

Few authors have presented a name-based Future Internet Architecture *(FIA)*, such as Mobility First for *IoT* service platform (Li et al. (2013); Al-Radaei and Mishra (2013)). The architecture is ubiquitous and scalable with increasing number of smart phone users. It delivers a temperature sensor data from an Android phone directly to multiple applications. To utilize maximum resources and to deploy multiple sensors, Karvonen et al. (2014), have postulated a hierarchical architecture for *WSN*. It consumes less power by utilizing a wake-up radio signaling. The results supports the power efficiency using wake up schemes and is further used for estimating event frequency and channel conditions. Also, Morón et al. (2014), have presented health telemonitoring system for evaluating and characterizing medical Wireless Personal Area Network *(WPAN)* using smartphones and blue-tooth communication. The smartphone provides information gateway for gathering data from sensors and retransmits it to base station *via* Wi-Fi signal. It has its limitations while integrating with central server using cloud computing because smartphone does not provide proper gateway for gathering information. Another design, *i.e.*, handheld smartphone based *pH* sensor has been demonstrated for monitoring river water quality (Dutta et al. (2015)). It evaluates its *pH* level using bromocresol, green, chlorophenol red dyes' wavelength absorption condition. It provides reliable data but is not advantageous to deeper depth of rivers. To improve the mechanism of collecting data, a self-organizing *WSN* for remote water quality monitoring has been designed (Chung and Yoo (2015)). It helps in measuring physical parameters of water such as turbidity, *DO*, *pH*, conductivity, depth and temperature; for analyzing water quality variation in river areas. The data is stored in buffer for frequent time duration and is further transmitted to neighboring node for sending data to base station. The design has various challenges related to depth of water and multi-hop schemes.

ii. **Clustering based Techniques:** In clustering, bottom sensors are grouped together to relay data to surface station and consume more energy. In order to preserve energy, one sensor among bottom sensors is chosen as cluster head for data transmission. As an example, a cluster-centric cost-based optimization technique has been proposed for minimizing energy consumption and to increase lifetime of network (Wang et al. (2007)). The authors have also suggested Minimum-Cost Clustering Protocol *(MCCP)* for selecting potential clusters in order to reduce data-traffic during communication. This protocol is implemented in various systems for efficient transmission. Yang et al. (2008), have demonstrated an on-line water quality monitoring and management system that uses chemical oxygen demand sensor with an artificial neural network technology and a virtual instrument. It is observed from gathered information that the system provides an effective technique to water quality control for environmental protection. In order to improve the technique with automatic detection, O'Connor et al. (2011); Tripathi and Mishra, have postulated a visual sensor for off-line river monitoring. This sensor provides an estimation of extreme events at the site with longer sustainability and involves little maintenance. It sends timely alarms to take preventive measurements.

iii. **Distributed Sink based Techniques:** To compute the accuracy while communicating data from bottom sensors to the surface station, techniques based on distributed sink come in to existence in which sensors are added dynamically which can act as sink node or bottom sensors for better communication. As an illustration, the key benefits of implementing and integrating a multi-layered sensor network architecture, *namely*, Environmental Information Management Systems *(EIMSs)*, for environmental data gathering have been summarized (Pokorny (2006)). The system has its limitations of retaining the data quality of processed information (Pokorny (2006)). The system requires more sophisticated techniques for metadata processing. To retain the data quality and metadata processing, various developments in *WSN* have been studied that are used for analytical measurements (Diamond et al. (2008)). The authors have also inhibited the integration of *WSN* with sensors and analytical devices. The various issues have come across with these integration techniques and suggest it is possible to construct a solution according to the platform and application's requirements.

iv. **Energy Harvesting based Techniques:** A common challenge faced by above said techniques (mobile sink, clustering, distributed sink and network topologies), is related to power dissipation of the sensors. The batteries of the sensors are energy constrained and cannot be recharged easily. Therefore, in order to preserve the energy of the sensors, few of the researchers have provided the different topologies and communication techniques in real-time and multi-modal network to gather information. The strategies are worked upon with energy efficient sensors to sustain the topology in underwater for longer periods. For the purpose, Glasgow et al. (2004), have presented Real-Time Remote Monitoring *(RTRM)* and sensing technologies for statistical and mechanistic monitoring of water quality trends. These technologies are used by federal, state regulatory agencies, industries and academic laboratories for detection of environmental threats leading to fish kill events and potential human health impacts. To its modification, a technique is suggested by Bruggen and Braeken (2006), which explores the usage of wastewater after recycling it. The technique is intended for optimizing water consuming processes aiming at zero discharge of wastewater. The technique is beneficial for removal of particles, fibres and suspended solids but a zero discharge of wastewater is not entirely obtained.

2.2.2 Techniques based on Protocols

With respect to data transmission, efficient communication protocols among the sink nodes and surface stations are needed. It is due to the fact that high attenuation and scattering affects the acoustic communication. For example, Pompili and Akyildiz (2009), have presented an overview of solutions for medium access control, routing, transport-layer, and cross-layer networking protocols. These protocols are well suited for real world monitoring in underwater with its efficient communication capabilities to sense and transmit data over a long range distances. Moreover, these protocols help user to remotely control devices or autonomous robots for controlling their motion and sensing capabilities. King et al. (2010), have summarized various issues related to communication, development, deployment and testing of protocols for underwater *WSN*. It is reviewed that communication due to acoustic waves is difficult in underwater due to reflection, refraction, deployment, testing based simulations and real environments that are expensive in nature. With respect to protocols for communication, Yadav and Yadav (2016), have surveyed and examined various energy efficient protocols with issues on activities mainly data collection, clustering and routing. The protocols should fulfill the aspects like minimizing total energy spent in network, minimizing number of data transmission time and maximizing number of alive sensor over time or balancing energy dissipation among sensors. For the purpose, different protocols are being implemented by the researchers based on modulation, scheduling, localization and routing to provide faster transmission and to avoid collisions among the data traffic that minimizes the congestion on the sensors. Protocols based techniques are subdivided into modulation, routing; and are discussed.

i. **Modulation Techniques:** Modulation fastens the transmission through the conversion of data into bits and symbols using encoding schemes. For example, Sozer et al. (2000), have suggested that Collision Detection Multiple Access (*CDMA*) provides the most robust method for underwater network environment. Quasi-Orthogonal Space-Time-Frequency Codes *(QOSTFCs)* have been examined by Tran et al. (2007), to increase data rates and error performance in STFC Multiband *OFDM* Ultra Wideband *(MB-OFDM UWB)* communications systems. It increases the transmission power, and reduces higher decoding complexity at surface sink to analyze the monitored data. To efficiently transmit data to surface station, an optical fair scheduling in Spatial Time Division Multiple Access *(STDMA)* network is presented by Luque-Nieto et al. (2016). It provides optimal frame determination for sending data. The technique has increased throughput and performance with limited number of sensors (*say*, up to 12) but its performance is degraded with increase in the number of sensors, *i.e.*, 20, 30, 50, 80, *etc*.

iii. **Routing Protocols:** In routing, the routing-table keeps on updating the position of the sensors which further helps in finding the shortest route through single-hop or multi-hop techniques. It benefits in preserving the energy of the sensors and does not let collision to occur. Many researchers have enlightened the sensitivity in deployment and communication *via* routing protocols with respect to energy consumption, data gathering and route updating process. For example, Catipovic (1990); Kilfoyle and Baggeroer (2000), have addressed various limitations for using underwater acoustic telemetry. The complex computations have decreased the reliability of telemetry systems where video image transmission is used. The data rate is slower ranging from 1 to 500 kbps and its performance varies due to its dependency on channel phase, bandwidth and impulse response fluctuation rate. The use of *WSN* for ecological experiments have been studied by Suri et al. (2006); Doss et al. (2006). It is suggested that the lifetime of *WSN* are optimized by implementing low-level energy routing protocol and are used for applications in remote, hospital environments. To decrease cost, manpower and increasing the efficiency of data transmission various routing protocols are suggested. These protocols help in transmitting data by selecting the shortest route among source and surface station. In order to deal with data gathering, Pompili et al. (2006), have suggested a two-phase resilient routing which provide guaranteed survivability of the network to sensor and link failures. Few authors have designed new set of routing protocols considering factors like transmission mediums, energy consumption in terrestrial and underwater *WSN*. The protocols fail to provide the performance on the basis of sensor's localization. The reactive and proactive protocols *namely*, Ad-Hoc on Demand Vector *(AODV)*, Destination Sequenced Distance Vector Routing *(DSDV)*, Optimized Link State Routing *(OLSR)*, respectively, are appropriate for dynamic environment but cause large signaling overhead resulting into sensor failures (Huang et al. (2009); Horng et al. (2010)). Therefore, Dynamic Source Routing *(DSR)* based on fuzzy logic inference system is proposed. It estimates distance, angles among neighboring sensors and remaining energy among sensors; before forwarding a packet to destination. This protocol consumes less energy.

In summary, the key aspects to communication is efficient protocols that are implemented with deployment strategies having longer sustainability.

2.3 Gaps Identified

Based on the literature survey, following gaps are identified.

ii. **Erroneous in Localization:** Underwater acoustic channels are characterized by harsh physical layer environments influenced by transmission loss, noise, multi-path, Doppler spread, high propagation delay that leads to stringent bandwidth limitation. This limitation hinders in finding the actual position of sensors in underwater (Lloret (2013)). The technique of finding the correct position of sensor takes into consideration its mobility as major concern parameter in distributed environment. Therefore, there is requirement for strategy that can work for discovering the location of sensors.

iv. **Data Transmission:** The data is transmitted through the routing protocols which causes a large signaling overhead to establish routes for the first time. Since, network is modified each time due to sensor failures, updated topology information needs to be propagated to all connected sensors. This way, each sensor is able to establish an updated path for data transmission which is a time consuming process resulting into power degradation of sensors (Pompili et al. (2006)). Therefore, the issue is to design an efficient routing protocol for faster data transmission and to conserve energy of sensors.

v. **Energy Consumption Issue:** Energy consumption determines the lifetime of a *UWASN* as sensors use battery power as an energy source. Energy is consumed in three operations, *i.e.*, sensing task, communicating information, and processing the data. As, the battery-life is limited and the sensors are placed in a hostile environment, therefore, replacing the battery is impractical (Climent et al. (2012)). So, the issue is to minimize the energy consumption.

vi. **Data Gathering:** It is the process of collecting data from different sensors by removing the redundant data. This information is passed on to the sink node without the loss of information. There are various security holes in data gathering which is removed with data compression and data aggregation technique. The issue is to remove data redundancy as the bottom sensors send multiple data to the surface station.

vi. **Failure of Sensor:** Sensors are prone to failure because of unattended environment. A sensor may fail due to hardware, software problem. If any of the sensor fails, the working protocol should handle this type of failure (Sehgal et al. (2011)).

Chapter 3

System Development

3.1 Water Quality Monitoring Framework

In this section, the sewage water quality monitoring framework (*see* Fig. 3.1) is proposed that intends to monitor sewage water quality for any timely preventive measures for water treatments. It uses Multi-Parametric Sensors *MPS* that are controlled *via* smart phones deployed

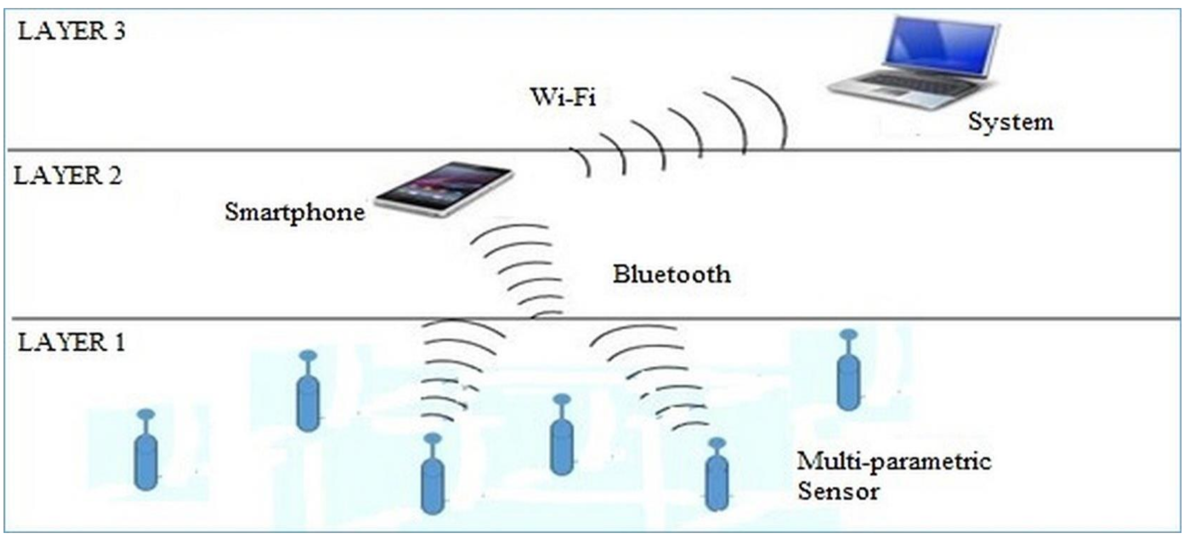

Figure 3.1: Framework for water quality measurement

in the targeted area for sensing and forwarding the gathered information to the connected gadgets like laptops. The framework defines three major layers and are discussed below.

(A) **Layer 1:** At this layer, Multi-parametric Sensors (*MPS*) are deployed that sense the data and are controlled by the micro-controller board, *namely*, *Arduino UNO*. The *Ar-*

duino UNO has 14 digital pins (input/output), Universal Serial Bus *(USB)* Connection, one power jack and bread board that simply connects with Personal Computer via *USB* cable. It is based on open-source prototype platform with Integrated Development Environment *(IDE)* which is used to write and upload the computer code to the physical board. The key features of *Arduino UNO* are -

- Manual controlling of the sensors *via* instructions.
- Provides feasibility to load codes directly onto the board using *USB* cables.
- Works on *IDE* platform which is simpler version of C++.

The Arduino board is programmed for communication among each other via Inter-Integrated Circuits *(I2C)* synchronous serial protocol. The *I2C* uses two lines for sending or receiving data, *i.e.*, a serial clock pin to pulse the board at regular intervals and serial data pin *(SDA)* for transmitting data between two Arduino boards.

The *(MPS)* are built on this board embedded with rechargeable batteries as a power source to keep sensor in active mode as shown in Fig. 3.2 (a). It is used for sensing *pH*, Temperature, Electrical Conductivity, Dissolved Oxygen, and Chloride in water. It uses an external *RF* connector to take signals; an expansion connector for increasing the memory size and a blue-tooth to send signals acoustically *via* angular communications. Acoustic signals are used to provide high speed transmission among nodes to carry digital data through the channel. The maximum bit rate achieved is 16 bits/second. The sensor is placed inside a casing of stainless conceals that is used for housing to protect its vulnerability to withstand the enormous water pressure (*see* Fig. 3.2 (b)). The data is collected and processed in 20 minutes intervals. The specifications of the *MPS* are shown in Table 3.1.

The *MPS* is interfaced wirelessly with smart phones through standard wireless protocols such as Wi-Fi or Bluetooth. It results into following advantages: (a) universal compatibility; (b) sensor operation is more elegant due to the absence of physical connection; (c) the smart phone communicates with multiple sensors at a time. The reconciliation of smart phones with *MPS* yields another class of sensors with expanded convenience and information versatility.

Table 3.1: Specifications of Multi-parametric Sensor

S. No.	Parameters	Specifications
1	Chip Board	Arduino i2c
2	Frequency Range	25 KHz
3	Communication Method	Bluetooth
4	Transmission Process	Angular
5	Memory	800 KB
6	Packet Size	532 bytes
7	Packet with error ratio (1/1000)	5 (packets)
8	Batteries (Panasonic Eneloop Pro Ni-MH)	2550 mAh

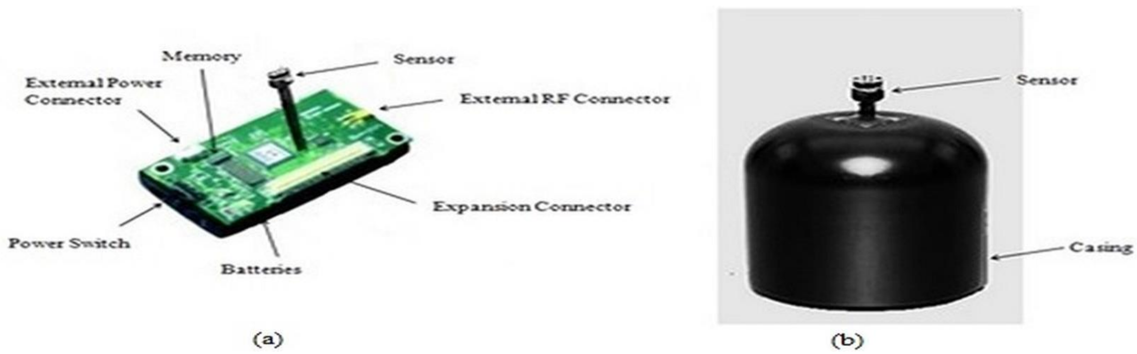

Figure 3.2: Multi-parameter sensor: (a) without casing and (b) with casing

(B) **Layer 2:** A smart phone is used at this layer that communicates with *MPS* either through Blue-tooth or Wi-Fi and provide fidelity to user for data capturing. The application stored on smart phone works as an interface and platform for acoustic data capturing. The software application is installed on handset Sony Xperia Z1 powered by Android application. The specifications of the smart phone are shown in Table 3.2. It is dipped into water and is sustainable up to 15 - 30 minutes for data sensing. Its interface is also available on laptop using 'throw' application. When the application is initiated, it prompts the user with a list of water quality parameters that are selected by touching its labeled button (*see* Fig. 3.3).

Once a particular parameter is selected, the application begins to guide the user through the measurement process in two steps (user-initiated). The first step ensures that the sensor is connected to the phone. If it is not connected, it asks for the pairing of the

Table 3.2: Sony Xperia Z1 specifications

Type	Specifications
OS/System Program	Android v4.2 (Jelly Bean)
Displaying Screen	Touchscreen TFT with 16M colors
Resolution	1080 x 1920 pixels
Processor	2.2 GHz Quad-Core Processor
Memory	2 GB RAM and 16 GB ROM
Camera	21 MP
WLAN	Yes
Bluetooth	Yes
GPS	Yes
Messaging	Yes
Battery	Li-ion 3000 mAh battery
Water Resistance	15-30 minutes

Figure 3.3: Data collection using smart-phone software (a) home screen, (b) prompts for enabling Bluetooth, (c) checking nearby devices, (d) data gathering, (e) data processing and (f) data sharing with external applications

sensor *via* Blue-tooth or Wi-Fi. Finally, the user selects the parameter to analyze and compute measurement of the desired parameter. The data is displayed numerically and is logged. At any point, during the measurement procedure, the user has right to press the home button on the smart phone to exit the application completely. All measurements made during the application are logged, and are exported as Comma Separated Values *(CSV)* excel file before the application is closed. The file is deleted after the application is closed.

(C) **Layer 3:** At this layer, data aggregation is done. Here a mobile device like a laptop or portable *PC* is available for large data acquisition and analysis. The intercommunication among *MPS*, smart phone, laptop and portable data collector is done through an ad-hoc network. The devices work at 2.4 GHz frequency. A Wi-Fi connection allows multiple sensor devices connection to a smartphone or laptop. On the basis of the depth or distance, both Wi-Fi and Bluetooth wireless communication standard are used for interconnection. The recognizing features of the framework are its high level of portability, easy operation through the Graphical User Interface *(GUI)*, high data mobility, and quick water quality measurement approach.

3.2 Testing Site Description

The Sewage Treatment Plant *(STP)* is located at Jaypee University of Information Technology, Waknaghat, Solan (*see* Fig. 3.4).

It is accredited by National Assessment and Accreditation Council *(NAAC)* in 2010 for treatment of sewage water such that re-usage is possible for irrigation and domestic purposes. The *STP* consists of a bar screen chamber which collects the raw sewage coming from the *inlet* within the sump after giving it permission to pass through a bar screen (*see* Fig. 3.5).

The bar screen removes coarse solids from the sewage. The pumped raw sewage is passed through a distribution box and loaded as four equal streams into the first stage of two stage Baffled Anaerobic Reactor *(BAR)*. The treated effluent as the outcome of the second stage *BAR* is allowed to flow into the augmented facultative pond for further treatment. The treated effluent out from the augmented facultative pond is passed through the multi-stage roughing

Figure 3.4: Site location: sewage treatment plant (a) model of sewage treatment plant, (b) augmented facultative pond, (c) wastewater collection tank, (d) bar pipe, (e) motor for treatment of water and (f) total flow rate of treated water

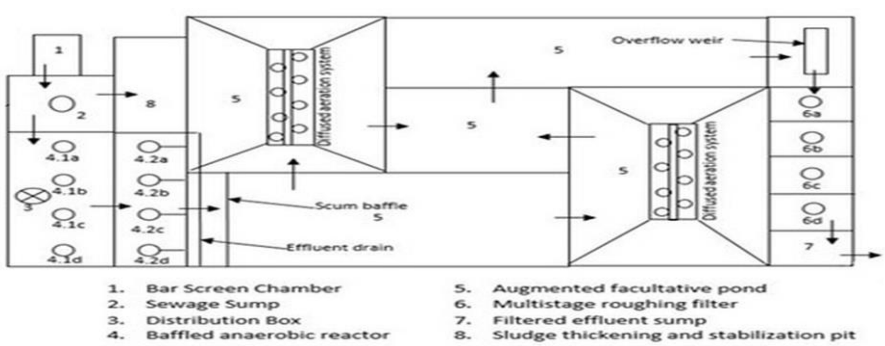

Figure 3.5: Layout of *STP*

filter. Effluent from the filtered effluent sump is allowed to overflow the sump and flow under gravity through a circular drain into the duck pond. The work flow for sewage treatment and disposal is shown in Fig. 3.6.

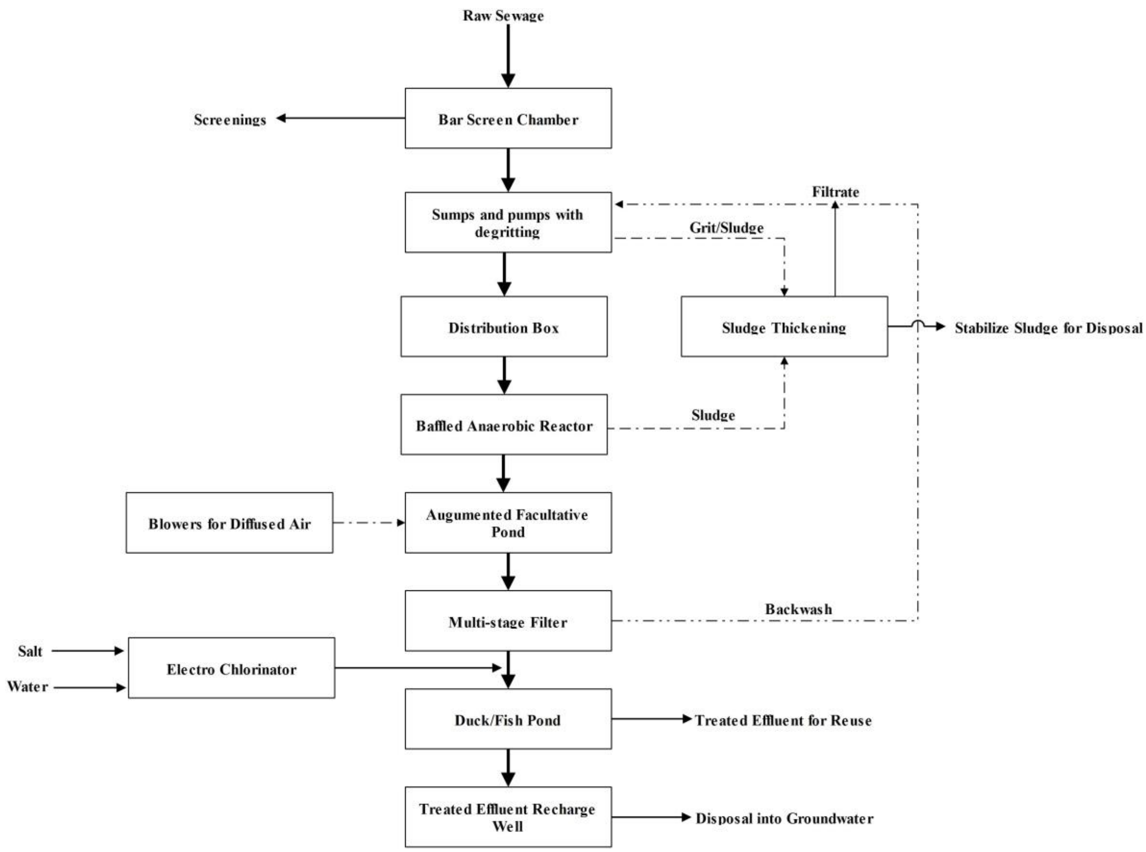

Figure 3.6: Work flow of sewage treatment

The underlying method, *namely*, Purification, entails for removing contaminants like domestic, human waste, effluents and run-offs; from sewage water. The purification is performed through various physical, chemical and biological methods. The purpose of purification is to reuse the water to maintain environment ecologically. The main use of treated water from sewage purification is for irrigation in agriculture or domestic cleaning. It undergoes the pre-treatment process for purification. The pre-treatment removes hard materials from raw sewage such that they don't clog or damage the sewage lines or pumps. The common objects removed are trash, tree limbs, leaves, branches, and other large objects. The sewage water passes through bar screen chamber where large objects like cans, rags, sticks, plastic packets, *etc*. are removed.

The solids are disposed off in landfill. The inflows sewage water is then passed through grit channel where velocity of inflow is adjusted in order that sand, grit, stones, and broken glass are settled down. These particles are removed as they damage pumps and other equipments. The equalization basins are used for temporary storage of diurnal and helps to hold incoming sewage during maintenance. These basins require discharge control using aerators to manage the flow, bypass sewage water and their cleanliness. At-last, fat and grease are removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank are used to support recovering the fat as a froth. Thus, the sewage water is purified. For further analysis, the treated sewage water is checked against its water quality parameters that are monitored using sensors with existing traditional sampling methods and other good quality water like municipal, storage tank, rain and drinking water.

Chapter 4

Result and Analysis

4.1 Procedure for Framework Implementation

The *STP* treatment requires automated regular monitoring and removal of effluents present in the water. To achieve this, the proposed framework is well tested and analyzed at the specified location. As per requirement, two *MPS* are used in the sewage plant; one is placed at the *inlet* and the other at the *outlet* (*see* Fig. 4.1).

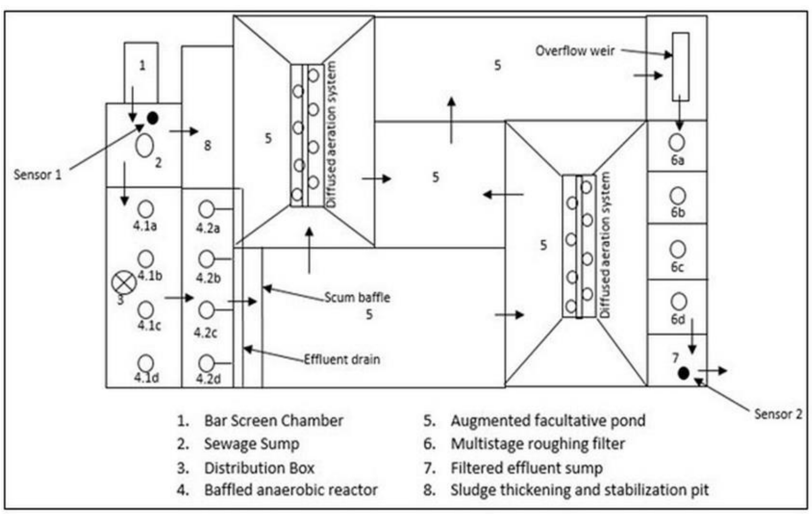

Figure 4.1: Framework implementation (a) block diagram for data collection and communication, and (b) sewage treatment plant with *MPS*

The *inlet* sensor is used for measurement of parameters for the raw sewage whereas the *outlet* sensor is used for the measurement of treated water parameters. The difference in measuring temporal and spatial parameters at *inlet* and *outlet* defines water quality. The flow diagram for data collection using smart phone is presented in Fig. 4.2. The measurement

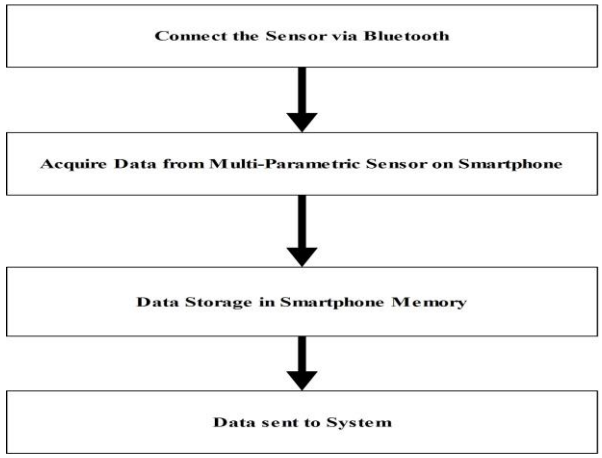

Figure 4.2: Flow diagram

procedure forms the following five steps:

1. The sensor-smart phone pairing is done for the first time use.
2. Selection of the parameters for measurement from the application title screen once it ensures that Blue-tooth is on and sensor is attached.
3. The measure is selected to perform the measurement.
4. The water sample is measured and displayed on the screen.
5. The measured data is logged and saved.

4.2 Result Analysis and Discussion

The water is sensed for spatial and temporal variations at the *inlet* and *outlet* of *STP* for the months of *June, July, August* and *September* 2018 during the day time. The observations are made twice a week in the respective months. These are discussed as hereunder:

4.2.1 pH

The *pH* factor calculates the acidity or alkalinity of water. If *pH* decreases, acidity in the water increases. The *pH* affects many chemical and biological processes in the water, *e.g.*, most of the aquatic animals flourish in the range of 6.5 to 8.0. The observed values are shown in Tables 4.1-4.2 and Fig. 4.3. The *pH* is calculated by the following Eq. (1).

$$pH = -\log[H_3O^+] \tag{4.1}$$

Table 4.1: Observed *pH* data *(inlet)* for four months

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	7.12	-	-	-	7.27	-	-	-	7.52	-	-	-	7.82	-	-	-	7.43
Tue	7.23	-	-	-	-	7.54	-	-	7.64	-	-	-	-	7.53	-	-	7.49
Wed	-	7.44	-	-	-	7.96	-	-	-	7.45	-	-	-	7.12	-	-	7.49
Thurs	-	7.67	-	-	-	-	7.69	-	-	7.49	-	-	-	-	7.34	-	7.55
Fri	-	-	7.72	-	-	-	6.53	-	-	-	7.58	-	-	-	7.64	-	7.37
Sat	-	-	7.73	-	-	-	-	6.69	-	-	7.84	-	-	-	-	7.32	7.40
Sun	-	-	-	7.19	-	-	-	6.94	-	-	-	7.89	-	-	-	7.45	7.37
Avg.	7.18	7.56	7.73	7.23		7.75	7.11	6.82	7.58	7.47	7.71	7.86		7.33	7.49	7.39	

Table 4.2: Observed *pH* data *(outlet)* for four months

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	7.65	-	-	-	7.35	-	-	-	7.56	-	-	-	7.82	-	-	-	7.60
Tue	7.61	-	-	-	-	7.49	-	-	7.54	-	-	-	-	7.73	-	-	7.59
Wed	-	7.55	-	-	-	7.36	-	-	-	7.75	-	-	-	7.41	-	-	7.52
Thurs	-	7.43	-	-	-	-	7.41	-	-	7.89	-	-	-	-	7.39	-	7.53
Fri	-	-	7.48	-	-	-	7.43	-	-	-	7.95	-	-	-	7.89	-	7.69
Sat	-	-	7.34	-	-	-	-	7.45	-	-	7.31	-	-	-	-	7.56	7.42
Sun	-	-	-	7.70	-	-	-	7.58	-	-	-	7.63	-	-	-	7.52	7.61
Avg.	7.63	7.49	7.41	7.53		7.43	7.42	7.52	7.55	7.82	7.63	7.73		7.57	7.64	7.54	

In the month of *June*, at the *inlet*, *pH* values were sensed between 7.1 and 7.8 that shows lesser acidic nature of the water. After the treatment, the *pH* ranges from 7.4 – 7.6 at the *outlet*. Thus, change in parameters depicts that the required normal conditions of treated

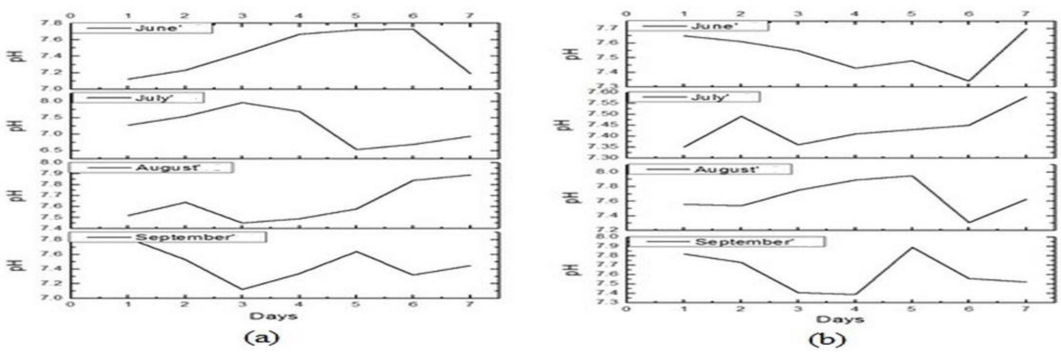

Figure 4.3: Graph for *pH* (a) an *inlet* observation and (b) *outlet* observation

water to reuse.

In month of *July*, at the *inlet*, the *pH* values varied from 6.8 – 7.8, *i.e.*, towards the lower acidic nature of water. However, at the *outlet*, the *pH* values appeared between 7.4 and 7.55. The sensed reading displays the normal ranges of *pH*.

For the month of *August*, the parameter at the *inlet* shows that there is an improvement in the quality of sewage water due to rain. The *pH* values ranges between 7.4 and 7.9. At the *outlet*, *pH* was sensed between 7.5 and 7.75, making the treated water free from growth of algal blooms.

During the month of *September*, at the inflow, the *pH* values varied from 7.3 – 7.9. At the *outlet*, the *pH* is noted in the range of 7.5 – 7.75. This reading manifests that the water is fit for domestic and irrigation purpose.

4.2.2 Temperature

The temperature plays a vital effect on the activities and growth of organic beings in the water. The rise in temperature increases the chemical reaction and hence, affects the organic beings. The amount of heat released or absorbed gives rise to changes in the temperature, which is calculated using Eq. (2) below.

$$\Delta T = \frac{Q}{mc} \tag{4.2}$$

where ΔT, Q, m and c represents the difference in temperature, the released or absorbed heat, mass and defines the particular heat, respectively. The observed results are shown in Tables

4.3-4.4 and Fig. 4.4.

Table 4.3: Observed data of temperature at *inlet*

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	29	-	-	-	30	-	-	-	28	-	-	-	29	-	-	-	29.00
Tue	30	-	-	-	-	30	-	-	30	-	-	-	-	29	-	-	29.75
Wed	-	31	-	-	-	30	-	-	-	28	-	-	-	29	-	-	29.50
Thurs	-	33	-	-	-	-	29	-	-	28	-	-	-	-	29	-	29.75
Fri	-	-	30	-	-	-	28	-	-	-	29	-	-	-	28	-	28.75
Sat	-	-	30	-	-	-	-	28	-	-	30	-	-	-	-	30	29.50
Sun	-	-	-	30	-	-	-	28	-	-	-	28	-	-	-	33	29.75
Avg.	29.50	32.00	30.00	30.00		30.00	28.50	28.00	29.00	28.00	29.50	28.50		29.00	28.50	31.50	

Table 4.4: Observed data of temperature at *outlet*

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	29	-	-	-	30	-	-	-	30	-	-	-	30	-	-	-	29.75
Tue	29	-	-	-	-	30	-	-	30	-	-	-	-	28	-	-	29.25
Wed	-	29	-	-	-	29	-	-	-	28	-	-	-	29	-	-	28.75
Thurs	-	29	-	-	-	-	29	-	-	27	-	-	-	-	29	-	28.50
Fri	-	-	29	-	-	-	30	-	-	-	27	-	-	-	29	-	28.75
Sat	-	-	29	-	-	-	-	30	-	-	29	-	-	-	-	31	29.75
Sun	-	-	-	30	-	-	-	30	-	-	-	29	-	-	-	31	30.00
Avg.	29.00	29.00	29.00	30.00		29.50	29.50	30.00	30.00	27.50	28.00	29.50		28.50	29.00	31.00	

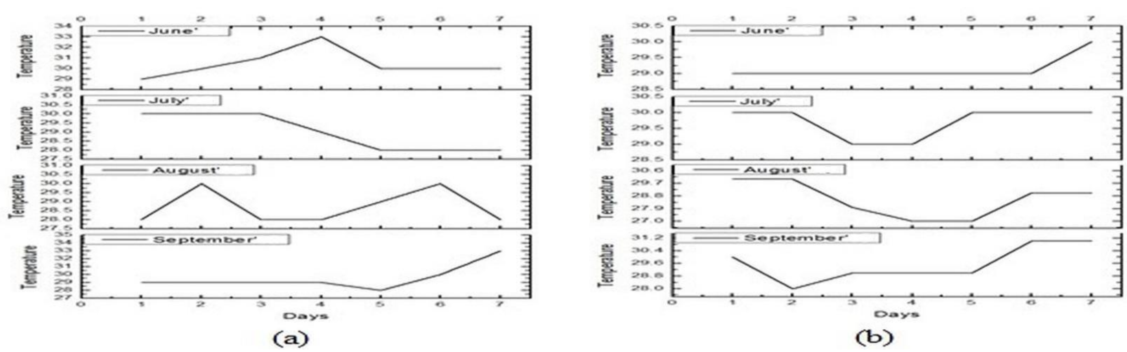

Figure 4.4: Graph for temperature (a) an observed data at *inlet* and (b) observed data at *outlet*

In *June*, the temperature varied from 29 – 32 (˚C) at the *inlet* that depicts higher temperature. After treatment, the temperature ranges as 29 – 30 (˚C) at the *outlet*. This temperature is normal for growth of plants.

In the month of *July*, the temperature ranging from 28 – 30 (˚C) at the *inlet*, which is high. However, at the *outlet*, temperature varied from 29 – 30 (˚C). This suggests that the temperature is at a higher side due to the rainy season.

In *August*, the temperature at *inlet* is recorded as 28 – 29.5 (˚C). This change in temperature shows improvement in the parameter reading, but is unfit for reuse as this readings is suited only for the growth of algal blooms. At the *outlet*, the temperature varied from 27 – 30 (˚C) making the treated water free from algal blooms.

During the month of *September*, at the inflow, the temperature remained between 28.5 and 32 (˚C). The temperature shows the nominal ranges of temperature due to rain. At the *outlet*, temperature is sensed as 28 – 31 (˚C). This suggest the normal range of temperature and the treated sewage water can be reused for domestic and irrigation purposes.

4.2.3 Dissolved Oxygen

The Dissolved Oxygen *(DO)* is necessary for flora and fauna residing underwater. The aquatic animals require *DO* for respiration and phytoplankton needs *DO* for respiration; when there is no light for photosynthesis processes. The data collected at *inlet* and *outlet* are shown in Tables 4.5-4.6 and the observation graph is shown in Fig. 4.5. The *DO* concentration is calculated on the basis of amount of Titrant added. The formula used is given in Eq. (3) as:

$$DO\,(mg/l) = Amount\ of\ Titrant\ Used\,(mL) \tag{4.3}$$

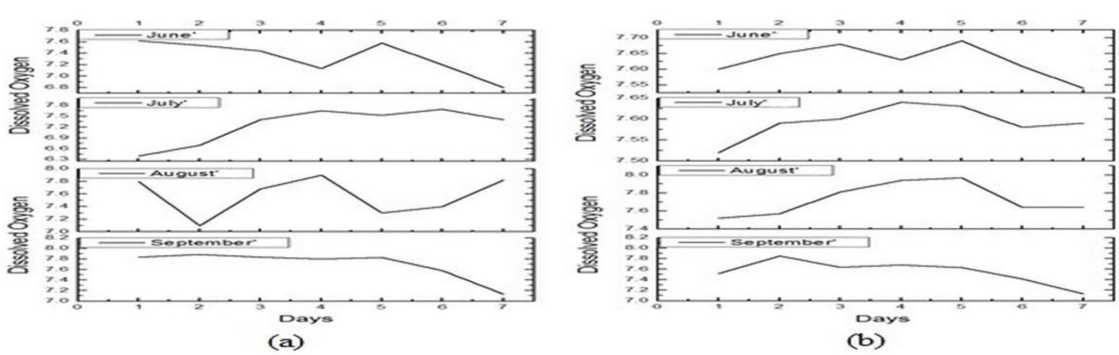

Figure 4.5: Graph for dissolved oxygen (a) four months data at *inlet* and (b) four months data at *outlet*

Table 4.5: Four months data of dissolved oxygen *(inlet)*

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	7.62	-	-	-	6.40	-	-	-	7.80	-	-	-	7.84	-	-	-	7.42
Tue	7.54	-	-	-	-	6.70	-	-	7.10	-	-	-	-	7.89	-	-	7.31
Wed	-	7.44	-	-	-	7.40	-	-	-	7.68	-	-	-	7.84	-	-	7.59
Thurs	-	7.13	-	-	-	-	7.65	-	-	7.90	-	-	-	-	7.80	-	7.62
Fri	-	-	7.58	-	-	-	7.53	-	-	-	7.30	-	-	-	7.83	-	7.56
Sat	-	-	7.20	-	-	-	-	7.70	-	-	7.40	-	-	-	-	7.58	7.47
Sun	-	-	-	6.80	-	-	-	7.40	-	-	-	7.82	-	-	-	7.13	7.29
Avg.	7.58	7.29	7.39	6.60		7.05	7.59	7.55	7.45	7.49	7.35	7.83		7.87	7.82	7.36	

Table 4.6: Four months data of dissolved oxygen *(outlet)*

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	7.60	-	-	-	7.52	-	-	-	7.52	-	-	-	7.52	-	-	-	7.54
Tue	7.65	-	-	-	-	7.59	-	-	7.57	-	-	-	-	7.85	-	-	7.67
Wed	-	7.68	-	-	-	7.60	-	-	-	7.81	-	-	-	7.64	-	-	7.68
Thurs	-	7.63	-	-	-	-	7.64	-	-	7.94	-	-	-	-	7.68	-	7.72
Fri	-	-	7.69	-	-	-	7.63	-	-	-	7.97	-	-	-	7.63	-	7.73
Sat	-	-	7.61	-	-	-	-	7.58	-	-	7.64	-	-	-	-	7.42	7.56
Sun	-	-	-	7.54	-	-	-	7.59	-	-	-	7.64	-	-	-	7.13	7.48
Avg.	7.63	7.66	7.65	7.53		7.60	7.64	7.59	7.55	7.88	7.81	7.58		7.75	7.66	7.28	

In the month of *June*, the values for *DO* appears between 6.5 and 7.5 (mg/l) at the *inlet*, showing that oxygen is less for the growth of plants. After treatment, the *DO* is sensed between 7.5 and 7.7 (mg/l) at the *outlet* and depicts that the water has sufficient level of oxygen required for flora and fauna.

In *July*, at the *inlet*, the *DO* is ranged between 6.6 and 7.5 (mg/l) depicting less oxygen due to effluents added. However, at the *outlet*, *DO* is sensed as 7.5 – 7.65 (mg/l) and is under the required normal conditions for *DO*.

In the month of *August*, *DO* is sensed as 7.3 – 7.9 (mg/l) at the *inlet*. The change in *DO* is suited for the growth of algal blooms. At the *outlet*, *DO* is ranged from 7.5 – 7.9 (mg/l). This suggests that water is treated to sufficient level in order that there is no growth of algal blooms within this required changes.

In *September*, *DO* is in the range of 7.3 – 7.9 (mg/l) at the *inlet*. This shows the decrease in the range of *DO* due to rainy season. At the *outlet*, *DO* as 7.2 – 7.8 (mg/l) suggesting the nominal range of *DO* and has suitable measurements that helps for the growth of plants. Thus, the treated sewage water is suitable for the reutilization with respect to the irrigation purposes.

4.2.4 Electrical Conductivity

The increased level of Electrical Conductivity *(EC)* is critical for aquatic animals as their tolerance is up to specific ranges and depends on the climatic conditions and pollutants. It increases during or after rainfall as the Total Dissolved Solids *(TDS)* of water increases and is calculated by the estimation of *TDS* in water which is measured in ppm or in mg/l. As the *EC* is used to measure capacity of water for conducting electrical currents, it is related to dissolve salts in water and is calculated by through Eq. (4) as below:

$$EC\,(\mu S/cm) = \frac{TDS\,(ppm)}{0.64} \tag{4.4}$$

The observation collected at *inlet* and *outlet* are described in Tables 4.7-4.8 and Fig. 4.6.

Table 4.7: Electrical conductivity data of four months *(inlet)*

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	233	-	-	-	176	-	-	-	351	-	-	-	260	-	-	-	255
Tue	219	-	-	-	-	177	-	-	385	-	-	-	-	321	-	-	276
Wed	-	299	-	-	-	196	-	-	-	349	-	-	-	410	-	-	314
Thurs	-	236	-	-	-	-	232	-	-	305	-	-	-	-	354	-	282
Fri	-	-	233	-	-	-	155	-	-	-	339	-	-	-	336	-	266
Sat	-	-	188	-	-	-	-	383	-	-	342	-	-	-	-	394	327
Sun	-	-	-	198	-	-	-	376	-	-	-	361	-	-	-	217	288
Avg.	226	268	211	187		187	194	380	368	327	341	311		366	345	306	

In *June*, at *inlet*, the *EC* is sensed between 180 and 270 (mg/l), showing less soluble minerals. After treatment, *EC* ranges between 320 and 360 (mg/l) at *outlet* which specify the good measure of conductivity dissolved.

In the month of *July*, *EC* varied from 187 – 380 (mg/l) which shows presence of few minerals due to rain. However, at the *outlet*, *EC* as 340 – 370 (mg/l) which is due to the

Table 4.8: Electrical conductivity data of four months *(outlet)*

Months	June '18				July '18				Aug '18				Sept '18				Avg.
Weeks→ Days↓	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Mon	331	-	-	-	310	-	-	-	363	-	-	-	334	-	-	-	335
Tue	340	-	-	-	-	375	-	-	342	-	-	-	-	312	-	-	342
Wed	-	320	-	-	-	343	-	-	-	333	-	-	-	345	-	-	335
Thurs	-	321	-	-	-	-	391	-	-	343	-	-	-	-	325	-	345
Fri	-	-	373	-	-	-	341	-	-	-	394	-	-	-	397	-	376
Sat	-	-	345	-	-	-	-	342	-	-	381	-	-	-	-	380	362
Sun	-	-	-	380	-	-	-	350	-	-	-	343	-	-	-	345	355
Avg.	336	321	359	345		359	366	346	353	338	388	339		329	361	362.5	

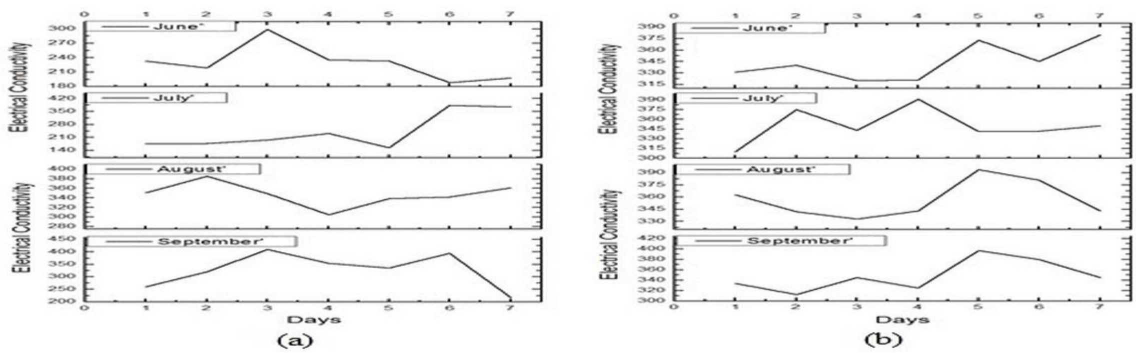

Figure 4.6: Graph for electrical conductivity (a) data observation at *inlet* and (b) data observation at *outlet*

effluents added for treatment.

In *August*, *EC* as 300 – 370 (mg/l) at the *inlet*. This required change in EC is suited for growth of flora and fauna. *EC* is ranged from 335 – 390 (mg/l) providing treated water free from algal blooms.

In the month of *September*, *EC* is sensed as 305 – 368 (mg/l) at the *inlet*. This shows the mixture of effluents due to rain. At the *outlet*, *EC* is sensed as 328 – 363 (mg/l). This reading manifests that the water is fit for domestic and irrigation purposes.

Finally, the spatial and temporal observations made at the *inlet* and the *outlet* of the sewage water treatment plant are presented in Fig. 4.7. It highlights the overall percentage data for four months. The percentages for algal blooms, *pH*, temperature, *DO* and *EC* are 71, 7, 8, 7 and 7, respectively at the *inlet*, while these are 64, 8, 9, 12 and 7, respectively at the *outlet*. Thus, the outflowed water has shown reduction in algal blooms and other effluents. It confirms that the water can be reused for domestic as well as irrigation purposes.

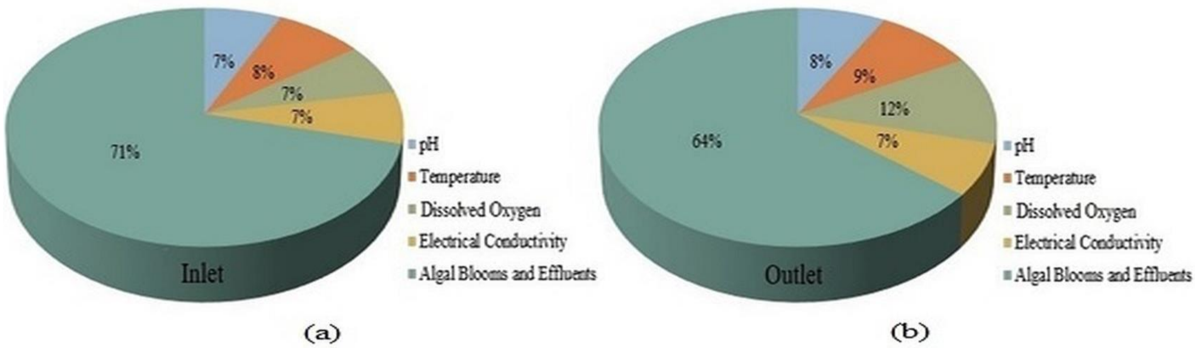

Figure 4.7: Spatial and temporal variations in sewage water (a) at *inlet* and (b) *outlet*

Thus, from the above observations and measurements, it is concluded that the proposed framework works well at *STP* and helps in monitoring water for reuse. On the other hand, the ad hoc network enables to have a regular and instant monitoring at the *inlet* and *outlet*. It also helps in collecting data at the surface station for further analysis and to take timely preventive measures.

4.3 Comparison with Traditional Method

The traditional method of sewage water monitoring involve sampling where samples are collected manually and sent to labs for experimentation to validate its quality. This evaluation process is a time consuming, as the experiment undergoes various chemical tests. For the purpose, it requires equipments which are costly and hence,higher maintenance cost. Moreover, they need regular monitoring and manpower. On the other hand, the proposed framework in this research article enables a user to measure data on-site with live experimentation on sensed data. This data is sent to smart phone *via* Blue-tooth. Later, the smart-phone sends the collected data on *PC* or laptop where data analysis is performed. Thus, the results are obtained in a short span of time; and is indeed a fast, trustworthy and an economical process of monitoring of sewage water; with no additional manpower. Keeping in the view to check sewage water quality, the spatial and temporal parameters are collected, tested using traditional and proposed methods, respectively. A comparison is carried out for the same day or month's observations using both methods. The comparison of the observed data at *inlet* and *outlet*; are shown in Tables 4.9-4.10 and Figs. 4.8-4.9.

Table 4.9: Comparison of Parameters collected at *inlet*

Parameters	Months	Traditional Method	Proposed Method
pH	June ’18	7.49	7.42
	July ’18	7.32	7.22
	August ’18	7.61	7.65
	September ’18	7.59	7.51
Temperature (°C)	June ’18	32.19	30.37
	July ’18	27.26	29.12
	August ’18	28.11	28.75
	September ’18	31.37	29.37
Dissolved Oxygen (*mg/l*)	June ’18	7.12	7.21
	July ’18	7.33	7.19
	August ’18	7.24	7.53
	September ’18	7.80	7.72
Electrical Conductivity (*mg/l*)	June ’18	235	223
	July ’18	209	237
	August ’18	359	336.75
	September ’18	289	332

From the graphs at *inlet* (*see* Fig. 4.8), one can observe the data collected using traditional methods provides a fluctuating results of all the temporal and spatial parameters in comparison to the data obtained from proposed method. The variation in observed data using lab evaluation sampling (traditional) is due to various chemical processes and solvents added to find the results. This would lead to falsification of adding more effluents to the sewage water for providing treatment up to a good level but with more chloride and acidic nature which is not suited for irrigation purposes. Due to more concentration added up, the temperature gets normalized but *pH* increases whereas dissolved oxygen and electrical conductivity decreases. Here, the proposed terminology suggests an accurate method to give observations. Moreover, it also helps in adding correct amount of treatment process with less solvents to be added.

After purification, the treated sewage water is checked at *outlet*. The observed graphs

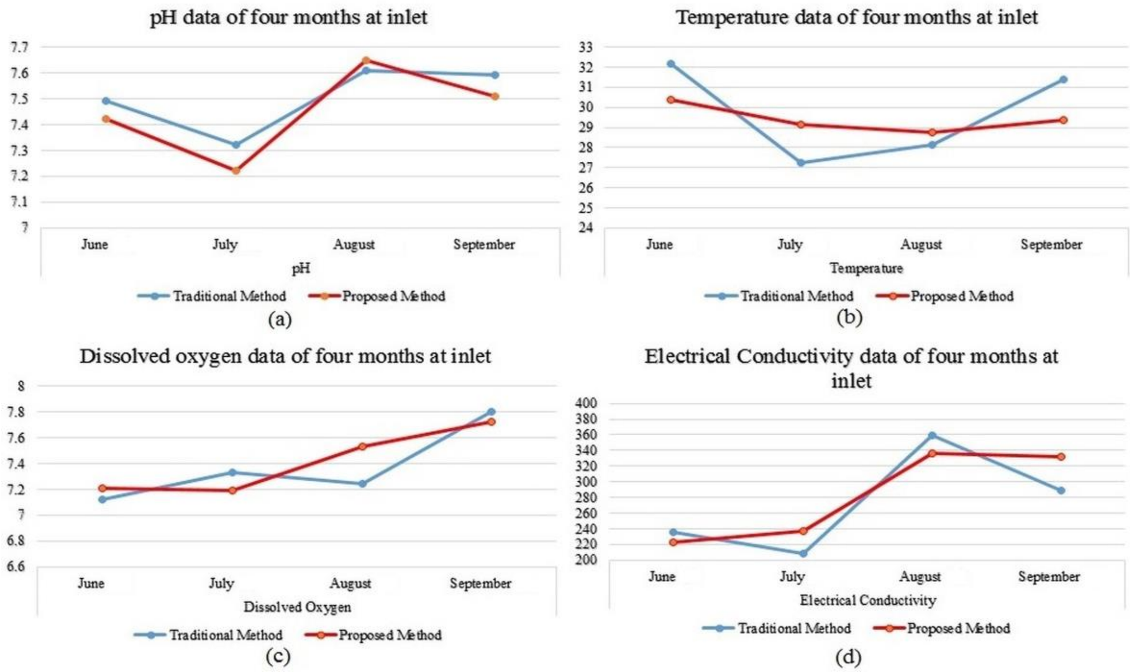

Figure 4.8: Comparison of observed data of four months at *inlet* (a) *pH* (b) temperature (c) dissolved oxygen (d) electrical conductivity

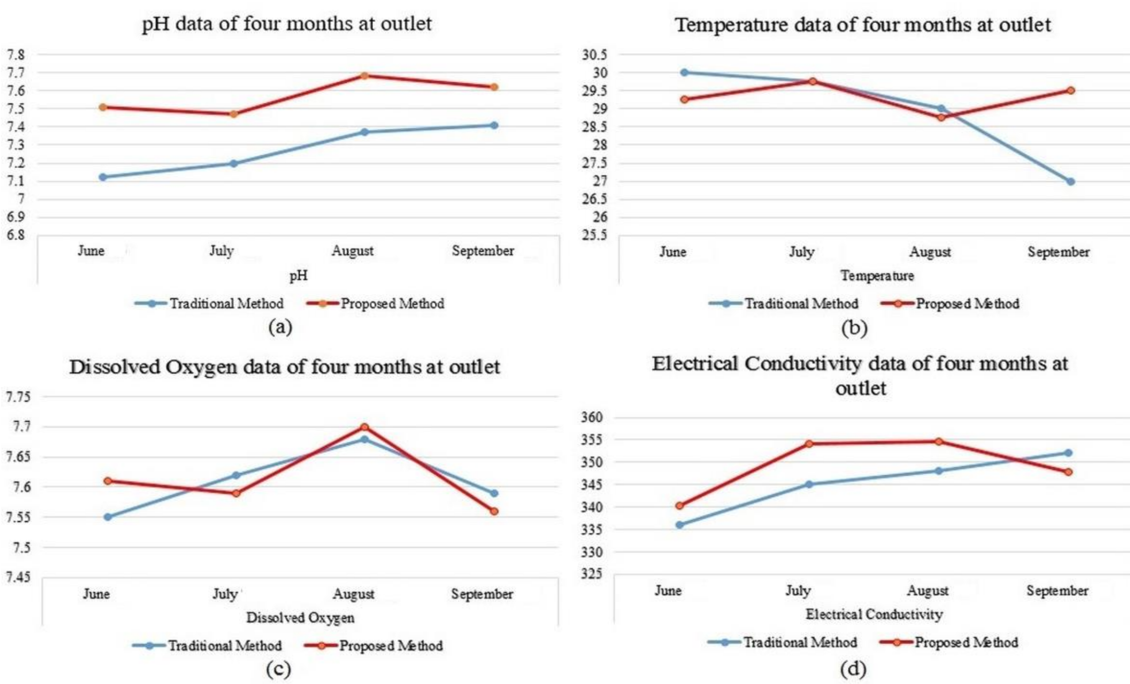

Figure 4.9: Comparison of observed data of four months at *outlet* (a) *pH* (b) temperature (c) dissolved oxygen (d) electrical conductivity

Table 4.10: Comparison of Parameters observed at *outlet*

Parameters	Months	Traditional Method	Proposed Method
pH	June ’18	7.12	7.51
	July ’18	7.20	7.47
	August ’18	7.37	7.68
	September ’18	7.41	7.62
Temperature (°C)	June ’18	30.00	29.25
	July ’18	29.75	29.75
	August ’18	29.00	28.75
	September ’18	27.00	29.50
Dissolved Oxygen (*mg/l*)	June ’18	7.55	7.61
	July ’18	7.62	7.59
	August ’18	7.68	7.70
	September ’18	7.59	7.56
Electrical Conductivity (*mg/l*)	June ’18	336	340
	July ’18	345	354
	August ’18	348	355
	September ’18	352	348

depict that the collected data using traditional method provide higher acidic nature of water with less dissolved oxygen and conductivity; whereas the data collected using proposed method tell about the correct amount of solvents added in purification process by virtue of which the various temporal and spatial parameters get normalized. In traditional method, more chemicals were added in the purification process by virtue of which the water is not suitable for irrigation purposes as it affects soil fertility as well as plants whereas the proposed terminology provides the sewage water that fit for irrigation purposes.

From above discussions, it is concluded that the sewage water is monitored correctly with proposed framework providing accurate values of physical parameters. Thus, it suggests that water is fit for re usage for domestic and irrigation purposes.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

To deal with real world applications like monitoring, pollution, habitat prevention, *etc.*, various deployment strategies are adopted using *WSN*. It is realized that the dynamic deployment of sensors has lead to falsification in sensing data and covered area. This is due to sensors' communication range and water constraints like path loss, ambient noise, Doppler effect and propagation delay. Therefore, this project work intends to propose an *MPS*, a communication technique for data transmission.

A novel water quality monitoring framework for sewage is proposed that enables a user with minimal training, to make instant measurements of water quality parameters without sampling. The Multi-Parametric Sensor (*MPS*) used for the purpose is portable, cost-effective, and easy to deploy. A strategy is explored in which the sensors leverage the compactness, computing power, and intuitive touch-based displays of smart-phones. A model based on wireless sensor node is tested that communicates with smart-phone through bluetooth. The data is sensed at *inlet* and *outlet* for spatial and temporal variations and is collected at smart-phone. It further transmits data to the surface station for thorough analysis. It is envisaged from the gathered data that the framework helps in regular monitoring and timely treatment of water.

5.2 Future Scope

In future, the performance of the sensors can be improved by incorporating diffusing elements into the path which would reduce the sensitivity of the measurement. Moreover, its power consumption could be improved through the usage of a more energy-efficient Bluetooth and custom-built electronics that would optimize the circuit in a great manner.

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