Gas monitoring station in hazardous environment with gases containing

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Abstract. Landfill sites collect tons of municipal solid waste (MSW) using an open dump mechanism, causing gases to emerge, which may cause disease and the greenhouse effect. Mainly, landfill environments are observed using a portable system that does not continuously monitor and measure emitted gas levels. It is also difficult to evaluate changes in landfill emissions over the long term unless they are monitored at regular intervals according to a detailed plan. This paper presents a new monitoring method to measure gas levels in landfill sites, which documents dynamic changes in gas composition concentrations over the long term. The system was placed in the middle area of the landfill and was charged using solar panels for convenience and greater efficiency during monitoring. While the instruments that are currently available are used for a specific parameter, this system can measure eight parameters, i.e., ambient concentration of methane (\textsuperscript{CH} \textsubscript{4}), carbon dioxide (\textsuperscript{CO}_2), carbon monoxide (CO), temperature, humidity, wind direction, wind speed, and voltage level. The system was evaluated regarding its ability to monitor gas parameters continuously.

1. Introduction
A hazardous environment that contains poisoning gases could be harmful to people who reside nearby. One of the places which could be considered as a hazardous environment is a waste landfill site. It could also be a significant source of land, air, ground, and surface water pollution and harmful for nearby communities \cite{1}. In Indonesia, municipal solid waste (MSW) has reached 64 million tons per year in 2017 \cite{2}. It could be a potential problem because the open dump landfill system is mainly used. Furthermore, the statistic of the Central Bureau showed that 84.51\% of MSW was disposed of without shorting it \cite{3}.

The landfill exposes various poisoning gases, such as methane (\textsuperscript{CH}_4), carbon dioxide (\textsuperscript{CO}_2), carbon monoxide (CO), and other gases depending on the waste mix. The potential problem of landfills could be affected by emissions of non-collected gases, where the situations depend on climate conditions. These conditions cannot be controlled \cite{4}. Since a landfill covers a large area, and there is no gas collection system, the number of emission gases in the air should be predicted to prevent the negative effects.
effect of nearby people [5]. It is difficult to identify the effect of each individual caused by environmental contaminant exposure. Emitted gases can be considered the main factor of negative effect on health in sort and long-term effect. Some people worked at the landfill are potentially inhaling these gases and contracting diseases. Most of them can have coughs, chest tightness, breathlessness, and they suffer from an extraordinary range of illnesses that may be attributed to volatile organic compounds [6]. A study showed a relationship between the distance of houses with gas levels to the final spot of landfill [7].

Furthermore, waste landfill sites can also be a source of greenhouse gas (GHG), which is generally known as the responsible for increasing global warming [8][9]. Even this condition has been known, there is still a lacks actions to measure or monitor the environmental condition. Thus, how the landfill sites could contribute to gas emissions or diseases is difficult to observe. Regarding this issue, introducing a control and monitor system as preventive measures should develop a warning system [9].

Some studies have demonstrated the ability of gas detectors to measure the methane gas in-point using a scanning method [10][11]. The measurement process involves an open area mechanism, where the gas concentration is influenced by wind speed. The landfill environment is mainly observed using a portable system that continuously monitors and measures the emitted gases to inform the concentration. So, evaluating changes in landfills over the long term is difficult to determine unless it is conducted at regular intervals according to a detailed plan. In contrast, a continuous monitoring method, which could measure the gas level, is needed. This method needs a stationary monitoring system that should be developed and arranged according to some parameters, such as the selected gases, sampling method, sampling equipment, how well construction, and depth of screened intervals [12]. This method requires an expensive system, which combines mass balance, stationary plume, and dynamic plume [13]. Considering this situation, this paper describes how developing an internet-based monitoring system to inform the air condition of waste landfills continuously.

The developed system measures some parameters to find out how to monitor hazardous gases. Here, CH$_4$, CO, CO$_2$ are measured with temperature, humidity, wind direction, and wind speed. Since the developed system is placed in the landfill area, the electrical energy uses a solar system. A voltage sensor is attached to the system to monitor the battery used. The developed system is a prototype to connect the station at the final spot of the landfill site, which is connected to central information. Here, the working state of the station and how the data will be sent to the center will be discussed.

2. Methodology

2.1. Gas Emission in landfill site
Landfill sites produce gases by decomposing organic materials composed of 50% CH$_4$ and 50% CO$_2$ and a small amount of non-methane organic compounds. CH$_4$ gas is the most potentially causing GHG, 28 to 36 times more effective than CO$_2$ trapping heat in the atmosphere, as the information of the Intergovernmental Panel on Climate Change (IPCC) assessment report (AR5).

Estimated CH$_4$ emissions were carried out on a lab-scale as the prior measurement of ambient CH$_4$ concentrations, measured vertically using a portable gas detector. The gas detector was hanged at the surface to measure variation conditions, such as CH$_4$ flow rates, wind speed, the position of the gas detector, and cover utilization [14]. From that study, the correlation between ambient CH$_4$ concentration (x) and CH$_4$ flux (y) was obtained, which uses significant (p<0.01). The correlation equations can be determined as follows.

$$R^2 = 0.7109 \text{ and } y = 0.1544x$$

(1)

2.2. Situation of landfill
This research was carried out in a waste landfill named TPA Supit Urang, i.e., the waste disposal center in Malang city, Indonesia, in 1993. Figure 1 shows the TPA Supit Urang landfill area from a satellite taken by Google Maps. The landfill is divided into six areas, covering 31 ha, where 190,053 people live surround it [15]. The volume of waste disposal each day can reach 1,500 m$^3$/day or 375 tons/day.
86.67% of it can be collected at the waste disposal center. The composition of waste disposal mainly consists of organic garbage, i.e., 65%, while the remains are plastic, paper, metal, rubber, glass, and others [16].

The Supit Urang landfill receives garbage in the open dumped and produces CH4 gas. It was estimated that 5828.90 tons had been distributed to 319 households surrounding the landfill in 2018 [17]. However, it has no report about GHG emissions emitted into the air since this landfill uses the open dumped system.

In this research, the monitoring system uses a station placed at the center of the landfill with GPS positions of -7.982614, 112.577876. Then, the system will monitor, record, and give information on environmental conditions. Regarding the broad area of the landfill, with no electrical system, the station collects data and sends them wireless to the internet cloud. Then, the data will be received by the central host to analyze the data.

![Satellite view of the TPA Supit Urang.](image)

**Figure 1.** Satelite view of the TPA Supit Urang.

### 2.3. Methodology

The design method explains the Architecture of the Monitoring System of the Waste Disposal Center. The monitoring system is designed to observe the air condition of the final spot of the waste disposal center (TPA Supit Urang) using the internet-based system called Monitoring Station. The monitoring station takes the environmental data surrounding TPA Supit Urang. The data consist of eight parameters, i.e., CH₄, CO, CO₂, wind direction, wind speed, temperature, humidity, and battery voltage level, which are collected and send to the webserver at the Central Host in Universitas Negeri Malang via internet connection. The data can be accessed by three users, i.e., admin, government, and public. Admin has the privilege to access and change the system structure, while the government can access the data in real-time and historical data needed, and the public can only see the report of historical data and the current condition. The developed system is shown in figure 2.

![Diagram block of the developed system.](image)

**Figure 2.** Diagram block of the developed system.
The system can use four layers, i.e., device, network, cloud management, and application layers [18], described as follows.

2.4. Device layer

This developed system's device layer is considered the monitoring station, which has functioned as the sensing and monitoring devices. This system uses eight sensors, i.e., temperature, humidity, wind speed, wind direction, carbon monoxide (CO), carbon dioxide (CO$_2$), methane (CH$_4$), and battery's level. The function of the sensor attached to the monitoring system has specifications explained as follows.

The primary gas which is emitted in landfills is CH$_4$. Thus, the CH$_4$ sensor has the primary function of monitoring the gases sensor, which monitors ambient CH$_4$ exposure from landfills [19]. Besides CH$_4$ as the dominated gas produced, which is about 55%, CO$_2$ also has a high concentration emitted from landfills, about 45% [20]; then, a CO$_2$ sensor is attached to this station. CO gas can be measured in emission gases in landfills because of solid waste degradation, where the gas concentration will increase when CH$_4$ concentration is low [21].

The concentration of gases is significantly affected by wind direction, and wind speed since gas concentration measured by the monitoring station is gas emitted large landfill area with open dumping system, so wind direction and wind speed sensors are added to the system. Furthermore, the monitoring system needs an electrical power source since the station is placed in a center landfill far from the electrical source. Then the electrical power source for the station is supplied using a solar panel system. This system is influenced by climate since Malang city has the characteristic that rain and cloud often occur. This situation affects the charging process for the battery used in the solar panel. Then the voltage level sensor is attached to the monitoring system to maintain the solar panel system. If the battery is insufficient, the electrical power will be switched off; while the battery is charged sufficiently, the electrical power will be switched on automatically, while the system usually starts work to capture data.

The sensors are integrated into the Arduino microcontroller to process the data, while the output is shown at liquid crystal display (LCD), while monitoring data are saved at the memory card. The data taken by the sensor are submitted to the Central Host using GSM module SIM800L via internet connection. The electrical system is shown in figure 3. Furthermore, the system is accomplished with a warning indicator that will blink on when the situation in the spot is harmful to the system; for example, the temperature is too high, or the battery's level is too low.

![Figure 3. Block diagram of the electrical system.](image-url)
2.5. Network layer

The proposed system is connected to the host using the GSM module via internet connection. GSM800L module [22] is used here, which supports quad-band GSM/GPRS network [23]. The module is connected to the microcontroller via Universal Asynchronous Receiver-Transmitter (UART) port, which supports AT command interface with auto baud detection.

To recognize a huge number of data from various monitoring stations, the ID station is determined firstly as STx representing station number "x." It is followed by sequentially data from the real-time clock (RTC) with the format of year-month-date (yyyy-mm-dd), hour:minute:second (hh:mm:ss), temperature (T), wind speed (S), wind direction (D), CO, CH₄, CO₂, humidity (H), voltage (V), which separated by punctuation comma. A format is used to manage the data collected from the sensor, as shown in table 1. Thus, the format data is represented as follows.

STx, yy-mm-dd,hh:mm:ss,xx.xx,xxx.xx,xx.xx,xxx.xx,xxx.xx,xx.xx,xx.xx,xx.xx,xx.xx

(2)

Table 1. Format data from sensor.

| Sequence   | Data Type | Format Data | Unit |
|------------|-----------|-------------|------|
| ID Station | String    | STxxx       | -    |
| RTC        | Integer   | yy-mm-dd,hh:mm:ss | - |
| Temperature| Float     | xx.xx       | C    |
| CH₄        | Float     | xxx.xxx.xx  | ppm  |
| CO         | Float     | xxx.xxx.xx  | ppm  |
| CO₂        | Float     | xxx.xx      | ppm  |
| Wind Direction | Integer | xxx        | deg  |
| Sequence   | Data Type | format data | Unit |
| Wind Speed | Float     | xx.xx       | m/s  |
| Humidity   | Integer   | xx          | %RH  |
| Voltage / VIT | Float | xx.xx      | V    |
| Current    | Float     | xxx.xxx.xx  | mA   |

| Sequence | Data Type | Format Data | Unit |
|----------|-----------|-------------|------|
| Duration (t) | Integer | xxxxxxx    | Second |
| GPS      | Longitude F | xxxxxxxxxx | - |
|          | Latitude F  | xxxxxxxxxx | - |

2.6. Cloud management layer

The data from the monitoring station are sent to the webserver using two methods. The first method is named a normal situation, which collects the data from the monitoring station in each minute and saves them in a memory card; after 15 minutes, the collected data are sent to the webserver. This method is used to avoid data losses during data traffic in internet clouds. The second method is named an emergency, where besides saving data in each minute, the data are also pushed to be sent to the webserver directly. This mechanism will be done when the situation in the landfill is in an emergency, such as the temperature increase daily, which may alert that the landfill is burnt, or the gases concentration increase normally, which may inform that sensors work inappropriately or in hazardous situations occur.

The data from both mechanisms update the database in a web server cloud, where the data are used for data management, controlling, and reporting. When the emergency occurs, the system will send a notification using Google firebase. The detailed information is shown in figure 4.
Figure 4. Cloud management layer schema for internet send, process, and the result of data.

The developed system works as shown in figure 5, while figure 6 shows the flowchart of the monitoring system at the network server.

In this research, the monitoring station is placed at a waste disposal center in a city as a measurement node. In this research, the sample node is Malang city in Indonesia. Each waste disposal center could have one or more nodes representing monitoring stations. The database of the proposed system is developed to capture the data sent by the monitoring station, as shown in figure 7. Here, the database consists of tables, i.e., tbl_node, tbl_station, tbl_humidity, tbl_co, tbl_temperature, tbl_ch4, tbl_direction, tbl_speed, tbl_co2, tbl_scala, and tbl_user represent tables to store data of node, station,
humidity, CO, temperature, CH$_4$, wind direction, wind speed, and CO$_2$, respectively. The table of tbl_scala is used to store ambient data for limit values of healthy environment determined by the regulation of the Indonesian government about occupational health and safety. The table of tbl_user is used to store data of the user, which could access data of the monitoring system. User data are categorized into three privileges, i.e., admin, government, and public. The public can access it if they register to the system. These tables are connected user Entity-Relationship (ER) diagram, as shown in figure 7.

![Figure 7. Database of a web server as the Central Host.](image)

2.7. Application Layer
In the developed system, the web-based computer and Android applications have some functions, i.e., (1) show the data in real-time; (2) report the data like document, and (3) give the notification if the gas level exceeds the limit. To connect the data and user, the application layer shows the interface between system and user. The user is divided into three kinds in this system, i.e., admin, government, and public. Admin has the privilege to access all data; the government can access monitoring data in real-time and also access the historical data, while the public can access if they register to the system; then they will access to monitor real-time data. The dashboard of the user interface system is shown in figure 8.

![Figure 8. Administrator dashboard for manage logging process.](image)

3. Results and discussion
The experiment measures gas in landfill area; the station is placed at longitude -7.982614, latitude 112.577876. The high of the station is 2 m over the waste surface. The method for experimenting is used to evaluate fluctuation in concentration. Here, we observe changing gas concentration daily.
3.1. Monitoring Results of CH$_4$

The average results of CH$_4$ when it was running in ten days are shown in figure 9. This stage aims to find the daily changing of gas concentration in the morning, afternoon, and night. From the result, CH$_4$ gas concentrations show decreasing at daily around 00.00 a.m. to 24.00 p.m. It shows that new disposal waste is going to decompose at night.

![Figure 9. Averages of 10 days CH$_4$ gas concentration.](image)

3.2. Monitoring Results of CO$_2$

In the case of the running results of CO$_2$ sensors for ten days, the daily changing of gas concentrations is shown in figure 10. From the result, CO$_2$ gas concentrations show relatively constant at daily around 24 hours.

![Figure 10. Averages of 10 days CO$_2$ gas concentration.](image)

3.3. Monitoring Results of CO

Hereafter, the running results of CO sensors for ten days, the daily changing of gas concentrations are shown in figure 11. From the result, CO gas concentrations need to be observed regarding the situation in a landfill whether there are activities, which can affect the gas concentration, such as waste burned.
Figure 11. Averages of 10 days CO gas concentration.

After all, the situation of TPA Supit Urang should be observed furthermore, whether it is still safe for people whose life and work are surrounding it.

4. Conclusion
The propose system was placed in the middle area of the landfill. The result shows that the monitoring system can show the changing of gas concentration, where the instruments are used to measure the ambient concentration of methane (CH\textsubscript{4}), carbon dioxide (CO\textsubscript{2}), and carbon monoxide (CO). The system was evaluated regarding its ability to monitor gas parameters continuously. The concentrations are affected by the decomposing process of waste at the landfill, especially at the night stage. Furthermore, the system should be analyzed in more detail and was charged using solar panels for convenience and greater efficiency during monitoring.

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