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Water pollution and carbon dioxide emissions from solid waste landfills: probabilistic monitoring and evaluation

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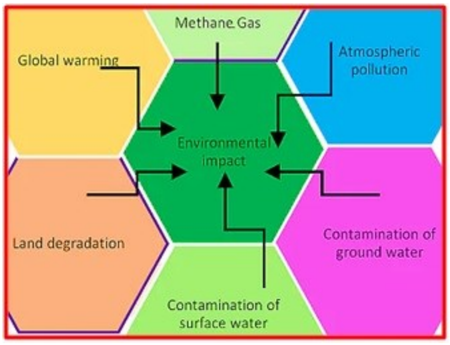
Graphical abstract



Abstract

Owing to increased population, the ground water pollution and disposal of solid waste from the domestic, commercial and the industrial sources has become higher. Mainly, leachate from sanitary landfills increase the ground water pollution and disposal of solid wastes may produce the emission of carcinogenic greenhouse gases. The gases include Carbon-dioxide (CO_2), Nitrogen-dioxide (NO_2), Methane (CH_4) and Hydrogen Sulphide (H_2S) which will contributes to the major and detrimental in nature. To know about the extremity of the gases, implementation of integrated sensors networks can transmit and store data in the cloud using the Internet of Things (IoT) to perform future prediction using Machine Learning Algorithm. To estimate ground water pollution, sample locations have been chosen using random sampling method which holds 89% efficiency in data sampling. Due to the increased proportion of liquid and solid waste at 17:93 ratio existence in the city, the study elaborates the health impacts of pathogens by pointing as a cancer capital of around 34% influence rates. Based on the CO_2 emission and water pollution analysis, the modelling is done using Linear Regression Machine Learning algorithm which flags up the emission rate that could occur for the next three months with 86% accuracy. Also, appropriate mitigation measures can be suggested to the local government in the view of reducing both ground water pollution and the gaseous emissions. Finally, the identified pollution potential in the Vendipalayam site is compared with other landfill sites level of pollution for providing the adaptive measures further enhances environmental sustainability.

Keywords: IoT emission gas monitoring, linear regression, future prediction, environment sustainability

1. Introduction

Toxic chemicals prevail everywhere due to industrialization, commercial activities, waste dumping facilities, etc. Under Indian context, from a Landfill site there is an intense release of contaminants directly or indirectly to the land which in turn pollutes soil initially later the ground water (Aziz *et al*., 2010; Bagheri *et al*., 2020). Majorly Gaseous pollutants is released from the solid waste dumping sites in very short period of time (Bergersen *et al*., 2014). The major emissions were found to be from Carbon-dioxide (CO2), Nitrogen-dioxide (NO2), Methane (CH4) and Hydrogen Sulphide (H2S) gases (Bo-Feng *et al*., 2014). Greenhouse gas emissions has been found to cover major concern in recent years. The world greenhouse gas emissions released from the disposal activities contributes to about 2.8% of the total emissions (Bolyard *et al*., 2019). Methane emission concerns about three to four percentage of annual GHG's emissions worldwide. To avoid the adverse effects of waste management practices, alternatives for the solid waste practices such as reducing, recycling and reusing the generated waste has been implemented in many countries (Cao *et al*., 2019). Due to increased recycling methods, the method of land filling and the amount of generated waste in these landfills is getting reduced with time (Chen *et al*., 2020). But majority of the cities in India do have this Non-Engineered Landfills still today where Methane and Carbon-dioxide, by-products from anaerobic decomposition of the organic wastes, are found to be the main constituents of landfill gas (Chiemchaisri *et al*., 2013). The analysis of different municipal solid waste management background in concern to the greenhouse gas emission, energy recovery and the probability of executing thermic transformation strategies is also challenging task nowadays (Couth *et al*., 2011; Das *et al*., 2016). Due to highly informal in nature, sanitary department is facing lot of issues without the real time data for future predictions (Dmitrienko *et al*., 2018). In order to monitor those emissions in a real time, the sensors with data retrieval facilities plays an important role and further aids in depicting the emissions trend in an appropriate manner (Dong *et al*., 2017; Du *et al*., 2018). Many studies portrayed the prediction method for transferring novel GDP based on the carbon-dioxide emission data and simulations considered carbon-dioxide emission data on four economically heterogeneous nations (Fallahizadeh *et al*., 2019). Sijia Qu et.al summarized the methane emissions trend from 2015 to 2050 by integrating IPCC technique with the SD model in Chinese Cities which is the motivation for prediction techniques (Friedrich and Trois, 2013). Mingxi Du et.al concentrated on Intergovernmental Panel on Climate Change (IPCC) and the first-order decay techniques along with greenhouse gas inventory guidelines for quantifying municipal solid waste landfills - Methane emissions (Ghosh *et al*., 2019). Because of the heterogeneous nature of the waste, notable variations are identified in emissions between different zones indicating different stages in waste degradation process and various environmental conditions (Huang *et al*., 2022).

By considering this research gap into account, the study aims to monitor the gaseous emissions from the landfill site and estimate the rate of emission of gases like Carbon-dioxide (CO2), Nitrogen-dioxide (NO2), Methane (CH4) and Hydrogen Sulphide (H2S) from the dumping yard which helps to suggest appropriate mitigation measures for the reduction of the same in and around the study area. Also, to enhance the research aspect further, a linear prediction model is developed using time series linear regression algorithm by considering daily waste generation rate impact on the ground water. Further prevailing unsanitary conditions due to industrial discharges and non-engineered landfill sites increases the proximity of water borne diseases in the city space. So, to identify the level of ground water pollution potential from the study area various sample points are selected using Random Sampling method. The Chemical characterization of groundwater is carried out to evaluate the standard of groundwater in favor of checking its adequacy for drinking and irrigation purposes.

2. Municipal solid waste investigation area and its impacts on environment

Erode is a city which covers the seventh largest agglomeration in Tamil Nadu. The total area is measured to be 109.52 Sq.Km and population is around 567000. Location co-ordinates of Erode are 11°2027"N 77°43'02"E. An average of 250 MT/day wastes are generated every day around the city. The locations of a dumping yard must be situated outside the city premises, that it should obeys the existing rules and regulations imparted by the government in turn reduce the overall collection and disposal cost liable to the society and environment (Hwang *et al*., 2017).

The collection vehicles depart from Erode Municipal Corporation reach various locations to collect the Municipal solid waste on regular basis (Hwang *et al*., 2017). The Primary data regarding the collection and management of solid waste practices are collected from municipal corporation office in Erode city. The secondary information in the context of collection system, type and characteristics of waste, location of disposal sites, average rate of waste generation per day, number of vehicles available in the corporation for waste collection and its capacity, number of storage bins were obtained from the corporation office (Ilic and Ödlund, 2018). The overall solid waste constituents available from various source of waste disposal dumped in the landfills. In usual, door to door waste collection method is highly adopted in this locality. Once collection process is over, the waste collection vehicles reach dumping yard for further disposal of the wastes. During this unloading process, there is a significant release of gaseous emission from the Vendipalayam dumping yard. As far as Erode is concerned, over the last 61 years the municipal solid waste generated is being dumped at Vendipalayam yard spreader over 19.45 acres and 7.4 acres capacity in Vairapalayam yards. Recent investigations shows that the amount of waste accumulated in the dump yards over the years are 4.45 lakh cubic meter and 0.90 lakh cubic meter respectively. The particulate and gaseous emissions that's increasing in Vendipalayam dumping site further causes frequent fire accidents, unpleasant odor from waste and Ground water contamination which also take to periodic protests by people living near the yard (Ke *et al*., 2018). In order to suggest better practices for cutting down these noxious emissions, it is mandatory to identify the rate of emissions generated from the solid wastes in the site (Kristanto and Koven, 2019). So based on the survey conducted nearby site about the emission of gases, emission monitoring sensors are designed to monitor the same in Vendipalayam area. Majorly Carbon-dioxide, Nitrogen-dioxide, Methane and Hydrogen Sulphide gases are monitored during solid waste disposal process in landfill site to know about the emission concentration there by effective measures can be recommended further to render the balance occurring in the eco-stability (Kumar and Muhuri, 2019).

3. Methods and materials

3.1. Proposed iot based emission monitoring system on the vendipalaym MSW landfill

The emission monitoring sensors, which provides the rate of emission for the following identified four types of gases emitting from the solid wastes generated in the dumping yard (Kumar *et al*., 2004). The vairapalayam dumpyard undertaken for the proposed solid waste monitoring and maintenance sitemap is shown in Figure 1a to show the major dumping of municipal solid waste for recycling micro compost centre. The Internet of Things (IoT) concept is used and sensors are connected to the electronic display through the node integrated circuit. The device to which the estimated data has to be sent is connected with the particular sensor setup and the help of a Wi-Fi module. The Node MCU (Master Control Unit) acts as the controller and the outputs are displayed in LCD (Liquid Crystal Display) as shown in Figure 3b. The sensor produces a potential difference equal to the concentration of gas emission which got out from the solid wastes generated (Kumar *et al*., 2016). This proposed work integrates the monitoring of four gas sensors and derives the output using Multiplexing technique to the Wi-Fi ports for wireless communication. The proposed design holds AD8194ACPZ (Surface Mount type), 4–channel analog multiplexer is preferred to read out four outputs appropriately. Sometimes if the voltage is not enough, boost converter can be used to escalate the voltage. By changing the resistance of the material inside the sensor, some emission values can be obtained which is measured as an output as shown in Figure 1b (Kuo *et al*., 2011).

Figure 1a. Vairapalayam dumpyard Location sitemap

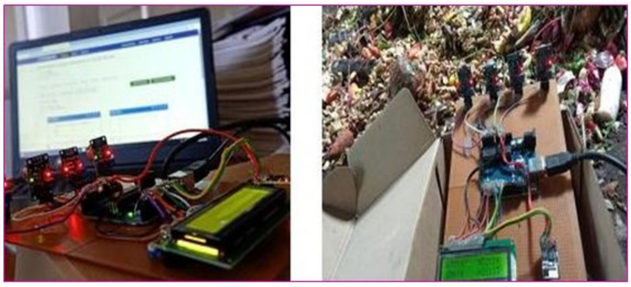


Figure 1b. IOT based gaseous emission monitoring device in the investigating area of MSW

The primary embedded software programme, which collects data from the sensors through Grove connectors, will be operated by the Node MCU. The gathered data is cleaned up before being uploaded to the cloud. The controller will sound an alarm when it finds out-of-bounds data (Lee *et al*., 2016). Architecture that is designed to be flexible and modular, with individual components that may be added, changed, or even eliminated without affecting how the other components perform.

3.2. System architecture and decision-making tool

Four levels make up the suggested architecture (Zhang and Huang, 2014). Connectivity: The MQTT (Message Queue Telemetry Transport) protocol will be used by the municipal solid waste management system to connect to the cloud. Clients can publish to and subscribe to a broker using the publish/subscribe protocol MQTT. Security: It works by creating a permanent connection between a device and a MQTT broker using WebSocket. Through client x509 digital certificates and Transport Layer Security (TLS), the WebSocket connection will be protected. Each device will receive a client x509 certificate that will be stored in a safe memory on the Node MCU through a secure out-of-band technique (Zhang *et al*., 2012; Zhu *et al*., 2019). Scalability: Cloud computing solutions give us the option to add resources, including storage. After that, the entire collection of data is uploaded to the cloud, where we may view and use it. Energy Harvesty: particularly for long-term, low-consumption electronic systems that run on their own. The system can potentially be powered by solar energy because to its low power usage capable of interacting with any MQTT broker that accepts MQTT over Web sockets as shown in Figure 2.

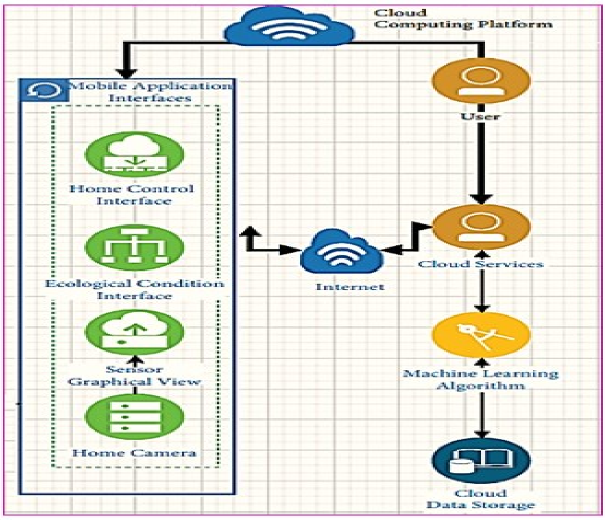


Figure 2. IoT architecture for data processing and decision making

```
% TODO - Replace the [] with channel ID to read data from:
readChannelID = [];
% TODO - Replace the [] with the Field ID to read data from:
fieldID1 = [];
% TODO - Replace the [] with the Field ID to read data from:
fieldID2 = [];

% Channel Read API Key
% If your channel is private, then enter the read API
% Key between the '' below:
readAPIKey = '';

%% Read Data %%

% Read first data variable
data1 = thingSpeakRead(readChannelID, 'Field', fieldID1, 'NumPoints', 30, 'ReadKey', readAPIKe

% Read second data variable
data2 = thingSpeakRead(readChannelID, 'Field', fieldID2, 'NumPoints', 30, 'ReadKey', readAPIKe

%% Visualize Data %%

scatter(data1, data2);
```

Figure 3. ThingSpeak Code for receiving the emission gas data using MQTT protocol

The proposed architecture starts with physical layer of four integrated sensors data acquisition followed by analyzing the ecological condition to communicate to the gateway. Once it reaches the network layers, the most pointed data acknowledgement will be initiated with cloud server for continuous data processing and storing in the cloud under specified decoding as shown in Figure 3. An open-source firmware and development kit called Node MCU aids in the creation of IoT-based application frameworks for municipal solid waste (MSWM) management emission gas monitoring system (Lee *et al.*, 2016).

3.3. Analysis of gaseous emissions

A complex Application Programming Interface (API) for IO devices was made easy to use by Node MCU. The amount of effort spent configuring and modifying hardware devices can be decreased with the aid of APIs. The Node

MCU has the benefit of being programmable with an open-source IDE and a range of programming languages. Using the Arduino IDE, the emission gas monitoring code will be directly uploaded to the node MCU device. In the meanwhile, a little Wi-Fi integrated chip called the ESP8266 is employed. For storing and retrieving data from objects that use HTTP (Hypertext Transfer Protocol) through the Internet or a local area network, ThingSpeak is an open-source internet of things (IoT) platform and API (LAN-Local Area Network). Bitrates of the each hub ports are examined and trend rate will be taken with timestamp as shown in Figure 4 by confirming the enhanced throughout for the entire wireless communication. It is inferred from Figure 4 that the bit rate was slow of around 14dB initially and when it attains proper signal to noise ratio holding stronger signal strength it reaches to around 24dB to show that the wireless communication is in continuous without loss of data packets.

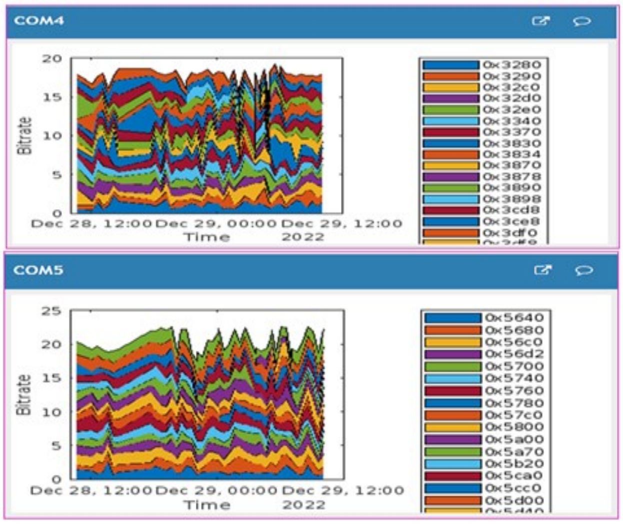


Figure 4. Bitrate analysis of four ports on transmitting emission gas data

3.4. Proposed model

It also functions as a data collector, gathering information from node MCU devices and loading it into the software environment for analysis of past data. The core of the ThingSpeak system is a channel, which consists of a data field, a position field, and a status field. Users have access to a wide variety of embedded devices and web services to incorporate the internet of things (IoT) supported with MATLAB (Matrix Laboratory) codes as shown in Figure 5. Additionally, it can gather, store, process, visualise, and act on data coming from sensors or actuators like Arduino, Node MCU and Raspberry Pi. Applications for sensor logging and position tracking are supported by ThingSpeak, for instance.

Path-loss and interference are two of these characteristics that are influenced by the propagation channel environment (LLiu and Zheng, 2020). Empirical channel models and deterministic channel models are the two types of channel models used to describe radio wave propagation. However, accurately applying deterministic channel models will result in incredibly complex mathematical formulations for handling real-world issues that involve an infinite number of elements and several types of material with various electromagnetic properties. Empirical channel models describe radio wave propagation based solely on measurements and observations. These models can also produce accurate predictions with a fair amount of computing. Empirical channel models are frequently employed in network planning because they produce reliable prediction results with a reasonable computing cost. In the proposed work, to examine the efficiency of data transmission, each port bit rates are analysed in the ThingSpeak platform by storing reception rate for every minute of ports 4 and 5.

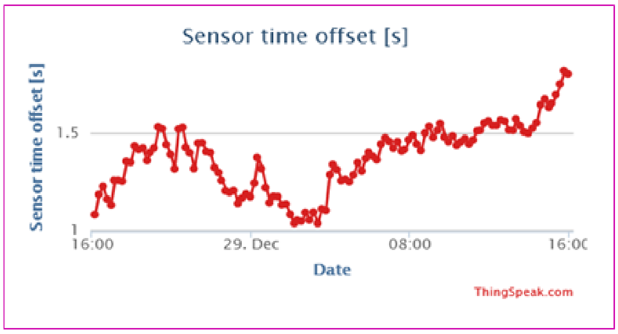


Figure 5. Estimated sensor offset value for acquiring real-time data from the landfills

Since, the module starts to fetch the data from the surrounding landfill, there will be influence of extreme temperature, pressure and humidity to fetch the emission gas rate. Hence, the sensor offset has been observed by taking the lag spectrum on the sending of data from the sensors which is given in Figure 5. It confirms that the once the four emission gas values retain at the same level, the sensor offset values leads to higher level of 1.7s otherwise when there exists the change of emission gas influence, the sensors send data to the cloud server by having sensor offset as minimum as 1.02s. Hence, adaptive continuous emission gas monitoring system for Municipal Solid Waste is developed and experimental data have been recorded for data analysis (Liu *et al.*, 2022).

4. Results and discussion

4.1. Real-time analysis of the vendipalaym mulnicipal waste composition on the available landfills

There are roughly 56,789 people living in the undertaken area of Vendipalayam, and most of them live in single-family homes. With an average daily generation per inhabitant of 1.9 kg, the entire village area generates 89,457 tonnes of overall waste products annually. The solid wastes that were transported to the Vairapalayam yards in 2022 — including both residential and commercial waste was investigated in this study, as well as waste that was accepted from neighbouring Erode concerned communities. Municipal hazardous solid trash drop-offs and some construction wastes are also included in the municipal wastes. A total of 79,963 tonnes of municipal waste were produced in 2022, of which 48,223 tonnes (32% of the material received in 2022) were organic waste. 24,763 tonnes (36% of the total) of the dry materials were recyclables and mixes. The analysed solid wastes constituents are shown as Figure 6.

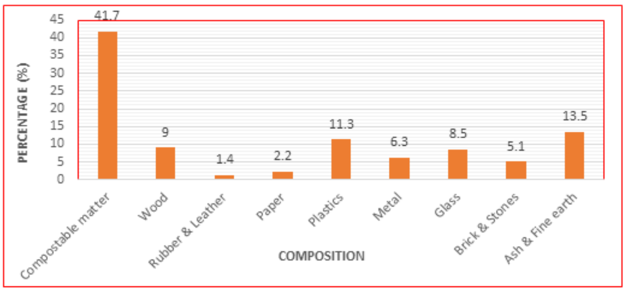


Figure 6. Physical composition of solid waste

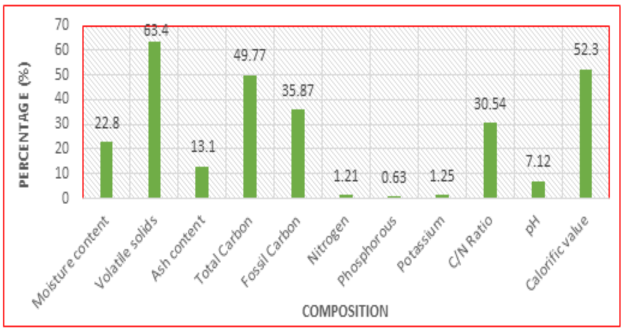


Figure 7. Chemical composition of solid waste

From the Physical Characterization of solid wastes, the following are identified such that landfill mostly consists of Municipal solid waste the highest fraction present is Compostable Matter and accounts for 41.7%. The Lowest fraction is Paper with 2.2%.

From the Figure 7, the Chemical Characterization of solid wastes is examined to find out the parameters like volatile solids, ash content, moisture content, calorific value, total carbon, pH, C/N ratio, etc after extensive segregation. The highest composition identified is volatile solids with 63.4% followed by calorific value and total carbon content of 52.3% and 49.77% respectively. Nitrogen, Phosphorous and potassium concentration is very less as the soil encourages only stunted growth of plants. Once the physical and chemical constituents of the municipal solid waste available in the Vendipalayam area is examined, the main intention of analyzing the economic stability and eco-friendly of the specified environment is important. So that the emission gases evolving seem to be the most influencing harmful parameter which have to be examined to warn the nearby municipal sector to enhance the human well-being of that Vendipalayam area. Hence using IoT module, the four gaseous emission carbon dioxide and nitric oxide followed by hydrogen sulphide and methane were measured using gas sensor and stored in the cloud. In order to observe the hazard level of the gas impact, the data were retrieved from the cloud and subjected to data analysis using machine learning algorithms. Table 1 shows the retrieved real-time data of the gaseous emission from the solid waste landfills of the Vendipalayam yard.

Table 1. Cloud retrieved rate of gaseous emissions from the solid waste landfill zone in Erode

Day	Daily Average (in ppm)			
	CO_2 (x10^3)	NO_2 (x10^3)	CH_4 (x10^3)	H_2S (x10^3)
DAY 1	30.33	10.04	3.52	9.26
DAY 2	27.93	10.45	3.12	10.66
DAY 3	27.93	10.11	3.12	8.635
DAY 4	31.92	9.86	3.5	9.22
DAY 5	29.89	11.3	4.8	9.83
DAY 6	32.23	10.7	4.57	10.92
DAY 7	33.78	10.78	4.12	10.23
DAY 8	33.09	10.04	3.53	9.25
DAY 9	33.11	10.04	3.54	9.26
DAY 10	33.08	9.8	3.54	9.27
DAY 11	33.06	10.04	3.65	9.40
DAY 12	33.02	9.61	3.65	9.27
DAY 13	32.96	10.02	3.65	10.40
DAY 14	33.71	10.66	4.24	10.26
DAY 15	32.98	9.91	3.66	9.27
DAY 16	32.94	9.1	3.66	9.25
DAY 17	32.92	10.2	3.66	9.51
DAY 18	32.91	9.91	3.66	9.26
DAY 19	32.89	9.93	3.66	9.27
DAY 20	32.88	10.1	3.68	9.29
DAY 21	32.88	9.94	3.68	9.5
DAY 22	32.86	10.05	3.68	9.3
DAY 23	33.75	10.07	3.71	9.36
DAY 24	33.78	10.09	3.73	9.38
DAY 25	30.33	10.04	3.52	9.26
DAY 26	30.73	10.24	3.9	9.42
DAY 27	28.33	10.65	3.5	10.82
DAY 28	28.33	10.31	3.5	8.795

DAY 29	32.32	10.06	3.88	9.38
DAY 30	30.29	11.5	5.18	9.99
DAY 31	32.63	10.9	4.95	11.08
DAY 32	34.18	10.98	4.5	10.42
DAY 33	33.49	10.24	3.91	9.44
DAY 34	33.51	10.24	3.92	9.45
DAY 35	33.48	10.24	3.92	9.455
DAY 36	33.46	10.24	3.92	9.455
DAY 37	33.42	10.23	3.92	9.455
DAY 38	33.36	10.22	3.92	9.455
DAY 39	34.01	10.96	4.51	10.45
DAY 40	33.28	10.21	3.93	9.46
DAY 41	33.24	10.21	3.93	9.46
DAY 42	33.22	10.21	3.93	9.47
DAY 43	33.21	10.21	3.93	9.47
DAY 44	33.19	10.23	3.93	9.48
DAY 45	33.18	10.23	3.95	9.5
DAY 46	33.18	10.24	3.95	9.5
DAY 47	33.16	10.35	3.95	9.51
DAY 48	34.05	10.37	3.98	9.57
DAY 49	34.08	10.39	4	9.59
DAY 50	34.04	10.41	4	9.6
DAY 51	40.18	11.98	5.24	11.68
DAY 52	43.89	12.14	5.35	12.02
DAY 53	45.02	12.82	5.60	12.81
DAY 54	47.24	13.41	5.89	13.08
DAY 55	49.87	14.59	6.08	13.92

Table 2. Statistical model ranking result to find the most priority gas emission

Descriptive Statistics					
Gas ranking	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
CO_2 (x10^3)	55	27.93	49.87	33.6860	4.12690
NO_2 (x10^3)	55	9.10	14.59	10.5055	.92725
H_2S (x10^3)	55	8.635	13.920	9.88545	1.053580
CH_4 (x10^3)	55	3.12	6.08	4.0349	.64555

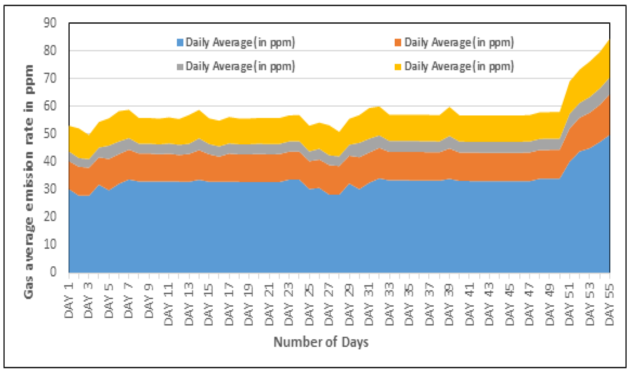


Figure 8. Graphical representation of various gas emission rate statistics

In order to analyze the environmental sustainability, the multiple gas emission data have been undertaken, but when it comes to control strategy it is important to concentrate on the most predominant factors for better prevention. Since four gases such as carbon dioxide, Nitrogen dioxide, Hydrogen sulphide and methane have been monitored for 55 days have been taken for validation as shown in Figure 8. It is very important to identify the most prioritizing factor among four to get proper alert and warning to the nearby location to resolve the global issues of human health. Hence initially, the data are put to the descriptive statistics analysis, to find the individual impact on the ranking wise analysis. Table 2 gives the numerical result of the descriptive statistical model with ranking from 1 to 4 in which carbon dioxide emission takes the highest priority as compared with NO_2, H_2S and CH_4. Because CO_2 emission holds the maximum emission rate of 49.87 (x10^3) kg holding mean of 33.6860 with standard deviation of 4.126. Also, CH4 attain the least ranking by mean around 4.034 with standard deviation as 0.6444 with the maximum emission rate of 6.08(x10^3) kg.

Further, to evaluate the correlation among the gaseous emission due to the existence from the same municipal solid waste area, it is important to evaluate the significance level on the monitored datasets. Partial correlation analysis is carried out to find the individual emission rate coefficient value. From Table 3 it is inferred that the CO_2 holds the correlation factor of 1 which indicates the most influence on the gathered gas emission rates. Others followed by NO_2 and H_2S by ignoring the CH_4 which infers that it holds the least coefficient value with null-hypothesis. The significance value of CO_2 indicates its less than 0.05 indicates the strong dominant correlation on comparing with the other emission rates of the Vendipalayam area for further alertness and precaution steps of analysis.

Table 3. Correlation coefficient value of emission gas for finding the highest priority

Correlations					
Ranking 1st three options			CO_2 (x10^3)	NO_2 (x10^3)	H_2S (x10^3)
Partial correlation coefficient ranking orders	CO_2 (x10^3)	Correlation	1.000	.331	.409
		Significance (2 - tailed)	.	.015	.002
		df	0	52	52
	NO_2 (x10^3)	Correlation	.331	1.000	.671
		Significance (2 - tailed)	.015	.	.000
		df	52	0	52
	H_2S (x10^3)	Correlation	.409	.671	1.000
		Significance (2 - tailed)	.002	.000	.
		df	52	52	0

From this multiple gas sensors emission rate descriptive statistical results, the emission of carbon dioxide seems to be in higher rate as compared with nitrogen dioxide, hydrogen sulphide and methane. Hence there should be the need of continuous emission monitoring equipment's for suggesting Greenhouse gas mitigation measures and validating the sources of carbon dioxide emission is necessary to reduce the gas rate in and around Vendipalayam zones.

4.2. Real - time assessment of carbon dioxide sources and its characterization

4.2.1. Assessment of CO2 emissions

Since identifying the source the carbon dioxide emission is important, the proposed work starts with the recording of carbon emission from different disposal methods like Open burning/Incineration, Composting and Land treatment units was determined using empirical formulas from 2006 IPCC guidelines (Ma *et al*., 2019) to predict the CO_2 inventories from the solid wastes incurred in the landfill site based on Daily waste generation rate. The data required for detailed analysis is listed below which has been taken for the proposed research work:

WF = 1

DM / TS = 77.2 %

CF / CC = 49.77 %

FCF = 35.87 %

OF = 100 %

$EF_{compost}$ = 0.44 kg CO_2

4.2.2. Carbon emission from open burning / incineration

CO_2 emission due to open burning or incineration of municipal solid waste was calculated using 2006 IPCC Guidelines for National Greenhouse gas (GHG) inventories. Equation 1 is used to calculate the carbon dioxide gas emission from the incineration as follows

$$CO_2 Emissions = MSW \; x \; \Sigma \left(WF \; x \; DM \; x \; CF \; x \; FCF \; x \; OF\right) x \left[\frac{44}{12}\right] \quad (1)$$

CO_2 Emissions = CO_2 emissions (kg CO_2/ day) (0.05053); MSW = Municipal solid waste as wet weight incinerated or open-burned (MT/day); WF = Fraction of waste type in the MSW; DM = Dry matter content; CF = Fraction of carbon in the dry matter; FCF = Fraction of fossil carbon in the total carbon of component; OF = Oxidation factor; 44 = Molecular weight of CO_2 (kg/kg-mol); 12 = Molecular weight of carbon (kg/kg-mol).

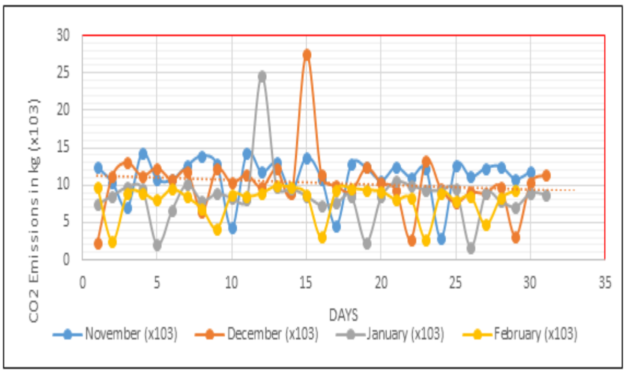


Figure 9. Recorded Carbon Emission from Open Burning / Incineration

Figure 9 confirms that the maximum CO_2 emission of 14,337 kg is recorded in the month of November is on 4th and the minimum emission occurred is 2,920 kg on 24th November. For the December maximum and minimum emissions are 27,574 kg and 2346 kg respectively. In the month of January 24,674 kg of CO_2 is emitted as maximum and 1,701 kg as minimum rate. The emission inventories have started to decrease to 9,946 kg as maximum and 2,578 as minimum CO_2 emission in the month of February.

4.2.3. Carbon emission from composting facility

The CO2 emission from the composting facility was determined by the following Equation 2 as given

$$ECO2 = EFcompost \left(Mcompost \; x \; TS\right) \left(0.3396\right) \quad (2)$$

ECO2 = CO2 emissions (kg CO2/ day); EFcompost = CO2 emission factor for composted material (kg CO2/ kg dry solids); Mcompost = Municipal solid waste deposited to the compost process (MT/day, wet basis); TS = Total solids content of waste material (i.e., Dry matter content)

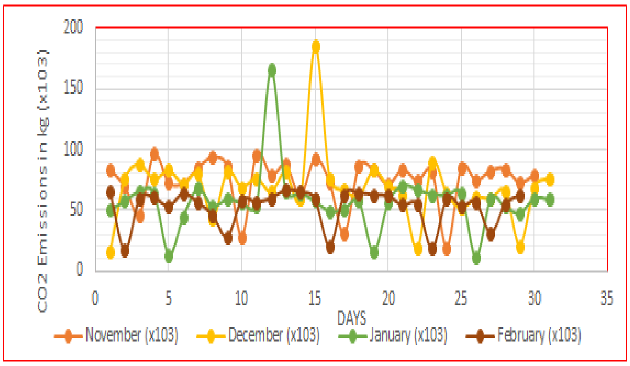


Figure 10. Recorded Carbon Emission from Composting Facility

From Figure 10 it is inferred that the maximum CO_2 emission of 96,355kg is recorded in the month of November is on 4th and the minimum emission occurred is 19,625kg on 24th November. For the December maximum and minimum emissions are 1,85,320 kg and 15,764 kg respectively. In the month of January 1,65,827 kg of CO_2 is emitted as maximum and 11,434 kg as minimum rate. The emission inventories have started to decrease to 66,845 kg as maximum and 17,326 kg as minimum CO2 emission in the month of February.

4.2.4. Carbon emission from land treatment units

It is finally vital to examine the carbon dioxide emission from the land treatment units to decide which month, the gas emission seems to be in higher range to design the alert system from the local control sector. The following Equation 3 considered to evaluate the CO_2 emission from the land treatment unit:

$$ECO_2 = Mw \ x \ TS \ x \ CCw \ x \ [\frac{44}{12}] \qquad (3)$$

ECO_2 = CO_2 emissions (kg CO_2/ day) (1.4088); Mw = Municipal solid waste deposited to the land treatment unit (MT/day, wet basis); TS = Total solids content of waste material (kg dry solids / kg wet solids); CCw = Carbon content of waste material (kg C/ kg dry solids); 44= Molecular weight of CO_2 (kg/kg-mol);12= Molecular weight of carbon (kg/kg-mol).

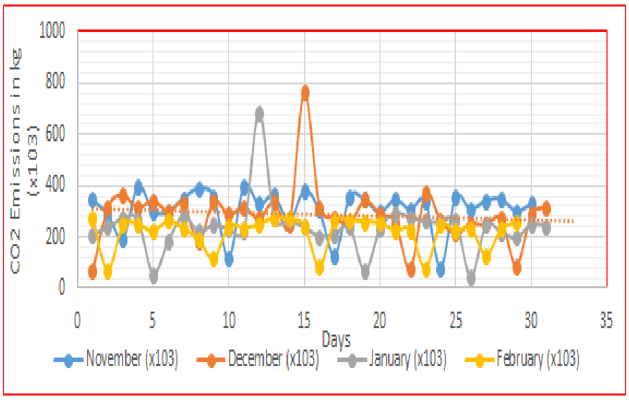


Figure 11. Recorded Carbon Emissions from Land Treatment Units

From Figure 11 it is clear that the maximum CO_2 emission of 3,99,719 kg is recorded in the month of November is on 4th and the minimum emission occurred is 81,415 kg on 24th November. For the December maximum and minimum emissions are 3,64,534 kg and 65,397 kg respectively. In the month of January 24674kg of CO_2 is emitted as maximum and 1701kg as minimum rate. The emission inventories have started to decrease to 9946kg as maximum and 2578 as minimum CO_2 emission in the month of February. From the graphical analysis, the alert system has to be formulated mainly on the January month to control the emission of carbon dioxide to the vendipalayam area mainly by the land treatment units. Because its impact is in much higher rate as compared with composting facility followed by open burning and incineration.

Recommendations: Based on the experimental real-time analysis, few recommendations may be implemented as best practices for preventing emission of greenhouse gases as follows:

- 3 R (Reduce, Reuse and Recycle) Principles can be pursued for decreasing the waste generation and disposal rates.
- Suitable Segregation and Treatment methods shall be opted by all the individuals at the source of generation itself for best results.
- Landfill Gas recovery, Improved Landfill practices may be suggested for the improved management strategies.
- By the expanded sanitation coverage and via controlled composting, significant Greenhouse gas emissions can be reduced.
- Recovering energy from refuse (landfill gas, anaerobic digester, biogas and incineration) form will form a gradual reduction of those emissions through the preservation of raw substances, enhanced energy, material competence and fossil fuel avoidance.
- Adequate waste treatment methods and financial inducement will enrich the waste management options to attain the diminution goals.
- By creating Awareness on mitigation potentials could be made useful to reduce greenhouse gases emission.
- Collection of Coordinated National and International data using the smart sensors will found to provide overview of the emission trends to pollution control board officials to suggest proper treatment methods.
- Standardized data analysis after field validation of models shall be continued to identify the impacts occurred due to emission phenomenon.
- Performing life-cycle assessment (Carbon Footprint) periodically using ICT (Interactive Communication Tools) tools may help to decrease the catastrophic effects of noxious emissions.

Table 4. Measured ground water pollution (Monthly Average)

Sample Locations (20 Acres)	pH	Hardness	BOD (mg/L)	COD (mg/L)	Chlorides (mg/L)	Sulphates (mg/L)	TDS (mg/L)	Alkalinity (mg/L)	EC (ppm)
S1	8.9	337	7.35	28	1266	296	814	453	1271
S2	8.3	326	6.81	27	1729	245	862	412	1589
S3	8.7	351	7.07	31	1320	282	820	440	1312
S4	8.1	315	6.77	21	1755	325	792	400	1603
S5	6.9	260	5.51	13	1853	280	912	361	1637
S6	9	228	7.83	36	1200	358	621	468	1197
S7	5.6	192	4.21	34	2098	286	967	298	1744
S8	7.8	268	6.12	26	1800	312	714	384	1623
S9	8.5	283	7.13	31	1685	269	828	426	1573
S10	6	216	4.58	28	1997	259	926	344	1645

Table 5. Predicted ground water pollution range for 2023 (January-April) based on 2022 pollution occurrence rates

t	year	quarter	deviation from normal performance (%)	MA (4)	CMA	St	De-seasonalize	Predicted
1	1st Quarter (2022)	1	1.8			1.18	1.53	3.76
2		2	1.1			0.72	1.53	2.39
3		3	3.8	2.55	3.05	1.15	3.30	4.02
4		4	3.5	3.55	3.68	1.08	3.24	3.93
5	2nd Quarter (2022)	1	5.8	3.825	3.7	0.90	6.42	3.43
6		2	2.2	3.575	3.68	0.77	2.87	3.03
7		3	2.8	3.8	3.56	1.13	2.47	4.64
8		4	4.4	3.325	3.37	1.21	3.63	5.15
9	3rd Quarter (2022)	1	3.9	3.425	3.88	0.90	4.32	3.97
10		2	2.6	4.35	4.4	0.77	3.39	3.49
11		3	6.5	4.45	4.56	1.13	5.74	5.33
12		4	4.8	4.675	4.87	1.21	3.96	5.89
13	4th Quarter (2022)	1	4.8	5.075	4.98	0.90	5.32	4.52
14		2	4.2	4.9	5.01	0.77	5.47	3.96
15		3	5.8	5.125		1.13	5.12	6.01
16		4	5.7			1.21	4.70	6.62
17	Next Quarter	1	?			0.90		5.07
18		2	?			0.77		4.42
19		3	?			1.13		6.70
20		4	?			1.21		7.36

4.3. Analyzing the impact of solid waste landfills on the ground water

Municipal solid waste (MSW) landfills are widespread, and the numerous hazardous items they house present a major threat to both the local environment and human populations. Because municipal solid waste from the local dumping site could be a source of pollution, areas close to landfills are more likely to have contaminated groundwater. Due to the sharp expansion in population, the effect of landfill on the surface and groundwater has been the subject of numerous research in recent years. Users of the local groundwater supply and the environment are both at significant danger as a result of this groundwater contamination. Once debris has been placed in a landfill, leachate may percolate to the ground's surface and cause contamination. Groundwater and the accompanying aquifer become unreliable for home water supply and other applications when contaminated by such leachate. The use of leachate-contaminated groundwater from these dumps is the threat to human health that is most frequently mentioned. Groundwater resources have been documented to be contaminated by MSW Landfill Leachate in a number of studies, particularly from unlined and uncontrolled landfills. In undeveloped and emerging nations, where landfills are typically uncontrolled open dumps and hazardous industrial waste is also co-disposed with municipal garbage, the threat posed by such landfills to groundwater resources is greater. By analyzing the greenhouse gas impact and assessment on concern with municipal solid waste management, it is very vital part to examine the quality of the ground water for the human survival on the Vendipalayam area. To evaluate the contamination of surface and groundwater, a variety of methods can be applied. It can be evaluated by either measuring the contaminants experimentally or estimating them through mathematical modelling.

From different locations, Groundwater Samples (Point Sources) are collected on daily basis for two months and water quality parameters such as pH, Turbidity, Chlorides, Sulphates, Alkalinity, Total Hardness, Electrical conductivity, TDS were analyzed in and around the dumping yard and Monthly average values are displayed in Table 4. Many locations shows that the water quality level is not pertaining to the permissible limits due to waste dumping activities and untreated effluents from industrial discharges. Due to seasonal differences in the type of waste dumped and different climates, it is observed that changes in solid waste creation and chemical properties take place (Saravanan *et al*., 2023; Arumugam *et al*., 2022). Additionally, it is discovered from the chemical properties of solid waste that variations in concentration level happen when waste layers deteriorate. The depth of the garbage pits at landfill sites varies, hence the waste layer's thickness is not constant. The temporal change of ground water pollution levels is also caused by the fluctuating age and thickness of waste compartments.

From Table 4, it is inferred that the with levels of wastewater parameters including Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), ammonium nitrogen, turbidity, and solids that are many times higher than those in municipal effluents, the leachate that is thus produced is a high strength wastewater. If soluble or suspended organic materials, ammonium nitrogen, and inorganic ions such heavy metals are not adequately collected, processed, and safely disposed of, leachate produced as a result of moisture release, precipitation, and infiltration will readily grow. In order to predict the ground water pollution for the upcoming month for better resolvent, hardness and chlorides parameters are considered as the main primary parameters to find the future forecasting of ground water pollution range.

To execute the linear regression analysis, find the abnormality have to be identified, so the normal standard range of hardness and chlorides threshold values have to be fixed as the boundary limit. The ideal range for drinking water hardness is between 80 and 100 mg/L. In the majority of the province's regions, water with a hardness of over 200 mg/L is regarded as bad, and water with a hardness of over 500 mg/L is typically regarded as inappropriate for residential use (Sundar *et al*., 2022). Chloride in drinking water must not exceed a maximum of 250 mg/L. Instead of health factors, this criterion is based on taste considerations.

Table 6. Regression output for the ground water pollution

Regression Statistics								
Multiple R	0.862							
R Square	0.838							
Adjusted R Square	0.8183							
Standard Error	1.222							
Observations	16							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	16.346	16.346	10.929	0.0001			
Residual	14	20.938	1.4955					
Total	15	37.284						
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95%**	**Upper 95%**
Intercept	2.117	0.641	3.3018	0.005	0.7420	3.4929	0.742	3.492
X Variable	0.2192	0.066	3.3059	0.005	0.0770	0.3615	0.077	0.361

Time series forecasting of ground water pollution using linear regression analysis have been executed. The dataset is derived from the water analysis test taken from ten sample area location of vendipalayam to examine the impact of municipal solid waste landfills on the localized areas. It is inferred that it is not only the affects the environment sustainability but also the ground water due to the deposition of chemicals influences by the solid wastes. Table 5 gives the input of the forecasting as the deviation range of ground water of 2022 year samples taken from the water test report to predict the possible ground water pollution range to occur in the 2023 first quarter months. The dataset is validated by taking moving average for every quarter analysis followed by finding the center moving average to get the threshold level for the 2023 pollution prediction. By taking intervals of centre moving average, the slope value of the best fit line of the linear regression will be finalized to fit the successive quarter deviated dataset. Table 6 gives the regression summary output to find the probability of the forecast model on finding the 2023 first quarter ground water pollution range in percentage.

From Table 6, it is confirmed that the predicted ground water pollution estimation for 2023 model holds the R square value of 83.8% making the analysis to be best fit with the real-time validating model. Also, the standard error is found to be less than 2 confirming the residua rates are in the normal probability distribution template. Further, to analyze the null-hypothesis, the significance value is found to be less than 0.05 shows that the model gets well formulated from the given dataset. The sum of square value for the residual is around 20.938 with sufficient sig value holds higher degree of probability. The F-distribution of the test statistic is null under the null hypothesis. The F-statistics holds value of 10.929

determine which statistical model better represents the population from which the data were sampled, it is most frequently applied when contrasting models that have been fitted to data sets.

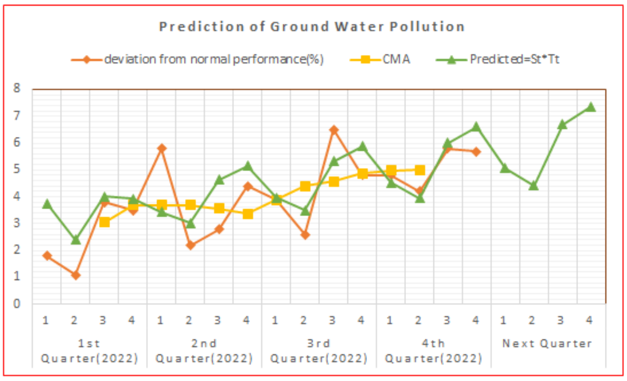


Figure 12. Predicted ground water pollution of the proposed area of vendipalayam

Figure 12 shows the predicted visual representation of the Vendipalayam ground water pollution probability possible to occur in future. From the regression summary graph, it shows that an active landfill is influenced by age, type of garbage discharged, and climatic circumstances, according to the variation in Vairapalayam yards leachate characteristics. Both varieties pose a serious concern to the environment and public health due to their extremely high contamination potential compared to municipal sewage. The outcomes of the leachate toxicity bio assay further demonstrate how crucial it is to conduct such eco-toxicological evaluations in order to identify detrimental effects on the environment. The study unequivocally shows that leachate can cause serious harm if it is permitted to immediately leak into surface water or reach the groundwater aquifer. Therefore, upgrading the landfill is strongly advised in order to manage and reduce the effect of Vendipalayam municipal solid waste on the quality of the groundwater surrounding the dumping area.

5. Conclusion

In this proposed work, initially the ground water pollution potential is identified, by considering ten different locations in and around Vendipalayam dumping yard. From the samples collected it is clearly known that eight out of ten locations have ground water pollution. Also, a multidisciplinary combined approach is implemented to prevent the pollution using cloud computing techniques. Preliminary step has been taken for designing the networks of Internet of Things and sensors were wirelessly connected to the cloud which in turn provide continuous monitoring of the greenhouse gases emissions during the waste collection process in a minute wise manner, instead of weeks. This continuous gas emission monitoring system will help in reducing the pollution phenomenon and waste along with the likelihood of miserable events in the study area. Based on the waste generation data computed, a linear projection of gaseous emission is done for the next two months using Python coding. Periodic monitoring and analysis of COx, H2S, NOx and CH4 emissions along with cloud computation techniques will help in achieving better ambient air quality standards by suggesting the appropriate control measures then and there to the local officials for ensuring Environmental sustainability in and around the Vendipalayam dumping yard in Erode district. The results obtained from the modelling of COx, H2S, NOx and CH4 emissions shows that, the peak emission of Carbon-dioxide, Hydrogen sulphide, Nitrogen-dioxide and Methane will occur at a rate 57.87(x103) PPM on the 60th day, 19.92(x103) PPM on the 57th day, 22.12(x103) PPM on the 59th day and 19.12(x103) PPM on the 60th day respectively. Also, future forecasting of the ground water pollution is increasing exponentially based on the linear regression prediction model. So, this kind of models will help the decision makers to explore the futuristic carcinogenic emissions which will occur in and around Vendipalayam dumping yard along with the ecofriendly best practices.

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