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Design of Landfill Site Monitoring System to Study the Health Effects of Greenhouse Gases using Autonomous Sensing Nodes

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***Abstract:** India is a second largest populated country and fastest growing economy in the world, with the rapid urbanization, facing a challenge of massive waste management, as the municipal councils are depositing solid waste at dumping yard within or city outskirts haphazardly. Open dumping of solid waste resulted in emission of greenhouse gases like, methane (CH4), Carbon dioxide(CO2), carbon monoxide(CO) and volatile organic compounds(VOCs) that have calculated risks on human health, leads to ground, air and ground water pollution around the landfill sites.*

In this paper we propose to design an interconnected, interoperable remote monitoring system, to study the effects of greenhouse gas concentration level on human health at the surroundings of solid waste dumping yard/landfill site at Kuppam town (Chittoor (dist), Andhra Pradesh, India). We have conducted the real-time survey on health condition of human beings living at the surroundings of waste dumping yard. In this study, we designed a self-powered autonomous sensing node by incorporating industrial gas sensors & measured the concentration levels of greenhouse gases at the center of the site & 300-500 meters away from the dumping yard. The measured concentration levels of gases are uploaded to the IoT servers, and user-friendly Smartphone application is developed to read the greenhouse gas data from IoT servers using API Keys. Comparison of measured concentration level is made against the standard exposure levels (TLV) with duration, to alert the peoples living at the surroundings of MSW site. Surroundings of MSW site monitoring needs a greater attention to address the health issues related to emission of greenhouse gases from dumping sites. The monitoring system has shown satisfactory result in terms of measurement of concentration levels, its exposure limits with the duration and finding the health effects on human beings.

***Index Terms:** Greenhouse gases, Industrial gas sensors, duping yards/landfill sites, Health effects, IoT, WSN and Smartphone Application.*

I. INTRODUCTION

Solid waste management and monitoring is a major issue, which is gaining more importance in a rapidly growing country like India, as millions of tons of municipal waste is being just dumped in scientific engineered landfill sites or unscientific dumping yards. Invariably, Over the period of time the degradation/decomposition of municipal solid waste emits greenhouse gases (GHG)/Landfill gases (LFG) [1], contains typically 60% of Methane gas (CH4), 40% of Carbon Dioxide (CO2) & wide ranges of volatile organic compounds(VOC's) [2] [8].

The LFG is produces by an anaerobic degradation of organic matter in the dumping yard/landfills; equation 1 gives the anaerobic breakdown of waste (Tchobanoglaus et al. 1993; Aitchinson 1996) [18] [24].

$$C_aH_bO_cN_d + nH_2O = XCH_4 + yCO_2 + wNH_3 + 2C_5H_7O_2N + \text{energy} \quad \text{------------(1)}$$

Where; $C_aH_bO_cN_d$ → Biodegradable organic matter's empirical formula

$C_5H_7O_2N$ → chemical formula of the microbial mass.

The LFG generation starts after about 3-6 months period, from the waste deposited in the landfill/dumps depending on the amount and rate at which waste decomposition undergone before landfilling [7]. The quality and quantity of LFG produced is based on the rate of degradation of waste. The LFG emission into the environment & surrounding area is influenced by following factors like; atmospheric pressure around the MSW site, type of soil, moisture content in the air, temperature around landfill and age of the landfill (Schorff and Jacobs 2006) [7].

The greenhouse gases emission from landfill sites / dumping yards is not only being emitted into the environment, but more importantly, these gases migrate beyond the landfill boundary to the living area [3]. The greenhouse gas emission at landfill sites/ dumping yard poses greenhouse effect/global warming on a large (global) scale, but the gas emission may be detrimental to the surrounding(local) environment of the site, especially health implications on the living beings at the proximity of the dumping yards [6][20]. The health impacts are so crucial, as carbon dioxide (CO_2) poses Asphyxiation (suffocation) risk it is denser than air [4], while excessive Methane (CH_4) gas concentrations may result in the death of surrounding vegetation [5], as it is highly flammable in range of 5-15% v/v. The gases like Carbon monoxide (CO) & Hydrogen Sulphide (H2S) are highly toxic in nature, consumption above concentration limits may lead to death.
The most of epidemiological investigations conducted by Dolk et al.,Elliott et al., Vrijheid et al. show that landfilling sites are likely be related with a slight increment in the dangers of congenital anomalies [10]. The most detailed examination did by Elliott et al. recognized a conceivable little relationship between nearness areas to landfill sites and the event of inborn anomalies,

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however a few signs recommend that any expansion is expected at any rate somewhat to factors other than the landfill site [13].

The major pitfalls of epidemiological studies using distance of residence from the MSW site (the vicinity to a site) as a factor for the exposure to LFG gases emitted from the landfill sites, as opposed to evaluating the exposure of population to the specific LFG concentrations from the landfill sites in the investigation. Therefore, researchers recognises the future work should be directed on exposing population to the LFG emitted from the landfills and their associated health effects on the human beings.

The present research work concentrated on studying the health effects of LFG(GHG) concentration levels around the Kuppam dumping yard with real-time survey & measuring the LFG concentration levels at the landfill site & 500 to 1000 Meters away from the site, where the peoples living around. We selected the Kuppam municipal waste dumping yard for the study

The proposed research work involves the development of a small, energy efficient, autonomous sensor nodes to measure the landfill gases at the selected locations using industrial sensors. The type of industrial sensors selected for measurement are based on the factors like Cost, accuracy, range & Power consumption, they are; Infra-red (IR) based sensor(CDM6840) for Carbon dioxide (CO_2) measurement, Electrochemical sensor (TGS5460) for Carbon monoxide (CO) measurement & Semiconductor sensor (TGS2611) for Methane (CH_4) measurement.

The remote monitoring of LFG concentration at and around the selected site is enabled by uploading the real-time information about gas concentration levels to Internet of Things (IoT), thereby the real-time data can be accessed through web-sites / IoT platforms and through the interactive mobile applications, so that everyone can access the real-time data and get awareness about the amount of greenhouse gas concentration they are exposed daily around the landfill sites.

II. MATERIALS & METHODS

2.1 Study Area

Municipal waste open dumping yard located at Netaji Road Kuppam, Andhra Pradesh, India has been selected for studying the greenhouse gas emissions & its hardous health effects on the peoples living in and around 1 km radius from the dumping yard. The waste dumping site located east-south region of the town.

Figure2.1: MSW dumping site, Netaji road Kuppam.

The site receives approximately 50 to 100 tonnes of waste every day with having no gas collection unit, therefore the LFG is directly emitted to open environment & also most part of it migrates to the surrounding living area around the site.

2.2 Sapling of LFG & Sample Analysis

In this research study, the concentration of LFG emissions are measured by developing autonomous gas sensing nodes incorporating the industrial sensors, CDM4860 (CO_2), TGS5340 (CO) & TGS2611 (CH_4). The sensing nodes are powered by solar energy for portable LFG measurements. Here, one sensor node is placed at the center of the dumping site & remaining at the boundaries of the site, but to study & measure the level of LFG concentration emitted to the surrounding places up to 500m, one of the portable autonomous sensor nodes is used. The concentration levels of greenhouse gases were measured starting from the center of the landfill site, and then measurement is extended up to 50 meters, 100m, 200m & 500m radius surrounding the site. The amount of gas concentration was also measured at different houses situated at the proximity of the dumping site. The sampling of data was carried out up to 6 months starting from June 2018 to November 2018, finally, after the interpretation & processing of the data, it was uploaded to Internet of Things (IoT) for remote monitoring through mobile applications & web links.

2.3 Methodology

2.3.1 Remote Monitoring

There are four possible approaches to monitoring gaseous emissions at MSW landfill sites. These are passive sampling, active sampling, continuous monitoring and remote monitoring (McGettigan et al., 2000). Remote monitoring method/approach was adopted to perform real-time measurements autonomous sensing nodes, developed by incorporating Infra-red & chemical industrial type gas sensors. The real-time measurement of greenhouse gas concentration levels was carried-out at and/or around the selected study area for an around 6 months. IPCC default method was used to analyze the emission concentration and daily exposure levels at the sites.

2.3.2 Data storage & IoT Mobile Application

Landfill gas emission measurements were carried out using fixed and portable autonomous gas sensing nodes up to 500m distance from the site.

Then the measured gas concentrations were analyzed & uploaded to IoT database for further assessment of health risks around the study area. User-friendly Mobile Application reads the real-time data from the IoT analyses the concentration levels & displays the possible health effects by comparing the standard threshold levels (screening values) framed by IPCC [20].

2.4 Risk Assessment & Standard Guidelines:

In order to assess the health effects of gas emissions on human beings, a real-time survey has been conducted during June 2018 to November, 2018 at nearby houses surrounding the site. The real-time survey includes questionnaires: queries of health status Viz Disease type, frequency of occurrence & age. Based on the surveyed data and measured gas concentration levels, Risk assessment was carried out, considering the standard safety daily intake of gas concentration levels. Risk assessment is based on the chronic daily intake of LFG concentration levels was calculated from equation (2) below [6]:

$$EC = \frac{Cair\ x\ EF\ x\ ED\ x\ ET}{AT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, **EC** → Exposure concentration (in mg/m3),

C_{air}→Air median concentration of each pollutant (in mg/m3),

EF → Exposure frequency (250 days/year),

ED →Exposure duration (25 years),

ET → Daily exposure time (8/24h),

AT → Average time (365 days/year ED).

Next, the exposure concentration obtained was compared with standard limit values (Screening values) established to estimate the hazardous health effects of LFG's from the regulation and guideline given.

Table I & II give the standard guidelines for GHG exposure threshold limit values;

Table I: Standard Exposure limit values of CO2 [25]

Table II: Standard Exposure limit values of CH4 [25]

TLV:-Threshold Limit Value, TWA:-Time Weighted Average, STEL:-Short Term Exposure Limit, IDLH:-Immediate Dangerous to Life & Health.

III. RESULTS AND DISCUSSION

In order to study the hazardous health effects associated with greenhouse gas [GHG] emissions around the landfill/dump site, designed a portable embedded device using industrial sensors shown in figure 3.1 and conducted measurement of GHG concentration at MSW filling site, 100 m, 300 m & 500 m away from the site near the resident areas. The concentration of GHG measured from the pointed places can be established by comparing Threshold Limit Value (TLV) and the daily chronic intake can be established by Exposure Concentration (EC) obtained.

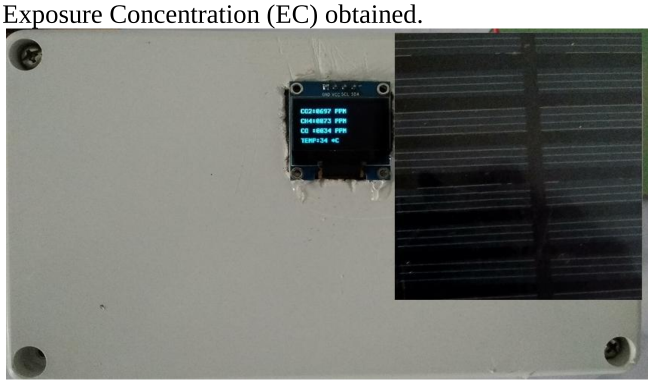

Figure 3.1: Self-Powered GHG Measuring Embedded Device

The American Conference of Governmental Industries Hygienists (ACGIH) recommended TLV-TWA of 5,000 ppm; i.e TWA of CO2 concentration that may be exposed during a normal 8-hour/work day & 40 hour/ work week. Additionally, ACHIH recommend a short-term exposure limit (TLV-STEL) 30,000 ppm (0.3%) for 15 minutes. OSHA has set a permissible exposure limit for CO2 of 5,000 ppm by value (0.5%) [21], This is the recommended maximum concentration exposed to in an 8-hour period. The Occupational Safety & Health has no permissible exposure limit for CH4, but according to NIOSH & ACGIH maximum recommended safe concentration limit during an 8-hour period is 1,000 ppm (706.3 mg/m3) [22]. OSHA's former limit for CO was 50 ppm as 8-hour time-weighted average (TWA), According to ACGIH, TLV-TWA of 50ppm with a TLV-STEL of 400ppm [21]. But may be based on a study by Schulte (1964/Ex. 1-366) the exposure to 100 ppm CO for 4-hour is excessive.

Figure 3.2 to Figure 3.5 shows measured concentration of CO2, CH4 & CO at the pointed places from the MSW filling site.

TLV-TWA	TLV-STEL	IDLH
5,000 ppm	30,000 ppm	40,000 ppm

CH4 Exposure limit (ppm)	Levels & Effects
1000	8-hour/day Daily Chronic Intake Threshold Limit Value (TLV) by NIOSH
50,000 to 150,000	Potentially Explosive Concentration Levels
500,000	Oxygen Deficient atmosphere (Asphyxiation)

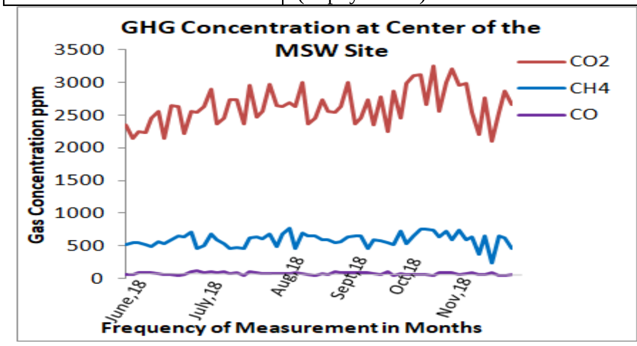

Figure 3.2: GHG measured concentration at the Center of MSW site

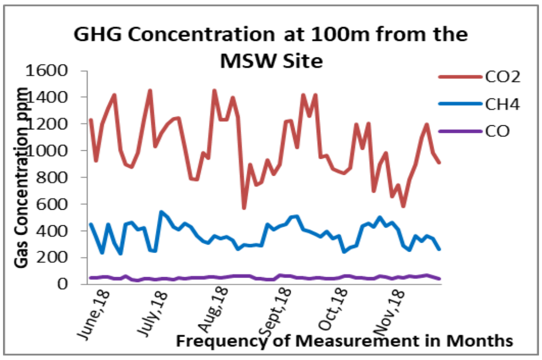

Figure 3.3: GHG measured concentration at the 100M from MSW site

The graphs in figures 3.2-3.5 shows the measured concentration levels of CO2, CH4 & CO over the period of 6 months, around 60 samples were collected at pointed places from the MSW filling site.

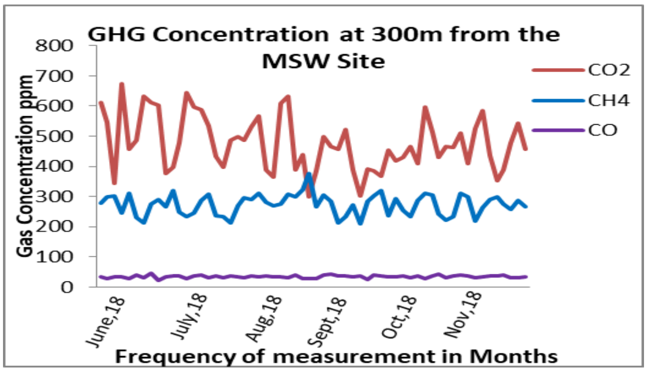

Figure 3.4: GHG measured concentration at the 300m from MSW site

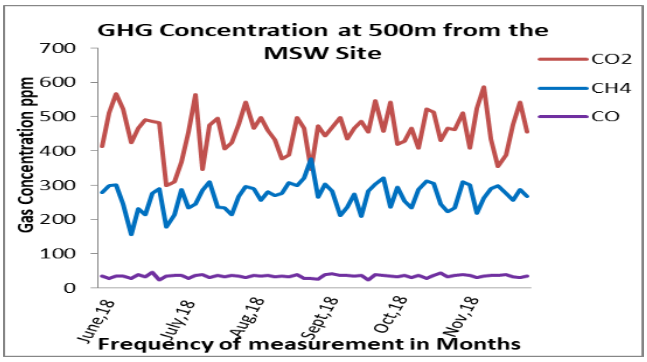

Figure 3.5: GHG measured concentration at the 500m from MSW site

From figure 3.2, GHG emission concentration measured at the center of MSW site, varies from 2100 ppm to 3450 ppm for CO2, 300 ppm to 750 ppm for CH4 & 45ppm to 100ppm for CO gases. Figure 3.3 shows GHG emission concentration measured at the 100 meter from MSW site, varies from 610 ppm to 1450 ppm for CO2, 220 ppm to 550 ppm for CH4 & 38ppm to 55ppm for CO gases. Figure 3.4 shows GHG emission concentration measured at the 300 meter from MSW site, varies from 298 ppm to 680 ppm for CO2, 210 ppm to 390 ppm for CH4 & 35ppm to 40ppm for CO gases. Figure 3.5 shows GHG emission concentration measured at the 500 meter from MSW site, varies from 290 ppm to 670 ppm for CO2, 160 ppm to 365 ppm for CH4 & 25ppm to 35ppm for CO gases.

Table III: The Measured Value of Concentration & Chronic Daily Intake of Greenhouse Gases

Table IV: Real survey data analysis showing health condition around MSW Site Kuppam

Resident Name	Symptoms	Frequency of Occurrence
M.Mani	Malaria,Cough , Drowsiness	1 Week
M.Permal	Cough, Allergy ,Fever	1-15 Days
M.Hanieef	Fatigue, Cough , Dangyu Fever	7 Days
A.Jaffer	Asthma,Fever	1-10 Days
K.Muniappa	Asthma, Bad Smell,Fatigue	1 Week
Sujatha	Cough,Asthma ,Drowsiness	1-5 Days
Kavitha	Fever, Sleeplessness	5 Days
Mohan	Cough, Allergy, Cold	4 Months
Muni lakshmi	Cough, Headache	1 Week
Kanchanamma	Vomits, Headache	1 Week
China Raju	Asthma, Malaria	2 Months
Venu Raj	Tb, Asthma	1 Week
Krishna	Fever ,Cough	1 Week
J Balaji	Nausea, Allergy	1 Week
Naveen	Drowsiness	1 Week

Table III shows the summary of measured concentration and calculated chronic daily intake i.e Value of Exposure Concentration (EC) of CO2, CH4 and CO greenhouse gases at different locations from the MSW site. From Table 2 it is found that CO2 & CH4 are below the threshold limits given by ACGIH & NIOSH, but CO concentration exceeds its TLV-TWA of 50ppm as per ACGIH at MSW filling Site. Similarly, at 100m from the MSW site CO just likely exceeds the TLV and CO2, CH4 are well within the TLV.

Real survey conducted around the MSW site data analysis shows that, about 15 residents are suffering from various diseases as shown in Table IV.

IV. CONCLUSION

Hence with this research work, we tried to study the health issues associated with LFG emissions around the waste dumping site by designing low cost, low power autonomous sensing node.

Conducted real survey to know the status of resident's health & LFG concentrations around the MSW site up to 6 months, survey data shows residents staying at the proximity of the site are facing some health issues mentioned in table IV. Therefore here we designed a self-powered, intelligent embedded device to measures and analyzes the measured LFG concentration, compares with the standard TLV levels to alert about the health effects associated with constant exposure of GHG. Finally the measured data was uploaded to IoT clouds for remote access & monitoring. Designed a user-friendly mobile application for accessing concentration levels of GHG at the selected sites for creating awareness to the residents around the landfill sites about health effects of greenhouse gases emitted to the surrounding areas. The designed embedded autonomous sensing device with infrared and chemical sensors has shown satisfactory results with good accuracy.

Measurement Location	Greenhouse gas concentration in ppm			EC (ppm)		
	CO2	CH4	CO	CO2	CH4	CO
MSW Filling Site	2100-3450	300-750	45-100	332.36-844.54	74.26-184.12	11.35-24.74
100m from MSW Site	610-1450	220-550	38-55	150.25-355.21	54.56-377.67	10.10-14.08
300m from MSW Site	298-680	210-390	35-40	204.65-167.35	52.46-96.28	9.17-10.35
500m from MSW Site	290-670	160-365	25-35	71.38-164.59	40.03-90.32	6.87-9.17

Therefore effective real-time monitoring of landfill gas emissions around MSW sites, with alerting may reduce the health risks on the living beings.

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