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Diurnal and Seasonal Variations in Carbon Dioxide Emissions in a Solid Waste Management Facility, Akure, Nigeria

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***Abstract*— Municipal solid waste (MSW) is a significant contributor to greenhouse gas emissions through decomposition and waste life-cycle processes. The available literature is scanty on fluctuations of carbon dioxide (CO_2) emissions from MSW facilities especially in tropical developing countries like Nigeria. This study monitored seasonal variations in the CO_2 levels emitted at an open dump in the solid wastes management facility, Akure. For a year, wastes brought to the MSW facility from three major sources, viz: markets, residences and other non-specific sources dumped on roadside were assessed for their physical composition and the amount of waste generated. Air CO_2 levels were monitored at seven critical locations Laboratory (L), Organic Fertilizer (OF), Plastic Recycling (PR), Overhead Tank (OT), Sorting Area (SA), Gatehouse (GH) and Outside(O) every day for a week at 9.00am, 12.00 noon and 2.00pm , during the dry and rainy seasons using a P-Sense Plus CO_2 meter AZ-7755 (USA) and computed. Results indicate that the total wastes generated (paper) from all the sources were 5,834,005.0± 5,079633.8 (wet season) and 4,266,871.0±3,745,337.8 kg (dry season), respectively. There were no significant differences in the carbon dioxide levels in the morning: 506.9 ± 71.1 and 537.0 ± 91.8 ppm; 450.6 ± 28.4 and 456.0 + 10.8 ppm; 442.6± 19.4 and 448.0 ± 10.4ppm for the L, SA and GH; in the noon: 415.0 ± 15.9 and 458.5 ± 44.1ppm; 427.3 + 20.5 and 443.5 ± 10.4 ppm and 425.6 ± 14.3 and 438.0 ± 0.12 ppm for PR, OT and GH and the afternoon: 434.3 ± 45.3 and 438.0 ± 7.2 ppm for GH only in the wet and dry seasons respectively. The atmospheric CO_2 data in the study area showed clear seasonal and diurnal variations as evident in values of 438.00 to 630.0 ppm in the dry season and 407.3 and 506.9 ppm for wet season. These values were above the regulatory limit of 400.00 ppm specified by the National guideline values. The study suggested periodic monitoring of air carbon dioxide levels keeping in mind the seasonal variations.**

***Index Terms*— Solid waste management; Carbon dioxide emissions; Seasonal variations; Municipal solid waste.**

I. INTRODUCTION

Global warming has become a matter of public concern in the last few years. This could be mainly attributed to the trapping of enormous quantities of typical gases (termed as ‘‘greenhouse gases’’) in the earth’s atmosphere resulting in greenhouse gas (GHG) effect thereby increasing the ambient temperatures. In the last few decades, the greenhouse gases produced by human activities have been predominating over those of natural origin [1]. The waste sector is a significant contributor to greenhouse gas (GHG) emissions accounting for approximately 5% of the global greenhouse budget [2].

Carbon dioxide emissions to the atmosphere have risen steadily since the beginning of the industrial revolution. Furthermore, conservative estimates suggest that the world energy demand will double by the middle of this century [3]. Municipal solid waste is a significant contributor to greenhouse gas emissions through decomposition and life-cycle activities/ processes. The majority of these emissions are as a result of landfilling, which remains the primary waste disposal strategy internationally [4]. Waste sector emissions have grown steadily globally and are expected to increase in the forthcoming decades especially in developing countries like Nigeria. This is because of increase in population and GDP [5]. In recognition of this, the Clean Development Mechanism (CDM) established by Kyoto Protocol in 1997, recognized waste and its disposal as one of the sectors identified for greenhouse gas reduction.

When solid waste (SW) is disposed in waste dumps and landfills, most of the organic material will be degraded over a period of time, ranging in a wide span from less than one year to several decades. The majority of this process will be biodegradation and mineralization. Site conditions at the disposal sites determine the biodegradation process whether it is aerobic or anaerobic. The main degradation products are carbon dioxide (CO_2), water and heat for the aerobic process and methane (CH_4) and CO_2 for the anaerobic process. The CO_2 produced and released to the atmosphere contributes to global warming and the emissions need to be reported in national greenhouse gas inventories under the United Nations’ Framework Convention on Climate Change [6]. Near-surface carbon dioxide concentrations have been documented in several cities across the world (Vancouver, Canada; Kuwait city, Kuwait; Mexico City, Mexico; Basel, Switzerland; Nottingham, U.K; Phoenix, USA) to evaluate the dynamics of atmospheric carbon dioxide over short periods of time [7]; [8]; [9];[10]; [11]; [12]. The majority of these studies analyzed daily and diurnal fluctuations in carbon dioxide concentrations and concluded that the major source of carbon dioxide is from vehicular traffic.
There is paucity of information on fluctuations of carbon dioxide from sources of solid waste management especially in developing countries like Nigeria. Although open waste dump fires are widespread in Nigeria, there appears to be

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little research undertaken on them. Open dump fires can cause problems for operators and the fire service, and nuisance for local residents and there may be potential health risks involved. If open waste dump sites fire is ignored, or undiscovered, the fire can become large and dangerous. Assessing air quality within the vicinity of open dump sites fire will help to anticipate the impacts on the concentration of greenhouse gases into the atmosphere that could contribute to climate change on one hand and examine its implication on dump site workers and recyclable waste pickers on the other hand. The study therefore intend to monitor to determine, if there are seasonal variations in the environmental carbon-dioxide levels emitted at the open dump in the Integrated Solid Wastes Management facility which is the major method of disposal of solid wastes in Akure and in many Nigerian cities.

II. MATERIALS AND METHODS

Study Area

Akure is the capital of Ondo State in Nigeria. It is an indigenous African town that lies between latitude 7° 15′ 0″ N and 5° 11′42″ East of prime meridian [13]. The present population of the city according to the 2013 Census Projection is more than 387,087 people [14]. The majority of the people are "Yoruba" while other ethnic groups constitute a smaller proportion of the population. Most of the people are engaged in petty trading and small-scale business, while others are civil/public servants. Akure has several public, private and social amenities such as the Ondo State Specialist Hospital, banks, industries, post office, higher institutions such as the Federal University of Technology Akure (FUTA), Federal College of Agriculture, Akure, Water Corporation and over 700 schools made up of both public and private nursery, primary and secondary schools.
The Integrated Waste Recycling Plant at Akure was commissioned by one of the former Presidents of Nigeria, Chief Olusegun Obasanjo on the 14th of June, 2006 and began operations on the 1st of December, 2006. The conceptualized capacity of the plant was 25 Tons/day, 5Tons/day and 5Tons/day for Organic Fertilizer, Plastic recycling and Metal Scrap Recycling, respectively. However, the plant was running below the design capacity due to several reasons. The total period of production is 8 hours daily. The Recycling Plant is managed by a Project Manager who is a Research and Development Officer in the State Government and reports to the Director of the Planning, Research and Strategy Department of the Ondo State Waste Management Authority. The recycling plant was designed and installed by Environmental Development Foundation under the supervision of Prof. Sridhar (One of the authors) and his team. The Plant consists of three Units namely; Material Recovery/Quality Control Unit, Material Processing and Production Unit and Marketing Unit. The initial size of the facility is 7 Hectares. That is, 6 Hectares for the Landfill and 1 Hectare for the recycling Plant. Presently, the Landfill has gone beyond the 6 Ha. The plant started with an initial size of 80 Workers but presently, the staff size is about 40 workers. Presently the plant is operated irregularly except the open dumping of waste at the large expanse of land adjacent to the recycling plant.

Study Design

An exploratory study design was adopted. The study involved physical characterization of the solid wastes brought to the plant by wastes disposal vehicles, monitoring of air carbon dioxide levels from various locations at the dumpsite including recycling plant.

Characterization and Quantification of solid wastes

Weight determination

Three major sources of wastes were identified:
Market: The wastes that emanate mainly from the markets which sell a variety of commodities including food and fancy goods.
Residential: The wastes are mainly residential wastes which are emanated from 21 zones in Akure city. The wastes generated in the zones were collected through Stratified Random Sampling, on the basis of the type of commodities
Roadside (Non-specific wastes): These wastes arise from trade and offices.

Methods

The characterization and determination of weights of the waste were carried out for a period of 12 months. The segregation waste was carried out by randomly picking a vehicle coming out of the Residential, the Markets and Roadside, once in a month. After the segregation at a central facility, the various components of the solid wastes were weighed using a 20kg capacity *Camry* kitchen weighing scale. The segregation of wastes into leaves; paper and carton; and nylon and plastics are shown in figures no 1, 2 and 3 respectively.. The results were computed for the number of trucks that bring in the wastes. Some of the wastes found in the facility and the opening burning of waste as a common practice which results in CO_2 emissions are shown in Figure no 4.

Fig No 1: Segregation of wastes in leaves

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Fig No 2: Segregation of wastes in paper and carton

Fig No 3**:** Segregation of wastes in nylon and plastics

Fig No 4: Open burning of waste as a common practice which results in CO_2 emissions

Monitoring of the Carbon Dioxide Level

The CO_2 was measured using P-Sense Plus CO_2 Meter AZ-7755 (USA). The monitor also has the in-built sensor to measure relative humidity and temperature. The monitor was calibrated using the manufacturer's guidelines prior to its use. The meter was turned on and held down simultaneously, 400 was entered as CO_2 calibration mode. 400ppm and "CAL" were allowed to blink on the LCD for a period of about 5 minutes until the blinking stopped signaling the completion of the calibration after which the meter automatically goes back to normal mode. The meter defaults to be calibrated the humidity with 33% and 75% salt solution, while the ambient condition is recommended to be at 25^o C

Monitoring of Carbon Dioxide Levels at the Waste Management Facility

At the recycling plant and dump site, carbon dioxide readings were taken at seven sampling points namely; Gate house, Roadside, Laboratory, Plastics Recycling unit, Organic Recycling Unit, Sorting Bay, Overhead Tank and Composting Unit. The meter was taken to a sampling point and placed about 80 cm from the ground. The meter was then switched on for 60 seconds after which the readings of the Carbon dioxide concentration in ppm which were displayed on the screen were recorded. The procedure was repeated thrice for each sampling point. The CO_2 monitoring was done every day for a week at 9.00a.m, 12.00 noon and 2.00 PM daily. The Temperature and Relative Humidity readings were also taken using the **-**Sense Plus CO_2 Meter AZ-7755 (Figure 5).

Fig No 5: P-Sense Plus CO_2 Meter AZ 7755 (USA)

III RESULTS AND DISCUSSIONS

Variations in wastes generation across seasons

Table 1 shows the variations in total wastes generation between the months of March to September, 2013 which represented the wet season and the months of October, 2013 to February 2014 which represented the dry season at the solid wastes management facility. From the wastes brought from all locations, LDPE and plastic was the most generated component of solid wastes with 9,159,995.0 $\pm$ 8,453,005.4 and 6,777,621.3 $\pm$ 6,313,977.0 kg in the wet and dry seasons with no significant difference; this was followed by food waste, paper and textiles with 7,794,894.0 $\pm$ 7,569,909.7 and 5,724,532.0 $\pm$ 5,596,562.0 kg; 5,834,005.0 $\pm$ 5,079,633.8 and 4,266,871.0 $\pm$ 3,745,337.8 kg and 1,785,388.8 $\pm$ 1,394,407.0 and 1,320,720.2 $\pm$ 1,026,759.0 kg in the wet and dry seasons respectively and all with no significant difference. From the above, it was evident that more wastes were brought to the facility during the wet season than the dry season although with no significant difference in composition, although this does not translate to increase in the emission of carbon dioxide. This can be adduced to the fact that during the wet season, there is high humidity as indicated in Table 2 which does not encourage

Table1: Variations in waste generation across seasons

Component	Wet Season		Dry Season		P- Value (<0.05)
	Weight (kg)	SD	Weight (kg)	SD	
Paper	5,834,005.0	5,079633.8	4,266,871.0	3,745,337.8	0.69
LDPE & Plastics	9,159,995.0	8,453,005.4	6,777,621.3	6,313,977.0	0.67
Food Waste	7,794,894.0	7,569,909.7	5,724,532.0	5,596,562.0	0.72
Leaves and Hay	869,107.0	846,914.9	638,293.0	626,156.8	0.72
Textiles	1,785,388.8	1,394,407.0	1,320,720.2	1,026,759.0	0.79
Wood	300,476.5	293,405.3	220,366.3	216,941.7	0.72
Metal	22,426.3	17,026.4	16,518.5	12,664.8	0.80
Can and Tins	129,212.0	111,946.9	93,641.0	81,254.9	0.68
Bottles	265,680.6	229,485.2	191,959.4	163,136.1	0.67
Tyres	93,920.1	54,224.8	69,380.4	40,056.8	0.84
Battery	24,500.9	14,145.6	18,099.2	10,449.6	0.84
Wire	12,498.5	7,216.0	8,876.8	5,125.0	0.83
POP	28,336.0	23,836.0	25,120.0	20,125.0	0.83

*The period of wet season was from March to September, 2013 while that of Dry season was from October 2013 to February, 2014

Table 2: Variations in relative humidity in various locations across seasons

Parameter (%)	Location	Wet Season		Dry Season		P – Value (<0.05)
		Mean	SD	Mean	SD	
Relative Humidity Morning	Laboratory	76.8	6.3	83.6	6.1	0.09
	Organic Fertilizer	84.1	6.8	86.9	7.3	0.29
	Plastic Recycling	81.9	5.7	86.0	9.6	0.24
	Over Head Tank	84.9	9.7	81.8	7.8	0.05
	Sorting Area	83.4	6.3	82.9	9.5	0.84
	Gate House	81.0	8.5	75.9	14.0	0.23
	Outside	78.6	10.4	77.1	12.6	0.47
Relative Humidity Noon	Laboratory	68.6	3.7	74.5	7.2	0.14
	Organic Fertilizer	71.0	12.6	65.8	7.3	0.18
	Plastic Recycling	68.4	12.9	60.6	5.5	0.17
	Over Head Tank	74.9	12.6	52.9	8.9	0.00
	Sorting Area	66.5	17.1	57.9	9.4	0.21
	Gate House	66.9	15.9	53.7	5.4	0.03
	Outside	68.0	15.4	54.2	8.2	0.01
Relative Humidity Afternoon	Laboratory	66.5	9.7	65.7	8.4	0.88
	Organic Fertilizer	67.2	13.4	55.8	3.1	0.04
	Plastic Recycling	65.8	12.1	53.8	3.4	0.04
	Over Head Tank	67.8	14.9	46.1	3.6	0.00
	Sorting Area	64.4	14.2	45.7	3.7	0.02
	Gate House	64.0	12.0	46.5	6.7	0.00
	Outside	61.7	11.3	49.9	6.8	0.05

burning thus preventing emission of carbon dioxide, while the temperature is higher in the dry season thus encouraging burning which leaves to higher emissions as shown in Table 3. It could also be observed that the standard deviation of the distribution of wastes generated were very high because the wastes were not evenly generated from the three locations.

Diurnal and Seasonal Variations in Atmospheric Carbon dioxide and Air Temperature at the Integrated Solid Waste Recycling Plant, Akure

Figure 6 reflect the seasonal variations in the carbon dioxide levels in the seven locations across seasons in the morning, noon and afternoon. It was reflected that in the morning, there were no variations of the carbon dioxide levels in the laboratory, sorting area and gate house with values of 506.86 ± 71.09 ppm and 537.00 ± 91.82 ppm, 450.57 ± 28.43 ppm and 456.00 ± 10.83 ppm and 442.57 ± 19.41 and 448.00 ± 10.38 ppm, for the wet and dry seasons respectively. At noon, there were no variations of the carbon dioxide levels in the plastic recycling, overhead tank and gate house with values of 415.00 ± 15.94 ppm and 458.50 ± 44.07 ppm, 427.29 ± 20.54 ppm and 443.50 ± 10.39 ppm and 425.57 ± 14.29 ppm and 438.00 ± 7.05 ppm for the wet and dry seasons respectively. At the afternoon there was no variation of the carbon dioxide levels at the gate house with values of 434.29 ± 45.28 ppm and 438.00 ± 7.19 ppm for the wet and dry seasons respectively.

These reflect the variations in the carbon dioxide levels at the waste facility in Akure. The levels of CO_2 ranged between 407.29 ppm and 506.86 ppm and in the wet season and 430.00 ppm and 630.00 ppm in the dry season which shows that CO_2 concentration present in the atmosphere were above the regulatory limit of 400 ppm [15]. The situation tends had gone beyond the statement that globally averaged atmospheric situations are 379 ppm [5] and are estimated to increase by 50-100 ppm by 2100 [16]. The atmospheric CO_2 data showed clear seasonal and diurnal variations. During the diurnal variation, the maximum CO_2 concentrations occurred in the morning during the wet season while it is otherwise during the dry Season. In the dry season, diurnal variation was caused by the fact that most of the burning was done during this period and it was usually more effective in the afternoons because of the dryness of the dump waste and increase in temperature which makes it more conducive for burning, thereby leading to the increase of the CO_2 concentration. This is contradictory to the results obtained from a study by [17]. This has great implications on the climate patterns as it has been established that approximately 45% of gas emitted from landfills is carbon dioxide and in

Table 3: Variations in air temperature in various locations across seasons

Parameter (^oC)	Location	Wet Season		Dry Season		P – Value (<0.05)
		Mean	SD	Mean	SD	
		28.4	1.6	28.0	1.1	0.56
	Laboratory	26.8	1.5	27.0	1.7	0.79
	Organic Fertilizer	27.1	1.4	26.8	1.9	0.77
Air Temperature Morning	Plastic Recycling	28.4	2.3	28.0	1.9	0.40
	Over Head Tank	28.1	2.5	28.6	1.5	0.67
	Sorting Area	28.6	2.8	29.6	2.7	0.46
	Gate House	28.6	2.8	29.0	2.5	0.62
	Outside					
		30.7	1.8	30.3	1.7	0.76
	Laboratory	29.6	2.9	31.0	0.7	0.23
Air Temperature Noon	Organic Fertilizer	30.0	2.5	31.5	1.5	0.17
	Plastic Recycling	31.3	5.1	35.4	1.9	0.05
	Over Head Tank	32.1	4.2	34.4	2.0	0.22
	Sorting Area	33.2	5.3	35.6	2.2	0.39
	Gate House	31.9	4.2	34.9	2.8	0.12
	Outside					
	Laboratory					
	Organic Fertilizer	31.3	2.8	30.3	1.6	0.56
	Plastic Recycling	30.3	2.9	31.8	1.1	0.13
Air Temperature	Over Head Tank	30.7	2.7	33.0	1.8	0.04
Afternoon	Sorting Area	32.0	3.4	36.0	2.2	0.03
	Gate House	32.4	2.7	36.5	2.1	0.01
	Outside	33.5	3.1	36.0	1.8	0.15
		33.4	3.1	36.2	2.2	0.02

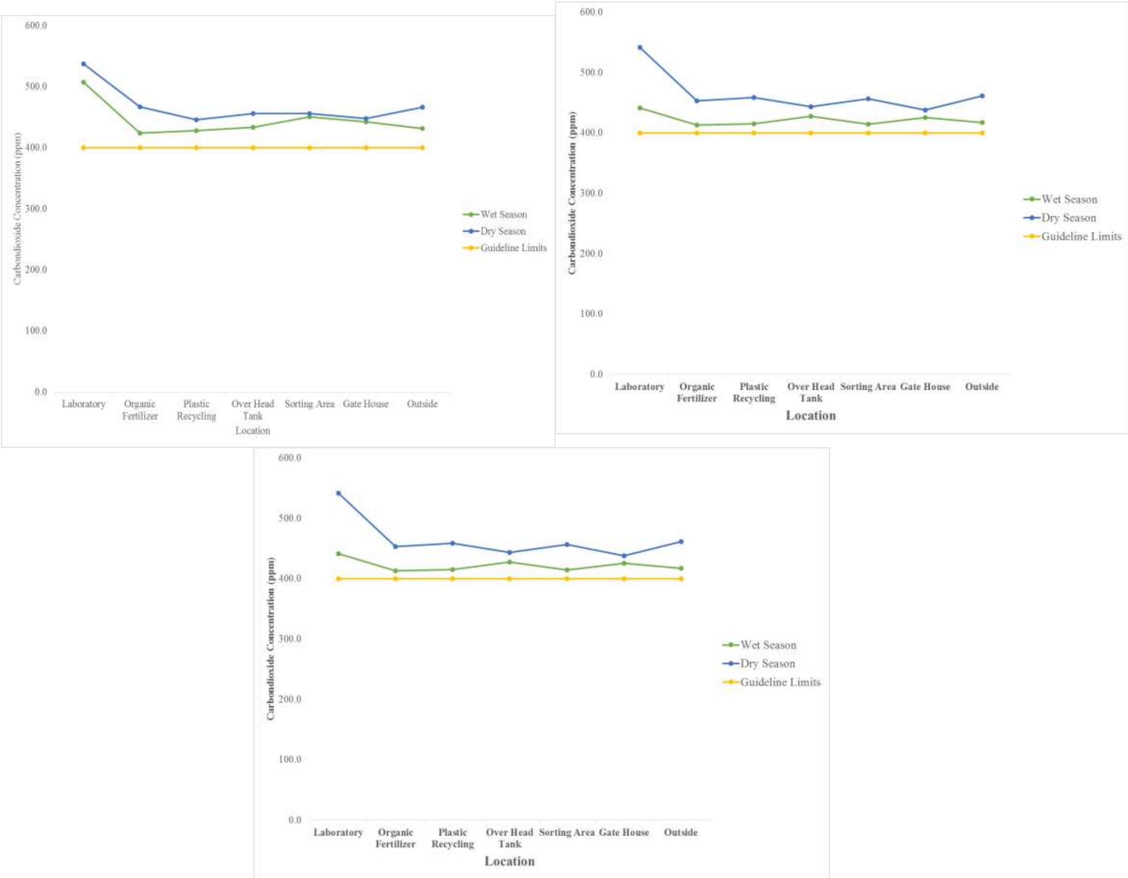

Figure 6. Variations in carbon dioxide levels in various across seasons (a) in the morning (b) in the noon (c) in the afternoon

terms of climate change it has global warming potential (GWP) of 1 [18].

To mitigate the emissions from CO_2 from open dumps, an intervention such as the utilization of a carbon dioxide extractor in a transfer station can be adopted. The solid wastes are brought to an enclosed transfer station and burnt and the extractor is attached to the enclosure thus preventing the CO_2 from going to the atmosphere.

IV CONCLUSION AND RECOMMENDATIONS

Conclusion

Open dumping is a major method of municipal solid waste management in Akure and Nigeria. A large volume of 40,558,278 kg per year for organic waste and 37,560.126 kg per year for paper and textiles generated in Akure provide a good source of raw materials for the establishment of a recycling plant. The atmospheric carbon dioxide data in the study area showed clear seasonal and diurnal variations as evident in values of 438 to 630 ppm in the dry season and 407.29 and 506.86 ppm for wet season for environmental carbon dioxide levels which were all above the regulatory limit of 400 ppm.

Recommendations

Further studies should be carried out to extend the characterization of solid waste generated in Akure beyond one year to verify the seasonal variation of solid waste. The monitoring of air carbon dioxide should extend beyond one calendar year to verify the seasonal variations of air levels carbon dioxide.

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Dr Olugbenga O. Elemile

Dr Olugbenga Elemile was born on 11th March 1975 in Ibadan, Oyo State, in Nigeria. He obtained BSc in Mechanical Engineering from the Obafemi Awolowo University Ile-Ife and went for Maters in Public Health (Environmental Health) at the University of Ibadan. He obtained his PhD in 2016 from the Civil Engineering Department, University of Ibadan, Nigeria specializing in Environmental and Water Resources Engineering. He has worked on public water supply for the past 15 years. He has also lectured in the College of Health Technology, Akure for over four years. His research interests includes building the capacity of people to manage wastes, minimizing carbon dioxide emissions from waste landfills, climate change and solid waste management and other activities. Dr Elemile is a member of Nigerian Network for Awareness and Action for Environmental Health (NINAAFEH), a Non- Governmental Organisation devoted to environmental sustainability. He is a registered member of the following learned and professional associations: Council for the Regulation of Engineering in Nigeria (COREN); Nigerian Society of Engineers (NSE) and the Nigerian Water Supply Association (NWSA) He is presently an Assistant Director of Engineering in the Ondo State Water Corporation. Dr Elemile has travelled far and wide to present conference and workshop papers in some nations in Africa.

Professor Mynepalli K. C. Sridhar

Professor Mynepalli Sridhar was born on 8th December 1942 in Vellatur, Andhra Pradesh, in India. He obtained BSc in chemical and biological Sciences and went for MSc (Biochemistry with Fermentation chemistry specialty) at MS University, Baroda, India. He obtained PhD from Indian Institute of Science, Bangalore, India, worked on wastewater treatment for 13 years before moving to University of Ibadan, Ibadan in 1977. His research projects ranged from water resources, eutrophication and pollution control, water treatment, low cost wastewater treatment, Phytotechnologies, waste management, environmental toxicology, and community mobilization. Developed waste to wealth projects since 1980s particularly compost and organo-mineral fertilizers, biogas for communities using stakeholder approach. He established several pilot scale or demonstration projects on waste to wealth which include organic fertilizer, plastics recycling, biogas, smokelsss charcoal/biochar and several other innovative processes in communities. He was a consultant to UNDP, UNICEF, World Bank, several NGOs and Government bodies and agencies. Traveled extensively and visited several waste management facilities in India, Switzerland, Sweden, Finland, Denmark, and USA. Trained various categories in environmental field and published over 400 scientific papers in books, journals and Technical Report. He was awarded 'Outstanding Researcher Award 2016' by the College of Medicine, University of Ibadan.

Professor Akinwale Coker

Akinwale Oladotun COKER holds a doctorate degree in Environmental Engineering of Nigeria's premier university, the University of Ibadan, which he obtained in 2002. He researched on Engineering Applications in the Management of Health Care Wastes from General and Specialist Hospitals in Ibadan, Nigeria. He had earlier in 1991, graduated with a Master of Science degree in Water and Wastewater Engineering from Obafemi Awolowo University, Ile-Ife, Nigeria. He had his first degree in Civil Engineering in 1987 at the University of Ibadan. Akinwale joined the same Department in 1991 as a Lecturer II and rose to become a Professor in 2010. His research works in over two decades at Ibadan have focused on Water Resources and Environmental Health Engineering.

Professor Coker has travelled far and wide to present conference and workshop papers in America, Europe, Asia and numerous nations in Africa. In addition, he has extensive consultancy experience in water resources and environmental health engineering. Along-side being a teacher and researcher at the University of Ibadan, Professor Akinwale Coker is currently the Director and Chief Executive of Nigerian Network for Awareness and Action for Environmental Health (NINAAFEH), a Non-Governmental Organisation devoted to environmental sustainability. He is also the current Head of the Department of Civil Engineering, University of Ibadan.