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African Journal of Environmental Science and Technology

Full Length Research Paper

Statistical modeling of diesel leaching rate in soils at base transceiver stations

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The process of modeling contaminant volume, rainfall intensity, and soil depth was investigated on diesel leaching and retention in soil subjected to oil pollution from five Base Transceiver Stations. The experimental runs were carried out over three operating parameters which include contaminant volume (50-350 ml), rainfall intensity (5- 10 mm/h), and soil depth (30 - 90 cm) using Response Surface Methodology. Among all variables, soil depth and rainfall intensity significantly influenced the diesel leaching rates. According to results that were found out via ANOVA, the model was fitted to the experimental data with high coefficients. Furthermore, using the statistical modeling approach, the rates predicted via RSM were estimated by varying the contaminant volume at 10 ml, rainfall intensity is 7.5 mm/h; soil depth yielded 54.3 cm while the amount of diesel leached and retained gave 5958.8 mg/L and 3682.5% respectively at the desirability of 1.00. However, at a soil depth of 30 cm, contaminant volume was found to be 50 ml, rainfall intensity is at 10 mm/h to obtain maximum diesel leaching rates, and the amount retained in the soil. The model was validated by computing the %error, which ranges between 0.04 and 8%. This indicates that the model can be implemented.

Key words: Diesel leaching, soil pollution, organic pollutants.

INTRODUCTION

This study is conceived out of the challenge faced by telecommunications companies from litigations and regulatory sanctions due to contaminations arising from maintenance activities at base transceiver stations (BTS) sites. Telecommunications companies have made huge investments in providing power at (BTS) sites to serve growing customers (Olukolajo et al., 2013; Patti and Siana, 2016). Diesel in soil has been known to contain Polycyclic Aromatic hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs). Polycyclic aromatic hydrocarbons are persistent organic pollutants (POPs) that are resistant to degradation, remain in the environment for longer periods (Venkata et al., 2009), and have the potential to cause adverse environmental effects (Kordybach, 1999). PAHs have unique stable structures that persist in the environment (Sugiura et al., 1997) and highly hydrophobic, so these have a strong attraction to soil particles (Sung et al., 2001). PAHs have

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been proven to contain compounds that affect underground water negatively. These compounds include xylene, toluene, and benzene. The process of utilizing these products associated with human mismanagement leads to the spill of these products in the environment in and around many BTS sites (Aderoju et al*.,* 2014). These compounds are harmful to aquatic life and by extension, humans. The consumption of aquatic products contaminated with the aforementioned compounds can lead to adverse health concerns that could result in organ failures, cancer in humans, and even death. It has also been proven that PAHs also inhibit plant growth by increasing soil PH and impeding the adequate flow of oxygen in the soil. The contaminants generated during generator maintenance cycles at BTS sites have proven to be harmful and toxic (Peter and Tien-Chien, 2018). This limitation of aerobic activities in the soil affects the growth of crops and plants thereby adversely affecting food generation and life sustainability in the impacted environment. Oil products, including petrol, not only modify the physico-chemical and biological properties of the soil but also contribute to limitations of the productive ability of arable crops (Wyszkowska et al., 2002). It is worthy of note that the source of petroleum products is crude oil. Crude is refined to get different petroleum products and by-products. These products are made through very complex mixtures of hydrocarbons. However, when these petroleum products are spilled onto the environment, there occur changes due to the action of sunlight and weather which breakdown its components. The analysis of the impact of the leaching rate of spilled diesel and waste engine oil on the environment can be done by analyzing total petroleum hydrocarbons (TPH). The changes in the TPHs are because of leaching of the petroleum hydrocarbons. As the hydrocarbons find their way into the soil, they change in form. The changes can be due to biodegradation of some of the compounds or in some cases as they volatilize. EPA (2017) noted that aerobic biodegradation is very effective in soils that are relatively permeable to allow the transfer of oxygen to subsurface soils where the microorganisms are degrading the petroleum constituents. However, not all petroleum products leach into the environment. Some are non-mobile and remain on the surface of the soil. The components that volatilize or remain on the surface of the soil are less harmful or impactful than those that leach into the soil. The latter are those we are more concerned with as they are most likely to impact soil quality, texture, and at times, underground water. Design of experiment and response surface methodology (RSM), as a statistical analysis technique, is a widely used methodology for analysis and optimization of the application of different factors or treatment technologies in the oil spill process (Sharma et al., 2009; Zahed et al. 2010). For instance, Mohajeri et al. (2010) employed RSM to optimize oil concentration biomass, nitrogen, and phosphorus concentrations in bioremediation of crude oil sediment samples during 60 days trial period, obtaining 83% removal under the optimum conditions.

Given this, the present study seeks to investigate the conditions in which the independent variables, contaminant volume, rainfall intensity, and soil depth influences the amount of diesel leached and retained in soil subject to pollution from diesel generators at BTS site.

MATERIALS AND METHODS

Description of the study area

Rivers State is one of the 36 states of Nigeria located between 6°58’26.508” E, 4°58’24.996” N. According to census data released in 2006, the state has a population of 5,198,716, making it the sixth-most populous state in the country (Mohajeri et al., 2010). Its capital and largest city, Port Harcourt, is economically significant as the center of Nigeria's oil industry. Rivers State is bounded on the South by the Atlantic Ocean, to the North by Imo, Abia and the Anambra States, to the East by Akwa Ibom State, and to the West by Bayelsa and Delta states. Rivers State is a predominantly low-lying pluvial state in southern Nigeria, located in the eastern part of the Niger Delta on the oceanward extension of the Benue Trough. The inland part of the state consists of a tropical rainforest, and towards the coast, the typical Niger Delta environment features many mangrove swamps. Rivers State has a total area of 11,077 km^2 (4,277 mi^2), making it the 26th largest state in Nigeria. Rainfall is generally seasonal, variable, as well as heavy, and occurs between March and October through November. The wet season peaks in July, lasting more than 290 days. The only dry months are January and February having little to no effect. Total annual rainfall decreases from about 4,700 mm (185 in) on the coast, to about 1,700 mm (67 in) in the extreme north. It is 4,698 mm (185 in) at Bonny along the coast and 1,862 mm (73 in) at Degema. For Port Harcourt, temperatures throughout the year are relatively constant with little variation throughout the seasons. Average temperatures are typically between 25−28°C. Some parts of the state still receive up to 150 mm (6 in) of rainfall during the dry period. Relative humidity rarely dips below 60% and fluctuates between 90% and 100% for most of the year (Olatunji et al., 2019) (Figure 1).

Description of the soil

The soil samples used in this study were obtained from BTS sites in Rivers State. Five samples were obtained from the study area. The samples were analyzed in the laboratory to determine the predominant soil type at BTS sites where the samples were obtained. The predominant soil types were obtained through grain size analysis using the hydrometer method. At the end of the laboratory analysis, it was observed that the soils at the BTS sites are predominantly made up of sand and silt with a little amount of gravel. Therefore, the 5 BTS site as sampled in the study area is shown in Table 1.

This study is designed to evaluate the modeling of leaching rates of different types of contaminated soils at BTS sites within Rivers State, Nigeria. Leaching refers to the movement or washing away of water-soluble compounds from the soil or into lower layers of subsoil while retention refers to the ability of the soil to hold or contain contaminants within a confined boundary. The different sites were sampled for diesel contamination. The different soil samples will be applied to the three soil samples collected above during dry and rainy seasons. The samples were collected using a

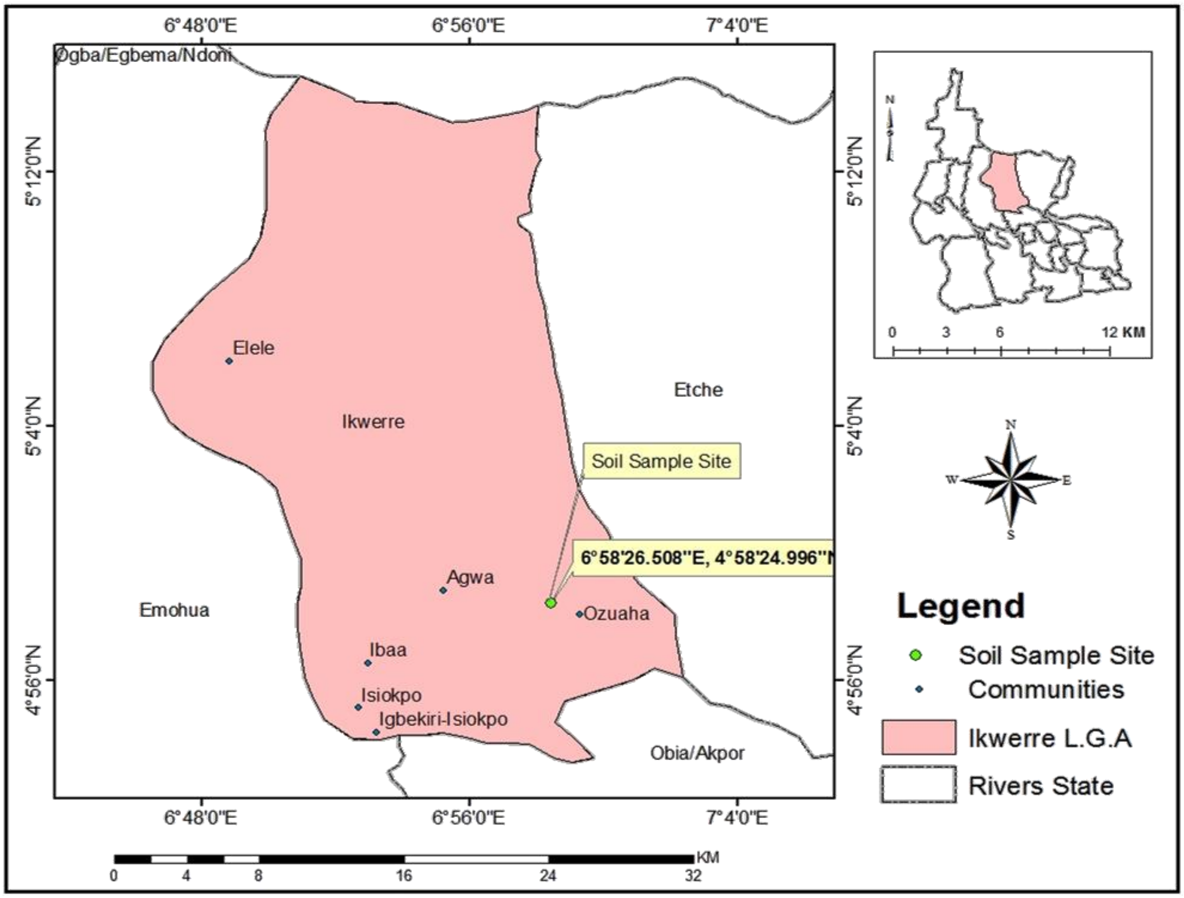

Figure 1. Map of the study area showing the BTS sites.

Table 1. Physical characteristics of the soil at different sites (grain distribution size using the hydrometer method).

BTS site	Coordinates		Clay	Silt	Sand	Gravel
Ahoada	5.0828° N	6.6585° E				
Buguma	4.7403° N	6.8619° E				
Emuoha	4.8843° N	6.8726° E				
Port Harcourt	4.8156° N	7.0498° E				
Degema	4.5699° N	6.9639° E				

mesocosm in which leachates were collected after applying contaminants four weeks each; leaching rates were measured weakly for each soil sample type and readings were recorded to ascertain the leaching rates of the soil samples for different weather conditions. There will be a site D that will be used for control where there is no form of mitigation and contamination. The site E will have a geosynthetic membrane (Polythene) as a control parameter for the pollutants. Each of these BTS sites will have an associated baseline study area to compare the level of pollution with the treatment site. The amount of diesel remaining will be measured at various depths for both the baseline and study area. Three BTS sites with high levels of contamination will be identified and samples of spilled diesel collected from these sites. The sites were selected based on complaints of diesel oil spillage by field support engineers or managed service vendors and Telecom infrastructure providers. Identification of sites and checks for appropriateness was done.

Design of experiment (DOE)

The experimental design was set up using DOE software Version 11.0.1. with 3^3 factorials. The variables and their range are given in Table 1. This range was carefully chosen based on previous studies. The variables are coded as contaminant volume (A), rainfall intensity (B), and soil depth (C) accordingly. Generally, each factor in Central Composite Design has five stages and grouped into three design points, which are identified as two stages of factorial points, well-defined as 1 and -1, (axial points), and a (center point) defined as 0 (Table 2). The center points are primarily repetitive trial arrays closer to the center of factor space to endorse

Table 2. Experimental design and level of independent process variables.

Independent variable	Unit	Factor	Coded level		
			-1	0	+1
Contaminant volume	ml	A	50	200	350
Rainfall intensity	mm/h	B	5	7.5	10
Soil depth	cm	C	30	60	90

Table 3. Diesel oil leaching and retention in soil as affected by independent variables.

Runs	A (ml)	B (mm/h)	C (cm)	Response 1: R (%)	Response 2: L (mg/L)
1	50	5	30	5325.27	5824.68
2	200	5	30	4511.43	5033.24
3	350	5	30	5045.33	2440.55
4	50	7.5	30	4309.87	4869.46
5	200	7.5	30	3646.81	5332.93
6	350	7.5	30	4311.76	4439.82
7	50	10	30	3567.00	3154.90
8	200	10	30	4199.32	5148.81
9	350	10	30	5066.66	5400.93
10	50	5	60	3976.33	7124.03
11	200	5	60	3233.91	6573.57
12	350	5	60	3556.31	4550.36
13	50	7.5	60	3880.34	6291.02
14	200	7.5	60	3772.12	6839.91
15	350	7.5	60	3752.45	6000.96
16	50	10	60	4860.28	4300.10
17	200	10	60	4492.45	6245.02
18	350	10	60	5337.21	6811.92
19	50	5	90	9843.15	2510.77
20	200	5	90	8773.15	2211.91
21	350	5	90	8773.50	153.170
22	50	7.5	90	9623.85	1265.76
23	200	7.5	90	9113.75	2044.96
24	350	7.5	90	10443.4	1292.45
25	50	10	90	11343.7	-540.34
26	200	10	90	11343.9	1345.03
27	350	10	90	11317.2	1900.13

R=Retained; L=Leached.

the best prediction potential. In the present study, there are 27 experimental runs (Table 3).

Experimental set-up and procedures

Samples were collected and sealed in plastic containers to be resampled. The reason for the resample is to remove materials that might impact the results or tests e.g. gravel, stones, wooden/plastic materials, and roots of plants. The soil in the plastic containers was kept sealed until they were ready for sampling to avoid contamination. Samples were preserved and characteristics of soil samples were obtained using guidelines found in the QAPP (Thompson et al., 2004). Instruments and apparatus used include, shovel, hand trowels, plastic bottles, auger, drilling bits, density measurement equipment, and sieves. For every randomly selected BTS within the study area, the soil samples were extracted at various depths of 30, 60, and 90 cm, as is consistent with the design of the experiment. For every 30 cm depth, 9 samples of undisturbed soil were collected using galvanized steel mesocosms. Similarly, for each of 60cm and 90cm depth, 9 samples of undisturbed soil were collected using galvanized steel mesocosms. The experimental set-up consists of 2 major aspects (1) Rainfall simulator set-up, and (2) Mesocosm set-up. The rain simulator, mesocosm set-up for collection of leachates, determination of total petroleum hydrocarbon, and soil hydrocarbon extraction water content were carried out.

Statistical modeling

Factorial design and response surface methodology were used for experimental design and data analysis. A 3^3 - factorial design with contaminant volume (A) in ml, rainfall intensity (B) in mm/h, and soil depth (C) in cm, as the independent variables were used. They were coded at three levels between -1 and +1. The ranges of the individual factors (independent variables) were chosen and presented in Table 2. The statistical design expert software was used to design the experiment and data analysis. Response Surface Methodology (RSM) was applied to predict the operating condition for the amount of diesel leached and that retained in the soil from our previous study. Three dimensional (3D) graphs were achieved, based on the effects of three process parameters on the two responses, as well as their interactions to obtain the optimum leaching rate and conditions for the amount of diesel retained in the soil. Table 3 demonstrates the responses (L and R) against the respective experimental run, designed using RSM. The response surface methodology developed a relationship between process variables (A, B, and C) and the responses (L and R). The RSM analysis and optimization of process parameters were carried out in design expert software.

RESULTS AND DISCUSSION

Experimental result

The experimental result for the response parameters as well as the independent variables is shown in Table 3, following the 27 runs from the experimental design.

Effects of independent variables on the amount of diesel leached and retained

The following graphs from Figures 2 and 3 show the interaction between independent variables on the amount of diesel oil leached and retained in the soil. The effects of the factors on the response were measured using a 3D surface plot and contour plots which indicate the interaction between the variables. It shows the factors (soil depth and rainfall intensity, contaminant volume) significantly affect the response variables that were leached, and retained.

In Figure 1A and B, there is a significant effect when rainfall intensity and contaminant volume are combined on the interaction of the amount of diesel retained in the soil. On the other hand, the response retained increased significantly as contaminant volume increases in Figure 1C and D. Similarly, the amount of diesel retained increased significantly with an increase in rainfall intensity at lower soil depth. This shows that at lower soil depth with a high rainfall leaching rate is reduced. Again, in Figure 4A, and B, leaching reduces as contaminant volume decreases at higher rainfall intensity. This is similar to Figure 3B, C where the amount of diesel leached decreased significantly as contaminant volume decreases with increasing soil depth. The case in Figure 3E and F also follows the same order which shows that the amount of diesel leached decreases at increasing soil depth and decreasing rainfall intensity.

Analysis and model equations

To perform a statistical analysis of the results Analysis of Variance (ANOVA) was used (Ceylan et al., 2008; Voneiff et al., 2014, 2013). As shown in Tables 4 and 5, contaminant volume (ml), rainfall intensity (mm/h), soil depth (cm), which are the operating parameters with three levels (-1, 0, and +1) were utilized for the diesel leaching process. The system responses were measured in terms of the amount of diesel leached and retained in the soil. The effect of operating parameters was investigated using 3^3 factorial, 27 runs experiments. Lack of fit test was observed to be non-significant, which is adequate, thus the model can predict the amount of diesel leached and retained within the design range of variables. Tables 4 and 5 show the analysis of variance (ANOVA) between the statistical model and experimental values for the independent variables (factors) and the response parameters as well as the coefficient of correlation for each response.

The model F-value of 230.86 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values < 0.05 indicate model terms are significant. In this case, B, C, AB, BC, A^2, B^2, C^2 are significant model terms. All values > 0.1 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The predicted R^2 of 0.9770 is in reasonable agreement with the adjusted R^2 of 0.9876; that is, the difference is less than 0.2. adeq precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 42.473 indicates an adequate signal. This model can be used to navigate the design space. This agrees with the postulations given by Ameen et al. (2019) and Ndukwu et al. (2019).

The final model equation in terms of actual factors:

$$\%Retained = 19468.4 - 12.3A - 1735.3B - 394C + 0.83AB - 0.028AC + 9.63BC + 0.02A^2 + 78.73B^2 + 3.51C^2 \quad (1)$$

where A is the contaminant volume (ml), B is the rainfall intensity (mm/hr) and C is the soil depth (cm).

The equation in terms of actual factors can be used to make predictions about the %retained for given levels of each factor. Here, the levels should be specified in the original units for each factor. The model F-value of 1167.57 implies the model is significant. There is only a

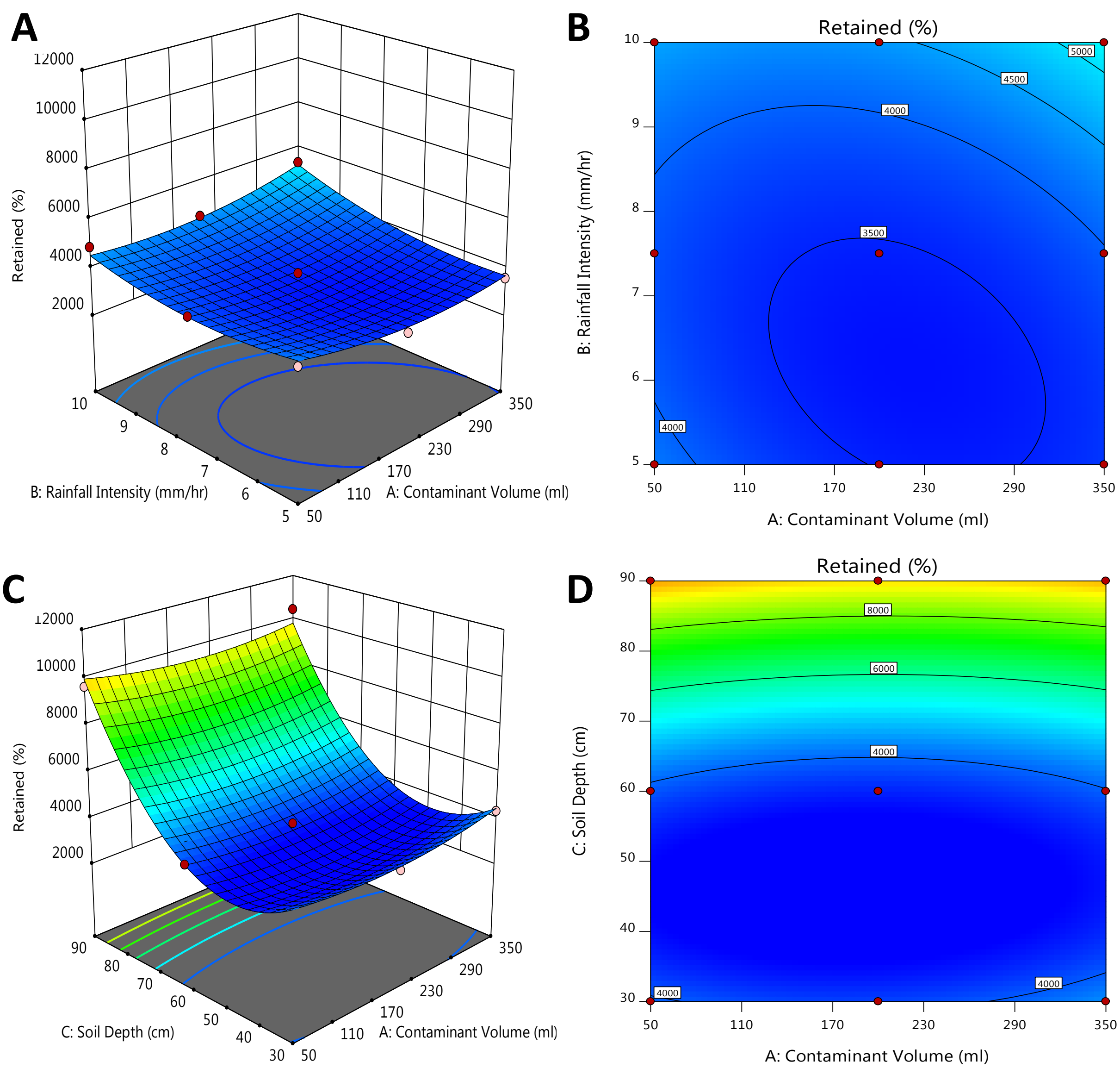

Figure 2. Showing the 3D surface and contour plots. A,B, Effect of rainfall intensity and contaminant volume on retained; (C, D, effect of contaminant volume and soil depth on retained.

0.01% chance that an F-value this large could occur due to noise. P-values < 0.05 indicate model terms are significant. In this case, A, B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms. Values > 0.1 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The predicted R^2 of 0.9948 is in reasonable agreement with the adjusted R^2 of 0.9975; that is, the difference is less than 0.2. Adeq precision measures the signal to noise ratio. However, a ratio greater than 4 is desirable. The ratio of 117.068 indicates an adequate signal. This model can be used to navigate the design space.

The final equation in terms of actual factors:

$$Leached\left(\frac{mg}{l}\right) = -2067.11 - 14.8A + 298.73B + 372.89C + 3.45AB + 0.031AC - 2.86BC - 0.034A^2 - 58.36B^2 - 3.43C^2 \quad (2)$$

Model validation

In this study, the statistical model was validated by comparing experimental and predicted values as well as the residuals obtained from the RSM analysis (Table 6). Also, a graph of experimental values of the amount of diesel leached and retained in the soil versus predicted values was generated (Figure 3). The effects of operating

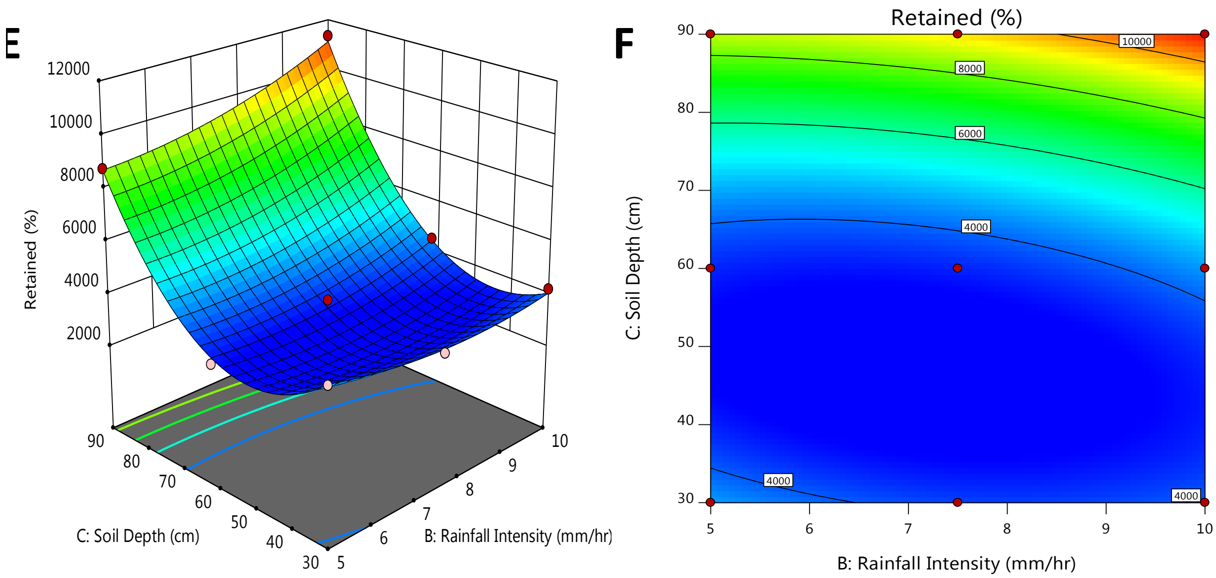

Figure 3. Showing the 3D surface and contour plots (E, F) Effect of rainfall intensity and soil depth on retained.

Table 4. ANOVA for the quadratic model, response 1: retained (%), R^2=0.9919.

Source	SS	df	MS	F-value	p-value	Remarks
Model	2.163E+08	9	2.404E+07	230.86	< 0.0001	Significant
A-Contaminant volume	42436.58	1	42436.58	0.4075	0.5317	
B-Rainfall intensity	4.004E+06	1	4.004E+06	38.45	< 0.0001	Significant
C-Soil depth	1.422E+08	1	1.422E+08	1365.61	< 0.0001	Significant
AB	1.153E+06	1	1.153E+06	11.07	0.0040	Significant
AC	1.871E+05	1	1.871E+05	1.80	0.1978	
BC	6.255E+06	1	6.255E+06	60.07	< 0.0001	Significant
A^2	1.233E+06	1	1.233E+06	11.84	0.0031	Significant
B^2	1.453E+06	1	1.453E+06	13.95	0.0016	Significant
C^2	5.982E+07	1	5.982E+07	574.50	< 0.0001	Significant
Residual	1.770E+06	17	1.041E+05			
Cor Total	2.181E+08	26				

parameters including contaminant volume, rainfall intensity, soil depth, which affects the amount of diesel leached/retained in the soil were studied utilizing 3^3 factorial experiments known as one of the methods of response surface methodology (RSM). Furthermore, parameters that significantly affect the leaching rates were evaluated and optimized. To obtain the maximum response of the experiment, the optimum values were determined from the model (Table 6). For this purpose, an experiment was conducted at the optimum operating conditions. Also, the percentage error obtained from the experimental response and the predicted response value was calculated by Equation 3:

$$\%\text{Error} = \frac{\text{Experimental value} - \text{Predicted value}}{\text{Experimental value}} \times 100 \qquad (3)$$

The results shown in Table 6 represent the small amount of error resulting from experimental and predictive values. Also, the proximity of these values confirms the validity of the model and the value obtained at the optimum condition. The computational error is mostly considered to be less than 3% acceptable and represents the accuracy of the model at about 97%. From Figure 5 (A-D above it can be seen that model fits the experimental data by comparison of predicted values versus the actual value. The amount of diesel retained in the soil yielded 5744.7% while the leached amount is 5716.8 mg/L at the desirability of 0.719.

Given a contaminant volume of 250 ml, rainfall intensity is 5 mm/h; soil depth is still 30 cm. The amount of diesel leached and retained is 4352.1 mg/L and 4559.6% respectively. In the modeling process, it was observed

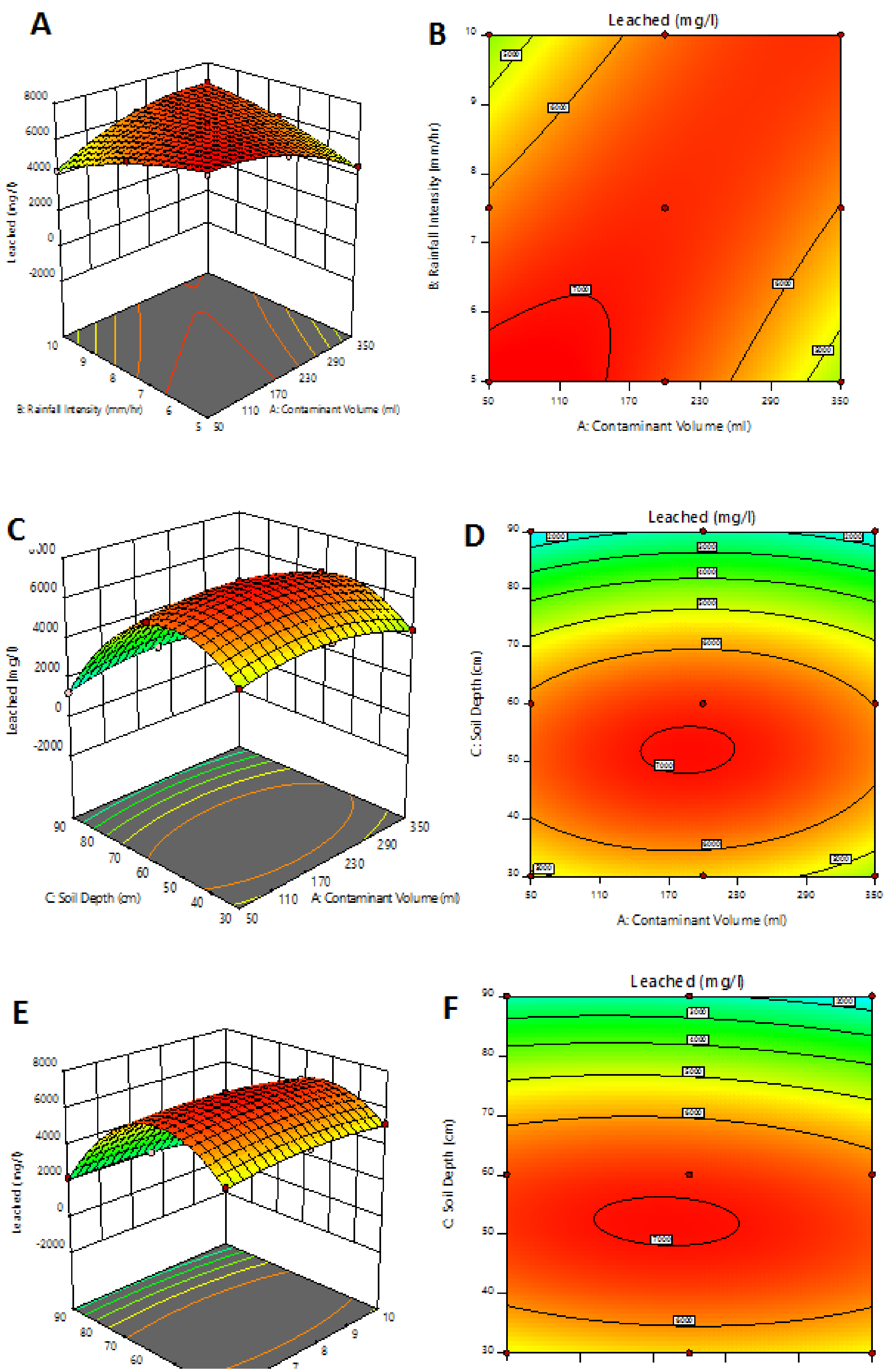

Figure 4. 3D surface and contour plots. A, B, Effect of rainfall intensity and contaminant volume on leached; C, D, effect of contaminant volume and soil depth on leached; E, F, effect of soil depth and rainfall intensity on amount of diesel leached.

Table 5. ANOVA for quadratic model for response 2: leached (mg/l), R^2=0.9984.

Source	SS	df	MS	F-value	p-value	Remarks
Model	1.313E+08	9	1.459E+07	1167.57	< 0.0001	Significant
A-Contaminant volume	1.820E+05	1	1.820E+05	14.57	0.0014	Significant
B-Rainfall intensity	3.918E+05	1	3.918E+05	31.36	< 0.0001	Significant
C-Soil depth	4.822E+07	1	4.822E+07	3859.71	< 0.0001	Significant
AB	2.006E+07	1	2.006E+07	1605.35	< 0.0001	Significant
AC	2.344E+05	1	2.344E+05	18.77	0.0005	Significant
BC	5.535E+05	1	5.535E+05	44.30	< 0.0001	Significant
A^2	3.506E+06	1	3.506E+06	280.65	< 0.0001	Significant
B^2	7.983E+05	1	7.983E+05	63.90	< 0.0001	Significant
C^2	5.734E+07	1	5.734E+07	4589.56	< 0.0001	Significant
Residual	2.124E+05	17	12493.44			
Cor Total	1.315E+08	26				

Table 6. The experimental and predicted values of leached and retained.

Runs	Exp - R	PD - R	Residual - R	Exp - L	PD - L	Residual - L	%Error- R	%Error-L
1	5325.27	5144.68	180.59	5824.68	5716.77	107.91	3.39119	1.852634
2	4511.43	4554.78	-43.35	5033.24	4948.08	85.160	-0.96089	1.691952
3	5045.33	4871.55	173.78	2440.55	2650.48	-209.93	3.444373	-8.60175
4	4309.87	4092.25	217.62	4869.46	4855.95	13.510	5.04934	0.277443
5	3646.81	3812.33	-165.52	5332.93	5380.07	-47.14	-4.53876	-0.88394
6	4311.76	4439.07	-127.31	4439.82	4375.28	64.540	-2.95262	1.453663
7	3567.00	4023.99	-456.99	3154.90	3265.60	-110.70	-12.8116	-3.50883
8	4199.32	4054.04	145.28	5148.81	5082.53	66.280	3.459608	1.287288
9	5066.66	4990.75	75.910	5400.93	5370.55	30.380	1.498226	0.562496
10	3976.33	4200.64	-224.31	7124.03	7246.39	-122.36	-5.64113	-1.71757
11	3233.91	3485.89	-251.98	6573.57	6617.47	-43.90	-7.79181	-0.66783
12	3556.31	3677.80	-121.49	4550.36	4459.65	90.710	-3.41618	1.993469
13	3880.34	3870.21	10.130	6291.02	6170.80	120.22	0.26106	1.910978
14	3772.12	3465.43	306.69	6839.91	6834.69	5.2200	8.130441	0.076317
15	3752.45	3967.32	-214.87	6000.96	5969.68	31.280	-5.72613	0.52125
16	4860.28	4523.95	336.33	4300.10	4365.68	-65.58	6.919972	-1.52508
17	4492.45	4429.14	63.310	6245.02	6322.38	-77.36	1.409253	-1.23875
18	5337.21	5241.01	96.200	6811.92	6750.18	61.740	1.80244	0.906352
19	9843.15	9571.73	271.42	2510.77	2593.26	-82.49	2.757451	-3.28545
20	8773.15	8732.12	41.030	2211.91	2104.12	107.79	0.467677	4.873164
21	8773.50	8799.18	-25.680	153.170	86.07	67.100	-0.2927	43.80753
22	9623.85	9963.31	-339.46	1265.76	1302.91	-37.15	-3.52728	-2.935
23	9113.75	9433.67	-319.92	2044.96	2106.57	-61.61	-3.5103	-3.01277
24	10443.36	9810.71	632.65	1292.45	1381.33	-88.88	6.057916	-6.87686
25	11343.72	11339.05	4.6700	-540.34	-716.98	176.64	0.041168	-32.6905
26	11343.85	11119.39	224.46	1345.03	1379.49	-34.46	1.978693	-2.56202
27	11317.22	11806.40	-489.18	1900.13	1947.07	-46.94	-4.32244	-2.47036

Exp=experimental values; PD=predicted values; R=retained; L=leached.

respectively. In the modeling process, it was observed that more amount of diesel was leached at lower soil depth with high rainfall intensity; while the lower amount of diesel was leached at high contaminant volume, at

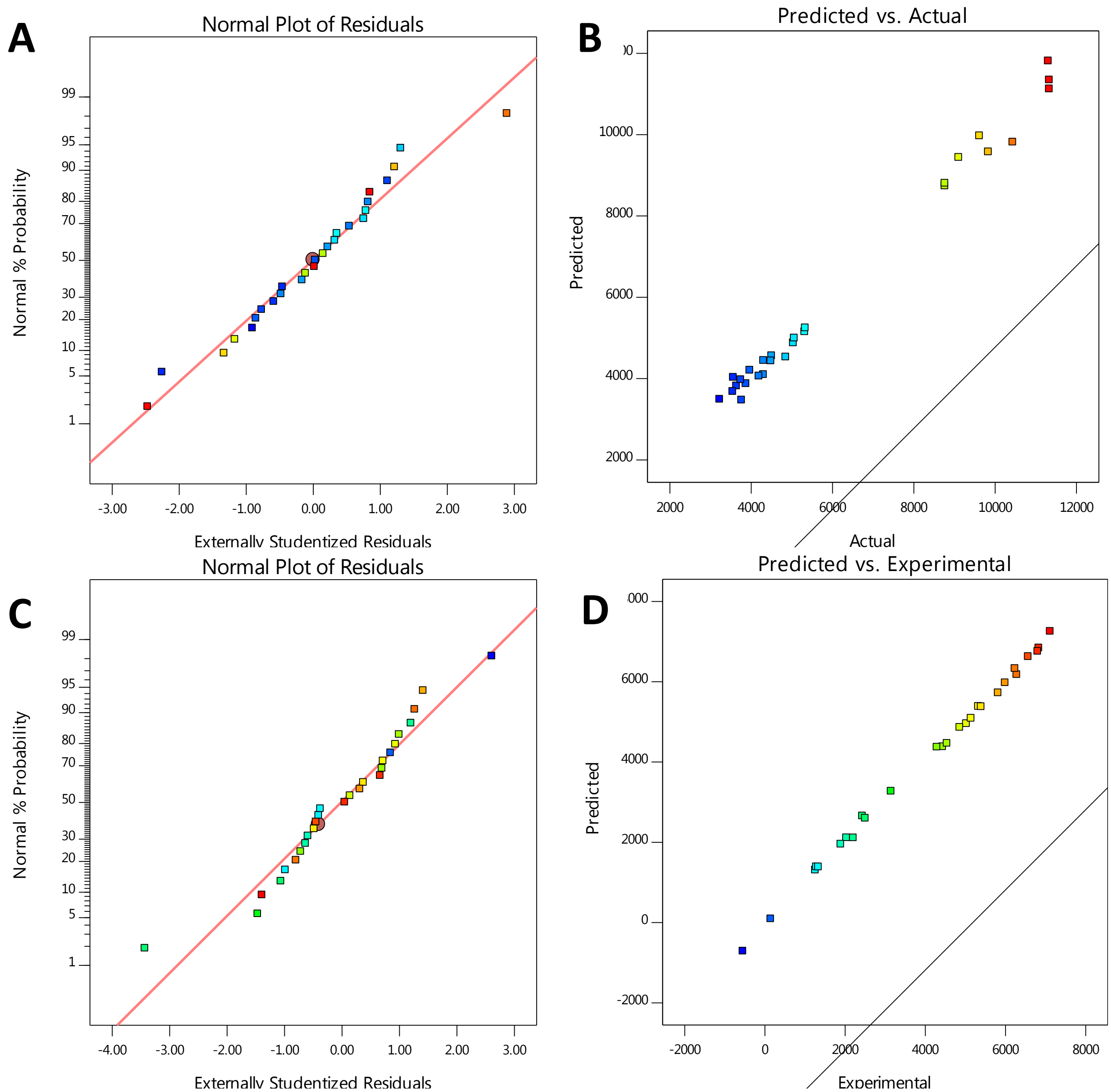

Figure 5. showing the normal plot of residual and predicted vs experimental values (A, B) amount of diesel leached (C, D) amount of diesel retained in the soil.

high soil depth and high rainfall intensity. Therefore, the quantity of diesel leached increases at lower soil depth with low rainfall intensity and high contaminant volume.

Conclusion

The amount of diesel leached and retained in a polluted soil at the telecommunication base station was studied using RSM by 3^3 factorials. The effects of operating parameters, such as contaminant volume (ml), rainfall intensity (mm/h), and soil depth (cm) on the amount of diesel leached/retained in the soil were investigated. According to the results obtained through ANOVA, the model was fitted to the experimental data with high coefficients. The amount of diesel leached is inversely proportional to the amount retained in the soil. The study also revealed that as contaminant volume increases, the amount of diesel leached decreases, and vice versa. Similarly, the amount of diesel leached increases as rainfall intensity increases. Additionally, the quantity of diesel leached increases as the soil depth increases but these changes/reverses when the soil depth exceeds 50 cm; while the corresponding amount of diesel leached is greater than 4200 mg/L. The correlation between the actual and predicted retained concentration indicated that there is a decent relationship existing between them. Further analysis of the graph reveals that the retained concentration hovers around the trend line given a line of best fit with a very high correlation coefficient and predictive relevance of 0.9919 and 0.9984 respectively. This implies over 90% accuracy for retained and leached concentrations. Consequently with very high regresion coefficient for retained and leached concentrations as well as accurate and acceptable agreement for predicted and adjusted concentrations, this implies that the quadratic model is accurate, effective and highly recommended for use.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Urban climate variability trend in the coastal region of Mombasa Kenya

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The world population in global south countries is increasing. This fast growth has heightened urban ecological footprint that contributes to anthropogenic forcing triggering of the climate system. From this study, climate variability trend dynamics in Mombasa County, a coastal urban area in Kenya was examined. A retrospective study was done (1989-2019) to determine the changes in temperature and rainfall in the area of study. The results show that climate variability was experienced in Mombasa with a maximum temperature t=-5.628, df=23, *P*:0.000 and a minimum of t= -5.401, df=23, *P*:0.000, total rainfall t=2.025, df=23, *P*:0.275. The linear regression analysis shows rainfall variation y = -9.588x + 1217.1 and temperature y =0.0258x + 29.888 with an increase of +0.4°C. The annual maximum temperature averages show heterogeneous distribution from kurtosis coefficient with little observed skewness.

Key words: Rainfall, temperature, urbanization, retrospective.

INTRODUCTION

Proliferating climate change extremes globally are daunting, staging undeniable global debates that have exponentially increased in different international fora (Herman and Treverton, 2009; Hannigan, 2014; Abate, 2019). Studies (Innocent, 2017; IPCC, 2018) indicate that global surface temperature averagely has increased by 1°C or 33.8°F and could triple by the next century. As the human population surge in cities, it has heightened urban ecological footprint necessitating more mega tones emission of greenhouse gases. This anthropogenic forcing anchored on urban-human activities has mushroomed urban heat highlands contributing to climate change, thus a trigger to the climate system.

Temperature and rainfall variations serve as long-term determinants to predict the future climate projections and scenarios (Mellander et al., 2018; Barton et al., 2019). The study aimed to examine trend variations in rainfall and temperature in Mombasa County, a coastal region in Kenya to ascertain the degree and level these climate variability variables had changed overtime. A thirty-year observed variation threshold (1989-2019) rainfall and temperature data was obtained from the Kenya Meteorological Department to determine observed climate variability in Mombasa County.

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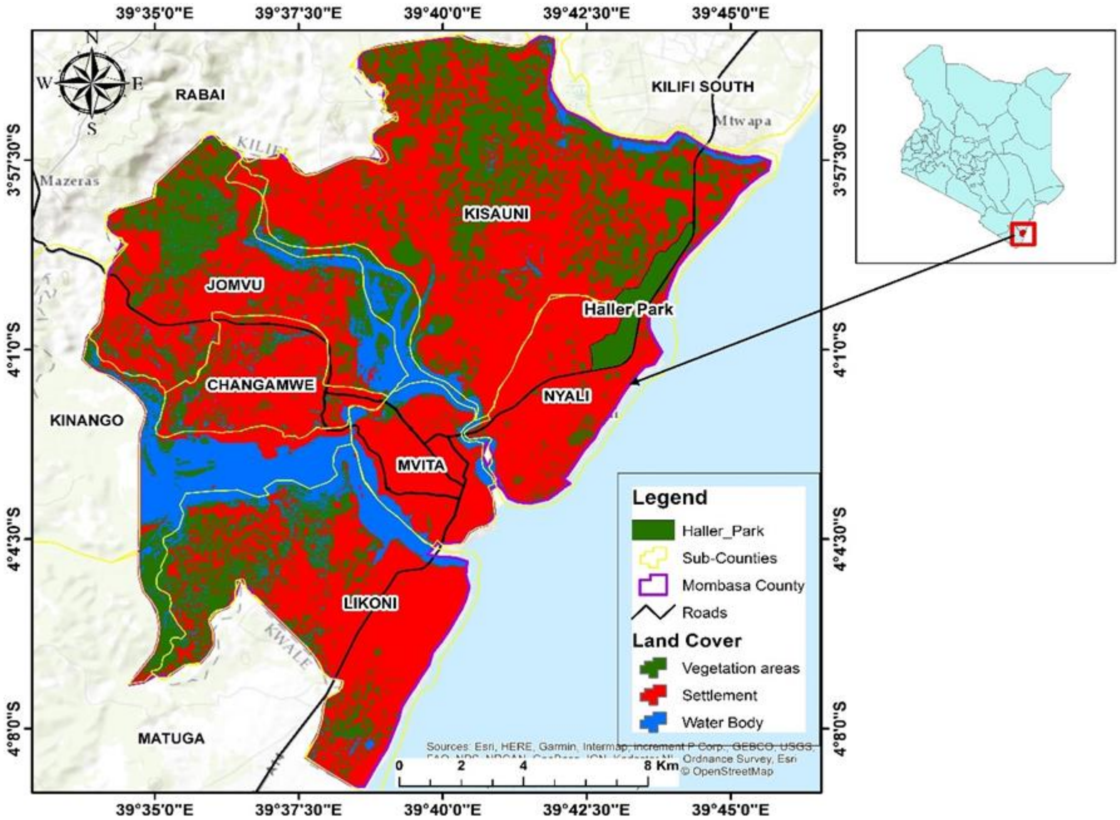

Figure 1. The map of Mombasa County, Kenya.

METHODOLOGY

A retrospective study between 1989 and 2019 on climate variability review was done at the coastal region of Kenya in Mombasa County. The county lies slightly below the equator on a latitude and longitude of -4°S, 39°E respectively (Figure 1).

Climate variability data was obtained from the Kenya Metrological Department. Both rainfall and temperature recordings for the region was run on times series to observe anomalies across the trend through simple regression analysis. One-Way-Anova was run to test the hypotheses under investigation. Kurtosis coefficient was used to determine the distribution patterns in temperature and temperature with simulated equation;

$$Kurtosis = \frac{\sum_{i=1}^{N} \frac{(X_i - \bar{X})}{N}}{s^4}$$

Where, $\bar{X}$ is the mean, s is the standard deviation and N is the sample size.

RESULTS AND DISCUSSION

Descriptive monthly average temperature

Temperature plays a crucial role when modelled for a more extended period to determine climate variation changes of the area (Graff Zivin et al., 2018; Turco et al., 2018; Grbec et al., 2019). The annual, monthly average, minimum and maximum annual average temperatures descriptively are shown in Tables 1 to 3, respectively. Descriptive statistics that include the mean, kurtosis, median, standard deviation and coefficient of variation are shown in the tables.

The coefficient of variance (CV) of average monthly temperature (Table 1) shows low and high ratios of standard deviation (SD) from the means. Averagely, March CV was the least with 1.56 (σ =0.44), where September averages had the highest with 2.65 with σ = 0.66. Comparing their dispersion from the mean, months with least CV had a low degree of variation from the mean, and those with higher CV ratio connotes that they had more degree of variation from the mean. From the distribution observation of the coefficient of kurtosis and skewness, the annual, monthly temperatures averages were evenly distributed with a coefficient kurtosis of -0.82 to 0.67, connoting heterogeneous distribution of average monthly temperature. However, even with the negative skewness observed, the measure of two-tailed thinness was neither highly concentrated to the left or right. The left highest (-ve) skewness was -0.82, where the right

Table 1. Average monthly temperature for the year 1989 to 2019.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Count	31	31	31	31	31	31	31	31	31	31	31	31
Mean	27.57	27.99	28.4	27.6	26.09	24.92	24.06	24.03	24.74	25.78	26.75	27.5
Std. E	0.1	0.09	0.08	0.126	0.14	0.09	0.11	0.11	0.12	0.1	0.1	0.1
Median	27.55	28	28.45	27.55	26.15	24.8	23.95	24.1	24.85	25.75	26.75	27.5
Mode	27.55	28	28.6	26.9	25.8	24.25	23.9	24.55	25.15	25.65	26.75	27.35
SD	0.54	0.51	0.44	0.7	0.76	0.1	0.62	0.63	0.66	0.54	0.56	0.57
SV	0.29	0.26	0.2	0.49	0.57	0.26	0.39	0.39	0.43	0.3	0.32	0.32
Kurtosis	-0.52	-0.82	-0.44	-0.4	0.44	-0.54	-0.29	-0.29	0.18	-0.45	0.67	0.55
Skewness	0.01	-0.05	-0.36	0.08	-0.67	0.58	0.24	-0.23	0.03	-0.25	-0.71	0.12
Range	2.1	1.9	1.8	2.8	3.35	1.75	2.65	2.6	2.9	1.95	2.25	2.6
Minimum	26.6	26.95	27.45	26.35	24.1	24.25	22.8	22.6	23.45	24.7	25.35	26.15
Maximum	28.7	28.85	29.25	29.15	27.45	26	25.45	25.2	26.35	26.65	27.6	28.75
CI (95%)	1.89	1.8	1.56	2.46	2.66	1.79	2.19	2.2	2.31	1.92	1.98	2
CV	1.95	1.83	1.56	2.54	2.9	2.04	2.59	2.6	2.65	2.11	2.11	2.06

SD: Standard deviation; Std E: Standard error; SV: Sample variance; CI: Coefficient of Interval; CV: Coefficient variance.

Table 2. Average minimum temperature for the year 1989 to 2019.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Count	31	31	31	31	31	31	31	31	31	31	31	31
Mean	22.94	23.2	23.95	23.85	22.5	21.27	20.32	20.23	20.88	22.02	22.92	23.23
StdE	0.13	0.15	0.13	0.16	0.17	0.15	0.16	0.16	0.16	0.17	0.13	0.13
Median	22.9	23.2	24.2	23.87	22.7	21.3	20.3	20.3	21	22.1	23	23.2
Mode	22.8	23.2	23.8	24.8	22.2	21.8	20.9	19.9	21.3	22	23	23.2
SD	0.74	0.82	0.71	0.91	0.94	0.81	0.88	0.89	0.89	0.92	0.75	0.75
SV	0.55	0.68	0.5	0.82	0.89	0.66	0.78	0.79	0.8	0.84	0.56	0.56
Kurtosis	0.71	-0.83	0.15	2.18	0.46	0.3	1.2	0.85	0.72	0.43	1.64	1.27
Skewness	-0.62	-0.1	-0.91	0.34	-1.14	-0.17	0.1	-0.55	-0.64	-0.37	-0.74	-0.63
Range	3.4	3	2.6	4.9	3.4	3.3	4.6	4.3	4.2	4	3.5	3.4
Minimum	21	21.6	22.3	21.7	20.2	19.5	18.1	17.7	18.6	20	20.8	21.3
Maximum	24.4	24.6	24.9	26.6	23.6	22.8	22.7	22	22.8	24	24.3	24.7
CI (95%)	0.255	0.294	0.255	0.314	0.333	0.294	0.314	0.314	0.314	0.333	0.255	0.255
CV	3.226	3.534	2.965	3.816	4.178	3.808	4.331	4.399	4.262	4.178	3.272	3.229

SD: Standard deviation; Std E: Standard error; SV: Sample variance; CI: Coefficient of Interval; CV: Coefficient variance.

skewness (+ve) was 0.67 across the trend in the past 30 years in Mombasa County (Table 1).

Descriptive minimum average temperature

Descriptive statistics of average minimum rainfall for Mombasa County for the years 1989 to 2019 is shown in Table 2. Statistical measures of central tendency and dispersion determine the spread, distribution, and trend of average minimum temperatures. Figure 2, the monotonic trend of the variables outlined by the linear. The standard deviation ratios from the mean show reliability variations. The month of March has the lowest CV of 2.965, thus less variation from the mean (μ =23.95). August had the highest reliability of variation from the mean with a CV of 4.399 and a SD of 0.89, unlike that of March (0.71). The average SD deviation difference across the trend is 0.1; therefore, a standard normal distribution for each annual minimum monthly temperature for Mombasa County.

Computed skewness shows a ranging scale of -0.91 to

Table 3. Average maximum temperature for the year 1989 to 2019.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Count	31	31	31	31	31	31	31	31	31	31	31	31
Mean	32.21	32.77	32.85	31.34	29.67	28.57	27.81	27.84	28.61	29.55	30.59	31.8
Std E	0.11	0.07	0.09	0.13	0.14	0.07	0.1	0.11	0.11	0.11	0.1	0.12
Median	32.2	32.8	32.8	31.5	29.7	28.5	27.8	28	28.6	29.5	30.7	31.8
Mode	32.1	32.8	32.7	31.7	30.1	28.3	27.5	27.5	28.6	29.5	30.9	31.4
SD	0.59	0.42	0.49	0.72	0.76	0.41	0.58	0.59	0.61	0.64	0.57	0.68
SV	0.35	0.17	0.24	0.52	0.58	0.17	0.33	0.35	0.38	0.41	0.33	0.46
Kurtosis	-0.19	0.26	-0.39	-0.57	0.65	-0.19	0.93	0.31	0.85	3.92	-0.13	0.84
Skewness	-0.24	-0.5	0.08	-0.32	0.25	0.56	0.13	-0.54	-0.04	-1.35	-0.52	0.64
Range	2.5	1.8	1.8	2.8	3.7	1.7	2.7	2.6	2.8	3.3	2.5	3.1
Minimum	31	31.7	32	29.8	28	27.9	26.6	26.3	27.1	27.3	29.2	30.6
Maximum	33.5	33.5	33.8	32.6	31.7	29.6	29.3	28.9	29.9	30.6	31.7	33.7
CI (95%)	0.21	0.15	0.17	0.25	0.27	0.14	0.2	0.21	0.22	0.22	0.2	0.24
CV	1.84	1.27	1.48	2.3	2.57	1.44	2.08	2.11	2.15	2.16	1.88	2.14

SD: Standard deviation; Std E: Standard error; SV: Sample variance; CI: Coefficient of Interval; CV: Coefficient variance.

0.1, evident that distribution was left tailed (negative). However, the observed coefficient of kurtosis (Ck) readings (Table 1) shows April with the highest Ck of 2.18 and February with a Ck of -0.83. Though, from the kurtosis scale, the highest reading was less than three (<3). Therefore, a platykurtic distribution was observed. This can be interpreted from that within the 30-year variability threshold in Mombasa, observed positive and negative extremes of minimum temperature annual averages were less of few. For observed linear regression (y=0.0283x + 21.823, R^2 = 0.1655), Figure 2 shows oscillated monotonic trend of minimum rainfall across the trend but with fewer extremes of between 22.5 and 20.5°C in minimum.

Across the trend (Figure 2), climate variability anomaly in minimum average temperature gained its highest lowest peak in the years 2003 and 2004 recording lowest temperature of 20.5°C compared to the noted anomaly in four years of 21.5°C in the year 2007. However, the minimum temperature had increased in the modelled 30-year period. The accumulated minimum annual average temperature increase was +0.8°C (Figure 2). Therefore, from the linear (R^2 =0.1655), the noted increase was approximately 16.55% across accumulated the trend.

Descriptive maximum average temperature

The descriptive statistics approach was applied to assess the trend and distribution of maximum temperature in Mombasa County urbanized area. Different forms of dispersion and measure of central tendency have been used to describe commutated data. Figure 3 shows the linear trend in the past 30 years in the area of study. The least observed coefficient of variance was 1.27, and the highest CV being 2.57. From the two monthly data findings (February and May) (Table 3), CV of 1.27 had low standard variation ratio from the mean (μ = 32.77) compared to CV 2.57 with (μ =29.67) that had higher reliability variation from the mean.

The kurtosis coefficients show ranged between -0.57 and 0.93. The skewed values (-0.5 to 0.64) indicate a normal distribution spread despite a high left tailed concentration trend. It can be observed, therefore, that despite left inclined skewness, the highest positive skew point was 0.64. The skew values indicate, therefore, that symmetry indicator was longer in the left (negative) compared to the right. The asymmetrical skewness is within the 1, -1 or 0.5, -0.5; thus, the temperature trend was moderately distributed.

The linear trend of temperature (Figure 3) show a monotonic character (y=0.0258x + 29.888). The upward and downward observed anomalies could cause extremes in maximum temperature. For instance, the highest maximum temperature peak was observed in 2011 with 31°C, where the temperature had increased in the past 30 years by +0.4°C. The finding supports the modelled past, present and future projections by the IPCC's AR5 that project temperature increase by 2100. Since the pre-industrial period, the earth's surface temperature has warmed by 1°C (Hansen et al., 2018; Feulner, 2019).

Since the pre-industrial period to date, the estimated anthropogenic warming range has surpassed the 1°C mark (Tokarska et al., 2019). A report by IPCC (2018) indicates that by 2050, earth's warming shall hit past 1.5°C, wherein the year 2100, the average temperature warming will averagely hit 2°C. From these observed

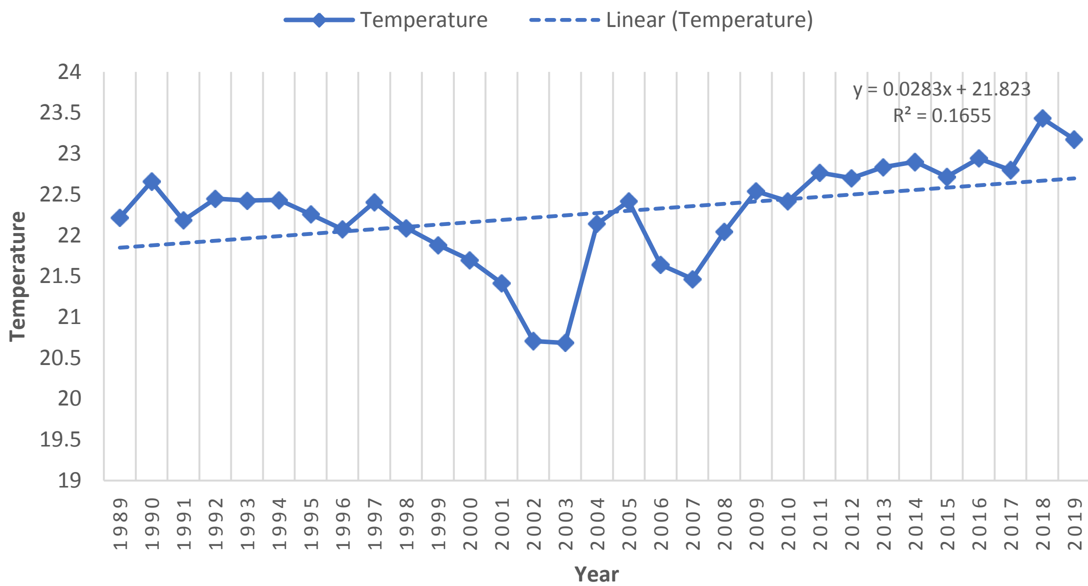

Figure 2. Minimum annual temperature for Mombasa Country (1989-2019).

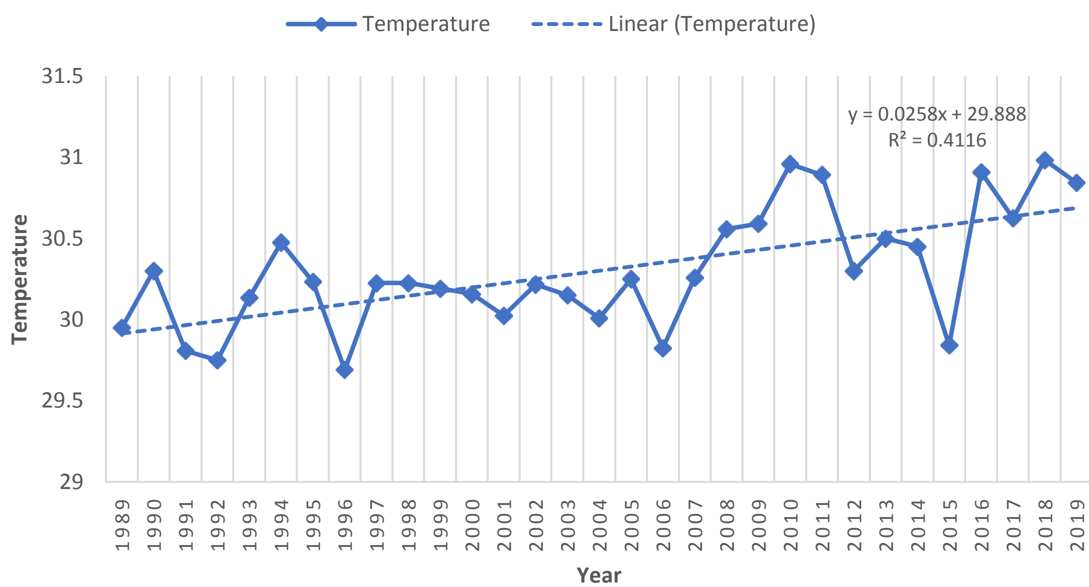

Figure 3. Maximum annual temperature for Mombasa Country (1989-2019).

projections, the observed average warming within Mombasa County of +0.4°C, adds to the global average warming index. Therefore, over the past 30 years, temperature variations in the Mombasa Country were positively contributing to warming.

Descriptive analysis of rainfall

Table 4 shows the descriptive rainfall data of Mombasa County in the past 30 years (1989-2019). Different descriptive statistics methods are indicated at the table, respectively. The coefficients of skewness (Cs), coefficient of variation (CV), sample variance (SV), coefficient of kurtosis (Ck) and Standard deviation (SD). A study by Hayelom et al. (2017) indicates that (CV) is important in the classification of the degree of variation. This classification is rated at a point scale as low (CV less than 20%), moderate (CV less than 30%), high (CV above 30%), very high (CV above 40%), and extremely

Table 4. Descriptive statistics of the rainfall data for the year 1989 to 2019.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Count	31	31	31	31	31	31	31	31	31	31	31	31
Mean	25.91	11.97	40.29	150.8	260.7	96.1	72.23	59.37	43.17	130.3	105.1	67.87
Std E	7.33	3.46	6.28	16.64	28.71	9.65	6.6	7.422	6.493	27.82	11.61	11.05
Median	16.2	3.3	34	137	229.7	97.3	64	45.1	38	68.2	89	52.2
Mode	25.9	0	#N/A	#N/A	#N/A	#N/A	#N/A	30.7	3.2	281.6	74.1	#N/A
SD	40.8	19.28	34.98	92.6	159.9	53.72	36.75	41.32	36.15	154.9	64.62	61.54
SV	1665	371.8	1224	8587	25558	2886	1350	1708	1307	23999	4176	3787
Kurtosis	15.08	3.27	3.78	-0.72	0.32	-0.47	-0.53	1.759	3.402	12.89	2.634	3.182
Skewness	3.53	2.06	1.69	0.68	0.78	0.26	0.495	1.477	1.804	3.154	1.386	1.7
Range	213.3	66.6	162	306.4	643.4	205.1	131.2	159.6	146.3	802.8	305	275
Minimum	0	0	0	26.8	21.4	4.1	20.2	14.5	3.2	16.9	11.5	0.5
Maximum	213.3	66.6	162	333.2	664.8	209.2	151.4	174.1	149.5	819.7	316.5	275.5
CI (95%)	14.36	6.79	12.32	32.62	56.28	18.91	12.94	14.55	12.73	54.53	22.75	21.66
CV	157.5	161.1	86.82	61.46	61.32	55.9	50.87	69.61	83.75	118.9	61.49	90.67

SD: Standard deviation; Std E: Standard error; SV: Sample variance; CI: Coefficient of Interval; CV: Coefficient variance.

high (CV above 70%). From Table 4, the total annual rainfall coefficient of variance and interval is above 5%, based on the kurtosis measure of distribution from the formula.

The computed data in Table 4 show 15.08 in January as the highest coefficient of kurtosis with -0.47 least kurtosis in June; thus, a platykurtic distribution (<3) was observed in June months. The platykurtic distribution of annual, monthly precipitation totals is also observed in April, May, June, July, August, and November. Other months recorded the kurtosis coefficient of (>3), thus an observed leptokurtic distribution. However, despite low values of skewness recorded, the distribution had a positive (+) skewness with normal distribution without negative (-) skewness observed across the distribution trend.

It is observed in the results (Table 4) that all the months had a high coefficient of variation (>30%); therefore, deploying a homogeneous character on their precipitation variations. From the mean annual precipitations (Figure 4), the range is observed to be low (1685 to 661 mm). The linear precipitation shows decline of rainfall of between 1989 and 2019 ($y = -9.5882x + 1217.1$, $R^2 = 0.0712$).

Across the linear trendline (Figure 4), precipitation anomalies were observed between the years 2004 and 2005 recording the highest rainfall 2157 mm, and the year 2012 to 2014 recording 1648 mm. Even with these peak precipitation anomalies, received precipitation in Mombasa County was decreasing across the trend. Evident that climate variability effect had been experienced in the county in between the years (1989 – 2019). The previous study by Sheriff (2019), shows variations in temperature and rainfall for 30 years (1986-2016) subjecting the area to climate variability effect.

To investigate if there is a significant variation in rainfall and temperature in Mombasa County, a paired t-test done on the meteorological data. The data was segmented into two data sets; the first data set consists of the measurements taken in the first two years that is 1989 and 1990 and the second data set consists of the measurements taken in the last two years that is 2018 and 2019. The first test was performed to test the difference between the mean rainfall between the first two years and the last two years. The assumptions were; that the level of rainfall in the last two years is significantly lower compared to the first two years of the collected data from Mombasa County.

H_0: The average rainfall of the last two years is equal to or higher than the first to years.

H_0: The average rainfall of the last two years is lower than the first to years.

The results (Table 5), shows that the mean rainfall for the last two years is significantly lower than that of the first two years [t (0.05, 23) = 2.025, P = 0.0275]. This implies that rainfall amount is decreasing significantly in the coastal region

Prior analysis indicated that the maximum temperature recorded in Mombasa County had increased over time. Using the paired t-test approach, the mean maximum temperature of the first and the last two years were compared and the results are as shown (Table 6).

Based on the findings above, it is evident that the maximum temperature of the last two years is

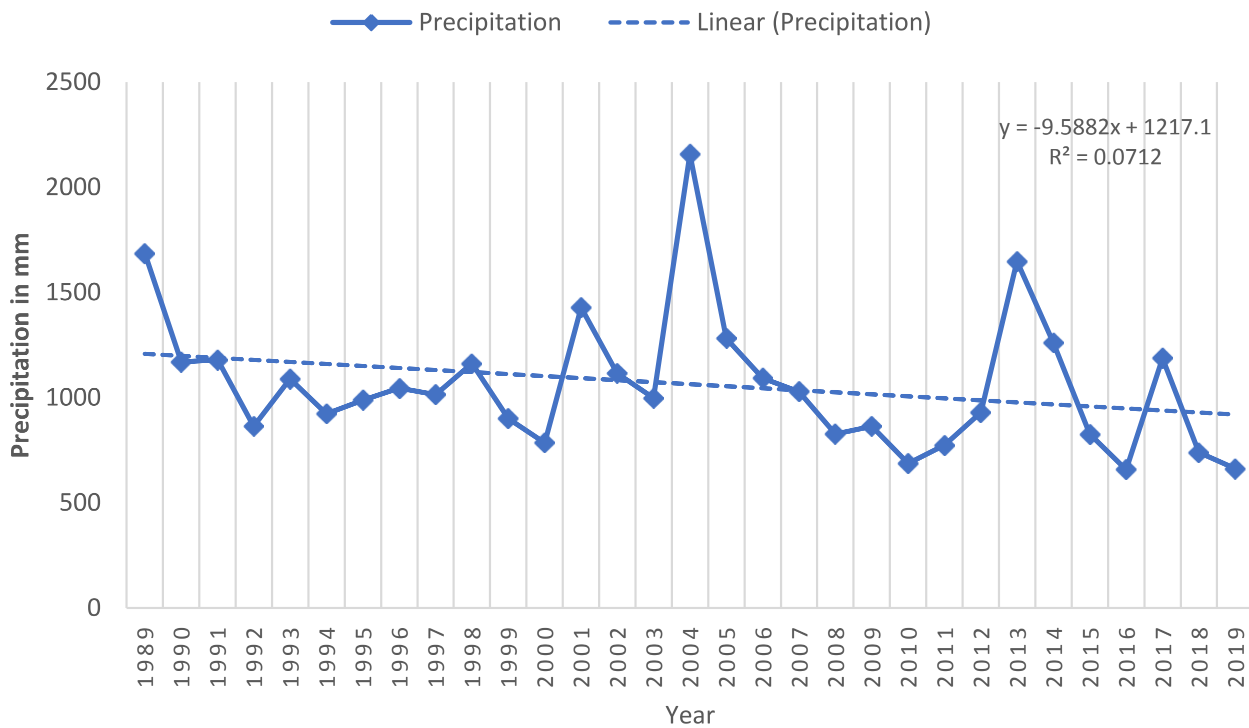

Figure 4. Total annual rainfall for Mombasa County (1989-2019).

Table 5. Rainfall variability t-test results.

	Paired differences					**t**	**df**	**Sig. (1-tailed)**
	Mean	**Std. deviation**	**Std. error mean**	**95% Confidence interval of the difference**				
				Lower	**Upper**			
Year 1989-1990 - Year 2018-2019	60.6042	146.6121	29.9271	-1.3047	122.5130	2.025	23	0.0275

Table 6. Maximum temperature t-test results.

	Paired difference					**t**	**df**	**Sig. (1-tailed)**
	Mean	**Std. deviation**	**Std. error mean**	**95% Confidence interval of the difference**				
				Lower	**Upper**			
Year 1989-1990 - Year 2018-2019	-0.7875	0.6854	0.1399	-1.0769	-0.4981	-5.628	23	0.000

significantly higher than the temperature of the first two years [t (0.05, 23) = -5.628, P=0.000]. Similarly, the minimum temperature of the regions was investigated to establish if a difference between the first and the last two years existed and the results are as shown (Table 7).

The results above show that the measured minimum temperature of the last two years is significantly higher than of the first two years [t (0.05, 23) = -5.401, p = 0.000]. Therefore, from the above t-test, the H_0: There is significant variations in temperature and rainfall in

Table 7. Minimum temperature t-test results.

	Paired differences					t	df	Sig. (1-tailed)
	Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
				Lower	Upper			
Year 1989-1990 - Year 2018-2019	-0.8667	0.7861	0.1605	-1.1986	-0.5347	-5.401	23	0.000

Mombasa County was accepted.

Conclusion

The coastal urban setting of Mombasa County had experienced the effect of climate variability. The changes in rainfall and temperature had been experienced in the past 30 years as per the modelled retrospective study period. Temperatures had increased over time and decline of average rainfall even with trend line oscillations propagated climatic extremes.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Greenhouse gas reduction and cost-benefit through improving municipal solid waste management in Ouagadougou

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Waste management is one of the major challenges of urban management in Sub Saharan African countries. The current difficulties in the management of solid waste are the result of poor mastering of concepts, approaches, and techniques. This paper aims to study the Greenhouse gas reduction and cost-benefit through improving municipal solid waste management in Ouagadougou. Since the site location is important for collection optimization, the paper was focused on the research of the technique to achieve this goal with two identified methods, the gravity method and the Quantitative System for Business software (WinQSB). The result showed that both methods got the same coordinate system (12.36943601; -1.513841578) which corresponds to street 3.22, Dapoya, Ouagadougou, Burkina Faso. The new site offers more benefits, especially in terms of cost reduction as well as greenhouse gas reduction. For example, ten million FCFA or twenty thousand 20,000 USD a year could be saved up.CO_2 emissions in the transport sector pose a key problem along with particle and NOx emissions. Also, 30 m^3 of gasoline is needed per week per truck to transport urban waste, which is released around 3,801.6 Kg of CO_2 per year by using an old transfer station. By considering the new transfer station because of the proximity of collection points, around 2,500.8 Kg of CO_2 per year is released which is less than CO_2 released in the old station.

Key words: Municipal solid waste, site optimization of transfer station, greenhouse gas reduction, solid waste landfill.

INTRODUCTION

Greenhouse gas (GHG) emissions resulting from urban waste services are a major cause of climate change. Climate change poses a major threat to sustainable urban development in Africa. Changes in the frequency, intensity, and duration of climate extremes (droughts, floods, and heatwaves, among others) will affect the livelihoods of the urban population, principally the poor and other vulnerable communities who live in slums and marginalized settlements (Kumssa et al., 2015) The number of GHG emitted due to waste management in the

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cities of developing countries is predicted to rise considerably soon (Friedrich and Trois, 2011); however, these countries have a series of problems in accounting for and reporting these gases (Cheyne, 2002). Some of these problems are related to the lack of a coherent framework for accounting and reporting of greenhouse gases from waste at the municipal level (Achankeng, 2003).

The condition of the municipal solid waste management (SWM) of Africa is critical. Under the general expansion of the human population and rapid urbanization in Africa, the amount of municipal solid waste is increasing drastically. However, the public authority capacity to implement the municipal SWM service in each country is limited. As a result, many municipal solid wastes are not collected or treated/disposed-off appropriately, which has caused public health issues and environmental problems. The urban population of Africa plays an indispensable role in the amelioration of the city sanitation environment, which is likely to triplicate in 2050 from about 450 million people (40% of the total population) and was linked with various kinds of economic infrastructure buildings. However, the current condition of the municipal SWM of African countries was reported that Municipal waste management is the responsibility of each municipality (city) or local government, but its implementation capacity is often weak, facilities and equipment are insufficient, and maintenance, management, and waste disposal are often not carried out properly. The central government or the provincial government's guidance, coordination, and management system for instructing the municipality are not in place appropriately.

As the cities are expanding and population increases, the existing capacity, and trend of waste management do not perform the desired level of service. The existing service of waste management is primitive and follows the collection-transportation-disposal hierarchy. Dumpsites in the city are increasingly difficult to obtain and trucking of wastes out of the city is growingly expensive. Local community-based waste collection schemes are a shining light but the secondary collection points are again gloomy. The disposal site is an uncontrolled dumping threads to surface and groundwater pollution. Proper handling and managing of waste have value if the 4 R principles: reduce, reuse, recovery, and recycling is followed. Large numbers of people are supported by waste picking and recycling activities, which may be unsanitary but important in terms of economics and reducing the quantities of waste requiring disposal.

Municipalities have to strengthen institutional capacity and financial management. The de-mountable container system is good but costly due to misleading with the actual concept (Amariei et al., 2009). The strong monitoring and incentive mechanism along with the possibility of installation of weigh-bridge at the dumpsite can make the system efficient. The crude way of waste disposal should be avoided as surface and groundwater are being polluted (Das and Bhattacharyya, 2015). The best option is the controlled management of dumpsite with compacted clay liner for the protection of ground intrusion and recirculation back of the leachate to the landfill allowing faster decomposition and reduction. Landfill gas can be controlled by installing vent pipes for releasing gas to the atmosphere or contracting out to any private company for the generation of energy (Burhamtoro et al., 2012).

Burkina-Faso, located in West Africa, has an area of 274,120 Km² where Ouagadougou is the capital located in the center of the country between the parallels 12° 20 and 12° 25 of latitude North and the meridians 1° 27 and 1° 35 of longitude West (Carling and Håkansson, 2013). On the administrative level, Ouagadougou is a decentralized territorial collectivity and led by a mayor elected by popular vote by municipal councilors. The demographics are difficult to appreciate by the divergent searchable and controversial sources of data, because of the lack of coordination of the actors involved in urban management in Ouagadougou.

For the present study, the demographic data available at the National Institute of Statistics and Demography was taken into account (Chang and Desai, 2003). According to this source, the city covers an area of about 21,000 ha and includes more than 50% of the urban population of the country. The current population of Ouagadougou is estimated at 1 500 000 inhabitants. The average household size was 5.6 people, ranging from 5 to 7 people (Beğen, 2002). The urban density is between 3458 and 4600 inhabitants per square kilometer or about 40 inhabitants per hectare (Zi-xia and Wei, 2010).

This research looks at the case of Ouagadougou indeed, piles of garbage and waste litter the streets and this has become a common sight in other Burkina cities as well. Municipalities are facing increasing difficulty in providing adequate services. The country legislation acknowledges the need to move away from landfill as the absolute solution. The legislation aims to clean up the city while limiting the wild dumps by adequate standards. To this end, the municipality of Ouagadougou has created an operational structure named "Direction de la property" in charge of the management of the waste. This paper analyzes the current state of solid waste management systems in Ouagadougou, improve the collection systems of the municipal solid waste management, and estimate greenhouse gas released from waste.

CURRENT STATE OF SOLID WASTE MANAGEMENT SYSTEM IN OUAGADOUGOU

Waste collection systems of the city of Ouagadougou

The city urban waste grows rapidly from year to year as

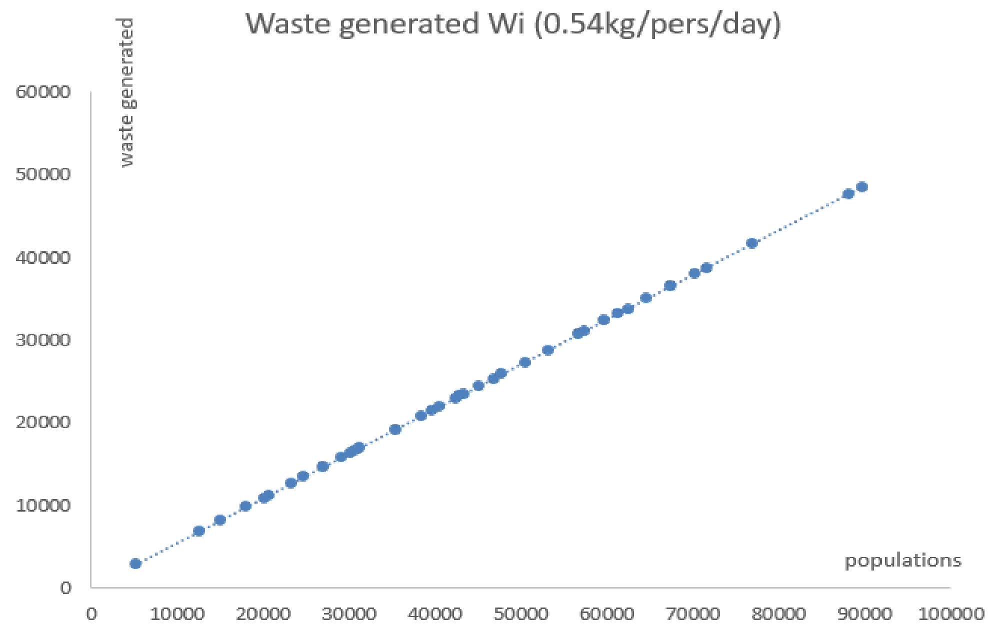

Figure 1. Waste generated by inhabitants of Ouagadougou.

shown in Figure 1. Solid Management in Ouagadougou has organized in three (02) stages (pre-collection collection, and transportation) (Botello-Álvarez et al., 2018). This organization requires the existence of two structures equipped with facilities to carry out this work, the existence of waste management infrastructures and the financial means necessary to ensure their operation. The solid waste collection is concerning every street according to the government plan (SDGD), which consist to divide the town into 12 areas; each area is led by one private enterprise (Ferronato et al., 2019). In Ouagadougou, the common method of the solid waste collection suggested is the door-to-door system, where waste is sourced separately and disposed of in fraction-specific containers that are located typically in outdoor waste sheds in inner courtyards of residential blocks (Feng et al., 2009).The MSW collection is carried out using private waste collection enterprises at a fixed cost, varied from 500 FCFA (1USD) to 1000 FCFA (2 USD) with the level of standing.

Pre-collection and collection

Pre-collection from households in the collection by the producer of waste using the bin. It should be noted that in our cities, pre-collection is done without a minimum of sorting at source. This job is provided by small enterprises and associations. The Environmental Services Department of Ouagadougou is responsible for urban technical management, including urban waste management. It is primarily responsible for collecting and transporting waste to a landfill (Das and Bhattacharyya, 2015). There are several collection routes along which each of the bins must be lifted twice a week. Each engine makes a maximum of 12 trips a day, five workdays a week (Ding et al., 2011). It consists of bringing the waste from the source of production to the collection or collection point (garbage bin or collection center). The collection of waste can be done either by the voluntary contribution of the users, or door to door by the small enterprise, associations, or the municipality. In the precollection and collection system in Ouagadougou, we have zero CO_2 emission from engines. The city used engines such as charts that emit no waste products that pollute the environment or disrupt the climate.

Transport

Transport is an operation that consists of recovering waste from the transfer station to final disposal. In the city of Ouagadougou, it is provided by the sustainable development department. The cost of transport is quite high and difficult to support communities that have difficulty in acquiring transport equipment but also to ensure their maintenance (Fei-Baffoe et al., 2014). As an example for the commune of Ouagadougou, transporting one cubic meter of waste to transfer station costs 4,500 F CFA (10 USD), the truck can transport up to thirty cubic meters. Transport from households to the landfill is carried out by private-public companies under the direction of the cleaning bureau (Cao et al., 2011).

CO_2 emissions in the transport sector pose a key problem along with particle and NOx emissions. If long-term climate protection targets are to be met, the transport sector must play its part by reducing its absolute CO_2 emissions. When it comes to the application of technical measures at source, part of the emissions reduction target could be achieved through greater use of alternative fuels and another part by reducing specific CO_2 emissions in conventional vehicles. 30 m^3 of gasoline is needed per week per truck to transport urban waste, which is released around 3,801.6 kg of CO_2 per year by using an old transfer station. By considering the new transfer station because of the proximity of collection points, around 2,500.8 kg of CO_2 per year is released which is less than CO_2 released in the old station. That means there are only two ways to reduce specific CO_2 emissions:

(i) By reducing fuel consumption in vehicles with conventional through reducing the distance of the trip.
(ii) By using renewable, low- CO_2 fuels – partly in conjunction with new engine technologies.

Landfill situation in Ouagadougou

In the city, the landfill is essentially dumping grounds. It covers an area of 70 ha. They lack the basic infrastructure that defines a landfill, such as membrane lines, impermeable liners, daily covers, and methane extraction infrastructure. The traditional method of landfills was to directly wad wastes in valleys and watercourses that are naturally formed or in artificial pits and pounds without any treatment to prevent wastes from diffusion and transference, which is called an informal landfill compared with the modern sanitary landfill. Since its opening in April 2005, Polesgo landfill receives most of the household waste produced in Ouagadougou. It has a capacity of 6.1 million cubic meters of waste and offers an operating capacity of 20 years. The landfill is located about ten kilometers north of the city and has two main charges: firstly, solid waste burial and secondly, solid waste valorization (composting, plastic recovery, etc.).

The two most important problems with our landfill are leachate, and greenhouse gases. Leachate is the liquid formed when waste breaks down in the landfill and water filters through that waste. This liquid is highly toxic and can pollute the land, groundwater, and waterways. Improper management of sanitary landfills will become a huge problem for the environment. The main pollution that occurs by the sanitary landfill is the generation of leachate which will affect groundwater, ecosystem, and human health because of the high content of organic compounds. Greenhouse gas constitutes a big challenge in the city. Organic material such as food scraps and green waste is put in a landfill; it is generally compacted down and covered. This removes the oxygen and causes it to break down in an anaerobic process. Eventually, this releases methane, a greenhouse gas that is 25 times more potent than carbon dioxide. The implications for global warming and climate change are enormous. Methane is also a flammable gas that can become dangerous if allowed to build up in concentration. Composting food scraps and green waste in a compost bin eliminates many of these problems. Another solution is to build a landfill lined with a membrane that is specially designed to catch methane in liquid form and prevent it from escaping into the air (Peidong et al., 2006).

Methane emission estimation from solid waste disposal

The calculation of methane emission will be estimated by using IPCC default method. This method is based on the main equation which is:

$$\text{Methane}\left(\frac{\text{Gg}}{\text{yr}}\right) = \frac{\text{MSWT} \times \text{MSWF} \times \text{MCF} \times \text{DOC} \times \text{DOCF} \times \text{F} \times 16}{12 - \text{R}} \times (1 - OX) \tag{1}$$

Where: MSWT is the total MSW generated (Gg/yr), MSWF is the fraction of MSW disposed to solid waste disposal sites, MCF is the methane correction factor (fraction), DOC is the degradable organic carbon (fraction) (kg C/kg SW) DOC_f is the fraction DOC dissimilated, F is the fraction of CH_4 in landfill gas, 16/12 is the conversion of C to CH_4, R is the recovered CH_4 (Gg/yr), OX is the oxidation factor.

On average 0.52 kg per person per day of Waste was generated in the capital of the country. The total amount of waste generated per year was estimated at 330 Gg/yr, therefore the city disposed of only 52% of municipal solid waste into the landfill site so the methane emission released was about 3,545 Gg/year. The method assumes that all the potential CH_4 emissions are released during the same year the waste is disposed of.

MATERIALS AND METHODS

It is needed to improve collection systems because the collection is the most important in solid waste system cost. Therefore, a little percentage improvement in the collection operation can produce an important saving in the overall cost. Two methods were identified as the center of gravity method and Quantitative System for Business (WinQsb), Figure 2 shows the study area. The map displayed the delimitation of the city in terms of the number of districts, villages, natural resources such as lakes, dams, etc.

Center of gravity

The gravity method is a geophysical technique that measures differences in the earth's gravitational field at specific locations. The

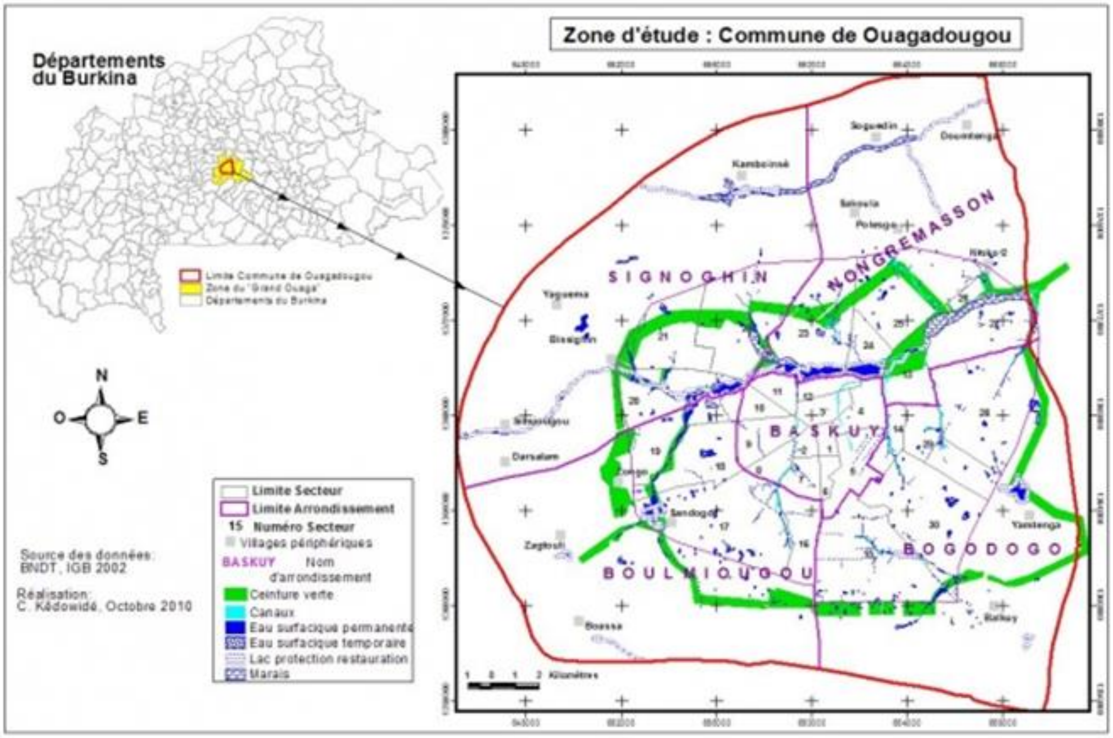

Figure 2. Location of the study area: Ouagadougou Commune.

gravity method is a relatively cheap, non-invasive, non-destructive remote sensing method. Gravity data in engineering and environmental applications should be collected in a grid or along with a profile with stations spacing five meters or less. Using the highly precise locations and elevations plus all other quantifiable disturbing effects, the data are processed to remove all these predictable effects. The most commonly used processed data are known as Bouguer gravity anomalies, measured in mGal. An accurate determination of the source usually requires outside geophysical or geological information (McDougall et al., 2008; Sheahan and Barrett, 2017).

In addition to obtaining a gravity reading, a horizontal position and the elevation of the gravity station must be obtained. The horizontal position could be either latitude and longitude or the x and y distances (meters or feet) from a predetermined origin. The required elevation accuracy for detailed surveys is between 0.004 and 0.2 m as well as to obtain such accuracy requires performing either an electronic distance meter (theodolite) survey or a total-field differentially corrected global positioning survey (GPS) (Simões et al., 2009). This method requires two steps, locate each of the existing collection points with (X; Y) coordinate system and find out the (X; Y) coordinate system of the new area by taking the average (X; Y) coordinate of all existing area.

$$x_0 = \frac{\sum xiLi \times Q}{\sum Li \times di} \qquad y_0 = \frac{\sum yiLi \times Q}{\sum Li \times di} \qquad (2)$$

Where (x_0, y_0) is the coordinate of the new transfer station, (x_i, y_i) is the coordinate of the existing transfer station ,Li is the Load to be transported between the old and the new area, Di is the distance between collection point and transfer station and Q is the shipping rate. In the case of Ouagadougou according to the formula, a barycenter coordinate was gotten as the initial solution, recorded as (x_1, y_1). The initial coordinate (x_1, y_1) was set into the formula and calculate the results as (x_2, y_2). Then the coordinate (x_2, y_2) was placed into the formula, calculate the results recorded as (x_3, y_3), and so on, and repeated until the results of two identical iterations (Sruthi et al., 2018). An optimum solution was gotten after 13 iterations.

WinQSB overview

The package of informatics programs, Quantitative System for Business (WinQSB) is a software system developed and maintains by Chang Yih from Georgia Institute of Technology (Tai et al., 2011), functioning under Windows, which is composed of 19 modules, each module is composed of others sub modules. The launching of a certain module allows processing the input data, obtaining the results, analysis, and interpretation. The extensions of the saved files are particular to each appealed module. The QSB (Quantitative Systems for Business) contains the most widely used problem-solving algorithms in Operations Research and Management Science (OR/MS).

The goal is to present a way to solve the facility location problem by using WinQSB software. The main question is where must we put a facility or a service to be able to minimize the total time and cost. Despite its simple description, the problem contains some of the most interesting and difficult notions of applied mathematics and especially of optimization theory. Using this software in practice has a real contribution to the development activities efficiency, ensuring a high economy of time by eliminating routine activities tied to the classic way of solving the problem. This program Facility Location and Layout, solve three facility design problems: facility

Figure 3. Schematic of old and new location according to our calculation.

location, functional layout, and line balancing.

RESULTS AND DISCUSSION

Selecting of the new transfer station location with gravity method

The selection of a site for any waste-related facility can be a sensitive issue, particularly for those living nearby. So identifying a good site for a waste transfer station can be a challenging process. Site suitability depends on numerous technical, environmental, economic, social, and political criteria. When selecting a site, a balance needs to be achieved among the multiple criteria that might have competing objectives. The center-of-gravity, or weight center, the technique is a quantitative method for locating a facility such as a warehouse at the center of the movement in a geographic area based on weight and distance (Tchobanoglous, 2009). Using this method to an existing collection point, a new location, more advantageous, was found. The result shows that (12.36943601; -1.513841578) is the best coordinate's location for the transfer station building. Figure 3 represents the location of the old and new transfer station based on the calculation as well as landfill location.

Location result with WinQSB

The facility location Model, also known as location analysis, is a branch of operations research and computational geometry concerned with the optimal placement of facilities to minimize transportation costs. The facility location problem can be classified as several new facilities to be located, the solution space, the size of facilities, the criteria used to determine the location, the distance measured, and so on. Based on these problems, the software can do some statistical analysis and find out the best site, in the case of Ouagadougou, the new coordinate system is corresponding to street 3.22, Dapoya, Ouagadougou, Burkina Faso. Table 1 recaps the cost between both transfers' stations using trucks. It shows that using the new transfer station is more beneficial to the municipalities. So the new transfer station is the most useful in general, and the profit is more and more important compared to old station.

Benefits of the new location

Communities need transfer stations to move their waste efficiently from the point of collection to distant, regional landfills. By consolidating solid waste collection and disposal points, transfer stations help communities reduce the cost of hauling waste to these remote disposal sites. The main benefit of the new transfer station is the reduction in transportation costs. Indeed, there is saving on the consumption of the fuel and as such, the cost of the garbage transport is minimized (Sun et al., 2009). The transfer station offers citizens facilities for average are located 20 km away from the center of the city. This saves travel time and the fleet can be better utilized for making extra trips resulting in ineffective cleaning and

Table 1. Cost result between both transfer stations using truck.

Collections points	Distance to the new transfer station (km)	Distance to the old transfer station	Waste generated (kg)	Qi	New transfer cost (FCFA)	Old transfer cost (FCFA)
1	15	20	16304.22	0.35	85597.16	114129.5
2	4.6	4.2	25821.72	0.35	41572.97	37957.93
3	4.7	3.6	30969.54	0.35	50944.89	39021.62
4	2.4	8.8	27254.34	0.35	22893.65	83943.37
5	8.3	6.5	30619.62	0.35	88950	69659.64
6	8.3	5.2	16752.96	0.35	48667.35	30490.39
7	3.4	6.8	14587.56	0.35	17359.2	34718.39
8	3.4	8.4	19145.16	0.35	22782.74	56286.77
9	16	20	12587.94	0.35	70492.46	88115.58
10	6.6	6.1	37962	0.35	87692.22	81048.87
11	17.1	9.3	33095.52	0.35	198076.7	107725.9
12	10.4	9.2	24369.12	0.35	88703.6	78468.57
13	20	21	32257.98	0.35	225805.9	237096.2
14	13.8	7.3	33720.3	0.35	162869	86155.37
15	8.2	8	36392.76	0.35	104447.2	101899.7
16	7.5	9.4	38679.12	0.35	101532.7	127254.3
17	4.3	13.9	34934.76	0.35	52576.81	169957.6
18	21	21	9745.38	0.35	71628.54	71628.54
19	3.8	11.6	41563.26	0.35	55279.14	168746.8
20	14.3	16.1	11187.72	0.35	55994.54	63042.8
21	9	12.2	15705.9	0.35	49473.59	67064.19
22	2.9	10.6	10860.48	0.35	11023.39	40292.38
23	22	22	23148.18	0.35	178241	178241
24	6.7	14.3	25262.82	0.35	59241.31	126440.4
25	6.9	14.5	21364.02	0.35	51594.11	108422.4
26	12	15	22913.82	0.35	96238.04	120297.6
27	8.3	15.4	23397.66	0.35	67970.2	126113.4
28	8.7	15.7	16880.94	0.35	51402.46	92760.77
29	9.9	16.9	21847.86	0.35	75702.83	129230.1
30	10.5	17.4	48449.88	0.35	178053.3	295059.8
31	21	22	6787.8	0.35	49890.33	52266.06
32	11.2	6.8	16607.16	0.35	65100.07	39525.04
33	7.7	14.7	13354.74	0.35	35991.02	68710.14
34	10.8	17.8	8159.4	0.35	30842.53	50833.06
35	22	22	28702.08	0.35	221006	221006
36	18.2	15.3	2792.88	0.35	17790.65	14955.87
37	25.5	26	20733.84	0.35	185049.5	188677.9
38	26	26.5	47613.96	0.35	433287	441619.5
Total					3511764	4208863

sweeping. It can also be noticed that the wear and tear of the tires and other components of vehicles are minimized by avoiding long trips and adverse conditions at landfill sites. Waste transfer station may be the most cost-effective when it is located convenient drop off waste as well; we have more abilities in waste handling and disposal alternatives. The small dumper placer vehicles need not have to travel long distances up to the landfill site, which on near a collection area (Tınmaz and Demir, 2006). The use of transfer station lowers collection costs, as crews spend less time traveling to and from distant disposal sites and more time collecting waste; this reduces costs for labor, fuel, and collection vehicle maintenance.

To understand how sensible it is to spend money on these emissions reductions, we can compare them to estimates of carbon's social cost, which quantifies the incremental damage resulting from emitting a ton of carbon dioxide and other greenhouse gases into the atmosphere. The long residence time of CO_2 in the atmosphere makes climate change a long-term problem. As a result, the key to reducing emissions in the future is to have low-cost alternatives to fossil fuels that are zero or low-carbon. The true total cost of investments or interventions today therefore must contain both their static, or face-value cost, and any spillovers those investments have for future costs of emissions reduction. The importance of a dynamic perspective is hardly new (Newell, 2017), but it is often neglected both in the public debate and in the literature on costs of abatement. Yet, the welfare benefits of even small growth rates in the efficiency of clean technologies may be large, as suggested by simulations in Hassler (Lazard, 2017).

DISCUSSION

To improve the collection system, site selection is important. There are many methods for choosing the best location; we have studied the center of gravity approach, and another method using WinQSB. With both methods, we have found the same result for implementing the new transfer station. However these methods have some limitations, but the WinQSB is more advantageous because of the ease of use of the software. It can find some solutions in very little time. This software is very useful for everyone and we even do not need any programming skills. The new site offers no doubt more benefits, especially in terms of cost reduction. For example, ten million FCFA (local currency) or twenty thousand 20,000 USD can be saved a year.

Of all municipal responsibilities, waste management remains one of the most complex, noble, and exciting for elected officials and their staff. Since it is a versatile field that requires taking into account a multitude of themes related to the environment, sanitation, economy, law, sociology, communication. Waste transfer station may be the most cost-effective when it is located near a collection area. The use of transfer station lowers collection costs, as crews spend less time traveling to and from distant disposal sites and more time collecting waste; this reduces costs for labor, fuel, and collection vehicle maintenance. The present results provide evidence that the new site has the potential to achieve emission from vehicles. To our knowledge, no previous study has calculated the potential savings within the transport sector in the city. Providing alternatives vehicles can contribute to CO_2 emission reduction.

Conclusion

This paper examines the greenhouse gas reduction and cost-benefit through improving municipal solid waste management in Ouagadougou. The waste is designated as a nuisance related to the growth of the city. This paper shows the problems and challenges related to municipal solid waste management; however, the difficulties encountered today in Ouagadougou in this area are also aggravated by the economic handicap of the country and the behavior of the people. Observation through the distribution of garbage piles in the capital of Ouagadougou is an opportunity to examine the collection system.

Since the site location is important for collection optimization, the paper was focused on the research of the technique to achieve this goal. Two main methods were identified, the gravity method and the Quantitative System for Business software (WinQSB). The result showed that both methods got the same coordinate system (12.36943601; -1.513841578) which is corresponding to street 3.22, Dapoya, Ouagadougou, Burkina Faso. The new site offers more benefits, especially in terms of cost reduction. For example, we could save up to ten million FCFA or twenty thousand 20,000 USD a year. All the difficulty will lie in finding a strategy reconciling technique-economic efficiency and socio-economic realities. One of the answers to this question already lies in the reduction of waste both in terms of production and collection.

CO_2 emissions in the transport sector pose a key problem along with particle and NOx emissions. In the case of Ouagadougou to transport urban waste, around 3,801.6 Kg of CO_2 is released per year by using an old transfer station. By considering the new transfer station because of the proximity of collection points, around 2,500.8 kg of CO_2 per year is released which is less than CO_2 out in the old station. As a preventive measure, a considerable reduction of the mobility of hazardous substances in landfills is then needed, even if the former and current practice have not yet resulted in serious damages. The landfill and its environmental impacts will be part of every country during the next generations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Possibility of improving solid waste management in senior high schools in the Ashanti region of Ghana

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Little attention has been given to solid waste management in Senior High Schools meanwhile their population and consumption pattern keeps on increasing. The study was conducted in senior high schools within the Ashanti Region to determine the composition and generation rate of solid waste in the selected senior high schools. An extensive field investigation was used for quantification and analysis of the composition of solid waste in fifteen senior high schools in the Ashanti Region of Ghana. Averagely, waste generated were organic (70.91%), rubbers and plastics (11.24%), metals (5.64%), textiles (4.67%), other waste (2.77%), glass/ceramics (2.64%) and papers (2.13%). The per capita per day generation rate ranged from 0.02 to 0.13 kg/cap/day with an average of 0.056 kg/cap/day. The population of the schools and generation rate per capita per day of the schools had a negative correlation coefficient (-0.05). More than 90% of the waste generated in the schools could be dealt with through waste reduction, recycling, and composting. It was recognized that a greater percentage of the waste generated in the selected senior high schools was organic and therefore composting should be encouraged as a way of effectively managing such components of the waste stream and whipping up the students' knowledge in waste as a resource.

Key words: Waste generation, solid waste, waste characterization, source sorting, composting.

INTRODUCTION

Solid waste management has become a critical issue in developing countries and the most crucial aspect in managing the solid waste generated is to ascertain the characteristics or composition of the said solid waste (Miezah et al., 2015). Solid Waste Management policies, plans, and systems cannot be successful without considering the characteristics or composition of the solid waste (Bolaane and Ali, 2004). Chung and Poon (2006) stated that data from waste characterization are essential for the selection of solid waste management systems and waste management policy formulation. Though data on solid waste composition are crucial in waste management, these data are lacking in most developing countries including Ghana (Miezah et al., 2015) and this affects the management of solid waste in these countries. Solid waste treatment and final disposal option such as reusing, recycling, landfilling and incineration is influenced by knowledge on waste characterization (Al-Jarallah and Aleisa, 2014). An effective and efficient integrated solid waste management system can only be successfully initiated with knowledge on characteristics and generation rate of the solid waste (Hettiarachchi et

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al., 2018).

Educational institutions in developing countries including Ghana are not left out in the problems of solid waste management and the first step in finding a remedy to this problem is to know the characteristics, generation rate, and per capita generation rate of the solid waste generated in these institutions. Meanwhile, studies conducted by Lehmann et al. (2009) and Zilahy and Husingh (2009) have revealed that educational institutions can play a significant role in promoting sustainable programmes in society. It should be noted that the population of these educational institutions especially Senior High Schools in Ghana is increasing rapidly due to introduction of free Senior High School education by the Government of Ghana (Tarlue, 2020). Besides, the quantity of waste generated and population are correlated and the main disposal methods of the waste generated in these institutions include crude dumping and open burning (Bundhoo, 2018). In Ghana, treatment facilities for waste generated are lacking and few landfill site available in some communities are not properly managed and as a result of that most people resort to clude dumping and open buring (Yoada et al., 2014). The senior high schools with their increasing poplations in Ghana are not left out of these practices. However, little or no study has been conducted to find out the types and quantities of waste generated in these schools. To address the waste management practices among the increasing student population in these schools call for a detailed study and analysis of the situation. This study, therefore, focused on the characterization and generation rate of solid waste in selected Senior High Schools within the Ashanti Region of Ghana to determine the potential approach for effective waste management systems for sustainable development. This study took into consideration both the characteristics and quantity of the generated waste using a direct waste sampling and analysis approach.

MATERIALS AND METHODS

All the schools were selected from the Ashanti Region of Ghana, which is located South of Ghana (Figure 1). It is the largest of 16 administrative regions currently operating in Ghana. It occupies a total land surface of 24,389 km² (10.2%) of the total land area of Ghana (Ghana Statistical Service, 2014). Kumasi is the capital of the region. In terms of population, however, it is the most populous region with a population of 4,780,380 accounting for 19.4% of Ghana's total population (Ghana Statistical Service (GSS), 2014). The region experiences double maxima rainfall in a year with an average annual rainfall of 1270 mm and ranges between 1100 and 1800 mm. Much of the region is situated between 150 and 300 m above sea level. Humidity is high during the wet months of the year and low during the dry months. The average humidity in the southern districts is about 85 and 65% in the northern part of the region (GSS, 2014).

For the purpose of the study, fifteen senior high schools selected from 180 senior high schools in the Ashanti Region using simple random sampling technique. Table 1 shows the sex and total students' population of the selected schools as of the 2017/2018 academic year.

Each selected school was visited to assess the conditions and situation on the ground to ensure that everything was ready for the study, giving prior notice about the exercise such that waste generated within the day would be kept in the dustbin or storage container for the sorting and weighing exercise to be done. Field collecting students were trained on how to sort and weigh solid waste as well as safety precautions with regards to the survey. The materials which were used for the survey included; plastic bags (30 L capacity each) of which two were allocated for each of the schools to cater for sorting and taking the measurement of waste; 10 dial spring scales (20 kg capacity) for weight measurement; plastic sheet for the sorting of waste into predetermined categories (organic, plastic/rubber, glass/ceramics, metal, textile, paper and other waste); personal protective equipment (hand gloves, nose mask and overall coat) and data recording sheets. In order to obtain a realistic weight, measurement of the amount of waste produced by a particular school was performed for three different days. The generated solid waste was sorted into organic, plastic/rubber, glass/ceramics, metal, textile, paper and other waste each time. Each waste component was weighed separately and recorded.

Direct sampling and analysis was the method considered for waste characterization (Moore et al., 1994). The solid waste generated at the selected point-of-generation (kitchen, dormitory, and dining hall) was conveyed to the waste disposal site for the sorting and weighing (collection, conveying and weighing usually took a maximum of three days). The weight of each category of waste was recorded on a data sheet and was structured with the predetermined categories. The solid waste sorting and weighing were done from September 2017 to February 2018. The weight percentage for each sub-category was calculated using the following equation:

$$Percentage\ composition\ of\ waste = \frac{Weight\ of\ individual\ waste\ category}{Total\ weight\ of\ all\ waste\ categories} \times 100\%$$

To determine the waste management practices in the senior high schools in the Ashanti Region, 60 students were selected purposively from each school and structured questionnaires were administered to the selected students. Assistant headmasters/headmistresses in charge of domestics were interviewed on the waste management practices in each school.

RESULTS AND DISCUSSION

Waste management practices in the schools

Results from the study revealed that all the selected schools had waste collection bins and 93.3% of the schools stored their waste in the bin for at most 24 h before taking the waste to the final disposal site while only 6.7% of the selected schools stored its waste for almost 72 h. Waste generated had high content of organic waste and according to Malakahmad et al. (2010), long storage of organic waste in containers may producing odour, breed microbes and insects. All the schools (100%) were willing to sort the waste generated and stored the waste differently if more waste collection bins are supplied (Table 2). However, all of them

Table 1. Student population of the selected schools as of September 2017.

School	Student population		
	Males	Female	Total
Ejisu-Juaben Senior High School	1795	1702	3497
Adventist	1320	1180	2500
Ejisu Senior High/Technical School	815	441	1256
Kumasi Academy Senior High School	1600	1100	2700
KNUST Senior High School	1587	1125	2712
Konadu-Yiadom Senior High School	460	747	1207
Amaniampong SHS	1117	1363	2480
Oduko SHS	237	200	437
St. Joseph SHS	1214	877	2091
St. Monica's SHS (Girls' school)	N/A	2100	2100
Anglican Senior High School	2500	1000	3500
Ejisuman Senior High School	1623	1626	3249
Prempeh College (Boys' school)	3079	N/A	3079
Agona S.D.A. Senior High School	1417	1543	2960
Nsutaman Catholic SHS	-	-	1725

SHS means Senior High School.

Table 2. Solid waste management practices in Senior High Schools in Ashanti region.

Waste management practices	Frequency (%)
Availability of waste collection bins	15 (100)
Duration of waste storage (hours)	
24	14 (93.3)
72	1 (6.7)
Willingness to practice source sorting	15 (100)
Waste disposal option	
Communal containers	1(6.7)
Crude dumping and burning	13 (86.7)
Incineration	1 (6.7)

indicated that they had difficulty in acquiring adequate dust bins for waste collection (personal communication with heads of the schools). Majority of the schools did not have an environmentally friendly way of disposing of their waste since 1 (6.7%) dispose its waste into a communal container, 13 (86.7%) practiced crude dumping and open burning of the waste generated and only 1 (6.7%) incinerated the waste generated (Table 2). The crude dumping could produce leachates that could contaminate surface and groundwater bodies (Naveen et al., 2017), while the burning of the waste materials could also produce pollutants that could potentially cause upper respiratory diseases (Jiang et al., 2016).

Knowledge and willingness to practice composting

Compost is a soil conditioner composed of organic matter that improves soil structure and can reduce the amount of chemical fertilizer required for crop production (Haight and Taylor, 2000). The survey indicated that 563 (62.6%) of the 900 respondents were aware of composting whilst 337 (37.4%) were unaware of it. Out of the 563 respondents, who were aware of composting, 3 (0.33%) thought animal feed was generated from composting, 7 (0.78%) though it was used for gas and 553 (61.4%) said it produced manure. On materials used for composting, 194(21.6%) thought any waste could be composted, 343(38%) thought food waste was the material used and 24 (2.7%) were not sure of the materials used in composting. Materials used and products generated from composting have been explained by many researchers to be organic materials and compost or manure respectively (Haight, 2006; California Air Resources Board (CARB), 2008; Smyth et al., 2010). Surprisingly, none of the students knew the processes involved in the generation

Table 3. Willingness to manage organic waste by composting.

Activity	Frequency (%)
Knowledge on composting	
Composting awareness	
Yes	563 (62.6)
No	337 (37.4)
Product obtained from composting	
Animal Feed	3 (0.33)
Gas	7 (0.78)
Manure	553 (61.4)
Material used in composting	
Any waste	194 (21.6)
Food waste	343 (38)
Undecided	24 (2.7)
Understanding of composting processes	
Yes	0 (0)
No	900 (100)
Willingness to practice composting	
Starting of composting	
Yes	523 (58.1)
No	195 (21.7)
Reasons for not starting composting	
Environmental pollution	16 (1.8)
No resources	58 (6.4)
No technical knowledge	80 (8.9)
Not interested	10 (1.1)
Number of time and space	31 (3.4)

of compost (Table 3). The youth plays an important role in executing national waste management planning and for such reason needs to be educated on resources potential of waste generated as is currently being practiced as a waste management strategy in many countries (Song et al., 2015).

Although a greater percentage (61.4%) of the respondents possessed knowledge on composting, the remaining without any idea of composting can be assisted through student education on composting (Alexander and Kennedy, 2002; Bartlett, 2011; Beben, 2015) since majority were ready to start it at home or school (Table 3). It has been initiated in Nepal, where the new curriculum was created to teach about waste with an emphasis on why people should reduce the amount of waste discarded and the benefits of composting over discarding waste (Solis, 2016). The concept was new to most of the students, however such students were ready to start learning the process and therefore were interested in composting their organic solid waste. The majority of students who were not ready to start composting their solid waste attributed to problems such as no technical knowledge, no resource, no time and space, environmental pollution whilst some said they were not interested in composting (Table 3). However, Mackenzie (2016) argued that composting is easier than one can think.

Physical composition of solid waste

The study showed that a sizeable portion of waste generated across the selected schools was organic waste, which had a percentage ranging from 43.5 to 91% (Table 4). The amount of organic waste generated in all the schools conformed to a study conducted by the World Bank, which indicated that solid waste generated in developing countries is made of 40 to 80% organic (World Bank, 2012). Organic wastes generated in the selected schools were discarded through crude dumping, but such waste could be used for composting rather than taking it to the open dumpsite due to its biodegradable nature (Malakahmad et al., 2010). Disposing waste on an open dumpsite, can attract vermins, pollute water bodies and soil. The study showed that plastic/rubbers were the next highest with a percentage between 4.8 and 19.3%. Empty water sachet and polythene bags dominated the plastics and rubber component and this might be a result

Table 4. Waste characterization and quantification in selected schools in Ashanti Region.

Selected schools	Waste composition (kg) (%)							
	Organic	Plastics /rubber	Glass /ceramic	Metal	Textile	Paper	Others	Total
Ejisu-Juaben Senior High School	317.9(62)	59.8(11.7)	27.2(5.3)	18.8(3.7)	30.9(6)	13(2.5)	45.1(8.8)	512.7(100)
Ejisu Senior High Technical School	59.9(61.2)	5.5(5.6)	5.6(5.7)	9.5(9.7)	8.4(8.6)	0(0)	9(9.2)	97.9(100)
Adventist Senior High School	273.9(83.9)	16.75(5.1)	0.76(0.2)	25.49(7.8)	3.08(0.9)	4.08(1.3)	2.3(0.7)	326.4(100)
Prempeh College	479.7(83.3)	51.09(8.9)	0(0)	37.8(6.6)	0.53(0.1)	4.09(0.7)	2.3(0.4)	575.5(100)
Kumasi Academy Senior High School	275(51.0)	104(19.3)	39(7.2)	60(11.1)	61(11.3)	0(0)	0(0)	539(100)
KNUST Senior High	176.3(58.1)	30.6(10.1)	3.6(1.2)	58.9(19.4)	7.8(2.6)	0(0)	26.5(8.7)	303.7(100)
Agona SDA Senior High School	816.5(87.8)	44.2(4.8)	38(4.1)	0.8(0.1)	6.7(0.7)	21.3(2.3)	2.5(0.3)	930.6(100)
Amaniampong Senior High School	245.4(67.9)	40.5(11.2)	3(0.8)	23.5(6.5)	43.5(12)	5.6(1.55)	-	361.5(100)
Oduko Boatemaa Senior High School	100.5(57.6)	40(22.9)	5.5(3.2)	11(6.3)	9.5(5.4)	6.1(3.5)	1.9(1.09)	174.5(100)
St. Joseph Senior High School	206.4(71)	35(12)	2(0.7)	3.5(1.2)	30(10.3)	10.2(3.5)	3.4(1.2)	290.5(100)
St. Monica's Senior High School	232.6(67.7)	54.5(15.9)	2(0.6)	13.5(3.9)	32(9.3)	4.8(1.4)	4.1(1.2)	343.5(100)
Konadu-Yiadom Senior High School	413.6(91)	11.2(2.5)	0.1(0.02)	1.6(0.4)	9.8(2.2)	17.9(3.9)	0.4(0.9)	454.6(100)
Anglican Senior High School	170(43.5)	105(26.9)	9(2.3)	45.5(11.6)	12(3.1)	13(3.3)	36(9.2)	391(100)
Ejisuman Senior High School	260.3(73.7)	23.9(6.7)	8.1(2.3)	16(4.5)	10.3(2.9)	15.2(4.3)	19.2(5.4)	353(100)
Nsutaman Catholic Senior High School	180.8(64.3)	45(16)	11.3(4)	9(3.20)	11.8(4.2)	11.3(4)	11.9(4.2)	281.1(100)
Mean	**280.59**	**44.47**	**10.34**	**22.33**	**18.49**	**8.44**	**10.97**	**395.70**

of the water consumption pattern of students and the use of polythene bags to wrap food and other items bought by students.

All the selected schools did not practice source sorting and this could affect organic components that could be used for composting and also affect the willingness to practice composting. The schools could generate revenue from the rubbers and plastics if source separation and waste recycling practices were adopted (Armijo de Vega et al., 2008; Smyth et al., 2010).

Currently, many recycling companies do purchase empty sachet containers and other plastics for recycling in Ghana. The third highest component in terms of generation was metals with the percentage ranging from 0.1 to 19.4%, followed by textiles, 0.1 to 12%, other waste, 0 to 9.2%, glass/ceramics, 0 to 7.2% and papers 0 to 4.3% (Table 4). The practice of source sorting could separate the metals which could be sold to steel processing companies. Recycling of metals for processing is being practiced in Ghana and other countries.

Waste generation rate

The per capita per day generation rate of the selected schools ranged from 0.02 kg/cap/day to 0.13 kg/cap/day with an average of 0.056 kg/cap/day. The highest rate (0.13 kg/cap/day) generated by Oduko Boatemaa Senior High School and Konadu-Yiadom Senior High School with a student population of 437 and 1207 respectively. With the student population of 2712, KNUST Senior High School generated 0.02 kg/cap/day, which was the least generation rate among all the schools. The rates of waste generation of all the selected schools were far below the national generation rate of 0.47 kg/cap/day for Ghana (Miezah et al., 2015). It might be a result of the involvement of day students in the schools who normally eat from the home. The study also focused on waste generated at the dormitories, kitchen and dining halls without taking into account of what was generated at other parts of the schools. Their foods were cooked in bulk at the kitchen, which could minimize the amount of waste generated from cooking and most of the students do not purchase food from outside. Though the

Table 5. Solid waste generation per capita per day.

School	Population	Per capita waste generated (kg/cap/day)	P-value
Oduko Boatemaa SHS	437	0.13^{a}	
Konadu-Yiadom SHS	1207	0.13^{a}	
Agona S.D.A. Senior High School	2960	0.10^{b}	0.015
Kumasi Academy SHS	2700	0.07^{c}	
Prempeh College	3079	0.06^{c}	0.655
Nsutaman Catholic SHS	1725	0.05^{d}	
St. Monica's SHS	2100	0.05^{d}	
Ejisu-Juaben SHS	3497	0.05^{d}	
Amaniampong SHS	2480	0.05^{d}	
St. Joseph SHS	2091	0.05^{d}	0.433
Adventist SHS	2500	0.04^{e}	
Anglican Senior High School	3500	0.04^{e}	
Ejisuman Senior High School	3249	0.04^{e}	0.083
Ejisu Senior High/Technical School	1256	0.03^{f}	
KNUST SHS	2712	0.02^{g}	0.04

Numbers of the same superscript within columns are not significantly different and vice versa; Level of significance was estimated at a 5% confidence level.

generation rates of selected schools were lower than what was estimated by the World Bank (2012) it conforms to the observation made by Kaza et al. (2018), which specified that population size has an undeviating bearing on waste generation rate per capita per day.

The study also revealed that schools with large populations generated less as compared to schools with less population. Oduko Boatemaa Senior High School had a population of 437 and its generation rate was among the highest recorded by the study. This might also be due to the hostel system used by the school. Students are allowed to cook their food under this system. Anglican Senior High School had the largest population (3500 students) and its generation rate of 0.04 kg/cap/day was nearly one-third of that of Oduko Boatemaa Senior High School. The generation rates of all selected schools were below the daily generation rate of 0.1412 kg/cap/day in educational institutions reported in Bangladesh (Hossain et al., 2013). The estimated average daily generation by weight of the schools was 131.69 kg/day. The generation rate of Oduko Boatemaa Senior High School was significantly different from Agona S.D.A. Senior High School ($p<0.05$) and that of Ejisu Senior High Technical School was different from that of KNUST and Ejisuman Senior High Schools. The generation rates of schools with the same parenthesis were not different but those with different superscripts were significantly different (Table 5).

The population and waste generation rate per capita per day of the selected schools showed a correlation coefficient of -0.05, which indicated that the larger the population, the less waste generated per person per day and vice versa. An ANOVA of the waste components showed that the components were significantly different from each other at 5% significant level (Table 6).

Determining the recycling potential of the solid wastes

Waste generation and composition affect the factors that determine the selection of waste management options and knowledge on this will not only succor managing the waste but will also improve public health (Hossain et al., 2013). Source separation of solid waste as an approach of waste management has been accentuated by numerous studies (Maklawe et al., 2016; Liao and Li, 2019; Kasavan et al., 2020). Waste segregation at source increases the reuse and recycling potential of waste components. Analysis of the overall total amount of waste generated by all the selected schools indicated that compostable organic waste had the highest amount (71.2%). However, none of the schools had started composting its waste. The survey showed that most students had heard of composting but did not know the processes involved. The second-largest portion of the waste stream was plastics and rubbers (11.26%) and the third was metals (5.65%). The percentage share of textiles, others, glass and papers were 4.68, 2.78, 2.48 and 2.14 respectively (Figure 2). Out of the 5926.27 kg of wastes generated by all the schools, 5761.67 kg were recyclable materials of which 4208.8 kg were compostable materials and 164.6 were non-recyclables. More than 90% of the waste generated in the selected schools in the Ashanti Region could be dealt with through waste reduction, recycling and composting activities

Table 6. Comparisons of the differences between the average waste components generated each day in the randomly selected schools.

Waste component	Days	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total	Average significance
Organics	Day 1	34.7	35.6	6.7	28.5	24	41.8	26.5	10.2	31	28.3	17.7	62.1	33.6	80.4	33.63	494.7	0.000007
	Day 2	28.1	36.7	6.2	33.8	16.9	49.8	28.7	22.5	18.3	20.3	20.3	62.5	27.5	96.1	27.47	495.2	0.000049
	Day 3	29.2	19	7.1	29.3	17.9	46.3	28.5	11	24	31.8	23.2	35.3	28.1	95.6	28.1	454.4	0.000051
	Total	**92**	**91.3**	**20**	**91.6**	**58.8**	**137.9**	**83.7**	**43.7**	**73.3**	**80.4**	**61.2**	**159.9**	**89.2**	**272.1**	**89.2**	**1444.3**	
Plastics	Day 1	6.1	1.2	0.6	20.5	2.6	1.9	4	5	3.2	4	12.3	8.4	3.1	2.4	3.1	78.4	0.002
	Day 2	6.4	0.7	0.7	8.2	5	0.6	5.3	4.2	3.3	5.3	10.8	3.3	3.4	6.4	3.4	67	0.000026
	Day 3	7.4	3.7	0.6	6	2.6	1.2	4.3	5.2	5.2	6	11.8	5.3	1.5	3.8	1.47	66.1	0.000038
	Total	**19.9**	**5.6**	**1.9**	**34.7**	**10.2**	**3.7**	**13.6**	**14.4**	**11.7**	**15.3**	**34.9**	**17.3**	**8**	**12.6**	**7.97**	**211.8**	
Glass and ceramics	Day 1	0.3	0	0.7	9.3	0.4	0	0.2	1	0	0	1	0	0.3	0.23	0.33	13.8	0.152
	Day 2	0.7	0.02	0.6	2.3	0.3	0	0.8	0.8	0.3	0	2	0	0.7	0	0.73	9.3	0.004
	Day 3	1.63	0.2	0.6	1.3	0.6	0.03	0	0	0.3	0.7	0	0	1.6	0.03	1.63	8.6	0.004
	Total	**2.63**	**0.22**	**1.9**	**12.9**	**1.3**	**0.03**	**1**	**1.8**	**0.6**	**0.7**	**3**	**0**	**2.6**	**0.26**	**2.7**	**31.6**	
Textiles	Day 1	0.6	0.63	1	15	0.9	1.5	5.2	1.2	3.3	4.5	1	0.02	0.6	2.8	0.57	38.8	.019
	Day 2	1	0.01	0.4	2.3	1.1	0.3	5.2	2	3.2	3.3	1.5	0.02	1.03	1.2	1.03	23.6	.001
	Day 3	1.8	0.4	1.5	3	0.6	1.5	4.2	2	3.5	2.8	1.5	0.13	1.8	3.1	1.83	29.7	.000012
	Total	**3.4**	**1.04**	**2.9**	**20.3**	**2.6**	**3.3**	**14.6**	**5.2**	**10**	**10.6**	**4**	**0.18**	**3.43**	**7.1**	**3.43**	**92.1**	
Metals	Day 1	2.2	0.3	1.2	11	12.1	0.5	2	1.3	0	1.2	6.3	12.3	2.2	1.3	2.23	56.1	0.005
	Day 2	0.6	4.8	0.7	4.3	11.2	0	2.3	1.7	1	1.8	4.8	0.3	0.6	0.3	0.63	35	0.009
	Day 3	2.5	3.4	1.2	4.7	3.8	0.1	3.5	0.7	0.2	1.5	4	0.02	2.5	0.8	2.47	31.4	0.000137
	Total	**5.3**	**8.5**	**3.1**	**20**	**27.1**	**0.6**	**7.8**	**3.7**	**1.2**	**4.5**	**15.1**	**12.6**	**5.3**	**2.4**	**5.33**	**122.5**	
Papers	Day 1	0	0.59	0	0	0	1.9	0.83	0	0	0	0	0.6	1.03	4.8	1.03	10.8	0.045
	Day 2	0	0.67	0	0	0	2.6	0.43	0	0	0	0	0.03	0.7	6.1	0.67	11.2	0.098
	Day 3	0	0.1	0	0	0	1.4	0.6	0	0	0	0	0.7	1.1	3.9	1.07	8.9	0.045
	Total	**0**	**1.36**	**0**	**0**	**0**	**5.9**	**1.87**	**0**	**0**	**0**	**0**	**1.4**	**2.83**	**14.8**	**2.77**	**30.9**	
Others	Day 1	2	0.1	0.4	4.8	3.8	0.1	0	0	0	0	3.8	0.3	2	0.4	1.97	19.7	0.008
	Day 2	2	0.1	1.5	4.7	2.2	0.1	0	0	0	0	5	0.4	2	0.4	1.97	20.4	0.007
	Day 3	2.5	0.6	1.1	3.2	2.9	0	0	0	0	0	3.2	0.1	2.5	0.07	2.47	18.7	0.003
	Total	**6.5**	**0.8**	**3**	**12.7**	**8.9**	**0.2**	**0**	**0**	**0**	**0**	**57**	**0.8**	**6.5**	**0.87**	**6.4**	**103.7**	

*All units are in kg/day; **Significance level estimated at 0.05; A=Ejisu-Juaben SHS; B=Adventis SHS; C-Ejisu Senior High Technical School; D=Kuamsi Academy SHS; E=KNUST SHS;F=Konadu Yiadom SHS; G=Amaniampong SHS; H=Oduko Boatemaa SHS; I=St. Joseph SHS; J=St. Monica's SHS; K=Anglican SHS; L=Prempeh College; M= Nsutaman Catholic SHS; N=Agona SDA Senior High School**;** O=Ejisuman SHS.

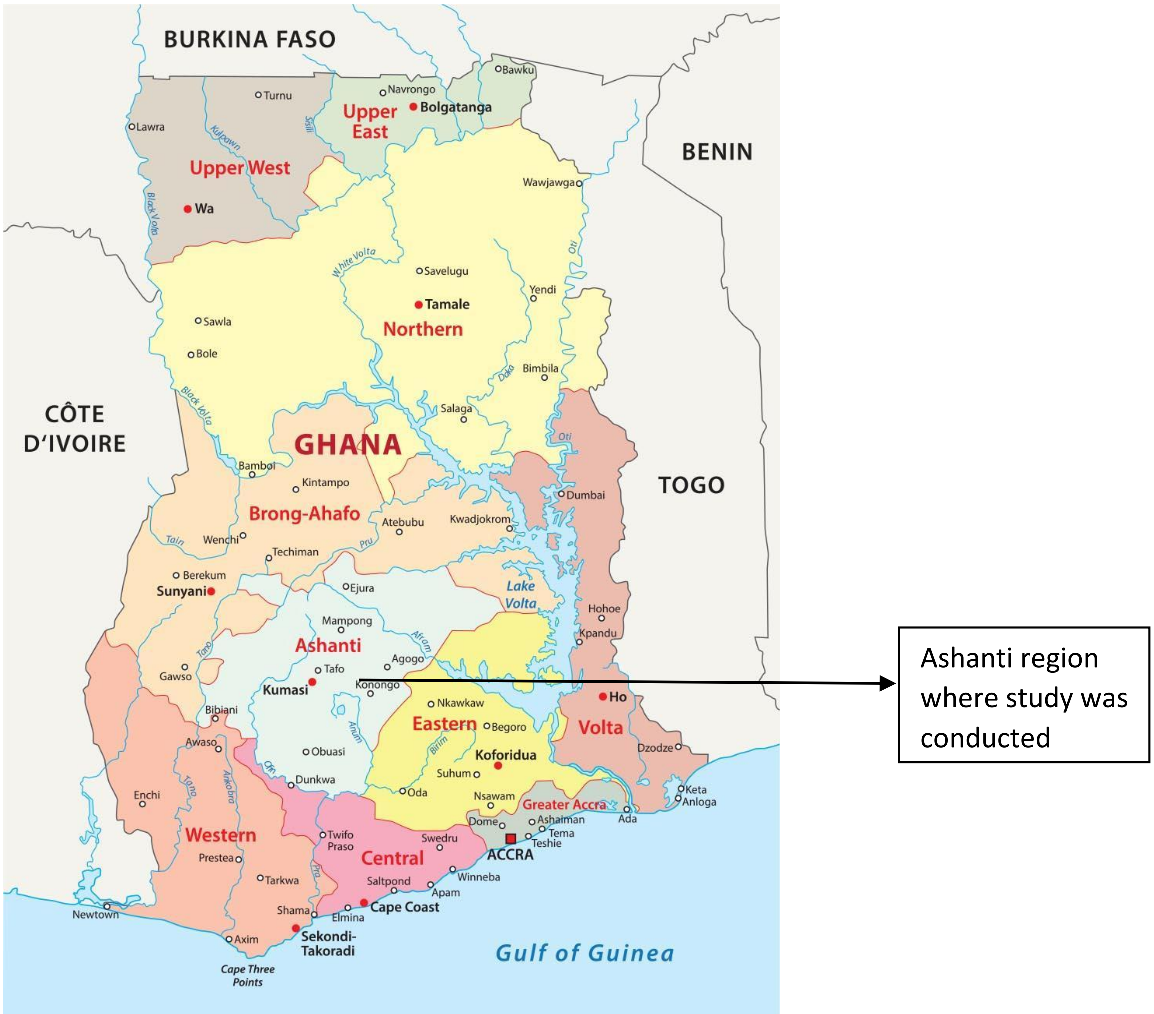

Figure 1. Map of Ghana showing Ashanti Region (Sampling area).
Source: Maps Ghana (www.mapsghanaa.com).

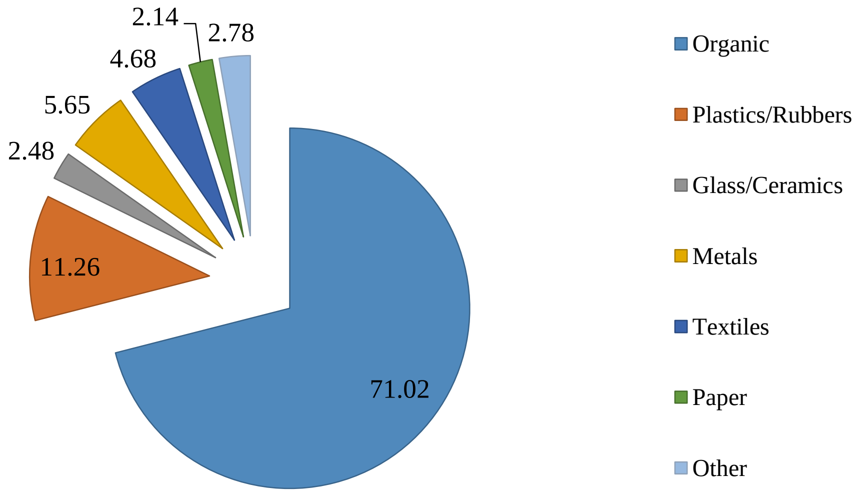

Figure 2. Overall composition of waste generated by the selected schools.

(Rada et al., 2020).

Conclusion

The percentage of organic waste was the highest in the waste streams across the selected schools and ranged from 43.5 to 91%. The organic composition varied among the various schools but these differences were not significant ($p > 0.05$). About 90% of the solid waste generated in the schools could be managed through waste reduction, recycling, and composting activities. Apart from papers, other waste, and organic wastes, there was a significant difference between the generations of the other components ($p < 0.05$). Rubbers and plastic waste was the second-highest fraction in the waste stream. Daily generation rate per capita of all the schools was far below the national generation rate of 0.47 kg/cap/day and less populated schools generated more waste than schools with large populations. Most of the senior high schools disposed of solid waste by crude dumping or open burning. Results obtained from the study suggested an immediate implementation of an integrated solid waste management system option as a way of preventing the unfavorable environmental effects resulting from the crude dumping and open burning of solid waste in senior high schools. Over 50% of students at the senior high schools have knowledge of materials used and products obtained from composting but lacked knowledge of the processes involved in it.

RECOMMENDATIONS

1. It was recognized that a greater percentage of the waste generated in the selected senior high schools was organic waste and therefore composting should be encouraged as a way of managing such components of the waste stream.
2. Source sorting at the point of generation should be encouraged by providing a specific type of dustbin for storing specified components of waste. Enough facilities/strategies should be provided to promote source separation exercise in the schools.
3. Recycling and reuse should be given priority to reduce waste generation volume and lessen the amount of waste that goes to the dumpsite, which will also reduce treatment, disposal cost, and pollution of the environment as practiced by most of the schools.
4. Crude dumping and burning of waste should be discouraged in the schools since they increase the amount of carbon dioxide in the atmosphere and pollution of water bodies.
5. Awareness of solid waste issues is very poor in senior high schools and need to be improved. Awareness can be improved through the introduction of WASH clubs or integration of Environmental Sanitation Education into the senior high school curricula.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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