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Full Length Research Paper

Seasonal variability of rainfall and thunderstorm in Guinea over the period 1981 to 2010

Ibrahima Kalil Kante[1,2,3*], Saïdou Moustapha Sall[1], Daouda Badiane[1], Idrissa Diaby[2] and Ibrahima Diouf[1,4]

[1]Laboratoire de Physique de l'Atmosphère et de l'Océan, Université Cheikh Anta Diop, Senegal.
[2]Laboratoire de l'Enseignement et de Recherche en Energetique Appliquée, Université de Conakry, Guinée.
[3]Direction Nationale de la Météorologie de Guinée, Face Jardin 2 october, Conakry. BP: 566, Guinea.
[4]NOAA Center for Weather and Climate Prediction, 5830 University Research Court, College Park, Maryland 20 740, USA.

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Republic of Guinea is one of the West African countries which share form a border with the southern part of the Sahel. It is located in the tropical area where the convective systems activities are intense with strong rainfall. Our results on Standardized Precipitation Index are coherent with the Sahel drought during the 1970s, and a recovery period of rainfall since the last years. The Standardized Thunderstorms Index shows positive anomalies (1981-1997) corresponding to the dry period of rainfall, while a negative anomalies is shown (1998-2010) for the wet period. This study highlights the relationship between thunderstorms and rainfall amounts in Guinea in the context of climate variability. Indeed, by categorizing the rainfall in two groups respectively weak and heavy, we calculated their correlations with thunderstorms. We found significant correlations between weak rainfall and thunderstorms. To appreciate the findings with the standardized anomalies of precipitation and thunderstorms, we also performed Rotations of Empirical Orthogonal Function and Principal Component Analysis to identify the coherent mode of the interannual variability of these parameters. We found that the first mode is the best Empirical Orthogonal Function which is coherent with is the results shown by the Standardized Index of Precipitation and Thunderstorms. To check the significance of each Empirical Orthogonal Function mode, we use the North's rule of thumb for estimating the sampling errors. It was noticed that no modes was concerned by sampling errors. And then, the rainfall seasonal cycle shows a unimodal rainfall regime, while the thunderstorms' one indicates a bimodal cycle. Our study could improve knowledge about rainfall amounts and thunderstorms variability, especially in climatic variability context.

Key words: Rainfall, thunderstorm, spatio-temporal variability, correlation.

INTRODUCTION

Republic of Guinea is one of the wettest countries in West Africa. The average of its rainfall amount can exceed 3000 mm per year. During the twentieth century, there was a decrease of rainfall amounts in most of the West African countries (Zhou et al., 2008). Indeed, the Figure 1 shows that despite heavy rainfall observed in Guinea, but the latter experienced a very marked rainfall decrease during the first decade of our study period

(1981-1991). This rainfall decrease is due to an overall reduction of rainfall in West African area. The marked rainfall decrease during the first over our area of study is consistent with findings from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (Smith et al., 2014), which highlighted that the West Africa region suffered changes due to natural and anthropogenic forcing. Nevertheless, there is still a large debate about the impact of anthropogenic climate change on decadal to multi-decadal rainfall variability over the West Africa (Nicholson et al., 2000; Giannini et al., 2003; Mohino et al., 2010). These changes have altered the rainfall distribution that presents large decadal and interannual variability. The decadal signal is modulated by anthropogenic factors, but also by large modes of natural variability, such as the Atlantic Multidecadal Oscillation. The interannual signal is mainly affected by the El Niño Southern Oscillation, the Tropical Atlantic basin, and internal atmospheric variability over the region. This is coherent with several works done on the Sahel rainfall where the 1970s correspond with a drought from 1970 to 1992, like (Solomon et al., 2007; Grist and Nicholson 2001; Nicholson et al., 2013; Hulme, 1992; Lamb and Peppler, 1992; Janicot and Fontaine, 1993; Le Barbe et al., 2002). Since the beginning of the 2000s, there is an improved rainfall trend in the central region of the Sahel (Ali et al., 2000; Nicholson et al., 2005), with a very wet year 1994. Guinea experienced this return to normal rainfall in the year 1994 significantly wet also (Figure 1).

In Guinea, rainfall is very important for the population's activities and ecosystems. Therefore, it defines different geophysical regions (Loua et al., 2017). Rainfall events are usually associated with meso-scale convective systems (MCS); especially that are the most frequently observed rainfall systems in the Sudano-Sahelian belt (Laurent et al., 1998; Laing et al., 1999). These rainfall events over tropical Africa and the Atlantic during the West African Monsoon period (WAM) are accompanied by thunderstorms. Many interesting results have been obtained from correlations between lightning activities and radar reflectivity, and between lightning and precipitation activities (Sheridan et al., 1997; Petersen and Rutledge, 1998; Soula et al., 1998; Zhou et al., 2002). These results exhibit a strong relationship between the raining convective system, lightning frequency and the intensity of precipitation (Béavogui et al., 2011). However, the relationship between thunderstorms and rainfall amounts is less documented in our area of study (Guinea). It is in this perspective, that we performed a climatological approach by studying this phenomenon in Guinea by considering 4 synoptic stations including one from each geophysical region. As part of this work, we consider the 12 synoptic stations of Guinea from four geophysical regions, having in each of them three stations. The main objective is to better understand the rainfall variability of Guinea in relation with the thunderstorms and to analyze the Empirical Orthogonal Function (EOF)/Principal Component (PC) to identify the coherent mode of interannual variability of them.

MATERIALS

Area of study

The area of study is as shown in Figure 2, located between the latitudes 7°N and 13°N, and the longitudes 15°W and 7°W. The Republic of Guinea is a West African country, with an estimated area of 245,857 km^2. It is subdivided into four geophysical regions: Lower-Guinea (LG, hereafter), Middle Guinea (MG, hereafter), Upper-Guinea Guinea (UG, hereafter) and Forest-Guinea (FG, hereafter). Each geophysical region has three synoptic weather stations.

The naming of the geophysical regions LG, MG, UG and FG is in accordance with their climate and topography.

The LG includes the synoptic weather stations of Boké, Conakry and Kindia; also called Maritime-Guinea because of its coastal position (near the sea). It is the coastal strip between Guinea - Bissau in the north and Sierra Leone in the south (around 300 km), about 100 to 150 km wide. It covers 15% of the country's total area. The marine marshes occupy around 360 000 ha area, including 260 000 ha of mangroves, the largest in West Africa (Frenken, 2005). It has a wet tropical climate, with rainfall reaching its maximum in August and can exceed 4,000 mm/year in Conakry.

The MG region includes the synoptic stations of Koundara, Labé and Mamou. It covers 26% of the country's total area. Fouta-Djalon massif occupy around 80 000 km^2 around and its highest point is Mount Loura (1 532 m), including the most mountainous region of Guinea. Its soil consists mainly of stepped plateaux often over 1000 m notched by valleys, dominating plains and depressions with an altitude exceeding 750 m and can exceed 1200 m in some places (Frenken, 2005). It is in this region where many rivers and streams of West Africa take their sources: Senegal and Gambia Rivers in the north, Koliba, Rio Grande, Fatala and Konkouré Rivers in the west, the Kaba Rivers, Kolente to the south, and Niger to the east. Its climate is marked by a relatively high day time thermal amplitude of up to 19°C at Labé.

The rainy season can range from five to eight months between Koundara and Mamou with an amount rainfall less than 1,300 mm to the north.

The UG region includes the synoptic stations of Faranah, Kankan and Siguiri covers 39% of country's total area. It is located between Guinea-Forest and Fouta-Djalon on the western edge of the Niger's vast basin. This region, with an average altitude of 500 m, has a slight relief which explains the rivers spreading. Its climate is Sudanian with an annual rainfall between 1600 mm in the south and 1200 mm in the north. It represents the arid or Sahelian area of Guinea because of the similarity of its climate with Sahel. Featuring a grassy savanna with plateaus and river plains (River Milo) that is rich in agriculture. While, seasonal thermal amplitude is

*Corresponding author. E-mail: ibrahima.kante@ucad.edu.sn. Tel: +221-77-305-94-03.

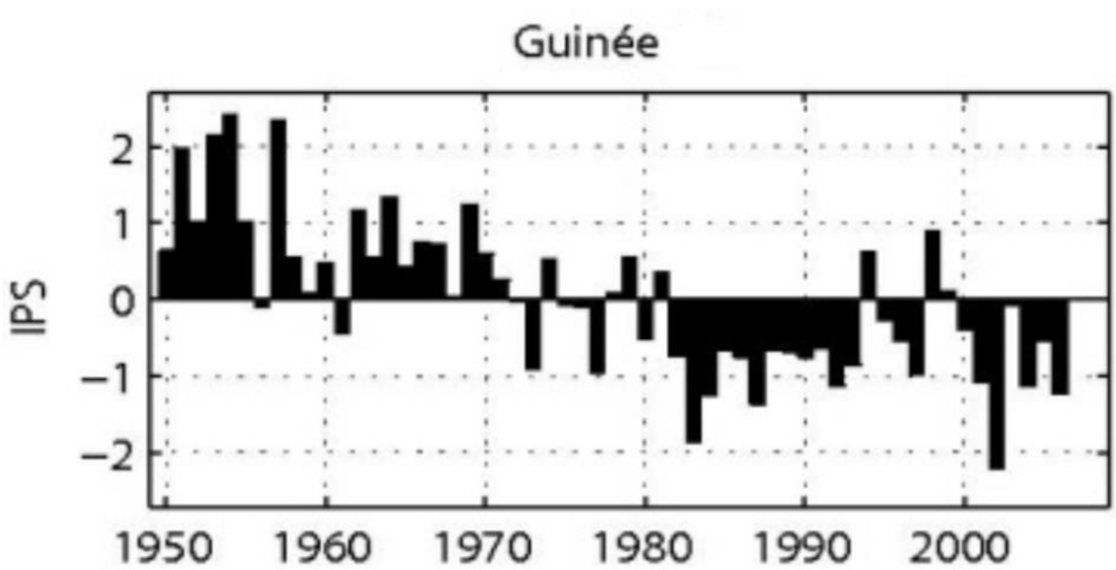

Figure 1. Standardized Precipitation Index (SPI) in Republic of Guinea from 1951 to 2010 (Louvet et al., 2011). The X and Y axis are years and anomalies respectively.

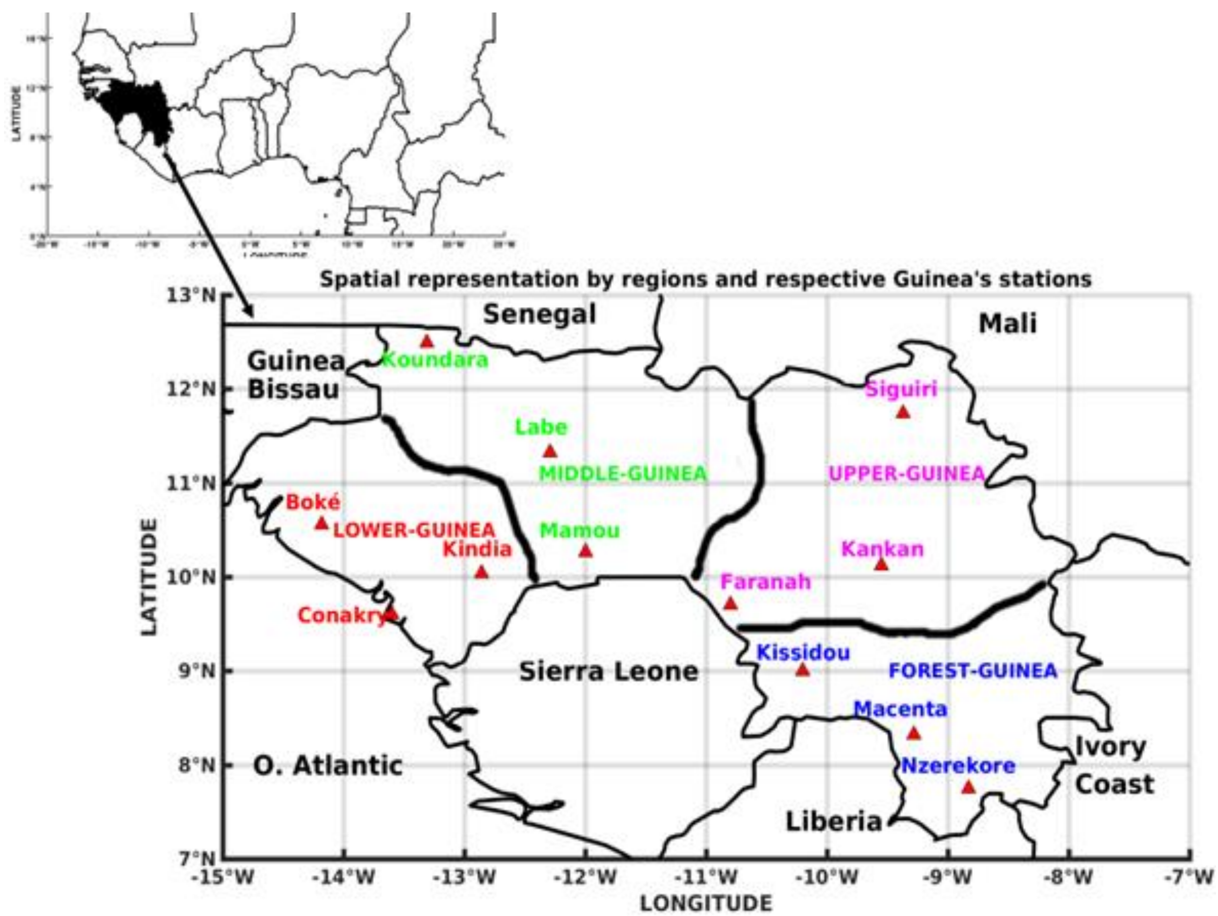

Figure 2. Meteorological observation stations. The map shows the meteorological stations locations used for the four (4) geophysical regions of Guinea: Low-Guinea (Boke, Conakry, Kindia), Middle-Guinea (Koundara, Mamou, Labe), Upper-Guinea (Faranah, Kankan, Siguiri) and Forest-Guinea (Kissidou, Nzerekore, Macenta).

Table 1. Situation of the available datasets by station, timescale and time period.

Station		Latitudes	Longitude	Altitude (m)	Parameters (monthly)	Time period
Low Guinea	Boke	10°56’	-14°18’	69	Rainfall - Thunderstorm	1981-2010
	Conakry	09°64’	-13°58	46	Rainfall - Thunderstorm	1981-2010
	Kindia	10°04’	-12°86’	458	Rainfall - Thunderstorm	1981-2010
Middle Guinea	Koundara	12°34’	-13°31’	90	Rainfall - Thunderstorm	1981-2010
	Labe	11°19’	-12°29’	1050	Rainfall - Thunderstorm	1981-2010
	Mamou	10°38’	-10°08’	782	Rainfall - Thunderstorm	1981-2010
Upper Guinea	Faranah	10°26’	-10°80’	358	Rainfall - Thunderstorm	1981-2010
	Kankan	10°12’	-9°55’	376	Rainfall - Thunderstorm	1981-2010
	Siguiri	11°74’	-9°37	361	Rainfall - Thunderstorm	1981-2010
Forest Guinea	Kissidou	09°19’	-10°11’	524	Rainfall - Thunderstorm	1981-2010
	Macenta	08°32’	-9°28’	542	Rainfall - Thunderstorm	1981-2010
	Nzérékoré	07°75’	-8°83’	467	Rainfall - Thunderstorm	1981-2010

important, extreme temperatures can vary from 14°C in the rainy season to 37°C in the dry season.

The FG region includes the synoptic weather stations of Kissidou, Macenta and Nzérékoré. This region corresponds to the southern part of Guinea and covers 20% of the area total of country. Its relief presence two mountains namely Mount Simandou and Mount Nimba, the latter is the highest in the country with 1,752 m altitude. The Mont Nimba Strict Nature Reserve is a UNESCO World Heritage Site and covers most of the ecotope, which is home to more than 200 endemic species: duikers, big cats (lions and leopards), civets, and two species of viviparous amphibians (Frenken, 2005). This region also enjoys a climate characterized by an unusually long rainy season (between seven and nine months) than LG, MG and UG. The Ziama Massif Biosphere Reserve is home to more than 1,300 plants species and more than 500 animal species.

Data

Observation data provided by the Guinea National Meteorology Service (GNMS) are used. Guinea's meteorological observation network has a very low density due to obsolete meteorological tools equipments and lack of performing weather observers. Many of these stations have several data gaps, which sometimes complicate the use of these data. For this purpose, twelve (12) synoptic stations (Figure 2) are selected for this study in which observation network is regular, and its data are trustworthy. These are monthly rainfall and thunderstorm data for 1981-2010 period (Table 1).

For thunderstorm data during 24 h of observations, at least one thunderstorm occurs that day is considered as a stormy day. Sometimes, thunderstorms can be observed without having rainfall at a given station. But there may be rains far from station, and this rainfall is not observed at station. However, to evaluate these thunderstorm data we compared to the ones estimated by Tropical Rainfall Measuring Mission (TRMM) which have resolution of 0.1 × 0.1 covering 1998-2013 period (Figure 3). They are called Lightning Imaging Sensor (LIS, hereafter) data. LIS is a scientific instrument integrated into the TRMM satellite, its data is used to detect deep convection without earth-ocean bias, to estimate the rainfall mass in the region and to multi-phase thunderstorm clouds with a weak vertical movement (Christian et al., 1999). The LIS 0.1 Degree Very High-Resolution Gridded Lightning Monthly Climatology (VHRMC) dataset consists of gridded monthly total lightning flash rates seen by LIS (NASA). This information can be used for severe thunderstorm detection and analysis, and also for lightning-atmosphere interaction studies (Rakov and Uman, 2003). We noticed in the four regions that, LIS data reproduce quite well the observations. Otherwise, the TRMM underestimated observations, but the peaks at the beginning of season (May or June) and its end of season (October) are coherent. We noticed likewise with minima which are observed in July or August.

In this purpose, we have considered 30-year climatological series recommended by World Meteorology Organization (WMO), which are the monthly cumulative data. These are the monthly cumulative of these data that we use in this work over the period 1981-2010. They are used to calculate the standardized index, seasonal cycle and interannual variability to investigate the spatio-temporal variability. And then, EOF and PC variables, correlation coefficients and a significance statistical test are used to better understand the relationship between rainfall and thunderstorms.

METHODS

The first part refers to the calculation of the Standardized Precipitation Index (SPI, hereafter), and Standardized Thunderstorms Index (STI, hereafter). The SPI is an index calculation method created by Mckee et al. (1993) (Equation 1). This statistical method allows to characterize the wet and dry period in a given rainfall data series, with respect to climatology (Ali et al., 2009). The usual manner of calculating the SPI is to average the standardized rainfall at each rainfall station for a given year. It quantifies also observed precipitation as a standardized departure from a selected probability distribution function that model the raw precipitation data (Keyantash and Dracup 2002). The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean (Ali et al., 2008). This index is often used in a very simple way by evaluating the rainy season (Keyantash and Dracup 2002). The rainfall series is wet if the SPI is greater than 0, and dry if the SPI is less than 0.

We applied the same thing on thunderstorms data for obtaining the STI. It also reports on the downward multi-year variability of thunderstorms and the return to normal values in Guinea.

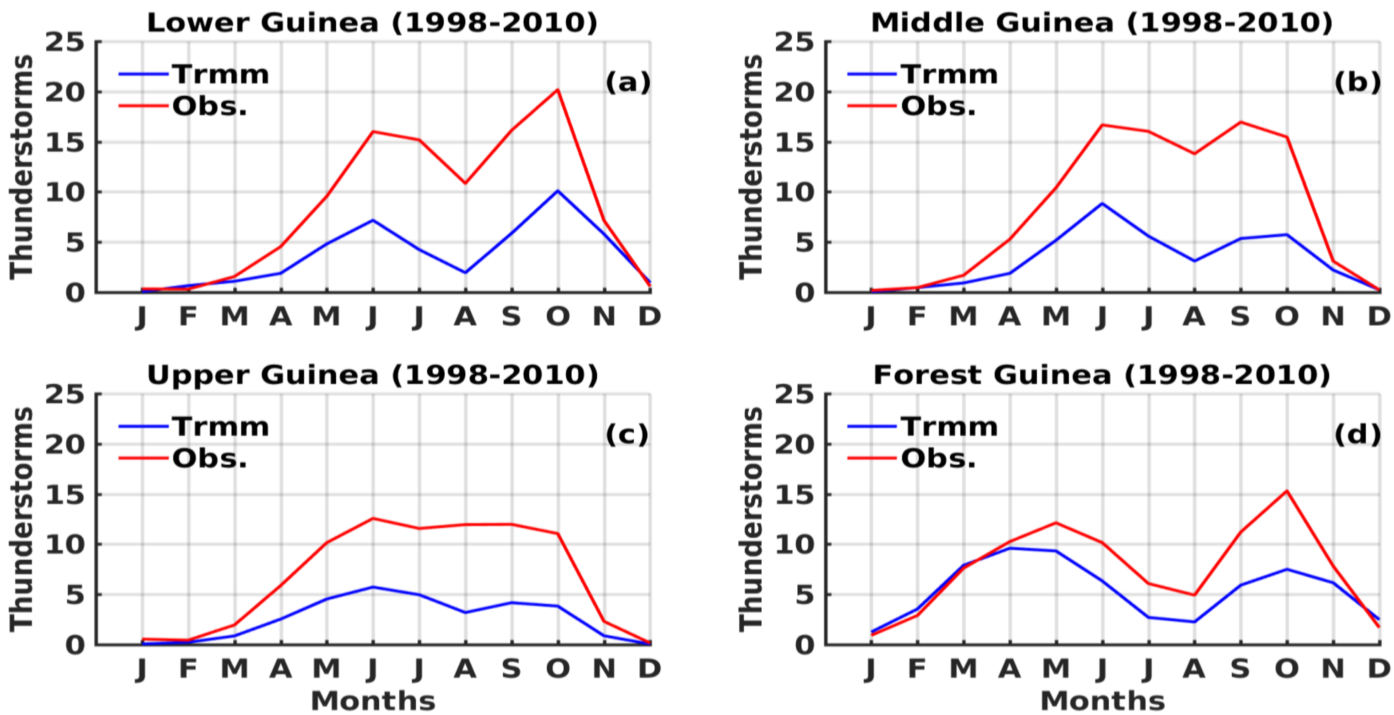

Figure 3. Comparison of seasonal cycles of thunderstorms (observation, red curve) and Lightnings (satellite, blue curve) in Guinea over 1998-2010 period. The X and Y axis are months and thunderstorms respectively.

$$I_i = \frac{X_i - \bar{X}}{\sigma} \quad (1)$$

where I_i: the calculated standardize index of the considered variable for a given year i; X_i: the annual value of the considered variable X for a given year i. $\bar{x}$: the calculated mean of all values of data set X of the considered variable. X_i. σ: Standard deviation calculated from the considered variable X.

The second part of the method focuses on the seasonal cycle of rainfall and thunderstorms in Guinea. It concerns rainfall amount and thunderstorms variabilities during the period 1981-2010. We evaluate the temporal evolution over the studied period of the rainfall and thunderstorms means in geophysical regions of Guinea using the spatial means of the 3 stations located in these regions. This allow us to determine the beginning and end of rainfall and thunderstorm seasons in Guinea.

The third part presents EOFs and PCs for our rainfall and thunderstorm series in Guinea. To realize this, the variables considered are the rainfall amount and thunderstorm occurrences at the twelve (12) stations. But before our analysis, we removed the trends in respectively rainfall and thunderstorm data. The decomposition of a set of complex data varying in time and space into a set of EOFs and time series of associated principal components provides a better understanding of the main modes of spatial variability (Deser and Blackmon 1995). This linear method is widely used in climatology for the processing of heterogeneous data (Richman, 1981). A basic method of data analysis was considered by Bouroche and Saporta, (1987) and Dawson (2016). The EOFs and PCs of a dataset describe a new base where, instead of a series of time-varying spatial observations, the dataset is represented as a set of fixed spatial patterns or modes, which represent a given amount of total variance. It allows extracting the maximum information, in simple form, from a very important dataset; it will highlight the inter-relationships between the variables and similarities or oppositions between observations (Poccard-Leclercq 2000). All of this data and a set of time series describe how each pattern changed over time. The method of this analysis is purely mathematical and does not depend on any physical property of the analyzed quantity (Abdi and Williams, 2010) applications, the first EOFs accounts for a large part of the total variance, allowing the study of one or two modes to provide insight into the variability embedded in the dataset (Deser and Blackmon 1995). The first mode EOF1 is the time series index that produces regression/correlation maps with the overall strongest amplitudes of data. The second one EOF2 is the time series index that produces regression/correlation maps with the overall strongest amplitudes after the variability associated with EOF1 is subtracted out of the data. And so on and so forth for modes EOFs 3 and 4. In short terms, the PCs are the main components, EOFs are the eigenvectors and the percentages obtained by modes are the eigenvalues (variance). Each empirical mode is formed by a space pattern and a time series which are derived from the eigenvalues and eigenvectors of the covariance (or correlation) matrix (Cattell, 1966). In recent years, the EOFs technique has been largely used to identify potential physical modes (Mestas-Nunez 2000). The problems that may arise by using EOFs or rotated EOFs is discussed by several authors. In Dommenget and Latif (2002) and North et al. (1982) main statistical uncertainty in the estimation of the EOFs is discussed. In the standard EOF analysis, it is assumed that the modes are orthogonal in space and time, and that the first mode is the one that maximizes the explained variance over the total dataset (Mestas-Nunez 2000). An overview of the different ways in rotating EOFs or defining the varimax rotation can be found in Richman (1986), North et al. (1982) and Kaiser et al. (1958). In our study, it is the varimax method that we use to get rotations of EOFs (REOFs) and PCs (RPCs) before plotting them.

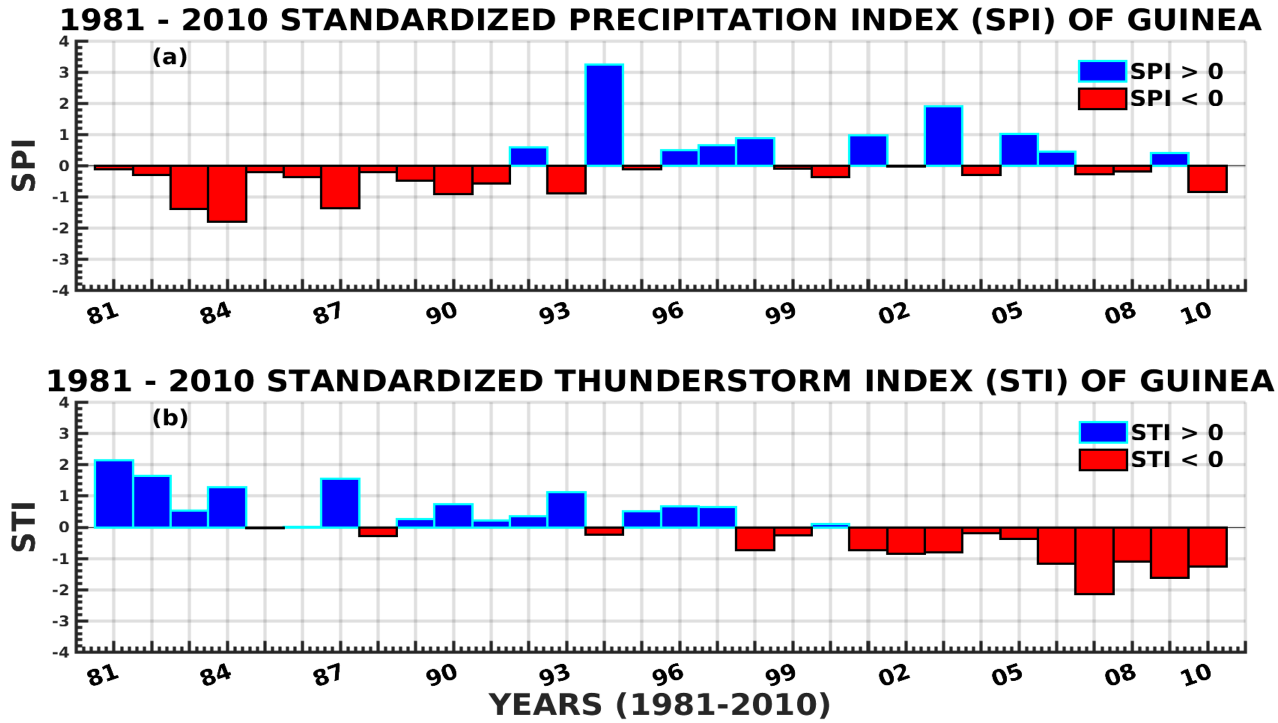

Figure 4. Standardized Precipitation Index (mm) and Standardized Thunderstorms Index (occurrence number). The X and Y axes are years and anomalies respectively. (a) Standardized Precipitation Index (SPI), and (b) Standardized Thunderstorms Index (STI) in Guinea, for the period 1981-2010.

The statistical significance thresholds used to capture the number principal components are given by the scree test (Mestas-Nunez 2000) and the North test (Dommenget and Latif 2002). We use North's rule of thumb for estimating the sampling errors (Equation 2) to test the significance of each EOF mode. The rule is simply that if the sampling errors of a particular eigenvalue Δλ are comparable to or larger than the spacing between λ and a neighboring eigenvalue, then the sampling errors for the EOF associated with λ will be comparable to the size of the neighboring EOF (Dommenget and Latif 2002). Δλ, allows also to determine the 95% significance errors in the estimation of the eigenvalues. The analysis of these results makes it possible to choose among the four modes of analysis considered which better interpret the rainfall and thunderstorm variability in Guinea. Here we would like to focus on problems of the EOF technique that are not due to statistical uncertainties and more inherent to the method itself (Dommenget and Latif 2002).

$$\Delta\lambda = \lambda\sqrt{2 / N} \qquad (2)$$

where λ:Eigenvalues of variances (%). Δλ: Samples errors of eigenvalues (%). N: Corresponding to number of modes.

Finally, the fourth method shows the link that could exist between rainfall amounts and thunderstorms. We first considered the rainfall and thunderstorms variables in two classes as in weak rainfall-thunderstorm (0-300 mm) and heavy rainfall-thunderstorm (300-600 mm). In Guinea, the weak daily rainfall amount is around 10 mm/day on average. Multiplying 10 mm by 30 days, we get 300 mm/month, that is, why we considered here 0-300 mm like weak rainfall and 300-600 mm likewise heavy rainfall. We also correlated large rainfall between 600 and 1200 mm, which is not presented in this document. The correlation coefficients allow us to determine the links between rainfall-thunderstorms and associated levels of significance. In the statistical data analysis, the following formula is used to find respectively the correlation (Equation 3) between the data sets and student test.

$$r = \frac{1}{N}\sum_{i=1}^{N}\frac{(x_i - \bar{x})}{\sigma_x}\frac{(y_i - \bar{y})}{\sigma_y} \qquad (3)$$

where x_i : cumulative of the whole series of the first variable; y_i: cumulative of the whole series of the second variable; $\bar{x}$: Calculated mean of all values of the data set x_i for the first variable; $\bar{y}$: Calculated mean of all values of the data set y_i for the second variable; σ_x: Sample standard deviation of all of the first variable x; σ_y: Sample standard deviation of all of the second variable y; r: Correlation coefficient, $-1 < r < 1$; N: the total number of values in the set of paired x and y data.

RESULTS AND DISCUSSION

The SPI (Figure 4a) of Guinea over the period 1981-2010 shows a rainfall deficit for the decade (1981-1990) corresponding to a drought period. These observed negative anomalies are coherent with the severe drought in the Sahel in the 1970's to 1991 but that was delayed for a decade (Nicholson et al., 2005). After about the 25

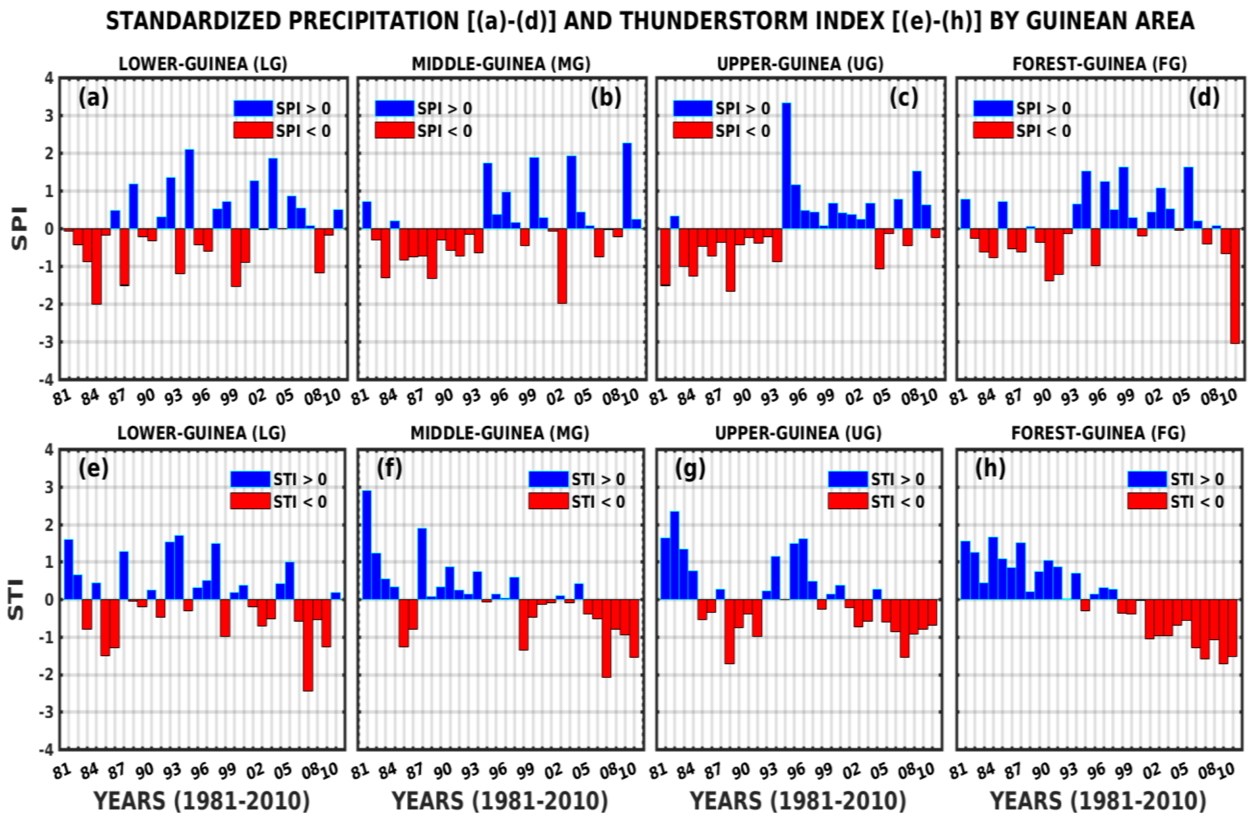

Figure 5. Standardized Precipitation Index (SPI) and Standardized Thunderstorms Index (STI). The X and Y axis are years and anomalies respectively. Standardized Precipitation Index [(a)-(d)] and Standardized Thunderstorms Index [(e)-(h)] by geophysical region of Guinea: Lower Guinea (LG), Middle Guinea (MG), Upper Guinea (UG), and Forest Guinea (FG).

dry years (1965-1990) in the Sahel, the wet years are mainly observed from 1994 (Ali et al., 2009). For the Guinea, the wet period is observed from 1992 up to 2010, with year 1994 showing an important positive peak. This finding over the Sahel is confirmed by other studies like in Ali et al. (2009) and Nicholson et al. (2005), but for Guinea area also, located next to Sahel, our study is among the first revealing this rainfall variability.

Nevertheless, the STI (Figure 4b) for Guinea, shows that the period 1981-1997 was regularly marked by positive thunderstorms anomalies corresponding to the dry period in term of rainfall. This could be caused by the frequency of dry thunderstorms which are not accompanied with rainfall. The overall STI variability indicates also negative anomalies during the period 1998-2010 corresponding to the wet period (Figure 3a).

To refine these results, we have categorized rainfall data in two groups: respectively weak (0-300 mm) and heavy (300-600 mm). Then we correlated these two rainfall categories with the corresponding thunderstorms to understand which is well correlated with thunderstorms (Relationship between rainfall and thunderstorms in Guinea, Sections). The years 1981, 1982, 1984 and 1987 are particularly very wet. Similarly, the years 2006, 2007, 2009 and 2010 reveal negative rainfall anomalies. This situation shows a downward trend in the thunderstorm's regime in Guinea during the period considered for this study.

Standardized index of rainfall and thunderstorms of Guinean regions

In the following, we indicate rainfall and thunderstorms variability in the four natural Guinean regions.

Standardized Precipitation Index (SPI) of Guinean regions

The results show dry and wet periods of rainfall observed in Guinea in each region during 1981-2010. In MG region (Figure 5b) located near the Fouta Djallon Mountains, we have a rainfall deficit during the decade 1981-1992. The UG region (Figure 5c) shows a rainfall deficit also for decade 1981-1993. The UG region is considered as the Guinea region with rainfall characteristic similar to Sahelian one. We noted that 1994, 1999, 2003 and 2009

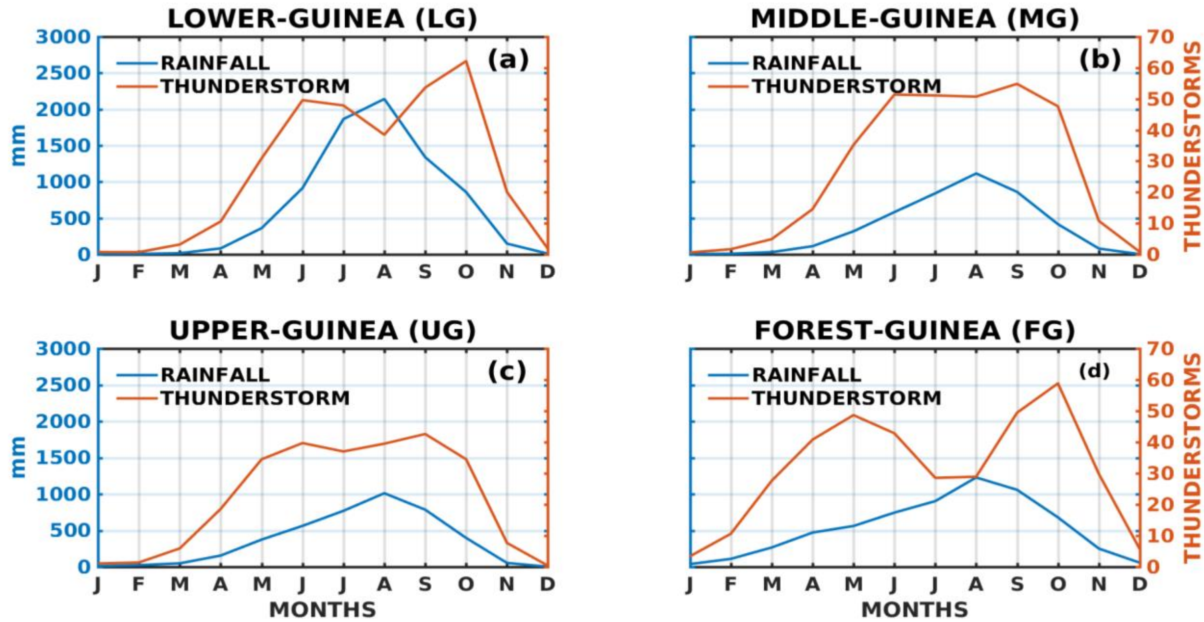

Figure 6. Seasonal cycles of rainfall (blue curve) and thunderstorms (red curve) in the different Guinean regions: (a) Low-Guinea, (b) Middle-Guinea, (c) Upper-Guinea, (d) Forest-Guinea. The X-axis in red and blue are respectively rainfall and thunderstorms. The Y axes are the years.

were particularly wet in MG region. And then, some wet years like 1994, 1995, 2008 and 2009 where 1994 were very wet in the UG region. This confirms that these two regions have shown the same rainfall variability that Guinea has underwent.

LG region (Figure 5a) and FG region (Figure 5d) have shown also this rainfall variability but not like MG and UG. While in FG region (Figure 5d), it is in the decade 1982-1992 that we note important negative rainfall anomalies and 2010 was particularly very dry. Over the LG region, 1984, 1987, 1993, 1999 and 2008 were particularly very dry during the observed drought in Guinea. This would mean that these regions have also suffered the same rainfall deficits and the return to normal rainfall as in Guinea.

Standardized Thunderstorms Index (STI) of Guinean regions

We have a remarkable decreasing thunderstorm activity observed in each region during 1981-2010. Figure 5e to 5h represents STI evolution for the four geophysical regions of Guinea, respectively. In the LG region (Figure 5e), we observed thunderstorms deficits during the years1981, 1987, 1992, 1993 and 1997 for this coastal area of Guinea, while thunderstorm surplus is found during the years 1985, 1986, 2007 and 2009. The situation of this region shows us that it is not concerned by this thunderstorm rate decreasing.

The STI in the MG region (Figure 5f), UG region (Figure 5g) and FG region (Figure 5h) region reveal deficits of thunderstorms during last decade (2000-2010). This confirms that these three regions have undergone this thunderstorm variability that Guinea has experienced. These regions have also experienced important negative thunderstorm anomalies namely during 1985, 1998, 2007 and 2010. For this purpose, we note in the Fouta Djallon region (MG), large thunderstorms surpluses recorded in 1981 and 1987. In the UG region (Figure 5g), surpluses and deficits (1988-1992) thunderstorm are alternatively shown, respectively in 1981-1985, 1993-1996 and 1988-1992. Whereas the STI in FG region (Figure 5h) indicates that the forest region is the only one with consecutive years with annual thunderstorms above average from 1981 up to 1991. The situation of this region shows that it is not concerned by the thunderstorms decreasing.

In summary, a multi-year of thunderstorms decreasing is observed in these three regions (MG, UG, FG), this is consistent with what has been observed in a general way about Guinea (Figure 5).

Seasonal mean cycles of rainfall and thunderstorms in Guinea

Considering each natural Guinean region, we show the seasonality of rainfall and thunderstorms. The Figure 6 indicates that Guinea rainfall (blue curve) and thunderstorms (red curve) have respectively unimodal \and bimodal variabilities.

Figure 6a and b, respectively for the LG and MG regions, represent the seasonal mean cycles of rainfall and thunderstorms. The seasonal mean cycle of rainfall is illustrated with a peak in August ranging up to 2200 and 1100 mm, respectively for LG and MG. Moreover, in LG, even if the largest of rainfall amount is found in August, month of July is also wet with a monthly amount close to the August peak. We noticed that July's rainfall of this region amount is larger than the peak of the other regions. The rainy season starts at the coast (LG), at Fouta Djallon (MG) and ends at the same moment, respectively in April and November. Otherwise, regarding the thunderstorms, these LG and MG regions present two peaks, respectively at the beginning and end of the season. They (LG, MG) both have a first peak in June (beginning of season) and a second peak (end of season), respectively in October and September. The months of March and November are respectively the start and the end of thunderstorms events in these two regions.

Figure 6c and 6d, respectively for the UG and FG regions, indicates the seasonal mean cycle for rainfall and thunderstorms. The seasonal mean cycle of rainfall is highlighted with a peak in August ranging up to 1000 and 1200 mm, respectively for UG and FG regions. In the UG region, the rainy season starts in April and ends in October, while in the FG, February and November are, respectively the starting and ending of the rainy season. In FG region, the rainfall can be extended up to ten months e.g. from February to November. Regarding the thunderstorms, seasonal mean cycle presents two peaks the first one at the beginning and the second one at end of season. In UG region, the thunderstorms peaks are observed in June (beginning season) and in September (ending season), while in FG, they are recorded in the earlier in May (beginning season) and end in October (ending season).

We deduce that in Guinea, rainfall has a unimodal regime with peaks in August in each region. The thunderstorms variability is also bimodal with two peaks, one at the beginning of season and second at the end of season, respectively corresponding to Inter-Tropical Convergence Zone (ITCZ) arrival and return. It is noted that, this migratory movement of ITCZ is followed often by meteorological phenomena such as thunderstorms, etc.

EOFs and PCs rotated of rainfall and thunderstorms in Guinea

EOFs and PCs rotated of rainfall in Guinea

Figure 7 represents the EOFs (in the first column) and PCs (in the second column) of rainfall in Guinea for the period 1981-2010. The first mode EOFs1 (Figure 7a) corresponding to the PC1 (Figure 7b), highlights distribution pattern more or less uniform over the entire domain, with positive rainfall anomalies in Guinea where the variance is 25.1%. This means that the EOF1 pattern shows us the overall strongest amplitudes of rainfall data. It corresponds to years characterized by positive rainfall anomalies (wet years). The PC1, indicates dry conditions at the beginning of climatological period (1981-1993) and wet conditions for 1994-2010 period, with the very wet year of 1994 which is consistent with the Figure 1. This means that the observed rainfall exhibited by EOFs1 pattern is related in majority to wet period.

The second mode pattern (Figure 7c) corresponding to PC2 (Figure 7d), reproduces a strong gradient of positive rainfall anomaly over the entire domain and highlights coastal of Guinea (LG), the south-eastern part (FG) with 22.3% of variance. These two regions represent the Guinean regions (map) where maximum rainfall amount is record. Around the Fouta Djallo Mountains, the negative rainfall anomalies are observed in the center explaining a deficit rainfall in this area. The wet patterns located in coastal part (LG) are explained by orographic behaviors and the oceanic influence, and the wet patterns around south-eastern (FG) are related to the forest impact. The corresponding PC2 shows very interannual rainfall variability compared to the PC1 with much fluctuation. The EOF3 (Figure 7e) represents 14.7% of variance with a different distribution compared to two previous modes. It shows an inter-regional dipole of rainfall, one at the coast (LG) and the other in forest area (FG).

However, the PC3 (Figure 7f) reveals some similarity in the interannual variability with PC2 with many fluctuations. The EOF4 (Figure 7g) clearly shows a distribution slightly similar to the second mode (EOF 2) with 12.9% of variance. And then, its corresponding PC4 (Figure 7h) indicates an inter-annual variability similar to PCs3. This means the adjacent EOFs are not well separated hence the North's rule of thumb is used to check them.

For this purpose, we checked the significance of each rainfall EOFs mode using North's rule of thumb for estimation of the eigenvalues (Figure 8). This rule informs that if a group of true eigenvalues (λ) lies within one or two $\Delta\lambda$ of each other, these eigenvalues form an "effectively degenerate multiplet", and sample eigenvectors (Dommenger et al., 2002). We notice on Figure 7 that no mode is concerned by this sampling where the difference (λ–$\Delta\lambda$, in green) is not one or two. We can conclude that the adjacent EOFs are physically separated from each other and they are not degenerate multiplet.

EOFs and PCs rotated of thunderstorms in Guinea

Figure 9 represent EOFs and PCs of thunderstorms in Guinea for the first four modes. The EOFs patterns for the first mode (Figure 9a) indicate an overall uniform positive anomaly of thunderstorms over the whole country with 38.5% of variance. EOF1 pattern shows a

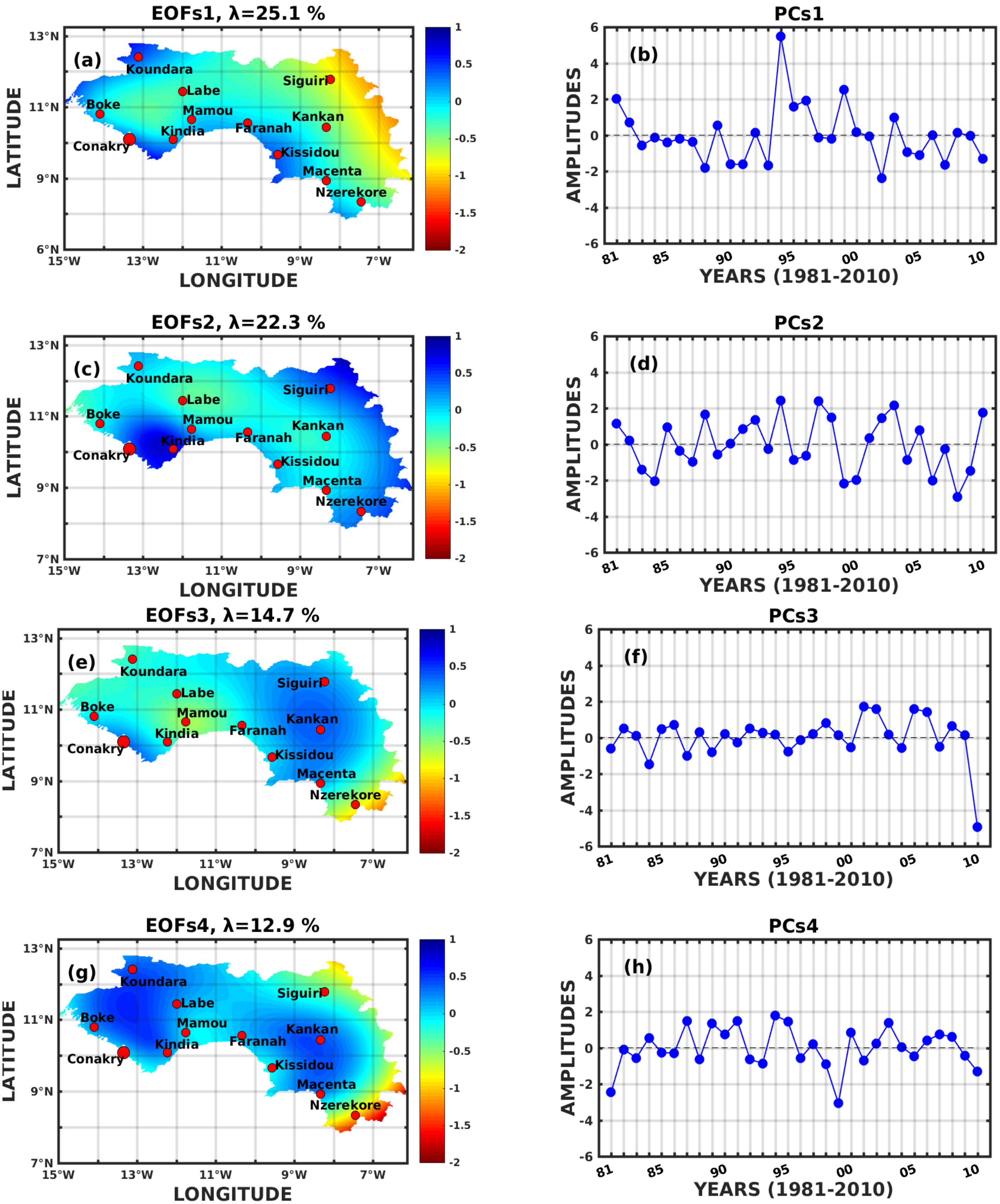

Figure 7. First four modes of the Rotated EOFs (REOFs) and the Rotated PCs (REOFs) of rainfall in Guinea. (a) EOF1 and (b) PC1, (c) EOF2 and (d) PC2, (e) EOF3 and (f) PC3, (g) EOF4 and (h) PC4. The X and Y axis of PCs are respectively anomalies and years.

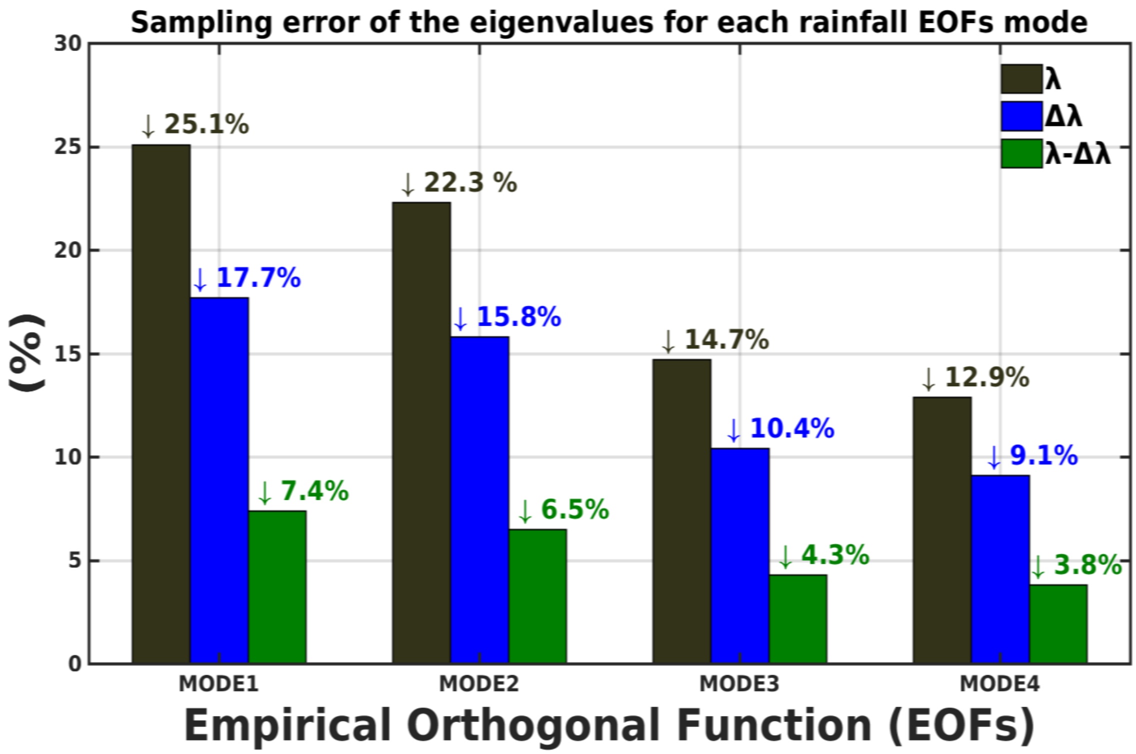

Figure 8. Sampling error of the eigenvalues for each rainfall EOF mode. Eigenvalues (λ, black), sampling error (Δλ, blue), difference between eigenvalues and sampling error (λ-Δλ, green). The X and Y axis are respectively EOFs and Percentage.

strong gradient everywhere over the coast (LG), Fouta Djallon (MG) and south (FG) which are areas where high occurrences of thunderstorms are recorded. This explains that EOF1 pattern shows the overall strongest amplitudes of thunderstorm data. Regarding corresponding PC1 (Figure 9b), a variability with a downward multi-year variability of thunderstorms is indicated during the 1988-2006 period which is close to what the Figure 4b has shown. It is for this reason that the observed thunderstorms in the country relative to the 1981-1993 period during which heavy thunderstorms are found.

The EOF2 pattern (Figureb 9c) with 18.1% variance shows a dipole of negative anomalies of thunderstorm in Guinea: one in the western part (around the coast) in LG region and another in southern area (FG). Otherwise, the western part (LG), central part (Labe) and the northern area (MG) of Guinea have a common positive thunderstorm pattern with a zonal gradient. These areas are localities where the thunderstorms are recorded mainly during the beginning and the end of the season. Moreover, the corresponding PC2 (Figure 9d) illustrates a variability of thunderstorms like the PCs1 revealing a downward trend.

The EOF3 pattern (Figure 9e) with 14.5% of variance explained, has a structure different from the two previous modes with an opposite dipole compared to the second mode where the strong signal is found in the coastal part of the country. However, the PC3 (Figure 9f) shows a similar variability to PC2, except for the period 2006-2010 with a downward multi-year variability like PC1. This configuration could be probably implied by climatic behavior, but we perform the North's rule of thumb below clarify this likeness modes. Finally, the EOFs corresponding to the fourth mode (Figure 9g) with 12.5% of variance, also presents a thunderstorm strong gradient of positive anomalies in the coastal part of Guinea and also in the central area (Mamou). The corresponding PC4 (Figure 9h) reveals a variability whose multi-year variability is mainly decreasing from 1989 up to 2001. Indeed, the strong negative signals of thunderstorm anomalies in East of the country concerns the 1989-2010 marked by a decline of thunderstorm events.

By testing the significance of each thunderstorm EOF mode using the North's rule of thumb for estimation of the eigenvalues. Each EOF will have different sampling requirements depending upon the nearness of neighboring eigenvalues (Dommenger et al., 2002). This rule indicates here that in groups or modes 3 and 4 of true eigenvalues (λ) that the difference (λ–Δλ) is inferior to two of each other, to form an "effectively degenerate multiplet", and sample eigenvectors (Figure 10). This confirms that there is no similarity in physics between EOFs 3 and 4. This means that adjacent EOFs of modes 3 and 4 are well separated and they are not degenerate

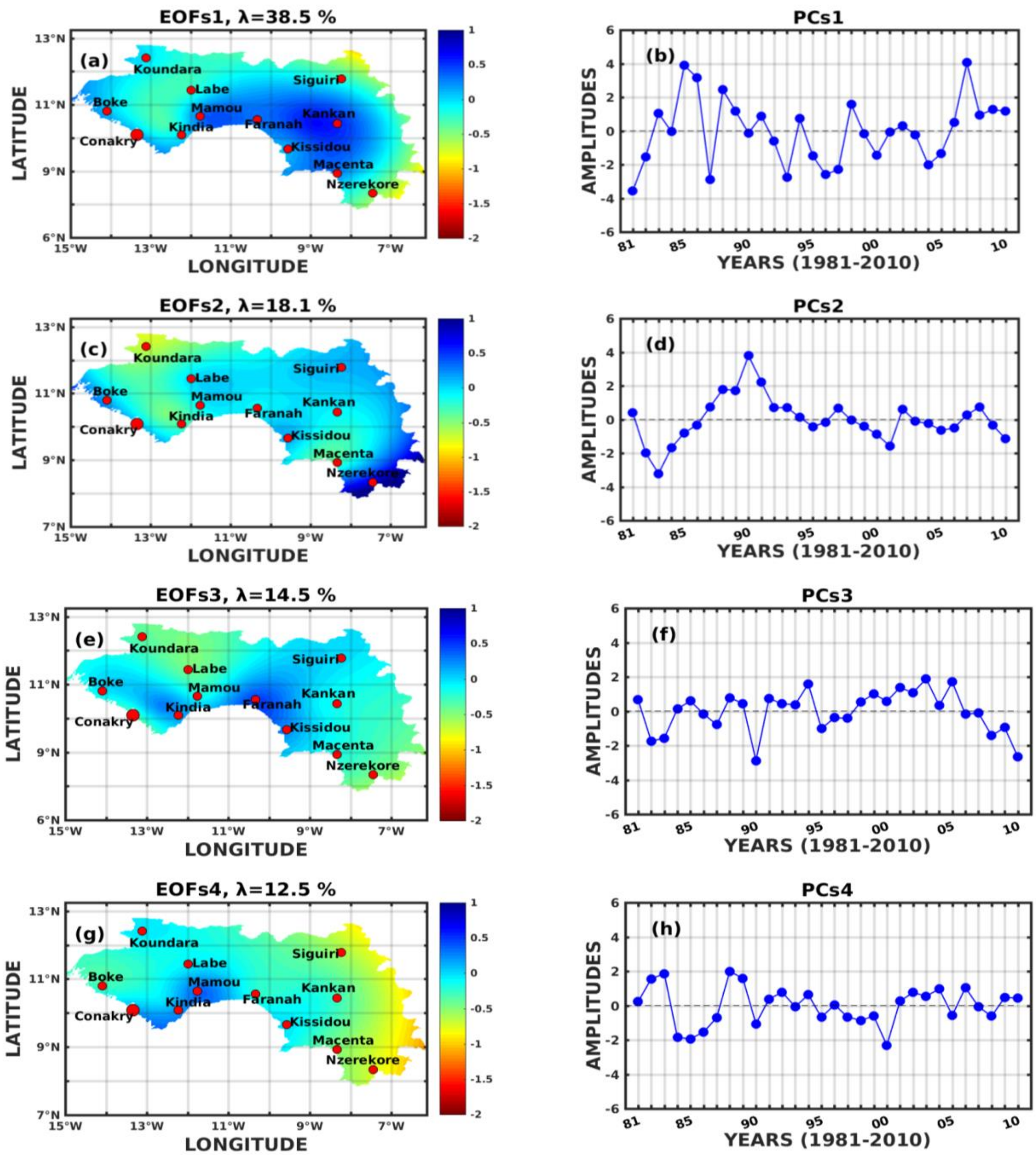

Figure 9. First four modes of the Rotated EOFs (REOFs) and Rotated PCs (RPCs) of thunderstorm in Guinea. (a) EOF1 and (b) PC1 (c) EOF2 and (d) PC2, (e) EOF3 and (f) PC3, (g) EOF4 and (h) PC4. The X and Y axis of PCs are respectively anomalies and years.

multiplet.

Relationship between rainfall and thunderstorms in Guinea

Firstly, we consider the overall rainfall and thunderstorms in Guinea; secondly, we divide the rainfall in two ranges: weak rainfall ranging between 0 and 300 mm and heavy rain amount between 300 and 600 mm, and then correlate these respective rainfall time series with corresponding thunderstorms.

It was noticed that LG (Figure 11a) and MG (Figure 11b) regions are illustrated with a very good correlation coefficient between rainfall and thunderstorms (respectively r=0.59 and r=0.78) for a significance of than

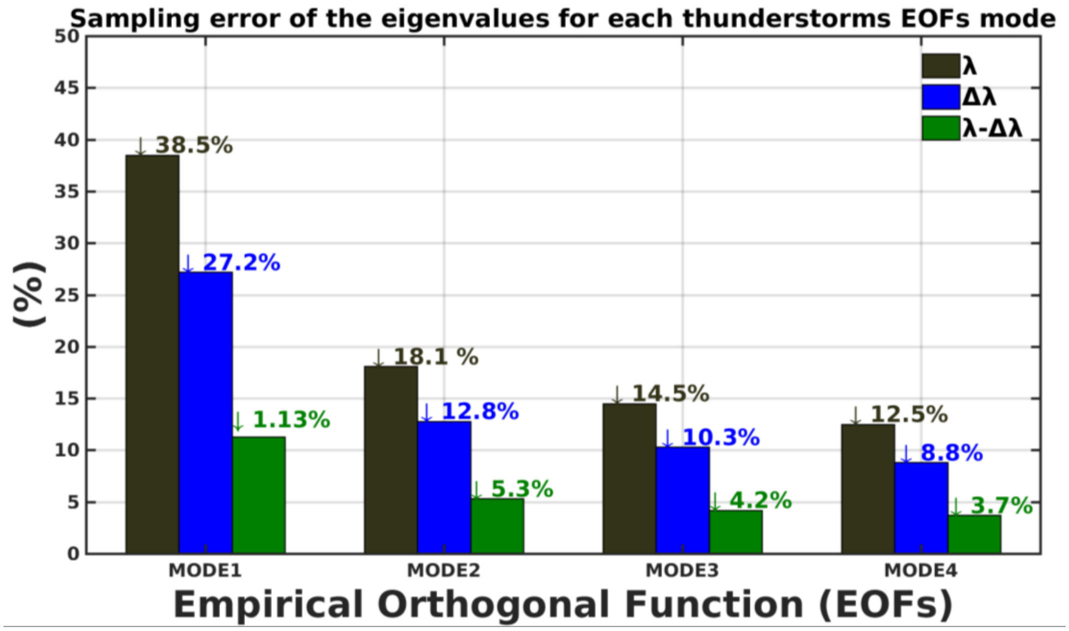

Figure 10. Sampling error of the eigenvalues for each thunderstorm EOF mode. Eigenvalues (λ, black), sampling error (Δλ, blue), difference between eigenvalues and sampling error (λ-Δλ, green). The X and Y axis are respectively EOFs and Percentage.

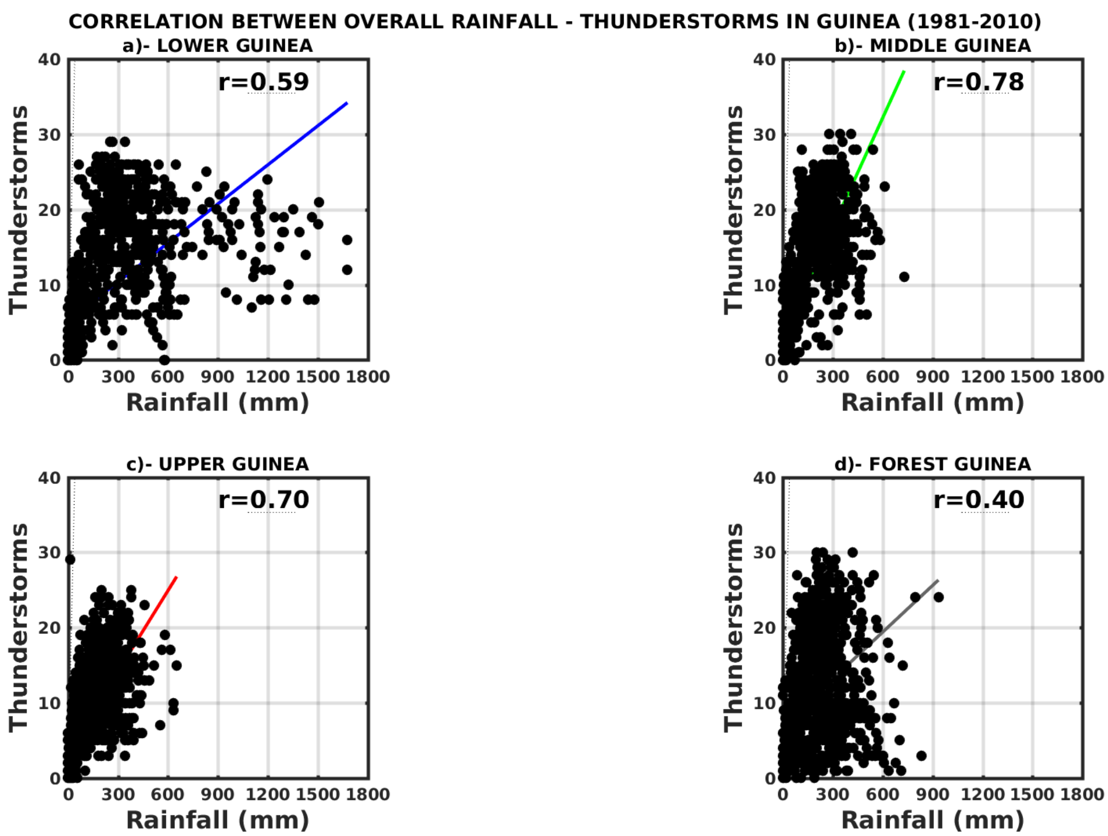

Figure 11. Correlation between rainfall and thunderstorms in Guinean regions: (a) Low Guinea (LG), (b) Middle Guinea (MG), (c) Upper Guinea (UG), (d) Forest Guinea (FG). The X and Y axis are respectively monthly rainfall amounts and monthly thunderstorms.

Table 2. Significant correlation between rainfall and thunderstorms by region with their respective stations.

Area and station		Parameter	Correlation (r)	Significance (%)
Low Guinea	Low Guinea	Rainfall-Thunderstorm	0.59	>95
	Boke	Rainfall-Thunderstorm	0.68	>95
	Conakry	Rainfall-Thunderstorm	0.58	>95
	Kindia	Rainfall-Thunderstorm	0.75	>95
Middle Guinea	Middle Guinea	Rainfall-Thunderstorm	0.78	>95
	Koundara	Rainfall-Thunderstorm	0.80	>95
	Labe	Rainfall-Thunderstorm	0.84	>95
	Mamou	Rainfall-Thunderstorm	0.72	>95
Upper Guinea	Upper Guinea	Rainfall-Thunderstorm	0.70	>95
	Faranah	Rainfall-Thunderstorm	0.77	>95
	Kankan	Rainfall-Thunderstorm	0.69	>95
	Siguiri	Rainfall-Thunderstorm	0.59	>95
Forest Guinea	Forest Guinea	Rainfall-Thunderstorm	0.40	>95
	Kissidou	Rainfall-Thunderstorm	0.63	>95
	Macenta	Rainfall-Thunderstorm	0.33	>95
	Nzérékoré	Rainfall-Thunderstorm	0.37	>95

95%. However, rainfall and thunderstorms relationship is more important in MG region than in LG region. It means that 35% (r^2=0.35) and 61% (r^2=0.61) of rainfall in LG and in MG, respectively, are stormy originated. This 61% correlated rainfall with thunderstorms in MG, is visible on Figure 6b where even in full monsoon (August) stormy activities persist in this region. These stormy activities are decreasing in the other three geophysical regions, which could be due to the influence of Fouta Djallon massifs (orography). It was also observed in UG (Figure 11c) and FG (Figure 11d) regions, that there are significant correlation of 0.70 and 0.40, respectively. It is therefore deduced that 40% (r^2=0.40) and 16% (r^2=0.16) of rainfall amounts storm derived from these respective regions and proportions. These results imply that the relationship of rainfall and thunderstorm in MG is stronger as compared to LG, UG and FG regions Table 2.

Relation between weak rainfall (0-300 mm) and thunderstorms in Guinea

Here, we correlate weak rainfall between 0-300 mm (Figure 12) and corresponding thunderstorm occurrences. In the four geophysical regions of Guinea (LG, MG, UG and FG), we note that rainfall is well correlated with thunderstorms. LG (Figure 12a) and MG (Figure 12b) regions show a significance correlation respective of r=0.85 and r=0.86. It means that 72% (r^2=72) of these weak rainfall in LG and 74% (r^2=74) in MG are stormy rainfall.

UG (Figure 12c) and FG (Figure 12d) regions indicate a good correlation of r=0.76 and r=0.65, respectively. This informs that in UG and FG regions 58% (r^2=0.58) and 42% (r^2=0.42) of weak rainfall are thunderstorms originated. We note that in Guinean geophysical regions, the weak rainfall is from stormy convective systems.

Relation between heavy rainfall (300-600 mm) thunderstorms in Guinea

For the heavy rainfall amounts between 300and 600 mm (Figure 13), which we correlated with thunderstorms in each Guinea region, LG region (Figure 13a) and MG region (Figure 13b) show low to very low correlations and negative, respectively r=-0.23 and r=-0.04. This means that in LG and MG regions, the heavy precipitation is not stormy originated and evolve in an opposite way. Concerning UG (Figure 13c) and FG (Figure 13d) regions, we note also negative and very low correlations between heavy rainfall and thunderstorms, respectively r=-0.03 and r=-0.19. We find that these correlations are all negative and relatively weak, which means that when rainfall are high, the links between thunderstorms and rain are no longer linear. That is to say, these two phenomena show an opposition in their evolution one grows the other decreases and conversely.

Conclusion

In general, during the climatological period (1981-2010),

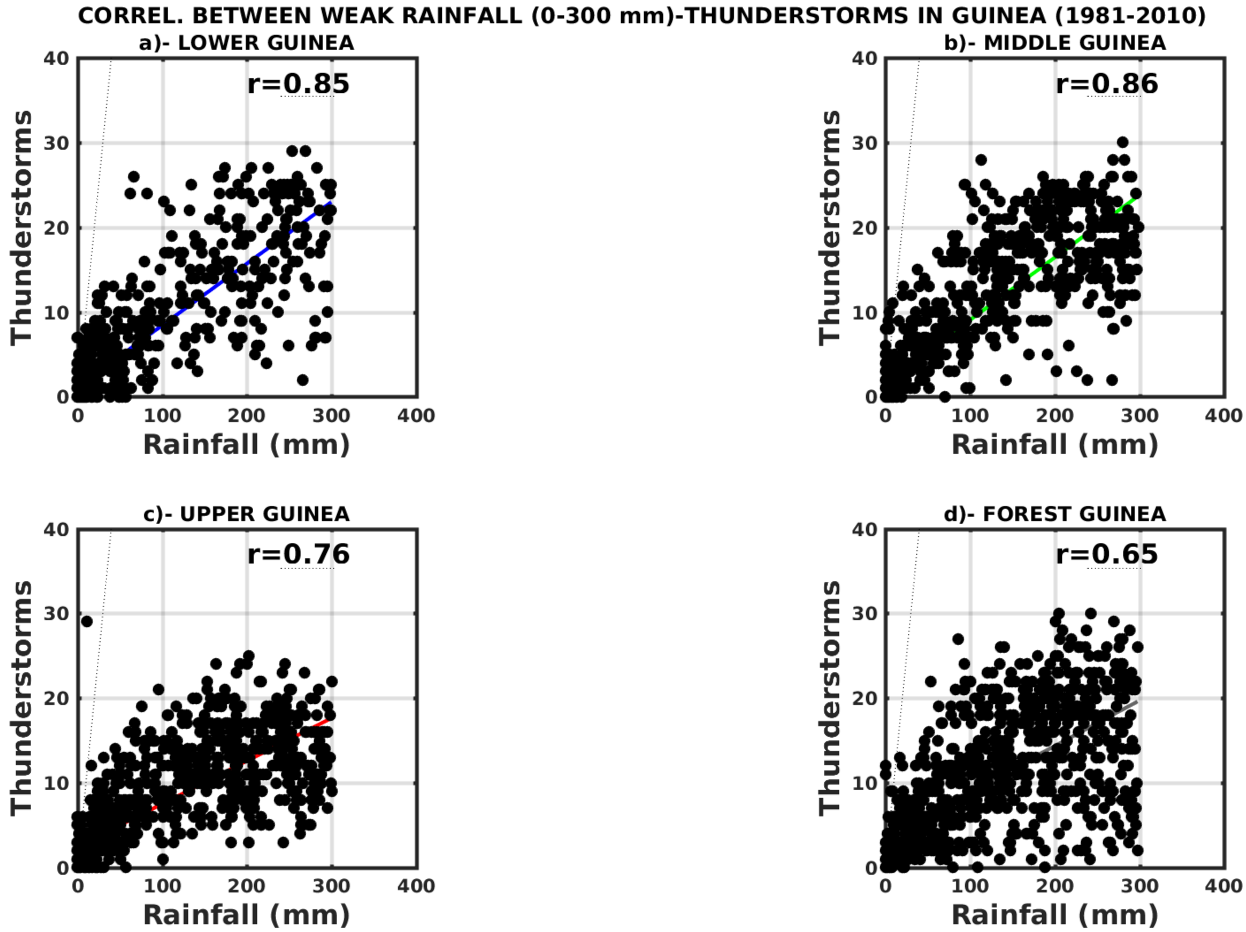

Figure 12. Correlations between the weak (0-300mm) rainfall and thunderstorms in Guinean regions: (a) Low Guinea (LG), (b) Middle Guinea (MG), (c) Upper Guinea (UG), (d) Forest Guinea (FG). The X and Y axis are respectively monthly rainfall amounts and thunderstorms.

the SPI highlights that Guinea also experienced the 1970's drought like the Sahel, a period followed by a wet rainfall regime including the very rainy year of 1994. Moreover, the STI exhibits a decrease of thunderstorms in Guinea during the rainfall recovery period with heavy rainfall but low correlated with thunderstorms. Regarding the four geophysical regions of Guinea, we have shown that the three ones (LG, MG, UG) experienced these episodes of drought like Sahel. The decline trend significantly for the thunderstorms in FG is compared to other regions of country. The recovery rainfall period is shown in all the different geophysical regions of Guinea, but particularly in MG where the findings are very coherent with results revealed in the overall Guinea. Otherwise, it is noted with the STI that all regions are concerned by the decline of thunderstorms during the rainfall recovery period, mainly in the FG region where results are better in agreement with the global STI. This decline would be due to heavy rainfall which is less correlated with thunderstorms.

In Guinea, the seasonal mean rainfall cycle likely indicates similar regimes in the four geophysical regions with an absolute peak in August. We conclude that in Guinea, rainfall has a unimodal regime with a peak in August. Regarding the thunderstorms, the seasonal mean cycle exhibits a bimodal evolution with two peaks, one at the beginning of season and second at end of season, respectively corresponding to arrival and ITCZ return.

In the EOFs and PCs analyses, mode 1 exhibits a homogeneous overall pattern of rainfall over Guinea and the expansion coefficient (PC1) confirms the drought and the rainfall recovery. This result is also shown with the SPI. Modes 3 and 4 of EOFs indicate a rainfall dipole in the wetter two regions (LG and FG) of Guinea. These two regions represent the Guinean regions where record maximum rainfall is observed. The first one is under oceanic and orography influenced implies the wet patterns in the coastal part (LG) and a second wet pattern around south-eastern (FG) is related to forest impact.

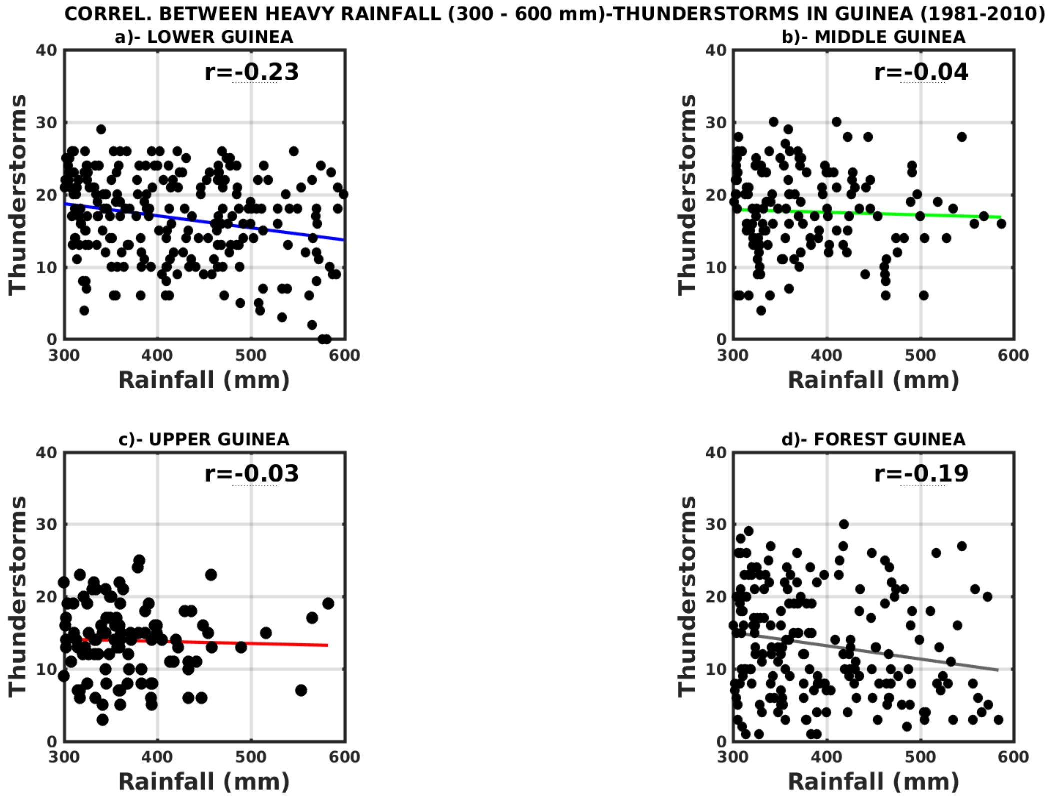

Figure 13. Correlations between heavy rainfall (300-600 mm) and thunderstorms in Guinean's regions : (a) Low Guinea (LG), (b) Middle Guinea (MG), (c) Upper Guinea (UG), (d) Forest Guinea (FG). The X and Y axis are respectively monthly rainfall amounts and thunderstorms.

Regarding the thunderstorms, mode 1 indicates a homogeneous pattern over Guinea with a strong gradient everywhere over the coast (LG), Fouta Djallon (MG) and south (FG) which are areas where high occurrences of thunderstorms are recorded. The corresponding PC1 confirms more or less a downward, and we note the same things on PCs2 to 4 found with the thunderstorm index too. This means that effectively the multi-year variability is decreasing, confirming that the second mode is better than others. According to the North's rule of thumb, we showed that concurrent rainfall and thunderstorm EOFs are well separated from each other with neither difference of one or two between eigenvalue and sampling error. These differences are either greater or less than 1.

Considering correlations between rainfall and thunderstorms in Guinea, significant coefficients are highlighted in LG, UG and MG, whereas in FG region the correlation values are low. In fact, rainfall in these areas increase with thunderstorms, that means that stormy convective systems mainly take place in these regions. Although the percentage of stormy rainfall in FG is lower. However, the weak rainfall and thunderstorms showed strong correlation values in the 4 regions varying between 0.65 and 0.86. This means that in Guinea, the weak rainfall are of stormy origin. Indeed, heavy rainfall and thunderstorms are less correlated with the low values of correlation and negative. This shows an evolution opposition of the two phenomena, that is to say when one grows while the other decreases and vice versa. Meaning heavy rainfall is not necessarily related to thunderstorms sometimes, but with other types of convective systems like vortex or large mesoscale systems (Jenkins et al., 2008). The significant correlations between rainfall and thunderstorms in the FG should be linked to the forest and orographic patterns which are potential storm triggers. This is consistent with Sall et al. (1999) and Mathon and Laurent (2001) results which showed that in Africa, the main mountainous areas generally correspond to the maximum of cloud cover.

CONFLICT OF INTERESTS

The authors have declared any conflict of interests.

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Solid waste management in urban communities in Ghana: A case study of the Kumasi metropolis

Paul Sarfo-Mensah*, Kwaku Obeng-Okrah, Albert Abraham Arhin, Theophilus Kwarteng Amaning and Richard Tetteh Oblitei

Bureau of Integrated Rural Development (BIRD), Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

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Globally, solid waste management has in recent times attracted massive attention, and one of the commonly cited areas is the sprawling cities and urban communities, where plastics and other solid waste have become major management challenge. In Ghana, solid waste management has become a major problem, particularly in urban settlements. The overall objective of the study was to investigate the key factors that underlie the effective urban solid waste management systems in Kumasi, the capital of the Ashanti region, and the second largest city in Ghana. In achieving the study objectives, exploratory and qualitative methods of research were adopted both in data collection and analysis. This comprised review of relevant literature, key informant interviews and observations. Results of the study showed that there was an inadequate budgetary allocation to manage solid waste in the Kumasi Metropolis. A deeper assessment of the situation further showed that bad attitude and the breakdown of sanctions for non-compliance with local authorities' solid waste management by-laws by citizens were important contributory factors. The study concludes that ineffective solid waste management systems have become a major challenge facing city authorities. This challenge must be addressed holistically because solid waste management is a multi-dimensional issue. The study recommends increased public education and awareness creation on the negative implications of indiscriminate waste generation and disposal on human and environmental health by urban and communal (chiefs/assemblymen) authorities for attitudinal change.

Key words: Community engagement, local attitudes, environmental management, non-compliance, sanctions.

INTRODUCTION

It is very distasteful, and perhaps shameful, that Ghana, a prominent member of the Economic Community of West African States (ECOWAS), has recently been ranked among the dirtiest counties in the world (UNEP, 2018). With this unpleasant accolade, it was the assumption of many environmentalists in the country that

***Corresponding author.** E-mail: psarfomensah@gmail.com.

at the very least the Metropolitan, Municipal and District Assemblies (MMDAs), which are the decentralized government authorities at the local and community levels, would facilitate a transformational process to improve the situation. However, a comprehensive solution continues to elude the assemblies as most of them still grapple with basic solid waste management problems. It was also the expectation that they would take waste management very seriously; surprisingly, this has not been the case. Most MMDAs have been unable to appreciate and prioritize the key factors that underlie their inability to adequately manage solid waste. The situation in urban communities is getting worse because of rapid urbanization and associated increased consumption patterns. According to IPA (2014), this challenge is grounded in a report which states that the world is becoming more urbanized and developed, and with populations rapidly increasing each year, and with consumption reaching historic levels. An inevitable natural consequence of this growing consumption trend is the rapid increase in the amount of solid waste produced.

Also, studies have shown that Ghana, like many African and developing countries, is facing enormous challenges in the fight against waste management in urban communities (Selin, 2013a). Solid waste management continues to present major challenges to (MMDAs). The country's growing population, increasing urbanization and economic growth and its attendant consumption patterns have combined to worsen the weak waste management systems at the local level (Songsore and McGranaham, 1993; Owusu-Sekyere et al., 2013; Anomanyo, 2004). According to Mensah and Larbi (2005), the average solid waste generation in Ghana per person is estimated at 0.47 kg/day giving a combined total of about 12,710 t of waste per day based on the current national population which is estimated at 27,043,093. It is further estimated that only about 10% of the total solid wastes generated throughout the country are properly disposed of (Mensah and Larbi, 2005). Available statistics indicate that the two major cities of Accra and Kumasi in particular, generate over 4,500 t of solid waste daily, which makes it extremely difficult for Waste Management Departments (WMD) of the assemblies to cope with the situation of collection of this huge volume of solid waste. In the case of Accra for example, the Environmental Protection Agency (2014) reports that 2800 MT of municipal solid waste is generated per day and approximately 2,200 t is collected leaving a backlog of 600 t in the streets, open drains and water bodies which eventually results in flooding during raining season and filthy environment. Generally, a large proportion, in the range of 30 to 50% of solid waste generated by residents is never collected. It is, therefore, apparent that the capacity of the MMDAs, which are responsible for the disposal of generated waste, are overwhelmed by the continuous increase of solid waste in the urban settlements.

An inevitable consequence of more consumption is the rapid increase in the amount of solid waste that is produced. It has become very common, therefore, that urban cities, particularly business district, bus and taxi terminals and low class residential areas, are characterized by sights of heaps of solid waste. Generally, there is seemingly low capacity of waste management expertise (Ampofo et al., 2016) weak institutional capacity (Mensah and Larbi, 2005), lack of practical know-how and adequate logistics/infrastructure to efficiently deal with the disposal of the ever-increasing volume of waste. What is much more worrisome is that MMDAs have been unable to appreciate and prioritize the key factors that underlie their inability to adequately manage solid waste. Therefore, this study examined the key factors that underlie solid waste management in the urban areas in Ghana using Kumasi, the Ashanti regional capital and the second largest city of Ghana, as a case study.

Study context

Most discourses on solid waste management in Ghana have underlined the seemingly break down of structures at the local government level that is mandated to deal with solid waste management (Selin, 2013b). This is premised on the factor that major cities and towns in the country are spilling with solid waste with its accompanying stench, polluting the air within the immediate vicinity and the environment beyond (Yoada et al., 2014). However, this indiscriminate disposal of solid waste has raised national debates and conversations that have not been able to identify factors underlying the poor waste management systems in the Kumasi metropolis. Authorities at the decentralized local government level have assigned inadequate budgetary resources as the major reason for their inability to address the situation. Indeed, inadequate financial resources may be a contributory factor as capital mobilization by the local authorities remains a major problem which has stalled socio-economic development of many cities and towns in Ghana (Boadi and Kuitunen, 2003). But others have argued that the human factor or local people's attitude towards solid waste management is the core problem (Fagariba and Song, 2016). They further suggest that the breakdown of sanctions for non-compliance with local solid waste management by-laws underpins the local authorities' inability to salvage the situation.

Other narratives and arguments have emphasized privatization of waste collection and disposal as one of the promising solutions to the mounting institutional constraints to waste management in urban areas including the Kumasi city (Oteng-Ababio, 2012). It is argued that the involvement of the private sector in waste collection, waste diversion programs could be better explored in collaborations with the informal sector

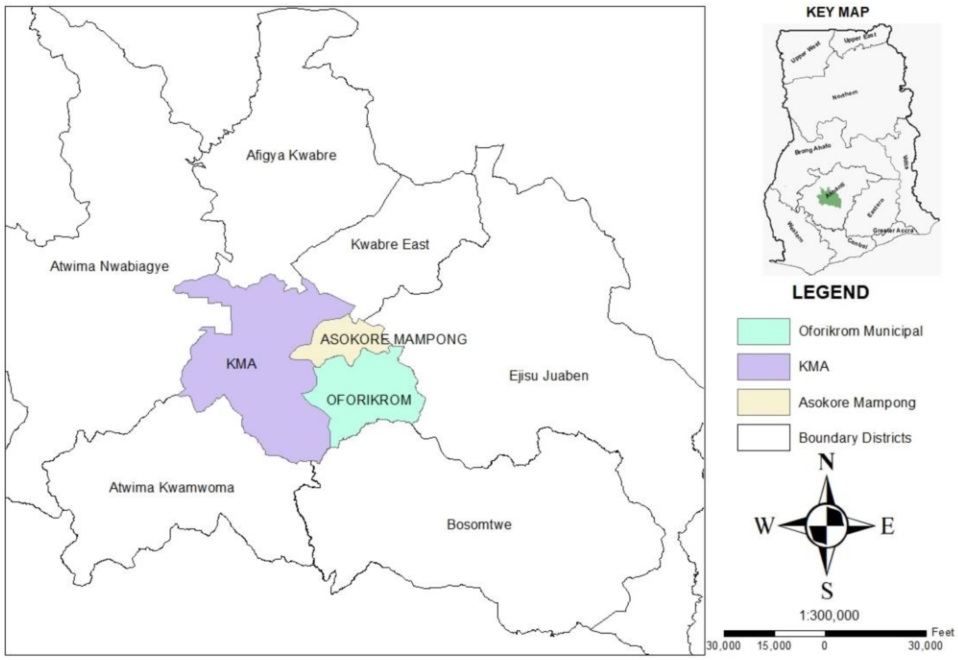

Figure 1. Map of the study area.

involved in waste recycling in the city. Indeed, findings from a study on municipal solid waste management system in Kumasi suggested three key components of successful arrangements with the private sector as competition, transparency and accountability (Asase et al., 2009).

Given these divergent views, the study decided that one of the best approaches to understand the ineffectiveness of the solid waste management systems in the Kumasi city was to start a research and development process which will include an engagement with stakeholders involved in solid waste management in the city. Within this context, the first major stakeholder was the institutions that preside over management of the city, which are the MMDAs.

METHODOLOGY

Study area

Kumasi is the second largest city of Ghana and is the capital of the Ashanti region in the forest area of the country. It is about 250 km north of the national capital, Accra. The city has a population of over two million people and it is a major transportation and commercial hub in the West Africa region. It is also the most important cultural tourism destination in Ghana because of the Ashanti kingdom. The city also boasts of the largest informal market, Kumasi central market, in the ECOWAS sub-region. It has the largest commercial district in the country and one of the biggest informal industrial complexes in Africa. These attributes have had implications for solid waste management of the city. Three purposefully selected local government administrative assemblies, otherwise known as MMDAs in the sprawling Kumasi city, comprised the study area. These were the Kumasi Metropolitan Assembly, Asokore Mampong and Oforikrom Municipal Assemblies as seen Figure 1.

Study design

The qualitative exploratory case study approach was considered appropriate for this study. This approach offered the researchers a better understanding of the existing problem (Naslund, 2002) and enhanced the collection of adequate information to identify issues that will set the focus for the next stage of the research. Indeed, this study is the first phase of a major research the team is undertaking on enhancing community sanitation through community engagement. In this phase of the research, qualitative methods were mainly used for data collection. This comprised review of relevant literature, key informant interviews and observations. As suggested by Mason (2002), through qualitative research we can explore a wide array of dimensions of the social world, including the texture and weave of everyday life, the understandings, experiences and imaginings of our research participants, the ways that social processes, institutions, discourses or relationships work, and the significance of the meanings that they generate.

Sampling, data collection and analysis

An interview guide was used to engage senior officers from the planning, waste management, engineering, environmental health, budget and finance departments of three purposefully selected local government administrative assemblies. The engagements offered the research team a very good initial understanding of solid waste management by the assemblies, including the opportunities and challenges that confront the assemblies. In all, a total of 24 respondents (eight from each assembly) were interviewed. These officers were purposefully selected based on their knowledge and role in the assemblies on the subject matter. Follow-up observations were undertaken along eight (8) selected transects within the study area (two in each assembly) to crosscheck information gathered from the key informant interviews. It was also used to select communities for the subsequent household survey, which will be the second phase of the research. During the data collection, the researchers ensured that informed consent procedures were followed. All interviews were tape recorded and later transcribed for analysis. The data was analysed qualitatively using an in-depth assessment of the various thematic areas.

RESULTS AND DISCUSSION

Institutional perceptions of solid waste

In this section we present local authorities understanding of solid waste. It was considered important as their understanding will invariably inform the management of solid waste. Interviews with the three local assemblies underlined two contrasting understanding of a solid waste. On one hand, solid waste is understood as a residue or a discarded item with little or no use to individuals, households or business units that must eventually be disposed of. This includes refuse, rubbish, garbage, sludge, debris, tailings, litter among others wastes that is typically produced from residential, industrial, commercial and institutional sources. As a key informant explains, *we see it as those plastics, papers and other materials that are of no relevance to individuals, households or business entities and had to be disposed of.* On the other hand, solid waste is also seen as a *resource-in-transition*, which directs attention to waste as a resource with varied economic values. This latter view of waste introduces relativity into the understanding of waste as *what is waste to one person may not necessarily be waste to another.* Despite this understanding of a waste as resource, assemblies are of the view that very little of the waste generated within Greater Kumasi is actually recycled or converted to further uses or resources because of capacity constraints. As such, the former view of solid waste as a residue or discarded item that has to be disposed of dominates the thinking and actions of the assemblies.

From the institutional point of view, solid waste comprise domestic solid waste, commercial or markets waste, industrial waste and medical hazardous waste. As such solid waste management is understood to mean all the processes related to the tasks of ensuring that waste generated ends up in the landfill sites, where they are treated. These processes include waste generation, gathering, collection, transportation, recycling, disposal and treatments. To effectively manage waste within Greater Kumasi, the local authorities have adopted two main management practices for collection; door-to-door collection and communal collection. Regarding door-to-door service, local authorities have given dust bins to specified households where collecting trucks go to their homes and collect the filled-up bins on weekly or other agreed times. This door-to-door service is applicable, however, to a small section of the population, usually in the first-class residential areas and places which are properly organized as explained by an official from the WMD. For most parts within Greater Kumasi, communal bin collection is the main approach deployed by the Assembly. Here, the assemblies have created transfer stations or communal disposal sites where households, businesses, traders and others have to send their waste to for onward collection and transportation to the landfill sites. An emerging practice in most parts of the metropolis is a situation where some unlicensed tricycle operators (locally known *as Aboboya)* visits some homes and collect their waste for disposal at a fee as seen in Figure 2. This appears to be very convenient to most homes and it is also creating employment opportunities for many male youth.

The views on solid waste management as expressed by the respondents were not entirely different from those expressed in literature (Lee, 1997; Furedy, 1997; Vigso, 2004; Miezah et al., 2015). In particular, the views correspond to Vigso (2004) who defined waste to constitute non-liquid materials arising from domestic, trade, commercial, agricultural, and industrial activities and from public services. Seeing waste as both a resource and a discarded item also correspond to Furedy's understanding of solid waste as residual materials that are considered to be of no use and must eventually be disposed of typically by dumping or incarceration (Furedy, 1997). Furedy used the term *would-be-waste* to conceptually drive home her view of seeing waste as a resource with economic value.

The effectiveness of the institutional arrangements for solid waste management

Institutional arrangement for waste collection and management

Local assemblies recognize that it is their responsibility to effectively manage waste spread across their respective jurisdictions. As a key informant established, *waste in the metropolis belongs to the assemblies. And that the WMD of the assemblies are mandated to deal with it.* This recognition by the assembly is important as it provides the basis for accountability. Several departments and agencies are involved when it comes to the management of waste in Greater Kumasi. The study showed that the WMD of Kumasi Metropolitan Assembly (KMA), and the Environmental Health Departments/Units of the various districts (in this case, Asokore Mampong and Oforikrom) are the main institutions involved in solid waste management. Among other things, the main functions of these departments/units are to: (i) Keep the Metropolitan/Municipal/District area clean; (ii) develop and continuously update an environmental sanitation plan; (iii) educate the public on how to keep the local environment clean; (iv) provide conveniently situated

Figure 2. A tricycle operator collecting waste.

refuse disposal points; (v) remove solid waste; (vi) dispose of waste safely (vii) manage sludge disposal and (viii) clean and carry out routine maintenance of drains. These agencies also work with the regional office of Environmental Health and Sanitation Directorate and Judicial system (including local magistrates) who prescribe sanctions for offenders of sanitation by-laws.

According to Ogawa (2005), inefficient institutional arrangements are at the heart of the many problems related to solid waste management in Africa. Here, it is argued that the lack of coordination among different agencies responsible for solid waste management often creates gaps and negatively affects solid waste collection and management. In the case of Kumasi, although several agencies are involved, the state agencies mentioned above are not directly involved in the waste collection, disposal and management of landfill sites. Instead, all these functions have been outsourced by the assemblies to private third parties. At the time of the interview, there were six contractors who have signed concession agreements with the Kumasi Metropolitan Assembly and the Asokore Mampong and Oforikrom Municipalities. These were Kumasi Waste Management Limited, Asadu Royal Waste, V-Max and Sakkem and Antoco. The management of the landfill sites has also been outsourced to J Stanley Owusu Ltd, a private firm. Each of these firms has obtained a concession or part of the Greater Metropolitan Area where it is responsible for waste collection. As private firms, it is assumed they would be more efficient and effective. Yet as the paper shows later, this has not really been the case.

Constraints associated with waste collection and management

Waste management is still a challenge for the various local authorities in Kumasi. Interviews and observations carried out as part of the study revealed significant dispersal of uncollected waste as well as the overflow of refuse in many bin collection or transfer points. This suggests that the institutional arrangement for waste management is not as effective as expected. Interviews revealed some constraints which undermine the arrangements for solid waste management in Kumasi. These include financial or budgetary constraints, operational and logistical constraints, and local attitudes and low enforcement of regulations. In the following sections, we discuss resource allocation and related constraints.

Financial resources

The municipal authorities are faced with problems of limited financial resources to effectively manage solid waste and its related activities. The metropolitan authorities are budget constrained and, therefore, lack operational funds to support comprehensive waste management and to create an acceptable and hygienically clean environment for healthy living. Discussions with officials of the WMD of the assemblies studied were conclusive that waste management is the biggest component of the assemblies' budget. Explaining the cost involved in waste management, a key informant at the WMD of the Kumasi metropolitan assembly narrated that:

This Assembly pays the contractor a huge sum, paying like GHS30.00 per tonne of waste and we generate around 1500 t a day, so you can realize that the figures are that big. Thus, in the Kumasi Metropolitan Assembly alone, at least GHC 45000 is the average daily expenditure by the assemblies on waste management. Funding is a major challenge. We really spend a lot. We are talking about millions of Ghana Cedis here (A senior metropolitan waste management official).

This realization was not too surprising. This is because many researchers have equally found limited financial resources as one of the major constraints of solid waste management in developing countries (Ogawa, 2009; Loshe, 2003). Loshe (2003) has maintained that in so far as urban populations expand and widen, demand for infrastructure and services including waste disposal would increase to put financial strain or local authorities. From our case study, the institutional arrangement governing waste management fuels the high cost involved in waste management. Per the present arrangement, the waste collection, disposal and treatment have all been outsourced to third parties. In certain areas, the assemblies pay a fixed cost to the contractors whether they perform to satisfaction, or not. It is interesting to note that some of the contractors have been engaged by the Central Government, but are paid by the metropolitan assemblies. Consequently, the assemblies spend a significant amount of resources on some of these contractors and leave very little to support the operations of the Environmental Health Departments that undertake community education, sensitization and enforcement of by-laws.

Another revelation from the study is that part of the assemblies' budget for waste management is often misapplied as part of it is used to pay the salaries of over-staffed and unskilled or under-qualified employees as well as private waste service providers/contractors. Indeed, the authorities confirmed unfulfilled financial commitments by the metropolitan assemblies as they still owe private waste contractors substantial amount of money. This affects service delivery as contractors withhold waste collection and disposal services compounding the already existing dire solid waste management situation in the metropolis. Further evidence from the study indicates that the limited number of vehicles, supervisors and solid waste collection crews are among the major challenges to effective solid waste management within the assemblies. This is the direct result of financial constraints and probably mis-appropriation of funds within the assemblies or WMD.

Under the Ghana Environmental Sanitation Policy and its related National Environmental Sanitation Strategy and Action Plan (NESSAP), the various MMDAs are to set aside a dedicated fund purposely for environmental sanitation which will be sourced from internally generated funds (IGF), transfers from central government and donor support (EPA, 2014). The associated problem is that while the central government expects the MMDAs to use their IGFs to support sanitation services, the MMDAs rather expect the funds from the central government for sanitation activities. The result is that the fund from the central government is almost always released late and the MMDAs don't generate enough internal funds for their projects and waste management, thus compounding the financial challenges facing the MMDAs.

The study revealed that the MMDAs receive financial support from the country's development partners. Discussions with the Metropolitan authorities, for example, confirmed that the assemblies have received a number of financial and material support from Alliance Francaise de Development (AFD) and the World Bank to support the management of solid waste through the financing of nine cells at the Oti landfill site to improve the facility. However, this support has not been enough to supplement the efforts of the local government in the management of solid waste in the metropolis.

It was also mentioned that platforms which would have enhanced the assemblies' ability to source for technology and research information to improve solid waste management have not been sustained due to financial constraints. For example, the National Environmental Sanitation Conference (NESCON), the first and second conferences which were organised in 2011 and 2012 respectively to showcase cutting edge technologies and strategies to deal with the sanitation problems in the country, could not sustained due to financial challenges from the assemblies and the sector ministry that is, Ministry of Local Government and Rural Development (MLGRD). It is, therefore, apparent that the MMDAs have inadequate financial resources to support waste management activities. This constitutes one of the major challenges facing national and local authorities and partly accounts for the MMDAs inability to manage solid waste effectively and efficiently.

Attitude towards solid waste management

The interviews at the MMDAs also revealed varying views about waste, and this we consider as a reflection of socio-cultural norms, tradition and beliefs. For instance, discussions with private individual group of waste collectors revealed that to them waste is a source of livelihood. There are limited employment opportunities and, therefore, to this group of people, the more waste people generate the higher income they get from collection. Further, discussions with other stakeholders and key informants indicated that people generally see solid waste generation and indiscriminate dumping as a worrying situation which needs serious attention. Indeed, people recognize waste as a serious human and environmental issue, but the irony of this recognition and concern sadly do not stop littering of plastics and other household waste. This indiscriminate littering attitude among some residents makes it extremely difficult for the waste management authorities to improve the existing environmental sanitation situation in the Kumasi metropolis. One other observation is that some people are seen throwing out waste from both moving and stationary vehicles. Further, people dump waste carelessly and shamelessly at lorry stations, public and other unauthorized places. There is this general excuse that, there is not enough trash bins around to dump waste into but astoundingly, even in areas where there are bins people still dump their waste indiscriminately.

One major underlying cause of this attitude and behavior is the lack of effective sanctions or control systems for punishing by the local authorities. This reinforces one major observation of the study that the traditional waste management systems are malfunctioning due to rapid urbanization. The increased rural-urban migration and concentration of the population in few urban areas, particularly regional capitals and major urban service centers, have exacerbated the situation. This has eventually made solid waste management an onerous task for the local authorities to cope with.

Another important observation made in respect of changing altitudes relates to the local perception which in the past underscored that management of solid waste was the collective responsibility of central and local governments as well as the communities or the general public as a whole. However, with the creation of the WMD in the assemblies, local people have the perception that solid waste management (collection and final disposal) is the sole responsibilities of the various assembly authorities. This finding compares favourably with earlier studies (Songsore and McGranaham, 1993; Vidanaarachchi et al., 2006) which emphasize that community members generally view waste management as the preserve of the local authorities. This shows lack of concern and understanding of the link between clean environment and good health.

During the group interviews with key staff of the assemblies studied, the problem of non-participation of communities in waste management was attributed to the attitude of a section of the society who has the perception that they have no impact on the decision-making process due to their low socio-economic status in the society. They further alluded that the attitude is not the general characterization of all people but rather differs among socio-economic groups. Those who belong to higher and wealthier socio-economic groups are more likely to have a positive feeling that they can involve themselves and make a difference regarding issues on environmental problems and can do something about these problems as they have the belief that they have the means and ability to make positive impact in addressing and fixing the waste problem. The opposite is true with members of the society who belong to the lower socio-economic groups who have less regard for environmental issues and, therefore, have no concerns in helping to address relating to waste management and sanitation, but rather concentrate on immediate family needs and livelihood. This perception agrees with earlier findings of researchers who argue that people of lower socio-economic stand are more concerned with employment and housing as their main priorities than waste management and sanitation issues (Periou, 2012).

The indiscriminate dumping of solid waste and the filthy environment are not common characteristic of the general environment of the Greater Kumasi city. Solid waste is well-managed in the first class residential areas in the metropolis where rubbish bins are available and the rich and affluent people easily afford payment for frequent door-to-door collection of generated waste by private waste companies. These areas, therefore, have clean and healthy environment. The contrast was found in the urban slums and outskirts of the city, where the urban poor live. These areas were found to be filthy with accompanying unpleasant smell. This indicates a direct link between poverty and filthy environment, and poor health.

The observations above on attitudes and behavior of local people and how they impact on solid waste management are underscored in the findings of (Al-Khatib et al., 2015). The researchers assert that public littering rates are caused by lack of social pressure to prevent littering, unrealistic penalties or lack of consistent enforcement, and lack of knowledge of the environmental effects of littering.

Law enforcement and sanctions

There exist national and local environmental legislation and policy to guide and ensure an effective management of solid waste. These include: (1) The 1992 Constitution of Ghana Section 41 (k) which states clearly that it is the duty and responsibility of every citizen to protect and safe the environment; (2) Criminal Code, 1960 (Act 29) provides that whoever places or permits any refuse, or rubbish or any offensive or otherwise unwholesome matter on any street, yard, enclosure or open space, except at such places as may be set aside by the local authority or health officer for that purpose commits a punishable offence; (3) Ghana Landfill Guidelines, 2002; (4) Manual for Preparation of District Waste Management Plans in Ghana, 2002 (EPA, 2014). The problem, however, is lack of political will to enforce policies and bye laws on sanitation and this is the key challenge to ensuring sustainable waste management. This has become a major institutional hurdle that greatly contributes to the present mismanagement of solid waste in the metropolis and other urban and rural settlements in the country. There is evidence of frustration on the part of local authorities to apply the lay down by-laws relating to sanction of offenders as captured in the box below.

At the law enforcement department, our main challenge is that when we send environmental cases to court, the courts are usually not interested and hence frequent adjournments of cases. And some of our traditional chiefs too impede our work. But when we have an issue of noncompliance of sanitation law, we tell them to take (legal) action. Sometimes, we wait and nothing happens. Sometimes too, we wait and somebody else such as a politician may come and intervene on behalf of the culprit to prevent prosecution. So those are some of the issues (A Metropolitan Waste Management Official).

This is a clear case of political interference which has contributed to the disregard of the local laws on waste management in the country. Offenders are quick to take refuge in chiefs and politicians (members of parliament and the local executives of the ruling party) who intervene to set them free in order to win votes during elections. Consequently, local authorities are powerless and ineffective in the application of sanctions. This finding confirms similar studies (Zhu et al., 2008; Ogbonna et al., 2002) which concluded that lack of enforcement of waste management legislation is a major impediment to achieving effective and sustainable waste management in Ghana. It is important to note that the national capital of Accra which has established sanitation courts is still grappling with serious problems of solid waste management. Thus, all the MMDAs have sufficient legislation covering waste management, but the authorities lack the political will to enforce them. The results are the unregulated rubbish dump and improperly discarded waste.

Additionally, the finding supports the view that in most situations, the heart of the problem with effective solid waste management in the developing countries is not the environmental legislation itself as some of these countries have more refined legislation than developed countries. The real problem, however, is the lack of enforcement of policies and laws which is a major institutional challenge that greatly contributes to the poor and ineffective management of solid waste in the urban settlements in the developing world. A case in point is Kenya where there exists sufficient legislation covering waste management, but local authorities lack the capacity to implement them (Ogawa, 2005; Al-Khatib et al., 2015).

Policy implementation

A review of policy documents on sanitation shows that broadly, Ghana has an Environmental Sanitation Policy with an associated NESSAP aimed at achieving filth-free and healthy environment with particular reference to the sanitation sector. This is a well-thought and laudable proposal on waste; *materials in transition (MINT)* have been greatly emphasized in both documents. The overall objective is to promote re-use, recycling and recovery of solid waste to create a more effective method from the current generate-collect-and-dispose philosophy. This noble idea is also expected to substantially cut down the operational cost of managing waste by MMDAs. Unfortunately, the ideas contained in this well-thought out document continues to gather dust as this policy is yet to be implemented. Thus, the ideas and plans to help effective waste management are in existence but poor or delayed implementation is not helping the cause. This observation may support the assertion that the range of waste management services is limited because waste management does not constitute a major priority for policy makers and planners (Henry et al., 2006).

This should not give the erroneous impression that the central government is unconcerned with general waste issues in the MMDAs and of course all other places in the country. Under the NESSAP programme is the proposal for the establishment of courts to deal specifically with sanitation offences. As a follow up of this proposal, eleven of such sanitation courts were established in the national capital of Accra only in the year 2010, sadly leaving the other major cities and towns. As at the time of this study, the other major settlements are yet to benefit from similar sanitation courts. Unfortunately, the purpose and impact of the sanitation courts are yet to be seen and felt as people are not deterred by the courts and Accra continues to be engulfed with more filth characterized by littering along the streets and choked gutters. The situation of littering still goes on unabated in the study metropolitan assemblies and their immediate environs and this could be attributed to delayed or poor implementation of policies on management of solid waste in the country. This calls for a very concerted action on implementation of policies on sanitation and solid waste management.

Human resources

Human resources relating to skilled manpower and technical know-how for waste management are either limited or, in some cases, totally lacking in the metropolitan assemblies covered under the study. The study has identified unskilled workforce as one of the major challenges facing local authorities in the management of solid waste. This situation of inadequate man-power has forced the metropolitan authorities to sometimes take ad hoc measures in the handling of solid waste which eventually become regular and permanent system of managing of solid waste.

Some of the waste management officials responsible for handling the complex issues involved in waste management have limited or no technical training in waste management. Further in-depth discussions with some key stakeholders revealed that more often than not, some of the waste management staff are employed based on their political affiliation to the party in power. The ruling party gives employment to these unskilled party followers as *thank you* and in exchange for their continuous votes during local and general elections. This situation makes it difficult to provide such people with the needed technical assistance. Relatedly, the study reveals that, in addition to the problem of unskilled manpower, workers of waste management generally have low social status and some of these workers are people from a specific social stratum. The self-employed young men who use tricycle known locally as *aboboyaa* to collect and dispose of garbage are mostly unsupervised and this compounds the indiscriminate dumping of solid waste. Of course, the local authorities do not have official contract with this group of individual solid waste collectors. Extra manpower hired from private waste companies to provide additional waste collection services are not frequently monitored. Generally, there is lack of or limited monitoring and evaluation of waste collection and disposal in the metropolitan assemblies.

Many researchers have argued that the absence of comprehensive waste management planning in developing countries is the direct result of lack of capacity with regard to the human resources available to manage solid waste (Marshall and Farahbakhsh, 2013; Schübeler et al., 1996; JICA, 2005), and findings of this study gives a true reflection of the assertion. This study further reveals that, there is general absence of actual quantitative statistical data on the actual volume of waste generation and production within the metropolitan assemblies which would have formed the basis for predicting and planning for quantity of future waste generation and its management. As indicated earlier, this is the result of lack of regular and inefficient monitoring and evaluation which makes it difficult for local authorities to keep abreast with changing trends in consumption and waste generation. This is an indication of inadequate organisational capacity in metropolitan and municipal solid waste management.

This finding also confirms earlier studies (JICA, 2005; Zurbrugg, 2002) which concluded that, the collection and analysis of solid waste data are generally not given sufficient attention by waste management authorities in developing countries. This study also shows inadequate development programmes for human resources. Consequently, there are limited opportunities for waste management administrators to gain the needed experience and become experts and to formulate and implement waste management plans that are tailored to the actual situation.

Logistics and service operation

One key contributing factor for achieving efficiency in solid waste management is the availability and sufficiency of the needed logistics. Unfortunately, this is not the case with the MMDAs in the country. The metropolitan authorities are struggling to cope with the problems of inadequate operational and maintenance culture. The WMD do not have adequate logistics relating to vehicles, garbage bins and communal dumps among others as seen in Figure 3. The identified problems also include weak waste transportation system that includes inadequate waste collection trucks most of which have broken down due to lack of routine maintenance. There is also the problem of inadequate supply of garbage containers and limited number of communal dumping sites with skips, and poor roads to landfill sites. The standard of skip ratio per population is estimated to be 1:700 but the indication is that the current skip ratio in the metropolis is far below the acceptable standard. The end result is the provision of inadequate services, operational inefficiencies, and limited coverage of garbage collection, indiscriminate disposal of waste and increasing pile of waste in the study area. This situation of inadequate logistical support has compelled the city authorities to centralize resources in the affluent areas of the city where the rich residents can afford payment for waste collection services.

This finding confirms that of studies which concluded that in the developing countries, only a limited part of the urban population generally receive services under municipal and metropolitan solid waste collection schemes, and that the people remaining without waste collection services are usually the low income population living in urban and rural areas (Al-Khatib et al., 2015; Vidanaarachchi et al., 2006).

Insufficient facilities has left the metropolitan authorities with no option but to contract the services of private waste companies to supplement their efforts and to close the logistical gaps in solid waste collection and disposal and ultimately the overall management of solid waste and disposal. Unfortunately, most of these companies are not very effective in solid waste collection and disposal than the local authorities. Moreover, it is often difficult for the assemblies to exert full control over the outsourced services from these private waste contractors due to their own operational deficiencies.

Figure 3. Picture of a communal waste dumping site in the Oforikrom Municipality.

The assemblies' main mechanism for dealing with these constraints includes continuous dedication of budget for waste management, reviewing performance of contractors, community education and sensitization. However, judging by the amount of uncollected waste within the study area, these mechanisms can be said to be ineffective.

Public education on waste management

Lack of education and public awareness of effective waste management practices have been identified as one of the key challenges facing local authorities. Indeed, appropriate strategies to achieve reduction in indiscriminate disposal of solid waste in the Kumasi city area include education and awareness programmes. Education at all levels is an important starting point in practical, effective and lasting municipal solid waste management.

Inferences drawn from separate discussions with local authorities and key informants are that there has not been extensive public education and awareness creation of the negative implications of indiscriminate waste generation and disposal on human and general environmental health. This is indispensable for a truly effective community cooperation and partnership in solid waste management. The discussions further revealed that the local authorities spend substantial part of their budgetary allocation on waste management to help keep a clean and healthy environment. Ironically, it is considered by some people as misapplication and, therefore, a waste of funds. They would have preferred that city authorities rather use the money on other activities or projects as remarked by a management official below.

It is a big challenge. Sometimes the assembly undertakes public engagements and we tell them we are spending so much in terms of waste management. They themselves think it is waste of money. They would rather prefer you build a hospital, school or something else; but for you to spend it on waste, they don't get it. So all those attitude is a problem. And you don't manage waste with zero resource or zero capital.

This is clear indication of ignorance and lack of public knowledge and understanding of the direct linkage between filthy environment and good human and environmental health. This may help to partly explain the apathy and the very low-participation of people in waste management activities.

The above community perception could also be explained in relation to social problems, such as unemployment and poverty which are inextricably linked to solid waste management. Indeed, some city authorities indicated that the urban poor and other low-income people in the city are more often than not concerned with their immediate needs and livelihood but not the quality of the environment and related issues. They further said that the urban poor in particular will be interested and willing to participate both directly and indirectly in waste management, for example recycling of waste activities, if it will earn them some income as a livelihood option. In addition, some respondents emphasized that this attitude and lack of interest in ensuring clean environment creates a culture of non-participation of communities in decision-making involving solid waste management. This may lead to a situation which enhances lack of community responsibility for pollution and waste issues and eventually create communities that have little or no knowledge of, and concern for their impact on the environment.

Therefore, education and awareness creation among stakeholders is considered very necessary and should be led by the metropolitan and municipal authorities in charge of management of solid waste, environmental and other professional health officers generally.

Conclusion

The overall objective of this study was to examine the key factors that underlie effective solid waste management in the urban areas in Ghana using Kumasi, the Ashanti regional capital and the second largest city of Ghana, as a case study. Results from this study have shown that solid waste management is a major problem which the city authorities are grappling with. Generally, there is inadequate management expertise, lack of practical or technical know-how and inadequate infrastructure for disposal of the increasing volume of solid waste. The assemblies spend huge sums of monies to manage solid waste and this is diverting limited resources needed for other development projects. Solid waste management in the city was found to be inefficient and therefore very expensive for the city authorities to finance.

The study also concludes that attitudes and behavior of local people, absence of social and environmental awareness, and lack of institutions promoting sustainable actions in waste management are key factors that underlie effective solid waste management.

Faced with limited financial resources, the local authorities' policy initiatives should be more towards education, workable sanctions and enforcement of bye-laws on solid waste management. In this respect, there is a need for effective collaboration among government and private agencies to ensure effective and workable management practices.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Household perception and willingness to pay for improved waste management service in Mamfe, Cameroon

Veronica Ebot Manga[1]*, Oru Thompson Oru[1] and Martin Ngwa Ngwabie[2]

[1]Department of Environmental Science, Faculty of Science, University of Buea, Cameroon.
[2]Department of Agricultural and Environmental Engineering, College of Technology, University of Bamenda, Cameroon.

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Lack of financial resources and public participation are major factors that constrain solid waste management in many towns in developing countries. This study sought to determine the willingness to pay (WTP) and the perception of the inhabitants of Mamfe, Cameroon for an improved solid waste management system. A total of 371 households were interviewed and data analysis to identify the determinants of WTP values was performed using multiple regression models (Probit and Tobit) and Contingent Valuation Method. Approximately 95.1% of the residents were concerned with the problems of solid waste management. 51.5% were satisfied with the present environmental conditions; with 74.5% of the opinion that water pollution caused by poor waste disposal presented the most serious environmental problem. Most of the respondents (85.1%) showed a positive attitude towards WTP for an improved solid waste management system. The monthly mean WTP was 1000FCFA ($1.73) per household and the annual WTP was approximately 180 million FCFA for the entire town. Regression analysis revealed that age, employment type, gender and income of the respondent have a significant relationship with willingness to pay at p<0.05. The trend of WTP and income variables (income and type of employment) was negative and significant implying that this payment could be afforded by a cross section (low, middle and high-income levels) of the population.

Key words: Cameroon, contingent valuation method, household, perception, solid waste management, willingness to pay.

INTRODUCTION

Pacione (2005) alludes to the fact that the provision of waste management services in any large city is an expensive undertaking that makes huge demands on the finances of local governments. Apart from making investments in capital equipment, money is also required for the day to day operational cost of the service in the procurement of fuel, spare parts and working gear (Boateng et al., 2016). Cameroon is ranked in the 144th position out of a total of 177 countries and it is one of a group of 20 countries for which the Human Development Index (HDI) worsened between 1990 and 2006 (UN 2006). Cameroon only achieved one of the seven goals

*Corresponding author. E-mail: ebotmangav@gmail.com.

on target: access to improved safe water (Parrot et al., 2005). The nation is considered a lower middle-income country with a gross national income per capita of US$1,320 in 2015, compared to an average of US$1,628 for all sub-Saharan African countries. The minimum wage is approximately FCFA 36 000/month or $72 (National Institute of Statistics, 2018) with 37.5% of the population living below the national poverty line, and 27% below the international poverty line of US$1.90 per day (World Bank, 2017). Most of the population have limited access to sanitation services, especially the poorest who live in areas with little infrastructure. Concerning the disposal of solid waste, the government covers 85% of the financial costs for the management of solid wastes for the major cities (most of them serving as regional headquarters) from the state budget and the Councils cover the remaining 15% (Ymele, 2012). This policy further deepens the spatial disparities between urban and rural areas. It is common for both residents and Council authorities in towns to dump waste of all sorts into roadsides, vacant lots, marshlands and water courses. This practice is associated with unsustainable and unplanned urban development and can give rise to air pollution, water pollution, poor sanitation and housing-related health risks. Uncollected and illegally or improperly disposal of wastes poses serious risks to public health and the environment (Wilson et al., 2003; Olley et al., 2006).

Previous studies on waste management in Cameroon have focused on technical aspects such as collection, treatment, disposal practices and their environmental implications (Vermande and Ngnikam, 1994; Ngnikam, 2000) and the legislative and regulatory aspects (Manga et al., 2008); with little attention on the financing of solid waste management. Municipal solid waste management is financed from three principal sources; taxes and revenues generated by Council activities, supplementary budgets from the state and lending facilities from the Government's Council Development Fund (FEICOM) (Manga et al. 2008). Nationally, there is very little exploitation of alternative sources of financing.

Public and private partnerships offer interesting alternatives to MSW services, particularly in terms of innovation (Ahmed and Ali, 2006). Non-governmental organizations (NGOs) and Community-based organizations (CBOs) operate in the informal sector and considerably alleviate the burden of the urban poor in African cities. They also operate in areas where the official operators do not have access because of poor road conditions. In a report on livelihood, the National Institute of Statistics remarked that there is an opportunity for NGOs and CBOs to implement garbage collection and transfers to garbage bins operated by the official operator Hygiène et Salubrité du Cameroun (HYSACAM) (INS 2002). Parrot et al. (2009) investigated some public-private partnerships in urban solid waste management in the city of Yaounde, Cameroon.

According to Parrot et al. (2009), the main waste service provider to the Yaounde Urban Council, (HYSACAM), signed limited official public-partnership with some small NGOs and CBOs (TAM–TAM mobile, GIC–JEVOLEC, ERA–Cameroon and Sarkan Zoumountsi) for the pre-collection of wastes from selected, mostly upper class neighborhoods. The authors report that some of these collaborations proved to be fatal in the long term mainly as a result of lack of funding, high membership costs and mis-targeted areas. Mckay et al. (2015) identified inadequate organizational structure; poor logistical support; lack of capital and technical expertise; inhibiting government policy and regulations; as well as low levels of awareness and education at the household level as the main inhibitors of growth in this sector. Mbeng et al. (2009) in their study reported that although information and awareness campaign are important drivers to behavior change in waste management, these do not necessarily translate into an increased participation in recycling or reuse initiatives because other factors such as economic incentives can hamper participation rate. These studies have so far, explored issues related to the participation of the private sector and public attitudes and awareness in the solid waste sector; they do not however address residents' willingness to pay (WTP) for solid waste management. The current study seeks to determine households' perception of solid waste management and the willingness to pay (WTP) using the contingent valuation method (CVM). This study carried out in Mamfe town (Cameroon) is of significance to towns with limited budgets that are interested in exploring user fees as sources of financing for SWM services under current privatization policy.

CVM uses survey questions to elicit people's preferences for non-market goods by asking them how much they would be willing to pay for specified improvements or to avoid decrements in them (Mitchell and Carson 1989). In its simplest form, the respondent is offered a binary choice between two alternatives, one being the status quo policy and the other alternative policy having a cost greater than maintaining the status quo. Debate over this method lies with issues linked to validity and measurements (Carson, 2000). However, despite these shortcomings, CVM has in recent years been extensively used in both developed and developing countries for valuation of a wide range of environmental goods and services (Whittington, 2002). Examples of recent application of CVM for solid waste-management services in developing country contexts include Niringiye and Omortor (2010), Wang et al. (2011), Amfo-Out et al. (2012), Ezebilo (2013), Addai and Danso-Abbeam (2014), Boateng et al. (2016). In these studies, the socioeconomic and contingent variables found to influence household WTP for solid waste management included the payment amount, age, income, household size, occupation, dwelling type and educational level.

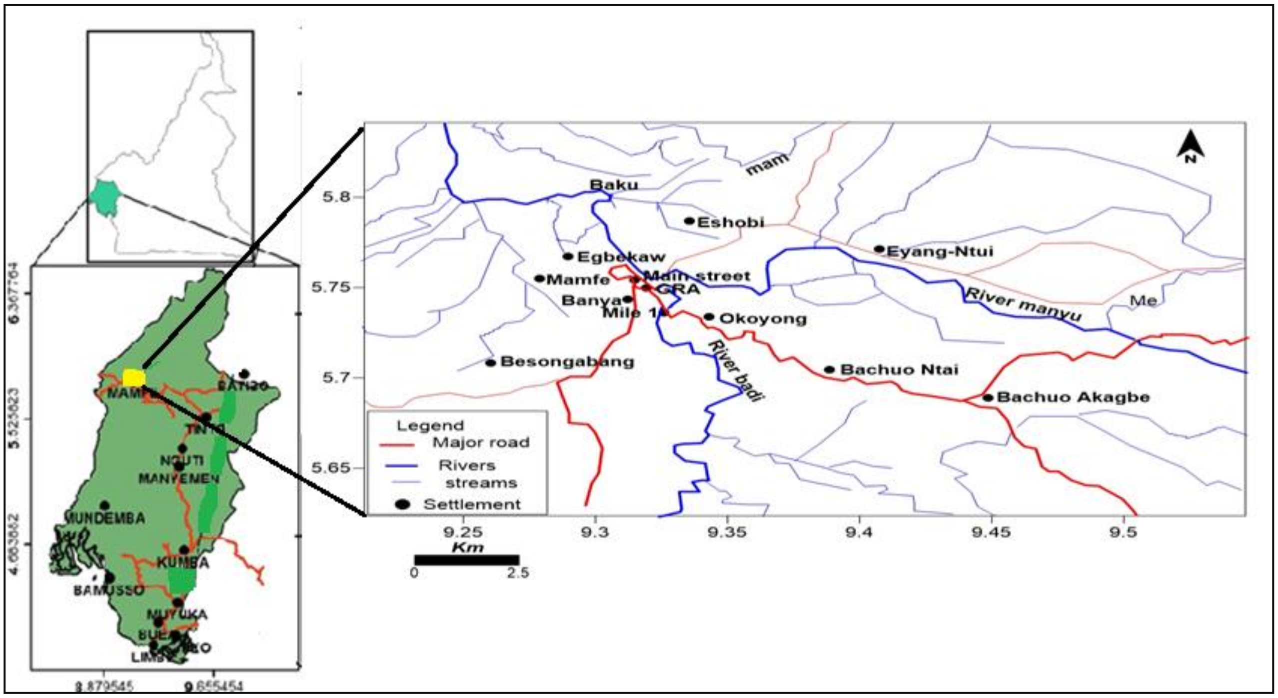

Figure 1. Map of Mamfe, Cameroon.

Addai and Danso-Abbeam (2014) used CVM to predict the determinants to pay in Dunkwa-on-Offin, Ghana. The results of the study reveal that willingness to pay for improved solid waste management is significantly related to level of education, gender, household size and age of the household head. Niringiye and Omortor (2010) in their study of the determinants of willingness to pay for solid waste management in Uganda, using the CVM, found that age influences willingness to pay.

MATERIALS AND METHODS

Study area

Geographically, Mamfe is situated at latitude 5.76° N, and longitude 9.28°E (Figure 1). Climatically, it is dominated by the Equatorial climate with high rainfalls (3500-4000 mm) and high temperature (30 -32°C). Mamfe is the capital town of Manyu Division in the South-West Region of Cameroon. It is richly watered by River Manyu with its tributaries at River Baku and River Badi which serves as the fishing ground and major travels roads from the town to Nigeria.

Mamfe is a traditional town characterized by the convergence of surrounding (indigenous) villages linked to the main urban center by new settlements with a population of 60,000. Arrey (2005) in a study carried out within the Mamfe Council (Mamfe Rural Council Monographic Study) classified the town into three sub-areas on the basis of commercial versus residential activities, years of existence and income levels. The three delineated areas are mixed in terms of income groups. For example, there are some households of high-income neighborhoods in the 'indigenous' part of the town, as well as individuals of low-income neighborhoods in the 'government residential area' part of the town.

Research design

The research adopted a mixed triangulation design. Stratified, purposive and random sampling techniques were used to select households for this study. Both primary and secondary data sources were used. Questionnaire survey, interviews with key personnel and observations were the main tools for data collection. Both qualitative and quantitative methods of data analysis were considered. Qualitative data played supplementary role and content analysis of the ideas, opinion, and concepts of data were considered. SPSS Version 21 was used for quantitative analysis of data. Contingent valuation method was employed to elicit household's willingness to pay for the proposed improvement in solid waste management service. With an estimated total of 15,000 households, and on the basis of Yamane (1967)'s sample size formula, a sample size of 377 households was selected for the survey. Household selection was a multi-stage process beginning with stratification of households into three socio-economic strata: high, middle and low-income groups based on the neighborhood. This activity was facilitated by exploiting a spatial economic zoning established by the Council (Arrey, 2005). A purposive sampling based on the standard of housing infrastructure was used to delineate income levels of households within the different income zones.

The data collection was made by hand-delivered questionnaires. Pre-test surveys were conducted in April in 10 randomly selected households in a town outside the study area. People who had no formal education were interviewed based on the questions in the questionnaire, while people who had formal education were handed a copy of the questionnaire (which were filled in the presence of survey assistants). The focus groups, personnel of Waste Management Board (the Hygiene and Sanitation Department authorities of Council) and those involved during the pre-test surveys contributed in the development of questions that were used during the main survey. Following the pre-test surveys, some questions in the questionnaire (e.g. presentation format for the valuation question and independent variables) were adjusted to reflect the concerns raised by survey assistants and respondents. The main survey was conducted during the months of May and June 2017.

Willingness to pay questions

The CVM was used to quantify each household's decision on whether or not to purchase an improved provision of solid waste management services. CVM is a type of stated-preference approach that employs a hypothetical market system to extract WTP or willingness to accept environmental goods (Carson, 2000). The single-bound Dichotomous CVM was used to acquire the necessary data for both WTP and the associated specific amount to pay.

With the understanding of the market scenario, the respondents were first asked if they will be willing to pay anything for the improvement scenario presented. The response was either 'yes' or 'no'. If the respondent answered "no", they were asked to give reasons why they were not willing to pay for the improved service and to state how they will properly manage their waste such that it will not lead to environmental damage. A 'yes' response to the participating question was followed by the selection from a list of monthly amounts they were willing to pay; (1) 500-1000 FRS; (2) 1000-1500FRS; (3) 2000-4000 FRS; and ≥5000 FRS. This was followed by selection of options relating to time and frequency of collection. The final question for those who answered 'yes' was to state the maximum monthly amount they will be willing to pay based on their selected options in the later. Respondents were then asked to state the maximum amount service charge (per month) they were willing to pay to solve the household solid waste problem**.**

The respondents were asked a series of questions relating to their perception of problems of solid waste and socio-economic status (educational level, income, age, gender, house ownership and other socio-economic determinants). The respondents were asked about their participation in sanitary campaigns and environmental concerns. Incorporation of individuals' socio-economic variables into the CVM helped the researchers to gain information on validity and reliability of the CVM results and increase confidence in the practical application of results obtained from the CVM empirical analysis (Haab and McConnell, 2002).

The empirical strategy

The main purposes of this study were to assess the residents' willingness to pay for improved solid waste management, the amounts and obtain the determinants of WTP. In this regard, the issue involved ''yes'' or ''no'' response, on one hand, and the elicitation of specific monetary value for the yes responses; on the other hand the calculation of mean WTP and the estimation of a parametric model that includes respondents' socioeconomic factors in the WTP function. Two models, that is Probit and Tobit were used to analyze the WTP of household. Firstly, since we do not know the random part of preferences and can only make probability statements about "yes" or "no", we used the Probit model to estimate the probability of WTP. Secondly, since the nature of the decision problem for determining the WTP is unknown, the Tobit model was used to identify the factors that determine how much the respondents were willing to pay for improved waste management services study.

Probit model

Despite its shortcomings, this model was found useful in this study, since it was aimed at providing information to policy makers on the possible interventions derived from the findings (1-3).

$$Yi^* = Xi\beta + \boldsymbol{\varepsilon}i \quad (1)$$

Where $\boldsymbol{Y}\mathbf{i}^*$ is the unobserved dependent variable. β is a parameter of the model (the intercept and coefficients), Xi is an exogenous set (independent) explanatory variables and εi is the error term, whereby:

$\boldsymbol{\varepsilon}i \propto \mathbf{N}\ \{0,^2\}$

If an individual household i is willing to pay, $\boldsymbol{\gamma}\mathbf{i}$ = 1 and otherwise $\boldsymbol{\gamma}\mathbf{i}$ = 0 (zero).

Mathematically, this is given by:

$$\mathbf{Yi} = \begin{cases} \mathbf{1}\ \boldsymbol{if}\ \boldsymbol{Yi} = \mathbf{1}\ (\boldsymbol{household\ WTP}) \\ \quad \mathbf{0}\ \boldsymbol{otherwise}, \end{cases} \quad (2)$$

When $\boldsymbol{Y}\mathbf{i}$ * = 1 then $\boldsymbol{\gamma}\mathbf{i}$ = 1 implying the specific household is willing to pay a positive price for the service. This probability that a household would be willing to pay can be estimated by the Probit model below:

$$\mathbf{Prob\ (Yi = 1/X) = (2\boldsymbol{\pi})\ ^{-1/2}exp\ (-(\boldsymbol{\beta}Xi)\ ^2/2)} \quad (3)$$

Where; Yi is the dependent Variable (willingness to pay) taking a value of 0 or 1.

Two categories of respondents were identified in terms of MWTP values. The first category included respondents that: - (i) were not satisfied with the current SWM services, (ii) considered SWM to be the responsibility of the government authority and (iii) had low income; and were expected or assumed to offer zero value for improved SWM. The second category included those that were (i) satisfied with the current SWM services, (ii) aware of the SWM system in place and, (iii) in the high-income bracket; and were expected to offer positive roughly distributed values. Since, the dependent variable (MWTP value), was not totally observed (it is censored at zero) and an OLS (ordinary least squares) estimator cannot be applied, a Tobit model for the observed MWTP was employed (Hagos et al., 2012).

Tobit model

The Tobit model identifies the factors that determine how much the respondents are willing to pay for improved waste management services. Tobit model for the observed maximum willingness to pay (MWTP) is given in terms of an index function (4-6):

$$\gamma i = \alpha + X'\beta + \boldsymbol{\varepsilon}i \quad (4)$$

That is,

$$MWTPi^* = \alpha + X'\beta + \boldsymbol{\varepsilon}i \quad (5)$$

$$MWTPi = MWTPi^* \text{ if } MWTPi^* > 0$$
$$= 0 \text{ if } MWTPi^* \leq 0 \quad (6)$$

Where: $\boldsymbol{Y}\mathbf{i}$ (MWTP*) is the dependent variable. In this case, it captures the respondents' unobserved maximum willingness to pay for improved solid waste management; MWTPi is a household's actual maximum willingness to pay for improved solid waste management; X' is vector of independent variables; β is vector of coefficients; α is the intercept; and εi is disturbance term, which is assumed to be normally and independently distributed.

Assuming that there is a perceived utility ($\boldsymbol{\gamma}$i) for paying for improved waste management services, and, a utility (0) for not paying for improved waste management services, β is vector of coefficients; α is the intercept.

MWTPi = α + β1age + β2 gender + β3income + β4education +

Table 1. Correlation matrix between independent variables.

Variable		Age	Educational level	Type of employment	Income	Gender
Age	Correlation	1	-0.54	-0.272**	0.319**	-0.161**
	Sig		0.125	0.00	0.00	0.003
Educational level	Correlation	-0.54	1	-0.089	0.132*	-0.40
	Sig	0.125		0.104	0.015	0.466
Type of employment	Correlation	-0.272**	-0.089	1	-0.540**	0.079
	Sig	0.00	0.104		0.00	0.147
Income	Correlation	0.319**	0.132*	-0.540**	1	-0.129*
	Sig	0.00	0.015	0.00		0.011
Gender	Correlation	-0.161**	-0.161**	0.079	-0.129*	1
	Sig	0.003	0.003	0.147	0.011**	

*Correlation is significant at the 0.01 level (2-tailed); ** Correlation is significant at the 0.05 level (2-tailed).

β5household-size+ β6type of house + β7house-ownership+ β8location+ β9sanitary inspector+ β10trust + εi

(if MWTPi* > 0 = Otherwise (if MWTPi*≤ 0). (7)

Before the Probit model was applied to analyze the effect of explanatory variables on WTP, a correlation matrix of the independent variables was analyzed to test for the occurrence of multi-collinearity among the exogenous variables. Multicollinearity is a serious problem when correlation coefficient is 0.8 (Gujarati and Porter, 1999). Begum et al. (2007) argue that a multiple regression model with a correlation coefficient greater than 0.70 among any two variables shows best in multi-collinearity. The correlation between the variables did not exceed 0.8 (Table 1). This shows that multicollinearity and collinearity are not serious problem in the estimated model. Adjusted R^2 values and F-tests have been tested for examining the theoretical validity of the CVM bids (Sumukwo et al. 2012).

Choice of variables

The variables (Table 2) used in the Probit and the Tobit models were based more on related studies by researchers as follows:

(i) Income. This variable refers to the monthly money income of the household in terms of franc CFA. It includes the income of the head of household from all sources. There is a general agreement in environmental economics literature on the positive relationship between income and demand for improvement in environmental quality (Afroz et al., 2009). There are many studies which have found that income is positively significantly related to the WTP for improved SWM services (Padi et al., 2015; Maskey and Singh, 2017). Therefore, we expected the income to affect the willingness to pay and its amount positively.

Like any other environmental and public good, whether households are willing to pay or not for an improved solid waste disposal, they are expected to be affected by various factors. Some of these factors with their prior expectations are defined as follows:

(ii) Age of the respondent. This variable refers to the age of the respondent in years. It is expected that the age of the respondent will affect the willingness to pay negatively. This is because older citizens because of their age make more mature decisions related to evaluating health and environmental issues (Afroz et al., 2009).

(iii) Educational level of respondent: It is hypothesized that education increases the individual's awareness and knowledge of the consequences of improper solid waste management. Thus, it is expected that the longer time in formal schooling (years), the more individuals will be willing to pay for improved waste collection and disposal. As such, educated will positively affect WTP (Sumukwo et al. 2012).

(iv) Households' size. This variable refers to the number of individuals in the household. In larger household members are more aware of the risk involved with unhygienic practices and thus crave for a better service by being more willing to pay for improved service (Hago et al., 2012). It is also expected that with more people in the household, there is likelihood for shared responsibilities in executing domestic tasks and solid waste management, rather than paying the Council to clean the environment.

(v) Household ownership. Individuals living in their homes would like to ensure that their surroundings are clean; this will improve the value of their property. This is in contrast with those renting who do not have any such interests. As a result, it is expected that those living in their own houses will be more willing to pay for the improvement as compared to their tenants (Hagos et al., 2012).

(vi) Type of house: This refers to the housing type in terms of housing units and physical space. It is a variable that is sometimes used to assess the physical space available to households. WTP is expected to be higher for those who live in confined area like flats/bungalows with limited compounds compared to those living in detached houses with compound.

(vii) Type of employment: This variable is based on the employment status (employer) and connotes aspects on the reliability of income. It is expected that households with more secure employment will show higher WTP for services; therefore, WTP decreases with employment status (lower security). This variable is intricately linked to household income.

(viii) Sanitary inspector: WTP for improved waste is expected to be positive for those in areas with no environmental inspector and negative for those in areas with the presence of environmental inspector.

Table 2. Description of explanatory variables used in this study.

Variable	Description	Unit of Measure
Gender (Nominal)	Gender of household head	(i) Male (ii) Female
Age (Ordinal)	Age of household head	(i) <25years (ii) 26-35 (iii) 36-45 (iv) 46-55 (v) ≥56years
Education (Ordinal)	Educational level attained by household heads	(i) Primary school (ii) Secondary school (iii) High school (iv) Post high school
Income (FRS/CFA) (Interval)	Total average monthly income of household	(i) <20,000 (ii) 21,000-50,000 (iii) 51,000-100,000 (iv) 100,001-250,000 (v) ≥250,000
Type of employment (Nominal)	Employment type of household heads	(ii) Government official (ii) Private official (iii) Farmer (iv) Businessmen (v) Retired (vi) Students
Household size (interval)	Total number of members currently residing in the house	(i) 1-2 (ii) 3-5 (iii) 6-8 (iv) >9
House ownership (Nominal)	Ownership of currently resided house	(i) Owned (ii) Rented
Type of house (Nominal)	Type of housing unit	(iii) Flats/bungalows (no compound) (iv) Detached with compound

(ix) Trust: This refers to trust developed between individuals and institutions, in this case 'Mamfe Council' which is the service provider. It is a variable that capture the community perception of the level of confidence they have for the service provider. It is expected that, the WTP will be positive for those household who trust in the reliability of the service provider and negative for those who do not.

RESULTS AND DISCUSSION

Socio-economic characteristics of the respondents

After eliminating missing or inconsistent answers to valuation questions, 371 (98.9%) responses are considered valid representative sample for Mamfe residents' population. The sex distribution of the sample is 56.9% females and 43.1% males. The age group with the highest frequency is 36-45 years, that is, 28.5% of the respondents, while those above 56 years account for 9.4%. The mean age of the respondents is 39.5 years. This implies that respondents are economically active and are able to earn more income. This can influence their decision to pay for an improved waste management service. Most of the respondents have attained the secondary school level of education. This implies that majority of the respondents have acquired basic educational knowledge, a factor that can influence their WTP. Income generated by most Mamfe residents is either through employment in the formal or business sector, with a mean income class of 50000-100000 FRS. This illustrates the huge gap in income with only 10.5% of the population in the high-income bracket. In terms of employment, the business sector is the highest (30%) followed by the government and the private sector (17.5 and 19.1% respectively) with the least being students and retirees (4.3 and 4.9% respectively). Over 70% of the respondents live in detached building (with compound) with close to 50% ownership. The household size with the most frequency (45.8%) is 3-5 persons.

Public perception of the local environment

The environmental quality of an urban landscape can portray the level of public environmental awareness of a community. Public awareness reflects many aspects of environmental status, such as people's knowledge, personal consideration and behavior, public capacity, and the local citizens' attitude towards sustainable society as a whole, etc. (Song et al., 2016). Over ninety percent (95.1%) of the respondents are very much concerned about the problems of environmental degradation; the illegal dumping of waste in streams, roadsides and gutters, and some of the health diseases that may come from poor waste management such as malaria, typhoid and cholera. However, only 51.5% of the respondents are satisfied with the current environmental situation of the town. Considering that only the HIRA currently receives some level of service (about once in two months); this level of satisfaction is quite high. Similar surveys in Ningbo, Quingdao, Zhuhai, Macau and Dalian city of mainland China showed satisfaction rates of 49.9, 72, 83.8, 92.4 and 95.5% respectively (Song et al., 2016). Concerning participation in environmental activities, 88.6% indicate that they have participated in one or two environmental activities organized by the Ministry of Environment on national environmental day and the usual "Keep Mamfe Clean" which holds every first Thursday of the month. Approximately, 74.5% of the respondents are of the opinion that water pollution poses the most serious environmental problem. With regards to their participation in waste separation, 73.1% indicated they are willing to sort waste at home if the government required them to do so.

Willingness to pay

Most of the respondents (85.1%) indicate that they are willing to pay some amount of money in the contingent market. For the 14.9% respondents who state that are unwilling to pay anything, 41% (23) indicate that they could not afford to pay, 36.4% are of the opinion that waste management is the responsibility of the government while 21% (12) do not consider the service important enough to pay for it. This supports the findings of Wang et al. (2014) and contradicts the findings of Seth et al. (2014) in which 62% of the respondents were unwilling to pay.

With regard to the valuation question, the response for the willingness to pay at each bid level ranges from 500 FRS to ≥5000 FRS per month (Table 3) with the majority (45.2%) of the respondents choosing the bid 500-1000 FRS while 7.7% selected the ≥5000 FRS bid. These chosen bids represent the minimum expected WTP of the respondents. The mean bid amount is 1000 FRS (with a 95% confident interval of 750 FRS and 1500 FRS representing the lower and upper limits respectively; approximately US$1.73: current exchange rate). This amount is comparable to those reported in previous studies, $1.98 in Ilorin (Ezebilo, 2013). The mean bid represents 1-2% of the respondents' mean income (50,000-100,000FRS bracket); higher than that obtained for Ilorin, 0.83% (Ezebilo, 2013). This percentage is still higher (2.8%) relative to the minimum wage of 36,000 FRS/month.

A validation question was asked to investigate the validity of households' WTP bids and their respective maximum WTP value; the results show that 6.3% of the households are not ready to contribute above what they bided. Nearly all the respondents (93.7%) expressed WTP response uncertainty (that is, they were WTP more than their maximum bids when prodded further and hence expressing uncertainty on their initial maximum WTP amounts). When expanding the samples to all households in Mamfe, using the total population of 60,000 inhabitants with a mean number of 4 people per household, the estimated number of households stands at 15,000. It can be deduced that the annual WTP value is approximately 180 million FRS /year. This projected value can be used as reference values to design a conservative payment scheme and determine the total available finance for a solid waste management system.

Factors determining willingness to pay

The Probit regression results of factors influencing households' WTP for improved SWM are presented in Table 4. The estimation result shows the likelihood ratio chi-square of 143.2(df=11) with a p-value of 0.008 meaning that the joint significance test of all variables in the model is significant at 5% level. This implies that the variables correctly predict the model. The Probit regression gave a Pseudo R-squared of about 0.6572, suggesting that approximately 65.72% of the variation in WTP is explained by the explanatory variables. This is an indication that the estimated Probit model has integrity; it is appropriate and is generally good. The validity of the Probit model in estimating households' WTP is in line

Table 3. Distribution of responses by bid amount.

Bid (amount in francs)/month	''Yes'' votes	Percentage
500-1000frs	140	45.2
1000-1500frs	79	25.5
2000-4000frs	67	21.6
≥5000frs	24	7.7

Table 4. Probit results for willingness to pay determinants.

	Parameter	Coefficients	S.E	Z	Sig.	95% Confidence interval	
						Lower bound	Upper bound
Probit	Age	0.038	0.059	0.646	0.004*	-0.077	0.153
	Gender	-0.010	0.121	-0.080	0.014*	-0.247	0.227
	Trust	-0.011	0.091	-0.123	0.902	-0.190	0.168
	Location (Residential area)	0.181	0.080	2.265	0.024*	0.024	0.338
	Number of persons living per household	-0.087	0.073	-1.194	0.233	-0.229	0.056
	Type of employment	-0.034	0.037	-0.918	0.059*	-0.106	0.038
	Educational level	0.028	0.054	0.515	0.607	-0.078	0.133
	House ownership	-0.032	0.131	-0.244	0.807	-0.288	0.224
	Income level	-0.092	0.057	-1.625	0.004*	-0.203	0.019
	Type of house	0.055	0.133	0.409	0.062*	-0.207	0.316
	Sanitary inspector	-0.156	0.096	-1.633	0.102	-0.344	0.031
	∆Prob>chi² (0.008)						
	∆LR chi² (11) 143.2						
	∆Pseudo R-squared (0.6572)						

PROBIT model: PROBIT (p) = Intercept + BX; *represents significance at 5%.

with related studies by Hagos et al. (2012) and Seth et al. (2014). The following independent variables: household type, educational level and house ownership are insignificant in determining WTP; whereas, gender, age, income level, location (residential area), type of employment and type of house are significant.

Gender shows a negative coefficient and is significant ($p<0.05$) on WTP. This indicates that female respondents are more willing to pay for improved solid waste management than males, a situation that can be explained by the fact that in Cameroon (more so in this locality that is more rural) women are traditionally responsible for maintaining hygiene and sanitation in the home; cleaning and waste disposal. This result lends credence to findings of Afroz et al. (2009) and Aggrey and Douglason (2010).

The positive coefficient for age ($p<0.05$) indicates that holding all other variables constant, older people are willing to pay more than younger people. This may suggest that older citizens make more mature decisions related to evaluating health and environmental issues, possibly due to their age. This result is in line with findings of Afroz et al. (2009) but contradicts the findings of Aggrey and Douglason (2010). The later held that older citizens view waste collection, as government responsibility and could be less willing to pay for it.

The variable type of housing is positive and significant. This indicates that WTP is higher for those who live in confined area like flats/bungalows with limited compounds compared to those living in detached houses with compound. In such units, the limitation of space (to permit on site disposal and reduce the immediate impact of poor waste disposal) can increase their demand for waste management services. This contrasts with findings by Ezebilo et al. (2013).

Households' income shows a negative and significant ($p<0.05$) relationship with WTP, indicating that holding all other variables constant, the income of the head of household even though significant did not have the expected sign on WTP. Thus, an increase in household's income does not necessarily increase the WTP for a better waste management service. This is contrary to economics theory which postulates that higher income households have a greater demand for waste management and are more willing to pay for it (Hagos et al., 2012; Maskey and Singh, 2017). The coefficient of the variable type of employment is negative and significant with WTP. This indicates that employment

Table 5. Tobit Regression results of factors influencing the amount of money respondents are WTP.

Variable	Coefficient	S.E.	t-statistic	p-values	95% Confidence Interval	
					Lower bound	Upper bound
Constant	1.764	0.241	7.333	0.000*	1.291	2.238
Gender	-0.035	0.039	-0.903	0.367	-0.112	0.042
Education level	-0.024	0.018	-1.363	0.174	-0.059	0.011
Age	0.042	0.019	2.167	0.031*	0.004	0.080
Household size	-0.032	0.024	-1.298	0.195	-0.080	0.016
Type of employment	-0.039	0.012	-3.201	0.002*	-0.062	-0.015
Type of house	-0.105	0.042	-2.529	0.012*	-0.187	-0.023
Household Income	-0.052	0.019	-2.721	0.007*	-0.089	-0.014
Household ownership	0.051	0.044	1.164	0.245	-0.035	0.136
Trust	0.031	0.030	1.033	0.302	-0.028	0.091
Location (Residential area)	0.034	0.021	1.154	0.057	-0.025	0.187
Inspector	0.057	0.038	1.842	0.081	-0.052	0.241

*Significant at p<0.05.

status (income reliability and job security) has an inverse relationship with WTP. This is contrary to the a priori expectation that households with more secure employment will show higher WTP for services. It, however, exhibits the same trend with household income; to which it is intricately linked.

Catalano et al. (2016) suggest that household income and other related variables (such as location of a household and type of employment) may show significantly negative relationship with WTP for a public good, which is more a problem of data rather than the consequence of an unexpected behavior. These authors intimated that if annual payments are small and can be afforded by a cross section (low, middle and high-income levels) of the population, and if fewer households of the studied population belong to the high-income group; this little variation cannot make the coefficient positive. This explanation is highly plausible in our study, where only 10.5% of the households are ranked as high income (≥250,000) level. This result can also be linked to the fact that low-income households have stronger demands for public SWM services, whereas the high-income may have the ability to employ private solutions as has been reported in previous studies (Wang et al., 2011, 2014). Also, low- and middle-income residential areas (LIRA and MIRA) inhabitants are more WTP for an improved waste management service than the high-income residents (HIRA); possibly because this area (HIRA) is receiving some level of service.

Determinants of the amount of money households

The Tobit regression results of factors influencing the amount of money respondents are willing to pay for improved waste management services are presented in Table 5. The theoretical validity of CVM bids (Tobit regression) was performed to check the behavior of WTP determinants (Mitchell and Carson, 1989; Sumukwo et al., 2012). The Tobit regression gives a Pseudo R-squared of 0.6572. Four of the exogenous independent variables in the demand for improved SWM are statistically significant (p<0.05) predictors for the maximum amount of money households are WTP for improved solid waste management service, that is, household income, type of house, type of employment and age of respondents. These four variables are also significant variables in the Probit model used in this study. Gender, which is significant in determining WTP, is not a significant predictor in the amount respondents are WTP. Similar observations were reported by Awunyo-Vitor et al. (2013).

The coefficients of age variable show positive and significant relationship with the amount of money the respondents are willing to pay for improved solid waste management. This may be explained by the fact that as people gets older, they tend to understand the need of a clean environment (Afroz et al., 2009). In addition, they may also know that access to funds by waste management organization can improve their services (Awunyo-Vitor et al., 2013). The coefficient of household income is negative and significant; implying that increase in household's income does not necessarily increase the amount residents are WTP for a better waste management service. This is contrary to economics theory which postulates that higher income households have a greater demand for waste management and are more willing to pay for it (Hagos et al., 2012; Maskey and Singh, 2017).

The coefficient for the variable type of employment is negative and significant. This implies that less reliable income source is a predictor of the amount households are WTP for the improvement of SWM services. This is contrary to the expectation that households with more secure employment will show higher WTP for services. Education is not statistically significant in either equation, in contrast to most CVM studies which show that, on average educated households are willing to pay for improvements in solid waste management services (Banga et al., 2011; Sumukwo et al., 2012). Seth et al. (2014) and Niringiye and Omortor, (2010) made the same observation, that is the insignificance of education in WTP.

Conclusion

A high level of concern over the problems of environmental degradation is displayed by the population (95.1%) with 74.5% of the opinion that water pollution posed the most serious environmental problem. Over fifty percent (51.5%) of the population indicated that they were satisfied with the current level of environmental sanitation. Participation in environmental activities, particularly the monthly 'keep clean' exercise is very high 88.6 and 73.1% indicated they were willing to sort waste at home; if the government required them to do so.

With regard to WTP for improvement in SWM services, over 85.1% indicated their willingness to pay some amount of money in the contingent market, with a mean bid amount of 1000 FRS (approximately US$1.73: current exchange rate). This represents 1-2% of the mean monthly income (50,000-100,000FRS) bracket. The trend of WTP and income variables (income and type of employment) is negative and significant. According to Catalano et al. (2016) this could result from the fact that annual payments are small and can be afforded by a cross section (low, middle and high-income levels) of the population. It is therefore possible that this could be a suitable take off fee for any such scheme.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Non-linear equilibrium and kinetic study of the adsorption of 2,4-dinitrophenol from aqueous solution using activated carbon derived from a olives stones and cotton cake

Aurelien Bopda[1], Donald Raoul Tchuifon Tchuifon[1], Nche George Ndifor-Angwafor[1], Giscard Doungmo[2] and Anagho Solomon Gabche[1,3*]

[1]Research Unit of Noxious Chemistry and Environmental Engineering, Department of Chemistry, Faculty of Science, University of Dschang, P. O. Box 67, Dschang, Cameroon.
[2]Institute on Inorganic Chemistry, Christian-Albrebrechts-Universität zu Kiel, Max-Eyth-Straβe 2, 24118 Kiel, Germany.
[3]Department of Chemistry, Faculty of Science, University of Bamenda, P. B. Box 39 Bambili, Cameroon.

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Olives stones and cotton cakes have been investigated as a cheap and available precursor used for the production of novel carbon using potassium hydroxide as chemical activating agent with 2:1 impregnation ratio at 1.5 M KOH. Carbonization was performed at 450°C for one hour. The activated carbons NOK and MK3 were characterized by Iodine Number, Fourier Transform Infrared (FTIR) spectroscopy, EDX Analysis, Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD) Analysis and Proximate Analysis (pH_{ZCN}, pH, volatile matter, fixed carbon). The effects of initial sorbate concentration and contact time on adsorption were evaluated. Errors analysis methods were used to evaluate the experimental data: Correlation coefficient (R^2), chi-square (χ^2), average relative error (ARE), sum of absolute errors (EABS) and root mean square error (RMSE) values were tested to find the best fitting isotherm. Elovich models provide the best fit in the uptake of 2,4-dinitrophenol by activated carbons NOK and MK3. Thus, among the isotherm models studied, it appears that the Dubinin-Radushkevich and Temkin (two parameters), Sips (three parameters) and Baudu (four parameters) models describe better the adsorption data. Error analysis showed that the models with two parameters better described the adsorption of 2,4-diniphenol data compared with the three parameter and four-parameter models.

Key words: 2,4-dinitrophenol, activated carbon, cotton cake, olives stones, isotherms, kinetics.

INTRODUCTION

In the present century, environmental problems have increased because of increasing population, consumption of natural habitat, and development of industrialization. These are causes for rapidly destroying the ecological

*Corresponding author. E-mail: sg_anagho@yahoo.com.

system and clean resources rapidly. Environmental pollutants may have organic and inorganic origins. Phenolic compounds as a class of organics which are generated by petroleum and petrochemical, coal conversion, phenol producing industries, and other chemical processes, are common contaminants in wastewater. 2,4-dinitrophenolas one of the vital nitro aromatic compounds is among the most toxic substances, and are commonly used in the manufacture of wood preservatives, explosives, pesticides, dyes, wood preservation agents, plasticizers, and pharmaceuticals (Tchieda et al., 2010). The maximum permissible concentration of nitrophenol in wastewater of 1 µg/L which was set by United State Environmental Protection Agency (USEPA) (Berardinelli et al., 2008; Mubarik et al., 2012). It has arisen as a serious problem in terms of its carcinogenicity and high toxicity as well as creating unpleasant taste and odor in water resources. 2,4-diniphenol has excessive impact on human health and causes nausea, sweating, vomiting, headaches, dizziness and weight loss. Additionally, skin lesions and cataracts are formed by exposure to 2,4-dinitrophenol (Miranda et al., 2006). 2,4-dinitrophenol toxin also affects the bone marrow, cardiovascular system and Central Nervous system (Luan and Plaisier, 2004). Therefore, the treatment of effluent containing such nitrophenols is of interest due to its harmful impacts in receiving waters. Various methods have been applied in the removal of nitrophenols from water and wastewater. These methods include distillation, coagulation, electrocoagulation (Bazrafshan et al., 2012), biological treatment, catalytic oxidation, ozonation (Biglari et al., 2017), solvent extraction, and adsorption (Tchieda et al., 2010; Mubarik et al., 2012; Tchuifon et al., 2014; Muhammad, 2018; Bopda et al., 2018).

Out of these methods, adsorption appears to be most widely used for 2,4-dinitrophenol removal (Muhammad, 2018; Bopda et al., 2018). Activated carbon adsorption has been cited by the USEPA as one of the best available environmental control technologies (Hamdaoui et al., 2005) because it is a cleaner, more efficient and cheap technology.

Previously, research working on various precursors for activated carbon has studied the possibility and efficiency of utilization of agricultural fibres as an adsorbent for Phenolic compounds removal in polluted water. Some of the low cost agricultural wastes that have been studied include: rice husk (Tchuifon et al., 2014; Okieimen et al., 2007; Ndifor-Angwafor et al., 2017), palm kernel shell (Abechi et al., 2013), lapsi (*Choerospondias axillaris*) seed stone (Sahira and Bhadra, 2013), cola nut (*cola acuminata*) shells (Ndi et al., 2014), bitter kola (*Garcinia kola*) nut shells (Kuete et al., 2018) and mixture of *Ayous* sawdust and C*ucurbitaceae* peelings (Ngakou et al., 2018). These agricultural wastes which are used to produce the activated carbons are generated in large quantities and in some cases might become difficult to dispose and have proven very effective in the adsorption of phenolic compounds removal in water.

The performance of an adsorbent can be studied from adsorption kinetics and isotherm data. The equilibrium correlation is developed using equilibrium isotherms. Also isotherms express sorbent interactions with the surface of adsorbent, that is, whether it is monolayer or multilayer sorption (Foo and Hameed, 2010). An analysis of the kinetic data is important because the kinetics describe the uptake rate of adsorbate, which in turn controls the resident time in the adsorbent-solution interface (Junxiong and Lan, 2009).

The aim of the present research was to explore the performance of activated carbon derived from a mixture of cotton cakes and olive stones for the adsorption of 2,4-dinitrophenol under different operating conditions including pH, contact time and initial concentration. The application of non-linear forms of equilibrium isotherms was to determine the appropriate isotherm for the purpose and kinetic studies were performed to check reaction nature of the adsorption phenomenon. Error analysis based on five different error functions was also performed.

MATERIALS AND METHODS

Cotton cake and olive stone were collected respectively from Zamay (Nord region Cameroon) and Bangangte (west region Cameroon) (Figure 1) and processed (Sugumaran et al., 2012). They were cut into small pieces of about 0.5 to 1 cm in size, dried under sunlight until all the moisture was evaporated.

Preparation of activated carbon

Preparation of activated carbon from olive stones (NOK) and mixture of cotton cake and olive stones (MK3) were carried out by chemical activation process with KOH activating agent at concentration 1.5 M. 120 g of different material were inserted into each of five flasks, and activating agent solutions with impregnation ratios was 2/1 (w/w) were added. The mixture was allowed for 30 min activation to take place before being dried in an oven set 105°C for 48 h. The impregnated samples were carbonized for 1 h at 450°C, at a heating rate of 5°C min^{-1}. After impregnation and carbonization, the pyrolysed carbons based KOH were leached with 1% HCl (v/v) for 2-3 H, were washed several times with distilled water until a neutral pH for the two carbons based KOH was achieved. Later, the carbon paste was dried in an oven at 110°C for at least 24 h which were later converted to powdered activated carbon of particle size lower than 100 µm and pestle before application. The prepared activated carbon was characterized by the adsorption capacity towards iodine using the standard test method for the determination of iodine number of activated carbon (ASTM, 2006).

Characterization of activated carbons

The activated carbons were characterized by Fourier transform-infrared (FTIR) spectroscopy, scanning electron microscopy (SEM), X ray diffraction (XRD), EDX analysis and proximate analysis (pH_{PZC}, pH, Bulk density, moisture content, ash content, volatile

Figure 1. Photography of selected lignocellulosic wastes (A: cotton cake; B: olive stone).

matter, fixed carbon content and matter soluble in water) by the method used by Abechi et al. (2013); Pongener et al. (2015); Abechi et al. (2013) and Pongener et al. (2015).

Batch equilibrium experiments and analytical method

Stock solution of 2,4-dinitrophenol at the concentration of 500 mg L^{-1} was prepared by dissolving 0.125 g of 2,4-dinitrophenol in 0.250 L of distilled water. Experimental solutions at desired concentrations were obtained by dilution of the stock solution with distilled water pre-adjusted to pH range from 2.0 - 7.0 with a 0.01 M HCl or NaOH solution. The different contact times varied between 0 and 180 min. The initial concentrations of the experimental solutions of 2,4-dinitrophenol were 20, 25, 30, 35, 40, 45 and 50 mg L^{-1}. 30 ml of the experimental solutions were placed in bottles and then 0.05 g prepared activated carbon was added to each bottle. After agitation for about during equilibrium time, the solution was filtered, and the filtrate analyzed to obtain the residual concentration 2,4-dinitrophenol by using the UV/Vis spectrophotometer at λ_{max} value of 320 nm.

Modelling theoretical background

Tables 1 and 2 summarizes the non-linear forms of the two, three and four parameter isotherms models and non-linear forms of kinetics models used respectively in this study.

Error functions analysis

In general, plus values of errors function are low it means more there is an agreement between the experimental and calculate data and more the model converges and becomes favourable, their functions are listed in Table 3.

RESULTS AND DISCUSSION

Characterization of activated carbons

Burn-off, yield and iodine number

Table 4 contains the burn-off, yield and iodine number for various activated carbons. It is deduced from this table that the yield obtained by the activation process of activated carbons of olives stone and mixed precursors has burn-off from 32 to 50% which, indicates that these carbons have microporous structure (Bansal et al., 1988).

Iodine number is defined as the number of milligrams of iodine absorbed by one gram of activated carbon powder. Table 2 gives the values of the iodine number of the samples. The iodine numbers of activated carbons prepared in this investigation lie between 520.00-591.00 mg g^{-1}. The higher Iodine number of the activated carbon is attributed to the presence of large microporous structure that results due to the reactivity of the activating agent KOH. Generally, the higher the iodine number, the greater the sorption capacity. The iodine number recommended as a minimum by the American Water Works Association for a carbon to be used in removing low molecular weight compounds is 500 (ASTM, 2006). The two factors that determine good iodine number are activation temperature and raw materials. This suggests that surface area increases in terms of microscopic pores. Iodine adsorption is usually associated with micro pores because of the small size of iodine molecule.

The proximate analysis

The proximate analysis was performed according to the ASTM methods was examined and shown in Table 5.

SEM analysis

The surface morphology of the activated carbons was studied by SEM techniques. In the chemical activation process, new pores are formed due to the reaction between carbon and the activating agents (Arvind and Hara, 2015). SEM micrographs of NOK and MK3 are shown in Figure 2. Figure 2 shows that the adsorbent

Table 1. Non-linear forms of the two, three and four parameter isotherms.

Parameter	Isotherms	Nonlinear forms	References
Two	Langmuir	$Q_e = \frac{Q_m K C_e}{1 + K C_e}$	Al-Duri and McKay (1988)
	Freundlich	$Q_e = K_f Ce^{1/n}$	
	Dubinin-Radushkevich	$Q_e = Q_m \exp(-K\varepsilon^2)$; ε= RT ln (1+1/C_e) ;	Gunay et al. (2007)
	Temkin	$Q_e = Q_m \frac{RT}{\Delta Q} \ln(AC_e)$	Ringot et al. (2007)
	Jovanovic	$q_e = q_m(1 - e^{k_j C_e})$	Rania and Yousef (2015)
Three	Redlich-Peterson	$q_e = \frac{AC_e}{1 + BC_e^{\beta}}$	Ayawei et al. (2017)
	Sips	$q_e = \frac{K_s C_e^{\beta}}{1 + a_s C_e^{\beta s}}$	
	Toth	$\frac{q_e}{q_m} = \frac{K_e C_e}{[1 + (K_L C_e)^n]^{1/n}}$	
	Hill	$q_e = \frac{q_{SH} C_e^{nH}}{K_D + C_e^{nH}}$	
	Kahn	$Q_e = \frac{Q_{max} b_k C_e}{(1 + b_k C_e) a_k}$	
Four	Fritz-Schlunder	$q_e = \frac{q_{mFSS} K_{FS} C_e}{1 + q_m C_e^{MFS}}$	Yaneva et al. (2013
	Baudu	$q_e = \frac{q_m bo C_e^{1+x+y}}{1 + bo C_e^{1+x}}$	McKay et al. (2014)
	Marczewski-Jaroniec	$q_e = q_{MMJ}(\frac{(K_{MJ} C_e)^{n_{MJ}}}{1 + (K_{MJ} C_e)^{n_{MJ}}})^{M_{MJ}/n_{MJ}}$	Ayawei et al. (2017)

Table 2. Non-linear forms of kinetics models.

Kinetics	Non-linear form	References
Pseudo-first-order	$q_t = q_e(1 - e^{-k_1 t})$	Ho (2004)
Pseudo-second-order	$q_t = \frac{k_2 q_e^2 t}{1 + k_2 q_e t}$	Ho and Mckay (1998)
Elovich	$q_t = \frac{ln(\alpha\beta)}{\beta} + \frac{ln\ t}{\beta}$	Chien and Clayton (1980)
Intraparticle diffusion	$Q_t = K_{id} t^{1/2} + C$	Weber and Morris (1963)

have rough texture with heterogeneous surface and a variety of randomly distributed pore size. The SEM images of NOK and MK3 are porous in appearance. Sample MK3 presents pores which are, apparently, more open (broad) compared to NOK material, which is explained by a mixture precursors used in this material. Sample MK3, the mixture of cottons cake and olives stone activated reduces the orderly pores development on the surface of the activated carbons. This can be a result of impurities such as tar produced by precursor in the mixture that could clog the pores and inhibit good pore structure development since the amount of activating agent stays constant during the production process.

EDX analysis

For the activated carbon having heterogeneous surfaces, EDX analysis was carried out on several zones of the

Table 3. Error functions and their equations.

Error function	Abbreviation	formula	References
Residual root mean square error	RMSE	$\sqrt{(\frac{1}{n-2}\sum_{i=1}^{n} q_{e,exp} - q_{e,calc}))^2}$	Sugumaran et al. (2012)
Hybrid fractional error function	HYBRID	$\frac{100}{n-p}\sum_{i=1}^{n}\frac{(q_{e,i,means} - q_{e,i,calc})^2}{q_{e,i,meas}}$	Mckay et al. (2014)
Average relative error	ARE	$\frac{100}{n-p}\sum_{i=1}^{n}\frac{(q_{e,i,calc} - q_{e,i,means})}{q_{e,i,meas}}$	
Nonlinear chi-square test	χ²	$\sum_{i=1}^{n}\frac{(q_{ecal} - q_{emeas})^2}{q_{emeas}}$	(Chan et al., 2012)
Sum of absolute errors	EABS	$\sum_{i=1}^{p}(q_{e,i,means} - q_{e,i,calc})$	Ayawei et al. (2017)
Coefficient of determination	R²	$\frac{\sum_{i=1}^{n}(q_{ecal} - q_{mexp})^2}{\sum_{i=1}^{n}(q_{ecal} - q_{mexp})^2 + (q_{ecal} - q_{mexp})^2}$	

Table 4. Burn-off, yield and iodine number for various activated carbons.

Variable	Yield (%)	Burn-off (%)	Iodine number (mg g^{-1})
NOK	62.88	37.12	523.46
MK	62.22	37.78	590.49

Table 5. The proximate analysis composition of NOK and MK3.

Property	NOK	MK3
pH_{ZCN}	5.67	6.01
pH	6.88	6.98
Bulk density (kg m^{-3})	471.60	617.20
Moisture content (%)	3.00	2.00
Ash content (%)	16.80	4.00
Volatile mater (%)	28.68	32.00
Fixe carbon content (%)	51.52	62.00
Matter soluble in water	0.47	0.38
Elements (%)		
C	92.49	94.72
O	7.51	5.28

material. The results of EDX analysis of studied (Figure 3) showed that these materials primarily consist of carbon and oxygen in different proportions. The presence of oxygen may be attributed to the little amount of moisture in the carbon. The carbon content in activated carbons from mixed precursors is greater than that from the simple precursors and oxygen percentage in activated carbons from simple precursors, is greater than in that from the mixed precursors. The high carbon % and low oxygen % in activated carbons are attributed to the volatilization of oxygen and hydrogen atoms. The results of typical EDX elemental microanalysis of the activated

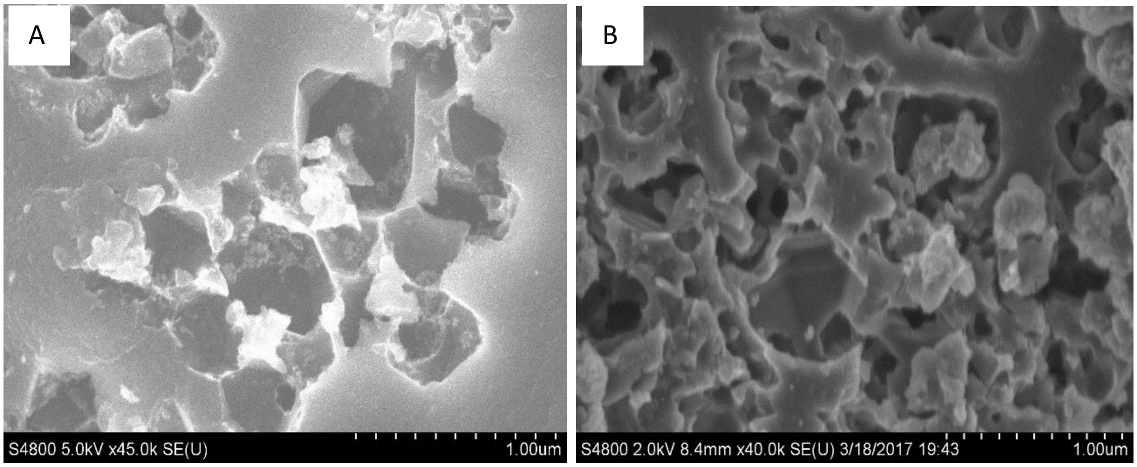

Figure 2. SEM micrographs of activated carbon of samples: A) NOK; B) MK3.

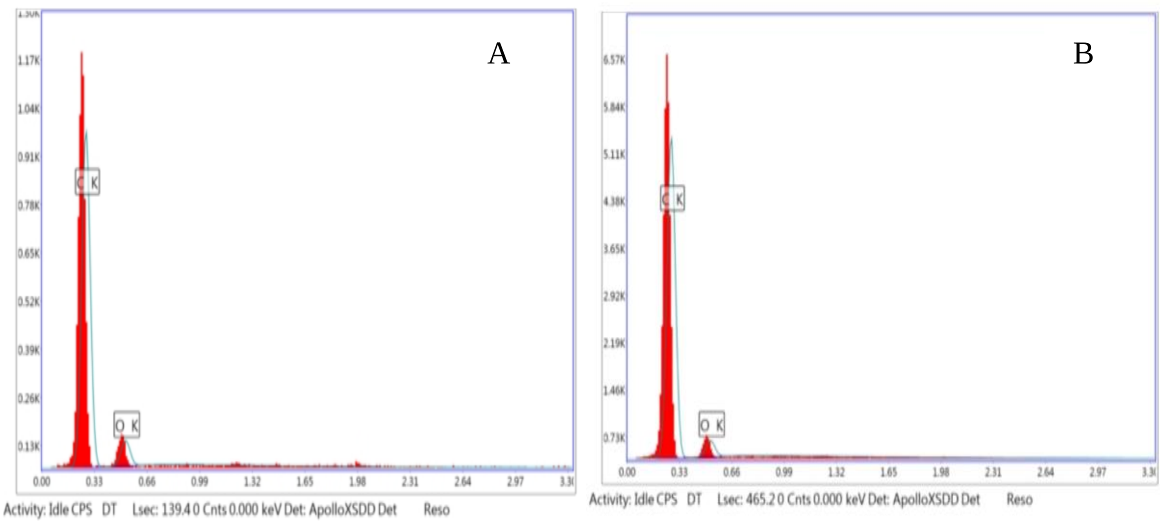

Figure 3. EDX elemental microanalysis of activated carbon of samples (A: NOK, B: MK3).

carbons in Figure 3 and the percentage of the element present in the different activated carbons is given in Table 5.

Fourier transform Infra-red spectroscopy (FTIR)

The FT-IR spectroscopy was used to determine the various functional groups present in adsorbent materials. The result depicts the absorbance spectra of the NOK and MK3 shown in Figure 4. The main components of the raw material olive stones are hemicellulose, cellulose, and lignin which have an aromatic character. The wide absorption at 3300 cm^{-1} is assigned to the O-H stretching vibration mode in alcohol and phenol. The vibration band at 3319 cm^{-1} was attributed to the acetylenic stretching. The region between 2915 and 2849 cm^{-1} have two intense peaks assigned to C-H stretching vibrations. The adsorption band at 1580 cm^{-1} is attributed to quinonic, monosubstituted alkene and carboxylate structures mean while the adsorption band at 1735 cm^{-1} is attributed to a carboxylic tautomeric structure (C=O). The bands located at 1100 and 1120 $cm^{-1}$are attributed to C-O stretching vibrations in alcohols and phenols (Virote et al., 2005). The bands observed between 800 and 500 $cm^{-1}$are due to out of plane deformation mode of C-H for alkenes aromatic rings. Bands observed at 600 and 400 $cm^{-1}$are ascribed to C-H in out-of-plane bending in the edges of aromatic rings or are assigned to cyclic amides (El-Hendawy, 2006). This behavior suggests that the activated carbon is mainly an aromatic polymer of activated carbon. The most important bands and peaks

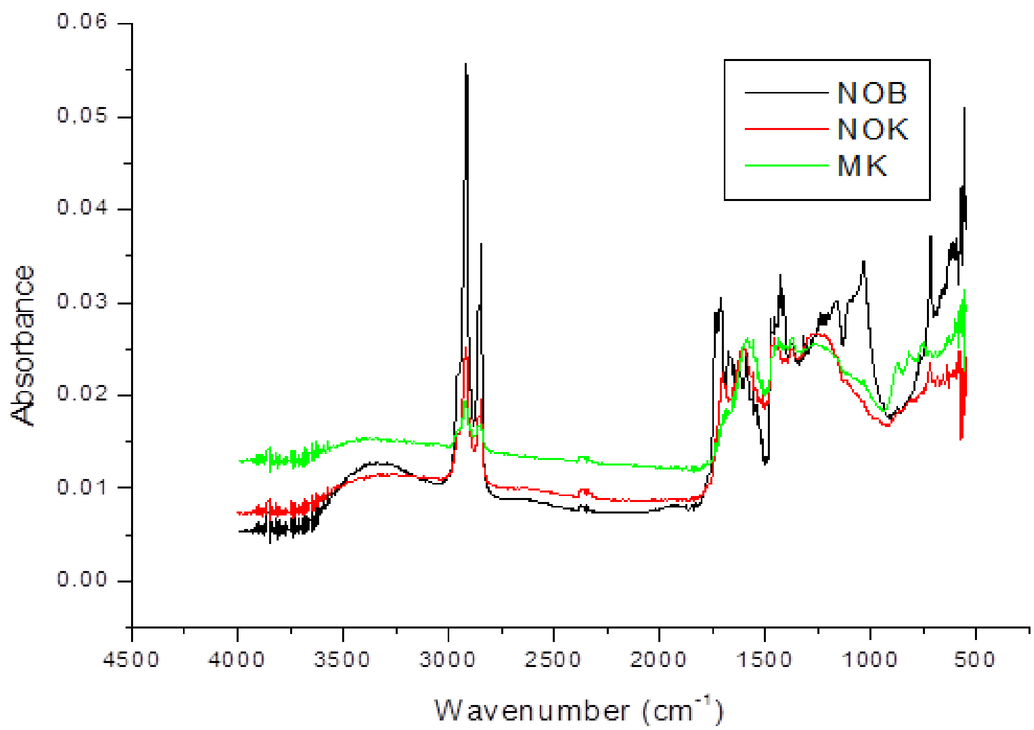

Figure 4. Fourier transform infrared spectra of olive stones (NOB), olive stones based activated carbon (NOK) and mixed biomass based activated carbon (MK3).

appearing on the spectrum of NOB are the same present on NOK but with low O-H and C-H intensities peak and this can be explained by carbonization which is at the origin of the atoms of C, O, H in the form of CO_2, H_2O, and aldehyde. These results are in agreement with these of Boehm titrations. The loss of the band of adsorption located at located at 1100 and 1120 cm^{-1}characteristic of the C-O can be explained by the fact why the process of chemical activation causes sometimes cuts of the chemical bonds and eliminates several volatiles substrates. The spectra of NOK have the same peaks. The most important bands and peaks appearing on the spectrum of MK3 are the same presented on NOK but with high intensities.

X-ray diffraction (XRD) analysis

The results of powder X-ray diffraction obtained for olive stones (NOB), and the activated carbons (NOK and MK) are presented in Figure 5. The existence of broad peaks indicates that the materials are amorphous (Omri and Benzina, 2012). For the olive stones biomass, a sharp peak appeared at $2θ = 18°$ and small sharp peak at $2θ = 24°$. This signifies an increasing regularity of crystalline structure, which will result in a better layer alignment. The absence of a sharp peak reveals that the activated carbon prepared from NOB and mixed biomass are mainly amorphous (Omri and Benzina, 2012). The disappearance of the sharp peaks is mainly due to the removal of lignin and the breakdown of the ester bonds between lignin and other components during KOH pretreatment and carbonization of the biomass. The amorphous nature of our activated carbon is an advantageous property for well-defined adsorbent. However, the small sharp peaks presented by the X-ray graph of NOK ($2θ = 21°$) indicates a very low crystallinity on this activated carbon resulting from better layer alignment. The sharp peaks are due to the presence of potassium carbonate and potassium oxide (Lillo-Rodenas et al., 2003). The broad peak found at approximately 19° for the two carbons confirm that the samples are nongraphited, and can have a high microporous structure (Zhao et al., 2009).

Adsorption study

Adsorption kinetics modeling

Study of adsorption kinetics is important because the rate of adsorption (which is one of the criteria for determining efficiency of adsorbents) and also the mechanism of adsorption can be obtained from non-linear kinetic studies. In this study, kinetic data were fitted with four models (pseudo-first-order, pseudo-second-order,

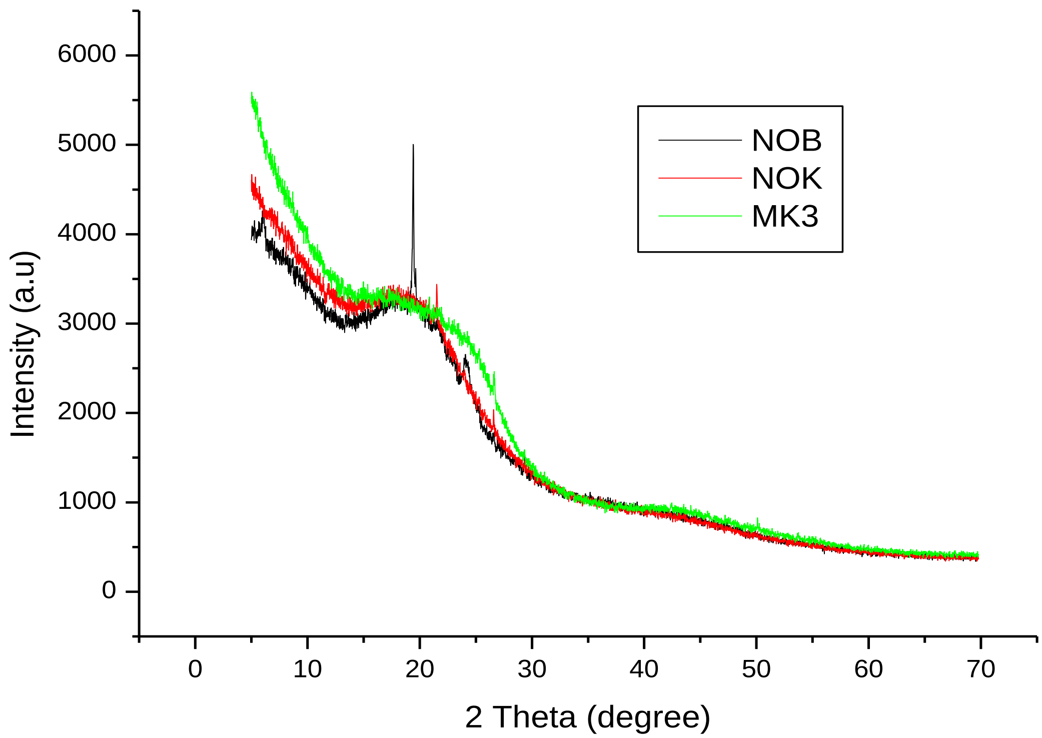

Figure 5. X-ray Diffraction of olive stones (NOB), olive stones based activated carbon (NOK) and mixed biomass based activated carbon (MK3).

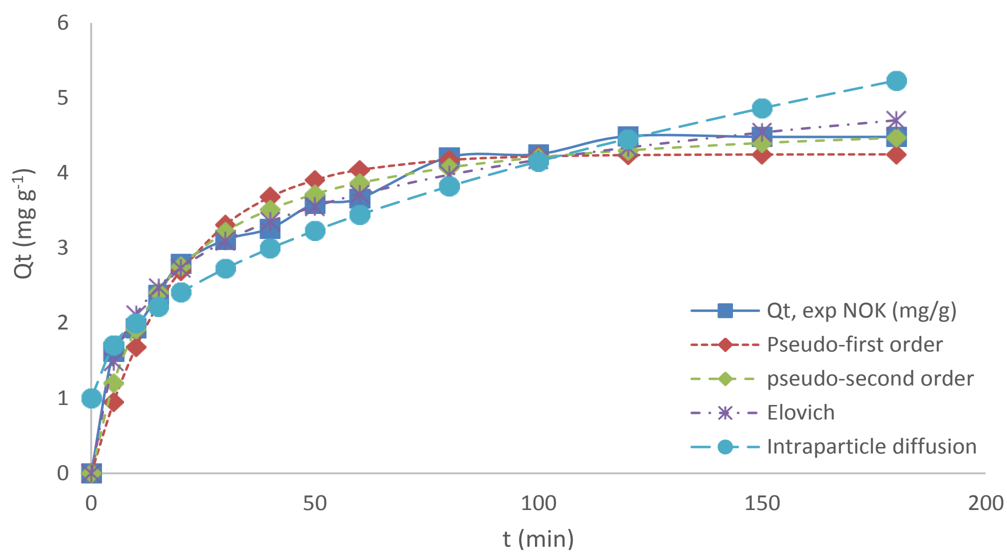

Figure 6. Comparison of measured and calculated Q_e values for kinetics onto activated carbon NOK.

intraparticle diffusion and Elovich model). Figures 6 and 7 shows the variation of the amount of adsorbed (q_t) as a function of time.

Table 6 shows the kinetic parameters obtained using the non-linear method. As can be seen from Table 6, the coefficients of determination for all models are very good. Elovich model equation's χ^2 values were lower than 0.232. Elovich models provide the best fit in the uptake of 2,4-dinitrophenol for any adsorbent, with smaller error values (ARE, EABS, RMSE and HYBRID) onto the

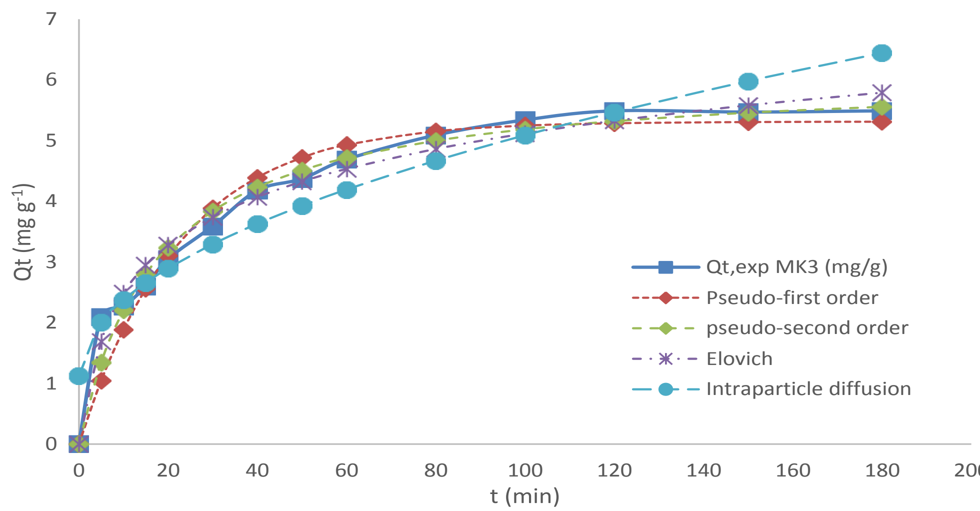

Figure 7. Comparison of measured and calculated Qe values for kinetics onto activated carbon MK3.

Table 6. Optimum kinetics parameters and their statistical comparison values onto activated carbon MK3.

N°	Model	Constant	Value	R^2	RMSE	χ^2	Hybrid	Area	EABS
MK3									
1	Pseudo first order	Q_e (mg g^{-1}) K_1 (1 min^{-1})	5.313 0.044	0.959	1.300	1.239	6.303	8.446	0.062
2	Pseudo second order	Q_e (mg g^{-1}) K_2 (g min^{-1}mg^{-1})	6.104 0.009	0.979	0.895	0.487	3.052	5.670	2.162
3	Elovich	α (mg g^{-1}min^{-1}) β (g mg^{-1})	1.002 0.874	0.966	0.823	0.232	2.009	6.054	2.086
4	Intraparticle diffusion	K_p (mg g^{-1}min$^{-0.5}$) C (mg g^{-1})	0.397 1.118	0.889	1.883	1.592	4.307	7.594	5.480
NOK									
1	Pseudo first order	Q_e (mg g^{-1}) K_1 (1 min^{-1})	4.248 0.050	0.954	1.086	0.653	4.523	9.207	3.253
2	Pseudo second order	Q_e (mg g^{-1}) K_2 (g min^{-1}mg^{-1})	4.844 0.014	0.984	0.612	0.199	1.481	4.581	1.645
3	Elovich	α (mg g^{-1}min^{-1}) β (g mg^{-1})	0.944 1.116	0.983	0.460	0.067	0.616	3.566	1.407
4	Intraparticle diffusion	K_p (mg g^{-1}min$^{-0.5}$)	0.315	0.879	1.567	1.389	3.488	7.926	4.571

different adsorbents. This suggests that the Elovich sorption mechanism is predominant and that the overall rate, extent of surface coverage and activation energy are favored at lower adsorbents amounts and the adsorption process appears to be controlled by the chemical process (Khalil et al., 2016). However, the Pseudo second order model can also be considered as an alternative option in defining the kinetic processes involved in this adsorption phenomenon. The Elovich equation was used successfully to describe second-order kinetics assuming that the actual solid surfaces are energetically heterogeneous (Demirbas et al., 2008).

Adsorption isotherm modelling

Non-linear regression can be a powerful alternative to linear regression because it offers the most flexible curve fitting functionality. For non-linear isotherm model, sum of square must be minimized by an iterative method. The non-linear regression line is the line that minimizes the sum of squared deviations of prediction (also called the sum of squares error). The smaller the standard error of the estimate the more accurate the prediction. The parameters of the different isotherms obtained by minimizing each error function and maximizing R^2 in an

Table 7. Optimum isotherm parameters and their statistical comparison values for two-parameter models.

N°	Model	Constants	Value	R²	RMSE	χ²	Hybrid	ARE	EABS
MK3									
1	Langmuir	Q_{max} (mg g^{-1}) K_L (L mg^{-1})	9.112 0.053	0.977	0.267	0.014	0.288	1.865	0.663
2	Freundlcih	K_F (L mg^{-1}) n	1.299 2.339	0.956	0.363	0.027	0.549	2.510	0.878
3	Temkin	a (L mg^{-1}) b (J mol^{-1})	1.760 1769.4	0.571	0.731	0.111	2.517	4.004	4.306
4	DR	Q_{max} (mgg^{-1}) K (L mg^{-1})	8.079 0.002	0.986	0.209	0.008	0.166	1.428	0.525
5	Jovanovic	Q_{max} (mg g^{-1}) K_J (L mg^{-1})	6.754 -0.060	0.983	0.225	0.010	0.198	1.562	0.567
NOK									
1	Langmuir	Q_{max} (mg g^{-1}) K_L (L mg^{-1})	13.867 0.014	0.919	0.549	0.080	1.680	4.276	1.102
2	Freundlcih	K_F (L mg^{-1}) n	0.339 1.369	0.917	0.555	0.081	1.681	4.568	1.181
3	Temkin	a (L mg^{-1}) b (J mol^{-1})	0.156 929.803	0.994	0.561	0.084	1.811	3.340	1.078
4	DR	Q_{max} (mg g^{-1}) K (L mg^{-1})	7.824 0.004	0.914	0.569	0.087	1.899	4.400	1.082
5	Jovanovic	Q_{max} (mg g^{-1}) K_J (L mg^{-1})	8.352 -0.022	0.920	0.548	0.080	1.681	4.214	1.085

iterative method and the corresponding values of the other error functions were shown in Tables 7 to 8. In addition, Figures 8 to 13 show the fitting values of non-linear regression analysis.

Two-parameter models

Table 7 shows the values of the corresponding two-parameter isotherms obtained using the non-linear method. The result of non-linear regression method also revealed that the Temkin and Dubinin-Radushkevich isotherms fit the data in the best way respectively for NOK and MK3. It was observed that the correlation coefficient value of all isotherm models studies are very good (> 0.9), exception the Temkin model for the sample MK3, and the low χ^2, ARE, EABS and RMSE values for these adsorbents. Dubinin-Radushkevich suggests a Gaussian energy distribution onto heterogeneous surfaces (Celebi et al., 2007). Based on the energies, the variation of energy of adsorption b (kJ/mol) resulting from the non-linearization of the Temkin model is positive. A positive value of b means that the adsorption process is exothermic. Therefore, by comparison, the order of the isotherms that best fits the four sets of experimental data in this study is Dubinin-Radushkevich > Jovanovic > Langmuir > Freundlich > Temkin for MK3 and Temkin > Jovanovic Langmuir > Freundlich > Dubinin-Radushkevich.

Three-parameter models

From Table 8, Sips isotherm overlapped and seemed to be the best-fitting models for the experiment for these samples. It was observed that the correlation coefficient for all isotherms model studied are very good (> 0.9). The Sips isotherm model show high correlation coefficients value for the two adsorbents with low χ^2, ARE, EABS and RMSE values, thus indicating that the models are able to describe equilibrium data perfectly. Therefore, by comparison, the order of the isotherm best fits the four sets of experimental data in this study is Sips > Redlich-Peterson > Khan > Hill > Toth for these adsorbents. These models are suitable for predicting adsorption on heterogeneous surfaces (Ayawei et al., 2017).

Four-parameter models

Table 9 shows the values of the four corresponding isotherm parameters obtained using the non-linear method. It was observed that the correlation coefficient

Table 8. Optimum isotherm parameters and their statistical comparison values for three-parameter models.

N°	Model	Constants	Value	R^2	RMSE	χ^2	HYBRID	ARE	EABS
MK3									
		A (L g^{-1})	221.901						
1	Redlich-Peterson	B (L mg^{-1})	170.344	0.956	0.363	0.027	0.686	2.509	0.878
		β	0.573						
		K_s (L g^{-1})	47.986						
2	Sips	a_s (L g^{-1})	0.026	0.959	0.354	0.026	0.649	2.447	0.857
		β_s	2.082						
		Q (mg g^{-1})	2.048						
3	Toth	K_e	0.247	0.749	0.624	0.080	2.158	3.711	1.276
		n (mg g^{-1})	0.841						
		Q_m (mg g^{-1})	256.773						
4	Hill	K_H (L g^{-1})	199.345	0.975	0.362	0.027	0.680	2.500	0.875
		n_H	0.436						
		Q_m (mg g^{-1})	0.405						
5	Khan	b_k(L g^{-1})	15.608	0.956	0.363	0.027	0.683	2.505	0.877
		a_k	0.574						
NOK									
		A (L g^{-1})	0.172						
1	Redlich-Peterson	B (L mg^{-1})	0.002	0.921	0.547	0.080	2.114	4.196	1.074
		β	1.477						
		K_s (Lg^{-1})	10.420						
2	Sips	a_s (L g^{-1})	0.013	0.920	0.549	0.080	2.121	4.155	1.069
		β_s	0.878						
		Q (mgg^{-1})	0.375						
3	Toth	K_e	0.433	0.918	0.554	0.081	2.098	4.545	1.176
		n (mg g^{-1})	0.538						
		Q_m (mgg^{-1})	833.736						
4	Hill	K_H (L g^{-1})	2403.866	0.915	0.555	0.081	2.111	4.560	1.172
		n_H	0.725						
		Q_m (mg g^{-1})	0.788						
5	Khan	b_k (L g^{-1})	0.360	0.917	0.554	0.081	2.099	4.523	1.169
		a_k	0.299						

value of all isotherm models studied is very good (> 0.9). The result of non-linear regression method also revealed that the Baudu isotherms fit the data in the best way for NOK and MK3. This model shows the low χ^2, ARE, EABS and RMSE values for these adsorbents. On the basis of the average percentage error values (Table 9), the Baudu equation of seems better than that of Fritz–Schlunder and Marczewski–Jaroniec. The values of the maximum adsorption capacity obtained using all the three four-parameter isotherms are lower than those calculated from the Langmuir model (Tchuifon et al., 2018). Therefore, by comparison, the order of the isotherm best fits the four sets of experimental data in this study is Baudu > Jovanovic > Marczewski-Jaroniec > Fritz-Schlunder.

Conclusion

The equilibrium and kinetic study adsorption of 2,4-dinitrophenol onto activated carbon was explained using non-linear methods. Error analysis provides information

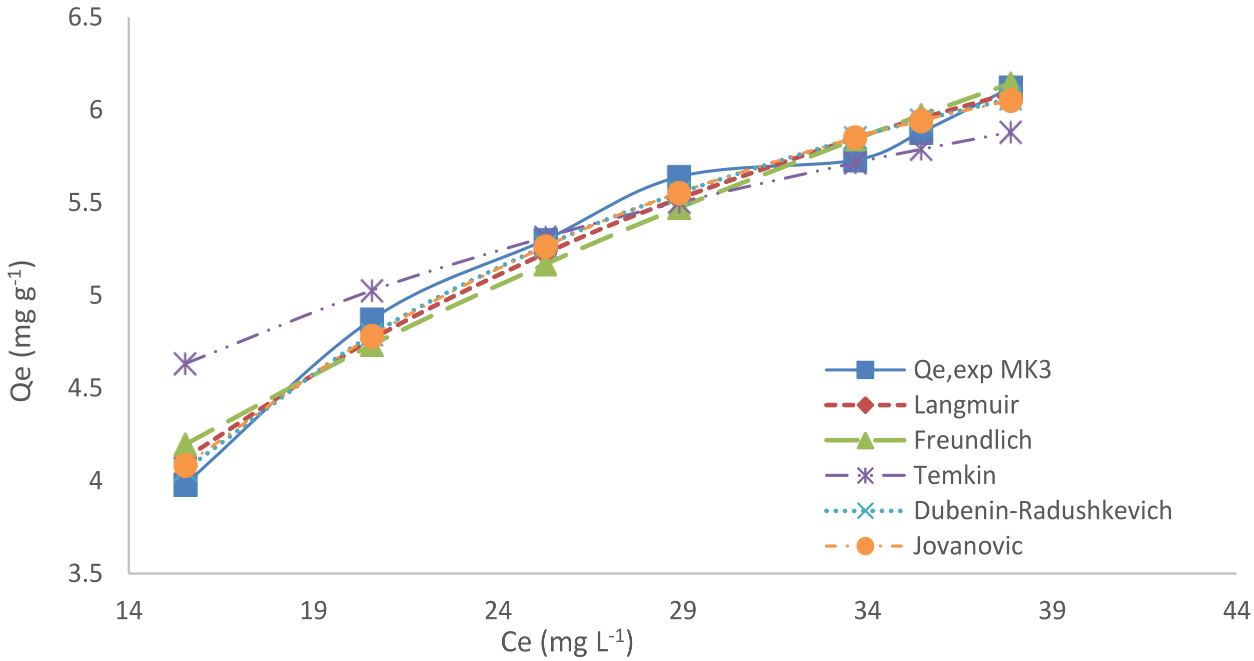

Figure 8. Comparison of measured and calculated Q_e values for two-parameter isotherms onto activated carbon MK3.

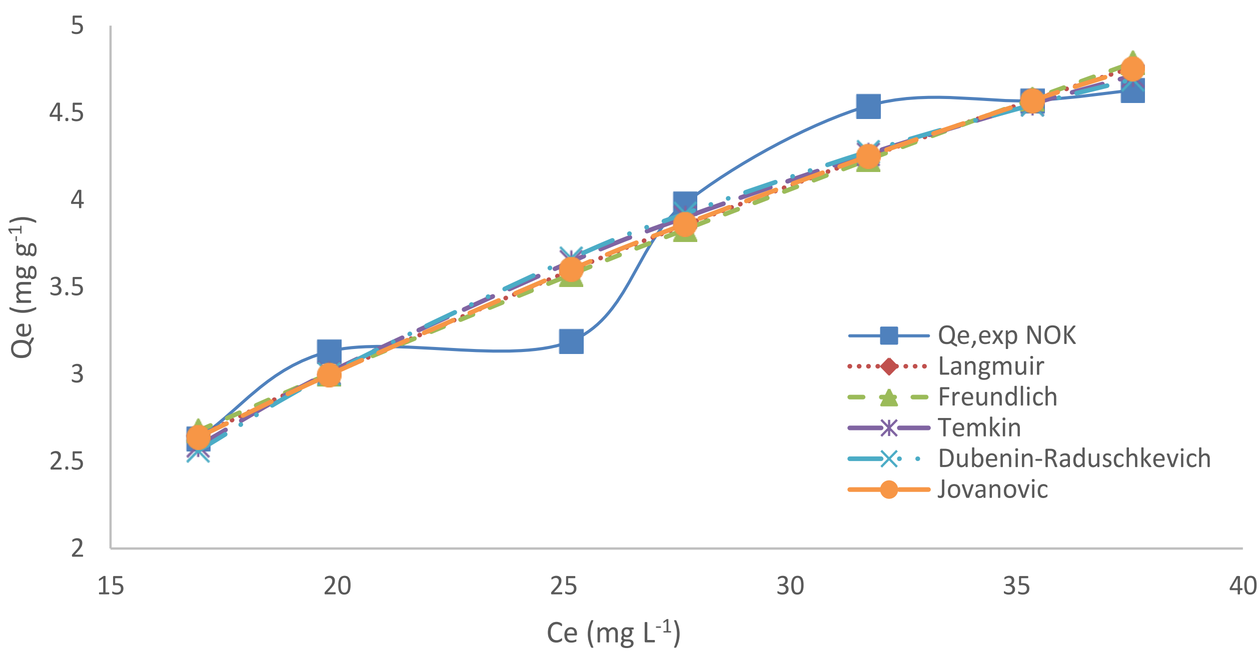

Figure 9. Comparison of measured and calculated Q_e values for two-parameter isotherms onto activated carbon NOK.

about fitness of these models on experimental data. The model with minimum error was selected best for adsorption data. In this work, the potential of two activated carbons, obtained from olive stone and mixture of cotton cakes and olive stones by chemical activation using KOH was investigated. The functional groups of these samples were determined using FTIR spectroscopy which was confirmed by using Boehm's titration and EDX analysis. XRD analysis showed that the raw material and activated carbons prepared are mainly amorphous.

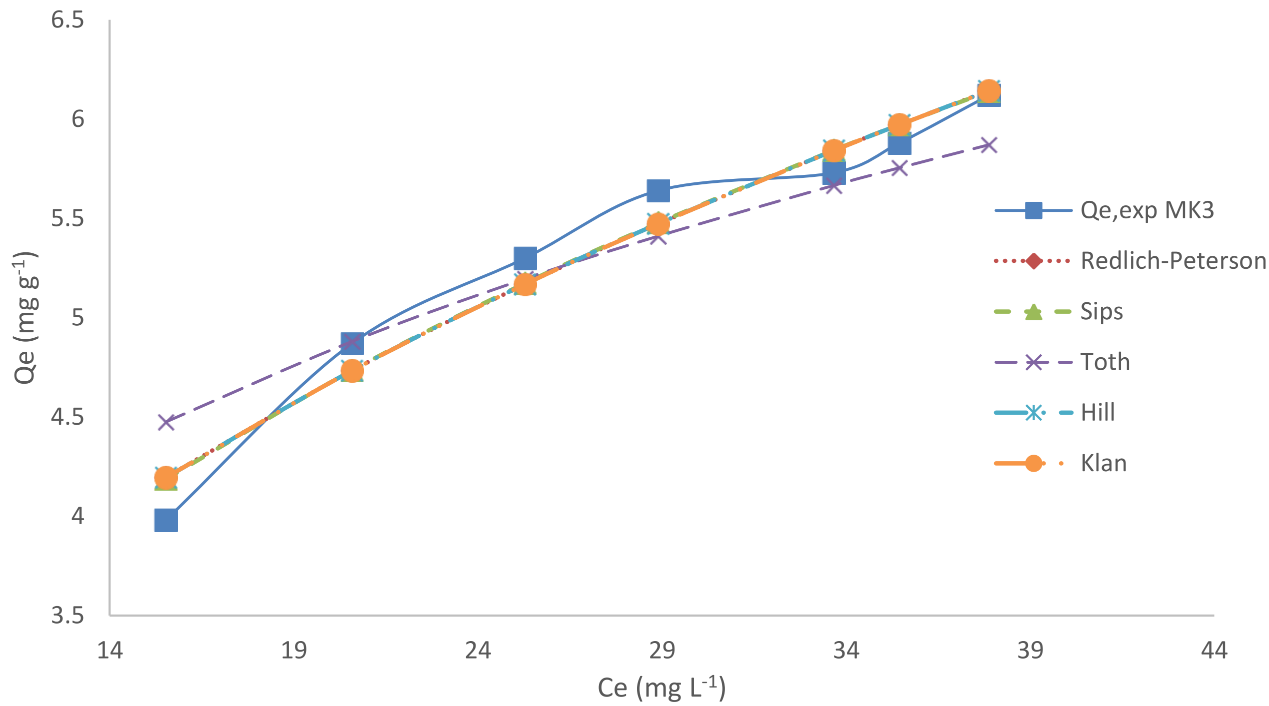

Figure 10. Comparison of measured and calculated Q_e values for three-parameter isotherms onto activated carbon MK3.

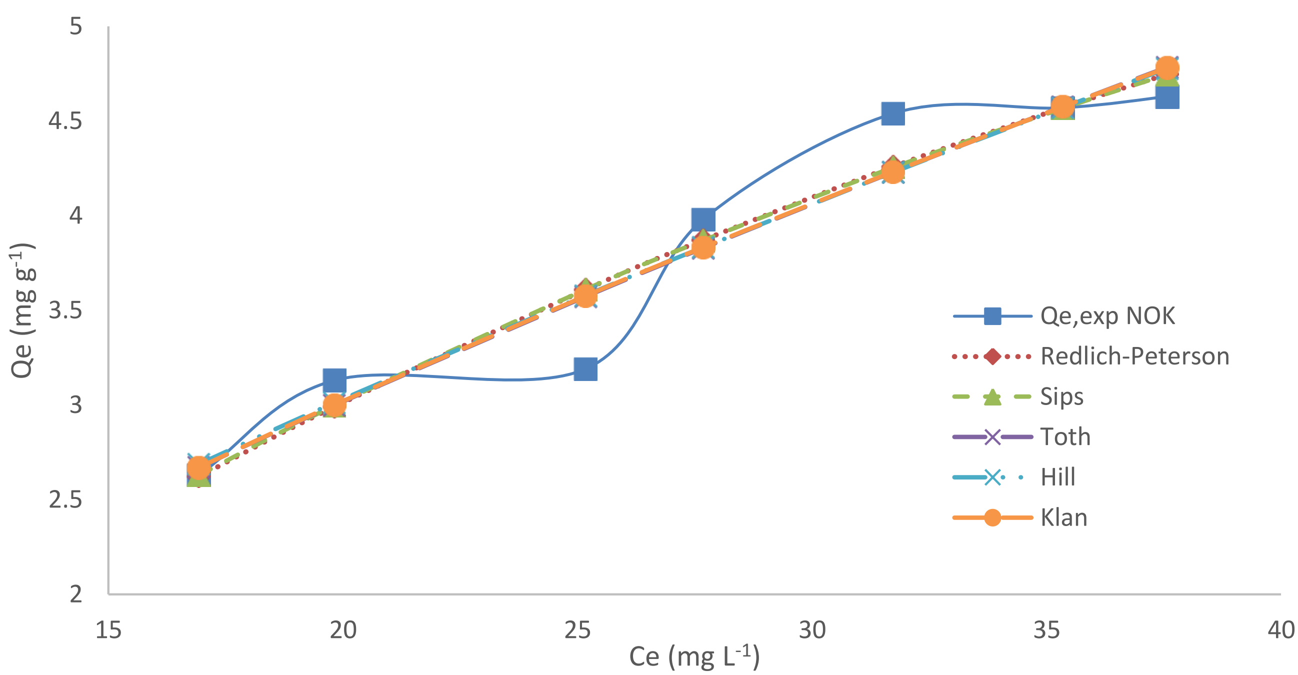

Figure 11. Comparison of measured and calculated Q_e values for three-parameter isotherms onto activated carbon CCK1.

SEM images showed an irregular and heterogeneous surface morphology with a developed and fragmented porous structure in various sizes. For all the systems examined, the Elovich kinetic model provided the best fits of the experimental data. For two parameter models Temkin and Dubinin-Radushkevich isotherms fit the

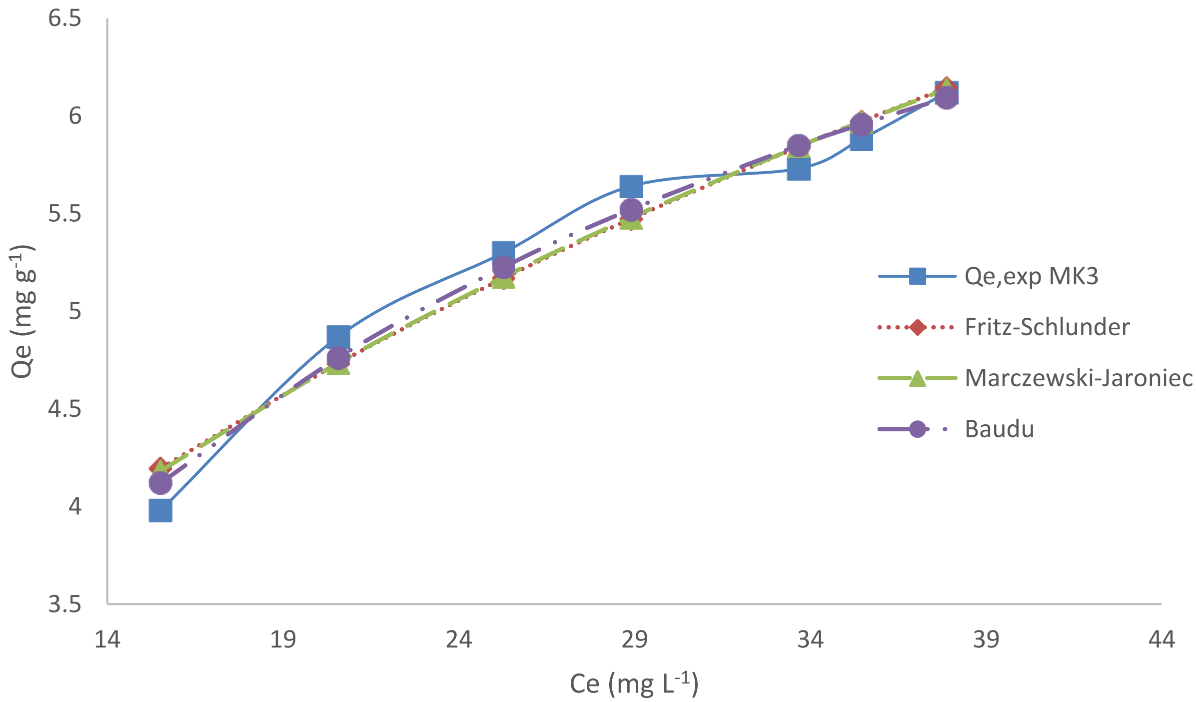

Figure 12. Comparison of measured and calculated Q_e values for four-parameter isotherms onto activated carbon MK3.

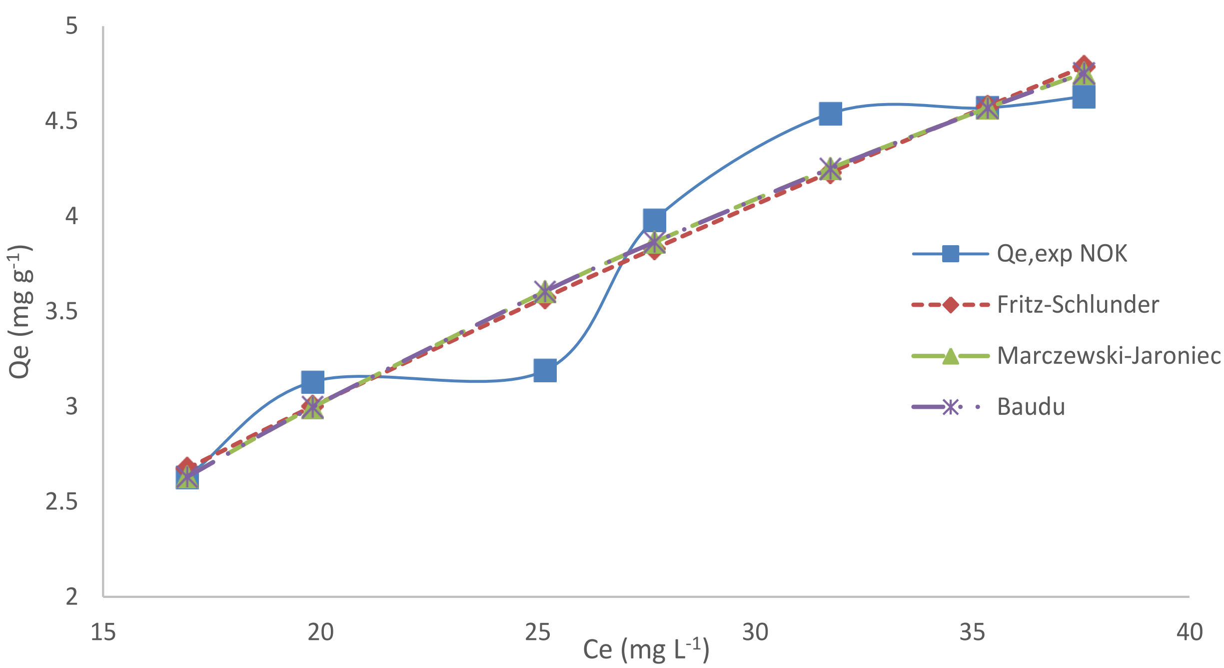

Figure 13. Comparison of measured and calculated Q_e values for four-parameter isotherms onto activated carbon NOK.

data in the best way respectively for NOK and MK3. For three-parameter models, Sips isotherm model was the best model. For four-parameters Baudu isotherms fit the data in the best way for NOK and MK3. Therefore, it can be concluded that the adsorption of 2,4-diniphenol is favorable onto NOK and MK3, and that all these activated

Table 9. Optimum isotherm parameters and their statistical comparison values for four-parameter models.

N°	Models	Constants	Values	R^2	RMSE	χ^2	hybrid	ARE	EABS
MK3									
1	Fritz-Schlunder	q_{mFS} (mg g^{-1}) K_{FS} (mg g^{-1}) q_m (mgg^{-1}) M_{FS}	40.7699 2.401 74.890 0.574	0.956	0.363	0.027	0.913	2.508	0.878
2	Marczewski-Jaroniec	q_{MMJ} (mgg^{-1}) K_{MJ} n_{MJ} M_{MJ}	221.135 0.065 0.156 0.891	0.960	0.349	0.025	0.839	2.405	0.843
3	Baudu	q_m (mg g^{-1}) b_0 x y	6.577 0.067 0.025 0.064	0.977	0.268	0.014	0.481	1.865	0.663
NOK									
1	Fritz-Schlunder	q_{mFS} (mg g^{-1}) K_{FS} (mg g^{-1}) q_m (mg g^{-1}) M_{FS}	5.79837 0.537 8.412 0.283	0.917	0.555	0.081	2.801	4.561	1.179
2	Marczewski-Jaroniec	q_{MMJ} (mg g^{-1}) K_{MJ} n_{MJ} M_{MJ}	14.250 0.030 0.786 1.345	0.919	0.549	0.080	2.828	4.179	1.078
3	Baudu	q_m (mg g^{-1}) b_0 x y	1.762 0.056 0.079 0.358	0.920	0.550	0.080	2.821	4.179	1.078

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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