OPEN ACCESS

African Journal of Environmental Science and Technology

September 2021
ISSN 1996-0786
DOI: 10.5897/AJEST
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJEST

African Journal of Environmental Science and Technology (AJEST) provides rapid publication (monthly) of articles in all areas of the subject such as Biocidal activity of selected plant powders, evaluation of biomass gasifier, green energy, Food technology etc. The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles are peer-reviewed

Indexing

The African Journal of Environmental Science and Technology is indexed in:

CAB Abstracts, CABI's Global Health Database, Chemical Abstracts (CAS Source Index), China National Knowledge Infrastructure (CNKI), Dimensions Database, Google Scholar, Matrix of Information for The Analysis of Journals (MIAR), Microsoft Academic

AJEST has an h5-index of 14 on Google Scholar Metrics

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Environmental Science and Technology is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

All articles published by African Journal of Environmental Science and Technology are licensed under the Creative Commons Attribution 4.0 International License. This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited. Citation should include the article DOI. The article license is displayed on the abstract page the following statement:

This article is published under the terms of the Creative Commons Attribution License 4.0
Please refer to https://creativecommons.org/licenses/by/4.0/legalcode for details about Creative Commons Attribution License 4.0

Article Copyright

Self-Archiving Policy

The African Journal of Environmental Science and Technology is a RoMEO green journal. This permits authors to archive any version of their article they find most suitable, including the published version on their institutional repository and any other suitable website.
Please see http://www.sherpa.ac.uk/romeo/search.php?issn=1684-5315

Digital Archiving Policy

The African Journal of Environmental Science and Technology is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.
https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Environmental Science and Technology encourages metadata harvesting of all its content. The journal fully supports and implement the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

OPEN ACCESS

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

creative commons

All articles published by Academic Journals are licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited.

Crossref

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

<idpf>

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajest@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJEST

Submit manuscript online http://ms.academicjournals.org

Academic Journals
73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor,
Kenyatta Avenue, Nairobi, Kenya.

Table of Content

Characterization of healthcare waste in Tanzanian zonal referral hospitals as a key factor for energy recovery 349
P. R. Mwaria, M. E. Kaseva and S. V. Manyele

Physicochemical and metal quality evaluation of the ground water of the chief town of Sinthiou Maléme Commune in Tambacounda (Senegal) 366
Maoudo Hane, Ibrahima Diagne, Momar Ndiaye, Cheikh Tidiane Dione, Dame Cissé, Birame Ndiaye and Abdoulaye Diop

Community views on water demands under a changing climate: The case of River Mpanga Water Catchment, Western Uganda 371
Isaac Mugume, Ronald Semyalo, Peter Wasswa, Triphonia Ngailo, Ronald Inguula Odongo, Joyce Lunyolo and Sulin Tao

Evaluating the rate of total electron content (TEC) production in ionosphere F2-layer to highlight winter anomaly by running thermosphere-Ionosphere-electrodynamics general circulation model 379
Emmanuel Nanéma, Moustapha Konaté, Christian Zoundi, Amadou Ousseini Kotia, Jean Louis Zerbo and Frédéric Ouattara

Biodegradation of hydrocarbon by Enterobacter sp IAA-01 isolated from hydrocarbon exploration site soil of Kukawa Northeastern Nigeria 384
Ibrahim A. Allamin, Falmata B. Dungus, Haruna Y. Ismail, Gambo Ismail, Usman Buka1, Hussaini Shettima and Amina U. Faruk

Vol. 15(9), pp. 349-365, September 2021
DOI: 10.5897/AJEST2020.2917
Article Number:B0435F667577
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Characterization of healthcare waste in Tanzanian zonal referral hospitals as a key factor for energy recovery

P. R. Mwaria[1], M. E. Kaseva[1] and S. V. Manyele[2*]

[1]Department of Environmental Engineering, School of Environmental Science and Technology (SEST), Ardhi University Dar es Salaam, Tanzania.
[2]Department of Chemical and Mining Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania.

Received 6 September, 2020; Accepted 20 April, 2021

In this study, healthcare waste (HCW) generated in four referral hospitals in Tanzania namely: Muhimbili National Hospital (MNH), Kilimanjaro Christian Medical Center (KCMC), Bugando Medical Center (BMC) and Tumbi Regional Referral Hospital (TRRH) was characterized to establish its feasibility for energy recovery. The HCW collected and loaded into the incinerators was weighed and its composition determined (as highly infectious, infectious, sharps and non–infectious waste). To achieve effective energy recovery, waste segregation and color coding system were assessed. The moisture content and heating values of the waste were determined experimentally, ranging from 9.3 to 9.9 MJ/kg. Using interviews, direct observations and field measurements, the HCW generation rates, number of patients per day, number of beds and incineration rates in each health care facility were determined. Results indicated that the HCW generated were 2345, 789, 807 and 232 kg/day at MNH, KCMC, BMC and TRRH, corresponding to 1.34, 1.02, 1.1 and 0.76 kg/capital/day, respectively. The major component of the waste stream was infectious waste (which ranged from 34 to 76%). The moisture content ranged from 16 to 72% with the mean value of 43%. Further analysis on the characteristics of HCW indicated high potential for energy recovery from waste incineration.

Key words: Waste characterization, waste generation rate, waste segregation, moisture content, calorific value of waste, composition of healthcare waste, incineration, heat recovery.

INTRODUCTION

Healthcare waste is the waste that is collected from hospitals, clinics and medical offices, ambulatory, surgical center, urgent care clinics, nursing homes, blood banks, birth centers and hospice homes (WHO, 2000). According to Diaz et al. (2008) developing countries face severe problem in managing the healthcare waste (HCW) because segregation of waste at the production point is not done adequately and in most of these

*Corresponding author. E-mail: smanyele@udsm.ac.tz. Tel: +255 654 994 277

countries HCW is still handled and disposed of together with domestic waste. According to Yu et al. (2014), the composition of HCW differs from one healthcare facility (HCF) to another depending upon the economic and cultural status of the patients and condition of the area where the HCF is located. Most literature give explanations about the risks associated with HCW such as air pollution and human health risks, but few literatures consider HCW as potential sources of heat energy (Bujak, 2009). Furthermore, in developing countries, energy reach waste which is potential for energy recovery is discarded. Mohee (2005) revealed that, an understanding of the characteristics of the waste to be incinerated is an important step for waste to energy practices. WHO (2016) pointed out that healthcare waste can be characterized by quantity, composition, bulk density, color coding and heating value. Diaz et al. (2008) contended that for energy recovery practices, it is necessary to characterize waste by quantity, composition as well as by heating value. WHO (2007) also suggested that, waste should be characterized according to material or its classification (e.g., sharps or infectious, pathological, chemical, radioactive, or non–risk waste, and by waste generation rate. Manyele and Lyasenga (2010) stated that if HCW is not properly sorted during generation, its handling becomes even more difficult due to contamination and sharps injuries. In the absence of adequate information on the characteristic of waste, it is not possible to design incineration plant for heat energy recovery. UNEP (2012) reported the type of waste treatment technology to be dependent on waste characteristic, environmental concerns and legal requirements in the specific region.

Marinkovic et al. (2008) reported that in the developed countries, hospital waste is segregated into color-coded and labeled bags or containers, but in developing countries, the implementation of the standards varies from one place to another. Bdour et al. (2007) describe the related issues to be lack of proper source segregation, lack of color coding and lack of records relating to waste composition and quantity. Consequently, some waste components such as pharmaceutical and domestic waste are mixed together. Stanković et al. (2008) pointed that in some cases, nothing is segregated except sharps. Shareefdeen (2012) revealed that sometimes carelessness of the paramedic staff results in mixing of non-hazardous waste and hazardous waste items such as human organs and radioactive items. Hence lack of source segregation, lack of color coding, lack of record keeping and carelessness of the staff are observed as some of the main issues leading to poor segregation practices across HCFs in the developing countries. Kagonji and Manyele (2011) reported that in Tanzania waste segregation is not done at the generation points because of poor environmental awareness as well as lack of financial capacity to procure waste bags and waste bins for segregation of waste. Waste collectors usually transfer some of the waste mixed up irrespective of the types and hazards posed by the waste involved. In this research, waste segregation at the selected HCFs is studied.

In Tanzania, generation of healthcare waste (HCW) has increased in the past ten years due to the increased number and size of HCFs, medical services and use of disposal medical products. In the study by Manyele and Lyasenga (2010) it was reported that there was a serious inadequacy in handling medical solid wastes in Dar es Salaam City. Due to poor control of wastes, hazardous wastes reached the dumpsite without notice. In addition, they have reported that, data on waste generation in Dar es Salaam was in adequate, making it difficult to plan for an efficient medical waste management system. Currently, within the HCFs in Tanzania, waste characterization is done only by color coding. According to Eleyan et al. (2013) color coding allows the waste to be categorized as highly infectious, infectious, non-infectious and sharps. In this study, HCW from the selected HCF's in Tanzania were characterized by quantity, composition and heating value notably, an understanding of the composition of HCW is fundamental for deciding on waste handling disposal alternatives and hence on WTE options. Diaz et al. (2008) pointed that proper characterization of the waste can also prevent accidents and exposure to waste by handlers including operators of the treatment facility. Waste characterization also provides the knowledge about heating value which is important when considering heat recovery from the incineration of waste (Bujak, 2010).

Calorific value of waste

Calorific value of medical waste is an important data for incineration, which governs the design and operation parameters of the incinerators. According to Yu et al. (2014), calorific value of waste is governed by the composition of the waste. In order to estimate the calorific value of the waste mix an average of the waste composition is found. Bujak (2010) revealed that knowledge of the low calorific value of the waste enables the estimation of the quantity of secondary fuel or the determination of the energy efficiency of an incinerator that integrates heat recovery system. Yu et al. (2014) pointed that a material can burn without supporting fuel when it has a calorific value of minimum 14.4 MJ/kg, this is almost dry wood. Bujak (2010) contended that, to know the overall calorific value of the waste, one need to measure the calorific value or estimate by analyzing the waste composition. Mohee (2005) commented that if the amount of waste is known, and the calorific value of the waste is known, it is possible to design the size of the incinerator and flue gas treatment system. According to Bujak (2010), there are two kinds of methods of measuring calorific value currently. The first is to estimate the calorific value of waste by element analysis (proximate analysis); the second is to measure calorific value of mixed sample by Bomb Calorimeter (ultimate analysis). However, there are great differences between the measured value by these two methods and the actual value because of the complex chemical elements of HCW. Since the ultimate analysis requires very expensive equipment and highly trained analyst, this research has opted for proximate analysis which requires standard laboratory equipment which is easy to run by a well-equipped scientist or engineer. In proximate analysis as the model for determining HHV/CV, the applied calculations are performed using Equation 1:

$$HHV = 0.3536F_C + 0.1559V_M - 0.0078A_C \quad (1)$$

where, V_M = Volatile matter; F_C = Fixed carbon; HHV = high heat value (in MJ/kg)

Colour coding for waste containers

Surveys have shown that an appropriate method of characterizing and segregating the waste is by sorting the waste into different colour code. However, there is no standard colour code to follow by all countries for the medical segregation. In this research, characterization of HCW according to color coding established by the WHO, have been studied.

According to Marinkovic et al. (2008) the element that is a deficiency in the existing colour coding system for the medical waste segregation is, unavailable of different containers for the subdivisions of medical waste. WHO (2011) recommends the subdivision of medical wastes as followed: microbiological waste, pathological waste, sharps, pharmaceutical waste, chemical waste, radioactive waste, non-recyclable waste and recyclable waste. Therefore, different colour coding has to be assigned to different waste for effective segregation. Thus, the recommended colour codes with few amendments are as shown in Table 1. According to WHO (2011), all waste must be segregated at the point of generation and all containers must bear international symbols with appropriate coding. Containers should never be filled above the ¾-full line indicated on the safety box.

Heat recovery from HCW

Bujak (2010) revealed that during the incineration, energy in the form of heat can be recovered from the incineration plant and be used for other purposes. He pointed that this is called waste to energy or energy from waste. Waste-to-energy (WtE) or energy-from-waste (EfW) is the process of producing energy in the form of heat from the primary treatment of waste or the processing of waste into a fuel source. Kothari et al. (2010) contended that most WtE processes generate electricity and/or heat right through combustion, or produce a combustible fuel commodity, such as methane, methanol, ethanol or synthetic fuels. Bujak (2009) reported that countries or regions with successful energy-from-waste sectors have ensured that energy-from-waste goals are incorporated into both their energy policies and their waste management policies. For example, in 2000, the European Union announced a “Green Paper” designed to protect energy resources, and established a road map to accomplish renewable energy targets. At the same time, it has forbidden the direct landfilling of wastes that can be converted to energy, in line with the Landfill Directive published in 1999. Psomopoulos et al. (2013) reveals that in Europe, heat and electricity from waste, distributed to households and industry substitutes the energy produced by conventional power plants, using fossil fuels. This helps to cut down CO_2 emissions and to reach the goal of 20% reduction of greenhouse gases by 2020.

Despite of its potential benefits to healthcare facilities in Tanzania, energy recovery from incineration of HCW has not been fully practiced because of a number of challenges. Bujak (2009) pointed that (WtE) project must meet certain basic requirements. In particular, the energy content of the waste, the so-called lower calorific value (LCV) of the waste must be at least 6 MJ/kg or above, throughout all seasons. The annual average lower calorific value must not be less than 7 MJ/kg (UNEP, 2012). The specific composition of the waste is also important. For instance, an extreme waste composition of only sand and plastics is not suitable for incineration, even though the average lower calorific value is relatively high. Furthermore, in order to operate the incineration plant continuously for energy recovery, waste generation must be fairly stable during the year.

RESEARCH METHODOLOGY

Study areas

Muhimbili National Hospital (MNH), Kilimanjaro Christian Medical Centre (KCMC), Bugando Medical Centre (BMC) and Tumbi Regional Referral Hospital (TRRH) were chosen to be the study areas in order to have comparison between National Referral Hospital (MNH) and other referral hospitals that are up country, with adequate interactions as indicated in Table 2. Also, to have difference between government and private owned facilities. The selected HCF was also suitable for this research in terms of availability of adequate information and data.

Data collection methods

Methods of data collection used in this study were interviews, direct

Table 1. Suggested colour code for different types of medical wastes (WHO, 2011).

No.	Color coding	Healthcare waste
1.	Red	Microbiological waste
2.	Yellow	Pathological waste
3.	Blue	Sharps waste (in a leak proof and puncture- resistant container)
4.	Brown	Pharmaceutical waste
5.	Orange	Chemical waste
6.	Silver	Radioactive waste
7.	Black	Non-recyclable waste
8.	Green	Recyclable waste

Table 2. Detail of the study area.

No.	Details	MNH	KCMC	BMC	TRRH
1.	Region	DSM	Kilimanjaro	Mwanza	Coastal region
2.	No of beds	1500	640	910	253
3.	Daily in patients	1200	520	650	180
4.	Bed occupancy rate	1380	580	850	210
5.	Daily out patient	1800	800	850	440
6.	No of staff	2700	1600	1200	420
7.	Ownership	Government	Private	Private	Government

observations on the waste management practices and direct measurements of the waste. In determining quantities of waste, healthcare workers were oriented on waste segregation. Waste was thus collected already segregated at the production point from every department and service delivery points. Composition of the waste from each HCF was observed and noted according to labels on the polythene bags, namely; high infectious waste, infectious waste, sharps, non–infectious waste and food waste, following colour coding procedures as recommended by WHO (2011). Other wastes such as radioactive waste, pharmaceutical waste and pressurized containers were not included in this study due to the fact that they cannot be incinerated. The waste was then weighed using top loading balance (model MB 640). The weighing exercise continued for 28 days. The average of waste generated per day was determined using Equation 2:

$$w = \frac{w_1+w_2+\cdots+w_n}{n} \qquad (2)$$

where w = average waste generated per day, w_i = daily waste generation recorded for n days.

The aim of conducting HCW weighing exercise was to determine the amount of waste which was collected at each HCF per day. Data obtained were used in the selection of proper type of incineration facility that could incinerate the waste collected at the particular HCF, aiming at recovering energy from the incineration of the waste. According to Diaz (2005), the design capacity of the incineration facilities normally ranges from 20 kg/h for intermittent duty, pathological and non-pathological systems to 2,830 kg/h for continuous-duty systems. For batch units, the capacities range from 70 kg/batch to 1,720 kg/batch. Appropriate precautions were taken during measurements whereby; protective gears like gloves, coats, and mask were worn as Personal Protective Equipment (PPE) for hygiene purposes.

Determination of waste composition

Since waste was collected already segregated in color coded bags, each bag was weighed separately, thus the percentage composition of each waste category was found using Equation 3:

$$P_c = \frac{w_j}{w_{cd}} \times 100\% \qquad (3)$$

where, w_{cd} = total waste collected per day (kg/day); P_c = percentage composition of each waste category (%), and w_j = total waste category generated per day (kg/day).

Determination of moisture content (M_C)

Table 3 shows the number of waste samples taken during laboratory analysis for determination of moisture content. A total of 32 samples were analyzed.

Table 4 summarizes distribution of waste samples collected from different HCFs during laboratory analysis for moisture content determination. The weights of samples after drying for 2 h at 105°C are also indicated. In Table 4, all symbols denoted by W, stands for measured weights, whereby, W_1 = fraction of all HCW; W_2 = pieces of boxes and papers; W_3 = food waste; W_4 = yard waste and pieces of boxes; Wd_1 = fraction of all HCW after drying; Wd_2 = pieces of boxes and papers after drying; Wd_3 = food waste after drying; and Wd_4 = yard waste and pieces of boxes after drying.

Table 3. Number of waste samples taken for determining moisture content.

Healthcare facility	Number of waste sample	Percentage (%)
MNH	16	50.00
KCMC	10	31.25
BMC	6	18.75
Total	32	100.00

Table 4. Moisture content for the samples selected from the selected HCFs.

HCF	Weight of raw waste samples				Weight of samples after drying			
	W_1	W_2	W_3	W_4	Wd_1	Wd_2	Wd_3	Wd_4
MNH	500	150	500	300	126	126	360	252
KCMC	500	500	300	-	260	155	225	-
BMC	500	500	300	-	320	344	235	-
TRRH	500	500	300	-	290	145	240	-

The moisture content of HCW was measured by using oven drying method. The empty dried crucible was weighed, and then the sample was placed on it and weighed together. Then they were dried in the oven at 105°C for 2 hours and weighed again. Then they were dried in the oven at 105°C for 2 hours and weighed again. The moisture content of the sample was calculated using Equation 4:

$$M_c\% = \frac{W - Wd}{W} x100 \quad (4)$$

Determination of high heating value (HHV) of HCW

In this study, each of the 32 samples used for determining moisture content was used to determine the HHV (calorific value). Yu et al. (2014), defined Calorific value as the amount of heat released for every unit dry mass of the waste burnt. Waste with high calorific value produces more heat than those with low values. According to Bujak (2015a, b), high amount of heat produced by dry waste provide additional fuel for incinerating the waste thus reducing the overall cost for fuel. If the released heat is significant, heat energy recovery options can be considered. A high calorific measurement implies that the waste could be suitable for incineration combined with heat energy recovery (Yu et al., 2014).

Laboratory analysis

In order to establish thermal energy potential (Calorific value) of HCW, proximate analysis which involve determination of moisture content as physical characteristics, volatile matter, ash content and fixed carbon was performed. The proximate analysis was done in order to estimate the calorific value of HCW. Samples from MNH, KCMC, BMC and TRRH were distributed in different categories for execution of proximate analysis.

Volatile matter (V_M)

The crucible with samples after drying (W_d) which was used during measurement of moisture content was covered with lid and then taken into muffle furnace, which was maintained at 950°C for 7 minutes (ASTM D-3175). The sample was cooled in air and weighed again as W_v. Loss in weight was reported as a volatile matter on percentage basis. Equation 5 shows the calculation of volatile matter.

$$V_M = \frac{W_d - W_v}{W} X100\% \quad (5)$$

Where; W_v = Sample from muffle furnace (after being heated at 750°C, for 2 h (gram)

Ash content (A_C)

The residual sample in the crucible (W_V) was heated without lid in a muffle furnace at 750°C for 30 minutes (ASTM D-3174). The crucible was taken out, cooled first in air, then in desiccators and weighed as W_A. The residue was reported as ash on percentage basis. And it was calculated by Equation 6:

$$A_C = \frac{W_V}{W_A} X100\% \quad (6)$$

Fixed carbon (F_C)

Since the material composition (100%) comprises of M_C, V_M, A_C and F_C, then to calculate F_C was just matter of algebra. F_C was calculated using Equation 7:

$$F_C\ \% = 100\% - (\%A_C + \%V_M + \%\ M_C) \quad (7)$$

The High Heating Value (calorific value) for each selected sample was calculated using Equation 8:

$$HHV = 0.3536F_C + 0.1559V_M - 0.0078A_C\ (MJ/kg) \quad (8)$$

Table 5. Determination of HHV for the selected waste samples.

Referral hospital	Sample	M_C	V_M	A_C	F_C	HHV (MJ/kg)	Average HHV (MJ/kg)
MNH	W_1	49	33	10	08	7.8955	9.9
	W_2	39	48	02	11	11.3572	
	W_3	72	16	07	05	4.2028	
	W_4	16	46	04	25	16.3076	
KCMC	W_1	48	33	08	11	9.6791	9.3
	W_2	25	55	05	14	13.4858	
	W_3	64	17	11	08	5.3933	
BMC	W_1	40	36	11	13	10.1234	9.8
	W_2	21	57	06	15	14.1045	
	W_3	60	21	13	06	5.2941	
TRRH	W_1	43	34	12	12	9.4502	9.3
	W_2	20	58	10	12	13.2074	
	W_3	62	20	11	07	5.5074	

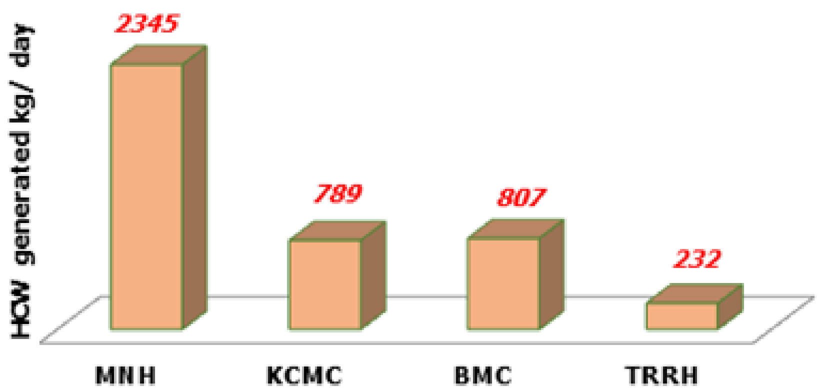

Figure 1. Total amount of waste generated in the Studied HCF.

Details are given in Table 5 for the four referral hospitals.

Estimation of Heat generation from waste incineration using HHV, data generated experimentally, the heat that can be generated from the waste for a given referral hospital was estimated from Equation 9:

$$Q_{gen} = HHV \times W_t \quad (9)$$

where, W_t = waste generation rate per day, excluding food waste.

RESULTS AND DISCUSSION

Total HCW generation in the selected HCFs

The amount of HCW generated were established to be 2345, 789, 807 and 232 kg/day in MNH, KCMC, BMC and TRRH, respectively, as shown in Figure 1. Another study on HCW generation rate in Dar es Salaam (Manyele, 2004), which included four sampled HCF's, (MNH, Mwananyamala, Agha Khan and University of Dar es Salaam health centre, established generation rate at MNH to be the highest. This study has established similar results in referral hospitals as indicated in Figure 1. Also, results from this study have shown that the lowest generation rate and per capital in the studied HCFs was from TRRH which has a generation rate of 232 kg/day and the generation rate of 0.76 kg/c/day. Literature data on the other hand, shows higher rate of medical waste generation of about 2,250 kg/day in Amana and 2,500 kg/day in Ligula hospital (Kagonji and Manyele, 2011).

According to Anicetus et al. (2020), waste generation rates were reported to be 325, 299, 143.4 and 232 for

Table 6. Quantity of waste produced in respect to number of beds in the studied referral hospitals.

HCFs	No. of beds	Inpatients	Waste in kg/day	kg/bed/day	kg/c/day
MNH	1500	1800	2345	1.56	1.30
KCMC	640	1000	789	1.23	0.79
BMC	910	800	807	0.89	1.01
TRRH	253	400	232	0.92	0.58

Table 7. Medical waste generation rates at Dar es Salaam (Kaseva et al., 1999).

Hospital	No. of beds	kg/c/day
Hindu Mandal	70	0.37
Amana, Ilala	130	0.26
UDSM Health centre	24	0.41
Temeke	140	0.15
Kariuki Mikocheni	150	0.79
Aga Khan	88	1.3

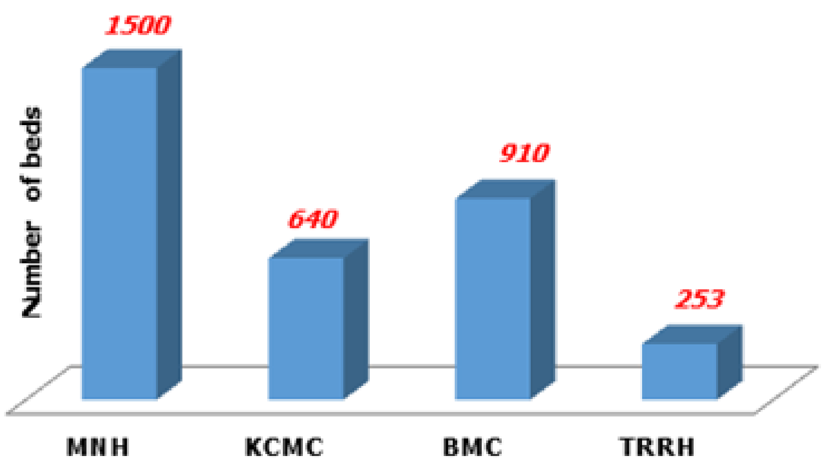

Figure 2. Number of beds in each of the selected HCFs.

MNH (based on waste collected at the small-scale incinerator), Mwananyamala Regional Hospital, Ilala Regional Hospital and Temeke Regional Hospital, respectively. Also, another study (Manyele, 2004) which was conducted outside Dar es Salaam reported that the rate of waste generation at a given hospital increases with the number of beds available and the occupancy rate (Table 6 and 7). This study has established similar results as presented in Tables 6 and 7. Figure 2 indicates the number of beds in each of the selected HCFs. Table 8 summarizes the color codes used for different HCW as observed in the selected zonal referral hospitals, composition of which was estimated by actual measurements as reported also by Kagonji and Manyele (2011).

Waste generation rate based on number of patients

Results obtained indicated that the mean value of waste generation rate was 1.30, 0.71, 1.00 and 0.51 kg/c/day for MNH, KCMC, BMC and TRRH, respectively, as indicated in Figure 3. In another study (Mato and Kaseva, 1999), it was indicated that waste generation for other HCFs in Dar es Salaam City (Hindu Mandal, Amana,

Table 8. Physical composition of waste at the selected HCFs.

HCF	Types of HCW	Color	Physical composition	Composition (%)
MNH	Infectious waste	Red	Pathological waste, placentas, condoms, pampas, blood serum, contaminated cotton, blood vessel, catheters, gloves and bandages, cannulas, blood bags, sanitary pads etc.	40.6
	Sharps	White/ yellow	Needles, scissor, slide, pinhead, glass test tubes, glass ampoule, lancets and slide covers	2
	Non - infectious waste	Green/ black	Plastics, bottles, paper waste, cardboards, cotton, bandages, gloves	33.6
	Food waste	Black/ green	Mixed kitchen food	24
KCMC	Highly infectious waste	Red	Blood vessel, placentas, blood bags, blood serum, contaminated cotton, gloves and bandages, pathological waste, sanitary pads, pampas, other blood contamination, catheters etc.	59
	Infectious waste	Yellow	Gloves, cottons, bandages, condoms, cannulas	11
	Sharps	White/ Yellow	Pinhead, glass test tubes, glass ampoule, scissor, lancets, slide covers, broken glass, needles, slide etc.	6
	Non-infectious	Black/ yellow	bottles, paper waste, cardboards, cotton, gauze, boxes, Plastics etc.	11
BMC	Infectious waste	Red	Contaminated cotton, blood bags, placentas, blood serum, blood vessel catheters, gloves, bandages, pathological waste, cannulas, condoms, sanitary pads, pampas etc.	32
	Sharps	Yellow	Pinhead, needles, scissor, slide, glass test tubes, glass ampoule, lancets and slide covers	2
	Non - infectious waste	Black	cardboards, gloves, plastics, bottles, paper waste, cotton, bandages etc.	49
	Food waste	Green	Mixed kitchen food	17
TRRH	Highly infectious waste	Red	Blood serum, blood vessel catheters, needles, syringe, contaminated cotton, gloves, bandages, pathological waste, cannulas, condoms, blood bags, sanitary pads, pampas, placentas, etc.	19
	Infectious waste	Yellow	bandages, condoms, cannulas, Gloves, cottons etc.	33.5
	Sharps	Yellow	Glass test tubes, glass ampoule, lancets, slide covers, broken glass, Pinhead, needles, scissor and slide	1.5
	Non - infectious waste	Black	Cardboards, cotton, gauze, boxes, Plastics, bottles, paper waste etc.	46

UDSM Health Centre, Temeke, Kariuki-Mikocheni, and Aga Khan were established to be 0.37, 0.26, 0.41, 0.15, 0.79, and 1.3 kg/c/day, respectively. Comparing with the results presented in Figure 3, it is evident that generation rate at referral hospitals is higher compared to other lower grade hospitals. According to Kagonji and Manyele (2011), waste generation rate per patient per day was also high about 1.8 (Amana) and 2.0 kg/c/day (Ligula), values of which are higher than those reported in Figure 3.

Waste generation rates based on number of beds

Waste generation rate (kg/bed/day) varied from the lowest (0.91) observed at TRRH to the highest (1.56) observed at MNH. Despite the large number of beds at MNH, the higher rate of waste generation shown in Figure 4 is an indication of higher generation rate in kg/day compared to other HCFs. This can be attributed to the large number of services offered, number of patient's effective waste collection and onsite transportation and storage.

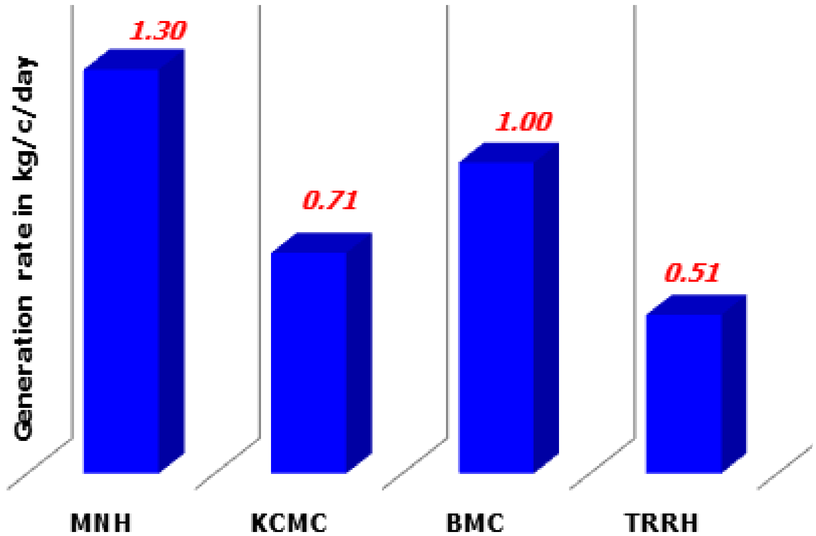

Figure 3. HCW generation rates in (kg/c/day) at studied HCFs.

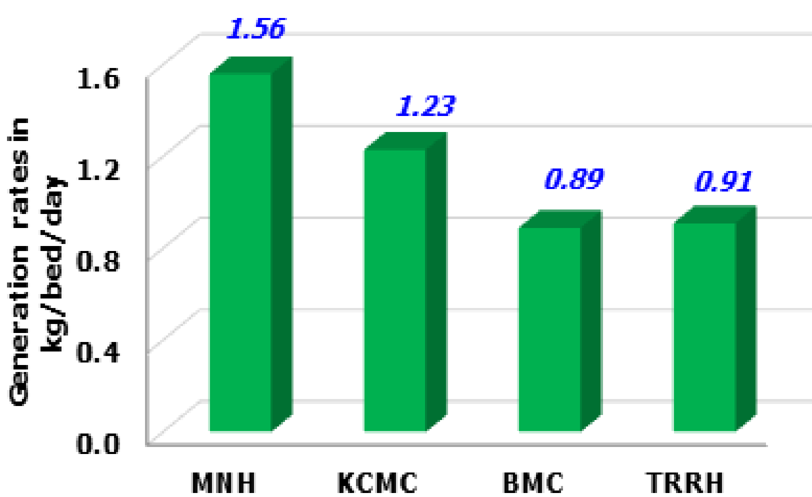

Figure 4. Waste generation rates based on number of beds.

Waste generation in different departments according to waste category

In this study waste in each department was categorized according to waste category namely infectious, sharps and non–infectious. The study reveals that the highest amount of waste generated at MNH was non–infectious in wards, while at KCMC it was sharps in surgical and medical wards. In BMC it was non–infectious in labour ward as indicated in Figure 5. The study reveals further that, among the studied HCFs, all departments at KCMC produced the highest amount of sharps waste, BMC produces the highest amount of non–infectious waste, and BMC produces the lowest amount of sharps waste as indicated in Figure 5. According to Matee and Manyele (2015), the labour ward produced the highest amount of sharps waste followed by Pediatrics ward at MNH. Additionally, higher values of sharp waste generation observed outlines the days with high demand on medical services due to emergency cases referred. Also, this implies that waste generated at KCMC is suitable for incineration with energy recovery because the

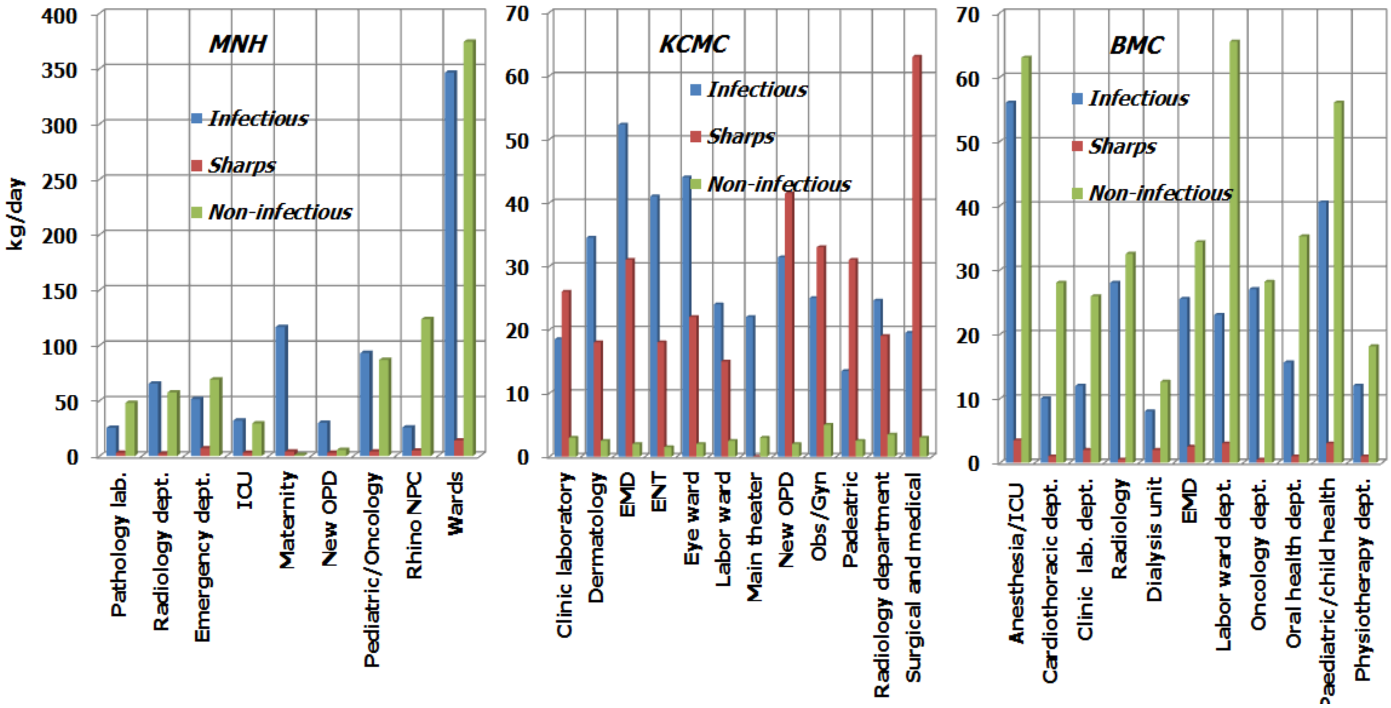

Figure 5. Waste generation rate in different departments according to waste categories.

composition of waste generated contains the highest amount of sharps waste when compared to MNH and BMC. Matee and Manyele (2015) revealed that, during the incineration process, sharps waste plays a big contribution to maximum temperature in the combustion chambers, thus, waste composition and the amount of waste fed into the incineration facility contributes to the incinerator performance. The study also revealed that waste composition at MNH contains the lowest sharp waste generation rate.

Total waste generation rates in different departments

The study on medical waste generation per department in kg/day in each of the research centers (sectional overview) revealed that the highest waste generation rate in MNH was 183.9 in pediatric or oncology, KCMC 85.5 in surgical and medical, BMC 122.5 in Anesthesia/ICU, respectively as indicated in Figure 6. Likewise, the lowest waste generation rate in MNH was 38.6 in OPD, KCMC 25 in theatre and BMC 22.6 in dialysis unit. In most of HCFs, the highest waste generation was found to occur in surgical and gynecology, orthopedic. Medical department produces the lowest amount as reported in the literature (Manyele, 2004). It is worth noting that such inconsistence in waste generation rates is due to the nature of activities performed in each department, number of patients, and nature of treatments in each department. Additionally, such overview will assist the hospital management to prepare effectively waste management weekly reports and annual cost for the waste disposal.

Daily waste generation data for selected waste types

The study reveals that the highest amount of non–infectious waste was produced in MNH, While KCMC generated the lowest amount of non–infectious waste. Also, the study showed that the highest infectious waste was generated in MNH, and the lowest amount was at TRRH. Likewise, the highest amount of sharp waste was generated in KCMC, while the lowest amount was in MNH as indicated in Figure 7. The inconsistence is due to the nature of treatment, technology used and level of waste segregation.

Composition of HCW

In this study, the composition of HCW was determined by considering types of HCW generated, colour coding and physical composition. Since waste was collected already segregated in colour coded bags, each bag was weighed separately. Thus the percentage composition of each waste category was found. Results show that a substantial

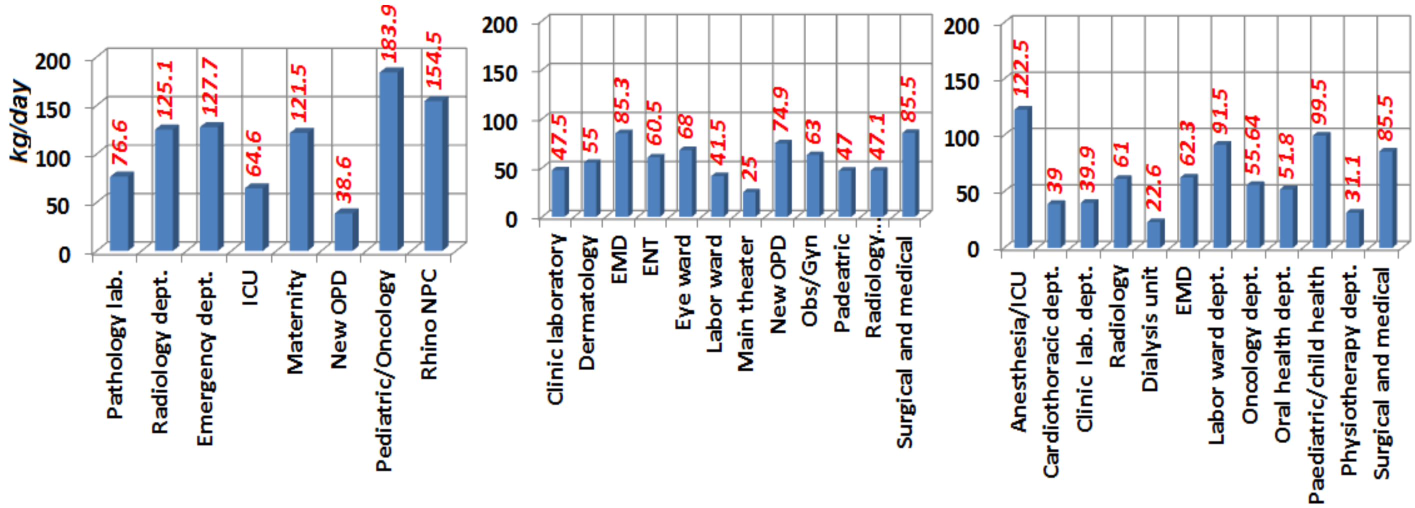

Figure 6. Daily total waste generation rates in different departments for the studied HCFs.

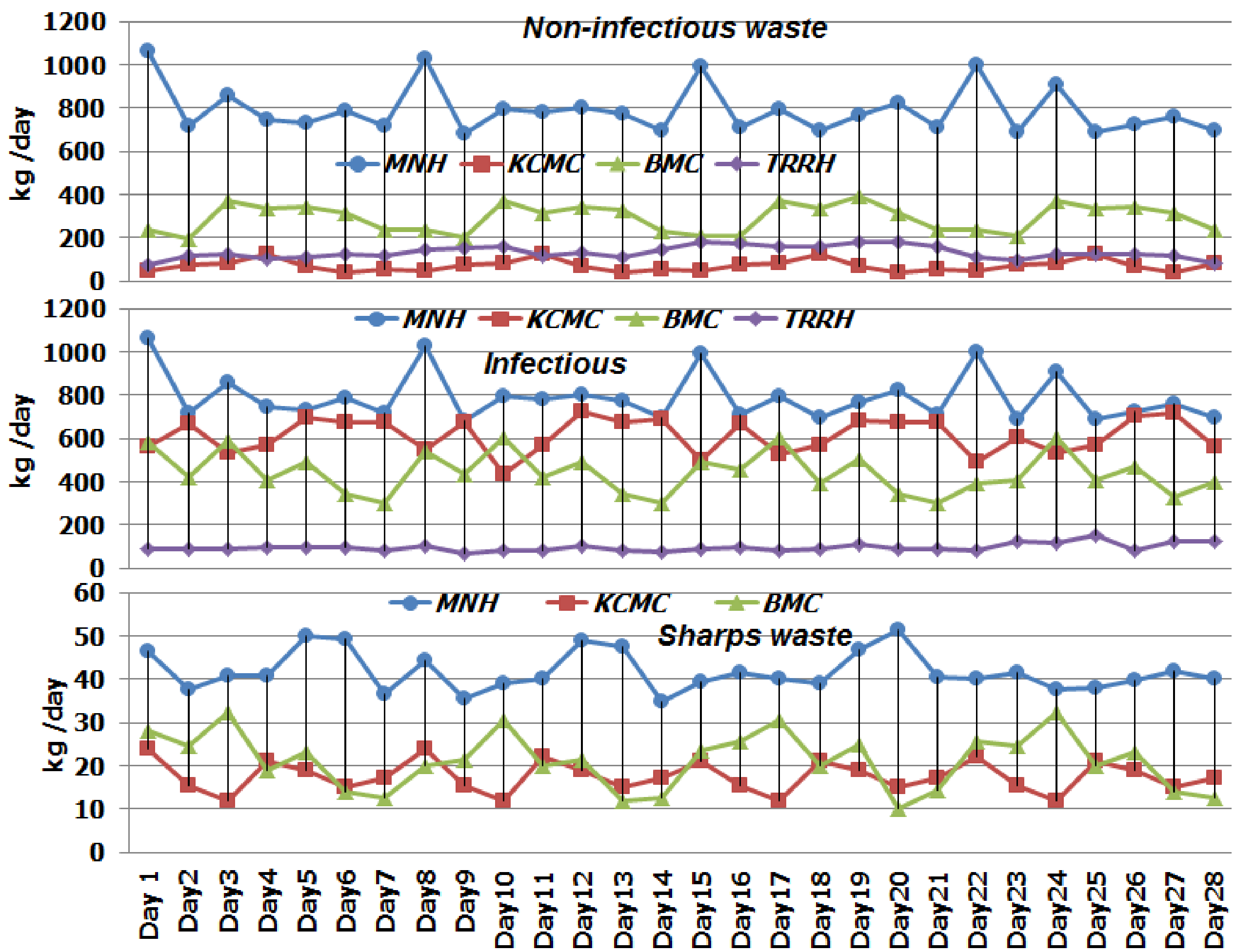

Figure 7. Daily waste generation time series for selected waste types (N = 28 days).

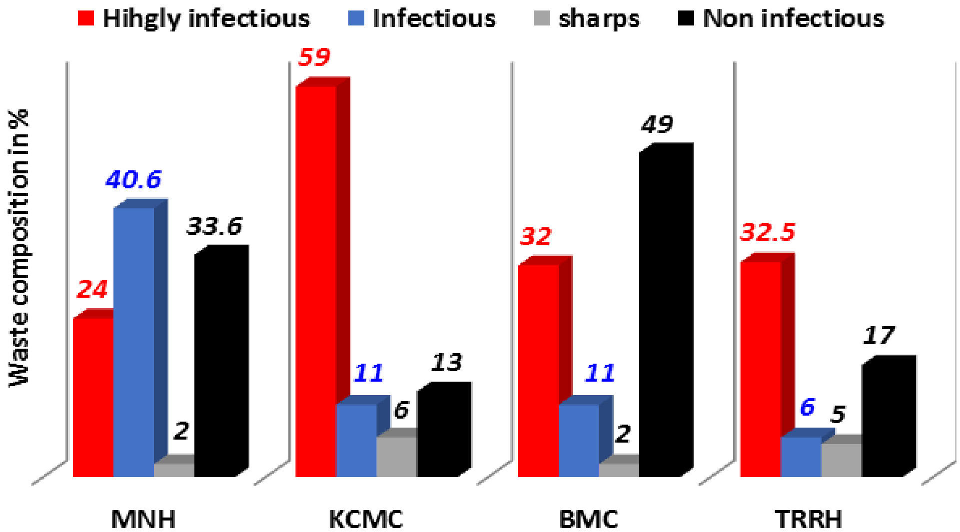

Figure 8. Average waste composition observed in the four referral hospitals.

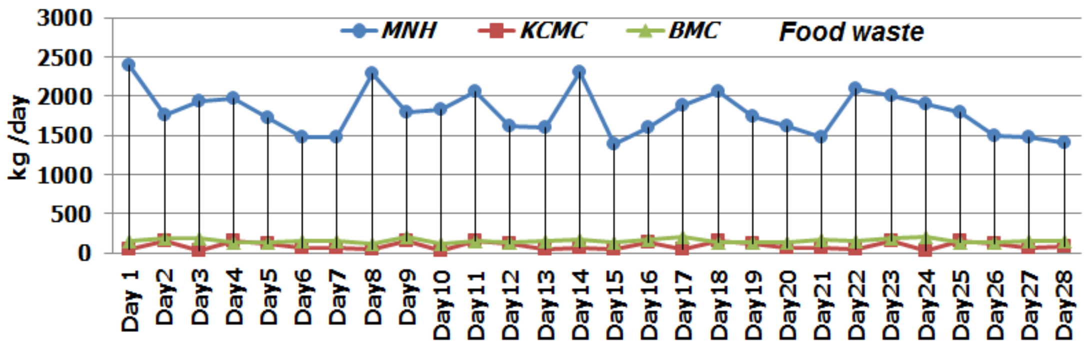

Figure 9. Daily food waste generation rate time series.

amount of waste consisted of paper products, bottles, plastic and textiles in the form of cotton and gauze. Results also show that, the major components in the medical waste stream was hazardous (from 34% to 76%), as indicated in Figure 8. This result indicates that, the percentages of hazardous waste in the studied HCF's are higher compared to the amount given by WHO (2015) which ranges between 10-25%. This is because segregation of the waste at the production point was not properly performed, so hazardous waste was mixed with non-hazardous waste.

In this study, waste segregation by color coding was assessed in four referral hospitals. Results show that KCMC generates 59% of highly infectious waste. This is the highest amount compared to the other selected HCFs as indicated in Figure 8. The reason can probably be that in KCMC the waste was poorly segregated at the production point in such a way that highly infectious waste was mixed with general waste. The other types of waste such as pharmaceutical, chemical, radioactive, recyclable and non-recyclable were not identified in this study because of poor segregation practices. However, there is no typical color code to follow by all countries for the HCW segregation.

Food waste generation rate as a candidate for energy recovery via bio-digestion

The study discovered that the highest amount of food waste was generated at MNH as indicated in Figure 9. In the studied HCFs, food waste generated is incinerated together with infectious waste. Paratosh et al. (2017), revealed that conversion of food waste into energy via

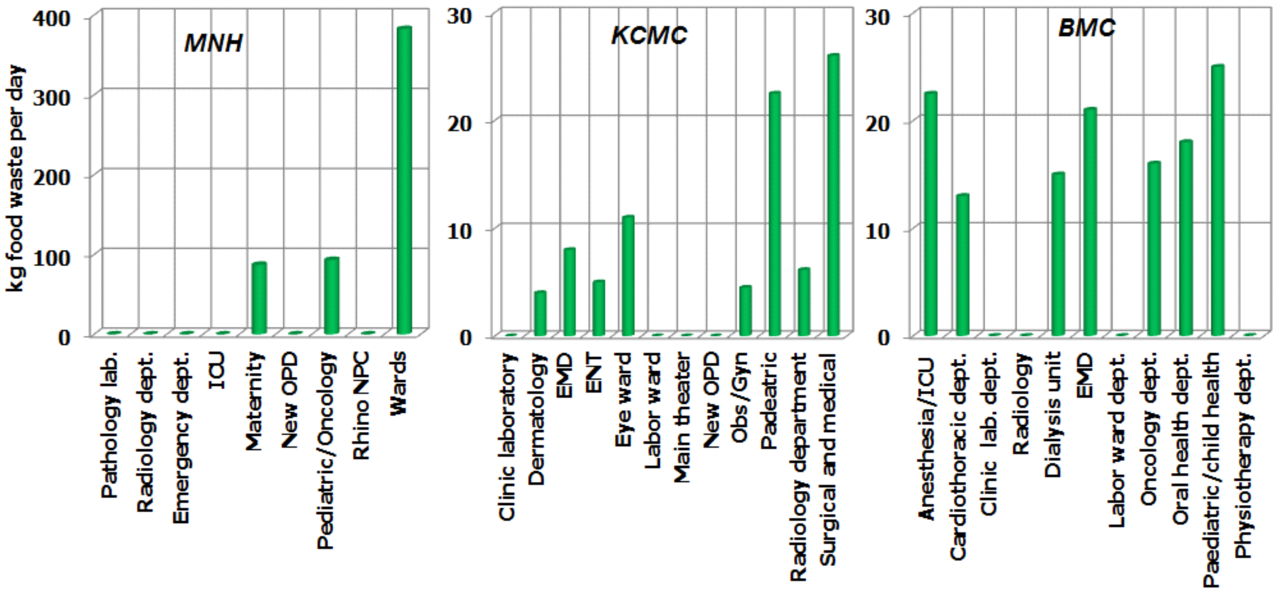

Figure 10. Food waste generation in different HCF departments.

anaerobic processes in terms of methane is economically worthwhile. According to Babalola (2020), the most appropriate alternative aimed at handling food waste is anaerobic digestion followed by composting. Incineration turn out to be the third most suitable alternative in terms of the overall results, while landfilling is presumed to be the worst case because of the substantial costs and low benefits. Generated waste at MNH is suitable for energy recovery via bio–digestion, for generation of bio gas but less suitable for incineration with energy recovery because food waste contains low calorific value.

Food waste generation in the studied HCFs

The study revealed that, departments that generated the highest amount of food waste were wards, surgical and medical, and pediatric in MNH, KCMC and BMC respectively as indicated in Figure 10. The amount of food waste generation depends on several factors such as the rate of in patients and bed occupation rates.

Color coding

Color coding surveys have shown that an appropriate method of identifying and segregating the waste is by sorting the waste into different colour code (WHO, 2011). The deficiency in the accessible colour coding system for the HCW segregation is unavailability of different containers for the subdivisions of the waste. WHO (2011) has suggested subdivision of HCW as follows: microbiological waste, pathological waste, sharps, pharmaceutical waste, radioactive waste, non- recyclable waste and recyclable waste. Thus, different colour coding has to be assigned to different waste for effective segregation as indicated in Table 1. Figure 10 shows the practical interpretation of waste characterization by colour coding in the studied HCFs. From these findings, waste bins covered with respective coloured polyethylene bags were expressed as flows: highly infectious waste-red; infectious waste–yellow and non-infectious waste-black/blue. Sharps waste is collected in the sharps box, yellow coloured as indicated in Figure 11. However, WHO (2011), has recommended further subdivision of the waste collected as indicated in Table 1.

Moisture content of waste

In this study, the moisture content of each of the analyzed sample was obtained, and the average moisture content was calculated, as shown in Figure 12. Results indicated that moisture content ranged from 16 to 72% with the mean value of 43% High moisture content of the waste reduces the heating value of the waste that causes the waste to consume more fuel when incinerated. This study has indicated that average HCW moisture content was high compared to the given standard of 15% by the total weight of the waste (UNEP, 2012). This implies that, more fuel will be needed for the incineration process.

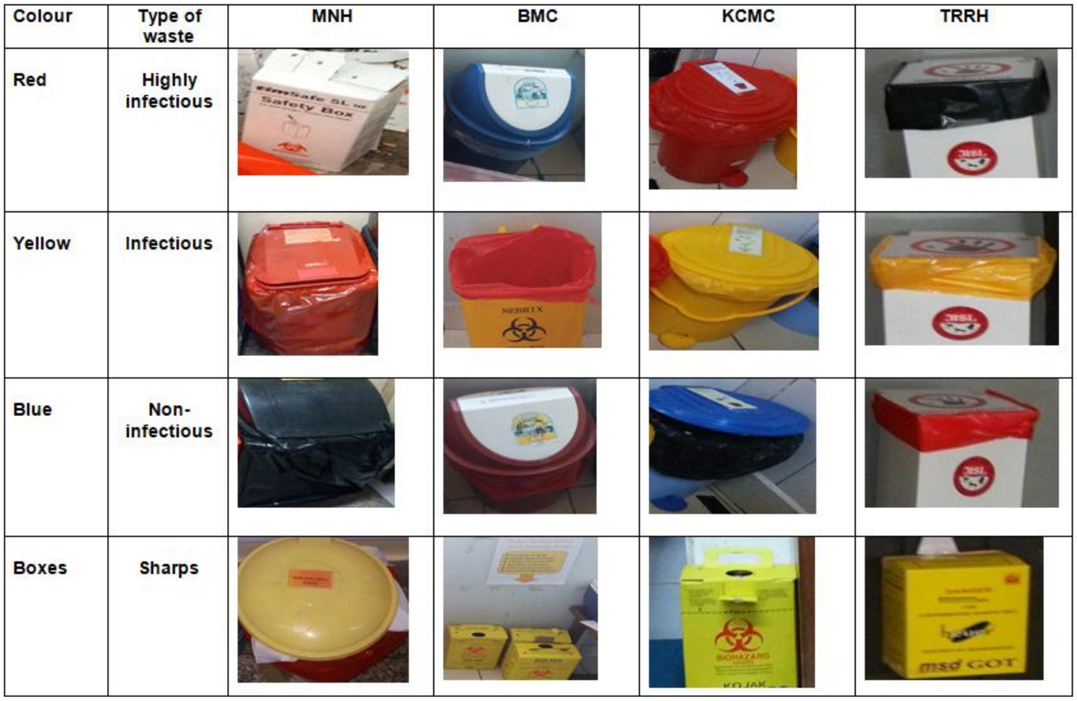

Figure 11. Waste characterization by colour coding in the studied HCF's.

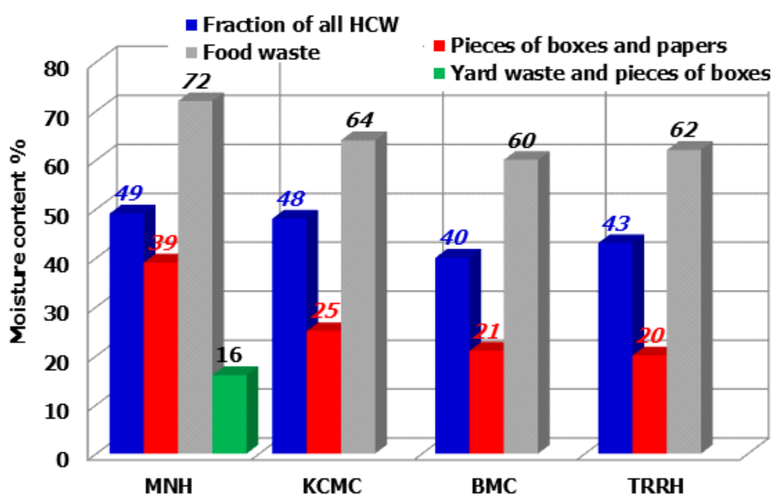

Figure 12. Moisture content of the selected waste samples.

Calorific value (heating value) of HCW

The average calorific value measurements of all samples from MNH, KCMC, BMC and TRRH were 9.9, 9.3, 9.8 and 9.3 MJ/kg, respectively as presented in Table 5. The results show that yard waste and pieces of boxes have the highest percentage calorific value of 16 as presented in Figure 13. The average calorific value of the HCW in MJ/kg ranged from 9.3 to 9.9 with mean value of 9.5. This value is above the recommended value of 7 MJ/kg (UNEP, 2012). This implies that the waste is suitable for incineration with heat energy recovery.

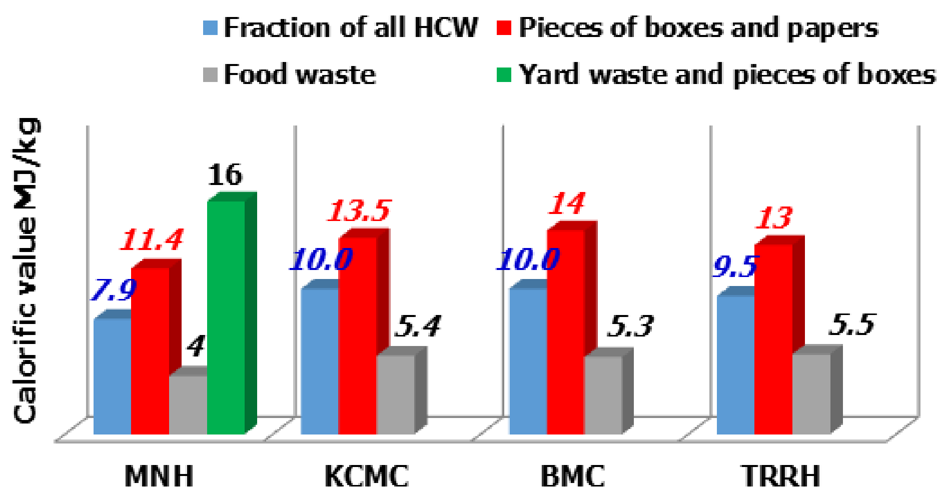

Figure 13. Calorific value of HCW samples in the four HCFs.

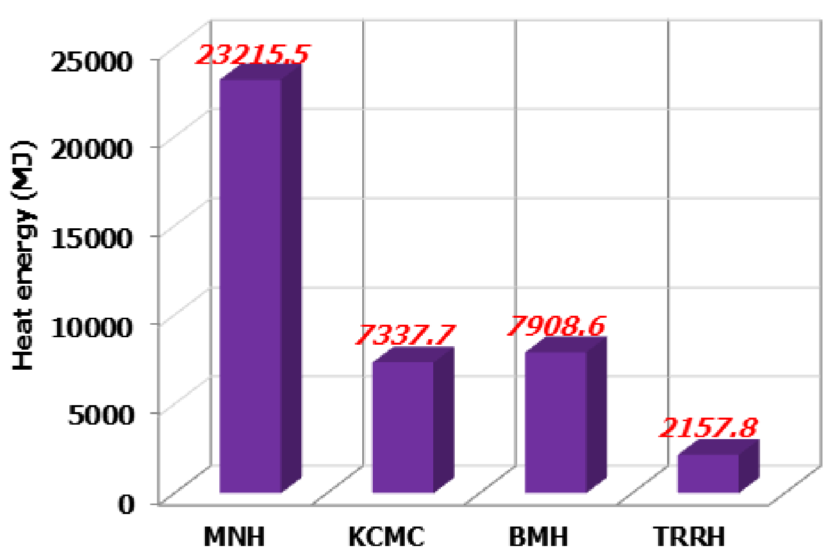

Figure 14. Heat energy generated per day at the selected HCFs.

Estimate of heat that can be generated via incineration based on HHV

The study found out that, heat energy recovered from the incineration of the HCW per day was 23215.5, 7337.7, 7909.6 and 2157.8 MJ/day at MNH, KCMC, BMC and TRRH, respectively, as indicated in Figure 14. The study revealed that, incineration capacity suitable for incineration of the generated waste can range from 50 to 120 kg/h for all the selected HCFs. Based on the results obtained from this study, waste generated from the selected HCFs can be incinerated with energy recovery.

Conclusion

The amount of waste generated at MNH, KCMC and BMC was enough for the sustainable energy recovery except for TRRH. Also, the generation rates at referral HCFs was higher compared to other lower grade HCFs. MNH had the highest waste generation rate based on number of beds among the studied HCFs due to the fact that MNH is the biggest HCF in Tanzania with big number of patients, thus with various services offered. All departments at KCMC produced the highest amount of sharps waste compared to MNH and BMC which produced the lowest amount. This implied that waste generated at KCMC was more suitable for incineration with energy recovery. Surgical, gynecology and orthopedic were the departments which produced the highest amount of waste compared to medical which produced the lowest amount. The inconsistence in waste generation rates is due to nature of activities performed in each department. The results from this study will assist the HCFs management to effectively prepare weekly waste management reports and annual cost for the waste disposal. The highest amount of food waste was generated at MNH which also generated the lowest amount of sharps waste. Thus, waste generated at MNH is suitable for energy recovery via bio – digestion which generates bio gases but less suitable for the incineration with energy recovery since food waste contains low calorific value.

Waste segregation was done through color coding, however, for effective waste segregation further subdivision according to WHO (2015) can properly identify kinds of waste to be incinerated in order to provide room for waste circulation which is really practiced in Tanzania. The percentage of hazardous waste produced was high (34-75%) compared to the amount provided in literatures which ranged between 10 and 25%. This implies that waste segregation at the production point was inadequately performed. Also, the mean value of the moisture content of the waste generated was 43 percent which is high compared to the value of 15 percent by the total weight of the waste from the literatures. This implies that more fuel was needed for the incineration process. Also, the mean average calorific value for the HCW generated was above from the recommended value in the literatures. This implies that waste generated was suitable for incineration with energy recovery. The estimated heat energy recovered in MJ that can be generated via incineration based on HHV for the generated waste was 23215.5, 7337.7, 7908.6, and 2157.8 for MNH, KCMC, BMC and TRRH respectively. This implied that heat energy can be recovered from the incineration of waste generated at the studied HCFs.

Findings provide information to the hospital decision makers and health workers for improvement of waste characterization practices. Also, this study has established a data base of information on the requirements for the heat energy recovery from the incineration of HCW. This study has shown that all studied HCF have enough HCW generation rate that encourages stakeholders and administrators to pay attention and promote strategies that will result in reducing the cost of incineration of HCW by practicing heat energy recovery. Based on the findings of this study, it is recommended that, waste characterization is a useful practice, since it gives information to hospital decision makers and implementers about the actual quantity, composition, and heating value of HCW for heat energy recovery purposes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Anicetus H, Manyele S, Saria J, Mbuna J (2020). Assessment of air pollutant emissions from healthcare waste incinerators of different design features. African Journal of Environmental Science and Technology 14(10):311-328.

Babalola MA (2020). A Benefit Cost Analysis of Food and Biodegradable Waste Treatment Alternatives. Sustainability 12(1916):1-17.

Bdour A, Altrabsheh B, Hadadin N, Al-Shareif M (2007). Assessment of medical waste management practice: A case study of northern part of Jordan. Journal of Waste Management 27:746-759.

Bujak J (2010). Experimental Study of the Lower Heating Value of Medical Waste. Polish Journal of Environmental Studies 19(6):1151-1158.

Bujak J (2015a). Production of Waste Energy and Heat in Hospital Facilities. Energy 91:350-362.

Bujak J (2015b). Thermal Treatment of Medical Waste in a Rotary Kiln. Journal of Environmental Management 162:139-147.

Bujak J (2009). Experimental Study of the Energy Efficiency of an Incinerator for Medical Waste. Challenges and Opportunities. Energies 8(12):14182-14196.

Diaz LF (2005). Editorial| Waste Management-Volume 25, Issue 6.

Diaz LF, Eggerth LL, Enkhtsetseg SH, Savage GM (2008). Characteristics of Health- Care Waste. Waste Management 28(7):1219-1226.

Eleyan D, Al-Khatib IA, Garfield J (2013). System Dynamics Model for Hospital Waste. Characterization and Generation in Developing Countries. Waste Management and Research 31(10):986-995.

Kagonji IS, Manyele SV (2011) Analysis of the Measured Medical Waste Generation at Amana and Ligula Hospitals Using Statistical Methods. African Journal of Environmental Science and Technology 5:815-833.

Kothari R, Tyagi VV, Pathak A (2010). Waste-to-Energy: A Way from Renewable Energy Sources to Sustainable Development. Renewable and Sustainable Energy Reviews 14(9):3164-3170.

Manyele SV (2004). Medical Waste Management in Tanzania: Current Situation and the Way Forward. African Journal of Environmental Assessment and Management 8:74-99.

Manyele SV, Lyasenga TJ (2010). Factors Affecting Medical Waste Management in the Lower- Level Health Facilities. African Journal of Environmental Science and Technology 4 (5):304-318.

Matee VE, Manyele SV (2015). "Analysis of Temperature Profiles and Cycle Time in a Large-Scale Medical Waste Incinerator", Engineering 7:717-732. http://dx.doi.org/10.4236/eng.2015.710063.

Mato RR, Kaseva ME (1999). Critical review of industrial and medical waste practices in Dar es Salaam City. Resources, Conservation and Recycling 25(3-4):271-87.

Marinkovic N, Vitale K, Janev HN (2008). Management of hazardous medical waste in Croatia. Waste Management 28:1049-1056.

Mohee R (2005). Medical Waste Characterization in Healthcare Institutions in Mauritius. Waste Management 25(6):575-581.

Paratosh K, Kushwaha SK, Yadav M, Pareek N, Chawade A, Vivekanand V (2017). Food Waste to Energy: An Overview of Sustainable Approaches for Food Waste Management and Nutrient

Recycling. BioMed Research International https://doi.org/10.1155/2017/2370927.

Psomopoulos CS, Stavroulakis C, Stavropoulos V, Themelis NJ (2013). Greenhouse gases emission reduction potential in Greece by implementing WTE facilities in strategically selected urban areas. Fresenius Environmental Bulletin 22(7a):2042-2047.

Shareefdeen ZM (2012). Medical Waste Management and Control. Journal of Environmental Protection 3:1625-1628.

Stanković A, Nikić D, Nikolić M (2008). Report: Treatment of medical waste in Nišava and Toplica districts, Serbia. Waste Management and Research 26(3):309-313.

UNEP (2012). Compendium of Technologies for Treatment /Destruction of Healthcare Waste Osaka: International Environmental Technology Centre, United Nation Environmental Program.

World Health Organization (WHO) (2000). Wastes from Health-care Activities. Fact Sheet No. 253, October 2000.

WHO (2007). Population health and waste management: scientific data and policy options. Copenhagen: WHO Regional Office for Europe http://www.euro.who.int/__data/assets/pdf_file/0012/91101/E91021.pdf

World Health Organization (WHO), (2011). Health-care waste management- Fact Sheet N°281© 2017 The author and GRDS Publishing. All rights reserved. Available Online at: http://grdspublishing.org/World Health Organization, 2004. Safe health-care management, Policy Paper, 2004.

WHO (2015). Health-care waste. Fact sheet no. 253. http://www.who.int/mediacentre/factsheets/fs253/en/

WHO (2016). “Guidance for Healthcare Waste Management in Low Income Countries.

Yu B, Huang Z, Zeng Y (2014). Analysis on the Component Characteristics and Calorific Value of Medical Waste. Journal of Chemical and Pharmaceutical Research 6(5):1558-156.

Vol. 15(9), pp. 366-370, September 2021
DOI: 10.5897/AJEST2020.2948
Article Number:F319FA167579
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Physicochemical and metal quality evaluation of the ground water of the chief town of Sinthiou Maléme Commune in Tambacounda (Senegal)

Maoudo Hane, Ibrahima Diagne, Momar Ndiaye*, Cheikh Tidiane Dione, Dame Cissé, Birame Ndiaye and Abdoulaye Diop

Faculty of Sciences and Technology, Organic Physical Environmental Analysis and Chemistry laboratory (LCPOAE)-UCAD, Dakar, Senegal.

Received 20 November, 2020; Accepted 17 March, 2021

In underdeveloped countries, particularly, medium rural areas, the subsoil waters constitute an invaluable resource. However, they remain fragile and vulnerable because of demographic pressure, uncontrolled exploitation of discharges, and absence of adequate cleansing system and husbandries. This present work aims to evaluate the physicochemical and metal quality waters of 10 wells collecting the ground water of Sinthiou Maléme commune. Results obtained by the spectrophotometric method showed that the waters are moderately mineralized, soft and acidic. Their average contents of salts (fluorides, chlorides and sulphates), minerals (calcium and magnesium) and nitrogen (ammonium, nitrites and nitrates) vary but remain in the optimum level recommended by WHO for drinking. It also revealed the presence and state of certain trace elements such as iron, copper and zinc. However, the parameters such as chromium hexavalent and phosphates ions respectively make these subsoil waters non- drinkable water. Thus, the development of a method for the efficient removal of hexavalent chromium in these waters is imperative.

Key words: Underground, wells, spectrophotometric, chromium hexavalent, phosphates, trace elements.

INTRODUCTION

In Senegal, particularly the rural medium area of the commune of Sinthiou Maléme, waters of well are considered as essential resources for agro-pastoral activities and drinking water in several households. These wells capture the water table which is subject to significant pollution of anthropogenic origin due to agricultural activities, anarchic occupation of space and lack of an adequate sanitation system (Ahoussi et al., 2010; Hounsou et al., 2010). In fact, the dominant economic activity in Sinthiou Maléme remains agriculture. The rate of access to the individual cleansing system is only 10% (PLHA, 2007). This locality has only traditional pit latrines. The commune is also disadvantaged because it lacks an evacuation system for disposing solid waste leading to the wild deposal of refuse in several places. These result in the spread of various pollutants (chemical,

*Corresponding author. E-mail: momndiaye@hotmail.com.

physical, metal and microbiological) in the underground table water which can likely modify the physico-chemical and metal composition of the water (Kanohin et al., 2017; Yapo et al., 2010; Ouandaogo-Yameogo, 2008). In addition, the acceptability of the water intended for consumption in this locality is generally based on its smell, color and flavor. However, good water should not only be drinkable, but must also meet certain physico-chemical, metal and bacteriological criteria that are well defined; it should be consumed without any notable health risk for its consumers throughout their lives (WHO, 2004). The present study aims to evaluate the physicochemical and metal quality of the well water consumed by the populations of Sinthiou Maléme in Tambacounda, Senegal. It will allow to see if the population that consumes this water run the risk of having water-borne diseases, such as diarrhea, cholera, typhoid, dysentery and other diseases due to the chemical composition of the water (fluorosis, lead poisoning, methemoglobinemia etc) in order to remedy it.

MATERIALS AND METHODS

Study site

The study was carried out in the chief town of the commune of Sinthiou Maléme. It is bordered in the North-West by the rural Community of Koussanar, in the South by the rural Communities of Ndoga Babacar, Maka Coulibantang and Nétéboulou, and in the East by the rural Communities of Koulor, Nétéboulou and Kothiary (Department of Bakel) (Figure 1). The commune (1349' 0 "N and 1355' 0" W) is located in the area of Tambacounda, Eastern part of Senegal. The climate is of soudano-sahélien type, characterized by two seasons: one rainy season and a dry season with a pluviometer varying between 600 to 800 mm. The dominant grounds remain the ferruginous grounds (laterites) and the depths of the ground water oscillate between 35 and 40 m (Kanfany, 2009).

According to the data provided by the local plan of hydraulics and cleansing of the rural community of Sinthiou Maléme, the population was estimated in 2006 at 20357 with a density of 16.86 inhabitants/km^2. Thus, the population is distributed on various villages but the density is much more significant on the level of the chief town because of the presence of the weekly market commonly called "Louma˝. The principal sources of pollution of the table water in this zone are the domestic, agricultural activities (infiltration of manures and pesticides) and pastorals (decomposition followed by the infiltration of the excrements).

Sampling

Sampling was carried out in a completely randomized design (Maoudombaye et al., 2016). On the whole, 10 domestic wells without cover were sampled (Figure 1) out of a total of 40 wells. The depth of the wells lay between 13 and 17 m with an average of 15.2 m curbstones varying between 90 and 100 cm. These wells are consumed by the majority of the populations. The samples were put in bottles and placed inside 500 ml polyethylene bag. Then they were sterilized, washed several times with water of the wells to analyze them and then they were closed hermetically. These water samples were carefully labelled and transported in a refrigerator at 4°C (Rodier et al., 2009) to the Department of Chemistry, University Cheikh Anta Diop, Dakar for organic and environmental analysis.

Measurement of physicochemical and metallic parameters

The physical parameters (pH and conductivity) are measured using a combined pH meter called HANNA instruments pH/conductivity HI. For the measurement of the pH, the apparatus was calibrated with buffer solutions pH = 7.01 then pH = 4.01. First, the pH mode is selected with the SET/HOLD button, after which the electrode is immersed in the sampled water. Finally, we waited a few seconds for the stability symbol at the top of the LCD to disappear and read the pH value displayed. For the conductivity, the apparatus was calibrated by immersing the probe in the clean calibration solution HI 7031 (1413 µS/cm). EC mode is selected with the SET/HOLD button and then the same procedure for pH is used. Plastic beakers are often used to minimize the electromagnetic interference. The hardness is measured by a colorimetric proportioning used to pour the sample into the tube up to the acceptable mark; then two drops of H 20 F color indicator were added. The reagent is withdrawn using a syringe set to zero; then it was poured drop by drop until the color changed (green coloring). At the end, the hardness is read on the syringe in mmol/L or in German degree (°d), then it is converted into French degree (°f) by multiplying with the factor, 1.78. The chemical and metallic parameters were measured by UV-visible spectrophotometry using a PF-11 round-cell photometer.

Analysis of samples by photometry

The water used for the sample to be analyzed was without the standard solutions of the reagents. The sample to be analyzed was prepared by adding reagents in 5 mL of water samples taken. It was very important to respect the order and time prescribed in the analysis protocol to ensure the reaction of the reagents with the analytics.

Principle of the analysis

The device was turned on, and the mode indicated (Visocolor, Visocolor Eco or nanocolor) in the protocol was chosen including the number of the filter to dose the element. The filter numbers were between 1 and 6 and each corresponds to a wavelength. The zero of the concentration was set before each determination to establish a zero reference for the measurement. To do this, the white tube was placed in the measuring well and the button was pressed to null zero. The photometer displayed zero and then indicates the sample was ready for analysis. The ready sample was placed in the measurement well and the M key was placed directly to obtain the concentration of the sample on the meter screen in mg/L.

RESULTS AND DISCUSSION

Parameters *in-situ*

Table 1 presents the minimal values (Min), averages (Moy) and maximum (max) values of the results of the physicochemical and metal analyses obtained in the whole wells, including the standard deviations of the 10 wells collecting groundwater in the study area. The values of Electric Conductivity (EC) and the Total of the Dissolved Solids (TDS) are 106 to 359 µS/cm with an average of 237.59 µS/cm and 56 to 171 ppm with an average of 119.5 ppm.

Electrical conductivity and TDS reflect the presence of

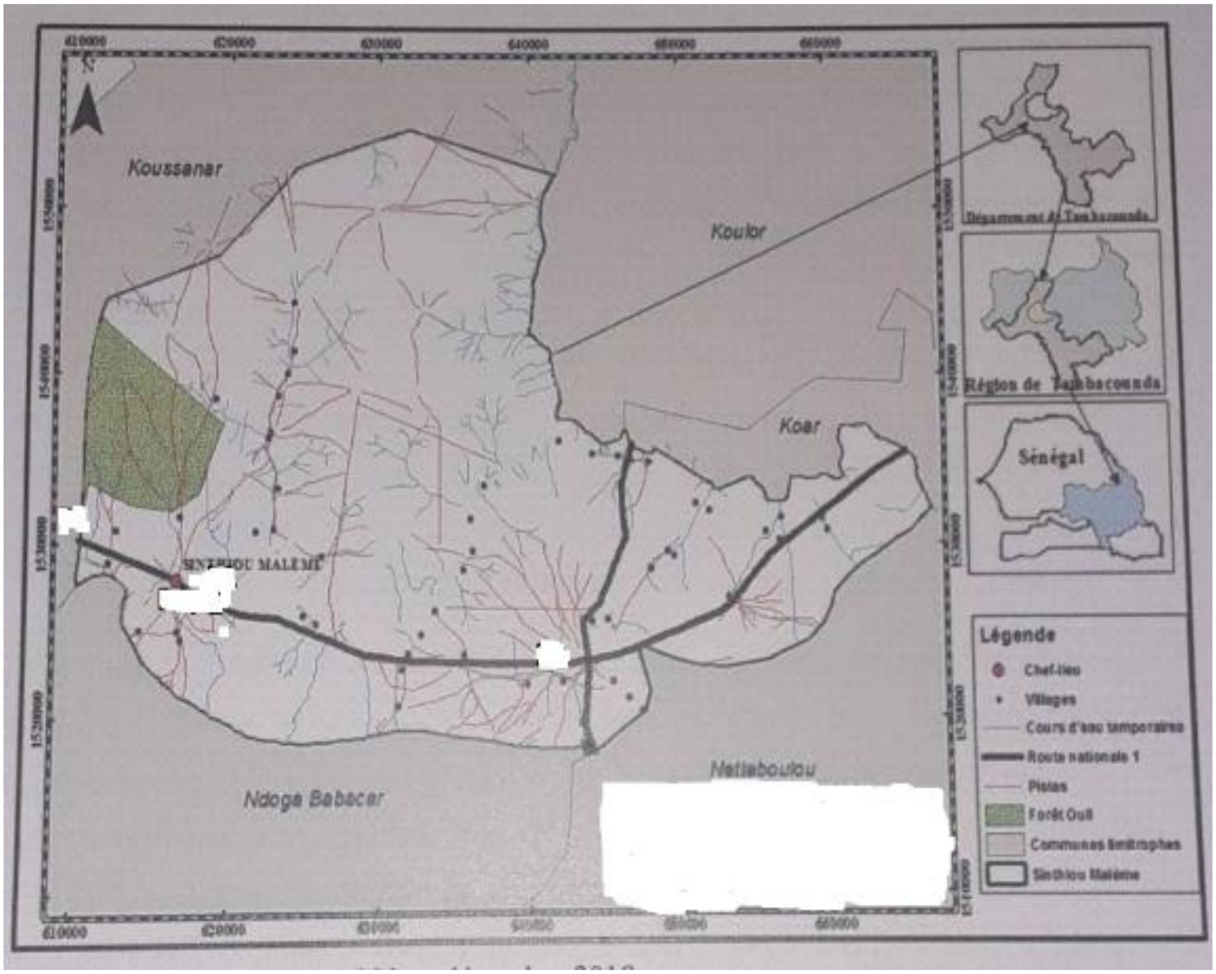

Figure 1. localization of the zone of study.

Table 1. Physicochemical and metal properties of water of wells.

Parameter	Max	Min	Moy	Standard deviation	Standards WHO
EC (µS/cm)	359	106	237.59	67.24	2000
TDS (ppm)	171	56	119.5	34.68	500
pH	7.58	5.81	6.68	0.57	6.5-8.5
TH (°f)	13	3.5	6.75	2.78	20
F - (mg/L)	1.3	< 0.1	0.61	0.35	1.5
Cl - (mg/L)	35	< 1	14.56	9.54	250
SO42- (mg/L)	72	< 20	38.11	17.92	250
PO43-(mg/L)	7.1	1	3.09	2.18	0.5
Ca2+ (mg/L)	71.12	7.12	32.70	16.33	100
Mg2+ (mg/L)	19.22	2.14	6.02	5.18	150
NH4+ (mg/L)	1.2	< 0.1	0.31	0.31	0.5
NO2- (mg/L)	0.27	0.02	0.14	0.09	3
NO3 - (mg/L)	91	< 4	34.87	30.77	50
Fe2+ (mg/L)	0.62	< 0.04	0.28	0.15	0.3
Cu2+ (mg/L)	0.3	< 0.2	0.22	0.04	2
Cr6+ (mg/L)	0.48	0.05	0.14	0.09	0.05
Zn (mg/L)	0.2	< 0.1	0.15	0.05	3

dissolved matter in water. Thus, we generally observed that the ground water of this zone is not very mineralized and that electric conductivity and the TDS are in perfect correlation. This could result in the low depths of wells (Sandao et al., 2018). In addition, a significant variation of conductivity is noted and TDS, with standard deviations of 67.24 µS/cm and 34.68 ppm. These variations could be related to the diversity of the probable geochemical processes responsible for the mineralization and salinization of this water. Failure to cover wells (open pit) could promote dissolution of solids from dust. However, these values are in phase with the WHO standards.

The pH of water tells us about the alkalinity or acidity of the water. An underground water having a low pH can indicate the presence of a pollutant on the table water level (Matini et al., 2009). Table 1 shows that the pH of this table water varies between 5.81 and 7.58 with an average of 6.68, and standard deviation of 0.57. These values show this water has slight tendency to be acidic. This acidity is probably related to the correlation between free CO2 and the rainwater which forms carbonic acid, reducing the pH of the water (Issa et al., 2020). The free CO_2 coming from the decomposition of the organic matter present in the ground or air would be considerable on the acidity of these water. However these waters remain within the acceptability level of WHO.

Minerals

Analysis of the table water shows that the water of the wells of this locality is not hard compared to the standards of WHO; its values oscillate between 3.5 and 13 °f with an average of 6.75 °f. The hardness (TH) of water generally indicates its contents of calcium (Ca2+) and magnesium (Mg2+) ions, which mainly results from the dissolution of limestone and dolomitic rock formation. These values are in line with the low levels compared to WHO standards for calcium and magnesium in these ground waters. However, these waters do not turn out to be dangerous for the health of consumers, but they cause scaling of the containers or interfere with domestic washing operations. Dimé et al. (2018) reported similar calcium and magnesium contents in characterizing the ground water located in a zone (municipality of Ngoundiane, Senegal) with strong industrial pollution.

Salts

The contents of salts such as fluoride, chloride and sulphate vary in water of this ground water. Their average values oscillate respectively between < 0.1 and 1.3 mg/L with an average of 0.61 ± 0.35 mg/L for fluorides; <1 and 35 mg/L with an average of 14.56 ± 9.54 mg/L for chlorides and < 20 and 72 mg/L with an average of 38.11 ± 17.92 mg/L for sulphates (Table 1). Furthermore, these results are in line with the value guide of WHO. However, the presence of the ion fluorides and chlorides in water must be controlled since they can cause medical disorders (Beaudoin, 2012) in particular dental fluorosis, cause unpleasant taste of drinking water and make it corrosive to pipe. The values obtained here are similar to those obtained by Gbohaida et al. (2016).

Nitrogen and phosphate

For the ground water of this locality, the average contents (0.31 ± 0.31 mg/L for ammonium; 0.14 ± 0.09 mg/L for nitrites and 34.87 ± 30.77 mg/L for nitrates) in nitrogen compounds are relatively high except ion nitrites (Table 1). The fairly high levels of nitrates and ammonium observed in these waters allow secondary inputs of anthropogenic origin. Indeed, Aulagnier and Vittecoq, (2007) and Klopp (2003) revealed that nitrate contents are higher than 10 mg/L in the water used for consumption which could reflect a contamination of anthropic origin. Otherwise, the low depth of the wells, the lack of hygiene (domestic wells not far from the latrines) and the agricultural and domestic activities (returns of used water and agricultural water, deposit of solid waste) would be the origin of the nitrogen pollution of water used for consumption. Concerning phosphate, as there are no industries that exploit phosphate in the zone, its high levels observed in the well water could be from the dissolution of chemical fertilizers or phosphate pesticides, which are pollution of agricultural origin (Touati et al., 2018). The Intrusion of the ground water, discharge of domestic wastewater and also the proximity of the latrines to the wells influence the contribution of phosphates in water. However the water of this locality has phosphate contents higher than the acceptable maximum value (Table 1) fixed by WHO. This could promote the development of algae (eutrophication) in the water after a few days of conservation.

Trace elements

Zinc, iron and copper are very important trace elements in the body at moderate levels unlike hexavalent chromium, which is more toxic than beneficial. The analysis of these in water of wells of the zone of study shows the presence of copper and zinc (0.22± 0.04 mg/L for copper and 0.15 ± 0.05 mg/L for zinc). On the other hand, chromium hexavalent and metallic iron were detected at varying concentrations (0.14 ± 0.05 mg/L and 0.28 ± 0.15 mg/L, respectively). The absence of industrial activity such as metallurgy could justify these low contents of copper and zinc compared to the standards of WHO insofar as the wells are far from the city. However, the origin of chromium VI and metallic iron could only be geological, in particular the predominance of ferruginous soil in the area, household waste discharges or even animal wastes (skins of the animals) (Maldonado, 2009). Metallic pollution from the garbage of artisanal mechanics can be added to these and cotton crops cultivated in the area. Consequently, the population consuming this well water is at risk since chromium VI contents are well above the standards recommended by WHO for drinking.

Conclusion

In this study, we analyzed the physicochemical parameters and some traces elements of the ground water of the chief town of Sinthiou Maléme commune. The waters are averagely mineralized and soft; their pHs is close to neutrality and have more or less acidic character. The photometric analysis of this water intended for human consumption shows that the water table in the study area is polluted. Indeed, the levels of phosphates and hexavalent chromium ions are far from the standard established by WHO. This situation could be explained by the low depth of the wells, their proximity to latrines, the geological nature of the tanks of the aquifers, the intensive use of manure and pesticides and finally the lack of hygiene and management of the garbage surroundings of the wells of the zone. All these realities can compromise the health of the populations consuming these waters due to the severe toxicity of chromium VI. For this purpose, it becomes necessary to develop an efficient method of removing hexavalent chromium from these waters. Furthermore, the study on microbial and toxicological indicators will be envisaged for an overall assessment of the portability of these waters.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors thank Macherey Nagel company for providing standard spectrophotometer and kits and Mr Paul Nkeng of the University of Strasbourg.

REFERENCES

Ahoussi EK, Soro N, Kouassi AM, Soro G, Koffi YB, Zade SP (2010). Application of the methods of analyses multivariate statistics being studied of the origin of heavy metals (Cu^{2+}, $Mn^{2+,}$ Zn^{2+} and Pb^{2+}) in water of the ground water of the town of Abidjan. International of Biological Chemical Sciences 4(5):1753-1765.

Aulagnier S, Vittecoq B (2007). Follow-up of the quality of subsoil waters of Martinique, countryside of rain season 2006: results and interpretation. Office report/ratio of geological research and miners Brgm/rp55499-Fr. P 77.

Beaudoin B (2012). Problems ecotoxicologist brought up to date of fluorides in municipal water. 15. https://core.ac.uk/download/pdf/51339825.pdf https://savoirs.usherbrooke.ca/handle/11143/7020

Dimé AKD, Diouf G, Dramé ET, Fall M (2018). Characterization physicochemical of the ground water located in a zone at strong industrial pollution: Case of the commune of Ngoundiane. Journal de la Société Ouest-Africaine de Chimie 46:23-28. http://www.soachim.org/files/volume%2046/4-AKD%20Dim%C3%A9%20et%20al,%20Vol046%20(2018)%2023-28.pdf

Gbohaida V, Agbangnan DCP, Ngossanga MB, Medoatinsa SE, Dovonon LFC, Wotto DV, Avlessi F, Sohounhloue DCK (2016). Etude de la qualité physico-chimique de l'eau de boisson dans deux localités du Bénin: Cotonou et Dassa-Zoumè. International Journal of Biological and Chemical Sciences 10(1):422-434.

Hounsou MB, Agbossou EK, Ahamide B, Akponikpe I (2010). Bacteriological quality of the water in the Ouémé basin: case of total and fecal coliforms in the Okpara, Djougou and Savalou reservoirs in Benin. International of Biological and Chemical Sciences 4(2):377-390.

Kanohin F, Otchoumou E, Yapo OB, Dibi B, Bony AC (2017). Physicochemical and bacteriological characterization of subsoil waters of Bingerville. International of Biological and Chemical Sciences 11(5):2495-2509.

Kanfany G (2009). Effect of organo-mineral fertilization on the growth and yield of the fonio. DEA thesis National Higher School of Agriculture in Thiés / Senegal.

Issa MSS, Mom SAB, Illias A, Ousmane B (2020). Hydrogeochemical characterizations and qualities of water of the ground water high catchment area of Korama, commune of Droum/area of Zinder (Niger/Africa of West). International of Biological and Chemical Sciences 14(5):1862-1877.

Klopp MW (2003). Isotopic study of the nitrogenized pollution of the tablecloth of Alsace between Sierentz and Ottmarsheim. Office report/ratio of geological and mining research Brgm/rp-52331- FR. P 69.

Maldonado DKL (2009). Characterization and origin of metals traces, hydrocarbons aromatic polycyclic and pesticides transported by the atmospheric repercussions and them surface waters in the basins perish-urban separative slopes. Thesis. Central School of Nantes, France.

Maoudombaye T, Ndoutamia G, Ngakou A (2016). Evaluation of the bacteriological quality of water well, drillings and rivers consumed in the oil basin of Doba in Chad. International of Recent Scientific Research 7(6):12236-12243.

Matini L, Sheep JM, Kongo-Mantono Ms (2009). Hydro-chemical evaluation of subsoil waters in urban environment in the South-west of Brazzaville, Congo. Africa Science 5(1):82-98.

Touati M, Benhamza F, Bouhafs F (2018). Impact of agricultural pollution on quality of subsoil waters in the perimeter irrigated Guelma-Bouchegouf (Northern Is Algerian). Review Sciences and Technologies, Synthesis 37:103-112. https://www.ajol.info/index.php/srst/article/view/182105

Republic of Senegal (2007). Ministry for Rural Hydraulics and the Hydrographic Network National, Ministry for Infrastructures and of the Cleansing Area of local Plane Tambacounda of hydraulics and of cleansing - PLHA the rural Community of Sinthiou Maléme.

Rodier J, Legube B, Merlet N (2009). Analysis of water, Dunod, Paris, France 1579 p.

Sandao I, Abdoubabaye Ms, Ousmane B, Michelot JL (2018). Contributions of the natural isotopes of water with the characterization of the mechanisms of refill of the aquifers of the basin of Korama, Area of Zinder, Niger. International of Biological and Chemical Sciences 12(4):1931-1954.

Ouandaogo-Yameogo S (2008). Groundwater resources in the urban center of Ouagadougou in Burkina Faso, quality and vulnerability. Thesis. University of Avignon and the countries of Vaucluse France. https://www.theses.fr/2008AVIG0040

World Health Organization (WHO) (2004). Directives of qualities for the drink water (3rd edition). 1.

Yapo OB, Mambo V, Seka A, Ohou MJA, Konan F, Gouzile V, Tidou AS, kouame KV, Houenou P (2010). Evaluation of the quality of water of well with use domesticates in the districts disadvantaged of four communes of Abidjan (Côte. d'Ivoire): Koumassi, Marcory, Port-Bouet and Treichville. International of Biological and Chemical Sciences 4(2):289-307.

Vol. 15(9), pp. 371-378, September 2021
DOI: 10.5897/AJEST2021.3036
Article Number: ABC942E67674
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Community views on water demands under a changing climate: The case of River Mpanga Water Catchment, Western Uganda

Isaac Mugume[1,2,3*], Ronald Semyalo[4], Peter Wasswa[1], Triphonia Ngailo[5], Ronald Inguula Odongo[1], Joyce Lunyolo[1] and Sulin Tao[6]

[1]Department of Geeography, Geo-informatics and Climatic Sciences, Makerere University, Uganda.
[2]Directorate of Forecasting Services, Uganda National Meteorological Authority, Uganda.
[3]Hub for Environmental and Atmospheric Research, Uganda.
[4]Department of Zoology, Entormology and Fisheries Sciences, Makerere University, Kampala, Uganda.
[5]Department of General Studies, Dar es Salaam Institute of Technology, Tanzania.
[6]Key Laboratory of Meteorological Disaster, Ministry of Education (KLME), Joint International Research Laboratory of Climate and Environment Change (ILCEC), Collaborative Innovation Centre on Forecast and Evaluation of Meteorological Disasters (CIC-FEMD), School of Applied Meteorology, Nanjing University of Information Science and Technology, Nanjing 210044, P. R. China.

Received 20 June, 2021; Accepted 17 August, 2021

Different sectors globally are experiencing the impacts of changing climate and water resources are among them. This study was conducted with an aim of examining the community views regarding the effect of changing climate on water demand over the River Mpanga Water Catchment. The study employed a cross-sectional survey using 111 household interviews; 14 Focus Group Discussions (FGDs) and 27 key informants interviews (KII). This study considered 14 villages and employed a mixed-methods study design. The analysis was conducted using SPSS software to derive the descriptive statistics. Qualitative information was analyzed using content analysis to conduct an in-depth analysis. The study found that the main source of water is tap water (72.1%) and the main use of water in the study area is domestic water use. This study also found that, breakage in water supply especially during the dry season (10 out of 14 FGDs) and poor quality of water especially the tap water due to chemical treatment (11 out of 14 FDGs) were the major challenges of water the community faced. Additionally, this study observed that 15 out of 27 KII considered drought as a major threat and that the area had experienced decreases in rainfall amounts over the months of January and February. Therefore, this study recommends that the providers of domestic water should invest heavily in technologies for improving water quality and amount; ensure sustainable and equitable rationing of water during scarcity; and promote incentives for water harvesting.

Key words: Community survey, water resources, River Mpanga.

INTRODUCTION

Globally, about 40% of the world's population is living under a high risk of the impacts of climate change (Nseka et al., 2021; Mukherjee and Siddique, 2019). This population, especially the population in developing countries is exposed to extreme weather events such as floods, heat waves and damaging wind among others

(Nimusiima et al., 2021; Nyakaisiki et al., 2019). Additionally, the changing climate is imposing increasing levels of economic losses and its impact to various sectors e.g. water resources, among others are becoming a great concern. For this reason, the changing climate is posing a great challenge to environmental water management (Capon et al., 2018; Murphy and Kitamirike, 2019) occasioned by unreliable rainfall (Mfitumukiza et al., 2020; Nyakaisiki et al., 2019). The main challenges relate to the demand and supply of water to the community. For example, the changing climate is driving shifts in global patterns of water and consequently affecting water security (Capon et al., 2018; Egeru et al., 2019). Therefore, the government of Uganda is examining the climate change risks into water resources and supporting integration of climate change adaption (Murphy and Kitamirike, 2019; Mwebaze, 2018).

Due to the changing climate and environment, e.g. increasing population pressure, water scarcity, loss of wetlands, and soil erosion (Amanyire, 2018; Capon et al., 2018), water management has been zoned to facilitate the implementation of catchment management zones (Egeru et al., 2019; Murphy and Kitamirike, 2019). This is further recommended by Mwebaze (2018) who opined that water allocation should be based on management zones. On the other hand, Egeru et al. (2019) advised to enhance the routine monitoring of catchment discharge. However, the development of these catchment management zones did not include climate change concerns as observed by Murphy and Kitamirike (2019). Therefore, mainstreaming climate change in catchment management plans is among the priorities of the Ministry of Water and Environment (Mfitumukiza et al., 2020; Murphy and Kitamirike, 2019). Moreover, the community over different areas in Uganda and other areas believe that the climate has changed (Mfitumukiza et al., 2020; Reta and Girum, 2019).

One of the catchments delineated by the Ministry of Water and Environment is the Mpanga catchment. This catchment is one the areas threatened by the changing climate. Additionally, it has suffered increasing land use and cover changes. These changes are also observed by Amanyire (2018) and Murphy and Kitamirike (2019) among others. The major land use/cover include cropland, forest, pasture, wetland, water body and settlement (Amanyire, 2018; Kakyo, 2019; Murphy and Kitamirike, 2019; Turyahabwe, 2019). Over the River Mpanga Catchment, the cultivated area increased by over 30% while grassland and forests decreased by about 32 and 11%, respectively over the period 1995-2015 (Amanyire, 2018). For this reason, the Ministry of Water and Environment has listed it as one of the catchments to integrate climate change in the management plans of the catchment (Amanyire, 2018; Kakyo, 2019; Murphy and Kitamirike, 2019).

The surface and ground water hydrology of River Mpanga catchment like other water catchments are highly sensitive to the altered precipitation, warming, increased evaporation, sea level rise and altered snow melt projected under many climate change scenarios (Capon et al., 2018). Egeru et al. (2019) have projected a net decrease of water resources base by 12.6% over the Nile Basin by 2040. Studies also show that small changes in climatic drivers potentially cause large changes in the flow regimes (Capon et al., 2018; Mugume et al., 2017). Additionally, the human water demands, especially for agriculture, are simultaneously expected to rise (Capon et al., 2018; Egeru et al., 2019) due to the changing climate. Freshwater ecosystems will furthermore be sensitive to climate change effects in the surrounding landscape which may exacerbate direct impact (Capon et al., 2018).

The demand of many water ecosystem goods and services are expected to increase under a changing climate (Nseka et al., 2021; Capon et al., 2018). This is likely to be worsened by human activities including siltation, eutrophication, water hardness, and toxicity (Amanyire, 2018). Overall, climate change is most likely going to reduce the availability and quality of environmental water allocations in most places as well as shifting these both spatially and temporally (Amanyire, 2018; Capon et al., 2018). In general, Amanyire (2018) recommended the population around the water catchments e.g. the River to be sensitized about the values, uses and laws regarding the sustainable use of water catchments.

MATERIALS AND METHODS

Study area

This study was carried out in mid-western Uganda. The study considered the Upper River Mpanga catchment (Figure 1) and used 111 respondents drawn from 6 sub counties (Busoro, East Division, Karambi, Kiko Town Council, South Division and West Division) which cover 14 villages (Bukwali, Busoro, Hakabale, Harakoto, Kampala Road, Karambi II, Kasojo, Kiko, Kisenyi, Mukusulya, Njara, Nkyakabale, Nyabinamba, Rwengoma) in Kabarole forming part of the Upper River Mpanga catchment.

The River Mpanga catchment is increasingly being exposed to land use/cover changes (Turyahabwe, 2019), including population pressure and changing climate (Amanyire, 2018; Tumusiime et al., 2019) yet it is the main source of water to the communities through different districts, namely Kabarole, Kyenjojo and Kamwenge (Tumusiime et al., 2019).

The catchment has an annual rainfall ranging from 600 to 1000 mm (Amanyire, 2018; Turyahabwe, 2019). The area is currently which it flows (Kakyo, 2019). This river flows over a distance of

*Corresponding author. E-mail: amooti23@gmail.com.

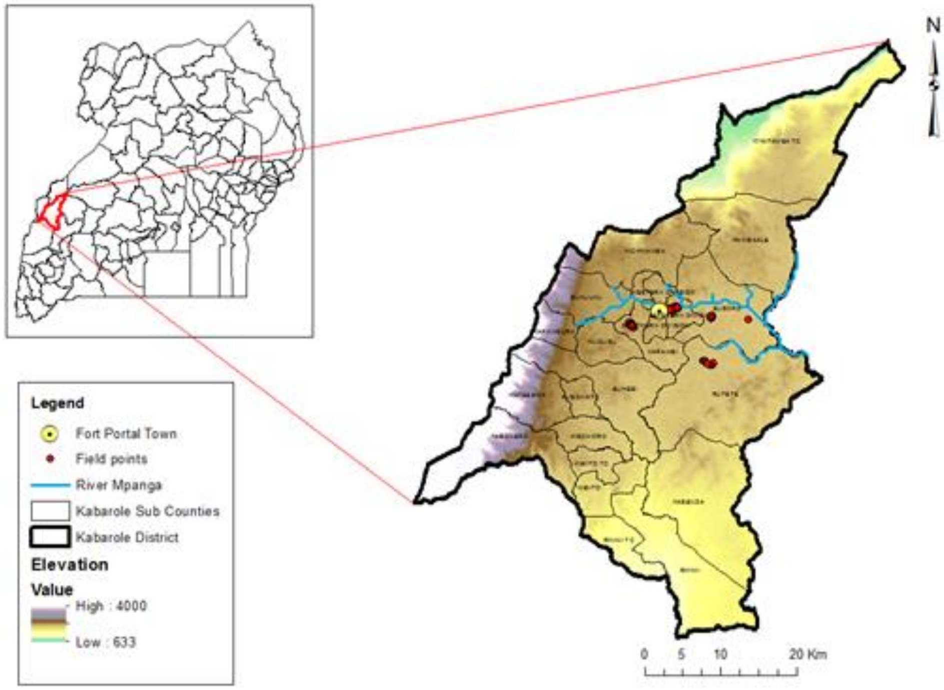

Figure 1. Map showing location of field work points obtained during the transect work through Mpanga River catchment in Kabarole district.

approximately 200 km, with an altitude ranging from 914 m (Lake George) to 2124 m (Rwenzori Mountains). It traverses three under high anthropogenic pressure due to high population growth rate and density and suffers a variety of poor land use practices such as deforestation, mining (sand, gravel and stones) by the local communities, water abstraction, poor waste disposal and agriculture (Tumusiime et al., 2019; Turyahabwe, 2019). These human activities compound to negatively affect the quality of water of River Mpanga directly and/or indirectly as it flows through Fort Portal town to rural areas. Additionally, there are large groundwater abstractions (Amanyire, 2018; Tumusiime et al., 2019) for different activities including domestic and industrial use.

Data and data sources

This study used a mixed methods approach. This approach to data collection is widely used in studies involving water demand management policies (Stavenhagen et al., 2018), and is recommended by Ransom et al. (2017). Additionally, the study employed a cross-sectional survey involving 111 household interviews (HHI). These households were randomly selected. Like Mfitumukiza et al. (2020), the study also conducted 14 gender-inclusive focus group discussions (FGDs) drawn from the 14 villages considered in the study. The participants forming the FGDs ranged from 8 to 10. Additionally, this study interviewed 27 Key Informants (KII) to cross-validate the information obtained from household surveys. The data obtained relates to demographic, household characteristics, sociological data, water availability and demand among others.

Data analysis

In this study, data analysis was done using descriptive statistics and in-depth analysis of qualitative information. Using SPSS, the descriptive statistics was carried out for the quantitative data to obtain means and frequencies for helping in drawing conclusions. The in-depth analysis was done for qualitative data. This in-depth analysis was conducted using content analysis, recommended by Mugagga et al. (2020). It included iterative forward-backward analysis of content obtained from FDGs and the household surveys to identify themes and make generalizations. This method is used in many qualitative research designs (Vaismoradi and Snelgrove, 2019).

RESULTS AND DISCUSSION

Socioeconomic characteristics of the studied sample

In order to understand the utilization of water over the study area, this study first considered the socioeconomic characteristics of the community over the study area. The study found that, on average, each household had about 5 people and that the household head had lived in the area for more than 12.6 years. Additionally, the study noted that the community appreciates that their population is increasing (75 out 111 household interviews (HHI)). The increasing population is exerting increased water abstraction. The study further found 7 out of 27 key informant interviews (KII) considered that the population is increasing polluting water while 6 out of 27 KII considered that the increasing population is destroying the available water resources.

The landholding of the household interviewed is shown

Table 1. Landholding status of the surveyed households.

Status of landholding	Frequency	
	Number	%
Acquired	66	59.5
Inherited	7	6.3
Encroached	25	22.5
Not Applicable	13	11.7
Total	111	100

Table 2. The main sources of water for the households surveyed.

Source of water	Frequency	
	Number	%
Water tap	80	72.1
Borehole	35	31.5
River	16	14.4
Water dam	4	3.6
Spring well	4	3.6
Rain harvesting	3	2.7
Total	142	127.9

in Table 1. The results show that majority of the respondents had bought and acquired the land. However, 25 out of 111 households had encroached land. Detailed analysis regarding the land encroachment showed that the sub-counties of East Division (8 out of 25), Karambi (8 out of 25) and Kiko trading center (6 out of 25) were outstanding.

Available water access points

The results showing the main sources of water are shown in Table 2. The results show that the main source of water in the surveyed areas is tap water (that is 80 households used tap water). This is supplied by the National Water and Sewerage Corporation, Fort Portal main branch (72.1%), followed by ground water abstraction using bore holes (31.5%). Our results do not show respondents using all the six sources concurrently. However detailed analysis shows that 2 respondents used borehole and water dam; 10 used borehole and tap water; 1 used borehole and river water; 1 borehole and rain harvesting; 3 borehole and spring wells; 14 tap and river; 1 tap and dam; 2 tap and rain harvesting; and 1 tap and spring wells. The results generally show that the distance to the nearest water source is largely less than a kilometer suggesting that water is within reach and since the majority of the households use tap water.

Additional analysis of the main source of livelihood (Figure 2) shows that the main sources of livelihoods for the households surveyed were carrying out small-scale business (41.4%) and crop farming (29.7%). Because of the multiple sources of water over the area and highly productive households, that is, 90.9% (Table 3) it seems that households can afford to access water, indicating that water insecurity may not be a problem.

Water uses

This study found that 98 out of 111 of the respondents considered the main use of water as domestic water use. Other water uses are shown in Table 3. Analysis of Table 3 shows that agriculture 25.2% (livestock: 18.9% and irrigation: 6.3%) is equally an area that uses water greatly. The study found industrial uses of water at 2.7%.

A related study by Adhikari et al. (2015) noted that water demand is expected to increase by the year 2040. The domestic water demand is expected to increase by 64% while livestock water demand by 44% and irrigation by 66% (Mwebaze, 2018). Adapting water resources management to climate change, however, requires integrated assessments of vulnerability across socio-ecological systems (Capon et al., 2018). This is because Mfitumukiza et al. (2020) observed that communities are now adopting drip irrigation as an adaptation strategy to the changing climate.

Challenges facing water use

The challenges regarding water use that were identified

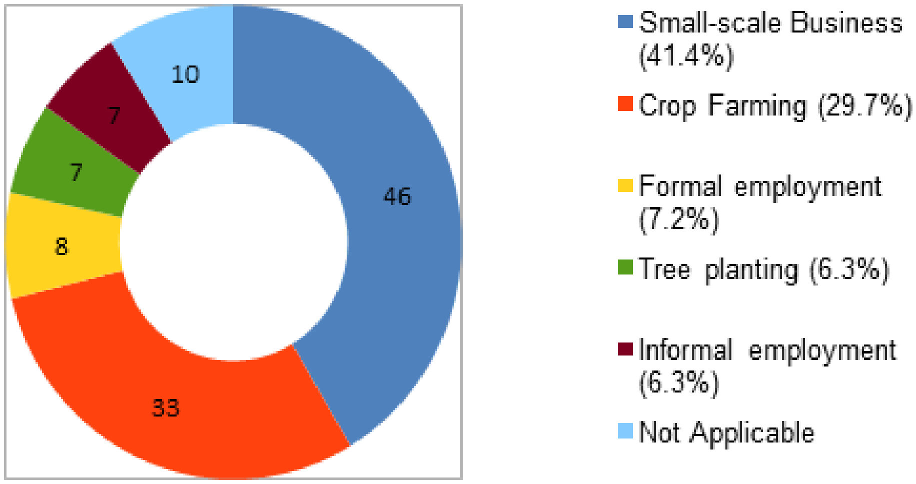

Figure 2. The main sources of livelihoods for the households surveyed.

Table 3. The main uses of water for the households surveyed.

Main use of water other than domestic	Frequency	
	Number	%
Livestock	21	18.9
Irrigation	7	6.3
Others (washing cars, recreational, water vending)	5	4.5
Industrial	3	2.7
Non response (only domestic use)	75	67.6
Total	111	100

by key informers during and the FDGs are shown in Table 4.

Analysis of the challenges facing community in accessing water shows that the leading challenges are: wells sometimes dry up (8); breakdown of boreholes (10); poor management of water sources (1); water sources not enough to many people (8); water is generally very expensive (8); on and off of tap water during dry season (10); and dirty water (11). These challenges compound to impress occasional water shortage. An investigation of households that have ever faced water shortage revealed that 53.2% experienced water shortage in the last 10 years. Of those who have ever experienced water shortage, 8.5% always suffer from water shortage; 25.5% consider that they regularly experience water shortage while 62.7% experience occasional water shortage.

Generally, in Karambi, the FGD participants pointed out that their community has fewer protected water points and analysis of the water sources in this sub-county shows that 89% of the households use the borehole as the main source of water. The urban communities generally consider that tap water is affordable but when disconnected, water becomes expensive for the case of a 20 L jerrycan. The studied communities also consider that water is becoming scarce due to increasing population. The increasing population often misuse water sources (especially the boreholes) leading to authorities to block access.

The occurrences of droughts and floods

The study found that 15 out of 27 Key Informants considered drought a threat. The study also noted that the community believes that droughts over the area increasingly occur during the months of January and February. Additionally, the community believes that there are very high chances of droughts occurring at least once a year. Flooding was also noted but it appears that flooding is not a major threat to the community compared to droughts. This is because the community considers that droughts normally reduces the supply of water (opinion of 12 out of 27 KIs); destruction of crops (opinion of 3 out of 27 KIs) among others. Additional analysis of January and February rainfall to corroborate the community views regarding rainfall in these months is as

Table 4. The main challenges the community faces in water use.

Theme	Challenge (No. of FGDs out of 14 FGDs)
General	Few protected water points (4) Wells sometimes dry up (8) Breakdown of boreholes (10) Poor management of water sources (1) Water sources not enough to many people (8) Water table goes down during drought (1)
Cost of water	In case it is tap water is disconnected, water is very costly (1) The water is expensive in terms of cost per 20 litre Jerry can Water is generally very expensive (8)
Supply of water	Scarcity of water especially during dry season (5) Road construction leading to break in supply (5) On and off of tap water during dry season (10) Low rate of water recharge (1) Many people served by a point source (2)
Quality of water	Dirty water (11) Usually not good for drinking (1) Too much chemicals that is put in water (6) Sometimes water smells (1) Water becomes silty (1)

‘No. of FGDs presents the total number of FGD that held the same challenge. The challenges were grouped in themes for comprehensive analysis.

shown in Figures 3 and 4. The analysis confirms that indeed January (Figure 3) and February (Figure 4) rainfall over the study area has been decreasing. This is evident for January (from 2000) and February (from 2003) at about 1.509 mm per year (Figure 3) and 1.858 mm per year (Figure 4, respectively.

The decreasing rainfall amounts present high chances of drought occurrences. Climatologically, the period December to February is normally a dry season over the study area (Amanyire, 2018; Turyahabwe, 2019; Nyakaisiki et al., 2019). The decreasing monthly rainfall during the month of January (Figure 3) and February (Figure 4) will likely cause water shortages. This situation poses increasing uncertainties in patterns of water supply and the associated demand (Capon et al., 2018) and can likely lead to environmental violence described by Branch (2018), especially if it is persistent. Additionally, studies show that East Africa experienced persistent droughts in 2016 and 2017 (Branch, 2018) which is evident in Figures 3 and 4.

Conclusions

This study was about community views on water demand under a changing climate and was carried out over the River Mpanga catchment in Western Uganda. The study shows that majority of the households have access to tap water (72.1%). Unfortunately, rainfall harvesting is still limited at about 3% suggesting that the kind of technology and equipment used could be expensive. This study also probably considers that the terrain of the study area is rugged thus limiting the application of rain water harvesting technologies. Additionally, households opt for other sources of water rather than rain water harvesting due to challenges associated with it. For example, the initial cost and installation of a rain water harvesting system is expensive for instance water tank of 100 L costs 50000 shillings and above which is costly to a low income earner, inadequate volume of roof runoff, unpredictable rain, poor quality water and difficulty to store it for a longer period.

The main use of water is for domestic purposes, but other than domestic, water is usually used for irrigation (18.9%). This implies that domestic water providers like the national water and sewage corporation should invest highly in providing high quality water. Regarding water quality, this study found that dirty and smelling water due to chemicals were the main challenge regarding using water over the area. One of the FDGs noted that the water is not normally good for drinking and strongly recommended that tap water should be boiled prior to

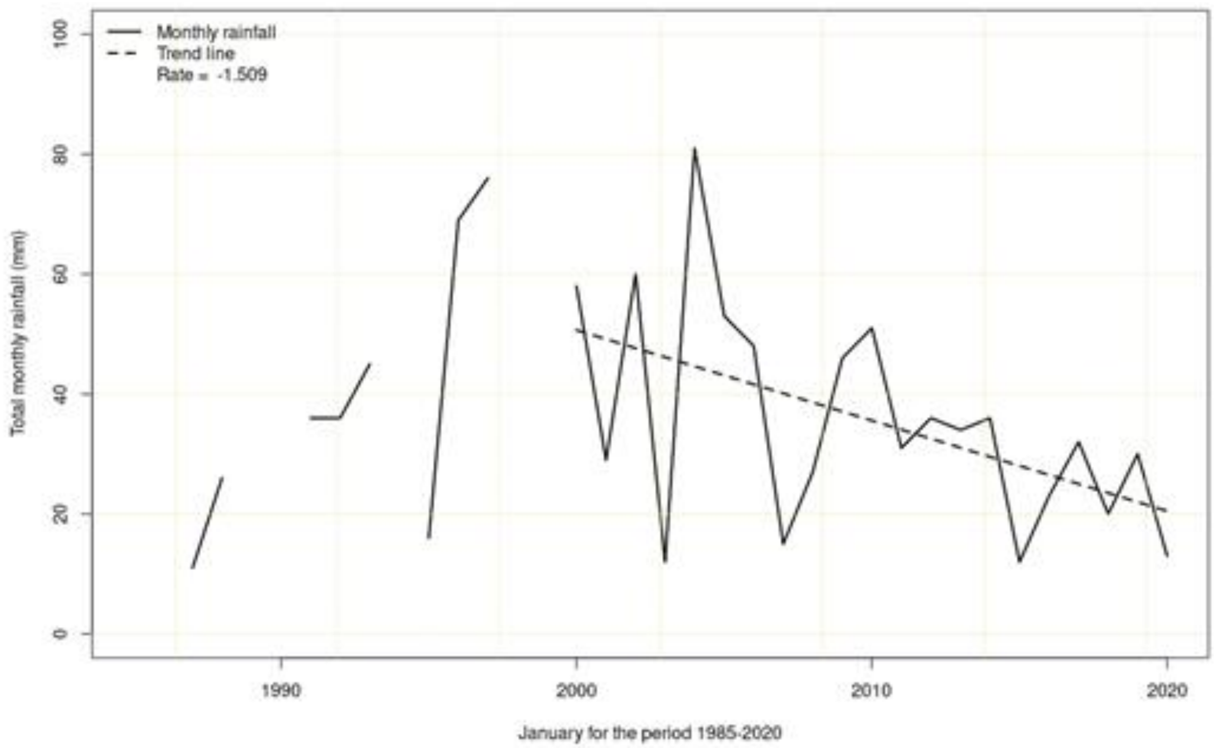

Figure 3. Monthly rainfall trends for the month of January.

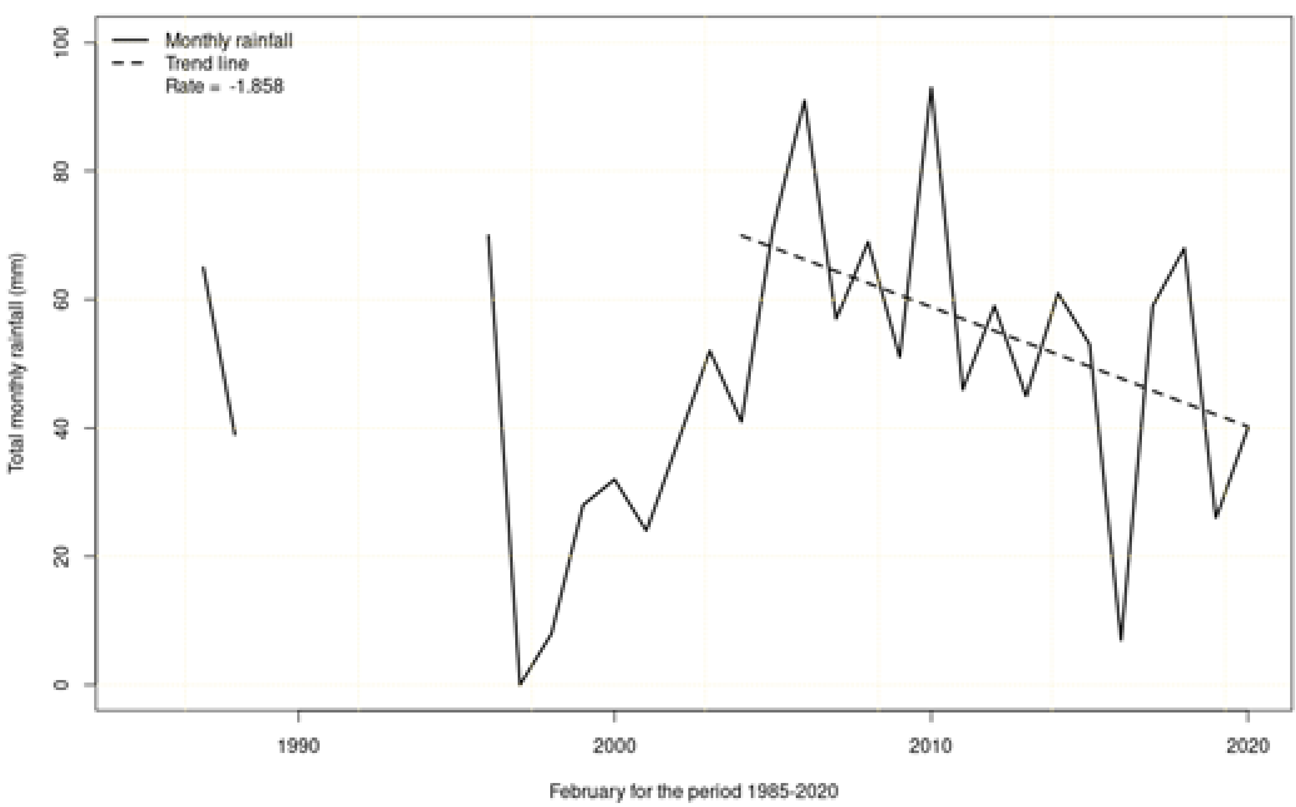

Figure 4. Monthly rainfall trends for the month of February.

drinking.

This study also observed that the community considers the climate to be changing and that this is evidenced by the declining rainfall amounts for the months of January and February. Empirical analysis also revealed that the total rainfall amounts in the months of January and February were largely decreasing at a rate of about 1.509 and 1.858 mm/year, respectively which validates the community views.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors appreciate the Ministry of Water and Environment and local authorities of Kabarole district for the technical support; Prof. Robert Marcant of University of York for the scientific guidance; and the African Academy of Science (AAS) for the financial support in data collection. The authors further express sincere appreciation to the project “Towards a Food Secure Future under a Changing Climate”, granted by the Government of Uganda through the program of Research and Innovations Fund of Makerere University for financing the publication of this study.

REFERENCES

Adhikari U, Nejadhashemi AP, Herman MR (2015). A review of climate change impacts on water resources in East Africa. Transactions of the ASABE 58(6):1493-1507.

Amanyire S (2018). Urban River Pollution: A Case Study of River Mpanga in Fortportal City, Kabarole District (Doctoral dissertation, Makerere University).

Branch A (2018). From disaster to devastation: drought as war in northern Uganda. Disasters 42:S306-S327.

Capon SJ, Leigh C, Hadwen WL, George A, McMahon JM, Linke S, Arthington AH (2018). Transforming environmental water management to adapt to a changing climate. Frontiers in Environmental Science 6:80.

Egeru A, Bernard B, Geofrey G, George OL (2019). Projected water resource dynamics in the sub-humid Upper Nile Water Management Zone of Uganda, East Africa. African Journal of Rural Development 3(2):753-760.

Kakyo M (2019). Examination of the water quality of river Mpanga. Doctoral dissertation, Makerere University.

Mfitumukiza D, Barasa B, Kiggundu N, Nyarwaya A, Muzei JP (2020). Smallholder farmers’ perceived evaluation of agricultural drought adaptation technologies used in Uganda: Constraints and opportunities. Journal of Arid Environments 177:104137.

Mugagga F, Nakanjakko N, Nakileza B, Nseka D (2020). Vulnerability of smallholder sorghum farmers to climate variability in a heterogeneous landscape of south-western Uganda. Jàmbá: Journal of Disaster Risk Studies 12(1).

Mugume I, Basalirwa CPK, Waiswa D, Ngailo T (2017). Spatial variation of WRF model rainfall prediction over Uganda. International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering 11(7).

Mukherjee N, Siddique G (2019). Assessment of climatic variability risks with application of livelihood vulnerability indices. Environment, Development and Sustainability pp. 1-27.

Murphy D, Kitamirike J (2019). Integrating Climate Adaptation in Water Catchment Planning in Uganda. International Institute for Sustainable Development (IISD). https://www.jstor.org/stable/resrep21969, accessed 29-04-2020 21:34 UTC

Mwebaze CE (2018). Sustainable water use in Lake Edward-George Basin: A case study of River Mubuku-Sebwe sub catchments. Doctoral dissertation, Makerere University.

Nimusiima A, Nalwanga F, Mugume I, Ogwang BA, Waswa P (2021). A community perspective of flood occurrence and weather forecasting over Kampala City. African Journal of Environmental Science and Technology 15(5):188-201.

Nseka D, Mugagga F, Opedes H, Wasswa H, Mugume I, Nimusiima A, Nalwanga F, Ayesiga P (2021). The damage caused by landslides in socio-economic spheres within the Kigezi highlands of South Western Uganda. Environmental and Socio-economic Studies 9(1):23-34.

Nyakaisiki K, Mugume I, Ngailo T, Nakabugo R (2019). The Use of Indigenous Knowledge in Predicting Changes in Seasonal Rainfall by Smallholder Farmers of Ruteete Subcounty, Kabarole District. Journal of Geoscience and Environment Protection 7(1):13-22.

Ransom E, Bain C, Bal H, Shannon N (2017). Cattle as technological interventions: The gender effects of water demand in dairy production in Uganda. FACETS 2(2):715-732.

Reta Z, Girum T (2019). Assessment of Community Perception on Climate Change in Selected Areas of Arbaminch District, Southern Ethopia. Assessment 9(1).

Stavenhagen M, Buurman J, Tortajada C (2018). Saving water in cities: Assessing policies for residential water demand management in four cities in Europe. Cities 79:187-195.

Tumusiime J, Tolo CU, Dusabe MC, Albrecht C (2019). Reliability of the Tanzania river scoring system (TARISS) macroinvertebrate index of water quality: a case study of the river Mpanga system, Uganda. Journal of Freshwater Ecology 34(1):541-557.

Turyahabwe C (2019). Assessment of Impacts of Land Use Changes on Water Resources of River Mpanga Catchment. Doctoral dissertation, Kyambogo.

Vaismoradi M, Snelgrove S (2019). Theme in qualitative content analysis and thematic analysis. In Forum Qualitative Sozialforschung/Forum: Qualitative Social Research 20(3).

Vol. 15(9), pp. 379-383, September 2021
DOI: 10.5897/AJEST2021.3051
Article Number: 3E84B1E67716
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Evaluating the rate of total electron content (TEC) production in ionosphere F2-layer to highlight *winter anomaly* by running thermosphere-Ionosphere-electrodynamics general circulation model

Emmanuel Nanéma[1,3*], Moustapha Konaté[2,3], Christian Zoundi[3], Amadou Ousseini Kotia[3], Jean Louis Zerbo[4] and Frédéric Ouattara[3]

[1]Institut de Recherche en Sciences Appliquées et Technologies (IRSAT), Centre National de la Recherche Scientifique et Technologique (CNRST), 03 BP 7047 Ouagadougou 03, Ouagadougou, Burkina Faso.
[2]Centre Universitaire de Gaoua, Université Nazi BONI, 01 BP 1091 Bobo-Dioulasso 01, Burkina Faso.
[3]Laboratoire de Recherche en Météorologie de l'Espace (LAREME), Université Norbert ZONGO, Koudougou, Burkina Faso.
[4]UFR/ST, Université Nazi Boni, 01 BP 1091 Bobo-Dioulasso 01, Burkina Faso.

Received 21 July, 2021; Accepted 10 September, 2021

The study deals with determining ionosphere parameter at low latitudes during the maximum of solar cycle 22 on quiet days. It uses Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) to carry out Total Electron Content (TEC) parameter in the ionosphere region. TEC time variability on summer and winter highlights a seasonal anomaly, a phenomenon observed since 1965 and which appears while radiations coming from the sun are more intensive in summer than in winter under low latitudes. A mathematical approach integrating the time values of TEC parameter is developed to calculate TEC total value during all the season. The study shows that the seasonal anomaly phenomenon is not observed at every time between summer and winter. Comparison of the rate of electrons production matches with solar radiation intensity between summer and winter during a short period. Apparition of *winter anomaly* phenomenon shows that ultraviolet and X-rays emitted from the Sun are not the only causes of ionization of particles in ionosphere. Other chemical or physical phenomena also contribute to enhance the concentration of electrons in the atmosphere. The estimation of the rate of TEC production in ionosphere F2-layer enables a comparison of summer and winter behavior in ionosphere layer. The study offers a good knowledge of *winter anomaly* phenomenon.

Key words: Total electron content, thermosphere-ionosphere-electrodynamics general circulation model, winter anomaly, maximum of solar cycle, quiet day.

INTRODUCTION

Ionosphere layer is the part of atmosphere that reflects radio waves. It lies between 50 and 800 km in the upper atmosphere. Ionosphere behaves like an obstacle for radio waves propagation. The property of this layer is due to its concentration in particles, essentially N_2, O_2, and O (Rishbeth and Gariott, 1969). These molecules and atoms are the major constituents of ionosphere layer (Bauer and Jackson, 1962; Bauer et al., 1964; Van Zandt et al., 1960; Van Zandt and Knecht 1964). The ultraviolet rays and X-rays coming from the Sun hit these particles and cause their ionization. This phenomenon creates different ions like O^+, NO^+, O^{2+} and e^-. The concentration of the different particles gives to the ionosphere some characteristics like its capacity to reflect or transmit the waves. Although the ions density is important in the ionosphere, this layer stays neutral electrically, and moves like a plasma. To investigate ionosphere layer, many models have been developed (Roble et al., 1988; Bilitza et al., 2014; Qian et al., 2010; Jin and Park, 2007; Bittencourt and Chryssafidis, 1994). All of them aim to carry out ionosphere parameters. Some models are based on data recorded on different stations while others use both data and mathematical simulation. In the study, we use Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) to carry out the Total Electron Content (TEC) in the F2-layer of the ionosphere. TIEGCM is a numerical model developed at High Altitude Observatory of National Center for Atmospheric Research (Richmond et al., 1992). The model uses input of 144 discrete values for longitudes and 72 values for latitudes. Running the model helps to get 90 output parameters that are obtained by a software program. Thermosphere General Circulation Model (TGCM) is the original version of TIEGCM. TGCM has been developed by Dickinson et al. (1981, 1984) and Roble et al. (1982), but gets a major development by coupling the ionosphere to the thermosphere (Roble et al., 1987, 1988). This gives the Thermosphere-Ionosphere General Circulation Model (TIGCM). The implementation of self-consistent electrodynamics leads to the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) (Richmond et al., 1992; Richmond, 1995). In a previous study (Nanema et al., 2020), *seasonal anomaly* phenomenon has been highlighted by use of International Reference Ionosphere (IRI) model. The present study deals with electron bulk surface density in the ionosphere F2-layer. The objective of this study is to compare the rate of electrons production between summer (very intensive solar radiations period) and winter (less intensive solar radiations period) under low altitudes. It will help to highlight the *winter anomaly* phenomenon. The study takes place at Ouagadougou station, located in West Africa. Maximum phase is considered in this study.

METHODOLOGY

The methodology of the study is based on the following core assumptions and principles (Zerbo et al., 2011; Ouattara et al., 2012; Gnabahou and Ouattara, 2012): (i) a season is characterized by its characteristic month (March for spring, June for summer, September for autumn and December for winter); (ii) maximum phase solar cycle is determined by Rz > 100 (where Rz is the yearly average of Zürich sunspot number); (iii) quiet days is determined by its Aa ≤ 20 nT and the five quietest days of a month describe all the season; (iv) the located station in this study is Ouagadougou (latitude: 12,4°N, and longitude: 358,5°E). The nearest values for latitude and longitude to Ouagadougou geographic characteristics in TIEGCM table of data are 12°N and 0° respectively.

Using the principle (ii), the following Equation 1 gives the expression of the TEC:

$$\mathbf{TEC(h)} = \frac{\sum_{j=1}^{n} \mathbf{TEC(h)_j}}{\mathbf{n}} \quad (1)$$

In Equation 1, TEC(h) is the hourly mean value of critical frequency for a selected month at h hour; $TEC(h)_j$ points out the hourly average value of critical frequency at h hour, and j the selected quiet day, n the number of quiet days. In the study, n = 5.

Local Time (LT) is linked to Universal Time by the following relation (Equation 2):

$$\mathbf{LT} = \mathbf{UT} + \frac{\mathbf{Longitude}}{\mathbf{15}} \quad (2)$$

Ouagadougou is located in West Africa, at longitude 358.5°E. Using the following approximation: 358.5° ~ 0°, Equation (2) becomes (3) as follows:

$$\mathbf{LT} = \mathbf{UT} \quad (3)$$

The last approximation is possible because of the proximity of Ouagadougou station to the Zero Meridian. The model is run in these conditions.

The evaluation of TEC parameter for the whole season is done by integrating the different TEC(h) values all daylong. TEC value is given by Equation 4 as follows:

$$\mathbf{TEC} = \int_0^{24} \mathbf{TEC(h).dh} \quad (4)$$

So, for the whole season, all the production of electrons due to the ionization in F2-layer is given by TEC calculated in Equation 4.

RESULTS AND DISCUSSION

Using the (ii) principle, the maximum phase of solar cycle 22 is 1990. In this year, by help of (iii) condition, the five quietest days are shown in Table 1.

For each characteristic month, TEC(h) can be generated by use of Equation 2. Equation 4 shows the area defined by TEC(h) profile and x-axis. This area defines the total value of TEC for the whole season.

In Figure 1, two areas are represented on the graph. The major part of TEC value on summer is hidden by that on winter, except from 04.00 LT to 07.00 LT. Table 2 is obtained by using Equation 1.

Figure 2 presents the comparison of TEC production between summer and winter at maximum solar phase,

*Corresponding author. E-mail: nanema_emmanuel@yahoo.fr.

Table 1. Five quietest days in the maximum phase of solar cycle 22.

Cycle	Phase	Year	Month			
			March	June	September	December
22	Max	1990	4, 10, 16, 17, 31	16, 17, 20, 21, 30	2, 3, 27, 29, 30	10, 11, 19, 21, 29

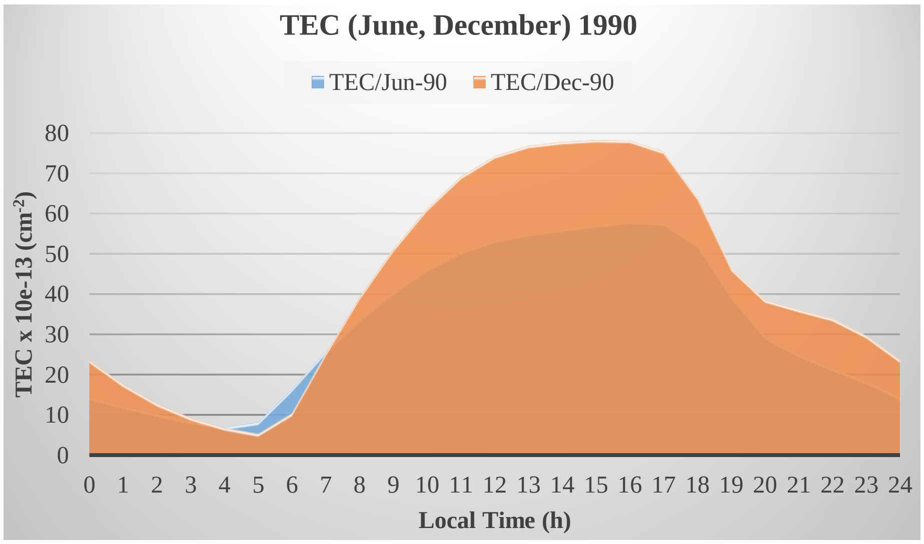

Figure 1. Total electron content variability at maximum solar phase.

Table 2. TEC production.

LT (h)	Season {TEC × 10^{-13} (cm^{-2})}	
	Summer	Winter
[0, 3] U [8, 24]	752.6088	1017.661
[4, 7]	57.2378	47.7284

derived from Table 2.

(a) From 00.00 LT to 03.00 LT and from 08.00 LT to 24.00 LT, TEC on winter hides TEC on summer. During this period, the rate of TEC production is around 35% superior in winter than in summer.
(b) From 04.00 LT to 07.00 LT, TEC on winter is lower than TEC on summer. Winter anomaly is not shown during this period. The rate of TEC production is around 20% superior in summer than in winter.
(c) During all the year, the rate of TEC production is around 32% superior in winter than in summer.

Solar radiations are less intensive in winter than in summer. The rate of TEC production is higher in winter than in summer. This shows an anomaly in TEC production, according to the intensity of solar radiation. This is the *winter anomaly* phenomenon which is well reproduced by TIEGCM from 00.00 LT to 03.00 LT and from 08.00 LT to 24.00 LT. This phenomenon has previously been highlighted by other authors (Yonezawa and Arima, 1959; Shapley and Beynon, 1965; Rishbeth et al*.,* 2000; Rishbeth and Muller-Wodarg, 2006). Solar radiation intensity cannot explain the apparition of *winter anomaly*. Other phenomena take place in atmosphere layer ionization. From 04.00 LT to 07.00 LT, TEC value in summer is higher than in winter. During this period, *winter anomaly* phenomenon does not appear.

Conclusion

This study is focused on the use of TIEGCM, a numerical model, to investigate ionosphere F2-layer by determining the total electron content parameter. A mathematical approach is used to evaluate the rate of seasonal TEC

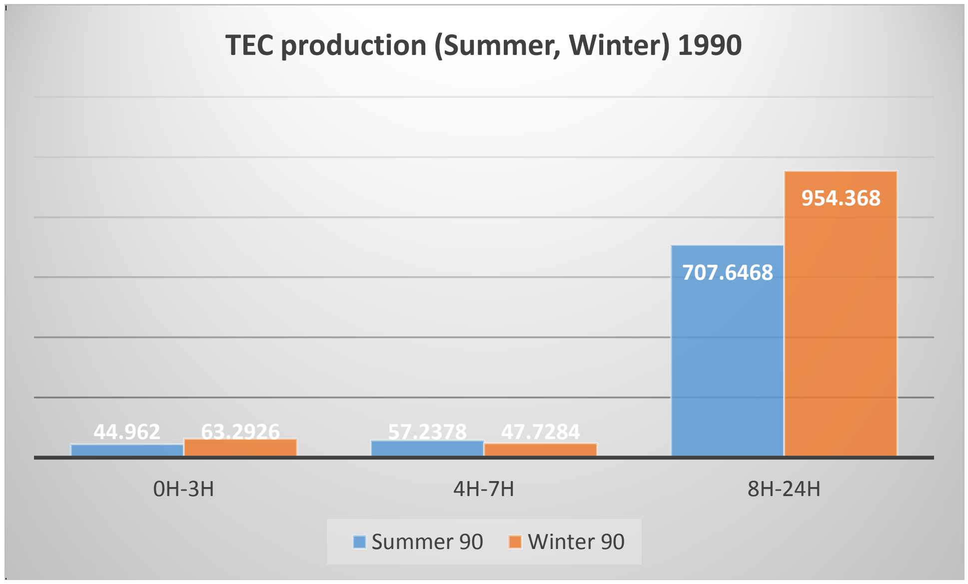

Figure 2. Comparison of TEC between summer and winter at maximum solar phase.

production at different seasons. This evaluation helps to highlight winter anomaly, a phenomenon that has been found already by different authors in previous studies. The rate of TEC production in winter is 32% higher than in summer. The study also shows that during a short period, the *winter anomaly* phenomenon is not observed. The result found in this study correlates with the other studies. This study also shows that solar radiations intensity is not the only cause of ionization in atmosphere layer; different phenomena can initiate it. In future studies, examination of these phenomena will be the target of our works.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Bauer SJ, Jackson JE (1962). Rocket measurements of the electron density distribution in the topside ionosphere. Journal of Geophysical Research 67:1675-1677.

Bauer SJ, Blumble LJ, Donley JL, Fitzenreiter RJ, Jackson JE (1964). Simultaneous rocket and satellite measurements of the topside ionosphere. Journal of Geophysical Research 69(1):186-189.

Bilitza D, Altadill D, Zang Y, Mertens C, Truhlik V, Richards P (2014). The international reference ionophere 2012-A model of international collaboration. Journal of Space Weather and Space Climate 4:A07.

Bittencourt JA, Chryssafidis M (1994). On the IRI Model Predictions for the Low-Latitude Ionosphere. Journal of Atmospheric and Solar Terrestrial Physics 56(3):995-1009. https://doi.org/10.1016/0021-9169.

Dickinson RE, Ridley EC, Roble RG (1981). A three-dimensional general circulation model of the thermosphere. Journal of Geophysical Research 86:1499-1512.

Dickinson RE, Ridley EC, Roble RG (1984). Thermospheric general circulation with coupled dynamics and composition, Journal of the Atmospheric Sciences 41:205-219.

Gnabahou A, Ouattara F (2012). Ionosphere variability from 1957 to 1981 at Djibouti Station. European Journal of Scientific Research 73(3):382-390.

Jin S, Park JU (2007). Ionospheric Tomography: A Comparison with the IRI-2001 Model over South Korea. Earth Planet Space 59(4):287-292. https://doi.org/10.1186/BF03353106.

Nanema E, Zoundi C, Drabo NK, Ouattara F (2020). Highlighting seasonal anomaly in ionosphere during minimum and maximum solar cycle phases. International Journal of Advanced Research 8(06):51-56. http://dx.doi.org/10.21474/IJAR01/11065

Ouattara F, Zoundi C, Fleury R (2012). Comparison between CODG TEC and GPS based TEC observations at Koudougou station in Burkina Faso. Indian Journal of Radio and Space Physics 41:617-623.

Qian L, Burns AG, Chamberlin PC, Solomon SC (2010). Flare location on the solar disk: Modeling the thermosphere and ionosphere response. Journal of Geophysical Research 115(A9):311. doi:10.1029/2009JA015225.

Richmond AD, (1995). Ionospheric electrodynamics using magnetic apex coordinates. Journal of Geomagnetism and Geoelectricity 47:191-212.

Richmond AD, Ridley EC, Roble RG (1992). A thermosphere/ionosphere general circulation model with coupled electrodynamics. Geophysics Research Letter 19(6):601-604.

Rishbeth H, Muller-Wodarg ICF (2006) Why is there more ionosphere in January than in July? The annual asymmetry in the F2-layer. Annales Geophysicae 24:3293-3311.

Rishbeth H, Gariott OK (1969). Introduction to ionospheric physics. In J. Van Mieghem (Ed.). International Geophysics Series pp. 160-189. Academic Press, New York.

Rishbeth H, Muller-Wodarg ICF, Zou L, Fuller-Rowell TJ, Millward GH, Moffett RJ, Idenden DW, Aylward AD (2000). Annual and semiannual variations in the ionospheric F2-layer: II. Physical discussion. Annales Geophysicae 18(8):945-956.

Roble RG, Ridley EC (1987). An auroral model for the NCAR thermosphere general circulation model (TGCM). Annales Geophysicae 5A(6):369-382.

Roble RG, Ridley EC, Dickinson RE (1982). Global circulation and temperature structure of the thermosphere with high latitude convection. Journal of Geophysical Research 87:1599-1614.

Roble RG, Ridley EC, Richmond AD, Dickinson RE (1988). A coupled

thermosphere/ionosphere general circulation model. Geophysics Research Letter 15(12):1325-1328.
Shapley AH, Beynon WJG (1965). Winter anomaly in ionospheric absorption and stratospheric warmings, Nature 206:1242-1243.
Van Zandt TE, Knecht RW (1964). The structure and physics of the upper atmosphere. In D. P. Le Galley & A. Rosen (Eds.), Space Physics pp. 166-225. Willey, New York.
Van Zandt TE, Norton RB, Stonehocker GH (1960). Photochemical rates in the equatorial F2 region from the 1958 eclipse. Journal of Geophysical Research 65:2003-2009.
Yonezawa T, Arima Y (1959). On the seasonal and non-seasonal annual variations and the semi-annual variation in the noon and mid night electron densities of the F2 layer in middle latitudes. Journal of Radio Research Laboratories 6:293-309.
Zerbo JL, Ouattara F, Zoundi C, Gyébré A (2011). Solar cycle 23 and geomagnetic activity since 1868. Revue CAMES Série A 12(2):255-262.

Vol. 15(9), pp. 384-389, September 2021
DOI: 10.5897/AJEST2021.3003
Article Number: 8BBFEF567718
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Biodegradation of hydrocarbon by *Enterobacter* sp IAA-01 isolated from hydrocarbon exploration site soil of Kukawa Northeastern Nigeria

Ibrahim A. Allamin[1*], Falmata B. Dungus[1], Haruna Y. Ismail[1], Gambo Ismail[1,2], Usman Bukar[1], Hussaini Shettima[1] and Amina U. Faruk[1]

[1]Department of Microbiology, Faculty of Sciences, University of Maiduguri, Maiduguri, Borno State, Nigeria.
[2]Northeast Zonal Biotechnology, Centre University of Maiduguri, Maiduguri, Borno State Nigeria.

Received 6 March, 2021; Accepted 11 May, 2021

The accidental release of diesel and other hydrocarbon to the environment lead to the pollution of the environment. The search for an environmentally friendly technique for the remediation of such polluted environment is not to be overemphasis. Microorganisms are used in the bioremediation of polluted environments. Hydrocarbon-degrading bacterium isolated from the hydrocarbon exploration site soil of Kukawa North-eastern Nigeria, and was studied for its biodegradation potential of diesel. Culture base techniques using nutrient agar and mineral salt medium supplemented with 1% diesel was used. The bacterium isolate was identified as *Enterobacter* sp. strain IAA-01. Identification was carried out using 16S rRNA sequencing and molecular phylogeny analysis using the Phylip software. Gravimetric analysis was conducted to measure the percentage biodegradation of the bacterium for 21 days, and confirmed using Gas chromatography (GC) analysis where the bacterium degraded diesel hydrocarbon 78% after 21 days and total degradation was revealed in GC analysis after 21 days. The results prevailed the ability of *Enterobacter* sp. strain IAA-01 effectively biodegrade diesel oil.

Key words: *Enterobacter sp*., biodegradation, gas chromatography, pollution.

INTRODUCTION

The intense increase in production, refining and distribution of crude oil and its products has conveyed with it an ever accumulative problem of environmental pollution (Afuwale and Modi, 2012).

The problem of environmental pollution due to oil and oil products is not limited only to oil producing countries but countries with large number of refineries and refining capacity such as Nigeria where the crude oil are being transported and refined, especially through oil producing region are susceptible to oil pollution (Oboh et al., 2006). The regions are characterised by detached, indiscriminate and highly unregulated disposal of petroleum products.

*Corresponding author. E-mail: ibnallaminmcb@unimaid.edu.ng.

Illustrious that even small release of petroleum hydrocarbons into aquifers can lead to concentrations of dissolved hydrocarbons far in excess of regulatory limits (Onifade and Abubakar, 2007). Apart from the indiscriminate disposals of oil there are also hydrocarbon pollution due to oil spills especially diesels and gasoline in Nigeria. Research findings have shown statistically significant impact of such reckless disposal on the ecosystem (Bayode et al., 2011). However, various remediation methods were employed to remediate hydrocarbon polluted soils and water, and the biological method turn to be environment friendly and cost effective, studies have shown that hydrocarbon degrading bacteria are naturally present in these environments and play a very important role in the removal of the pollutants (Allamin et al., 2014). Several species of the genus *Enterobacter*, *Bacillus,* *Micrococcus*, *Nocardia*, *Corynebacterium,* *Pseudomonas*, *Flavobacterium*, *Achromobacter*, *Alcaligenes* and *Proteus* are some of the commonly isolated degraders (Chikere et al., 2009; Afuwale and Modi, 2012). The main objective of this work is to isolate and screen bacteria with the ability to degrade hydrocarbon maximally and subject it to molecular characterization.

MATERIALS AND METHODS

Study area

The study area is Kukawa, one of the 27 local governments in Borno State Nigeria. Kukawa is located in the northern part of Borno bordering four other local governments of Abadam, Monguno, Guzamala and Marte. It also has international border with Chad with geographical coordinates 12°55'33'' North and 13°34'12'' East (Figure 1). It has an average elevation/altitude of 277 meters. The majority populations are into farming and fishing with estimated population of over 25,000. Kukawa is considered one of the potential crude oil prospecting area by the Nigerian National Petroleum Corporation (NNPC) (WFP 2018).

Sample site

Soil samples were collected from the exploration sites of Kukawa where Hydrocarbon exploration is taking place (Rasheed et al., 2012). The soil samples were collected with sterile trowel after clearing debris from the soil surface. Samples were collected in sampling bottles and were transported to the laboratory for further analysis (Waheed et al., 2018).

Microbiological analysis of soil sample

One gram each of the samples was weighed aseptically and placed into test tube containing 9 ml of distilled water the test tube was shaken vigorously in order to dislodge the microorganisms that adhered to the soil particles (Brito et al., 2006). The content of the tube was serially diluted. Aliquot (0.1 ml) from dilution (10^{-5}) was spread in triplicates on MSM modified and supplemented with 1% diesel $(NH_4)_2SO_4$ 0.1 g, K_2HPO_4 0.1 g, $CaSO_4$ 0.05 g, $MgSO_4{\cdot}7H_2O$ 0.2 g, $FeSO_4{\cdot}7H_2O$ 0.01 g, and distilled water 1.0 L, pH 7.0 with 1% diesel) oil agar (OA) for the enumeration of oil utilizing bacteria.

The plates were incubated at room temperature (30 ±2 °C) for 5 to 7 days. The colonies developed on the plates were counted and recorded as colony forming units per gram (cfu/g) of soil. Pure cultures of the isolates were obtained by repeated sub-culturing on media used for primary isolation. The pure isolates were obtained on agar slant for further characterization (Holts and Williams, 1994).

The rate of diesel oil degradation by selected microbial isolates was determined using gravimetric analysis and gas chromatographic spectrophotometric (GC) analysis techniques. One milliliter of nutrient broth grown isolates was inoculated into 100 ml of mineral salts medium in Erlenmeyer flask. Then 0.5 ml of diesel oil was supplemented as carbon source to each Erlenmeyer flask. Control flask contained no added organism, and then it was incubated on a shaking incubator at 150 rpm for 21 days. At 7 days interval, flasks per organism were removed and the amount of oil left was determined by extracting the residual oil with n-hexane gravimetrically using a weighing balance and the optical density was measured by noting the absorbance reading at 600nm wavelength in a spectrophotometer. The amount of diesel oil degraded was calculated using the formula (Latha and Kalaivani 2012):

$$\%\ \text{biodegradation} = \frac{\text{Control-Degraded}}{\text{Degraded}} \times 100 \quad (1)$$

Molecular identification of the strain

The genomic DNA was extracted using a commercial kit (GeneJet Genomic DNA purification kit, Thermoscientific, Lithuania) and amplified using the following PCR universal primers; reverse: 5'-TAC GGT TAC CTT GTT ACG ACT T-3' and forward: 5'-AGA GTT TGA TCC TGG CTC AG-3'. PCR was carried out under the following conditions: 1st cycle at 96ºC for 4 min as an initial denaturation; 30 cycles at 94ºC for 1 min for denaturing followed by an annealing stage at 58ºC for 1 min, an extension stage carried out at 72ºC for 1 min and a final extension at 72ºC for 7 min. The sequence was further deposited at the NCBI Gen bank and assigned an accession number of MG651780. For the phylogenetic tree analysis, twenty 16s rRNA sequences were obtained from Genbank showing the closest identity to *Enterobacter* species. The evolutionary analysis was carried out using MEGA6. A Neighbour-Joining method involving closest nucleotide sequences sourced from the BLASTn exercise was utilised to infer evolutionary history. The Maximum Composite Likelihood method was utilised to calculate the evolutionary distances. In the analysis, codon positions included were the 1st+2nd+3rd. Also, missing data and gaps were removed from all positions resulting in a final 1353 positions presented in the final dataset.

RESULTS

Molecular identification of the bacterium and characterization

Isolate IAA-01 was identified using a molecular phylogenetic analysis of the 16S rDNA sequence. Molecular identification begins with a BLASTn exercise on the NCBI Gen Bank database. The result shows a

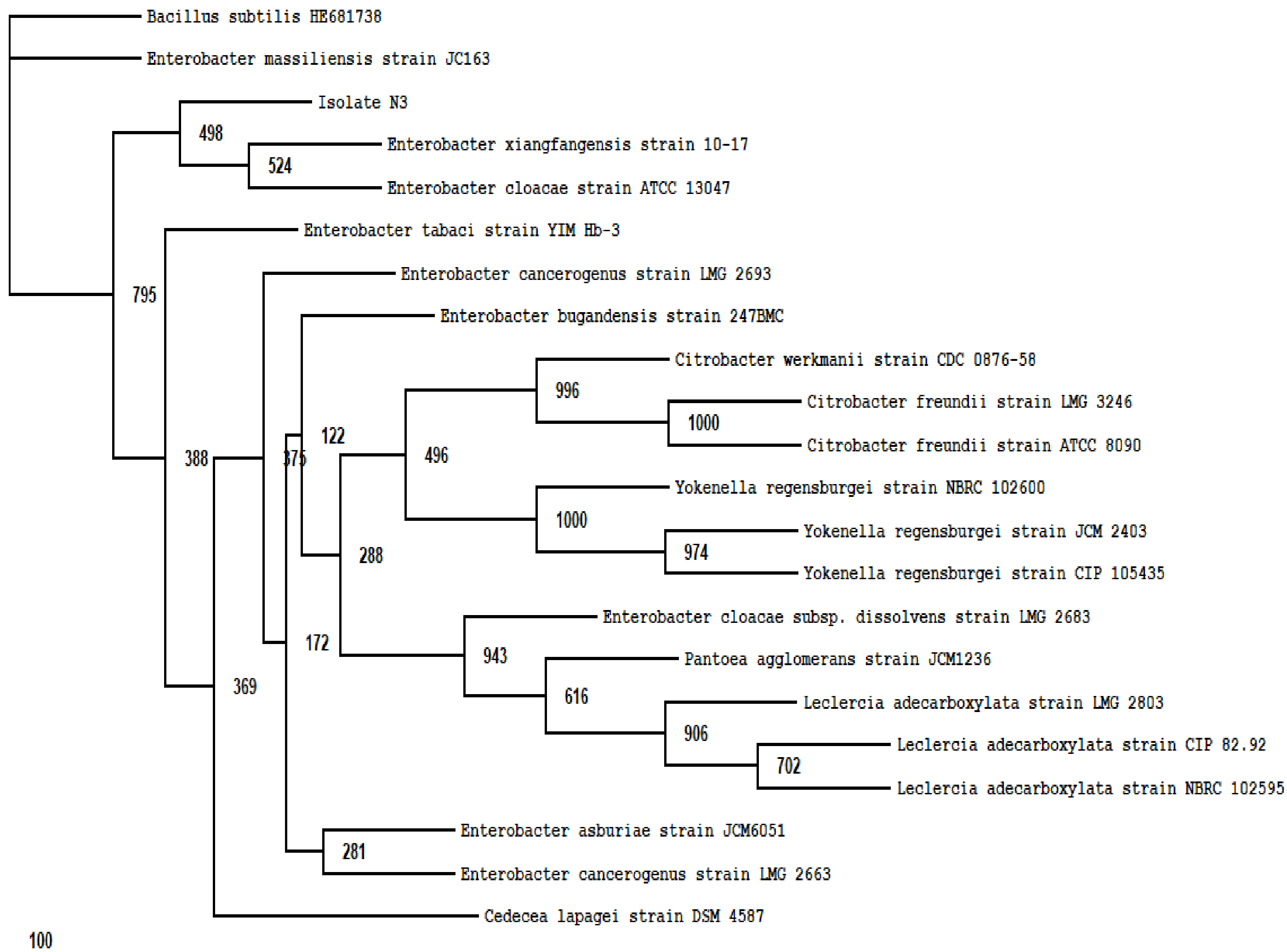

Figure 1. Neighbour-joining tree based on partial 16s rRNA sequence demonstrating the phylogenetic relatedness of strain IAA-01 to other bacterial species. *Bacillus subtilis* strain GO19 HE681738 as outgroup.

96% similarity to *Enterobacter* spp. The percentage of replicate trees (1000 replicates) is shown next to the branches (Figure 1) based on a bootstrap exercise. The bacterium is linked to several *Enterobacter* species clades such as *Enterobacter cloacae* but with low bootstrap values. At this stage, the bacterium was tentatively identified as *Enterobacter* sp. IAA-01.

The result of the study shows the biodegradation activity of hydrocarbon by *Enterobacter* sp. IAA-01 over time, from 0 days to 21 days. The bacterium was able to degrade 78.0% of diesel hydrocarbon after 21 days (Figure 2). The bacterial growth was also in consistent to the biodegradation with optical density (O.D) of 0.94 at 600nm wavelength at 21 days (Figure 2). The GC analysis shows the extent of degradation of the hydrocarbons over time of 0 day to 14 days with chromatographic peaks indicating degree of degradation by *Enterobacter* sp. IAA-01 where the first peak was for the solvent used for the analysis, whereas the subsequent peaks represent the hydrocarbon in sample (Figures 3 to 5).

DISCUSSION

Bacterial species isolated was screened in order to find out their biodegradation potentials. *Enterobacter* sp IAA 01 was able to utilize hydrocarbons as the sole source of carbon luxuriantly.

The bacteria had been reported by Ajayi et al. (2008)

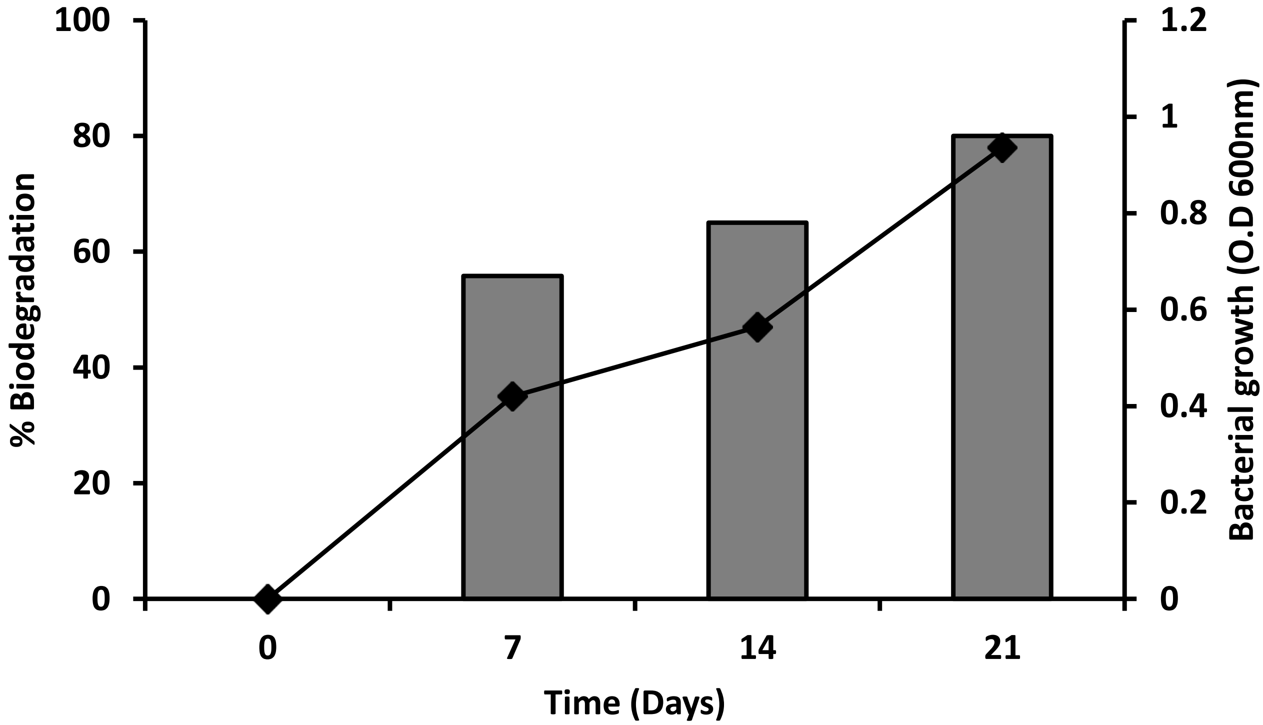

Figure 2. The percentage biodegradation and growth of *Enterobacter* sp. IAA-01 over time (0-21 days).

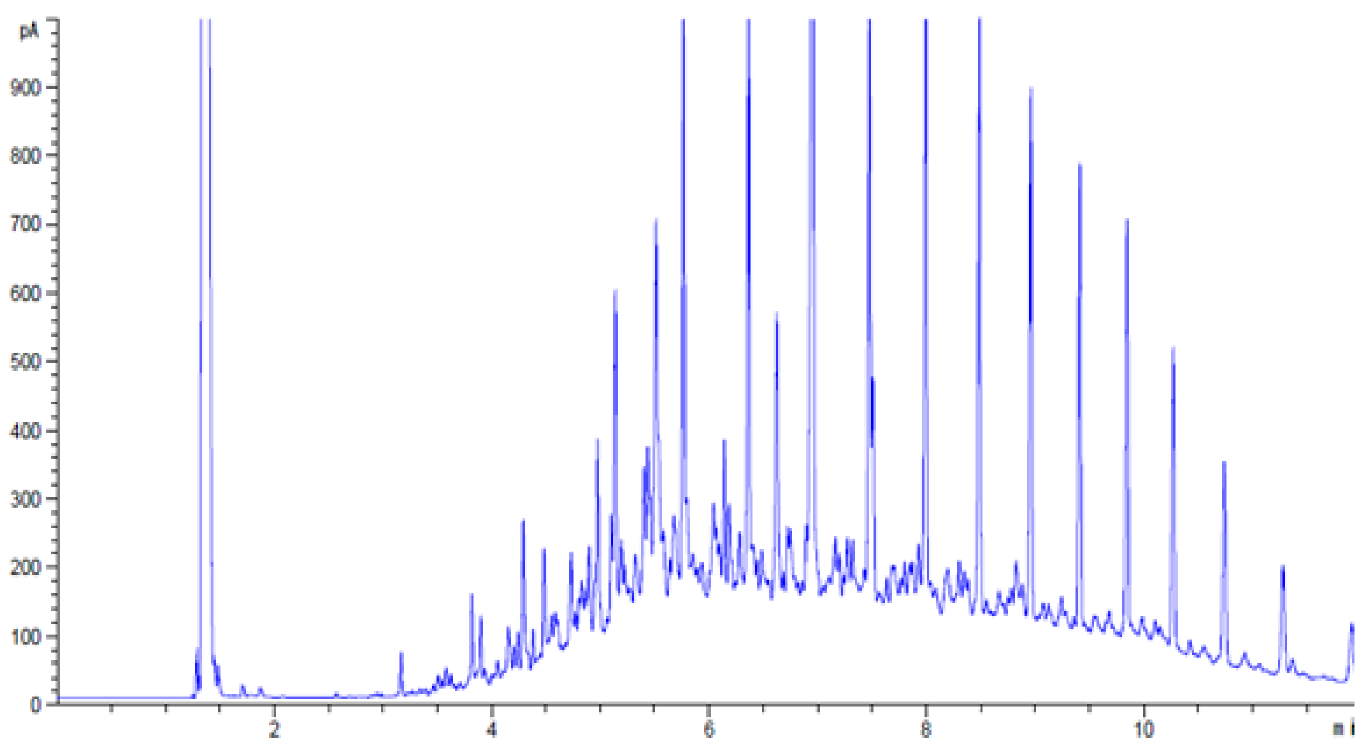

Figure 3. Chromatography peaks of hydrocarbon showing degradation of hydrocarbon constituent by Enterobacter sp IAA-01 in 0 days; X axis intensity count in (pA) Y- axis time (minutes).

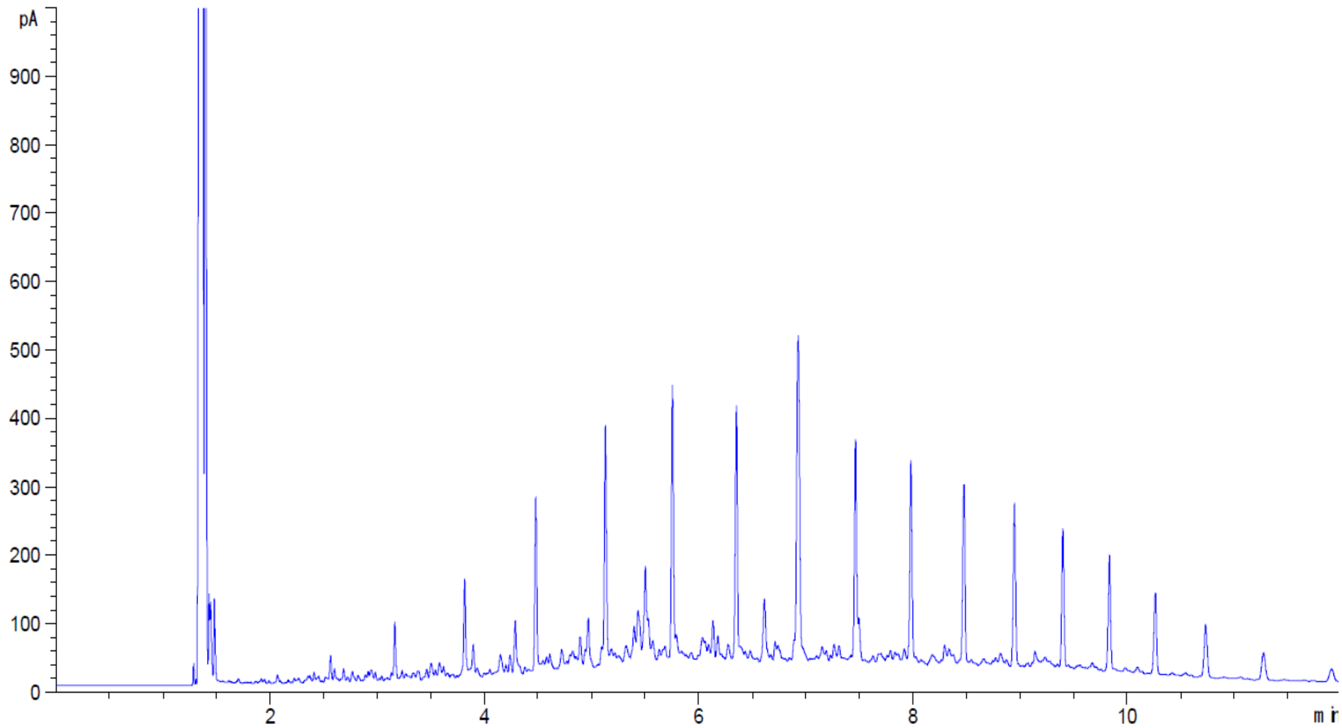

Figure 4. Chromatography peaks of hydrocarbon showing degradation of hydrocarbon constituent by Enterobacter sp IAA-01 in 7 days; X axis intensity count in (pA) Y- axis time (minutes).

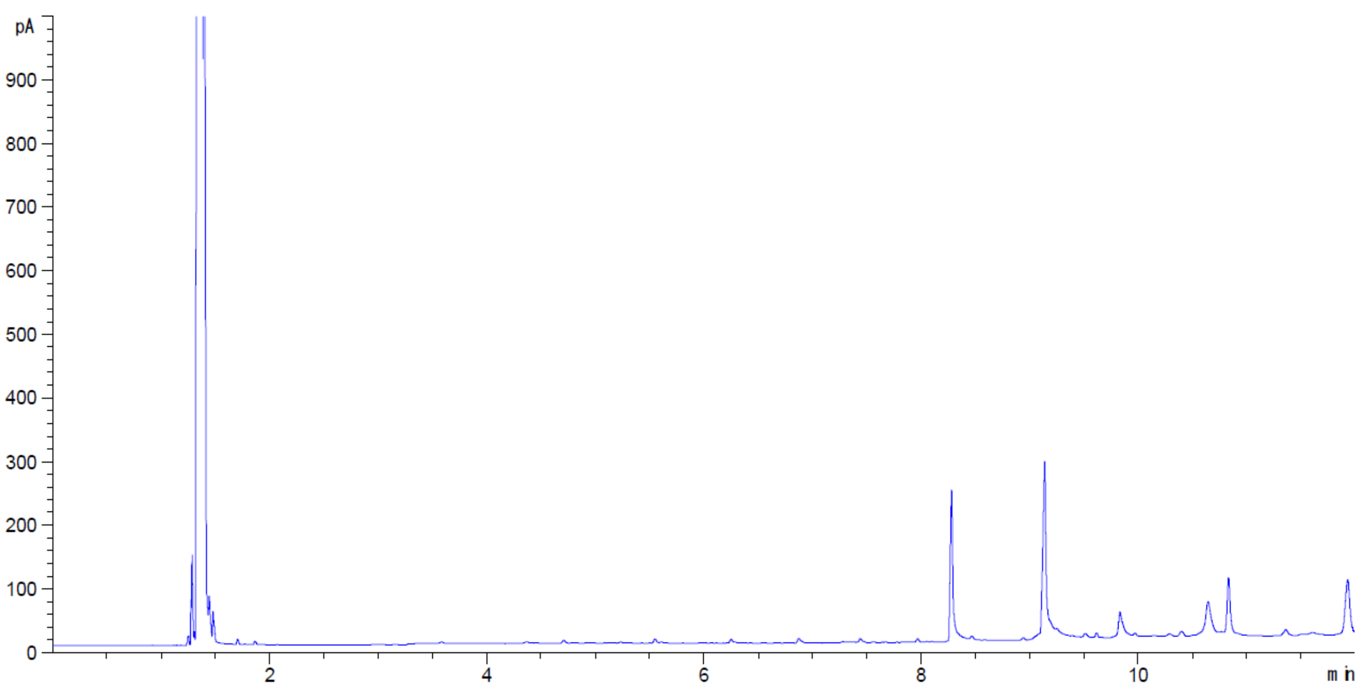

Figure 5. Chromatography peaks of hydrocarbon showing degradation of hydrocarbon constituent by *Enterobacter* sp IAA-01 in 14 days; X axis intensity count in (pA) Y- axis time (minutes).

as well as Malik and Ahmed (2012), as efficient hydrocarbon degraders. This means that *Enterobacter* sp IAA-01 used the hydrocarbon as a source of carbon and energy. The variation in the capacity of the isolates to utilize crude oil could be due to differences in the competence of hydrocarbon degrading enzyme. Generally, soils receiving micro-seepage of hydrocarbon tend to be dominated by bacteria utilizing hydrocarbon in a large number as reported by (Hitzman 1959; Klusman and Saeed, 1996; Leifer and Judd, 2002; Bashir, 2012). And their ability to withstand the toxic effect of the hydrocarbon constituents.

The study revealed that *Enterobacter* sp IAA-01 caused 78.0% oil degradation after 21days, (Figure 2). The efficient ability of the bacteria in degrading hydrocarbon has been reported by other investigators (Chikere et al., 2009; Afuwale and Modi, 2012). The results of GC analysis further confirmed the biodegradation potential of *Enterobacter* sp IAA-01 and revealed that the bacteria is capable of utilizing most of the hydrocarbon components especially straight chain alkanes, and cyclo-alkanes (Figures 3 to 5). Generally, the accepted pattern of susceptibility of hydrocarbon components to microbial degradation is n-alkane > branched alkanes > low-molecular weight aromatics > polycyclics (Bogan et al., 2003). However, system-specific exceptions to this pattern have been found (Makut and Ishaya, 2010). The GC analysis of the 0 day (Figure 3) comparatively shows non-degradation of all hydrocarbon components. Figure 4 shows hydrocarbon degradation pattern by, in which most of the alkanes and branch alkanes were utilized by the bacteria (Allamin et al., 2020), the remaining were aromatic compounds, which were difficult to degrade.

Conclusion

It can be concluded from these results that *Enterobacter* sp IAA-01 used in this study had considerably high ability of degrading hydrocarbon, because over time most of the chromatographic peaks of the hydrocarbon were utilized by the bacteria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

ACKNOWLEDGMENT

The authors would like to thank University of Maiduguri for nominating the research for sponsorship by TETFund.

Funding

This work was supported by IBR research grant TEFund 2019.

REFERENCES

Afuwale C, Modi HA (2012). Study of bacterial diversity of crude oil degrading bacteria isolated from crude oil contaminated sites. Life sciences Leaflets 6:13-23.

Ajayi AO, Balogun SA, Adegbehingbe K (2008). Microorganisms in the crude oil-producing areas of Ondo State, *Nigeria.* Academic Journals Scientific Research and Essay 3(5)174-179.

Allamin IA, Halmi MIE, Yasid NA, Ahmad SA, Abdullah SRS, Shukor Y (2020). Rhizodegradation of petroleum oily sludge-contaminated soil using Cajanus cajan increases the diversity of soil microbial community. Scientific Reports 10(1):1-11.

Allamin IA, Ijah UJJ, Ismail HY, Riskuwa ML (2014). Occurrence Of Hydrocarbon Degrading Bacteria In Soil In Kukawa, Borno State. International Journal of Environment 3(2):2091-2854.

Bashir AH (2012). Diversity and morphology of bacterial community characterized in topsoil samples from the Gaza Strip, Palestine. Research Journal of Microbiology 7(6):309-318.

Bayode OJ, Adewunmi EA, Odunwole S (2011). Environmental implications of oil exploration and exploitation in the coastal region of Ondo State, Nigeria: A regional planning appraisal. Journal of Geography and Regional Planning 4(3):110-121.

Bogan BW, Lahner LM, SulliVan Beilen WR, Paterek JR (2003). Degradation of straight chain aliphatic and high – molecular weight polycyclic aromatic hydrocarbons by a strain of *Mycobacterium austroafricanum*. Journal of Applied Microbiology 94:230-239.

Brito EM, Ranchou-Peyruse A, Verbaere A (2006). Characterization of hydrocarbonoclastic bacterial communities from mangrove sediments in Guanabara Bay, Brazil. Research in Microbiology 4(6):344-352.

Chikere CB, Okpokwasili GC, Chikere BO (2009). Bacterial diversity in a tropical crude oil-polluted soil undergoing bioremediation. African Journal of Biotechnology 8(11):2535-2540.

Hitzman DO (1959). Prospecting for petroleum deposits. US Patent 2880142.

Holt JG, Williams W (1994) Bergey's Manual of Determinative Bacteriology (1994). 9th edition, Baltimore. Advances in Applied Science Research 3(5):2789-2795.

Klusman R, Saeed M (1996). Comparison of light hydrocarbon microseepage mechanisms, in: Hydrocarbon Migration and Its near Surface Expression, edited by: Schumacher, D. and Abrams, M., AAPG Memoir, Tulsa pp.157-168.

Latha R, Kalaivani R (2012). Bacterial Degradation of Crude Oil by Gravimetric Analysis. Journal of Microbiology and Biotechnology 6:34-39.

Leifer I, Judd AG (2002). Oceanic methane layers: the hydrocarbon seep bubble deposition hypothesis. Terra Nova 14:417-424.

Malik ZA, Ahmed S (2012) Degradation of petroleum hydrocarbons by oil field isolated bacterial consortium African Journal of Biotechnology 11(3):650-658.

Oboh BO, Ilori O, Akinyemi O, Adebusoye SO (2006). Hydrocarbon Degrading Potentials of Bacteria Isolated from a Nigerian Bitumen (Tarsand) Deposit. Nataure and Science 4:3.

Onifade OA, Abubakar FA (2007). Characterization of Hydrocarbon-Degrading microorganisms From Isolated from Crude Oil Contaminated Soil and Remediation of the Soil by Enhanced Natural Attenuation. Research Journal of Microbiology 2(2):149-155.

Rasheed MA, Lakshmi M, Kalpana MS, Patil DJ, Dayal AM, Raju SV (2012). Evaluation of hydrocarbon charge using microbial and light gaseous hydrocarbon anomalies in the Seabed Sediment Samples of Gulf of Mannar, Kerala-Konkan Offshore Basin Natural Resources Research DOI: 10.1007/s11053-012-9189-x.

Waheed SM, Sangal P, Shukla S (2018). Microbiological analysis for hydrocarbon exploration. Environmental Risk Assessment and Remediation 2(3):1-7.

World Food Programme (WFP) (2018). Rapid food security Assessment in Doro Baga, Baga, Kukawa and Cross Kauwa (Kukawa LGA).

Related Journals: