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Sustainable Ambient Air Quality Monitoring System

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Sustainable Ambient Air Quality Monitoring System

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This thesis is dedicated to my wonderful parents, Mr. Suresh Aleti and Mrs. Kavitha Aleti for their constant support, encouragement, and motivation. I also dedicate this thesis to my brother, Mr. Anoop Aleti for all his support.

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Abstract

Deterioration of air quality is a growing concern in the world. Air pollution causes serious health problems and also can sometimes result in death. In order to assess air quality, long term and continuous monitoring of pollutant levels in ambient air are needed, such monitoring is often expensive, cumbersome, and resource intensive and so the monitoring programs often fail to succeed.

This research focused on designing an ambient air monitoring system by integrating (1) low-cost sensor with a battery, (2) repurposed materials to fabricate all-weather housing for air monitors, and (3) electronics needed to download the data to an on-site secure digital (SD) card, and to push the data wirelessly to the server. This monitoring system was tested at the selected locations in Harvey and Marrero Wastewater treatment plants (WWTPs) by monitoring hydrogen sulfide (H_2S) levels. Preliminary analysis was done for few days and also, the results were analyzed.

Keywords: Wastewater treatment, Hydrogen Sulfide, ambient air monitoring, Sustainable

1. Introduction

Air pollution is the major concern in most world cities. Exposure to high levels of ambient air pollution can cause major health problems and result in death. Globally, 3.7 million deaths were attributed to ambient air pollution in 2012 (WHO). Monitoring has an important role in improving the ambient air quality through a number of means such as (a) public education, (b) policy development, (c) behavioral changes, (d) research/innovation, (e) technology development, and (f) management strategies. High-quality equipment used in monitoring depend on various factors such as good sensors, high data logging capacity, battery life, portability, the range of pollutant detection, and waterproofing. The price of the equipment with all the best features will cost many thousands of dollars, so it is difficult for researchers/organizations with inadequate resources to afford this kind of high-end equipment.

The University of New Orleans (UNO) researchers pursued a goal to design an ambient air monitoring system by integrating sustainable materials and methods to deliver low-cost, reliable, and easy-to-use monitoring methods to meet the growing demands of air quality around the world. This is achieved by integrating the knowledge of environmental, computer science, and electrical/instrumentation engineering to develop a data logger for a sensor, and to construct a housing such that it is protected from rain, wind, bugs, and unwanted plants. A low-cost sensor manufactured by Detcon (DM 700) that does not have data logging capacity has been used by UNO. Efforts were made to use the sustainable materials to construct all-weather housing by considering various factors like air flow, the size of the housing to fit the sensor, place for the battery, a roof, a lock to protect the equipment, and monitoring height. Research work on usage of the various electronic devices such as Arduino (prototyping platform based on easy-to-use hardware and software), which helps in logging the data onto SD cards and push the data to the server, is also presented. This innovative design and integration of materials and methods for monitoring should be beneficial to a wider range of users. This monitoring system was tested at the Marrero and Harvey Wastewater treatment plants (WWTPs).

1.1. Wastewater treatment plants (WWTPs)

Wastewater treatment plants (WWTPs) reduce contaminants in the water such as suspended solids, pathogenic bacteria, biodegradable organics, and nutrients. The treatment may involve three stages: primary, secondary and tertiary.

Primary treatment is usually the first stage in WWTPs. It is designed to remove settleable organic and inorganic solids by sedimentation, and the materials that will float (oil, grease, and lighter solids) by skimming. BOD of the incoming wastewater can be reduced by 25% to 35% and the total suspended solids by 50-60% with primary treatment (Water Environment Federation 2005).

Secondary treatment is used to remove the dissolved and colloidal organic matter that escapes primary treatment. This is usually achieved by organic matter being consumed by microbes as food and thereby converting it to inorganic end products (carbon dioxide, water) for their own growth and reproduction. The biomass generated is removed by secondary settling, and pathogens are inactivated by effluent disinfection.

Tertiary treatment consists of additional treatment beyond secondary treatment. Tertiary treatment usually includes nutrient (nitrogen and phosphorus) removal and effluent polishing by filtration. Disinfection, typically with chlorine, is the final step before discharge of the effluent, and involves the injection of a chlorine solution at the head end of a chlorine contact basin. Figure 1 (Source: HLTHMAN, Volume 20, part 8) below shows the typical wastewater treatment plant process.

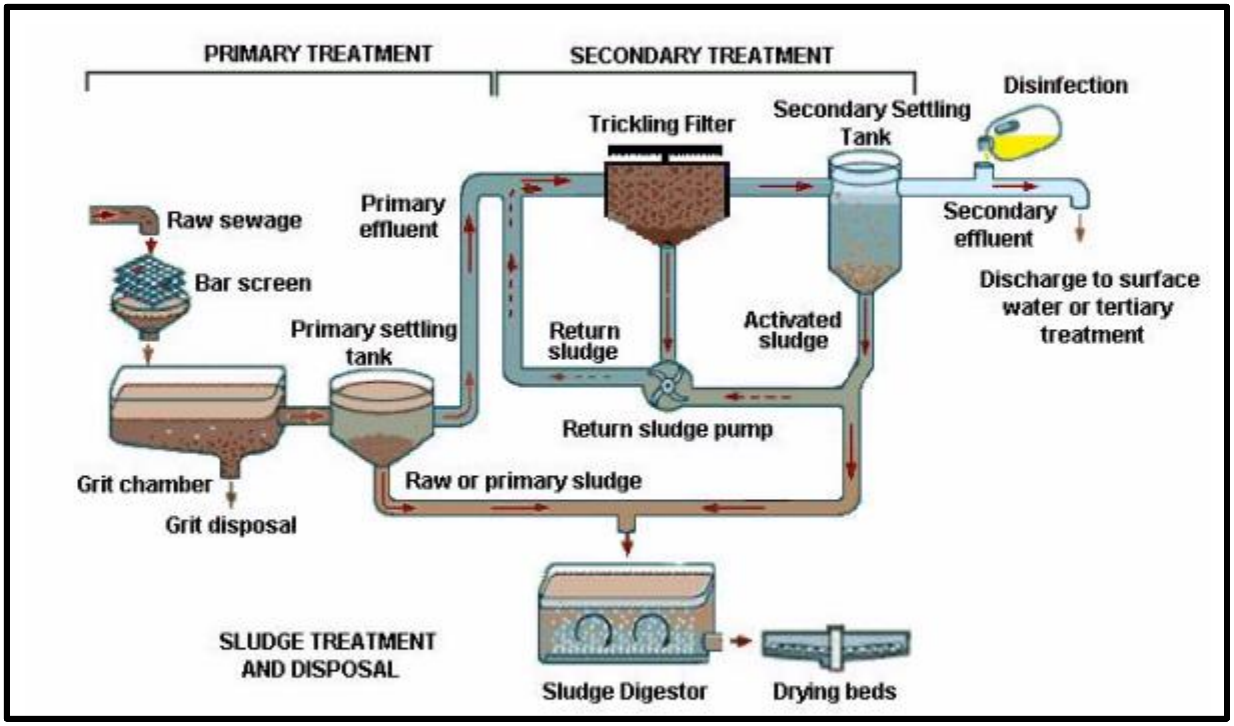

Figure 1: Typical wastewater treatment plant process

Wastewater treatment uses a lot of energy. During the process of treating the water, contaminants such as pathogens and volatile organic compounds can become airborne especially at sites of mechanical agitation, such as aeration, mechanical oxidation etc. One of the sources of air emissions at the WWTPs can be the delivery point of the pipe transporting the wastewater. Due to emissions from industrial wastewater, ambient concentrations of hydrogen sulfide (H_2S) in Odessa, Texas, registered at 335 to 503 ppb over 8 hours, 101 to 201 ppb over 24 hours, with H_2S an annual average of 7 to 27 ppb (Lana Skrtic, 2006).

Inorganics that have objectionable odors such as H_2S and ammonia (NH_3) are often found in high concentrations in WWTPs. Among all the pollutants released from the WWTP, H_2S is of major concern because of its high toxicity. Odor problems caused by H_2S emissions are a major nuisance, particularly in the vicinity of a variety of industrial and municipal sites, and are of health concern to the operators. Although odor sensitivity varies for individuals, hydrogen sulfide can be identified even at very low concentrations due to its rotten egg smell. Hydrogen sulfide is corrosive to metals such as iron, zinc, copper, lead and cadmium.

The amount of H_2S naturally found in the air has been estimated as 0.11-0.33 ppb (0.15-0.46 µg/m3) (Maine Department of Health & Human Services, 2006). Higher concentrations of H_2S can be observed near the sources. Natural sources of H_2S include crude oil, natural gas, salt marshes etc. Some major industrial sources of H_2S include extraction and refining of petroleum products, rayon textile production, chemical manufacturing, and waste disposal. Major municipal sources include WWTPs and solid waste collection, storage, transfer and disposal facilities. Although the major concern of a WWTP is to remove the contaminants in water; air pollutants, solid waste, water pollutants produced from the treatment processes should also be of concern. Preliminary odor monitoring was conducted within the immediate area of Marrero and Harvey WWTPs by using ambient air monitoring system. This research is helpful to researchers or facilities wanting to monitor H_2S through low-cost techniques. Selected spots of monitoring include locations of high concentrations like head works, clarifier tanks, and trickling filters. The ambient H_2S monitoring results from both plants are compared and analyzed for variations and similarities.

2. Scope and Objectives

2.1. Overall Objective

Primary objective of this research was to design and develop, a low-cost, automated ambient air monitoring system (sustainable monitoring system) for use in many scenarios. Secondary objective is to test the developed system at the Marrero and Harvey treatment plants to quantify the H_2S concentrations within the immediate area of the treatmetn plants. Knowing quantitative H_2S values will help assess any future improvements that can be achieved through installation of odor control equipment as well as a variety of other odor management techniques/practices.

2.2. Specific Objectives

- Identify a low-cost sensor to monitor H_2S at WWTPs.
- Integrating the knowledge of environmental, computer science, and electrical/instrumentation engineering to develop a data logger to that sensor.
- Construct housing for that equipment by using repurposed materials such that it is protected from rain, wind, bugs, unwanted plants, and thieves.
- Integrate the data logger, sensor, battery, and housing to develop an ambient air monitoring system.
- Test the developed monitoring system by monitoring H_2S at various locations within the immediate surroundings of Harvey and Marrero WWTPs over a period of time.
- Understand and document “hot spots” within the observation area
- Compare the results with the ambient air quality standards.
- Determine the feasibility of low-cost system approach for ambient air monitoring.

3. Literature Review

3.1. Ambient air quality monitoring

Deterioration of air quality is a growing concern in most world cities. Population growth and increased demands for electricity, fuel, rapid industrialization, and urbanization are significant causes leading to global air pollution (Kura et al., 2013). The major risk factor for the global disease is the exposure to ambient air pollution (Brauer et al. 2015). Air pollution is one of the most important environmental health risks in both developing and developed countries (WHO, 2005). Major cities like Beijing, Shanghai, New Delhi, Mexico City, and Hong Kong repeatedly make the list of worst cities in the world for air quality. Many air pollutants viz., criteria air pollutants, hazardous air pollutants, and GHG's cause deleterious effects on human health, animal/plant life, and property.

Air quality monitoring plays an important role in improving the air quality of the environment, and it is of utmost necessity to integrate sustainable materials and methods to deliver low-cost, reliable, and easy-to-use monitoring methods to meet the growing demands of air quality management around the world.

In order to assess air quality, long-term and continuous monitoring of pollutant levels in ambient air is needed which is often expensive, cumbersome, and resource intensive. Also, as the air quality observations are needed at a number of locations over a long period to assess the regional air quality, the monitoring programs often fail to succeed.

High-quality equipment used in air quality monitoring depend on various factors such as good sensors, high data logging capacity, battery life, portability, the range of pollutant detection, and waterproofing, etc. The price of the equipment with all the best features will cost many thousands of dollars, so it is difficult for researchers/organizations with inadequate resources/money to afford these kinds of high-end equipment.

The University of New Orleans (UNO) researchers pursued a goal to integrate sustainable materials and methods to deliver low-cost, reliable, and easy-to-use monitoring methods to meet the growing demands of air quality around the world.

3.2. Previous studies about developing ambient monitoring system

There were few previous efforts to develop a microcontroller based cost-effective environmental monitoring system.

Vikhyat Chaudhry (2013) developed a monitoring system (Arduair) which is a small and portable measurement system that can include a gas sensor (such as CO, CO_2, NO_2, O_3, etc.) and a microcontroller that can be used by a number of people. Data logging feature was incorporated by using Arduino. An analog voltage is returned to the Arduino by the sensor, which is converted to resistance and then using the resistance, the concentration of the gas can be measured in microgram per cubic meter ($\mu g/m^3$). The Arduair was used to monitor and collect the data of carbon monoxide (CO) concentration of an area. The protection for the equipment from the weather was lacking in his study.

Ramya et al. (2016) contributed a study based on Arduino microcontroller based online ambient monitoring. The objective was to measure parameters such as temperature, relative humidity, CO_2 level and absolute pressure by using low power wireless sensors from the indoor spaces. These parameters are converted into data values by means of atmega328 microcontroller and the data values are loaded into the internet for remote monitoring. As it was designed to monitor from indoor spaces, protection of equipment from weather is missing. Also, as the data values are directly loaded onto the internet, logging data into the SD card is also missing to access the data without internet.

Kunal et al (2014) documented the construction and working of a cost-effective environmental monitoring system that runs on a battery power to monitor temperature, light intensity, and relative humidity. There were many previous efforts to develop an ambient monitoring system to monitor temperature and humidity. Many studies involved complex circuit programming and few do not. Few studies involved programming to receive the data through USB cable connected to the computer, and few programmed Arduino to receive the data directly through the internet, but no study has done both. And also, all the studies were lacking the design and construction of housing for the sensor and Arduino.

Arko et al. (2016) used Internet of Things (IOT) module to monitor in both indoor and outdoor environment. The data can be plotted and also be stored in the cloud accessible through the web. The system has the potential to be replicated and deployed in several locations to collect data and monitor their trends cost effectively as long as there is a connection to the internet. During rain or without an internet connection the design may not be efficient.

3.3. Equipment Shelter

While searching for a housing to protect sensor and Arduino setup against the wind, solar radiation, and rain etc., a lot of research has been done to purchase a cost-efficient housing that has the minimum required features. Many instrument shelters have been evaluated by considering cost and features to select an efficient one. Among all, the minimum cost of the instrument shelter that can weigh the sensor and Arduino setup was found to be in the range of $400. This has initiated the decision to construct a housing using sustainable materials and considering various factors like air flow, the size of the housing to fit the sensor, place for the battery, a roof, a lock to protect the equipment, and monitoring height. Few instrument shelters that were researched and evaluated for the application in this research are listed below.

The 380-605 Large Instrument Shelter, sometimes called as Cotton Region Shelter is an enclosure that is large enough to house several recording instruments to protect them against errors and damage due to solar radiation, the wind, and precipitation. The shelter is constructed of clear pine, painted with three coats of white latex paint and weighs around 70 lbs. It has louvers on all four sides and vents on the sides to provide natural ventilation while excluding solar radiation and precipitation, allowing the existence of ambient conditions inside. A lock and key are also included for security. The cost of this large instrument shelter is $855. Figure 2 below represents the picture of large instrument shelter.

Figure 2: Large instrument shelter

Small Instrument box: A box of painted wood provides ventilated shelter for instruments that need outdoors for monitoring. The roof is placed inclined to protect from rain. The cost of this small instrument box is $404. The lock is also provided to protect the equipment that is kept inside. The overall dimensions of the shelter are 23"height, 11"width, and 9"depth. Figure 3 below represents the picture of small instrument shelter.

Figure 3: Small instrument shelter

3.4. Odors in Wastewater treatment plants

The unpleasant odors from the wastewater treatment plant are a major nuisance for workers and the people living in the surroundings of the treatment plant. Odors can be caused either by gaseous inorganics or volatile organic compounds. They can result from the anaerobic decomposition of sulfur or nitrogen contained in the organic matter. Decomposition of the wastewater produces inorganic gases like sulfide, carbon dioxide, ammonia, and methane.

In the plant, the raw sewage first gets exposed to air at the influent pump station wet well. Then the wastewater is sent to head works that includes screens, the screening removal system, and grit chambers and then sent to primary clarifiers where the large inorganic solids get separated from the wastewater. At this site, the turbulence in the center walls volatilizes the odors as the wastewater cascades over the effluent weirs and through the effluent channel. Wastewater undergoing aerobic treatment in the aeration basins emits a characteristically musty odor. The sewer process that are released commonly include hydrogen sulfide, carbon dioxide, methane, ammonia, mercaptans, organic sulfides, and amines such as indole and skatole. Among these, all except carbon dioxide and methane are odorous.

Within the treatment plant, there are numerous sources that emit odors. Some of them include:

1. Headworks
2. Primary and secondary clarifiers
3. Solids holding and thickening tanks
4. Dewatering systems
5. Solids loading areas
6. Sludge digesters

Tables 1 list the odorous compounds in wastewater and Table 2 shows the potential for odor generation from common unit processes in a wastewater treatment plant.

Table 1: Odorous compounds in wastewater

Compound Name	Formula	Molecular Weight	Volatility at 25° C, ppm (v/v)	Detection threshold, ppm (v/v)	Recognition threshold, ppm (v/v)	Odor description
Acetaldehyde	CH_3CHO	44	Gas	0.067	0.21	Pungent, fruity
Allyl mercaptan	$CH_2{:}CHCH_2SH$	74		0.0001	0.0015	Disagreeable, garlic
Ammonia	NH_3	17	Gas	17	37	Pungent, irritating
Amyl mercaptan	$CH_3(CH_2)_4SH$	104		0.0003	-	Unpleasant, putrid
Benzyl mercaptan	$C_6H_5CH_2SH$	124		0.0002	0.0026	Unpleasant, strong
n–Butyl amine	$CH_3(CH_2)NH_2$	73	93 000	0.08	1.8	Sour, ammonia
Dibutyl amine	$(C_4H_9)_2NH$	129	8 000	0.016	-	Pungent, suffocating
Diisopropyl amine	$(C_3H_7)_2NH$	101		0.13	0.38	Fishy
Dimethyl amine	$(CH_3)_2NH$	45	Gas	0.34	-	Putrid, fishy
Dimethyl sulfide	$(CH_3)_2S$	62	830 000	0.001	0.001	Decayed cabbage
Diphenyl sulfide	$(C_6H_5)_2S$	186	100	0.0001	0.00021	Unpleasant
Ethyl amine	$C_2H_5NH_2$	45	Gas	0.27	1.7	Ammonia like
Ethyl mercaptan	C_2H_5SH	62	710 000	0.0003	0.001	Decayed cabbage
Hydrogen sulfide	H_2S	34	Gas	0.0005	0.0047	Rotten eggs
Indole	$C_5H_4(CH)_2NH$	117	360	0.0001	-	Fecal, nauseating
Methyl amine	CH_3NH_2	31	Gas	4.7	-	Putrid, fishy
Methyl mercaptan	CH_3SH	48	Gas	0.0005	0.001	Rotten cabbage
Phenyl mercaptan	C_6H_5SH	110	2000	0.0003	0.0015	Putrid, garlic
Propyl mercaptan	C_3H_7SH	76	220 000	0.0005	0.02	Unpleasant
Pyridine	C_5H_5N	79	27 000	0.66	0.74	Pungent, irritating
Skatole	C_9H_9N	131	200	0.001	0.05	Fecal, nauseating
Sulfur dioxide	SO_2	64	Gas	2.7	4.4	Pungent, irritating

Thiocresol	$CH_3C_6H_4SH$	124		0.0001	-	Skunky, irritating
Trimethyl amine	$(CH_3)_3N$	59	Gas	0.0004	-	Pungent, fishy

Reference: (WEF/ASCE, *Odor Control in Wastewater Treatment Plants*, Manual of Practice No. 22, 1995)

Table 2: Potential for odor generation from common unit processes in a wastewater treatment plant

Process	**Odor Potential**
Flow equalization	High
Septage handling	High
Sidestream returns	High
Preaeration	High
Screening	High
Grit removal	High
Primary clarification	High
Suspended growth processes	Low
Fixed film processes	Moderate
Chemical treatment	High
Secondary clarification	Low
Tertiary filtration	Low
Disinfection	Low
Sludge thickening/holding	High
Aerobic sludge digestion	Moderate
Anaerobic sludge digestion	Moderate
Thermal sludge conditioning	High
Storage sludge lagoons	High
Sludge vacuum filter	High

Sludge centrifuge	High
Sludge belt filter	High
Sludge drying beds	High
Sludge composting	High

Reference: WEF/ASCE, *Odor Control in Wastewater Treatment Plants*, Manual of Practice No. 22, 1995

Inorganics that have objectionable odors such as H_2S and NH_3 are often found in high concentrations in WWTPs. Among all the pollutants released from the WWTP, H_2S is of major concern because of its high toxicity.

3.5. H_2S toxicity

Hydrogen sulfide is an extremely toxic substance. It is heavier than air and can exist in higher concentrations in the lower portion of manholes. It is a colorless gas that has a distinctive rotten egg smell at lower concentrations. Odors will be detectable in concentrations as low as 0.008 parts per million (ppm) or 8 parts per billion (ppb) (Department of Environmental Quality, Michigan) and also at concentrations from 4.3 to 45.5 percent in air, H_2S gas is very explosive (EPA, Ohio). Inhalation of hydrogen sulfide can cause cardiovascular, hematological, and neurological effects and could sometimes lead to anosmia through high-level exposure. Prolonged exposure to a hydrogen sulfide concentration in the range of 2 to 5 ppm can cause bronchial constriction, nausea, headaches, and sometimes insomnia, etc. Through exposure to high-level hydrogen sulfide concentrations, sometimes unconsciousness may occur quickly and eventually, lead to death. The mortality in acute hydrogen sulfide intoxications was reported to be 2.8% (Arnold et al., 1985) in 1985 where formerly it was 6% in 1977 (World Health Organization, 1981). Measures to reduce H_2S emission levels should be implemented to minimize the harmful health effects on the workers and the public.

The Agency for Toxic Substances and Disease Registry (ATSDR) indicates a limit of 70 ppb for acute exposure and 20 ppb for intermediate exposure (ATSDR, 2006). The Occupational Safety and Health Administration (OSHA) has also provided limits for hydrogen sulfide exposure. The acceptable ceiling concentration of hydrogen sulfide is 20 ppm, and 50 ppm for a maximum one-time exposure during an 8-hour work shift. The National Institute of Occupational Safety and

Health (NIOSH) recommended a ceiling limit of 10 ppm for a 10 minute average (NIOSH, 2016). There are no international standards for H_2S. However, many countries have “short-term” (usually 30 minutes) standards, which range from 6 to 210 ppb (James Collins et al., 2000). Maine Center for Disease Control and Prevention proposed the H_2S limit of 30 ppb (30 minutes) for acute exposure and 1 ppb (1 year) for chronic exposure. Table 3 shown below represents the health effects of H_2S at various concentrations.

Table 3: H_2S range and its effects (OSHA)

Concentration (ppm)	**Symptoms/Effects**
0.00011-0.00033	Typical background concentrations
0.01-1.5	Odor threshold (Rotten egg smell is first noticeable). Odor becomes more offensive at 3-5 ppm.
2.00-5.00	Prolonged exposure may cause nausea, tearing of the eyes, headaches or loss of sleep. Airway problems (bronchial constriction) in some asthma patients.
20	Possible fatigue, loss of appetite, headache, irritability, poor memory, dizziness.
50-100	Slight conjunctivitis and respiratory tract irritation after 1 hour. May cause digestive upset and loss of appetite.

3.6. Previous studies regarding odor monitoring at WWTPs

Devai et al. (1999) reported that Hydrogen sulfide is a dominant gas emitted from the Baton Rouge’s wastewater treatment plants. The median value of the H_2S concentration measured at the three plants at Baton Rouge was found to be 0.31 µg S/l. The concentrations measured were typically below 10 µg S/l.

Bergeron (2016) conducted a study on odor monitoring at the New Orleans East Bank WWTP by monitoring H_2S for four months. The study reported the highest H_2S concentration at the East bank WWTP as 1.37 ppm monitored near the Headworks and 95.1% of the readings observed at the plant were below 0.25 ppm. Designing and developing an automated cost-efficient ambient air monitoring system were lacking. The equipment used was OdaLog gas logger that has a data logger with high capacity, battery, portability, software, and weather shield. The price of this equipment with all these features is above $3000.

An odor monitoring study by Halageri (2012) at the Jefferson parish East Bank WWTP reported that the 95% of the H_2S concentration readings were in the range between 0-5 ppb. However, long-term observations were needed to check the compliance of the plant H_2S emissions with the standards. Different kinds of monitors were used to find the concentration of H_2S. Development of a cost-efficient monitoring system was lacking.

4. Methodology

1. Identify a low-cost sensor to monitor H_2S at WWTPs

Research has been done to identify a sensor that is cost-efficient to monitor H_2S at WWTPs. DM-700 sensors manufactured by Detcon INC were selected for this research. These Portable H_2S monitors were used for monitoring at the treatment plants. It runs on battery and is capable of measuring values between 0 and 9ppm with 0.01ppm as the limit of quantitation (LOQ). The monitors have a quick response time, long term calibration stability, and low power consumption, making it most suitable for field monitoring work. The sensors are specifically designed for harsh and extreme locations as well as wide temperatures and humidity ranges. They were placed 1-2 m above the surface while monitoring. Figure 4 and figure 5 below represent the Detcon sensor.

Figure 4: Detcon DM700 series sensor

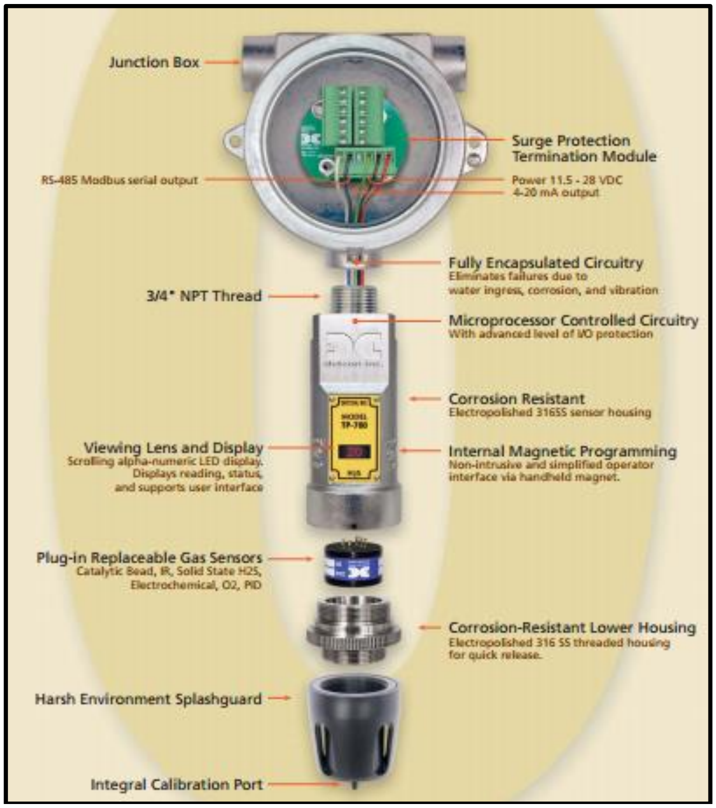

Figure 5: Anatomy of Detcon 700 series sensor

Principle of Operation

These gas sensors are based on electrochemical cells. Sensitivity to specific target gasses is achieved by changing composition of any combination of the sensor components.

The operation of electrochemical sensors is based on reacting with the gas of interest and thereby, producing an electrical signal which is proportional to the gas concentration. An electrochemical sensor consists of a working electrode (or a sensing electrode), and a counter electrode that is separated by a thin layer of electrolyte. Figure 6 below show the typical electrochemical sensor setup

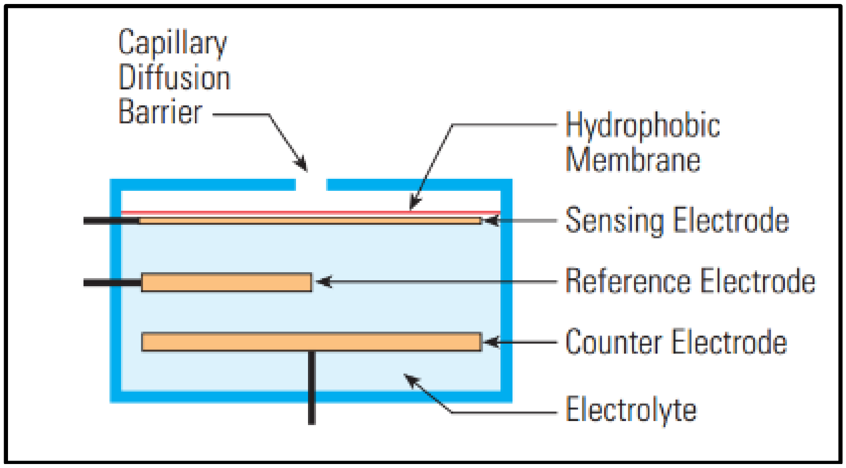

Figure 6: Typical electrochemical sensor setup

Battery needed to power the analyzers

For the entire setup, the battery is needed to supply the power to run the Arduino setup and the sensor. The battery used was manufactured by Amstron power solutions (12V, 7.0Ah). It is non-spillable, rechargeable, sealed lead acid battery. Figure 7 represents the battery selected for the sensor. The unit can operate for one day for a single charge.

Figure 7: Battery

2. Developing a data logger to that sensor

Assembly of the electronics/instrumentation needed for the data logger

Arduino is an open-source prototyping platform based on easy-to-use hardware and software. Arduino boards can read inputs - a finger on a button, light on a sensor, and turn it into an output - activating a motor, turning on an LED. A set of instructions can be given to the microcontroller on the board to do various tasks by using the Arduino programming language (which is coded based on Wiring), and the Arduino Software (IDE), based on Processing. Figure 8 is a picture of the Arduino.

Figure 8: Arduino

In this research, programming/instrumentation was developed by using Arduino to log the data onto an SD card, and a server using Wi-Fi.

(a) Electronics needed to download the data to an on-site secure digital (SD) card

In this type, logging the data from the sensors is processed by the Arduino and is stored locally on an onboard SD card of the Arduino assembly. The data from the SD cards is collected manually and stored in a local database and then data can be analyzed. The system components are illustrated below:

i. **Detcon Gas Sensors:** Detcon model DM-700 is a non-intrusive sensor designed to detect and monitor gaseous pollutants (hydrogen sulfide/carbon monoxide/ozone/ nitrogen dioxide, etc.) in the air over wide ranges using electrochemical sensor technology. It is corrosion, water, and vibration resistant unit. In this research, DM-700 sensor that monitors H_2S was used.

ii. **Arduino Uno:** The Uno is a board based on the ATmega328P microcontroller. It has 14 digital input/output pins (of which 6 can be used as pulse width modulation (PWM) outputs), a 16-MHz quartz crystal, 6 analog inputs, a USB connection, a power jack, a reset button and also an in-circuit serial programming (ICSP) header. It contains everything needed to support the microcontroller and connected to a computer with an AC-to-DC adapter, USB cable to power it and also a battery to get started.

iii. **Arduino software:** The Arduino can be programmed using the Arduino language which is based on C/C++. The open-source Arduino software makes it easy to write Arduino language code and upload it to the board. It runs on Windows, Mac OS X, and Linux.

iv. **Adafruit Data Logger Shield:** It is an add-on circuit board which has an SD card interface and a real time clock that timestamps all the data with the current date and time.

v. **TTL to RS-485 Converter Module:** TTL to RS-485 converter board allows easy conversion of TTL signals to RS-485 levels so that they are compatible with Arduino.

(b) Electronics needed to push the data wirelessly to the server

In this type, logging the data from the sensors is processed by the Arduino and is pushed over Wi-Fi to a remote database, and then data can be analyzed. The system components of this method are: Detcon gas sensors, Arduino Uno, Arduino software, TTL to RS-485 Converter Module for Arduino were presented above. Also required is an ESP8266 ESP-01 Serial Wi-Fi wireless transceiver module.

ESP8266 ESP-01 serial Wi-Fi wireless transceiver module: This add-on circuit board can be connected to any Wi-Fi network by adding the network authentication details while programming the Arduino. This helps to push data to the server.

3. Construct housing for the equipment

Housing Made from Repurposed Materials

The housings are made to accommodate a sensor, battery, and the Arduino setup. They are comprised of several recycled and cost-efficient materials. The main body of the housing is made of a 32-inch long, 8-inch inner diameter PVC pipe, along with bolted ½-inch stainless steel trimmings for the door (which is attached using three bolted hinges) and lining on the inside for extra waterproofing. The roof is made from a stainless steel mixing bowl, fastened by 1-inch bolts, and raised 2 inches off the top of the housing to provide a means of air flow into the housing. A steel grate is bolted at the bottom of the housing, so the air can easily flow to enter/exit from the housing. The sensor is held by two 1-1/2-inch bolts that hook into the fasteners that are already present on the sensor and are fastened with bolts and wing nuts for easy removal. The battery is held by a ½-inch wide, 4-inch long stainless steel hook that is bolted above the monitor position. The Arduino is placed on top of the battery. The entire housing is fastened to a triangular stand made of 24-inch long, 1-inch square steel tubing. All of the bolt holes are then caulked for extra waterproofing. The monitor housing costs around $100 and was constructed using the help of a caarpenter.. Figure 9 shows the monitor housing made up of re-purposed materials.

Figure 9: Monitor housing and stand

4. Integration of the sensor with Arduino setup and housing

The entire Arduino setup is connected to the sensor by proper wiring and the data can be logged onto an SD card or the server using Wi-Fi. The data can be logged at different time intervals (say, 5 sec, 10 sec, 1 min, etc.) by changing the programming code accordingly. One minute logging interval was selected for this research

Figure 10 shows the entire Arduino setup connected to the sensor and figure 11 shows the entire Arduino setup, the sensor along with the battery placed in the housing. Continuous ambient air monitoring can be conducted by using this entire set up by involving limited manpower.

Figure 10: Arduino setup connected to sensor

Figure 11: Housing with entire Arduino setup, sensor, and a battery

5. Testing the developed system by monitoring H_2S at Marrero and Harvey WWTPs

Efforts were made by the researcher to Monitor H_2S at various locations using the entire set up within the immediate surroundings of Marrero WWTP and Harvey WWTP to estimate the odor nuisance to the neighbors. The monitoring was conducted in the months of June and July 2015. Although monitoring was the primary objective, documenting "hot spots" within the observation area and also understanding the important sources and hierarchy of sources of H_2S within Marrero WWTP and Harvey WWTP were also specific objectives.

Many factors were considered while selecting monitoring locations for H_2S monitoring at Marrero and Harvey Wastewater Treatment Plants. Some of these factors include, but are not limited to:

- Safety: The location was selected such that the monitor is protected from theft and also it should not block the way for the workers.
- Convenience and accessibility: The housing along with monitor was placed at a location such that it is convenient to replace the battery.
- Sources of H_2S Emissions: The preliminary analysis was conducted at the two treatment plants for 2 days to observe the locations that have highest concentrations (Headworks, Clarifiers, Trickling filters etc.)
- Wind Direction: The monitors were placed by observing the wind direction.
- Feedback from the H_2S monitor: Based on the results of the preliminary analysis, locations were selected by considering the feedback from the monitor (considering sites that have only recorded highest concentrations).

Six locations were identified at the Marrero WWTP, and five locations were identified at Harvey WWTP. Table 4 and table 5 below show the latitudes and longitudes of the selected monitoring locations (pegs) at Marrero and Harvey WWTPs respectively.
Figure 12 (Marrero WWTP) and Figure 13 (Harvey WWTP) represents the selected monitoring locations (pegs) used for this research.

Table 4: Latitudes and longitudes of locations at Marrero WWTP

Location	Latitude	Longitude	Location description
1	29.87875	-90.116417	Near headworks
2	29.877183	-90.115917	Final clarifier 1
3	29.877833	-90.116167	Final clarifier 2
4	29.877867	-90.115967	Between new activated sludge unit and aerobic digestion tank
5	29.877583	-90.115567	Chlorination Basin
6	29.87775	-90.1154	New final clarifier

Figure 12: Marrero WWTP with monitoring locations

Table 5: Latitudes and longitudes of locations at Harvey WWTP

Location	Latitude	Longitude	Location description
1	29.876944	-90.065833	Near headworks
2	29.87625	-90.065933	Primary clarifier 2
3	29.87625	-90.065367	Trickling filter
4	29.876933	-90.066383	Final clarifier 2
5	29.876817	-90.066333	Solid contact basins

Figure 13: Harvey WWTP with monitoring locations

The H_2S monitoring took place in the months of June and July in 2015, and the daily total monitoring period lasted for two-three hours from 6:30a.m. - 9:30a.m by monitoring for 15 to 30 minutes at each location.

5. Results and Data Analysis

Detcon DM-700 with a data logging unit (Arduino and SD card) was used for monitoring at the Marrero and Harvey WWTPs. The readings were taken 2-4 feet above the ground. The data was downloaded from all the SD cards onto the computer. The latitudes and longitudes of the location were taken by using IPhone application named “Altimeter”. The data was analyzed and organized according to the location and also graphs were developed by using the software tool. The code was developed using javascript to develop graphs for H_2S concentration versus time on each day at a particular location. H_2S concentration readings and time will be given as an input, and data is retrieved from SQL database. The graphs developed by using this coding were placed in Appendix A

5.1. Marrero WWTP

Marrero Plant is surrounded by a busy neighborhood. The equipment was used for monitoring at a total of six locations during the monitoring period. The detailed monitoring results are given in the appendix A. Table 6 represents the average, the minimum and maximum concentrations of H_2S at each selected location.

Data observed for ambient H_2S concentration monitoring:

Table 6: Concentrations (averagee, min, max) of H_2S at specific location at Marrero WWTP

Latitude	Longitude	Peg	Location	Dates	Avg (ppm)	Min (ppm)	Max (ppm)
29.87875	-90.1164	1	near headworks	7/8/2015	0.07	<LOQ	0.27
29.87875	-90.1164	1	near headworks	7/9/2015	<LOQ	<LOQ	<LOQ
29.87875	-90.1164	1	near headworks	7/13/2015	0.99	0.41	1.42
29.87875	-90.1164	1	near headworks	7/14/2015	1.6	0.98	2.94
29.87875	-90.1164	1	near headworks	7/17/2015	0.09	<LOQ	1.1
29.87718	-90.1159	2	near final clarifier 1	7/8/2015	0.95	<LOQ	1.95
29.87718	-90.1159	2	near final clarifier 1	7/9/2015	0.89	0.25	1.96
29.87718	-90.1159	2	near final clarifier 1	7/13/2015	0.66	0.47	0.83
29.87718	-90.1159	2	near final clarifier 1	7/14/2015	1.56	0.98	2.52
29.87718	-90.1159	2	near final clarifier 1	7/17/2015	2.15	1.03	3.86
29.87783	-90.1162	3	near final clarifier 2	7/13/2015	1.82	0.59	4.79
29.87783	-90.1162	3	near final clarifier 2	7/14/2015	0.9	0.48	1.48
29.87783	-90.1162	3	near final clarifier 2	7/17/2015	0.43	<LOQ	2.21

29.87787	-90.116	4	between new activated sludge unit and aerobic digestion tank	7/8/2015	0.82	0.32	1.65
29.87787	-90.116	4	between new activated sludge unit and aerobic digestion tank	7/9/2015	0.86	<LOQ	1.61
29.87787	-90.116	4	between new activated sludge unit and aerobic digestion tank	7/13/2015	<LOQ	<LOQ	<LOQ
29.87758	-90.1156	5	near Chlorination basin	7/8/2015	<LOQ	<LOQ	<LOQ
29.87758	-90.1156	5	near Chlorination basin	7/9/2015	0.04	<LOQ	<LOQ
29.87758	-90.1156	5	near Chlorination basin	7/13/2015	0.06	<LOQ	0.2
29.87758	-90.1156	5	near Chlorination basin	7/14/2015	<LOQ	<LOQ	<LOQ
29.87758	-90.1156	5	near Chlorination basin	7/17/2015	0.1	<LOQ	0.34
29.87775	-90.1154	6	near new final clarifier	7/8/2015	<LOQ	<LOQ	<LOQ
29.87775	-90.1154	6	near new final clarifier	7/9/2015	<LOQ	<LOQ	<LOQ
29.87775	-90.1154	6	near new final clarifier	7/13/2015	<LOQ	<LOQ	<LOQ

Data analysis by location

Tables and figures represented below show the distribution of concentration ranges at each location. This gives an idea about the percentage of concentrations that exceed the limits set by agencies. Table 7 and figure 14 represents the table and a pie chart showing percentage distribution of H_2S concentrations at the location 1 respectively. In the same way, tables and figures are given below for all the locations at the Marrero WWTP.

Location1 (near Headworks)

Table 7: H_2S ranges and percentages at location 1

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	48.05
2	0.5 - 1	14.29
3	1 - 1.5	25.97
4	1.5 - 2	6.49
5	2 - 2.5	3.90
6	2.5 - 3	1.30

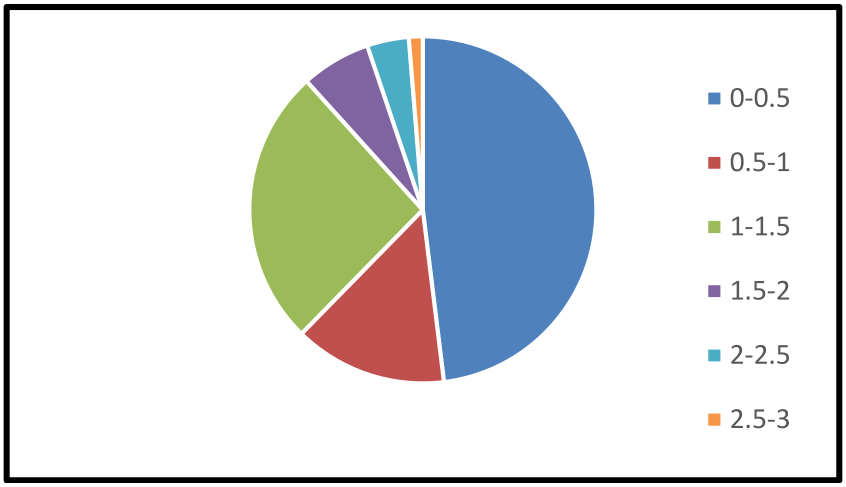

Figure 14: H_2S ranges (ppm) and percentages at location 1

Location 2 (near Final Clarifier 1)

Table 8: H_2S ranges and percentages at location 2

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	11.39
2	0.5 - 1	32.91
3	1 - 1.5	27.85
4	1.5 - 2	13.92
5	2 - 2.5	6.33
6	2.5 - 3	3.8
7	3 - 4	3.8

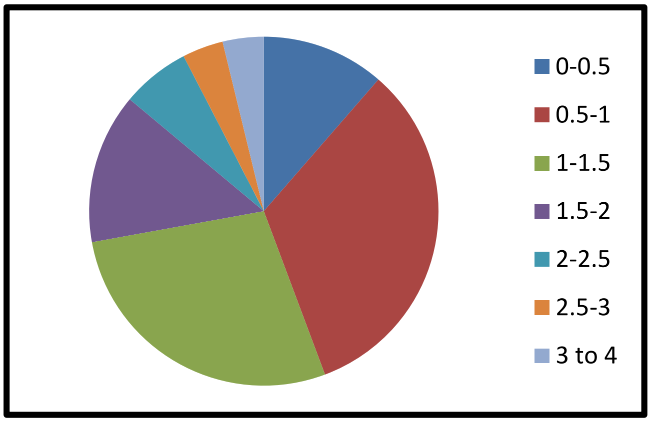

Figure 15: H_2S ranges (ppm) and percentages at location 2

Location 3 (near Final Clarifier 2)

Table 9: H_2S ranges and percentages at location 3

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	22.03
2	0.5 - 1	44.07
3	1 - 1.5	22.03
4	1.5 - 2	3.39
5	2 - 2.5	6.78
6	2.5 - 3	0.00
7	3 - 4	1.69

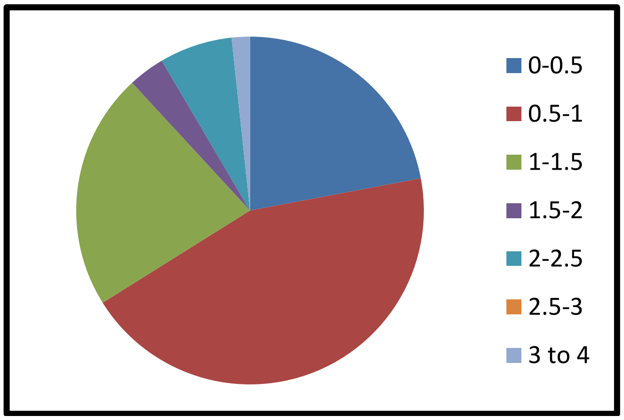

Figure 16: H_2S ranges (ppm) and percentages at location 3

Location 4 (Between new activated sludge unit and aerobic digestion tank)

Table 10: H_2S ranges and percentages at location 4

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	39.13
2	0.5 - 1	41.30
3	1 - 1.5	13.04
4	1.5 - 2	6.52
5	2 - 2.5	0
6	2.5 - 3	0
7	3 - 4	0

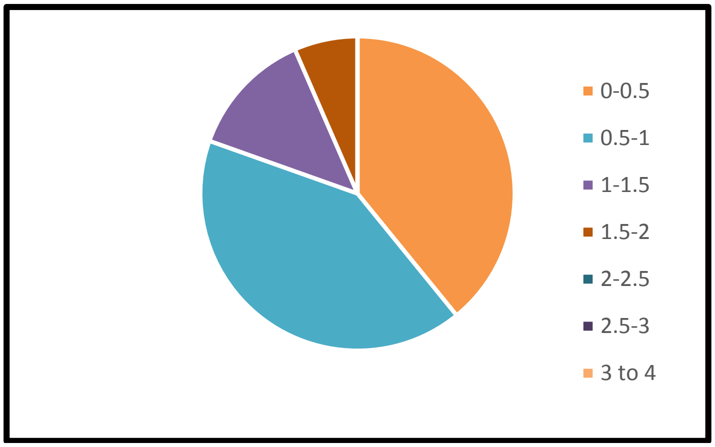

Figure 17: H_2S ranges (ppm) and percentages at location 4

Location 5 (Near Chlorination Basin)

Table 11: H_2S ranges and percentages at location 5

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	100
2	0.5 - 1	0
3	1 - 1.5	0
4	1.5 - 2	0
5	2 - 2.5	0
6	2.5 - 3	0
7	3 - 4	0

Location 6 (Near Final clarifier)

Table 12: H_2S ranges and percentages at location 6

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	100
2	0.5 - 1	0
3	1 - 1.5	0
4	1.5 - 2	0
5	2 - 2.5	0
6	2.5 - 3	0
7	3 - 4	0

Surprisingly, highest 15-min average concentration (2.15 ppm) on a single day was observed at the location 2 (near final clarifier 1) and the second highest concentration (1.82 ppm) was observed at the location 3 (near final clarifier 2). 14% of the recorded readings are above 2 ppm at the location 2 and 9% of the readings are above 2 ppm at location 3.

The highest concentration observed at the Marrero WWTP is 4.79 ppm at location 3 (near final clarifier 2). Second highest concentration is 3.86 ppm at location 2 (near final clarifier 1). The monitor was kept very far from the headworks and that was suspected to be the reason for not observing high concentrations at location 1 (near headworks) when compared to clarifiers.

5.2. Harvey WWTP

The Harvey Plant is surrounded by open land, a canal, and a neighborhood. Monitoring took place at a total of five site locations which were selected based on the preliminary analysis and wind direction. The detailed monitoring results are given in the appendix A. Table 13 represented below show the daily average, minimum and maximum concentration of H_2S at each location.

Data observed for ambient H_2S concentration monitoring

Table 13: Concentrations (average, min, max) of H_2S at specific location at Harvey WWTP

Latitude	Longitude	Peg	Location	Dates	Avg (ppm)	Min (ppm)	Max (ppm)
29.876944	-90.06583	1	near headworks	7/20/2015	0.08	<LOQ	0.31
29.876944	-90.06583	1	near headworks	7/23/2015	0.08	<LOQ	0.28
29.876944	-90.06583	1	near headworks	7/24/2015	0.03	<LOQ	0.18
29.87625	-90.06593	2	near primary clarifier 2	7/21/2015	0.44	0.2	0.58
29.87625	-90.06593	2	near primary clarifier 2	7/23/2015	0.36	0.2	0.55
29.87625	-90.06593	2	near primary clarifier 2	7/24/2015	0.3	0.21	0.47
29.87625	-90.06593	2	near primary clarifier 2	7/29/2015	0.34	0.22	0.45
29.87625	-90.06593	2	near primary clarifier 2	8/5/2015	0.3	0.21	0.47
29.87625	-90.06537	3	near trickling filter	7/20/2015	0.6	0.23	1.03
29.87625	-90.06537	3	near trickling filter	7/21/2015	0.32	0.21	0.44
29.87625	-90.06537	3	near trickling filter	8/5/2015	<LOQ	<LOQ	0.44
29.876933	-90.06638	4	near final clarifier 2	7/20/2015	1.72	0.98	3.17
29.876933	-90.06638	4	near final clarifier 2	7/21/2015	1.12	0.5	2.34
29.876933	-90.06638	4	near final clarifier 2	7/22/2015	1.93	0.23	4.1
29.876933	-90.06638	4	near final clarifier 2	7/23/2015	1.09	0.28	1.69

29.876933	-90.06638	4	near final clarifier 2	7/24/2015	0.84	0.29	1.75
29.876933	-90.06638	4	near final clarifier 2	7/29/2015	0.64	<LOQ	1.5
29.876933	-90.06638	4	near final clarifier 2	8/5/2015	0.17	<LOQ	0.5
29.876817	-90.06633	5	near solid contact basin	7/20/2015	0.94	0.38	1.78
29.876817	-90.06633	5	near solid contact basin	7/21/2015	<LOQ	<LOQ	<LOQ
29.876817	-90.06633	5	near solid contact basin	7/22/2015	0.21	<LOQ	0.62
29.876817	-90.06633	5	near solid contact basin	7/23/2015	0.22	<LOQ	0.72
29.876817	-90.06633	5	near solid contact basin	7/24/2015	0.28	<LOQ	0.77

Data analysis by location

Tables and figures represented below show the distribution of concentration ranges by each location. This gives an idea about the percentage of concentrations that exceed the limits set by agencies. Table 15 and figure 18 represents the table and a pie chart showing percentage distribution of H_2S concentrations at the location 2. In the same way, tables and figures are given below for all the locations at the Harvey WWTP.

Location 1 (Near headworks)

Table 14: H_2S ranges and percentages at location 1

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	100
2	0.5 - 1	0
3	1 - 1.5	0
4	1.5 - 2	0
5	2 - 2.5	0
6	2.5 - 3	0
7	3 - 4	0

Location 2 (Near Primary clarifier)

Table 15: H_2S ranges and percentages at location 2

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	87.27
2	0.5 - 1	12.73
3	1 - 1.5	0
4	1.5 - 2	0
5	2 - 2.5	0
6	2.5 - 3	0
7	3 - 4	0

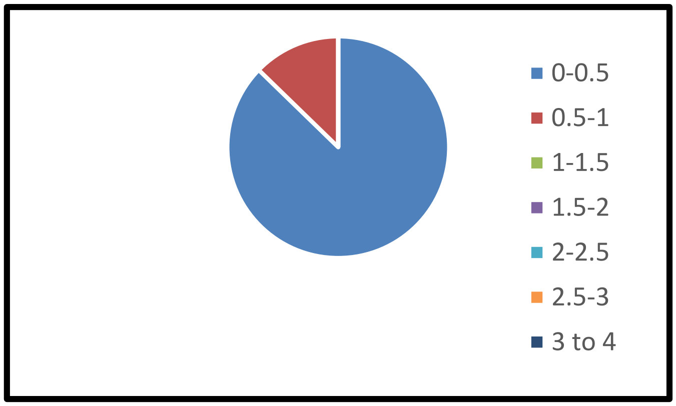

Figure 18: H_2S ranges (ppm) and percentages at location 2

Location 3 (Near trickling filter)

Table 16: H_2S ranges and percentages at location 3

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	78.79
2	0.5 - 1	18.18
3	1 - 1.5	3.03
4	1.5 - 2	0
5	2 - 2.5	0
6	2.5 - 3	0
7	3 - 4	0

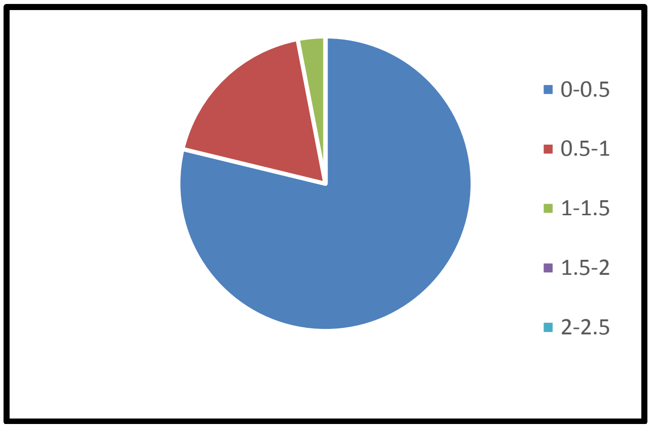

Figure 19: H_2S ranges (ppm) and percentages at Location 3

Location 4 (Near Final clarifier 2)

Table 17: H_2S ranges and percentages at location 4

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	15.58
2	0.5 - 1	27.27
3	1 - 1.5	29.87
4	1.5 - 2	11.69
5	2 - 2.5	5.19
6	2.5 - 3	6.49
7	3 - 4	3.90

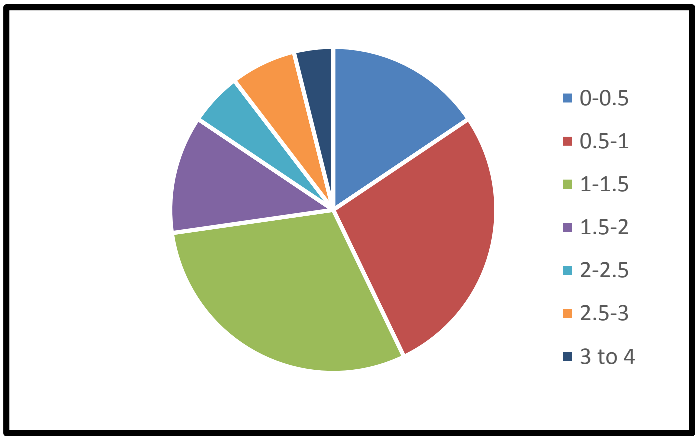

Figure 20: H_2S ranges (ppm) and percentages at location 4

Location 5 (Near Solid contact basins)

Table 18: H_2S ranges and percentages at location 5

Sl. No.	H_2S Concentration range (ppm)	Percentage
1	0 - 0.5	69.84
2	0.5 - 1	23.81
3	1 - 1.5	4.76
4	1.5 - 2	1.59
5	2 - 2.5	0
6	2.5 - 3	0
7	3 - 4	0

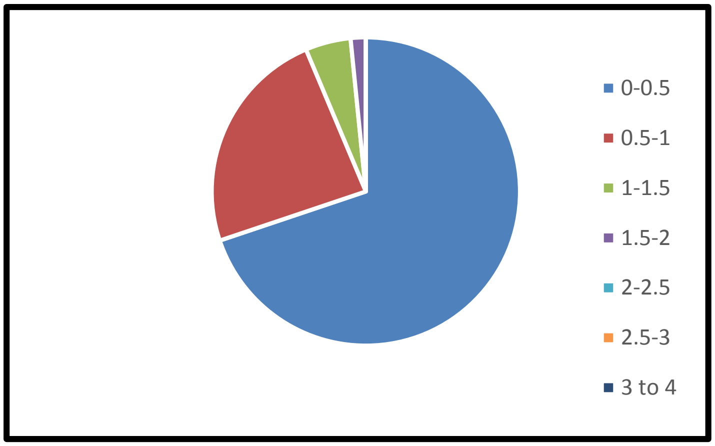

Figure 21: H_2S ranges (ppm) and percentages at location 5

Although the results are not conclusive, it does provide a vague idea of the locations at which the odor nuisance maybe worse in the facility.

Surprisingly, at the Harvey WWTP, highest 15 min average concentration (1.93 ppm) on a single day was observed at the location 4 (near final clarifier 2) and the second highest concentration (0.94 ppm) was observed at the location 5 (near solid contact basin). 16% of the recorded readings are above 2 ppm at the location 4. Other than location 4 (near final clarifier 2), no other selected site has recorded H_2S concentrations higher than 2 ppm.

The highest concentration observed at the Harvey WWTP is 3.17 ppm at location 4 (near final clarifier 2). Second highest concentration is 1.78 ppm at location 5 (near solid contact basin). The monitor was kept very far from the headworks and that was suspected to be the reason for not observing high concentrations at location 1 (near headworks) when compared to clarifiers.

6. Conclusions

As discussed earlier, air quality monitoring systems with good sensors, data logging capacity, portability, fancy looks are expensive, thus are not affordable to most communities that are severely affected by the air pollution. Many studies have indicated that the poorer communities are often associated with bad air quality which requires continuous air quality monitoring to understand and manage the problems associated with air pollution. This research effort under the supervision of UNO faculty was made to develop a low-cost, environmentally-friendly, and socially relevant ambient air quality monitoring system to address the air quality monitoring needs of the communities that are challenged with severe air pollution. Table 19 represented below shows the specifications of conventional air quality monitors (high features) and UNO's low-cost air quality monitors.

Table 19: Conventional air quality monitors Vs UNO's low-cost air quality monitors

Conventional Air Quality Monitors with high features			**UNO's low-cost air quality monitors**		
Pollutant	**Manufacturer**	**Other information**	**Pollutant**	**Manufacturer**	**Other information**
Hydrogen Sulfide (H_2S)	Company X	**The principle of Operation:** Electrochemical cell **Detection range:** 0.01-2 ppm **Features:** Datalogger with high capacity, battery, software, weather shield, and portable. **Cost: $4,050**	Hydrogen Sulfide (H_2S)	Detcon (DM-700)	**The principle of Operation:** Electrochemical cell **Detection range:** 0-9ppm with a resolution of 10 ppb **Features:** Water & corrosion proof, durable, but it has no data logger, battery, and software. **Cost:** \$800+\$100 +\$100 (Sensor + Arduino + Housing) = **$1000**

The present study gave the opportunity to use the sustainable principles (People, Planet, and Prosperity) in developing air quality monitoring system (equipment, data logging, data storage, and data transmission, and data analysis) that is affordable and purposeful. Table 17 compared the costs of conventional and ready-to-use, air quality monitoring equipment versus the UNO's sustainable air quality monitoring system approach. The cost was optimized from $4,050 to $1000. It should be noted that some conventional equipment offers more features than a particular monitoring scenario may require. Caution should be used in evaluating and selecting monitoring system to meet the project goals.

This research methodology can be further refined to develop sustainable ambient air quality monitoring systems for various regions and countries to meet their specific air quality monitoring and management needs.

The monitoring system was tested at the Harvey and Marrero WWTPs for only few days. As the objective was only to test the system, only 15 to 30 minutes of monitoring was conducted on each day, at each location. At the Marrero WWTP, the highest 15-min average concentration observed was 2.15 ppm and the minimum observed concentration was below the quantitation limit in the total monitoring period. Higher concentrations were found at location 2 (near final clarifier 1).

At the Harvey WWTP, the highest 15-min average concentration observed was 1.93 ppm, and the minimum observed concentration was below the quantitation limit in the total monitoring period. Higher concentrations were recorded at location 4 (near final clarifier 2) during the monitoring period. Higher concentrations observed near the final clarifier might be because as the sludge settles down, sulfides are formed with lack of enough oxygen.

The analysis was done to understand the distribution of H_2S concentration ranges at the Harvey and Marrero treatment plant (See Tables 20 and 21). The maximum percentage of the H_2S concentration readings observed during the total monitoring period at all the locations at both treatment plants was found to be below 0.25 ppm. Only few readings were found to be in the range of 2- 5 ppm. Therefore, long-term monitoring has to be conducted to correctly analyze the percentage distribution of H_2S concentrations at both the treatment plants.

Table 20: Distribution of H_2S ranges at Harvey WWTP

Sl. No.	H_2S range (ppm)	No. of observations	Percentage distribution
1	0-0.25	247	47.6
2	0.25-0.5	142	27.4
3	0.5-1	92	17.7
4	1-2	28	5.4
5	2-3	6	1.15
6	3-4	2	0.38
7	4-5	1	0.19

Table 21: Distribution of H_2S ranges at Marrero WWTP

Sl. No.	H_2S range (ppm)	No. of observations	Percentage distribution
1	0-0.25	260	40.12
2	0.25-0.5	68	10.49
3	0.5-1	136	20.98
4	1-2	131	20.21
5	2-3	35	5.4
6	3-4	11	1.69
7	4-5	4	0.61
8	5-6	3	0.46

H_2S concentrations at the WWTPs depend on various factors like WWTP age and efficiency, temperature, odor control equipment, wastewater residence time in the anaerobic environment, and more. The odor control equipment/ technology being used at the Harvey and Marrero WWTPs is Biotrickling filter with expendable staged polishing media for final removal. Biotrickling filters manufactured by Biorem technologies is being used at Marrero WWTP, and the Biotrickling filter manufactured by Purafil Inc. is being used at the Harvey WWTP.

The Marrero WWTP is 19 years older than the Harvey WWTP. From the results, higher concentrations of ambient H_2S were observed at the Marrero WWTP when compared to Harvey WWTP. It must be noted that monitoring was done in the immediate vicinity of the WWTPs, not in the community. The results of higher H_2S concentrations at the Marrero WWTP may be due to the age of the plant. Additional long-term monitoring is recommended to understand and benchmark the H_2S concentration profiles at these two monitoring plants.

7. Limitations and Future Recommendations

Monitoring was only conducted at a few selected locations in the immediate vicinity of the Harvey and Marrero treatment plants. Additional locations should be monitored to solidify the conclusion.

As the sensor (Detcon DM-700) was not based on Environmental protection Agency (EPA) recommended methods, the results obtained may not be as accurate as the standard methods. In addition, the data logger developed for the sensor using Arduino can log the reading that was recorded at the end of each minute. I recommend changing the code for the Arduino such that it records the readings for every 1 or 2 seconds and the web tool must be developed to calculate the average readings. This ambient air monitoring system should be tested along with the conventional expensive monitors manufactured by vendors by keeping them at the same location in the future to observe the variation in both the equipment (if any).

Monitoring was conducted only on few days. Long-term observations are necessary for the air quality research to strengthen the conclusion. Meteorological monitoring has to be done in the future, and emission rates at the sources of the WWTP should be calculated by inverse dispersion modeling using the long term H_2S concentration readings.

Preliminary monitoring was conducted for three days at the Harvey and Marrero WWTPs to select the locations. The monitors placed along the fence line at the two treatment plants recorded zeroes. So, fence line monitoring was not conducted. So, the fence-line monitoring can be conducted in the future.

In this research, the monitoring system was developed with H_2S sensor. Similarly, research can be continued by developing system using other gas sensors.

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9. Appendix A

Marrero: Location 1

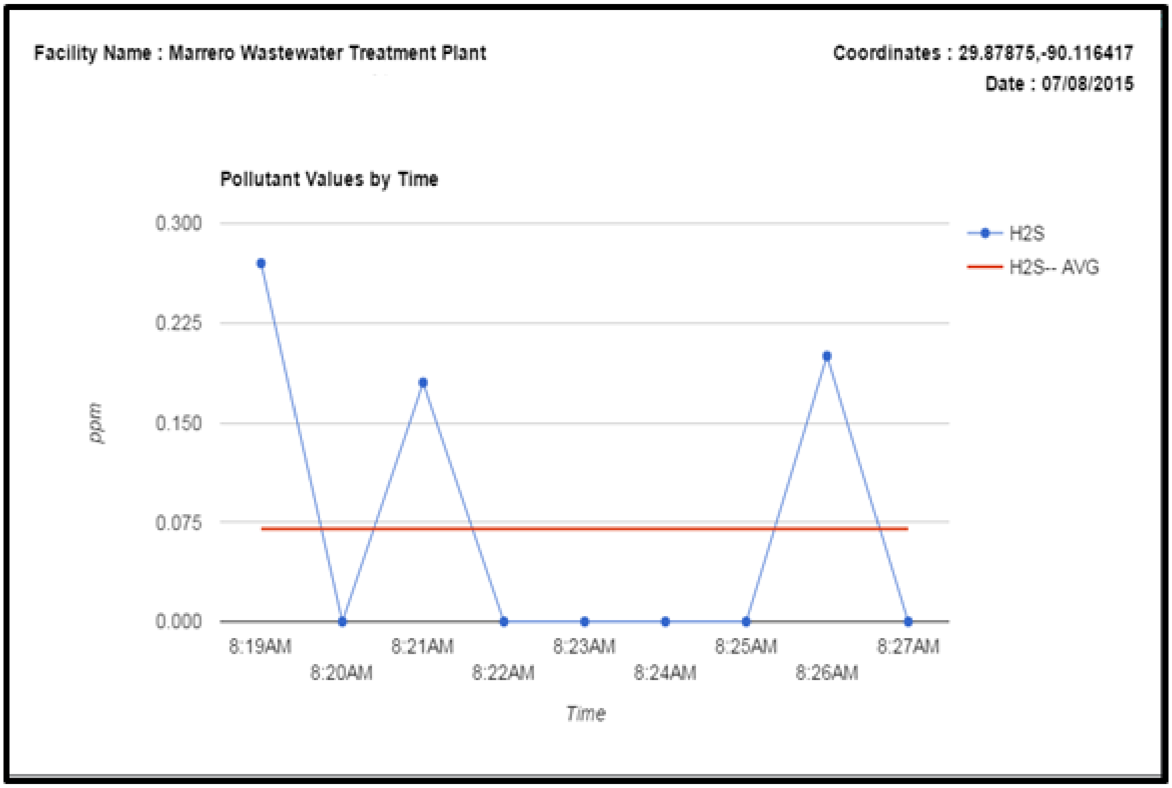

Figure A 1: Variation in concentration of H_2S over a period at location1

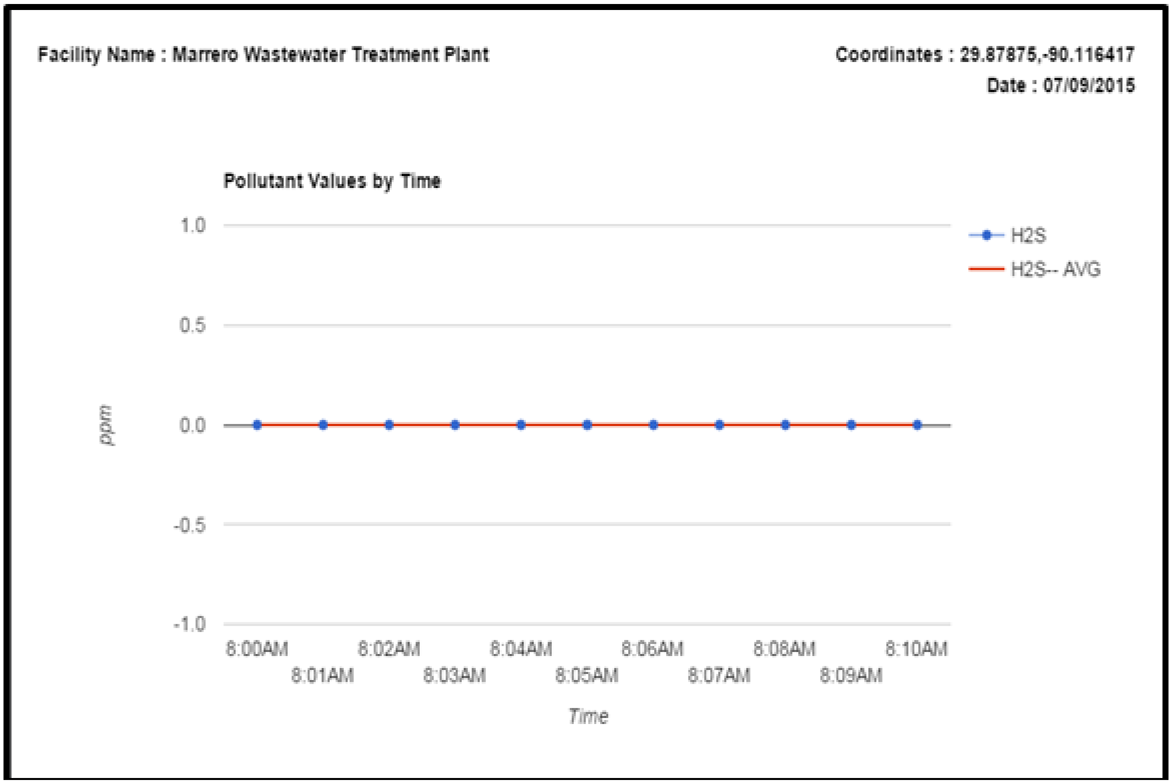

Figure A 2: Variation in concentration of H_2S over a period at location1

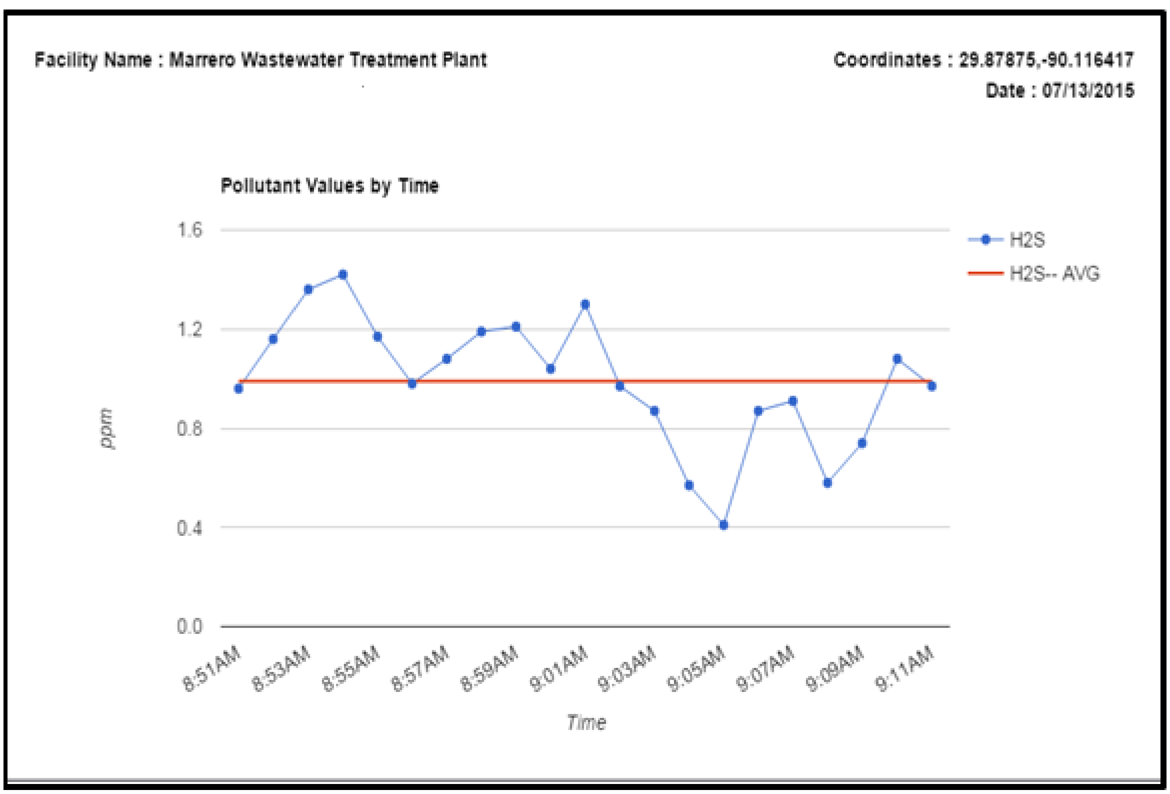

Figure A 3: Variation in concentration of H_2S over a period at location1

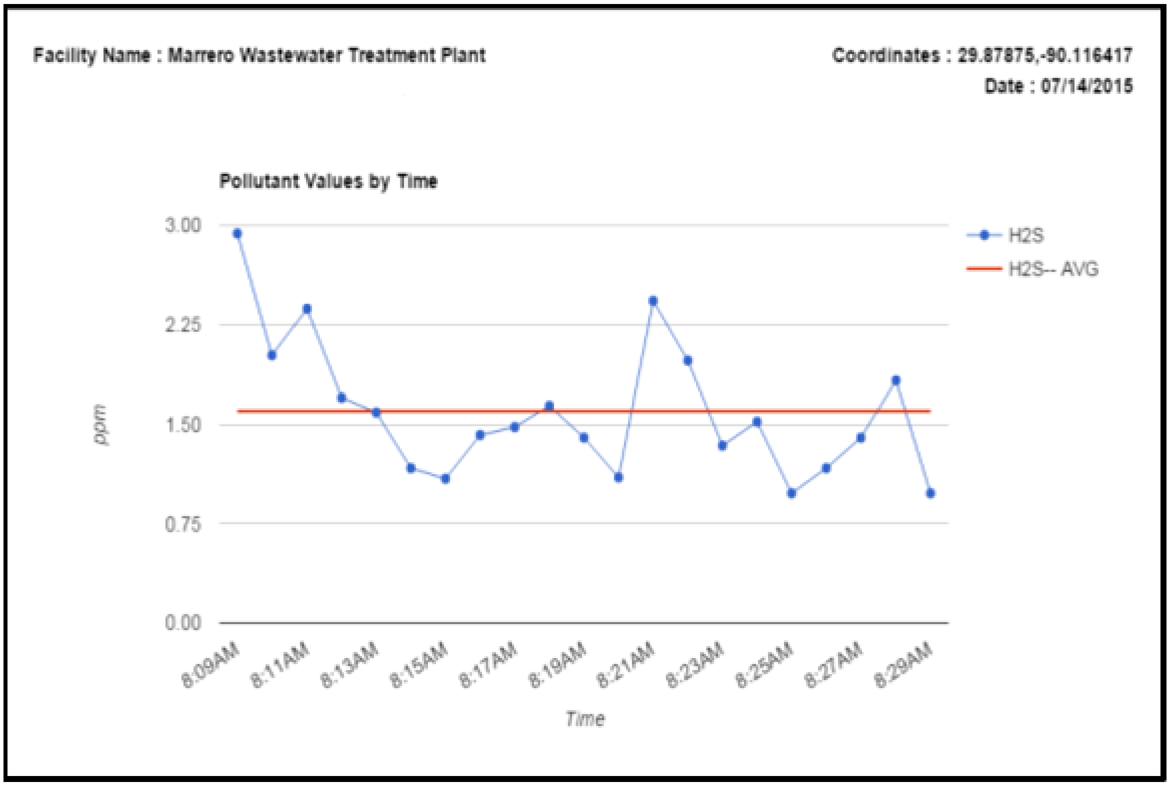

Figure A 4: Variation in concentration of H_2S over a period at location1

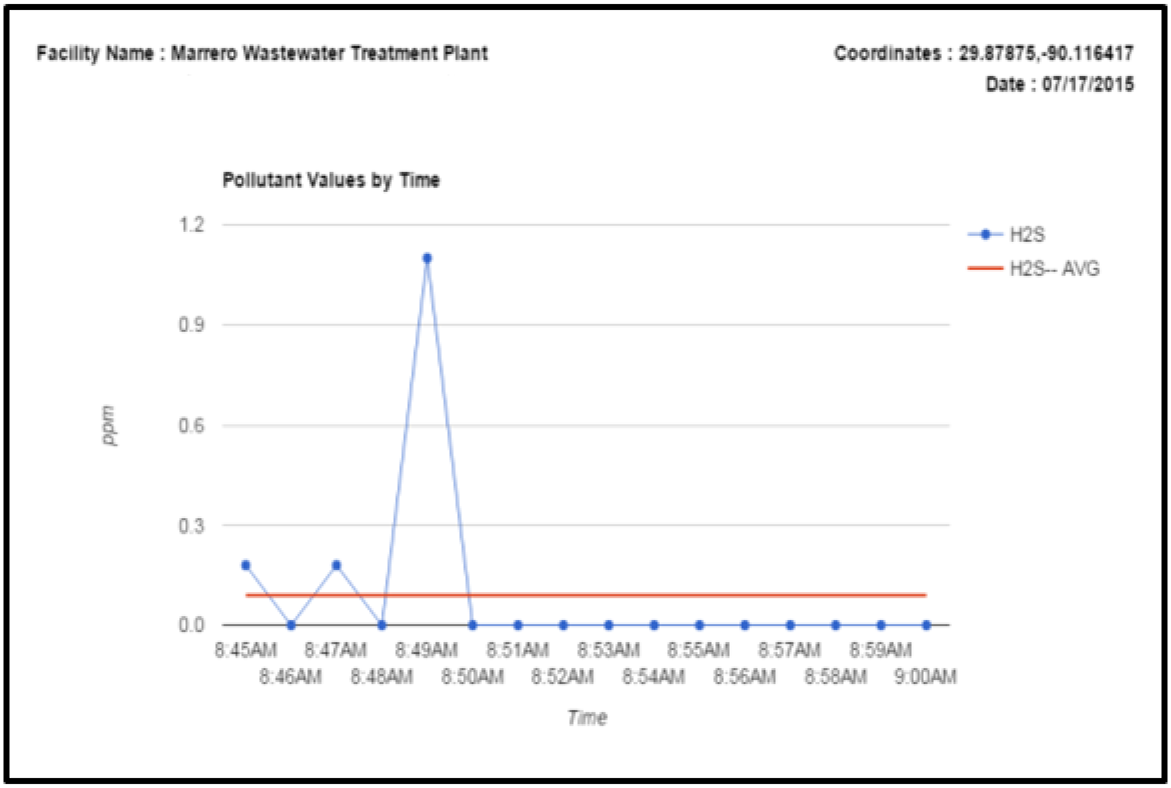

Figure A 5: Variation in concentration of H_2S over a period at location1

Marrero: Location 2

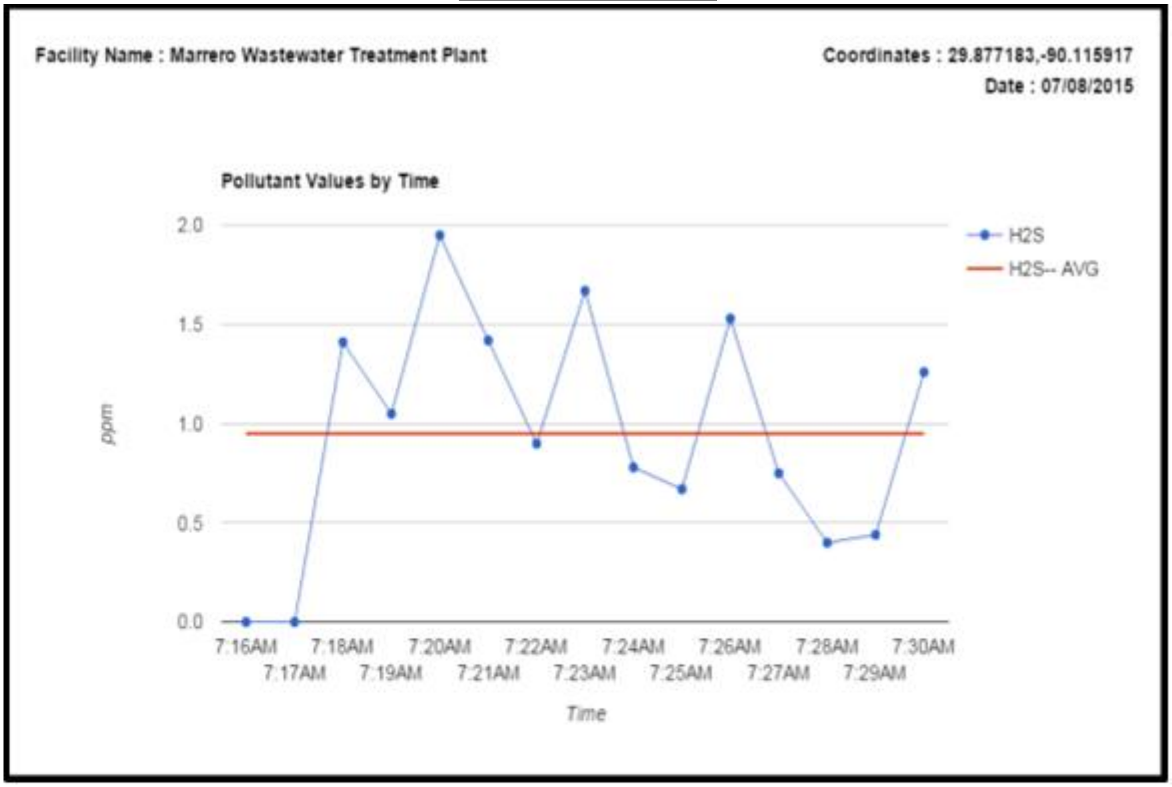

Figure A 6: Variation in concentration of H_2S over a period at location2

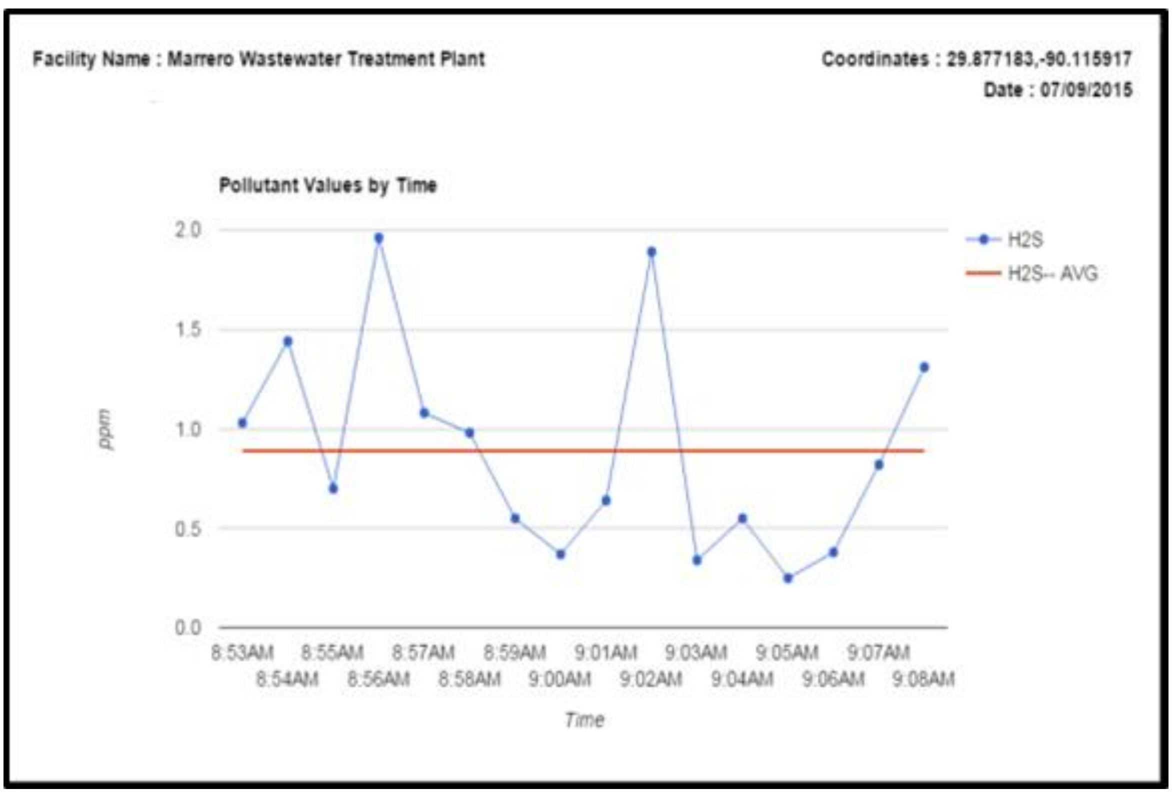

Figure A 7: Variation in concentration of H_2S over a period at location2

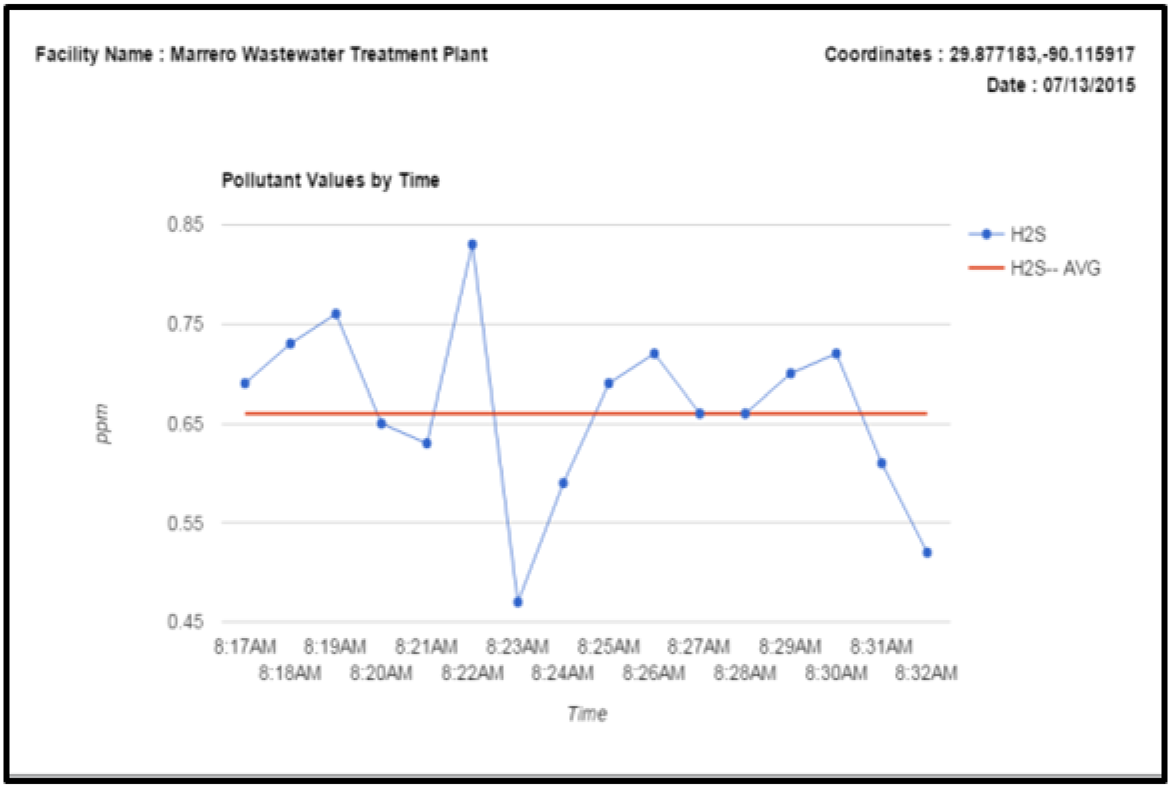

Figure A 8: Variation in concentration of H_2S over a period at location2

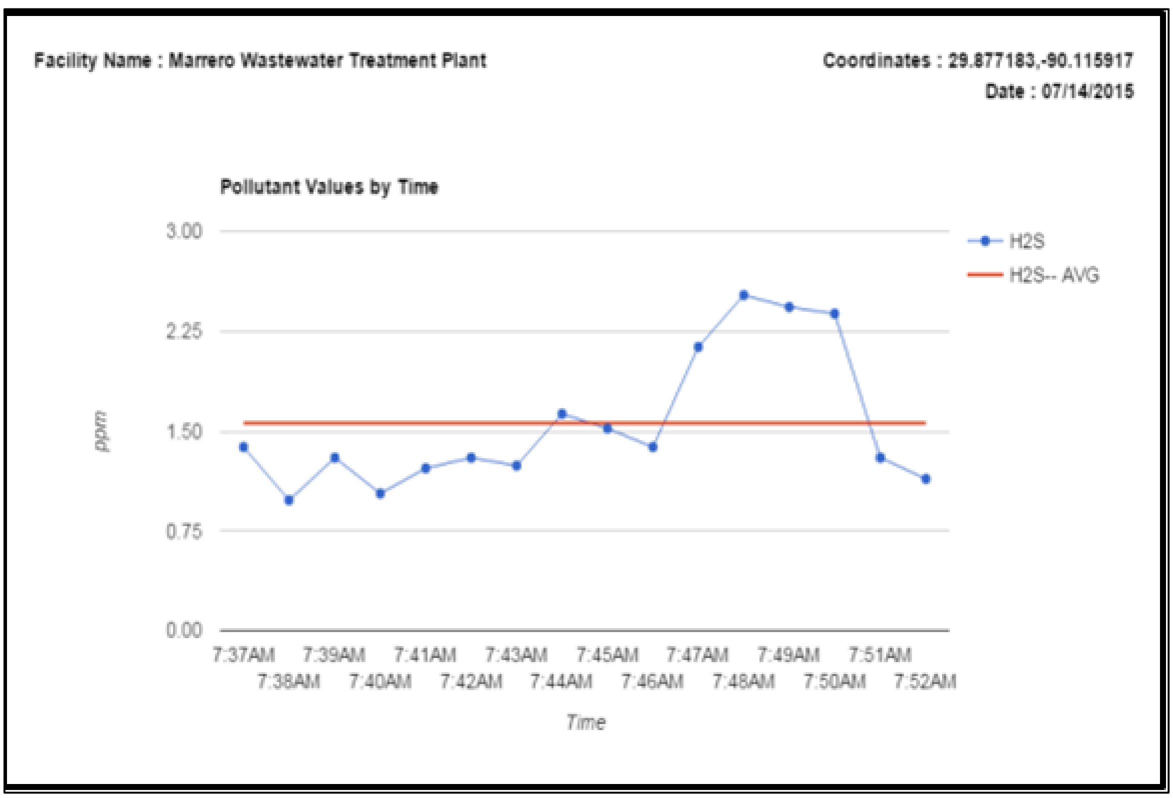

Figure A 9: Variation in concentration of H_2S over a period at location2

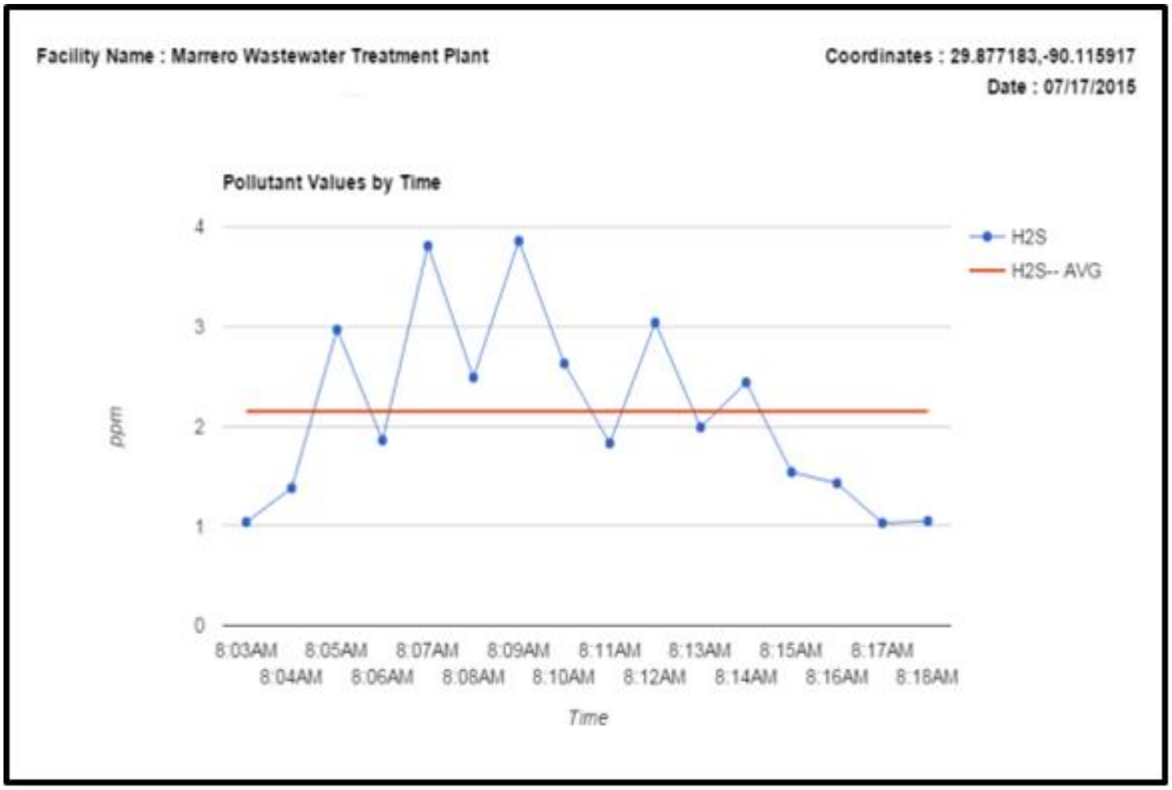

Figure A 10: Variation in concentration of H_2S over a period at location2

Marrero: Location 3

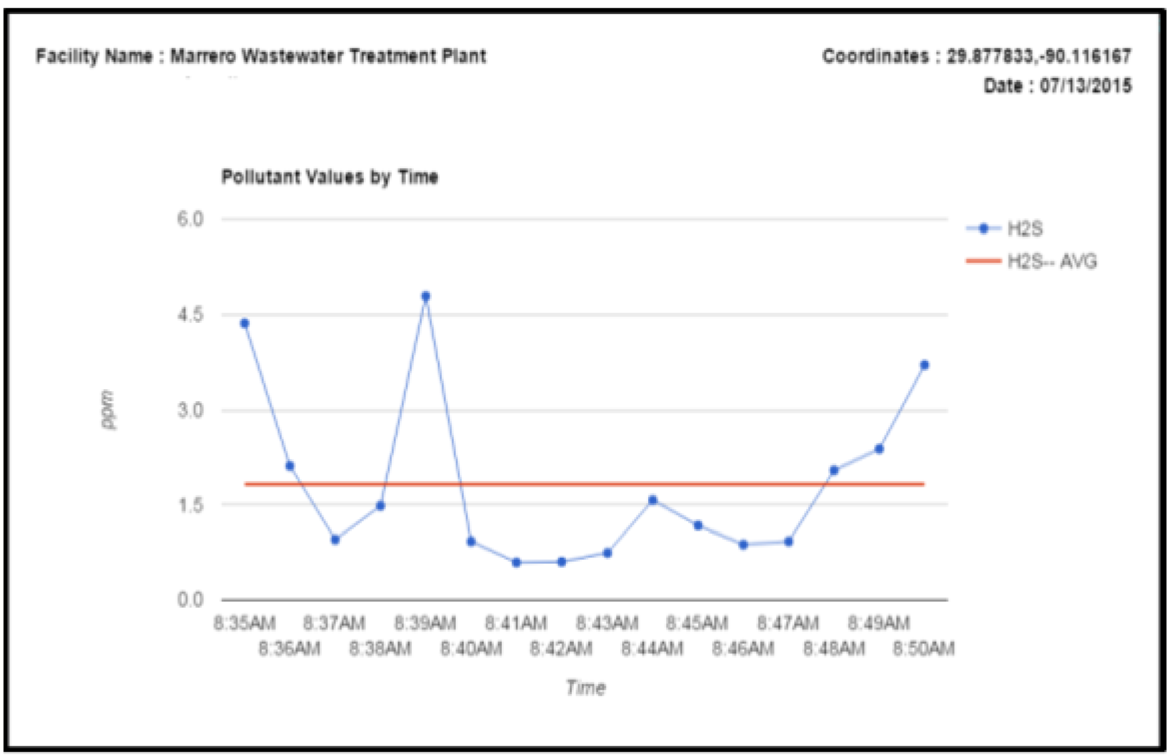

Figure A 11: Variation in concentration of H_2S over a period at location3

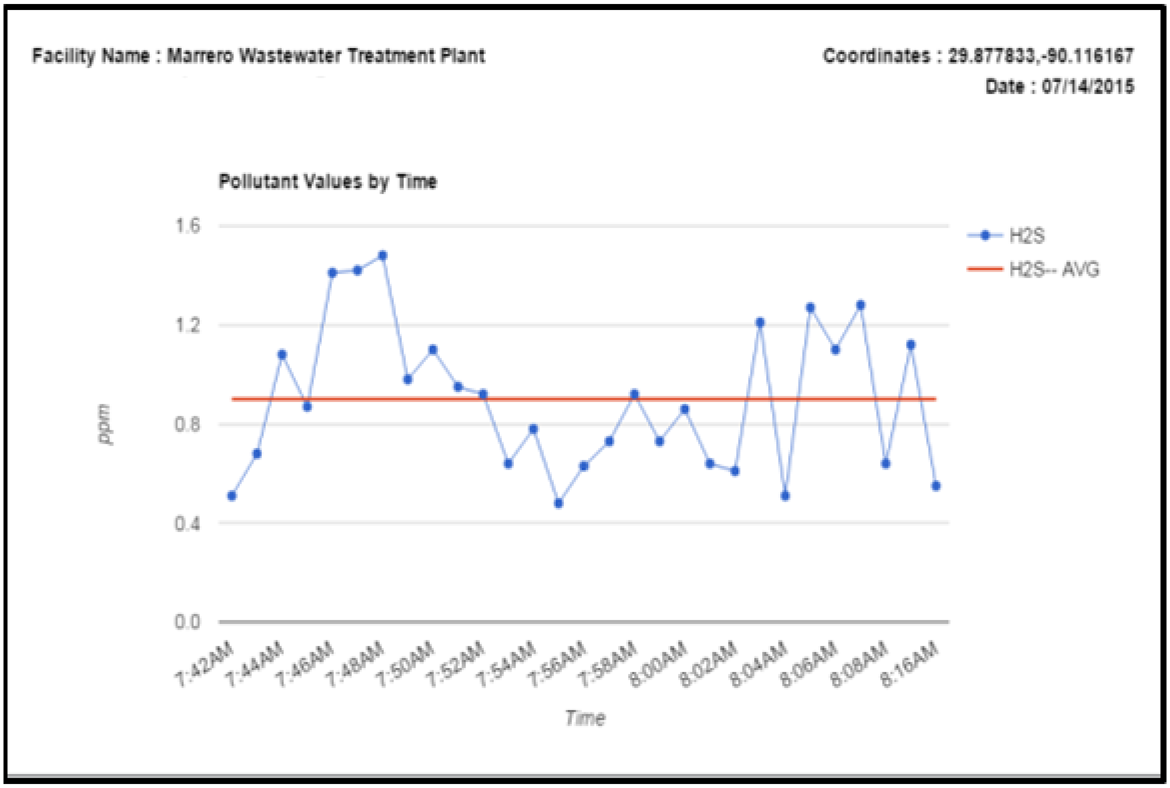

Figure A 12: Variation in concentration of H_2S over a period at location3

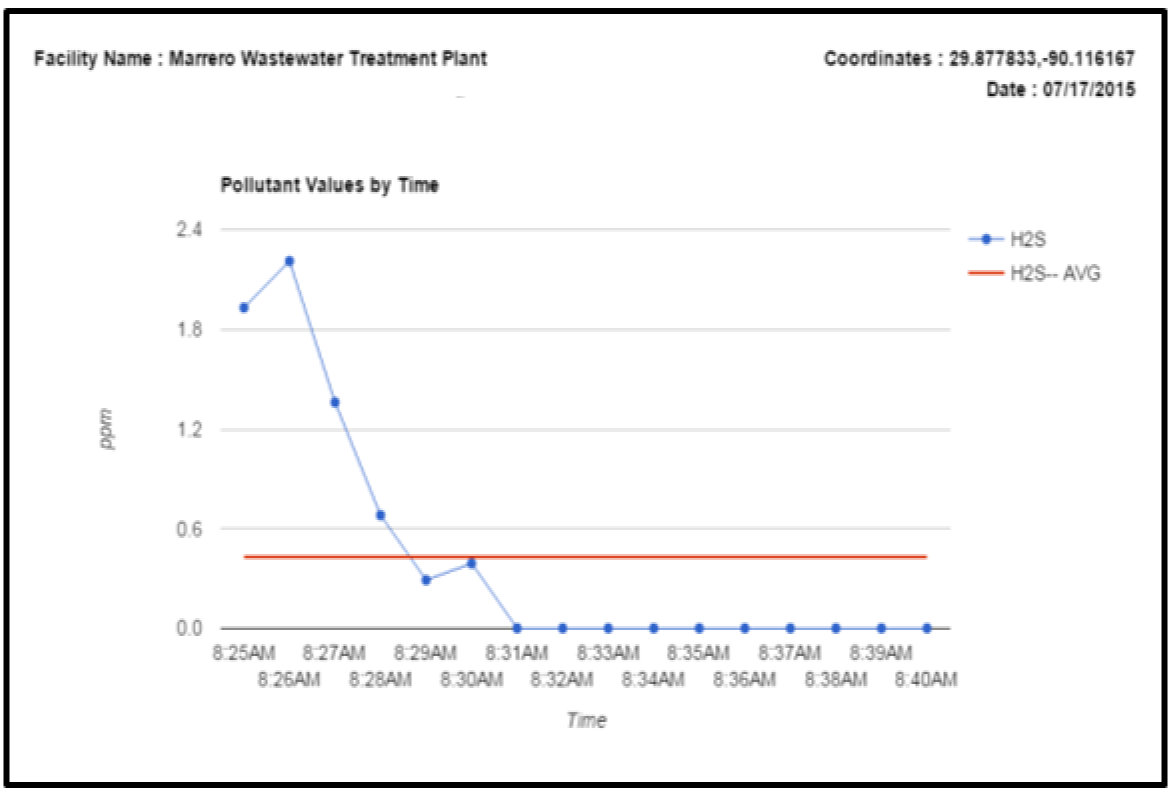

Figure A 13: Variation in concentration of H_2S over a period at location3

Marrero: Location 4

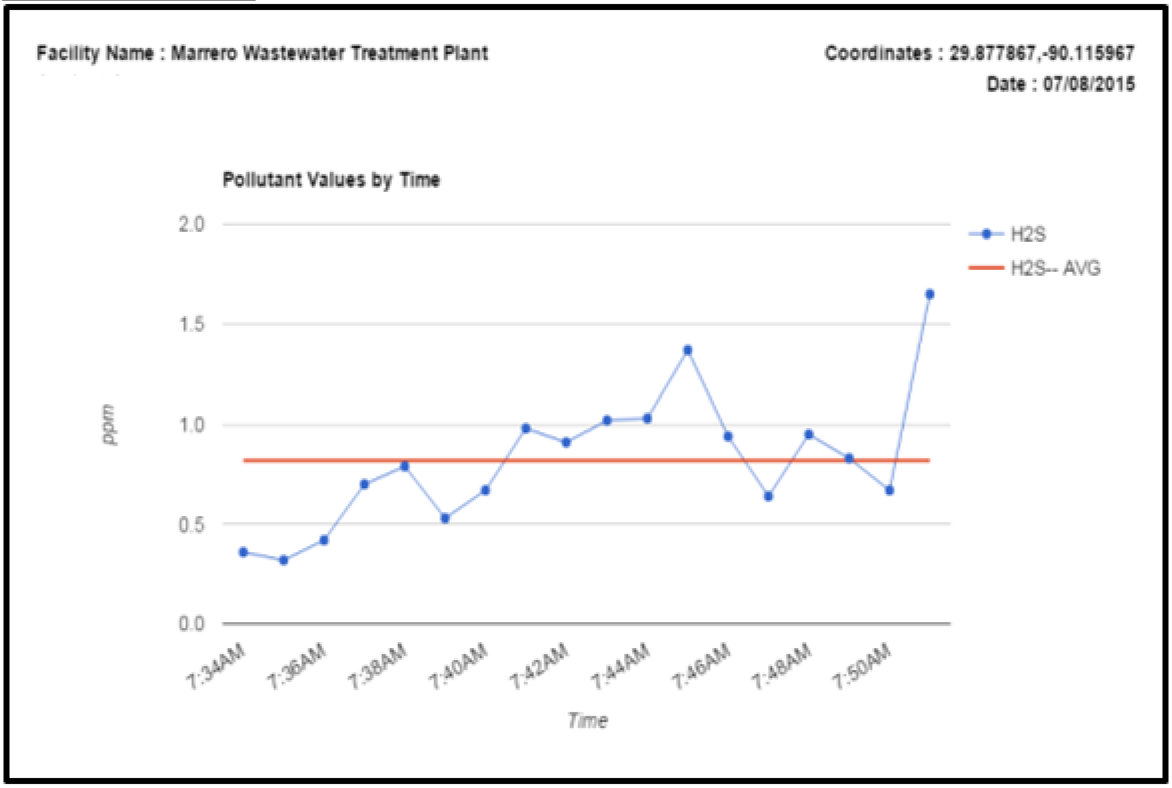

Figure A 14: Variation in concentration of H_2S over a period at location4

Figure A 15: Variation in concentration of H_2S over a period at location4

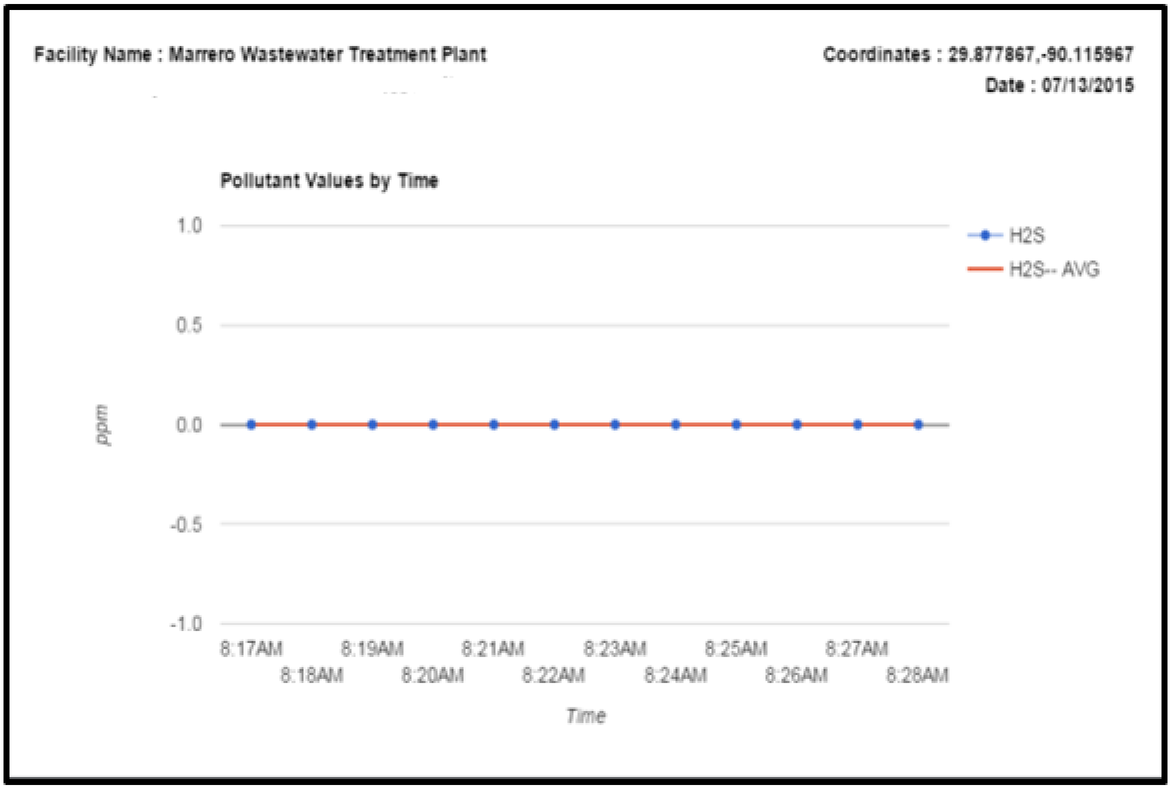

Figure A 16: Variation in concentration of H_2S over a period at location4

Marrero: Location 5

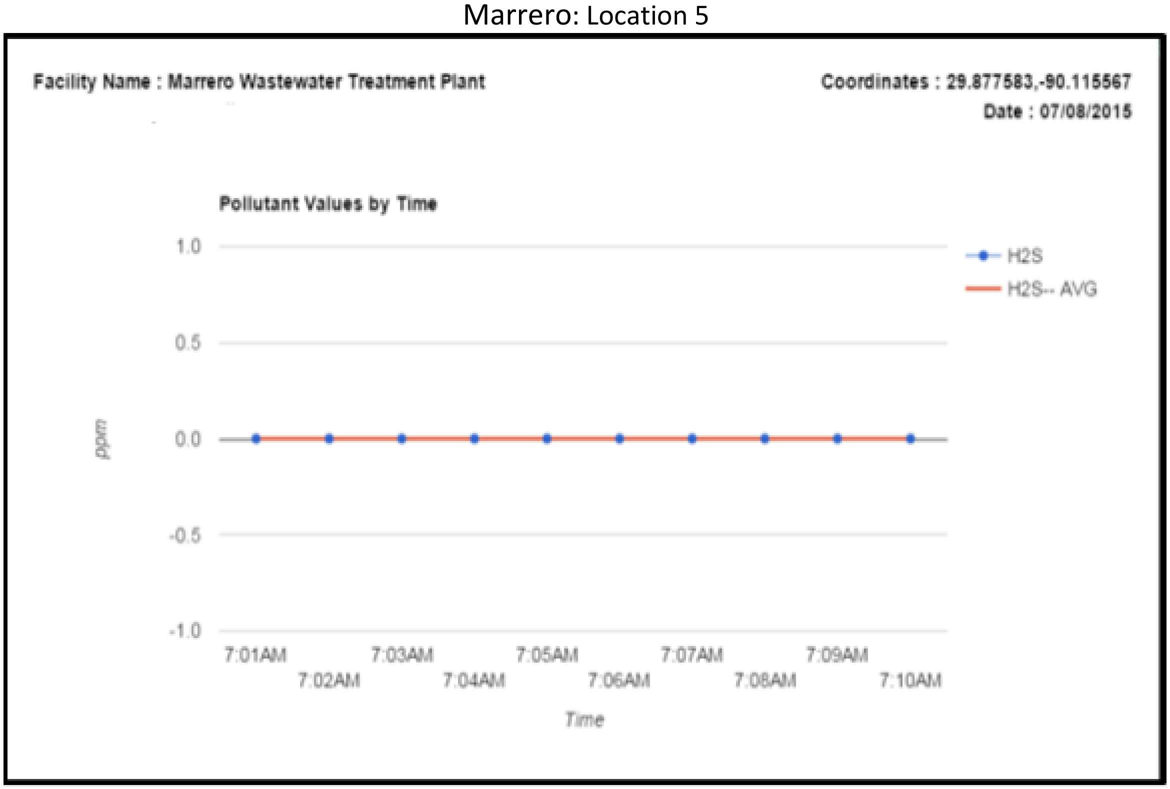

Figure A 17: Variation in concentration of H_2S over a period at location5

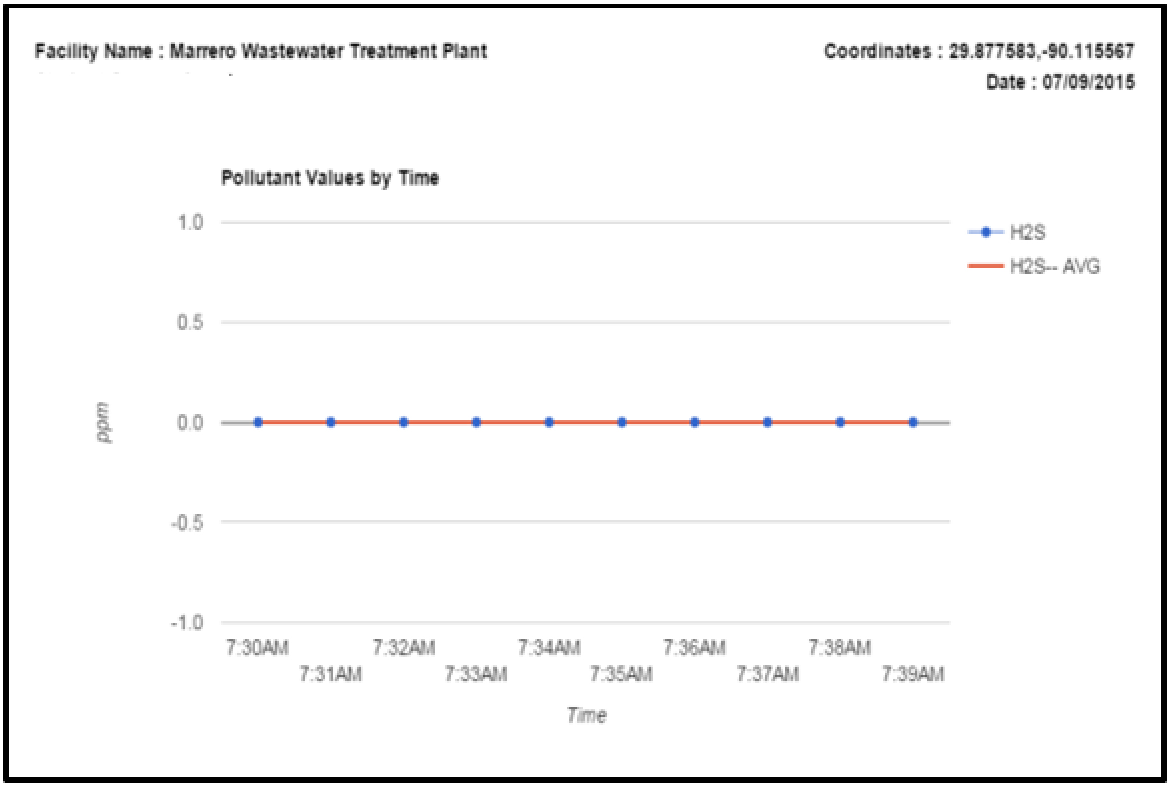

Figure A 18: Variation in concentration of H_2S over a period at location5

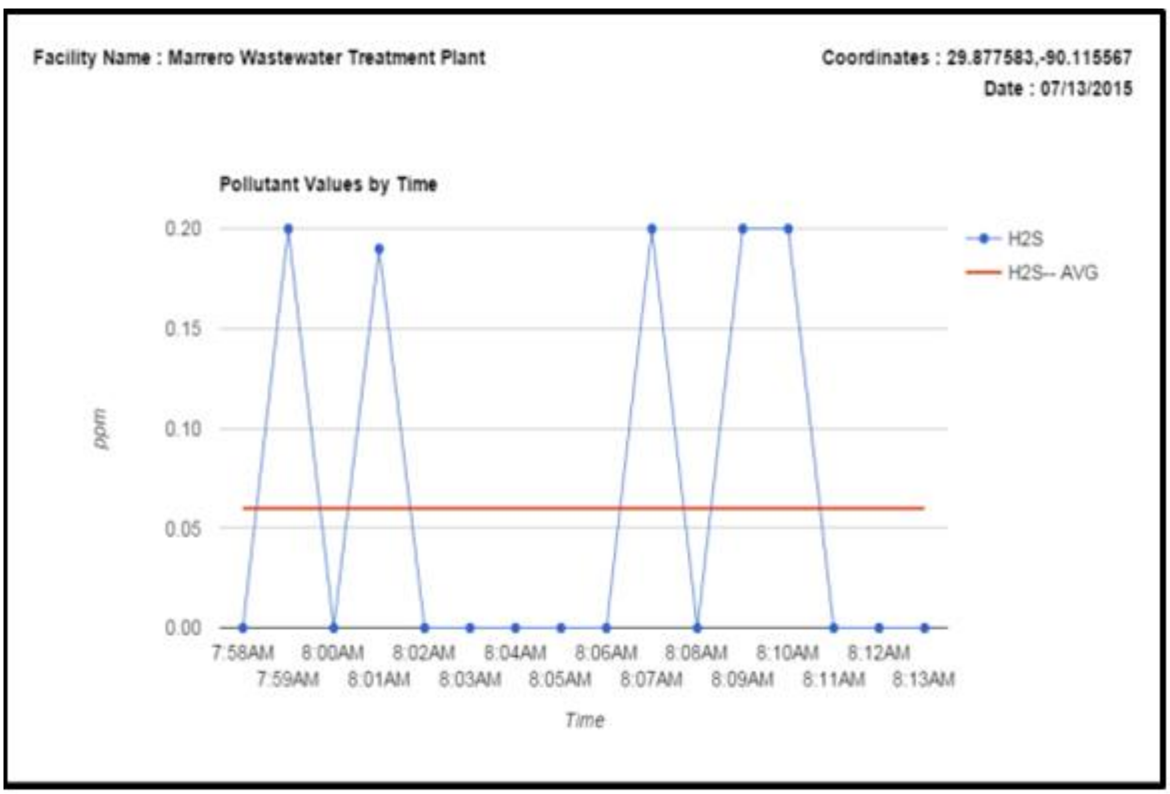

Figure A 19: Variation in concentration of H_2S over a period at location5

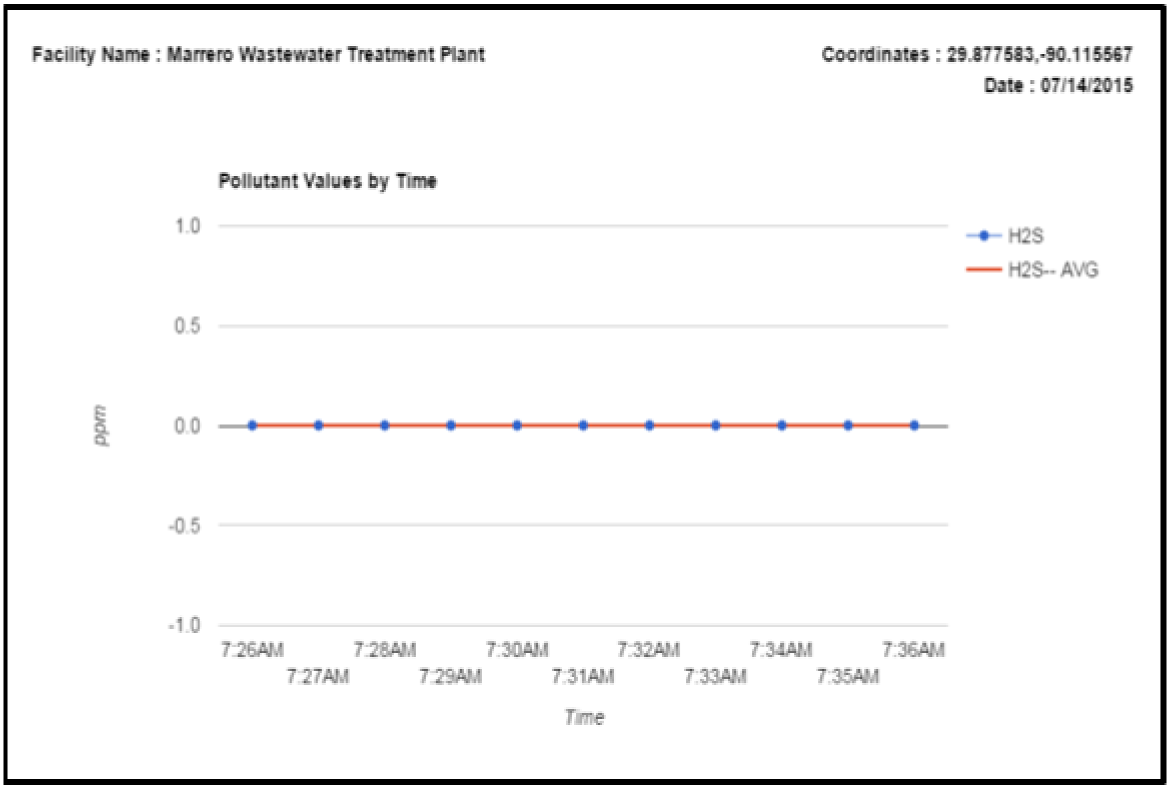

Figure A 20: Variation in concentration of H_2S over a period at location5

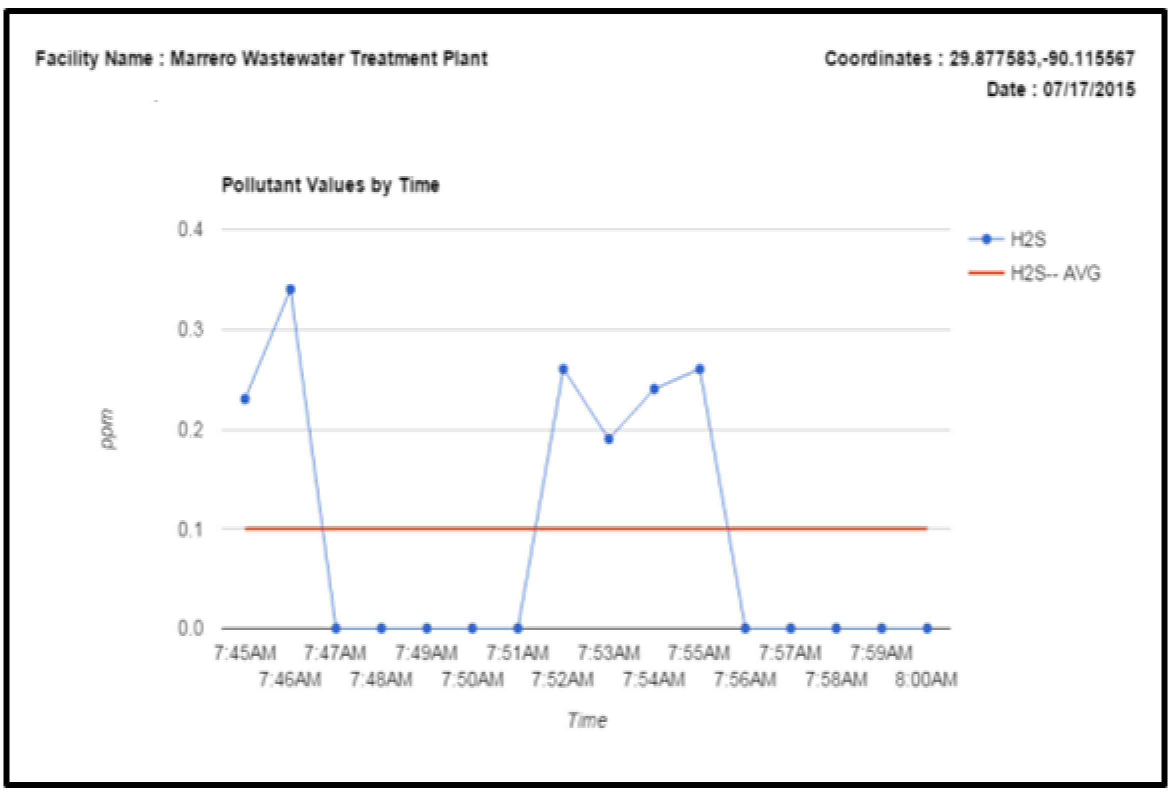

Figure A 21: Variation in concentration of H_2S over a period at location5

Marrero: Location 6

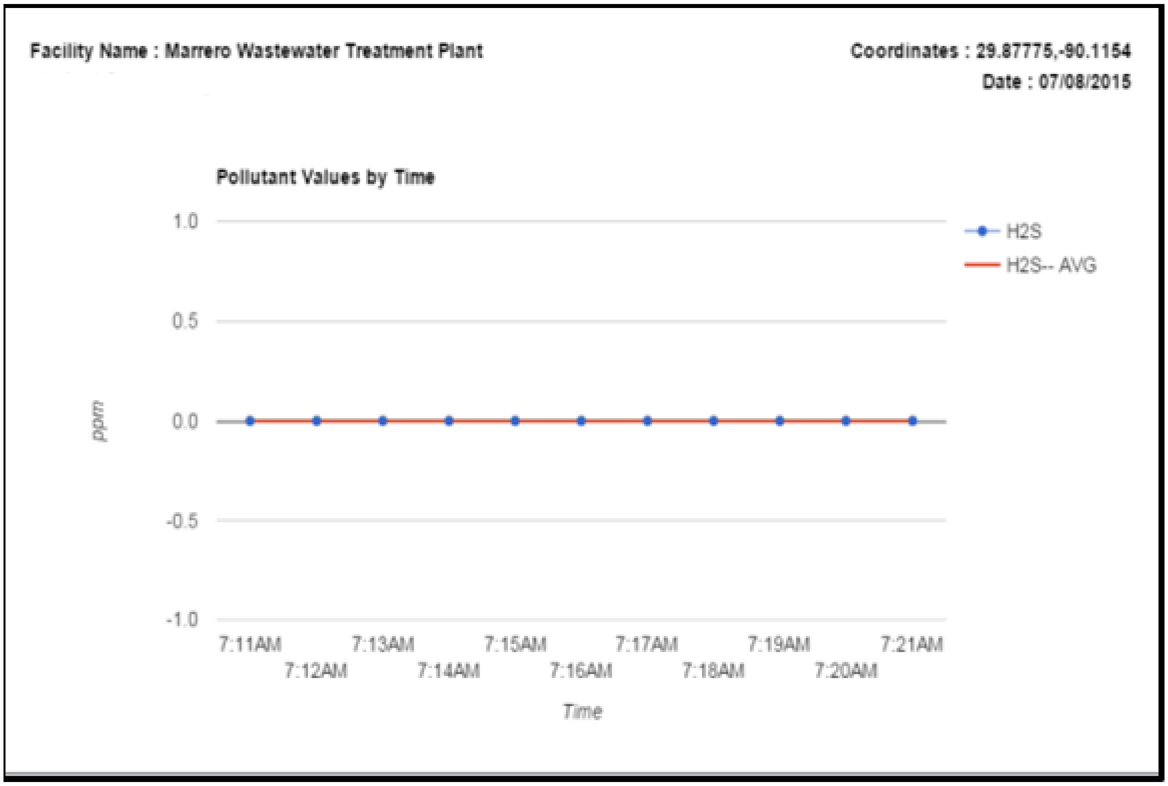

Figure A 22: Variation in concentration of H_2S over a period at location6

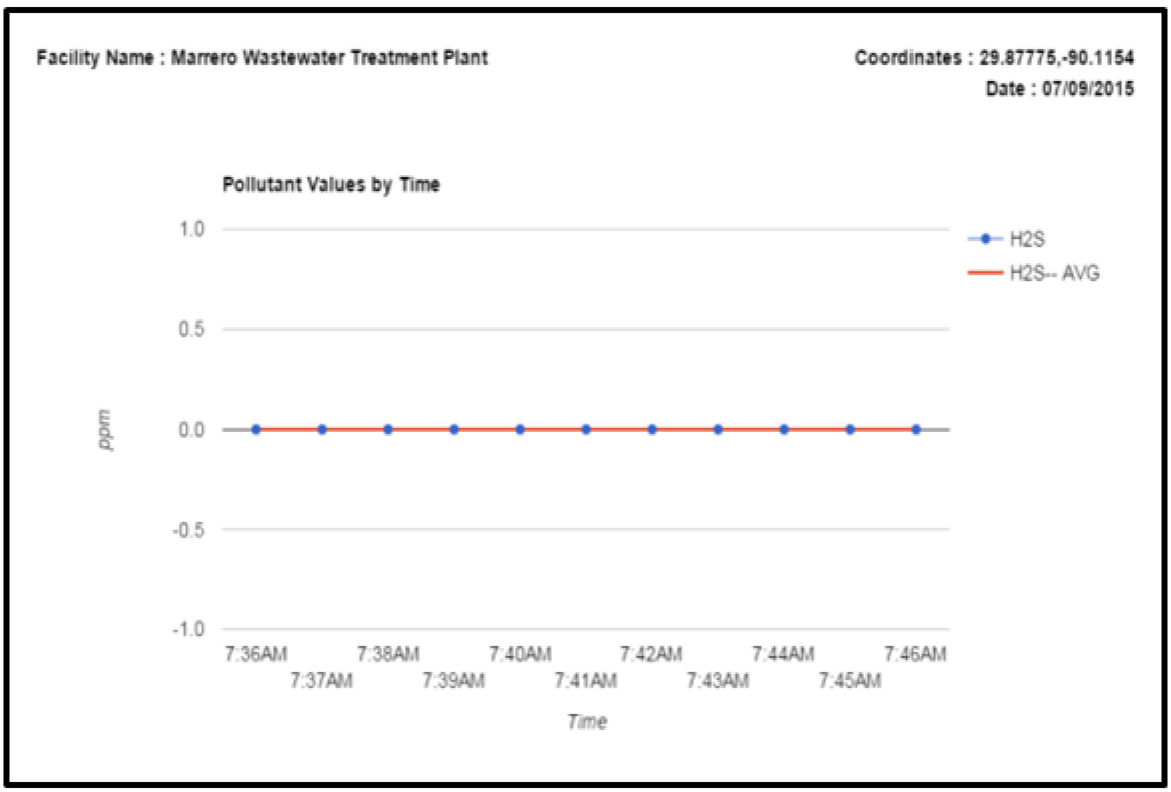

Figure A 23: Variation in concentration of H_2S over a period at location6

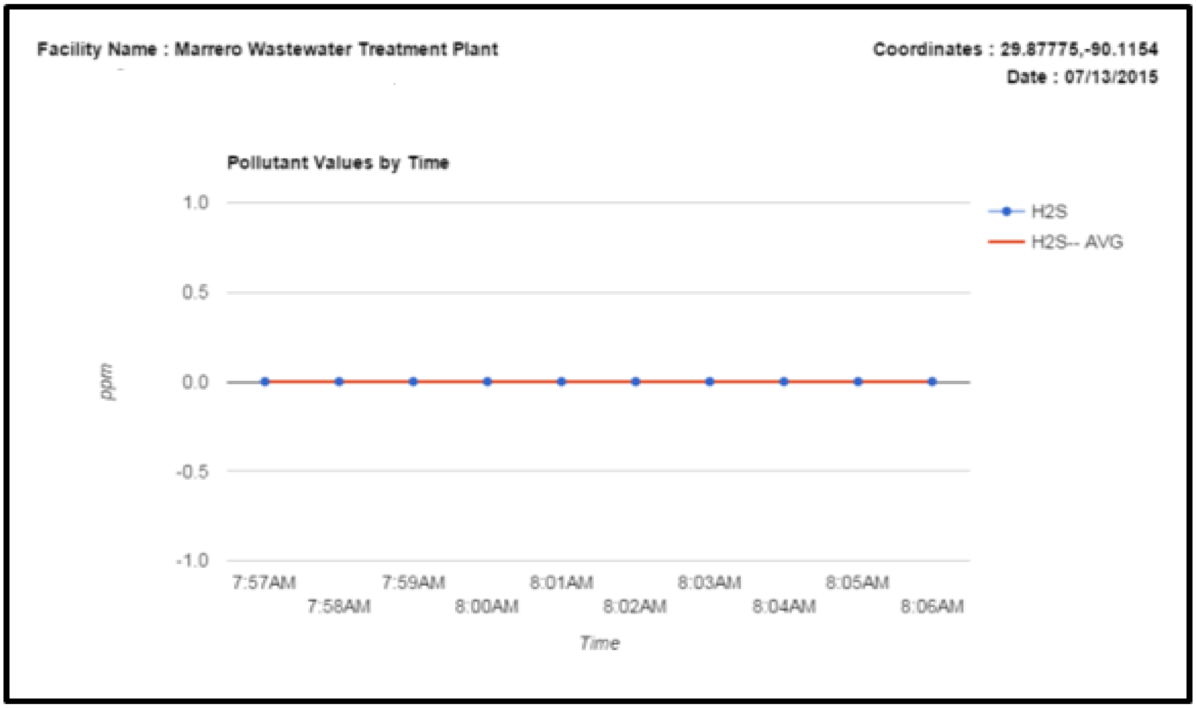

Figure A 24: Variation in concentration of H_2S over a period at location6

Harvey: Location 1

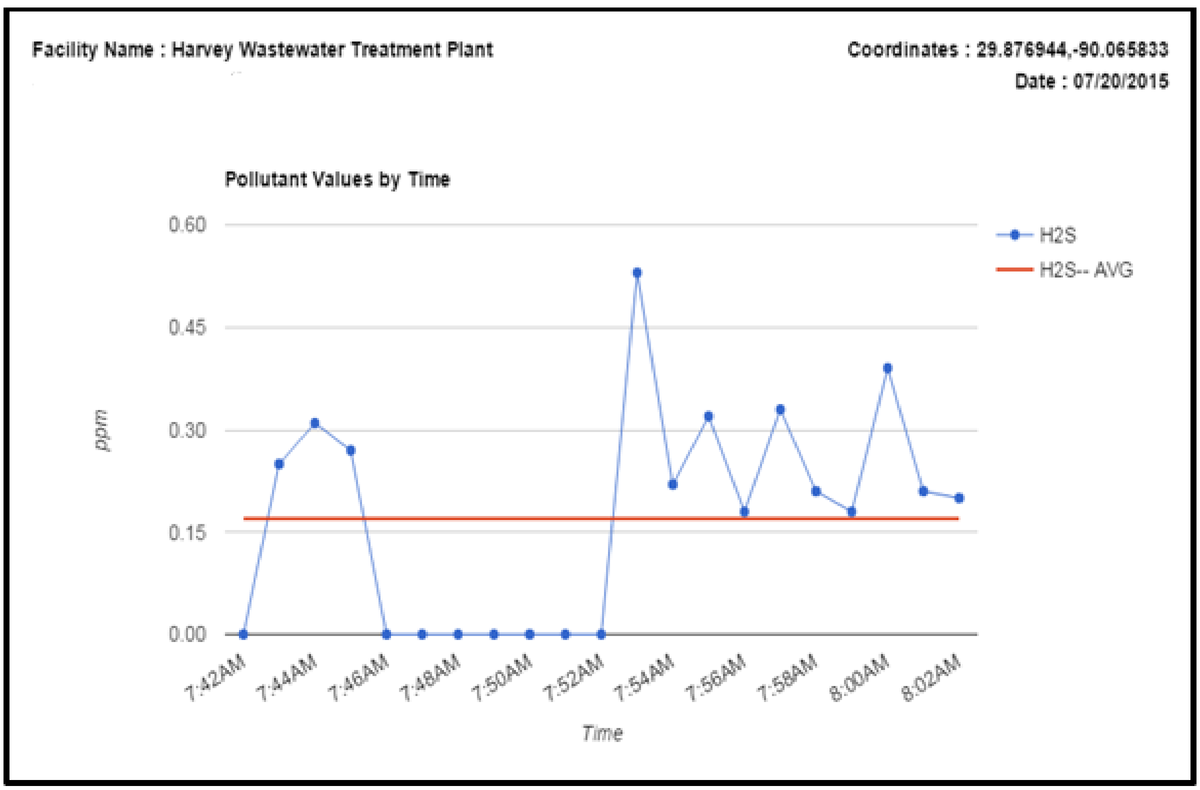

Figure A 25: Variation in concentration of H_2S over a period at location1

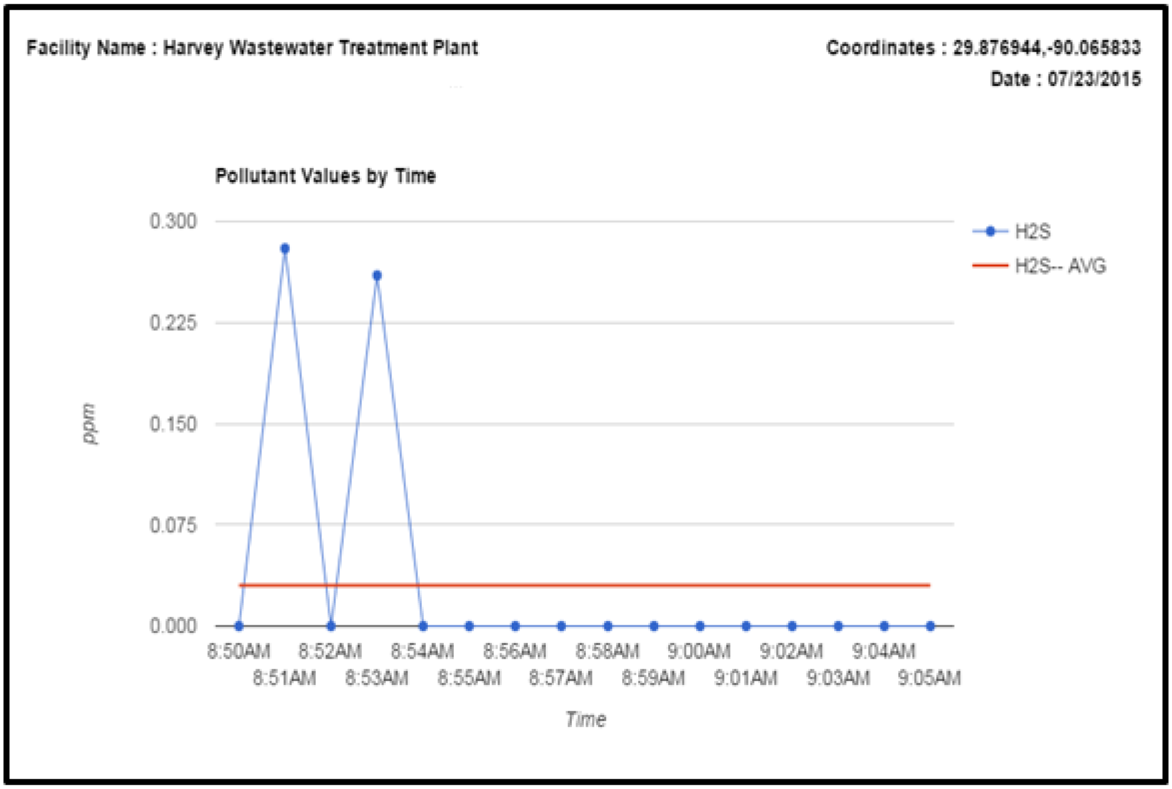

Figure A 26: Variation in concentration of H_2S over a period at location1

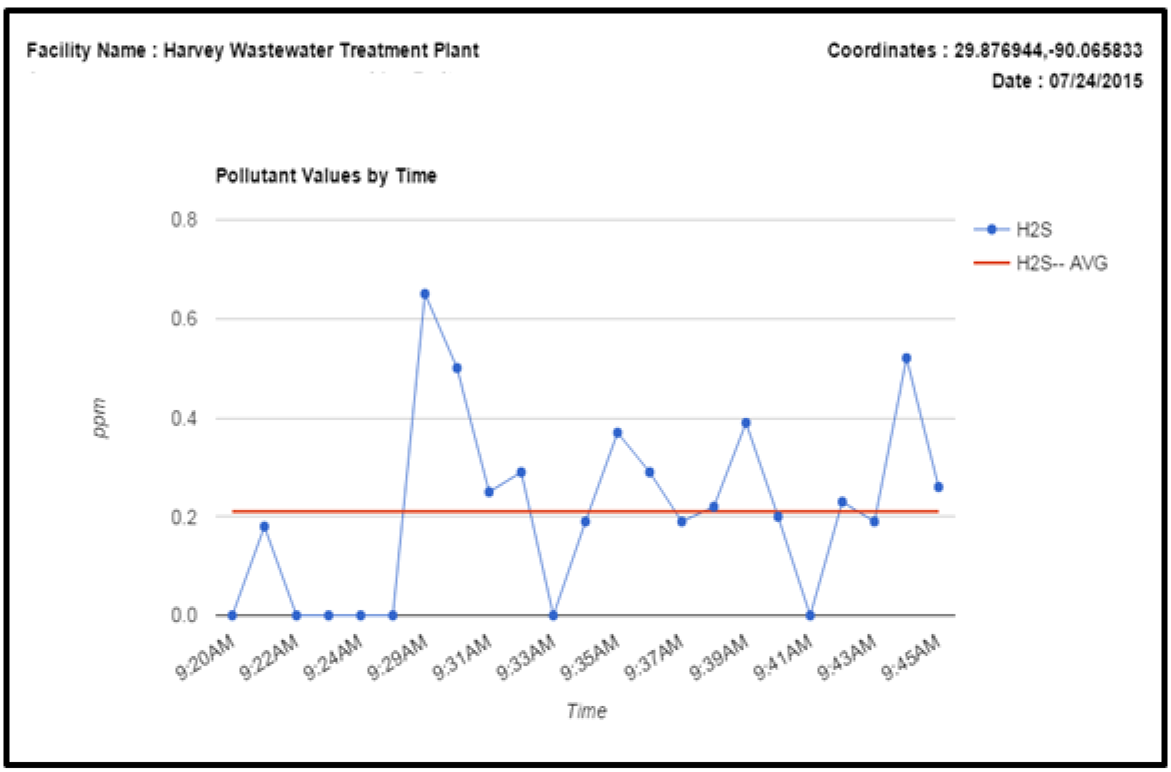

Figure A 27: Variation in concentration of H_2S over a period at location1

Harvey: Location 2

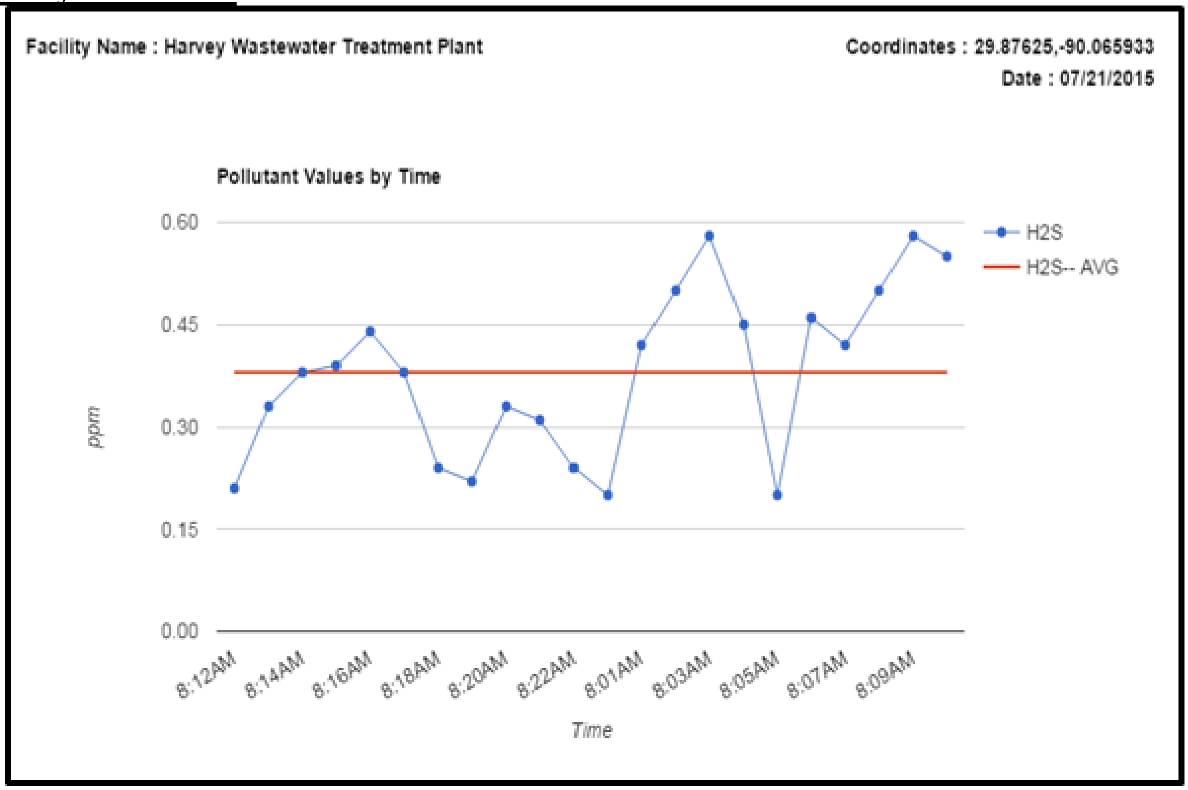

Figure A 28: Variation in concentration of H_2S over a period at location2

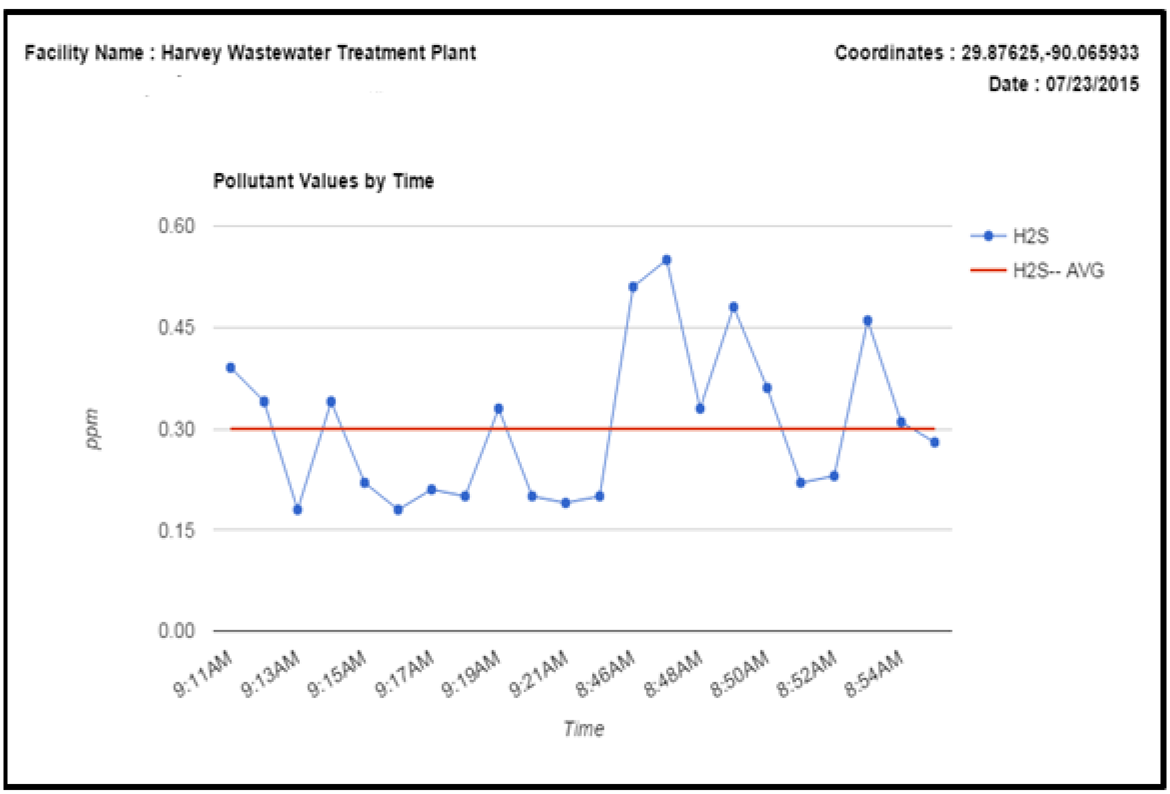

Figure A 29: Variation in concentration of H_2S over a period at location2

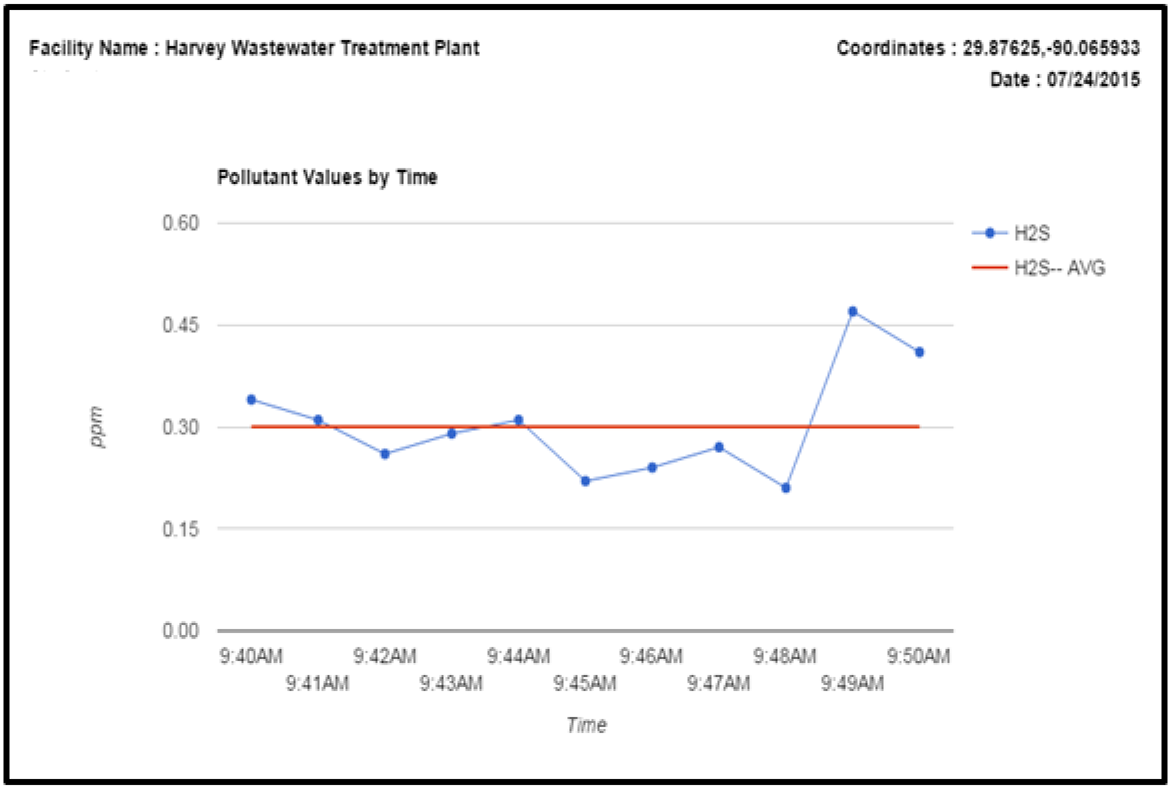

Figure A 30: Variation in concentration of H_2S over a period at location2

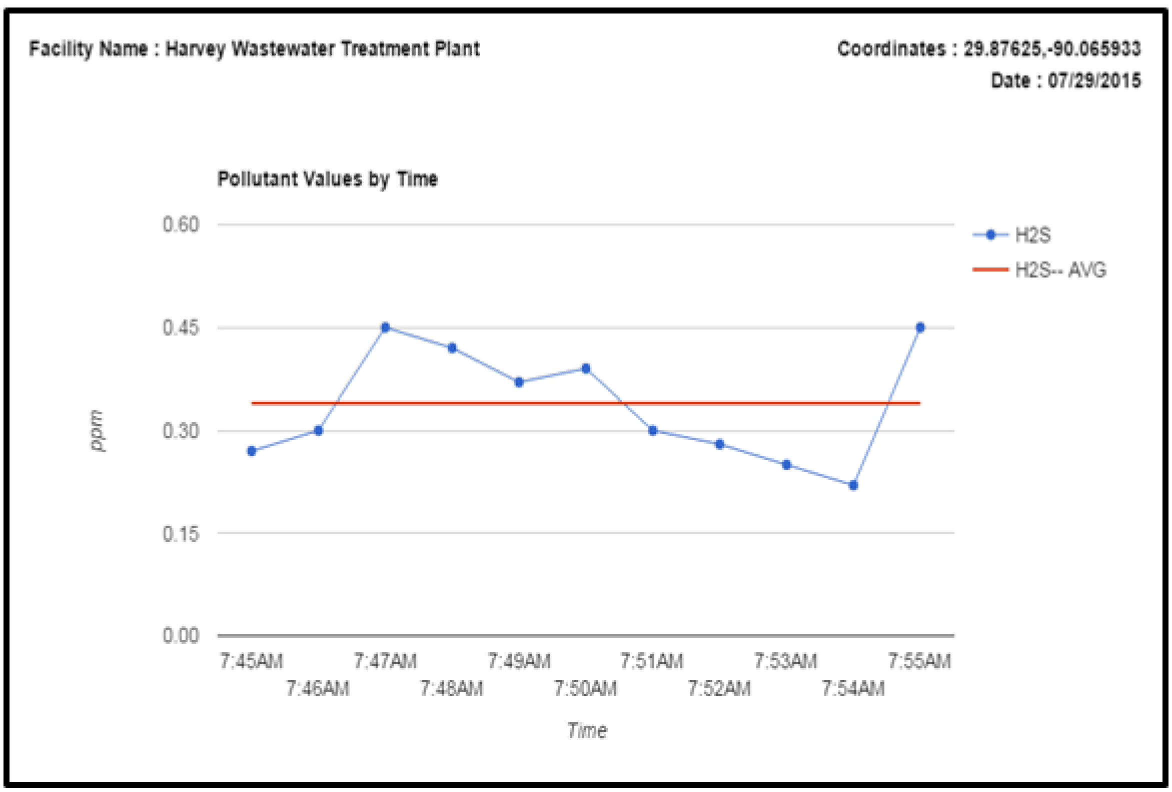

Figure A 31: Variation in concentration of H_2S over a period at location2

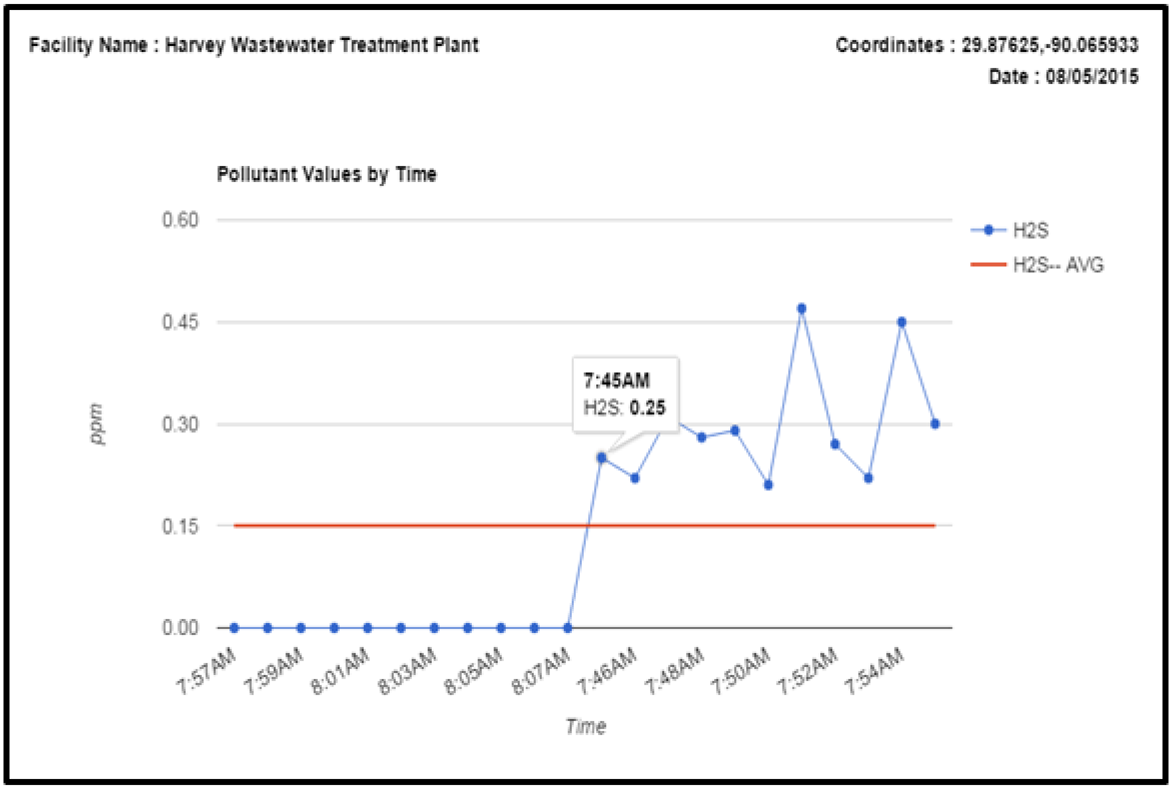

Figure A 32: Variation in concentration of H_2S over a period at location2

Harvey: Location 3

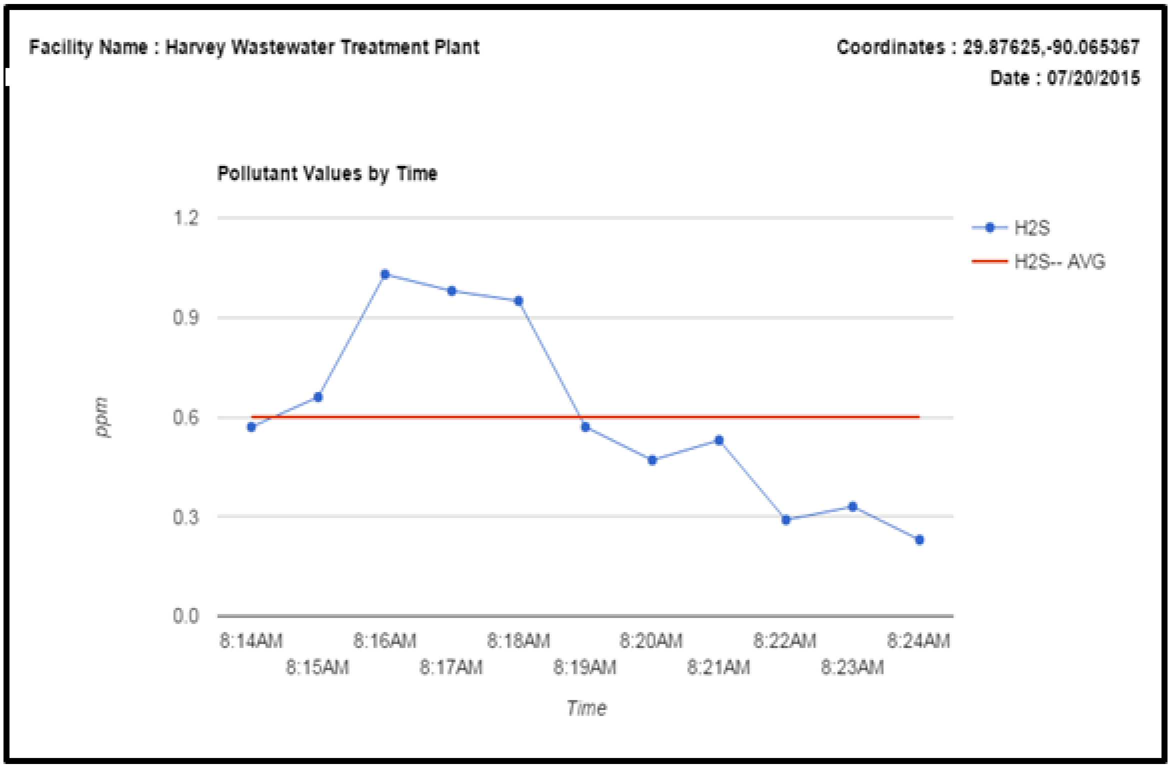

Figure A 33: Variation in concentration of H_2S over a period at location3

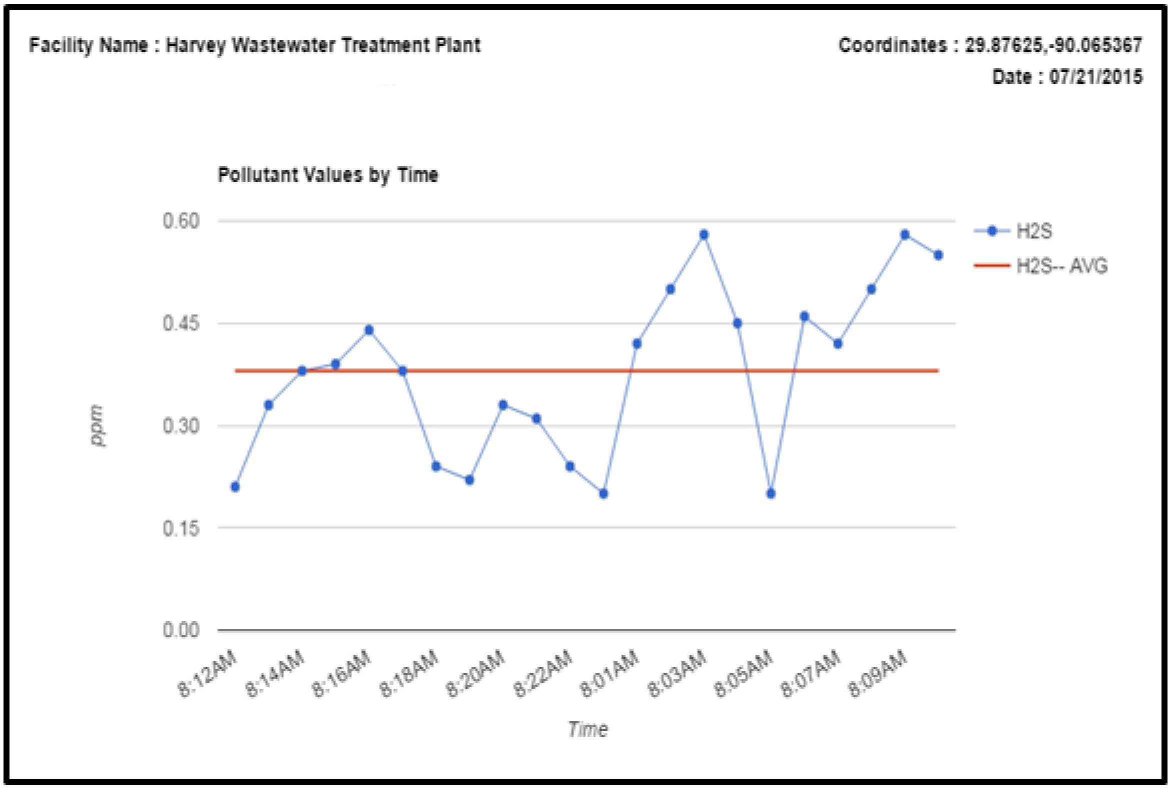

Figure A 34: Variation in concentration of H_2S over a period at location3

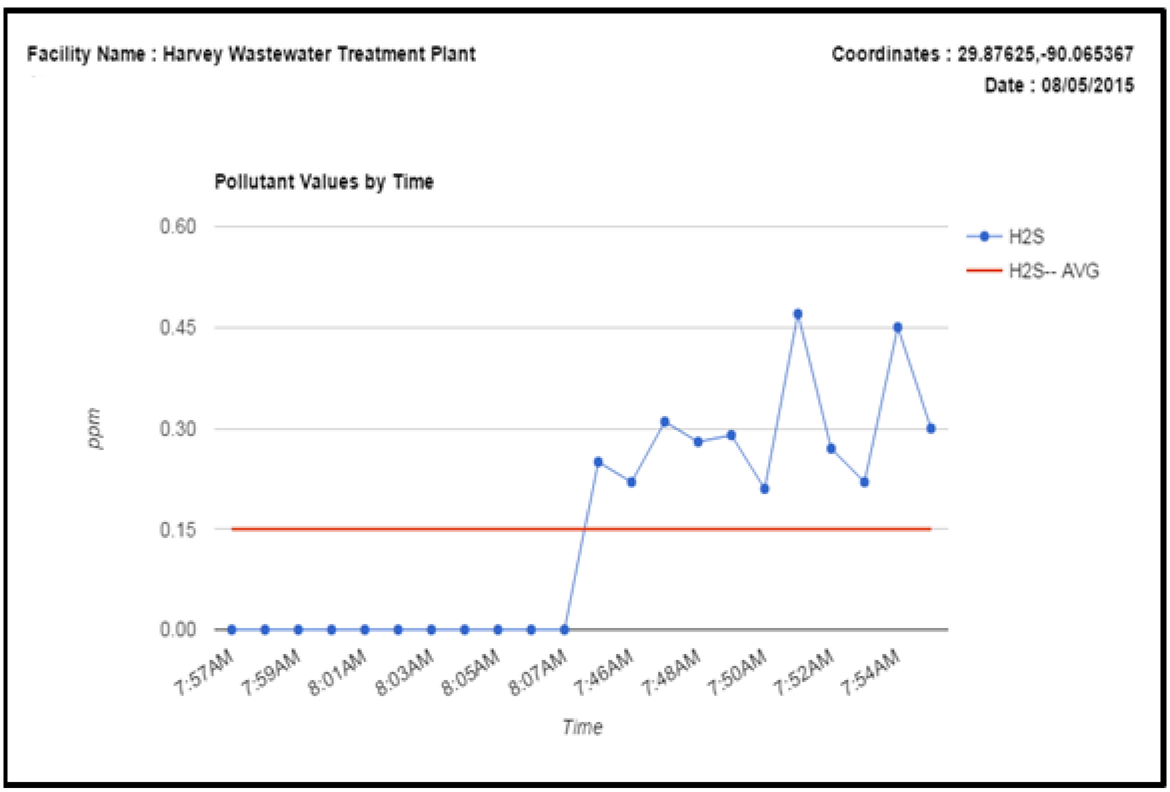

Figure A 35: Variation in concentration of H_2S over a period at location3

Harvey: Location 4

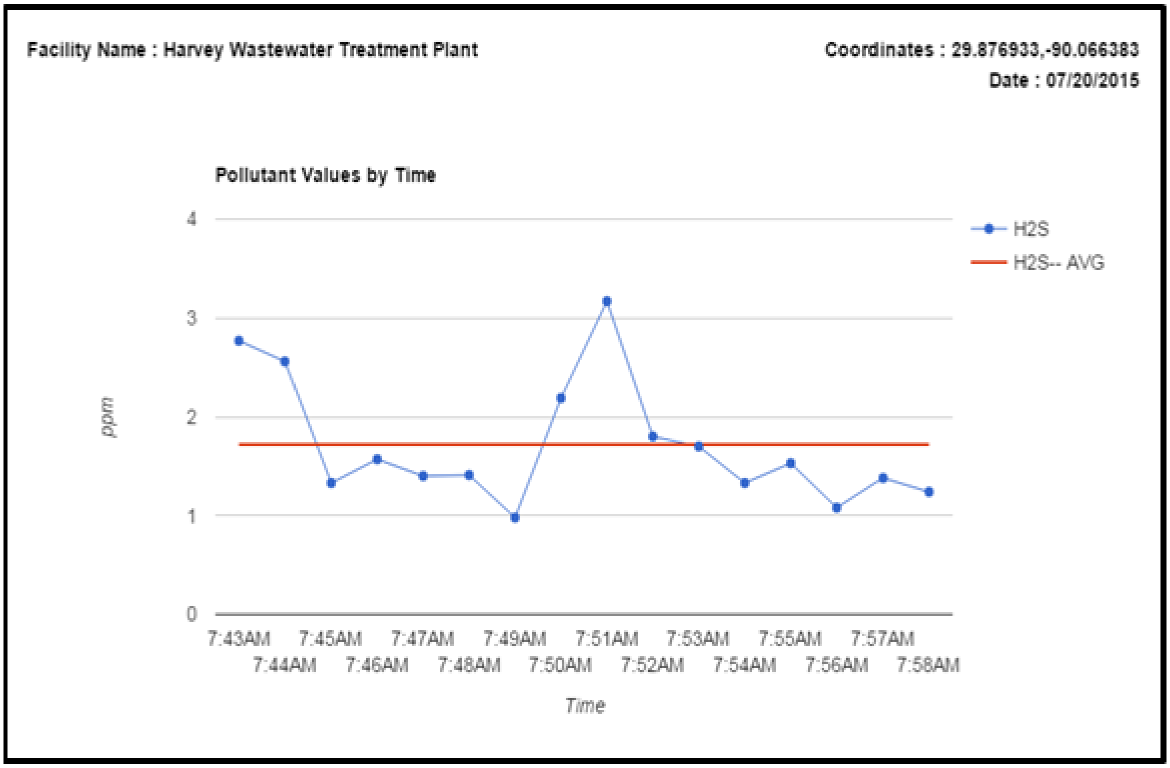

Figure A 36: Variation in concentration of H_2S over a period at location4

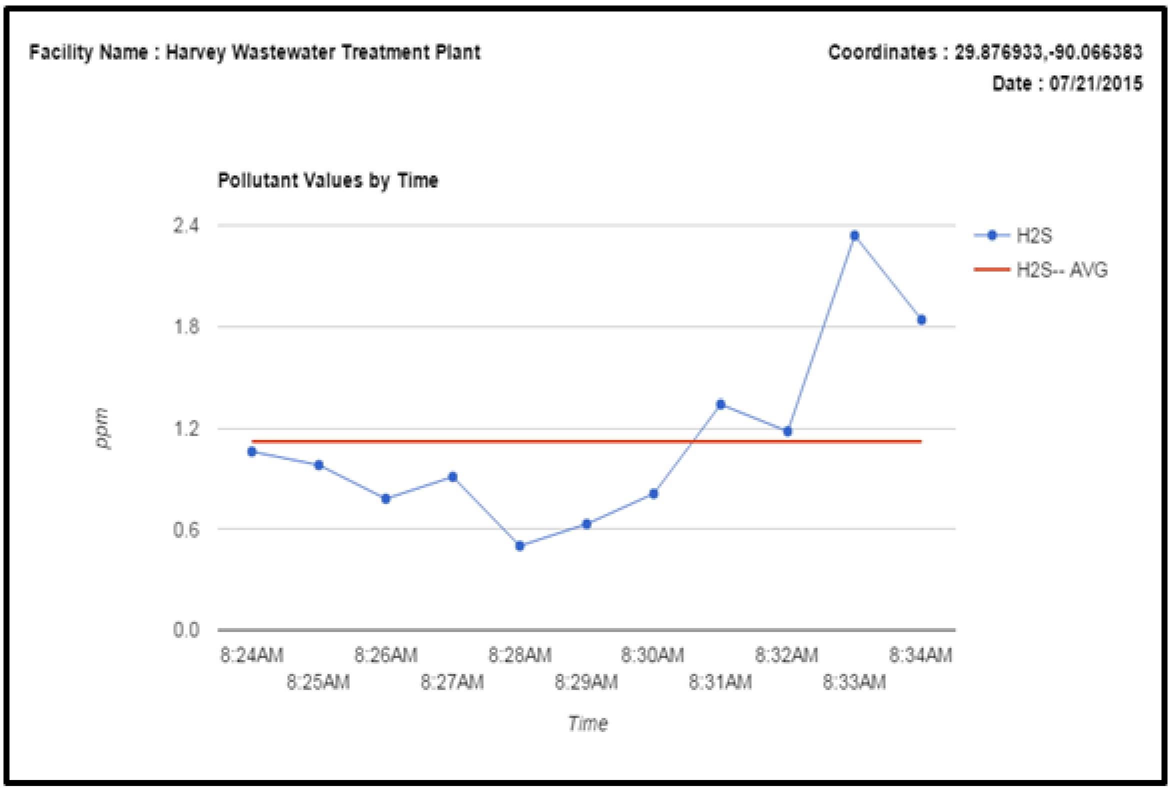

Figure A 37: Variation in concentration of H_2S over a period at location4

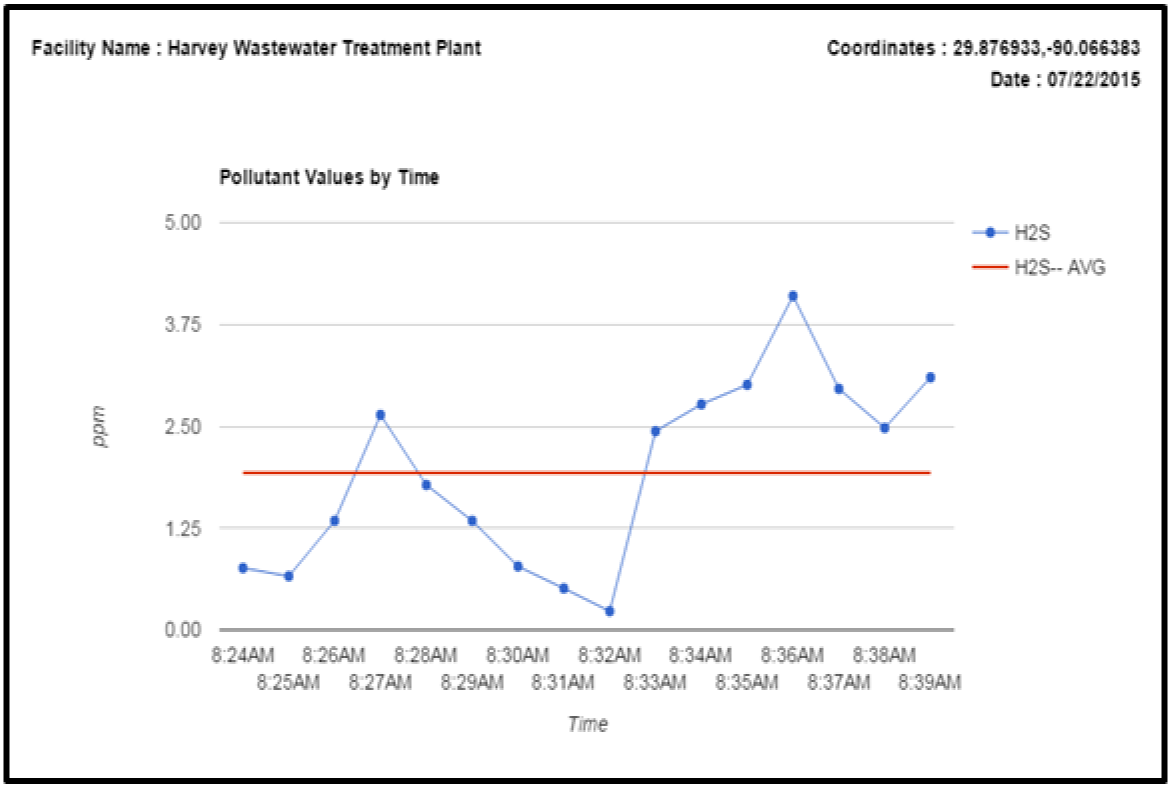

Figure A 38: Variation in concentration of H_2S over a period at location4

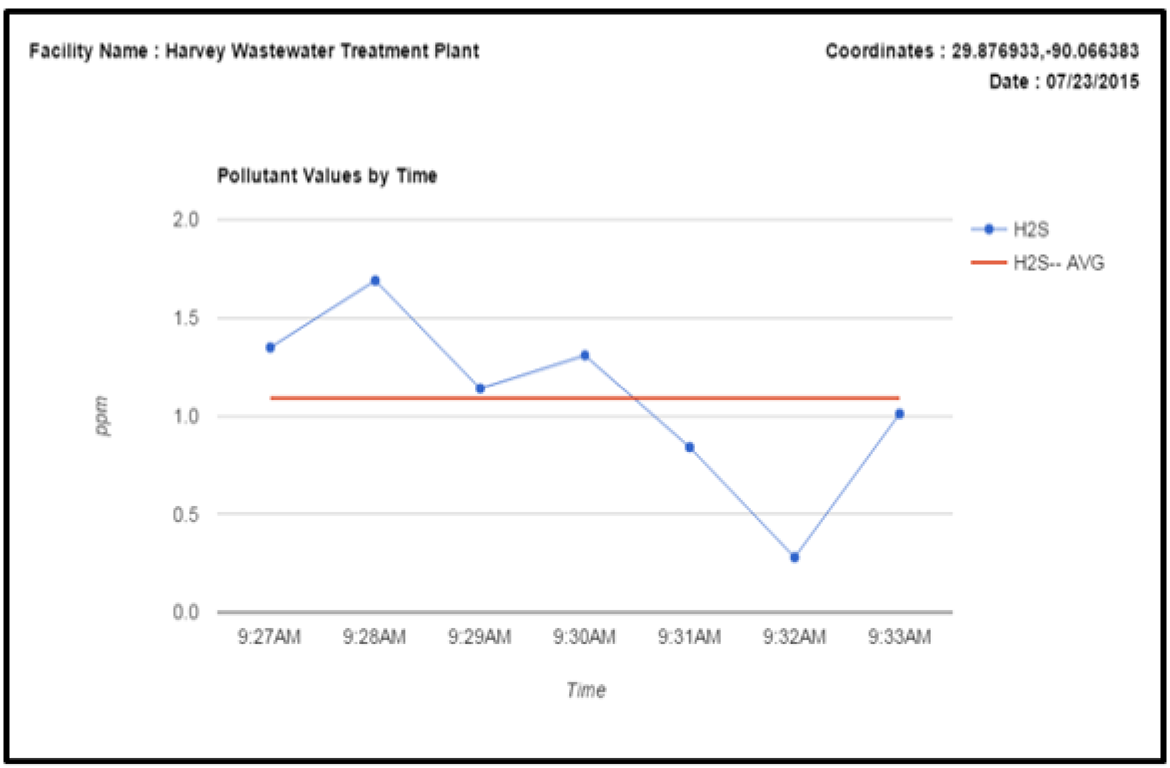

Figure A 39: Variation in concentration of H_2S over a period at location4

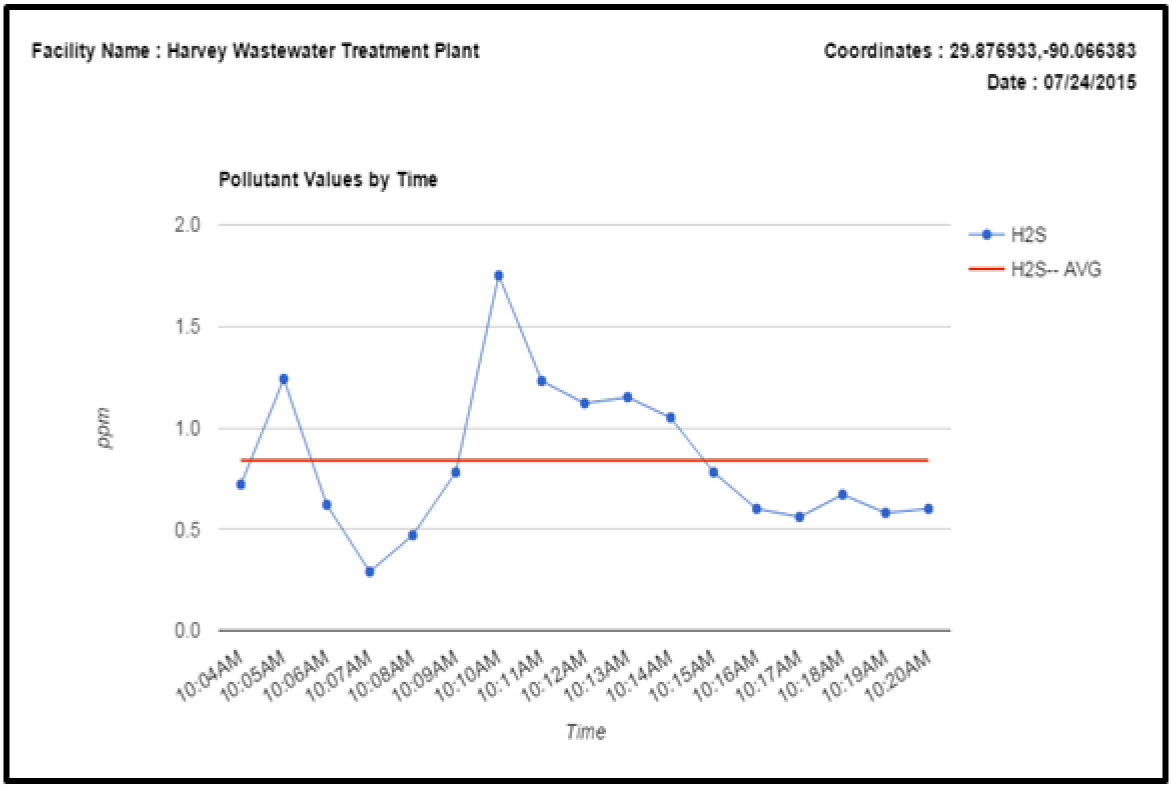

Figure A 40: Variation in concentration of H_2S over a period at location4

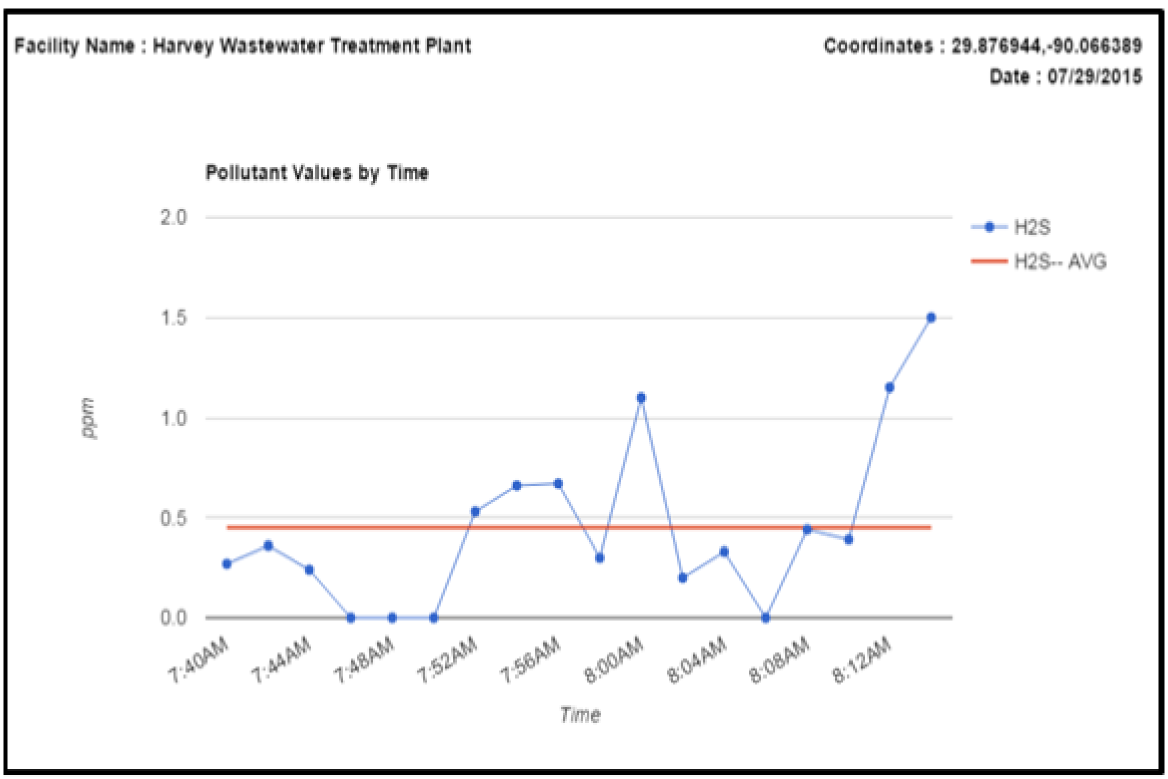

Figure A 41: Variation in concentration of H_2S over a period at location4

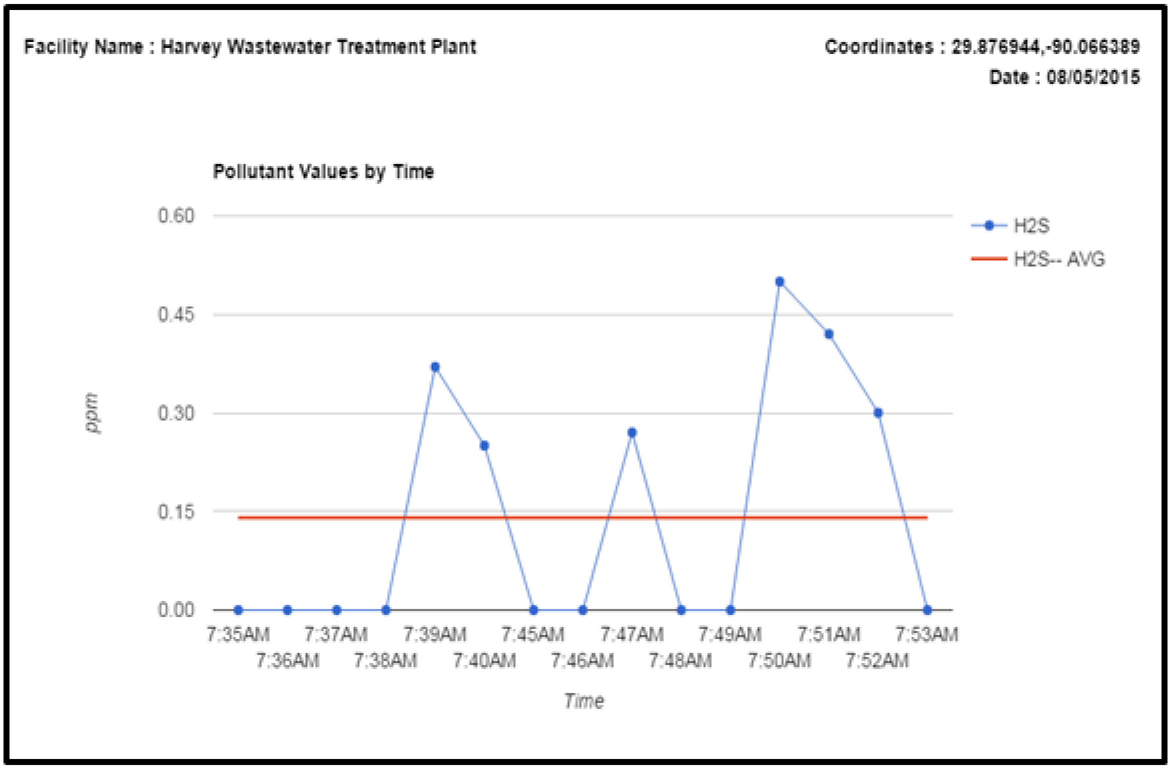

Figure A 42: Variation in concentration of H_2S over a period at location4

Harvey: Location 5

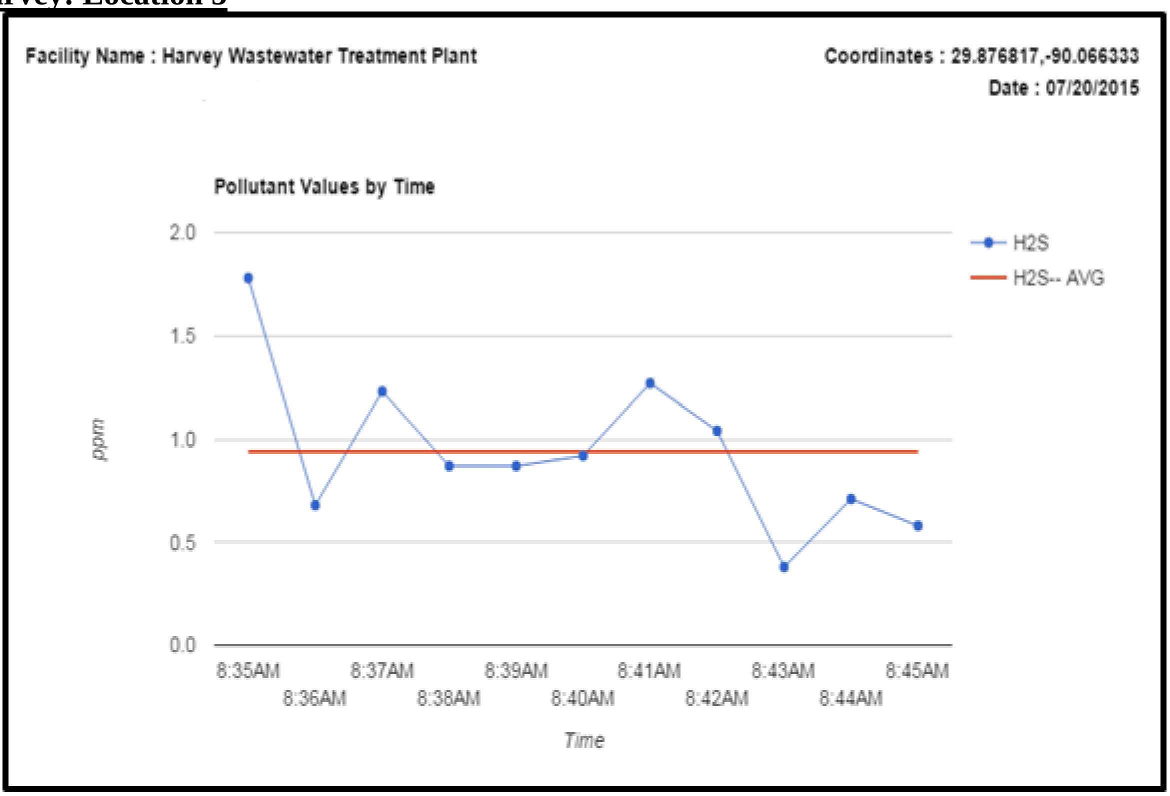

Figure A 43: Variation in concentration of H_2S over a period at location5

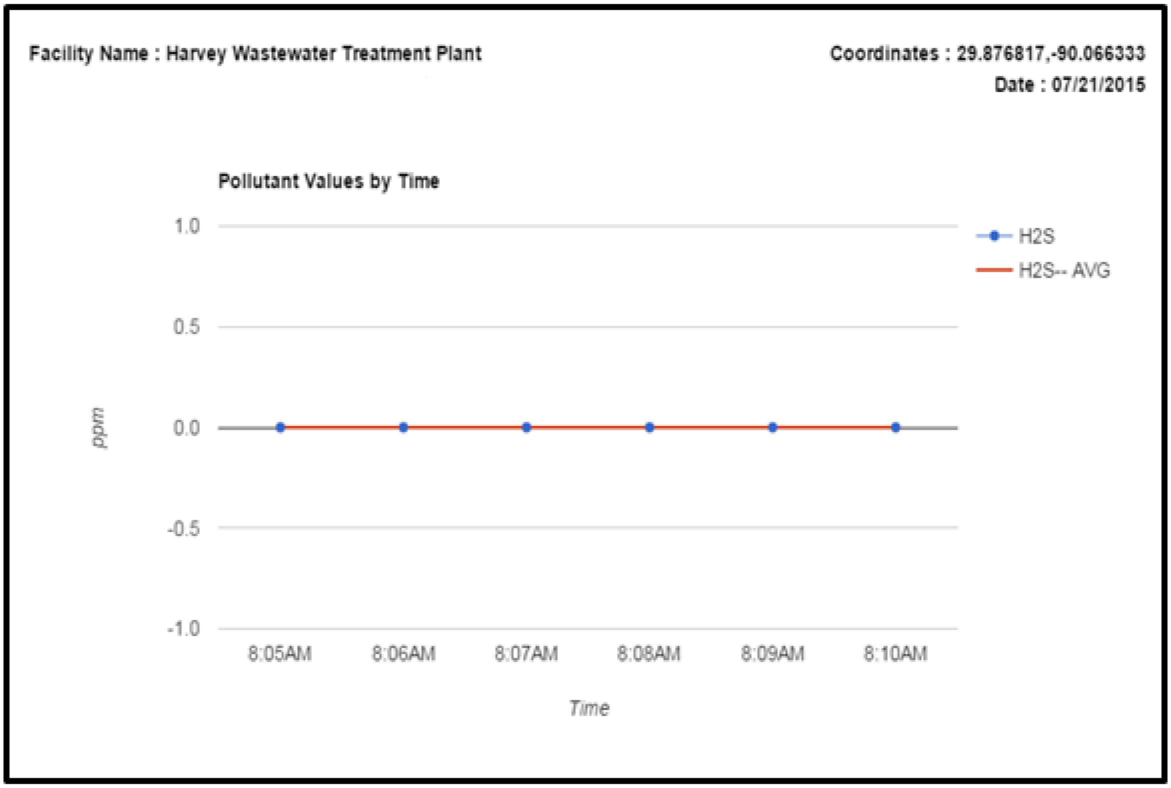

Figure A 44: Variation in concentration of H_2S over a period at location5

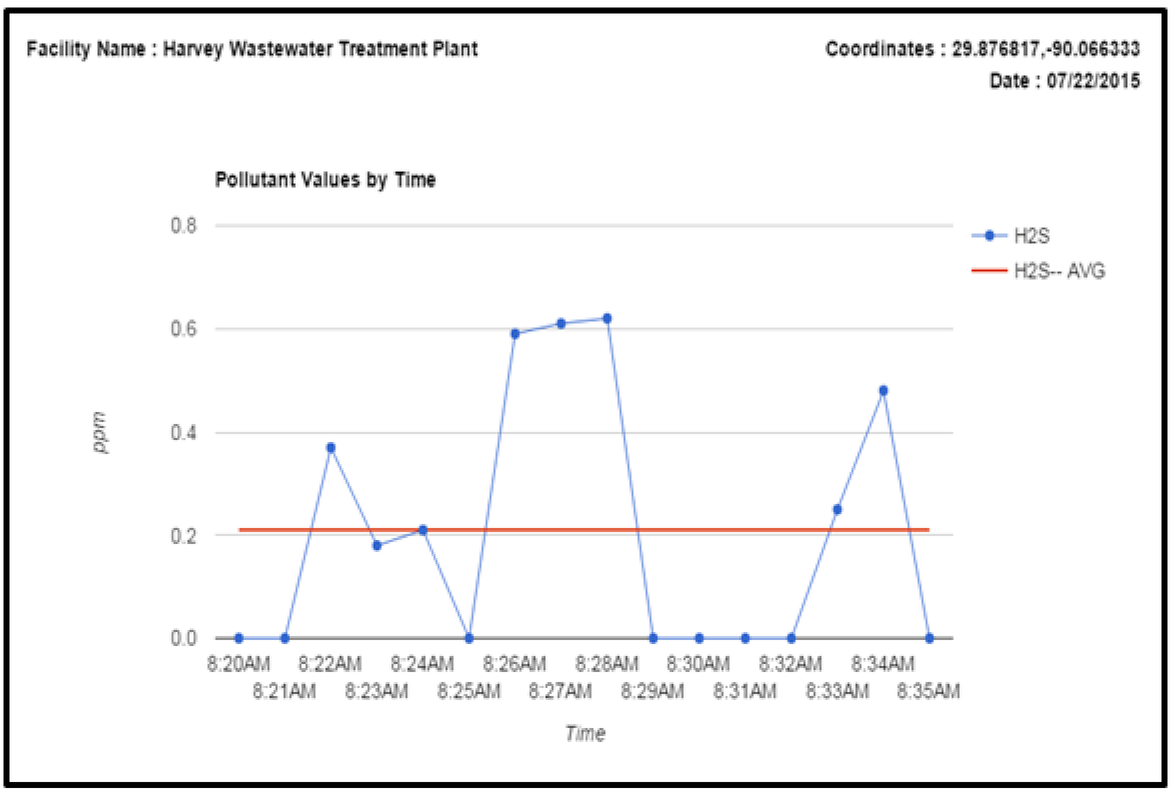

Figure A 45: Variation in concentration of H_2S over a period at location5

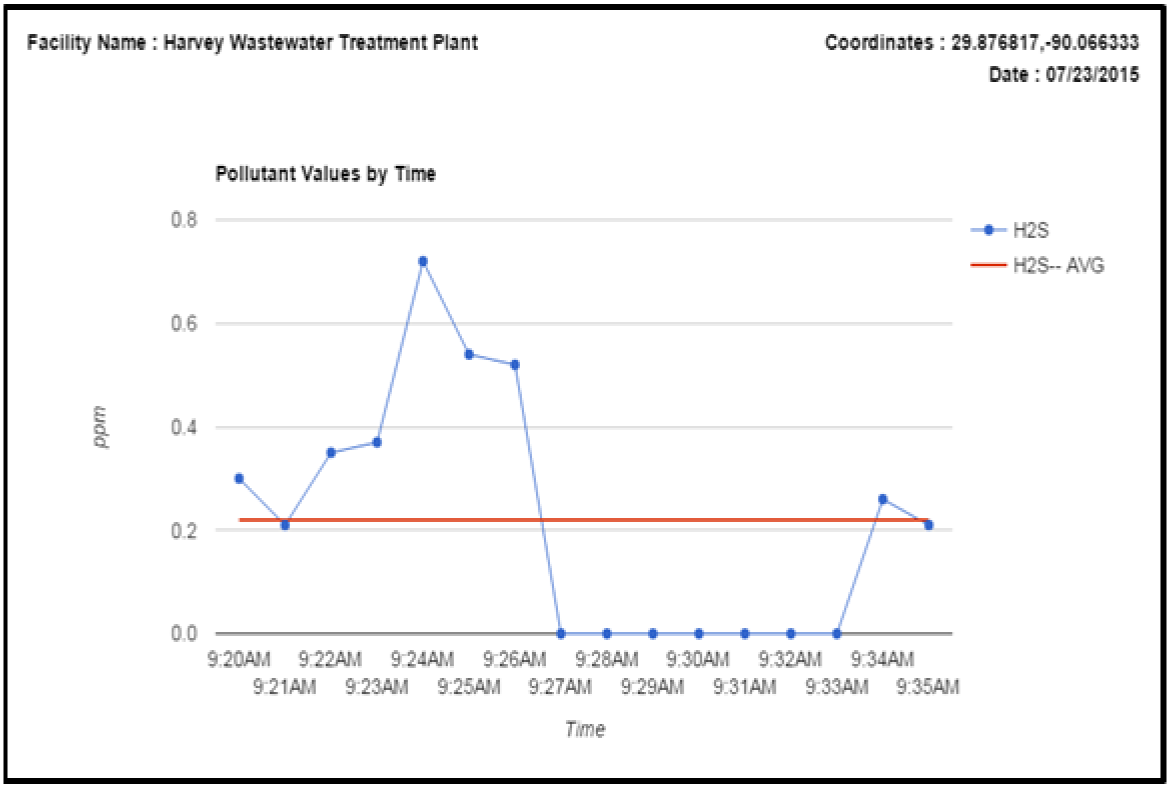

Figure A 46: Variation in concentration of H_2S over a period at location6

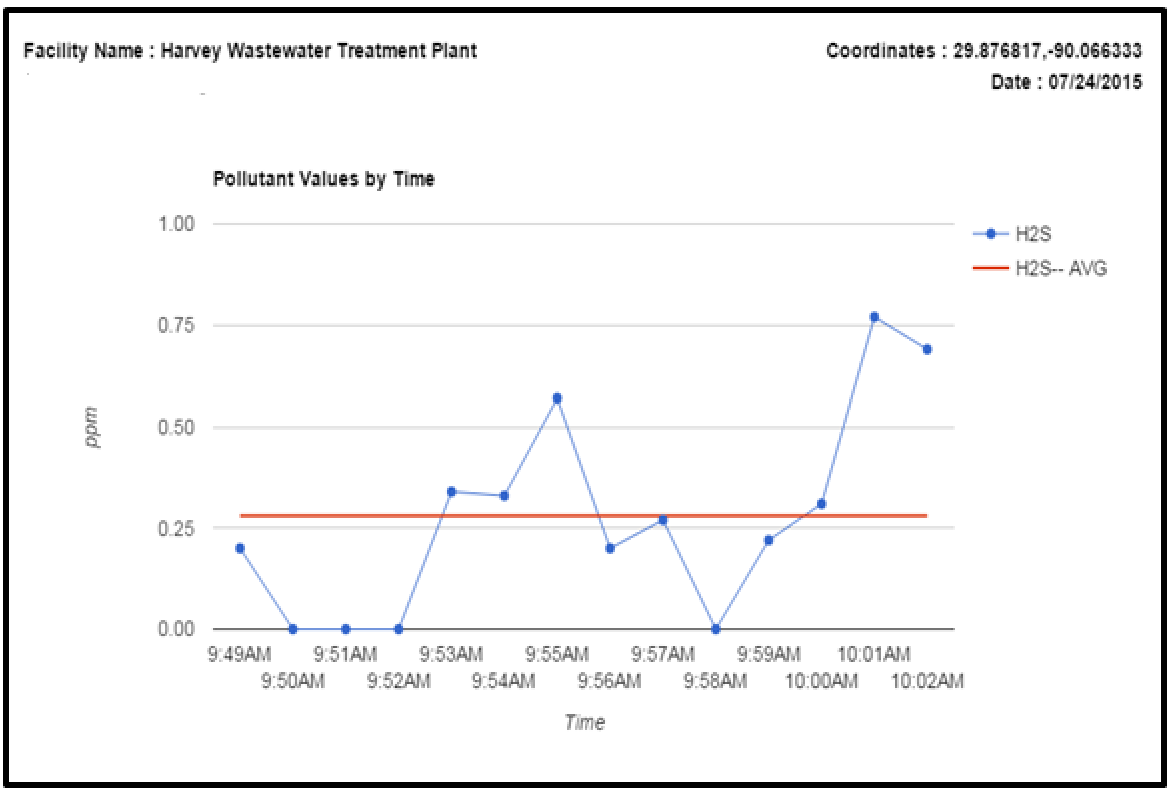

Figure A 47: Variation in concentration of H_2S over a period at location6

Vita

Poojitha Aleti was born in Hyderabad, India. She obtained her B.E. degree in Civil Engineering from Osmania University, Hyderabad in May 2014. In 2014, she joined University of New Orleans, Louisiana to obtain Master's degree in Civil and Environmental Engineering. She worked as a Graduate Research Assistant in Environmental Engineering (with a focus on Air Quality) under Dr. Bhaskar Kura while pursuing Masters and also interned with the Port of New Orleans in 2015. Her work in Environmental Engineering has been published as four conference papers at 109th Annual Conference & Exhibition of the Air & Waste Management Association in 2016. She has mentored 100 Brazilian students (summer, 2016) and 37 students (summer, 2015) in the Air Quality Monitoring, Modeling and Management research.