Wireless Sensor Node for Real—Time Sulfur Gas Emission Monitoring (Taal GEM)

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ABSTRACT

Disasters are life-threatening, sudden events triggered by environmental causes that injure people and damage property. Earthquakes, typhoons, floods, and volcanic eruptions all incur anywhere, often without warning. People need to be prepared before occurrence of any disaster. Disaster prevention and mitigation are integral to development activities. Through utilization of technology, this can be used to assist human needs in various methods of monitoring different types of parameters leading to preparedness of communities. Taal Volcano had several violent eruptions in the past causing loss of lives. Inside the small Crater Lake within Taal Volcano is a tiny volcanic island that emits sulfur and steam. These also rise from yellow fumaroles on the slopes of Taal Volcano and the cliffs on the interior of the crater. Because of its proximity to populated areas and its eruptive history, the volcano was labeled a Decade Volcano, commendable of close study to avoid forthcoming natural disasters brought by eruption. As an active volcano people should be prepared when eruption occurs to save lives, properties, and to prevent possible casualties. These reasons prompted the researcher to develop a device, “Taal GEM”, a gas emission monitoring device for predicting volcanic activity of Taal Volcano.The tools in developing and designing the Taal GEM were available gas sensors; data acquisition technology; communication technology; and environmental constraints. Furthermore, data was deployed to an online system and integrated a Decision Support System Platform via Global System for mobile communication. Performance system testing of the project using efficiency and safety requirements was done. Specifically the design and development of Gas Emission Monitoring Device made use of 2SH12-SO_2 sensor module, GSM module responsible for the transmission of data from the device to Online DSS and use non-corrosive and heat-resistant materials in the construction of the device suitable. Taal GEM was tested and proven to be efficient and passed its safety requirements based on safety practices.

Keywords: *gas emission, monitoring device, sensor node, Taal volcano*

1. INTRODUCTION

The Philippines, being oceanic in origin and part of circum—Pacific belt of fire is home to several active volcanoes. There are hundreds of volcanoes in the country, locally, there are twenty-three (23) active volcanoes which are closely monitored by PHILVOCS.

Among the active volcanoes is Taal Volcano, regarded as the second most active volcano in the country situated in the municipality of Talisay and city of Tanauan in Northern Batangas which is part of a chain of volcanoes along the island of Luzon. Based on the history of Taal volcano, one of the sign precursors to eruption is sulfuric odor and acrid fumes (PHILVOCS).

The Taal Volcano Observatory is the government agency mandated to conduct regular monitoring of the Taal volcanic activities. Various monitoring methods such as asseismic monitoring to monitor number of volcanic quakes and tremors, visual observations through live streaming of the crater's activities and monitoring of the main Crater Lake's water level and temperature are done. The agency monitors sulfur emission of Taal Volcano through direct sampling done on irregular basis. The use of correlation spectrometer, a known device capable of measuring sulfur emission in other volcanic sites was found inefficient due to several factors affecting the functions and operation of the device.

Within this project concept, monitoring can be done in a technology- integrated approach. Gas Emission Monitoring device “Taal GEM” will provide automated data collection from the immediate environment. Integration of data acquisition technology will make the data transmission to online decision support system possible. Moreover, sulfur dioxide level of alertness will be indicated in the online monitoring interface. This process will make the data accessible to the online system without any hazard to the user.

Significant Influence of SO_2 on Climate. Global climate change, prior to the 20th century, appears to have been initiated primarily by major changes in volcanic activity. SO_2 is the most voluminous chemically active gas emitted by volcanoes and is oxidized to sulphuric acid normally within the weeks. Trace amounts of SO_2 exert significant influence on climate. All major historic eruptions have formed sulphuric acid aerosols in the lower stratosphere that cooled the earth's surface 0.5°C for typically three years. Large volume of SO_2 erupted frequently appear to overdrive the oxidizing capacity of the atmosphere resulting in very rapid warming. Such warming and associated acid rain become extreme when basalt is erupted in much less than one million years. There are times when volcanic eruptions do not occur for decades to hundred years, the atmosphere can oxidize all pollutants, leading to a very thin atmosphere, global cooling and decadal drought. Prior to the 20th century, increases in atmospheric carbon dioxide (CO_2) followed increases in temperature initiated by changes in SO2. [1]

Electrochemical Sensor. This is used primarily to detect oxygen and toxic gases. Each sensor is designed to be specific to the gas it is intended to detect. Electrochemical sensors are essentially fuel cells composed of noble metal electrodes in an electrolyte. The electrolyte is normally an aqueous solution of strong inorganic acids. When a gas is detected, the cell generates a small current proportional to the concentration of the gas. [2]

Gas Sensor Systems for Environmental Monitoring and New Technology. Gas emissions resulting from volcanic eruptions may be monitored using sensors. According to Wilson (2005), a sensor is a device that converts a physical phenomenon into an electrical signal. As such, sensors represent part of the interface between the physical world and the world of electrical devices, such as computers. The other part of its interface is represented by actuators, which convert electrical signals into its physical phenomena. [3]

Data Acquisition Technology. Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software. Compared to traditional measurement systems, PC-based DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement solution. [4]

Global System for Mobile Communication (GSM). This is the most widely used cellular technology in use in the world today as it has. It has been a particularly successful cellular phone technology for a variety of reasons including the ability to roam worldwide with the certainty of being able to operate on GSM networks in exactly the same way - provided billing agreements are in place. GSM system was designed as a second generation (2G) cellular phone technology. One of the basic aims was to provide a system that would enable greater capacity to be achieved than the previous first generation analogue systems. GSM achieved this by using a digital TDMA (time division multiple access approach). By adopting this technique, more users could be accommodated within the available bandwidth. In addition to this, ciphering of the digitally encoded speech was adopted to retain privacy. Using the earlier analogue cellular technologies, it was possible for anyone with a scanner receiver to listen to calls and a number of famous personalities had been "eavesdropped" with embarrassing consequences. [5]

Web-Based Decision Support System. This is a computer-based tool used to support complex decision making. Although this applies very well to decision making in many purely technical areas, it falls short of reflecting one extremely important aspect of the decision making process, that is, the role of human factor.

One of the biggest challenges for DSS in facilitating access to information by a broad spectrum of stakeholders is that available information must directly address their concerns, how information is obtained from and presented, and how the access to the information is managed. Another challenge is associated with enabling nontechnical professionals to obtain answers to their questions, especially in cases where both questions and responses need not be expressed in technical terms. The information presented to non-specialists cannot substitute or hide the facts. This information must contain the same value as far as real consequences of options, but the form of this information should allow the straight forward description of impacts, perils, and benefits in layman terms[6].

Objectives of the Study

The study aimed to design and develop a gas emission monitoring device for predicting volcanic activity of Taal Volcano.

Specifically, the study aimed to (1) design and develop gas emission monitoring device with the following considerations: available gas sensors, data acquisition technology, communication technology, and environmental constraints; (2) implement the system in a controlled environment and integrate a Decision Support System Platform via Global System for Mobile communication; (3) perform system testing of the project using the following parameters: efficiency and safety requirements.

2. MATERIALS AND METHODS

Pertinent to the gathered information the hardware used and its functional specification were made. This made possible the development of microcontroller—based real—time monitoring system that will assist in the prediction of volcanic activity. Table 1 presents the Taal GEM hardware requirements.

Table 1
Taal GEM's Hardware Requirements

Hardware	Description
Global System for Mobile Communication	Communication medium responsible for the transmission of the collected data to online DSS
Microcontroller (Arduino Uno)	Main component that act as the brain of the proposed monitoring device
GSM Modem	Communication Protocol that is responsible for receiving the collected data from Taal GEM
GSM Antenna	Transmit GSM signal at specified frequency
SO_2 sensor module	Responsible for sensing the quality of sulfur dioxide presence in air in the locale
Solar Panel	Main power source of the device
Battery	Secondary power source of power in absence of solar energy
Charge Controller	Prevents overcharging of the battery from the power drawn from the solar panel

The study aims to continuously monitor the air quality of the specified location. Sulfur dioxide sensor will be used as it is the principal gas emitted by the volcano prior to eruption. Continuous sending of the collected data from the sensors to the remote online system Decision Support System will ensure the regular periodic monitoring in the vicinity of Taal volcano. Background information like previous volcanic activity before the actual, present monitoring procedure which will provide accurate and circumstantial information's are necessary to completely understand the design of Taal GEM. Project realization will undergo the process of planning and conceptualizing, designing, canvasing, purchasing, assembly, coding, testing and debugging.

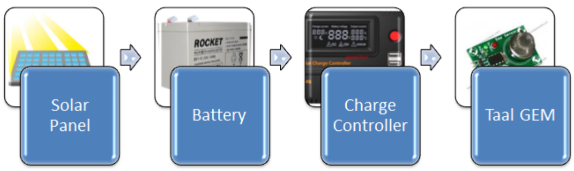

Figure1. Solar Power System Architecture

Figure 1 shows the Taal GEM solar power system architecture indicating the devices and components that complete the operation used by the researcher. Solar panel is used to generate electricity from sunlight since the device will be deployed to the main crater where there is no commercial supply of electricity. The energy from the sun will be stored on the 12V-DC battery as the source of power during night time. Charge controller protects the battery from over charging from the solar panel, over discharging, overload, short circuit, and reverse polarity connection problem. Taal GEM which is the load of the circuit is connected to the charge controller to attain the required voltage 5V for the Taal GEM circuit.

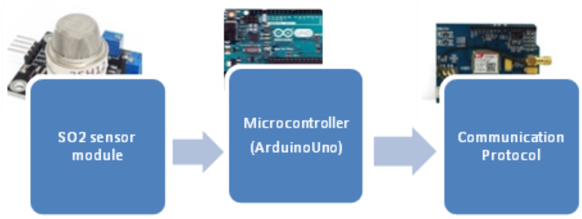

Figure 2. Taal GEM Sensor Node Architecture

Illustrated in Figure 2 is the sensor node architecture. SO2 gas sensors commonly have an output of analog signals; This will be interfaced and read by a microcontroller Arduino Uno with built—in Analog to Digital Converter. This feature is very useful to the project since it converts analog input from the sensors to digital signals needed for the transmission of sense value to the remote online system.

From the remote online system, transmission of data values is possible by the incorporation of GSM module in the MCU. The MCU, GSM shield allows its board to connect to the internet, send and receive SMS using the GSM library. Subscription to a mobile network, GSM Shield and a SIM card either prepaid or postpaid will allow the access to the network. SIM card contains Taal GEM's SMS recipient mobile number. Periodic monitoring has 5 schemes and can be configured through texting the device. Table 1 shows the periodic configuration's text format of Taal GEM.

Table2.Taal GEM's Configuration Text Format

Text format	Function
"0"	Give the current time sulfur level
".30"	Setting the periodic auto sending to every thirty (30) minutes
"1"	Setting the periodic auto sending to every one (1) hour interval.
"2"	Setting the periodic auto sending to every two (2) hours interval.
No text configuration	Default to every twenty four (24) hours interval of auto sending.

Shown in Table 2 are the Taal GEM's configuration text formats for the device auto sending scheme. The format varies in every 30 minutes, 1 hour, 2 hours, current and the default time interval of every 24 hours.

The GSM modem was also included in the system design. This modem is connected to Online DSS computer which also allows the computer to communicate with the GSM module of Taal GEM. This will be used to send and receive SMS from Taal GEM for data recording.

3. RESULTS AND DISCUSSIONS

Design and Development of GEM Device

The design and development of a gas emission monitoring device was done through the analysis of available gas sensor, data acquisition technology, communication technology, and environmental constraints.

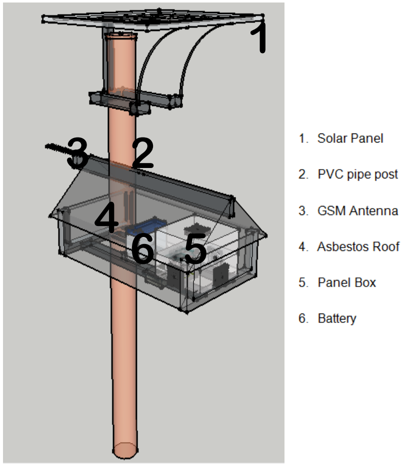

Figure 3. Taal GEM's physical structure

Figure 3 presents the parts of the device and how they are assembled. The device is composed of a solar panel, a PVC pipe post, a GSM antenna, asbestos roof, panel box, and battery. The parts of the device are made of metals, plastics, and other heat resistant materials capable of withstanding sulfur dioxide and high temperature.

Figure 4. The Completed GEM device

Figure 4 shows the actual picture of Taal GEM based on the specified design and materials requirements. The device has a total height and width of 1,805mm x 650mm, respectively. It has a solid and rigid support for the sensors and the solar panel.

Figure 5. SO_2 Sensor

Off-the-shelf gas sensor module capable of detecting the amount of sulfur dioxide gas in the area in threshold form was used in Taal GEM. Among the obtainable choices, the higher nominal range (0-500 PPM) that could detect larger amount of SO_2 gases in the location was chosen. This was interfaced to a microcontroller to further convert the said threshold into parts per million units.

Table3
Sulfur Dioxide Gas Sensor Module Specification

Gas Sensor	Specification
S02 sensor module (2SH12)	Size: 35mm X40mm, a X28mm 1* w *h
	Weight: 15g
	Concentration range: 1 – 500ppm
	Heating voltage: 5 + 0.2V (AC – DC)
	Working current: 150mA
	Looping voltage: DC5V (DC 24V)
	Clean air voltage: <1.5V
	Response time: <1S
	Power consumption: <0.8W
	Working temperature: - 10~50 degrees
	Load resistance: 10K (adjustable)
	Sensitivity: 3%
	Response Time: <1S (pre 3-5 minutes)
	Recovery Time: less than 30S
	Humidity: 95% RH (nominal humidity 65%RH)
	Service life: 5 years

Table 3 shows that the sulfur dioxide sensor module has specific size, weight, concentration range, heating voltage, working current, loop voltage, clean air voltage, response time, power consumption, working temperature, load resistance, sensitivity, recovery time, humidity and service life. Specifications were given and pre-determined by the manufacturer.

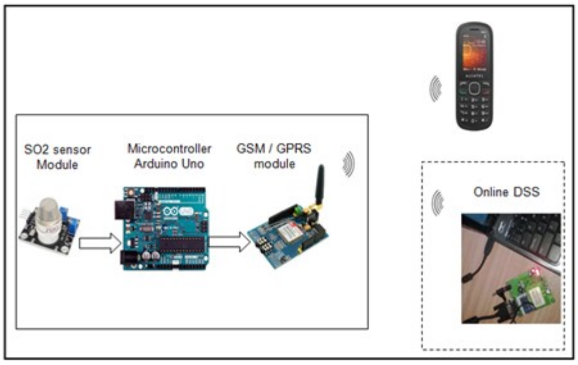

Figure 6. Data Acquisition Technology

Figure 6 illustrates the data acquisition from the device to mobile phone and to an online DSS. The process of monitoring the presence of sulfur dioxide in the air began with sensor reading. After determining the amount of the target gas, the sensor converted the value into measurable electrical signals threshold. Sensor module was interfaced with microcontroller digital inputs that converted the electrical signal to digital equivalent, the PPM value. This value was passed to the communication shield, the GSM module. The GSM module then sent the PPM value into a computer interfaced with GSM modem through an UART cable. The researcher used a basic phone as one of the message recipients of Taal GEM for monitoring, testing and simulation.

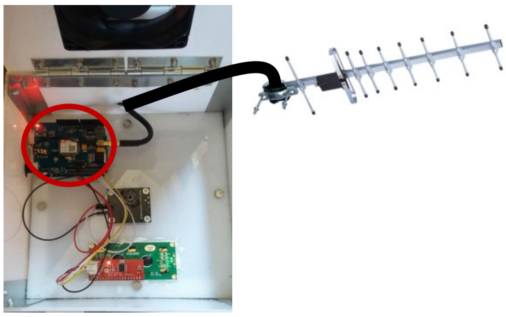

Figure 7. GSM Module Connections to the External GSM Antenna

To maintain communication technology from Taal GEM to the online DSS, GSM/GPRS module was utilized. A SIM card was inserted into this module and it operated through subscription to a mobile operator.

As illustrated in Figure 7, the GSM module was connected to an external GSM antenna. This module allowed Taal GEM to send and receive messages from the online DSS. The external antenna boosted network signal level in the location. The said antenna polarization type, either linear or vertical, had a rated power of 30W, and frequency of 2400-2500MHz.

Corrosion poses a high risk to the device due to exposure to different types of toxic gases and particulate matter in the area; thus, non-corrosive materials were used to ensure its safety, functionality, and durability.

Table 4 shows the characteristics of the materials used in the construction of Taal GEM. A common characteristic is the resistance to corrosion that will enable the device to last for a long period even after being exposed to noxious environment.

Table 4
Characteristics of the Materials used in the construction of Taal GEM

Material	Characteristics
Acrylic Board	- flexible and shock resistant than glass; abrasion resistant - UV and chemical damage resistant; can transmit or filter ultraviolet light - easily cleaned and cut - corrosion resistant - good insulator
Asbestos Ridge Roofing Sheet	- Naturally occurring fibrous material that, due to its non-corrosive and thermal properties has been used to manufacture a vast range of asbestos – cement roofing product - known properties are ability when heated, strength under tension, chemical resistance or absorbency, electrical resistance and heat resistance
Aluminum Flat Bar (6061) Aluminum Angular and Tubular (6063)	- easily formed, stamped, machined and welded - accepts coating and paints - resistant to corrosion - High strength and low weight
Polyvinyl Chloride (PVC) pipe	- Plastics are not conductive and are therefore immune to galvanic or electrolytic erosion, because plastics are corrosion resistant, plastic pipe can be buried in acidic, alkaline, wet or dry soil and protective coating are not required - possesses outstanding chemical resistance properties

As can be gleaned from the table, polyvinyl Chloride PVC pipe, aluminum flat bars, aluminum angle bars, acrylic boards, aluminum screws, and asbestos roofing sheets were used in development of the device. The chemical properties of the abovementioned metals or non – metals were the basis for selection these materials. Moreover, some of the factors considered by the researchers were the strength requirement, capability of being fabricated into the desired form, low cost, and availability for use at the required time and quantity.

Implementation of the System and Integration of a Decision Support System Platform

Data from Taal GEM was transported to online DSSvia communication protocol integrated in the device. This was done in periodic scheme set by the online DSS.

Figure 8 shows the periodic sending set at 30-minutes time interval.

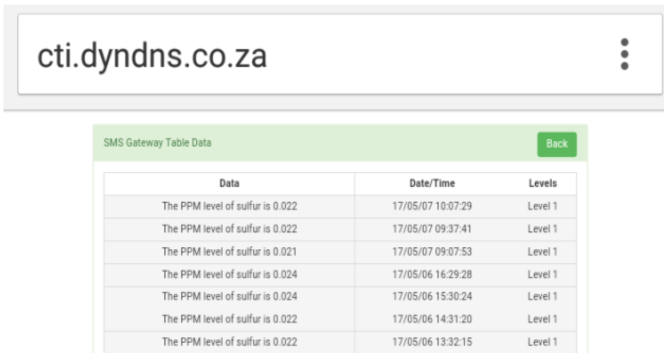

Figure 8. Taal GEM's Online Monitoring Interface

Level of alertness was also indicated in the interface based on the data collected from Taal GEM.

Shown in Table 5 are the effects of sulfur dioxide based on Occupational Safety and Health Standards (OSHS). Sulfur concentration, alert level and possible health effects.

Table 5
Adverse Health Effects of Sulfur Dioxide Exposure based on OSHS Standards

Sulfur Concentration	Alert Level	Effects
< 0.1 PPM	Level 1	Has minimal health effects or occupant complaints
0.1 - < 5 PPM	Level 2	Can produce some negative health effects among vulnerable populations, including asthmatics and others with respiratory issues
>5 PPM	Level 3	Likely to cause serious health effects or discomfort among all populations

System Testing of Taal GEM

The system testing of Taal GEM was based on efficiency and safety requirements. The said testing was based on trials and scientific procedures.

Testing the efficiency was done through SO_2 module testing and periodic auto-sending of data to the online DSS.

Table 6 shows the different ppm readings when the device was used in a controlled environment. Based on the table, four materials, namely cigarette, matchsticks, used motor oil, and rubber were used for system testing.

Table 6
System Testing of Taal GEM in Controlled Environment

Trial	Cigarette (PPM)	Matchstick (PPM)	Used Motor Oil (PPM)	Rubber (PPM)
1	0.0400	0.0280	0.0290	0.0360
2	0.0410	0.0330	0.0280	0.0340
3	0.0400	0.0290	0.0310	0.0340
4	0.0410	0.0320	0.0330	0.0380
5	0.0410	0.0310	0.0290	0.0360
Average	**0.0406**	**0.0306**	**0.0300**	**0.0356**

System testing was performed in the Chemistry Laboratory of the College of Industrial Technology of Batangas State University with the assistance of a chemistry Instructor. The DENR and DILG consultants advised the researcher not to set—up the device in Taal Volcano's crater as the said place is considered part of the danger zone. It was too risky on the part of the researcher with the recent earthquakes (April 4, 2017 epicenter at Tingloy, Batangas) and April 8, 2017 epicenter at Mabini, Batangas) with magnitudes of 5.4 and 5.9, respectively.

The testing comprised of five (5) trials as reflected in Table 6. The trials were done by burning the materials and allowing the device to draw in smoke. After five trials, the sensor was able to detect the SO_2 present in the materials used. Based on the results, the burned cigarette, matchsticks, used motor oil, and rubber had averages of 0.0406PPM, 0.0306PPM, 0.0300PPM, and 0.0356PPM, respectively. The said readings were acceptable to the 0-500PPM specified SO_2 range.

Simulation testing was also done using dummy data as shown in Figure 9. This aimed to show variations in the indicated levels based on the range set by OSHS standards stated in Table 5.

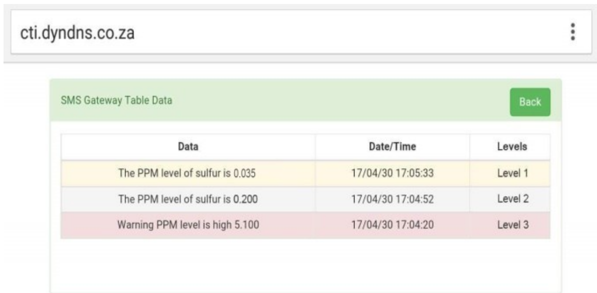

Figure 9. Results of the Simulation using Dummy Data

Another system testing was done using the online DSS interface as reflected in Figure 18 This figure shows the online interface screen shot of the 30-minute periodic monitoring scheme of Taal GEM. A discrepancy of about 3-4 seconds was found as that the device had no real-time clock and it only counted the delay. The device was able to transmit data for PPM level of SO_2, notwithstanding that the mark indicated "Level 1" which suggests that the air was still good to health and had minimal effects according to OSHS.

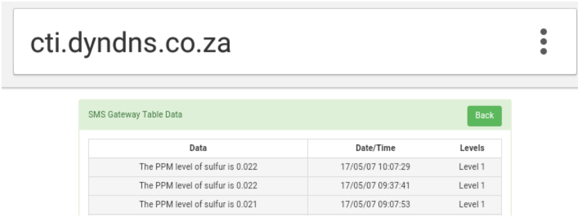

Figure 10. Online DSS Interface in a 30-Minute

Alternatively, Figure 10 shows the periodic scheme configuration text confirmation of Taal GEM.

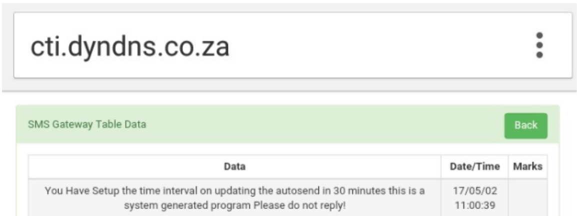

Figure 11. Periodic Scheme Configuration Text Confirmation

The periodic scheme configuration was possible when the online DSS texted the device to schedule the auto-sending by a text format. From the figure, it can be seen that the device was able to confirm the set-up done by the online DSS through SMS every 30 minutes. No reply was needed once the confirmation was done by the online DSS.

In terms of materials used, the analysis on environmental constraints proved that the device was resistant to corrosion and temperature. The material specifications are shown in Table 4.

Conversely, the electrical components were checked and safety requirements were met as indicated in a certification given by a professional electrical engineer. The certificate states that Taal GEM underwent careful technical evaluation through a series of simulations and testings and it was found to be operationally functional and safe.

Table 7. Electrical Equipment Inspection Checklist

Checklist	Yes	NO
● Device is properly grounded and insulated	✓	
● Flexible cords and cables free of splices or taps	✓	
● Cord jacket are securely help in place	✓	
● All cord / cable and raceway connections intact and secure	✓	
● In wet or damp locations, device is appropriate for the use or location or otherwise protected	✓	
● Interior wiring systems include provisions for grounding metal parts of electrical raceways, equipment and enclosures	✓	
● Sufficient access and working space provide and maintained about all electrical equipment to permit ready and safe operations and maintenance	✓	
● All unused opening in electrical enclosures and fittings closed with appropriate covers, plugs or plates	✓	

The safety inspection checklist of the Taal GEM can be gleaned from Table 7. From the abovementioned, the device was properly grounded and insulated. Flexible cords and cables were free of splices or taps that made connections more secured. Moreover, cords jackets were securely held in place with all cords/cable and raceway connections intact and secure. For wet or damp locations, the Taal GEM can be used with interior wiring systems properly grounded. There is also sufficient access and working spaces provided were all unused opening in electrical enclosures and fittings were closed with appropriate covers, plug or plates for safe operations and maintenance. With all aspects innocuous and secured, Taal GEM is accepted as a safe device for monitoring sulfur gas emission.

Furthermore, it was attested that the installation and wirings of the device conformed to relevant and applicable safety practices.

4. CONCLUSIONS

Based on the study, the following conclusions are deduced: (1) the completed gas emission monitoring device dubbed Taal GEM has an SO_2 sensor, a microcontroller, a communication technology, and a computer as data acquisition technology with GSM module. Its parts are made of non-corrosive materials; (2) the system is successfully integrated into an online decision support system; and (3) Taal GEM is proven to be efficient since it responds to the configured periodic scheme of data auto sending. Also, it is found to be safe to electrical wiring and installation practices.

RECOMMENDATIONS

Based on the aforementioned conclusions, the following are hereby recommended:

1. Additional sensor nodes in a wireless sensor network set-up may be deployed in different sulphur emitting spots in the main crater of Taal volcano to gather more data.

2. Additional testing parameters such as detecting the amount of carbon dioxide, methane and other gases may be used by future researchers.

3. An android application may be developed so that the data becomes available for viewing by mobile inquirers.

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