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African Journal of Environmental Science and Technology

Full Length Research Paper

Irrigation water quality analysis of Mitheu Stream in Machakos Municipality, Kenya

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Water samples for physico-chemical, heavy metals and bacteriological analyses were collected from 4 selected points along Mitheu Stream flowing through Machakos Municipality once every month from June 2019 to September 2019. The samples were analyzed in Kenya Plant and Health Inspectorate Service and Water Resources Authority laboratories then data subjected to one-way analysis of variance to test significant differences (P≤0.05). The results were compared with World Health Organization guidelines to assess the suitability of the water for irrigation use. Results showed that the levels of the Biological Oxygen Demand and the Chemical Oxygen Demand in Mitheu Stream were higher than critical values permitted by the World Health Organization for irrigation water. Nitrates and Sulphates were within critical limits; however, Phosphates were higher than permissible limits at all the sampling points. Heavy metals concentrations for Cu, Pb, Zn and Cr were within allowable limits for irrigation water, but Cd was above the limit. Both total coliforms and *Escherichia coli* counts exceeded allowable limits for irrigation water. As such, Mitheu Stream can be considered polluted and the water unfit for irrigation farming. The Municipal authorities, working with other relevant stakeholders should take appropriate measures to mitigate stream pollution from untreated effluent discharged into the stream.

Key words: Physico-chemical, heavy metals, total coliforms, effluent.

INTRODUCTION

Although sustainable development goal 6 requires all people to enjoy clean water and reliable sanitation services by 2030 (Hounslow, 2018), access to clean water and sanitation services is still a challenge globally and particularly in Sub-Saharan African countries (Andersson, 2018; Jeong et al., 2016). The problem will

only increase in tandem with urbanization pressure (Kakoi et al., 2016). Majority of the towns and cities receiving new immigrants lack efficiently functioning wastewater management systems (Silverman et al., 2013). As such substantial quantities of raw effluent are often channeled into urban streams and rivers (Abakpa et al., 2013). Such effluent is typically contaminated with bacterial, physical and chemical contaminants that pose serious risks to people and the environment if no treatment is done based on best practices (Fuhrimann et al., 2016; Putri et al., 2018).

Heavy metals and bacterial pollution are common in most streams flowing through urban areas in Sub-Saharan Africa (Zhang et al., 2016). Human exposure to these contaminants is enhanced through use of polluted stream water for irrigation farming (Qureshi et al., 2016). The danger of bioaccumulation of pollutants and the risk of ill-health is increased through consumption of crop commodities irrigated with contaminated water (Singh and Kumar, 2017; Kim et al., 2015). Kenya being a water-scarce country, irrigation farming in urban and peri-urban areas is popular and also fueled by the huge and ready market from the increasing population (Kavoo et al., 2016). The risk of diseases to both farmers and consumers of their crop commodities irrigated using water from polluted streams cannot be overemphasized (Bismuth et al., 2016). This study investigated the pollution status of Mitheu Stream within Machakos municipality with focus on physico-chemical parameters, selected heavy metals as well as bacterial counts. This stream is the main recipient of effluent discharged from the Machakos sewage treatment plant. Leafy vegetable farming is a major economic practice along the stream.

MATERIALS AND METHODS

Study area

This research study was done at various points along the Mitheu Stream located in Machakos municipality, Kenya (Figure 1). Machakos town has a population of 170,606 people (KNBS, 2019). Its sewage treatment plant is located along Mitheu Stream into which effluent is directly discharged. The treatment plant uses the activated sludge process to treat effluent. Physical observation of the treatment plant however suggests neglect, which points to poor functionality of the plant. Being a seasonal stream, Mitheu Stream water levels are maintained by seasonal rains and effluent discharged into it. Water from the stream is used for irrigation by farmers within Machakos municipality. Cases of farmer vandalizing the sewer lines to obtain enough irrigation water during the dry seasons have been observed. High demand for vegetables within the municipality has sustained the urban farming along this particular stream. Being a time-bound study, this research was conducted during the dry season with insignificant climatic variation. Unavailability of more funds did not allow a comparative analysis across seasons.

Water sampling and sample analysis

Four sampling Points (A to D) were selected along Mitheu Stream

as shown in Figure 1. Sampling Point A was far downstream, while Point B was immediately downstream of the Machakos town sewage treatment plant. Point C was where the treatment plant discharge entered into the stream. Sampling Point D was upstream of the sewage treatment plant. These sampling points were selected at strategic points along the stream to compare the levels of contamination as the stream flowed downstream. Samples were collected in triplicates once every month from June 2019 to September 2019. Samples for bacteriological analysis were collected using sterilized glass bottles to avoid contamination (Hsieh, 2018), and bacteriological loads (total coliforms and *Escherichia coli*) analyzed by use of the multiple tube technique in Water Resources Authority (WRA) Laboratory in Nairobi. The total coliforms together with *E. coli* were used to estimate the quality of water in Mitheu Stream with respect to bacteriological contamination. Samples for the physico-chemical parameters, that included Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Nitrates, phosphates, and sulphates were taken using acid-cleaned 500 ml polyethylene bottles, and analyzed in WRA laboratory, Nairobi using standard procedures as described by APHA (1998). Samples for heavy metal analysis were collected in clean 500 ml polyethylene bottles, and treated with 2mls concentrated nitric acid in Machakos University Chemistry laboratory. The samples were then transported to the Kenya Plant Health Inspectorate Service (KEPHIS) Analytical Chemistry Laboratories for heavy metal analysis using inductively coupled plasma mass spectrophotometer (Agilent 7900 series ICP-MS). Five heavy metals were analyzed in stream water in this study i.e. Cd, Cu, Zn, Pb and Cr. These metals were chosen due to their high probability of occurring in substantial concentrations in municipal effluent.

Statistical data analysis

One-way Analysis of Variance (ANOVA) was used to test the significant variations ($P<0.05$) in mean concentrations of heavy metals, physico-chemical parameters, and bacterial counts in water from the four sampling points. Tukey post hoc test was used to separate means where there were significant differences among the sampling points. All the data analyses were done using Statistical Package for Social Sciences (SPSS) version 21.

RESULTS AND DISCUSSION

Physico-chemical parameters

Levels of physico-chemical parameters measured on water samples from Mitheu Stream are presented in Table 1 and Figures 2 and 3.

Chemical oxygen demand and biological oxygen demand

The Chemical Oxygen Demand (COD) for the four sampling points ranged between 189.00 ± 196.44 MgL^{-1} and 1304.00 ± 604.45 MgL^{-1} (Table 1 and Figure 2). COD was lowest downstream at sampling Point A and highest in the discharge from the sewage treatment plant (Point C) as shown in Figure 2. COD is a measure of the amount of oxygen needed to oxidize all organic chemicals in a wastewater before it is discharged into
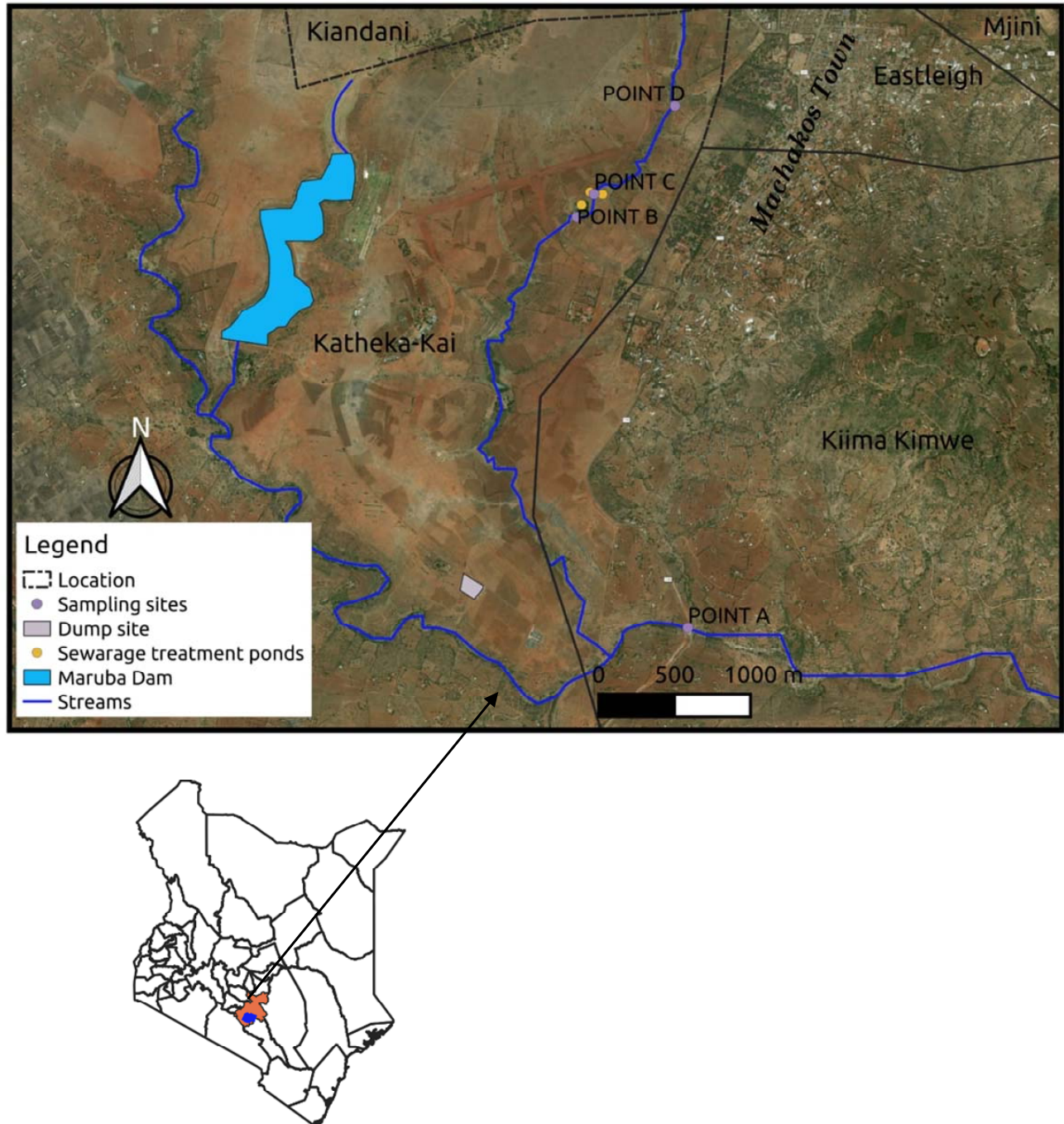
Figure 1. Map of the study area and sampling sites.

Table 1. Mean ± Standard deviations of physico-chemical parameters.

Site/parameter (MgL^{-1})	Point A	Point B	Point C	Point D	WHO limit	P-value
COD	189.00±196.44	325.50±132.94	1304.00±604.44	398.00±278.75	10.00	0.003
BOD	74.75±135.52	157.50±137.93	465.00±292.75	115.75±37.40	5.00	0.033
Nitrates	0.87±0.79	11.34±18.31	3.70±3.82	1.95±2.79	45.00	0.427
Phosphates	0.10±0.13	1.68± 2.75	0.38±0.10	1.74±2.91	0.10	0.555
Sulphates	17.21±18.25	29.92±20.96	122.31±86.87	32.59±32.61	250.00	0.035
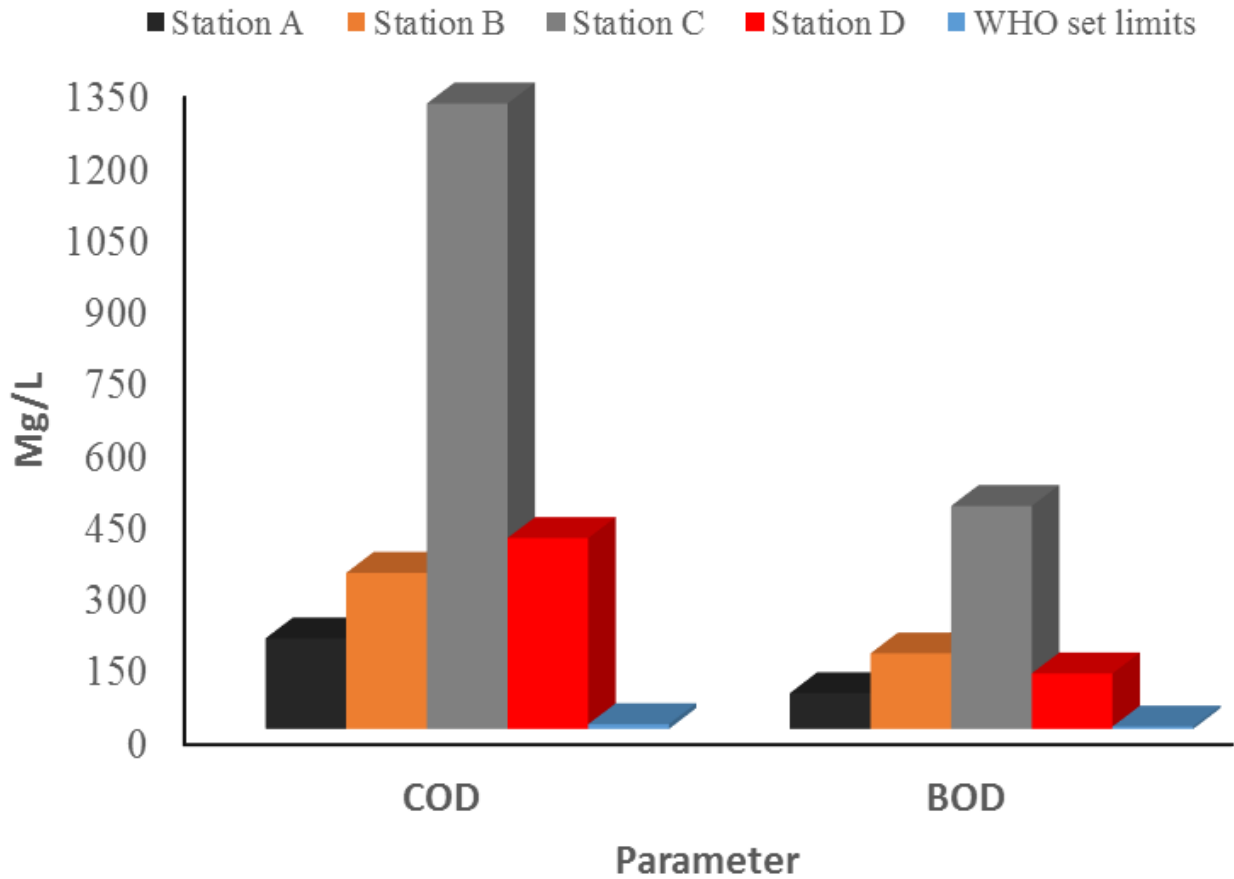
Figure 2. Levels of COD and BOD in Mitheu Stream.
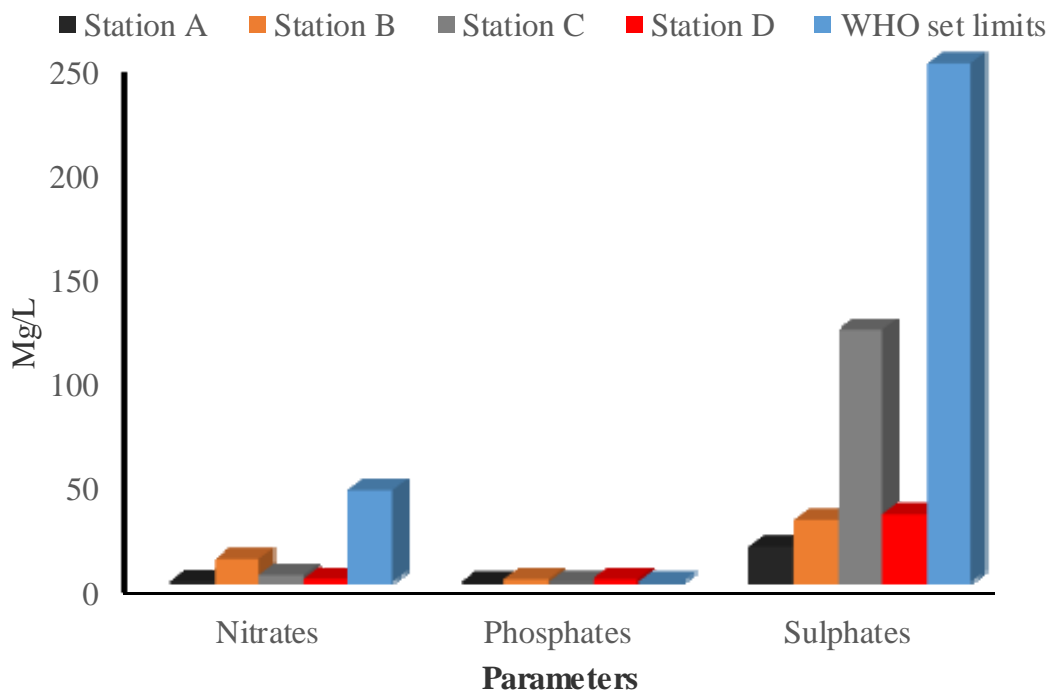
Figure 3. Levels of nitrates, phosphates and sulphates at Mitheu Stream.

water bodies (Islam et al., 2018). The significantly high levels of COD in effluent from the sewage treatment plant in Machakos town (Point C) indicated that it was not properly cleaned of the organic chemicals before being discharged into Mitheu Stream. The BOD observed was between 74.75 ± 135.52 MgL^{-1} downstream at Point A and 465.00 ± 292.75 MgL^{-1} in the sewage treatment plant discharge (Point C) as presented in Figure 2. BOD in wastewater is a measure of the oxygen needed to aerobically digest organic compounds by biological microorganisms (Mallika et al., 2017). Lower amounts of BOD signify improved efficiency of wastewater treatment plants. For this case the discharge from Machakos wastewater treatment plant had comparatively high levels of BOD implying its low efficiency in eliminating bio-organic waste. Organic chemicals were further washed into the stream from the farms alongside it. Despite this, dilution of effluent as the water flowed downstream lowered the concentrations of COD and BOD gradually from Point C to A. The COD and BOD had significant variations among the four sampling points (P≤0.05). However, Tukey's post hoc test showed that it was Point A downstream and Point C that had significant differences for both parameters. The high quantities of COD and BOD in all the sampling points were an indication the water in Mitheu Stream was not suitable for irrigation due to excessive amounts of organic chemicals. These organic chemicals pollute soils and are further absorbed by plants and transmitted to humans. The COD and BOD in Mitheu Stream were relatively high compared with those found in streams crossing Gondar town in north-west Ethiopia (Tessema et al., 2019). A comparison with the level of COD and BOD in Anko River, Assela town finds the concentration of these parameters to be relatively high in Mitheu Stream (Gebre, 2017).

Nitrates

The concentration of nitrates measured ranged from 0.87 ± 0.79 MgL^{-1} at Point A to 11.335 ± 18.305 MgL^{-1} at Point B as indicated in Figure 3. The concentration along the stream did not vary significantly (P=0.427). This high concentration just below the sewage treatment plant (Point B) was as a result of combination of the effluent from wastewater treatment plant and the municipal effluent getting into Mitheu Stream through broken sewer lines. Nitrates were however within WHO safe limits for irrigation water. This implied that nitrates pollution of Mitheu Stream did not pose a danger to the health of the farmers and residents of Machakos municipality.

Phosphates

High concentration of phosphates was recorded upstream at point D (Table 1 and Figure 3). The high phosphate concentration was attributed to the entry of raw effluent into the stream from vandalized sewer lines.

The discharge from the wastewater treatment plant (Point C) had relatively lower concentration of 0.38 ± 0.10 MgL^{-1}. However, this concentration was still higher than WHO recommended levels of phosphorous in irrigation water. This indicated that excessive phosphorous was not effectively removed from municipal wastewater in the treatment plant. Agrochemicals washed into the stream also could have contributed to increase in phosphorous in the stream. The concentration of phosphates did not vary significantly along the sampling sites (P=0.555). Phosphate concentration in three sampling points (Points B, C and D) was higher than WHO allowable limits for irrigation water. Higher phosphate content in irrigation water results to eutrophication and depletion of oxygen levels in water. Further, absorption of excess phosphates by vegetables could lead to their transmission to consumers resulting in health problems such as liver damage, muscle damage and kidney failure (Nyamangara et al., 2013). Eutrophication dries up a stream by excessive vegetative growth. Comparatively, the concentration of phosphates in Mitheu Stream was lower than levels found in a similar study in Anko River in Assela town (Gebre, 2017). The concentrations of phosphates were further found to be lower than their concentrations in a similar study in Gondar town, Ethiopia (Tessema et al., 2019).

Sulphates

The sewage treatment plant discharge (Point C) contained the highest concentration of sulphates measuring 122.33 ± 86.87 MgL^{-1} as shown in Figure 3. The high amount of sulfur in the sewage treatment plant discharge signified its high concentration in the municipal effluent from Machakos town as well as low efficiency in the elimination of sulfur by the treatment process. The lowest concentration of sulphates (17.21 ± 18.25 MgL^{-1}) was recorded downstream at sampling Point A and this could be attributed to dilution effect as water flowed downstream. There was significant variation between sulphates concentration in the sewage treatment plant discharge (Point C) and the rest of the sampling points (P=0.035). Decomposition of H_2S was responsible for the foul smell of the stream waters. The intensity of the odor is proportional to the quantity of sulphates in it. High amounts of sulphates in irrigation water lead to scaling of fruits and vegetable leaves (Lu et al., 2017). This is evident in fruits and vegetables that have visible scales. Sulphates are however not known to cause any direct health impacts to humans while present in irrigation water unless in very high concentrations that exceed 1000 MgL^{-1} (Moreno et al., 2009).

Bacteriological parameters

The highest counts of both total coliforms and *E. coli*

Table 2. Mean ± Standard deviations of Bacteria counts in water.

Site/parameter	Point A	Point B	Point C	Point D	WHO limit	P value
Total Coliforms (MPN/100 ml	4524.25±4615.32	100508.25±59895.92	180175.00±78885.08	240000.00 ± 0.00	1000	0.026
E. coli (MPN/100 ml)	1791.75±1685.87	111441.75±96477.92	151300±113913.88	229166.75±21666.50	Nil	0.125
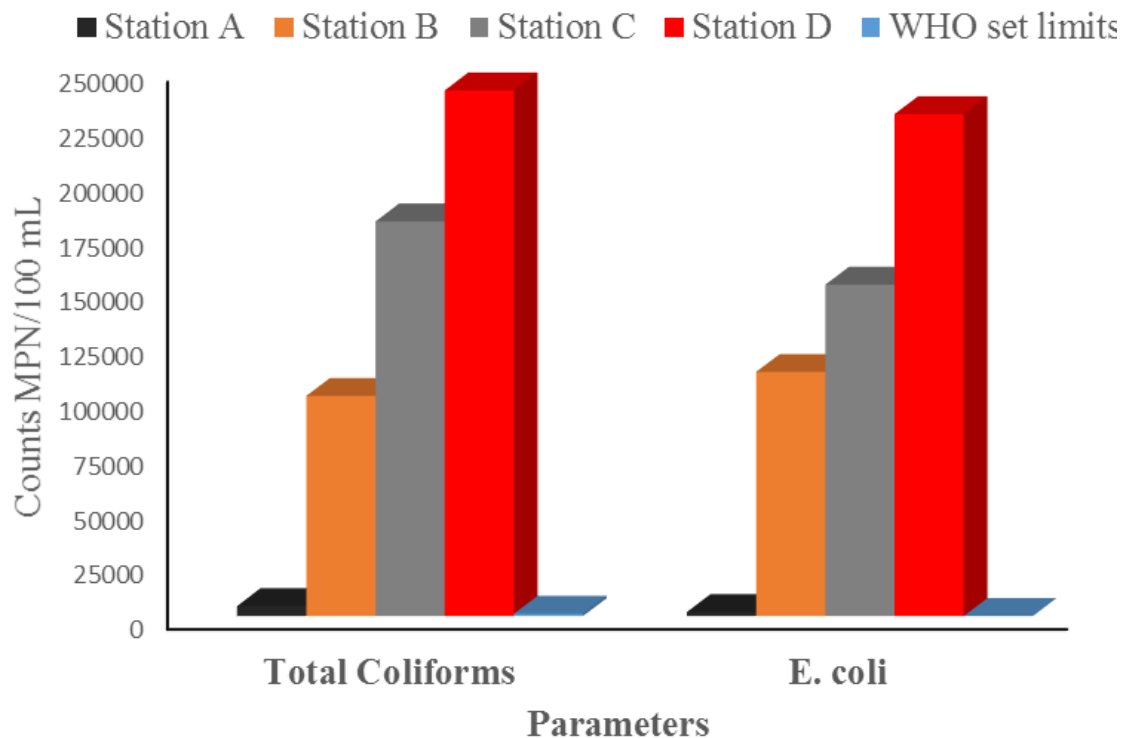
Figure 4. Bacterial counts in Mitheu Stream.

bacteria were upstream at sampling Point D at 240,000.00 ± 0.00 MPN/100 ml and 229,166.75±21,666.50 MPN/100 ml respectively (Table 2 and Figure 4).

The high bacterial counts at Point D were as a result raw effluent that entered Mitheu Stream from vandalized sewer lines. Comparatively, the downstream section (sampling Point A) had the lowest bacteria count for both total coliform and *E. coli* at 4524.25 ± 4615.316 MPN/100 ml and 1791.75 ± 1685.866 MPN/100 ml, respectively. This was as a result of dilution of effluent as water flowed downstream. Total coliform counts in the 4 sampling points were significantly varied as indicated by the P-value 0.026, however, *E. coli*

counts were not significantly different (P = 0.125). The counts for both Total coliforms and *E. coli* exceeded WHO permissible limits for irrigation water. Heavy bacterial contamination against WHO set standards implies possible transmission of bacterial-carried infections to farmers either by directly handling the stream's water or the residents who consume the vegetables. *E. coli* in particular is required to be below 1 for irrigation water (Ogbonna, and Ajubo, 2017). High concentrations of the virulent strains of *E. coli* lead to diseases such as diarrhea, urinary tract infections, and crohn's disease (Agwa et al., 2013). The high bacterial contamination was due to the municipal effluent from Machakos town that is channeled directly into Mitheu Stream due to vandalism of sewer lines by farmers who farm along the stream. Additionally, it is an indication of inefficient sewage treatment system within Machakos Municipality. Municipal sewage contains fecal matter that has high bacterial content and has serious risks to human health. A similar study in Athi River in Machakos County in 2015 found a higher bacterial contamination in River Athi (Wambugu et al., 2015). A comparison with a similar study conducted in Tamale Metropolis Ghana finds the urban stream in Machakos to be heavily polluted with both total coliforms and *E. coli* bacteria (Abdallah, 2018).

Heavy metals in water

Heavy metal concentrations in Mitheu Stream are presented in Table 3. Out of these five metals, only Cd was above WHO standards for irrigation water in three sampling points. One-way ANOVA revealed that the concentrations of the metals in the respective sampling points did not vary significantly (P>0.05).

The concentration of Cd ranged between 0.0019 ± 0.0015 MgL^{-1} (Point D) upstream and 0.0182 ± 0.0275 MgL^{-1} (Point A) downstream. The high concentration of Cd downstream could be linked to usage of phosphate fertilizers in the farms along the stream that got washed into the stream. Concentrations at Points A, B and C were higher than WHO limits for irrigation water. This implied unsuitability of the water from Mitheu Stream for irrigation with regard to Cd poisoning. The concentrations of Cu, Zn and Pb were below WHO limits for irrigation water for all the sampling points. The concentration of Pb ranged from 0.0011 ± 0.0019 MgL^{-1} at Point B to 0.0144 ± 0.0245 MgL^{-1} at Point C. The concentration of Zn ranged between 0.0281 ± 0.0487 MgL^{-1} at Point B and 0.1204 ± 0.1329 MgL^{-1} at Point A. The fertilizers and pesticides used in the farms along the stream possibly contributed to the high concentration of Zn downstream. Pb concentration at Point D was higher than other sections of the stream. The most probable source of Pb upstream of Mitheu Stream was municipal effluent discharged into the stream that possibly contained Pb washed from paintings in buildings within

Machakos town and vehicle garages at Machakos industrial area. Its concentration downstream of the wastewater treatment plant was below detectable limit. This indicated low susceptibility of Pb poisoning from municipal effluent in Machakos town. Cr concentration was found to range between 0.0003 ± 0.0005 MgL^{-1} at Point A and 0.0049 ± 0.0049 MgL^{-1} at Point D. All concentrations of Cr were below WHO limits for irrigation water. Compared with heavy metals concentrations in urban streams in a study conducted in Awash River in Ethiopia by Degefu et al. (2013) the concentrations in Mitheu Stream were lower. Similarly, concentrations of Cu, Zn, and Pb were lower compared to those of urban streams in Tamale Metropolis Ghana (Abdallah, 2018). The concentration of Cd in this study however, was slightly higher than that found in urban streams in Tamale Metropolis, Ghana (Abdallah, 2018). The potential sources of these heavy metals in Mitheu Stream were the municipal effluent within Machakos municipality and the agrochemicals (fertilizers and pesticides) used in the farms along the stream.

Heavy metals, particularly those studied in this research, have detrimental effects on stream ecosystems. They contribute to a reduction of dissolved oxygen in water and disrupt the optimum metabolic functioning of aquatic organisms such as zooplanktons, phytoplankton and fish (Lenka et al., 2018; Ghosh et al., 2015; Saha et al., 2011; Mahmoud, and Ghoneim, 2016) high concentrations of these heavy metals also interfere with the metabolic activities as well as physiological process of plants (Sayo et al., 2020). Dietary intake of heavy metals can have serious health effects on people such as damage to vital internal organs like the liver, kidneys and the brain (Mahmoud and Ghoneim, 2016; Ghosh et al., 2015; Saha et al., 2011). These negative effects give credence to the need to design appropriate pollution prevention and mitigation measures of effluent discharged into riverine systems within Machakos municipality.

CONCLUSION AND RECOMMENDATIONS

The high concentrations of COD and BOD in Mitheu Stream above WHO limits for irrigation water are a pointer to heavy organic load discharge. The sources of organic wastes need to be monitored, tracked and prevented. The high concentration of phosphates above WHO standards are an indication of poor sanitation services as well as long-term washing of agrochemicals into the stream. Phosphates are however not harmful to humans unless in extremely high concentrations. Sulphates and nitrates were within allowable limits in accordance to WHO standards for irrigation water. The high load of total coliforms and *E. coli* bacteria are an indication of poor sanitation services and their management in the municipality. The high concentration of Cd above the WHO limits for irrigation is a pointer to

Table 3. Mean ± standard deviations of heavy metals concentrations in water.

Site/parameter (MgL^{-1})	Point A	Point B	Point C	Point D	WHO limit	P-value
Cd	0.0182±0.0275	0.0118±0.0197	0.0162±0.0276	0.0019±0.0015	0.01	0.827
Cu	0.0015±0.0017	0.0011±0.0019	0.0144±0.0245	0.0040±0.0050	0.2	0.556
Zn	0.1204±0.1329	0.0281±0.0487	0.1102±0.1521	0.0308±0.0420	2	0.592
Pb	0.0024±0.0042	BDL	0.0002±0.0003	0.0289±0.0501	0.5	0.452
Cr	0.0003±0.0005	0.0031±0.0054	0.0018±0.0031	0.0049±0.0049	0.01	0.557

BDL is below detectable limit.

potential Cd poisoning through dietary heavy metal transfer. Overall, the use of this stream water for irrigation poses serious health risks to the farmers as well as residents of Machakos municipality, who are the main market for the leafy vegetables grown. The sewage treatment plant in Machakos is not operating as efficiently as would be expected. An audit of the system is needed in order to provide entry points to structural and operational changes toward best practices in effluent management. A multi-stakeholder approach is needed to develop and implement guidelines on prevention of stream pollution, urban farming and irrigation water use in such unique circumstances.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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African Journal of Environmental Science and Technology

Full Length Research Paper

An appraisal of high definition survey approaches in subsidence monitoring of crude oil storage tanks

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Vertical and horizontal motion of the solid earth surface due to geological and geodynamical phenomena are generally consequences of terrain deformation. Variations as a result of the deformation affect structures, particularly large storage facilities that are steel and/or concrete in nature. The criticality of these phenomena underscores the need to carryout regular measurements and monitoring of its effect in all dimension. Over the years, methods and instrumentation for subsidence monitoring has evolved from the conventional to the recently high definition surveying approach with an increasing need to detect and analyse deformation changes with clarity at any given time. The aim of this work was to appraise the high definition surveying approaches in subsidence dynamics of crude oil storage facilities. Classical instrumentations and the terrestrial laser scanning equipment were deployed based on the principles of geodetic positioning and mapping for overlity, verticality and radial displacement parameters determination using the two approaches. This paper will provide spatial information in terms of point clouds, 2D and 3D models, vertical and radial displacement of the crude oil storage facility. The work will further demonstrate the optimal capability of high definition surveying approach in our quest to constantly manage the complexities associated with subsidence. Several crude oil storage facilities in addition to other private storage facilities all over the country, require a policy to ensure regular monitoring and analysis of these facilities especially with the trend of earth tremors being experienced in parts of the country.

Key words: Subsidence, high definition surveying, radial displacement, crude oil facility, geodetic positioning.

INTRODUCTION

The advent of Terrestrial Laser Scanner (TLS) also referred to as High Definition Survey (HDS) with its current advancement in speed, has become a very useful survey equipment for various earth or near-earth based features that may be natural and/or man-made such as as-built surveys, 3-dimensional (3D) spatial point cloud generation, archaeological site mapping and modelling, terrain characteristics and associated changes (Hart et al., 2018).

Meanwhile before the advent of these new HDS

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measurement, scientist and most geoscientists use the total station which basically is the improvement based on combination of the conventional theodolites and electronic distance measurement equipment (EDM). This compact equipment with in-built software enhanced the measurement capability of both angular and linear dimension of earth-based measurements. The use of total station for mapping and other surveys like deformation is still very relevant in today's world and can be used for subsidence monitoring especially on large storage crude oil tank farm.

The solid earth is under some form of stress and strain which results to ground movements. They can be attributed to natural processes or to some anthropogenic activities on the earth or near-earth surfaces. These movements can be slow or rapid depending on the magnitude of the force and/or load exerted on the solid earth though soft and compressible in most cases, it can also be as a result of the fluctuations associated with ground water and other geodynamical phenomena, (Crosetto et al., 2005). This development is synonymous to the Niger Delta Area of Nigeria where there are increase of oil and gas extraction on a daily basis in addition to the myriads of oil storage facilities spread within the area both by government and private holdings.

Large vertical cylindrical steel tanks widely used for crude oil storage generally consist of a thin bottom plate cylindrical shell and fixed or floating roof. These large tanks are susceptible to various types of settlement. The settlement components could be uniform settlement planer tilt or differential settlement. The uniform settlement and planer tilt causes rigid body deformation or rotation of the tank. Minimal differential settlement under the tank wall can induce large distortions along the tank top and high stresses at the tank base or in the top wind girder (Hart, et al, 2019). This work would showcase a classical case of the deployment of the TLS and conventional survey method in the monitoring of standards steel crude oil tank in the Niger-Delta area. The need for subsidence measurement and monitoring stems from the fact that slow movements related to load of structures on the solid earth has the potential of long-term damage and risk (Okeke, 2005). The aim of this work was to appraise the High Definition Survey approaches in the subsidence monitoring of crude oil storage. The objectives of the study were: 1) to determine the verticality of a crude oil tank using a 3-D model derived from laser scanning and 2) to determine overlity of a crude oil tank using a 3-D digital model derived from laser scanning output. The determination of the overlity, verticality and subsidence using conventional total station and digital level will provide the basis for the comparative analysis of the two approaches. The difference is that instead of measuring 'discrete points', the laser scanner measures 50000 points per second and with a point spacing of 0.1 at 100 m. This results in a very dense 'cloud' of data points, each of which is to the same accuracy as those measured by Total Station.

MATERIALS AND METHODS

Study area description

The study area is located in the Bonny Island situated in the southern edge of River State in the Niger Delta of Nigeria near Port Harcourt which most appropriately is defined by the following coordinates in WGS84, 4° 26" 18.81 N,7° 9" 39.3E; 4° 25" 30.77 N,7° 10" 47.93 E; 4° 24" 39.45 N,7° 9" 51.26 E; 4° 25" 4.96 N,7° 8" 49.39 E. The study area as depicted in Figure 1 houses several crude oil storage facilities in varying shapes and sizes besides other oil and gas facilities.

Scope of the work

The scope of this work involves the deployment of contemporary laser scan equipment for scanning of crude oil tank 18 and show the processes involved from the *in-situ* checks to modelling. This is in addition to the conventional method (that is use of total station and level equipment) for subsidence monitoring of the same crude oil tank. The outputs of the two systems were reviewed both spatially and in 3-D for the laser scan, in order to generate the verticality, overlity and subsidence displacement from the two systems spatial and model output.

CONCEPTUAL REVIEW

The principles of light detection and ranging (Lidar) operation in typical mapping operations

The principles of LIDAR are quite simple; in explaining these phenomena scientifically, a LIDAR instrument emits a rapid pulse of laser lights at a surface some at 150000 pulses per second. The constant speed of the laser light is known hence the LIDAR instrument can calculate the distance between the source and the target with high accuracy. The distance or range can be computed as follows (Okeke and Moka, 2004; Okeke, 2005; Casu et al., 2016):

$$R = C \frac{t}{2} \tag{1}$$

Where, C = speed of light (299792.458 m/s); t=time interval between sending and receiving the pulse(ns), R= Range.
For range resolution the following formula is used:
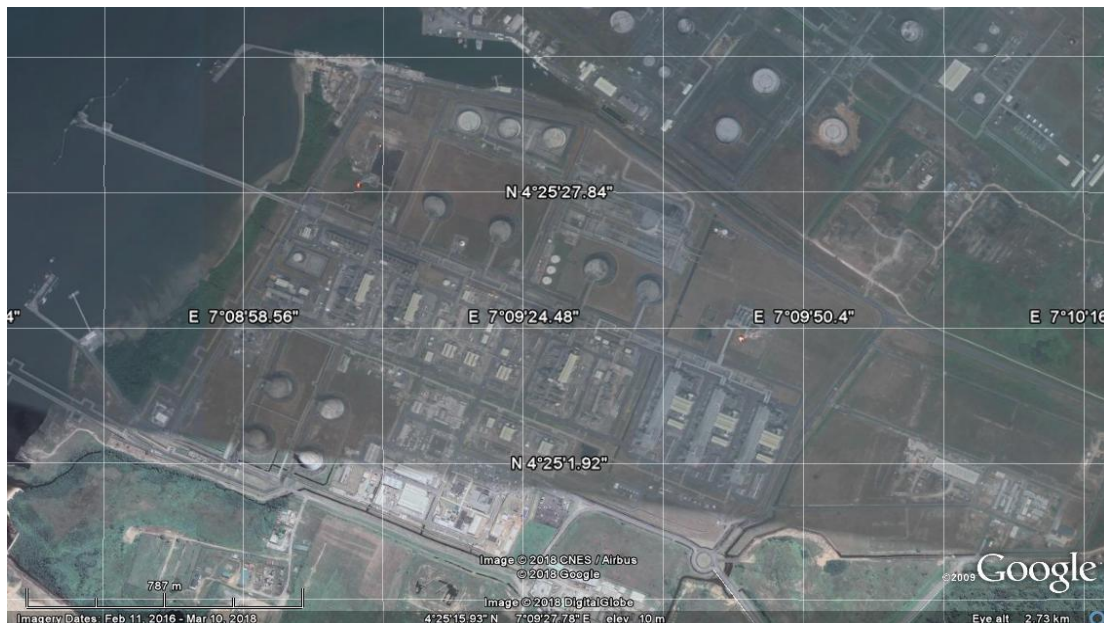
$$\Delta R = C \frac{\Delta t}{2} \tag{2}$$

ΔR= Range resolution, Δt= Change in time.

To calculate laser pulse travel time,

$$t = \frac{2R}{C} \tag{3}$$

To compute for a continuous wave laser range distance r and range resolution ΔR,

Figure 1. Aerial view of the study area.
Source: Google Earth Map (2018).

$$R = \frac{C}{2}\frac{\Phi}{2\Pi f} \qquad \Delta R = \frac{C}{2}\frac{\Delta\Phi}{2\Pi f}$$

$$(4a,b)$$

Where, C =speed of light (299792458 m/s), Φ =phase, $\Delta\Phi$ =Phase resolution (radian), f=frequency or number of wave cycles per unit time.

From Equations 1.0 to 4a and b it can be computed that the continuous wave range and repeating it in rapid succession, the instrument builds up a large collection of data of the object. In computing for pulses, the coordinate position, the orientation and location of the scanner gotten from the GPS and Inertia Measuring Unit (IMU), the angle of the scan mirror and the range distance to the object are easily derivable. The collection of points in coordinate format is referred to as point cloud.

The principles of total station operations

The total station is an instrument that combines both angle and distance measurement in the same system. The total station can measure slope distances as well as bearings. The slope distance with deduced horizontal angles and vertical angles is used to derive the horizontal distances and heights or depth of an object. Total stations are configured to carry out many survey tasks which also includes the storage of large set of data. The total station distance measurement is accomplished by the use of electromagnetic wave or a pulse. The electromagnetic wave passes through the atmosphere from the instrument to hit the target which usually reflect and return back to the instrument. Some total stations could operate as a reflectorless but the distances measured can use either the phase shift or the pulsed laser method. The simplest representation of the electromagnetic wave is the periodic sinusoidal wave motion which has its wavelength, frequency, speed and amplitude. These elements are used to estimate the distances, (Karl, 2004). For the pulse laser method, a pulse is derived from an

infra-red or visible laser diode which is transmitted through a telescope towards a remote end which is reflected to the instrument. For both cases, the mathematical relationship remains the same and is given as in Equation 5.

$$2D = Vt$$

$$(5)$$

Where, D =distance; V =velocity of pulse; t=time taken to and from the target.

To compute for the partial horizontal and vertical distances in the total station it uses the in-built software using the following formula as expressed in Equations 6 and 6.

Horizontal Distance (HD)= $LCos\alpha$ or $LSin\beta$ $\qquad$ (6)

Also, the Vertical Distance VD= $LSin\alpha$ or $LSin\beta$ $\qquad$ (6)

Where α = vertical angle and β = Zenith angle.

The total station accuracy is expressed as (*a mm + b ppm*). The *a mm* is an independent errors source that could be due to the unwanted errors caused by the total station internal components which could be errors in phase and transit time measurement. Similarly, *b* is the error expressed in part per million.

Methodology

The principles of the methodology will stem from traversing and differential levelling (that is Classical) and high definition survey methods based on laser scanning (that is modern). The fundamental principles of controls were deployed which include the establishment of six (6) GPS points within the Tank farm. This was followed by the extension of the control points to all the nine (9) tanks to be monitored with the aid of a Total Station and a Digital

Table 1. Specimen of the result of the terrestrial *in-situ* Checks.

Activity	Pillars	Values computed	Observed Value	Difference
Angle check	GPS-CP1GPS-CP2 GPS-CP3	89˚ 26' 48"	89˚ 26'45"	-00 00' 03"
Distance Check	GPS-CP2-GPS-CP1GPS-CP2- GPS-CP3	487.373 m	487.394 m	-0.021 m
Elevation	BONGPS4- BONGPS5	3.923 m	3.8966 m	0.026 m
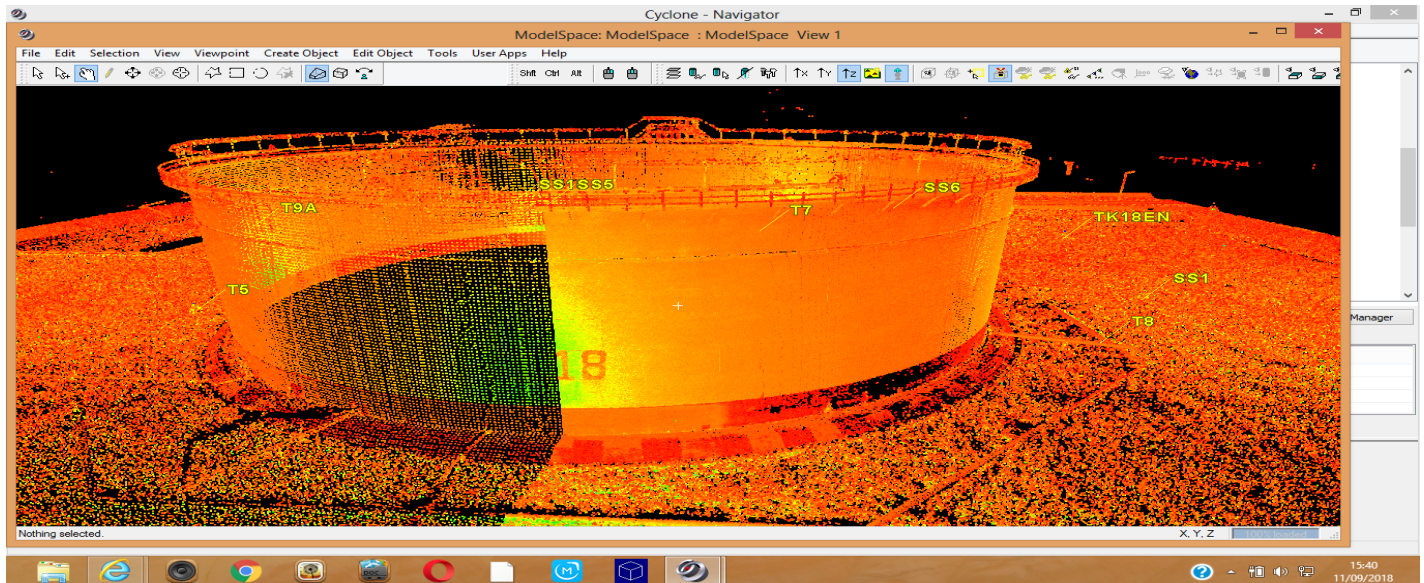
Figure 2. Scan view of an oil storage tank (Hart et al., 2018).

level instrument however, crude oil storage tank 18 was reviewed in this research. This process indicates deviations axially horizontally and vertically over a period of time in the event of loading or changes in the earth crust (Hart et al., 2018). The tank settlement surveys: subsidence, ovality and verticality were all based on the extension control points. The reference stations were set at BONGPS6. Position was then translocated to GPS-CP1 to CP6. The results of the *in-situ* process for control check as shown in Table 1 shows that the differences are within allowable limits for the use of the control stations.

Conventional approach-field procedure

Traversing was carried out using LEICA Total Station and was done in loops. This comprises three loops on the tank at three levels of the oil contents: low, middle and full levels. The traverse was based on the GPS points: GPSCP1, GPSCP2, GPSCP3, GPSCP4, GPSCP5 and GPSCP 6: and GPS extension controls around each tank. The tanks were marked 5m off the ground base at equal intervals. With the use of reflectorless total station the marked points at the base were bisected and tracked and its corresponding top of the tank was also tracked. Similarly, differential levelling was carried out using digital level which reads to four decimal places. The level was based on GPS pillars: BONGPS04 and BONGPS05 that proved in-situ and was extended to the tank site. The level was carried out on the already existing studs around the tanks. The level was done in two (2) loops-morning and evening at each oil level content of the tanks. That gave a total of six loops for each of the

nine tanks and a ground total of 54 loops for the nine tanks. Adjustments of the traversing and levelling data were classical carried out to guide the processing and analysis.

High definition survey approach

The Leica Scan station C10 was deployed for this research. The crude oil tank was scanned from six vantage positions to cover and create an overlap as shown in Figure 2. A total of six scanworld was generated. According to Ezeomedo et al. (2017), they described a scan world as a single scan or collection of scans which are aligned to a common coordinate system. It also contains control spaces and model spaces. The control spaces usually carry the constraint information that is used for the registration of multiple scans. Also, the model space contains information from the database that has been modelled (Hirt, 2015). During the scanning, a combination of the different scanning methods like the known back station, the resection method and the intersection methods were used depending on the setup method most suitable at the station. The data output from the exercise which is known as the point cloud are very dense such that current scanners can collect anywhere between 200 and 10000 points per second (Francis et al., 2018).

RESULTS

The vertical check in Table 2 using the total station

Table 2. Specimen of average vertical check with the total station.

Studs	Decimal of Deg.	Deg Min Sec
Stud1	0.088	00° 17' 11"
Stud6	0.084	00° 13' 45"
Stud7	0.082	00° 13' 45"
Stud12	0.017	00° 03' 26"
Stud17	0.016	00° 03' 26"

Table 3. Specimen of mean displacement of tank 18.

| Studs | Tank18 | | |
	Radial length	Mean radial length	Radial displacement
S1	33.674	33.585	0.089
S2	33.715	33.585	0.130
S3	33.677	33.585	0.092
S4	33.632	33.585	0.047
S5	33.588	33.585	0.003
S6	33.574	33.585	-0.011

Radial displacement ranged from 2 t0 130 mm.
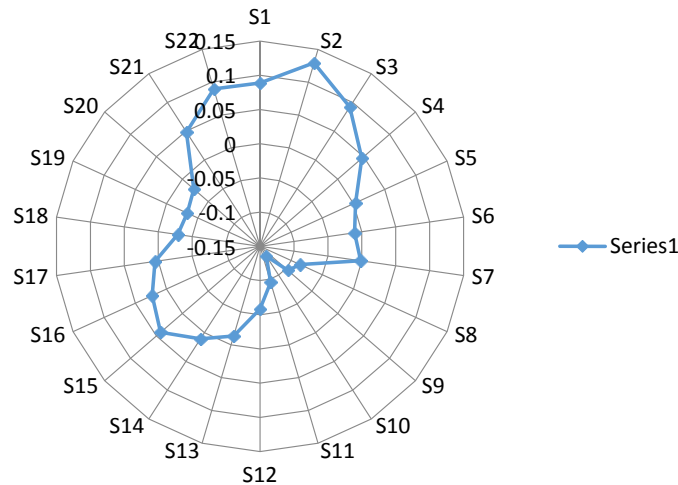
Figure 3. Radial displacement configuration of tank 18.

showed a maximum deviation of 17' 11" on stud 1 with minimum deviation of 3' 26" on studs 12 and 17. Similarly, the mean radial displacement as shown in Table 3 ranges from 2 to 130 mm and graphically demonstrated in Figure 3. In another vein, Table 4 describes the mean deviation of load variation viz. 2.4000, 10.7000 and 15.5000 m of tank level.

Figure 4, depicts the axis of a cylinder that was fitted through the point cloud and the statistics showing the fit quality can be seen in the fit quality Table 5. The axis of the cylinder when empty is shown in the image.

Table 6 describes the statistical information on the variability of the various levels of oil in the storage tank 18 as deployed by the scan models as shown in Figure 5 indicating the deviation as a function of the variation of the content level in tank 18. In the same vein, Figure 6 highlights the combination of the points of measurement using the classical (total station) and laser scan (high definition) techniques. The differentiation is in the colouration and markings.

Table 4. Mean Deviation of load variation of tank 18.

Tank Level								
2.4000 (m)		10.7000 (m)		15.5000 (m)		Deviation (m)		
Mean value low		Mean value middle		Mean value full				
						Mean of Mean	Low Dev.	Mid. Dev.	Full Dev.
STUD01	5.2064	STUD01	5.2001	STUD01	5.2027	5.2030	-0.0033	0.0030	0.0004
STUD02	5.2121	STUD02	5.2046	STUD02	5.2076	5.2081	-0.0040	0.0035	0.0005
STUD03	5.2206	STUD03	5.2124	STUD03	5.2150	5.2160	-0.0046	0.0036	0.0010
STUD04	5.2185	STUD04	5.2111	STUD04	5.2151	5.2149	-0.0036	0.0038	-0.0002
STUD05	5.2283	STUD05	5.2190	STUD05	5.2229	5.2234	-0.0049	0.0044	0.0005
STUD06	5.2458	STUD06	5.2361	STUD06	5.2398	5.2406	-0.0052	0.0045	0.0007
STUD07	5.2272	STUD07	5.2181	STUD07	5.2242	5.2232	-0.0041	0.0051	-0.0010
STUD08	5.2281	STUD08	5.2173	STUD08	5.2228	5.2227	-0.0054	0.0055	-0.0001
STUD09	5.2313	STUD09	5.2197	STUD09	5.2248	5.2253	-0.0060	0.0056	0.0005
STUD10	5.2238	STUD10	5.2124	STUD10	5.2171	5.2178	-0.0060	0.0054	0.0007
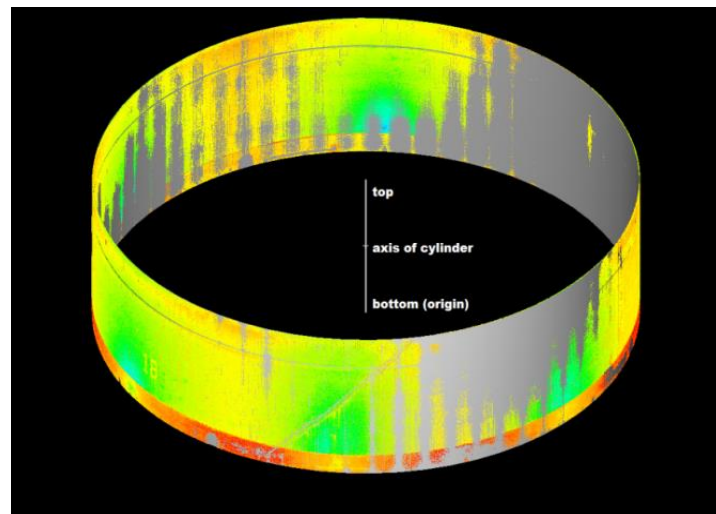
Figure 4. Specimen of the axis of a cylinder that was fitted through the point cloud.

Radial displacement

Figure 7 shows a comparison of the radial displacement at each stud as measured by the two survey instruments. As can be seen, there is a high degree of correlation. The average difference as measured by the two technologies was 6 mm. Figure 8 demonstrates the Radial Displacement Plots for every degree change, as derived from laser scan measurements and total station instrumentation.

Verticality

The current methodology for computing the Tanks verticality using a Total station is to calculate the vertical angle at 4 points (North-South and East-West). Laser scanning allows us to use the millions of surveyed points on the tank wall as shown in Figure 9, which we can 'best fit' a cylinder through. The axis of the cylinder indicates the overall tank verticality.

Tilt and subsidence

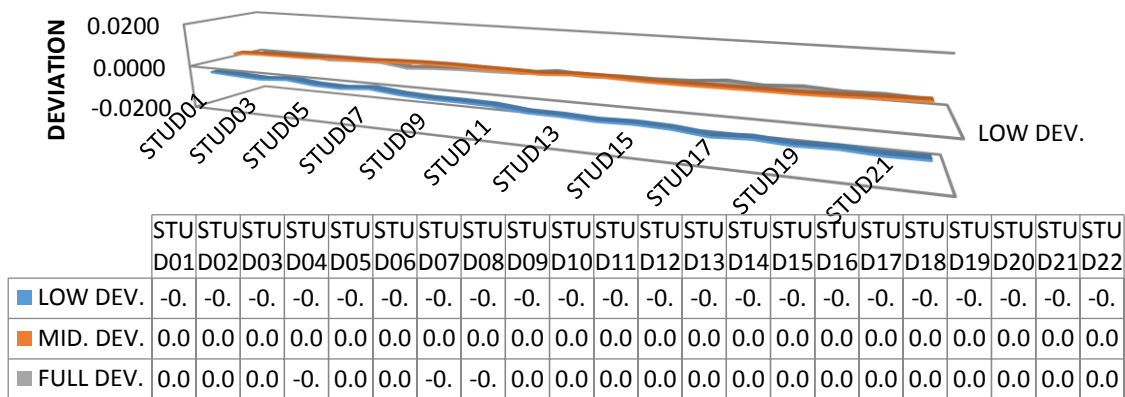The mean of the level of the studs is done and then the deviation to the mean is computed for the three states (empty, mid, full). With Laser scanning, we take a strip of points around the base of the tank (which is concrete). This shows if the levels are changing, which would show subsidence. It also allows to see if the ground is tilting and in which direction. These changes are shown in

Table 5. Overall Verticality Report Tank 18.

Empty	X	Y	Z		
Origin	522475.342	47591.862	4.902	DX*	DY*
Top	522475.359	47591.831	22.807	0.017	-0.031
Dia=	67.086				
Axis = (0.0010, -0.0017, 1.0000) **					
Med	**X**	**Y**	**Z**		
Origin	522475.343	47591.860	4.906	DX*	DY*
Top	522475.356	47591.843	22.738	0.013	-0.017
Dia=	67.099				
Axis = (0.0007, -0.0009, 1.0000) **					
Full	**X**	**Y**	**Z**		
Origin	522475.341	47591.862	5.008	DX*	DY*
Top	522475.352	47591.846	22.699	0.011	-0.016
Dia=	67.107				
Axis = (0.0007, -0.0009, 1.0000) **					

Table 6. Statistical Information on Oil Level Variation of Tank 18 using the Scan Models.

Empty	Mid	Full
Derived from cloud with 3567898 points	Derived from cloud with 3750056 points	Derived from cloud with 2515332 points
Fit Quality		
Error Mean = 0.000 m	Error Mean = 0.000 m	Error Mean = 0.001 m
Error Std Deviation = 0.045 m	Error Std Deviation = 0.045 m	Error Std Deviation = 0.043 m
Absolute Error Mean = 0.038 m	Absolute Error Mean = 0.037 m	Absolute Error Mean = 0.036 m
Maximum Absolute Error = 0.156 m	Maximum Absolute Error = 0.155 m	Maximum Absolute Error = 0.158 m

	STUD01	STUD02	STUD03	STUD04	STUD05	STUD06	STUD07	STUD08	STUD09	STUD10	STUD11	STUD12	STUD13	STUD14	STUD15	STUD16	STUD17	STUD18	STUD19	STUD20	STUD21	STUD22
LOW DEV.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.
MID. DEV.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FULL DEV.	0.0	0.0	0.0	-0.	0.0	0.0	-0.	-0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 5. Subsidence deviation of tank 18 at three oil content levels.

Figure 10.

CONCLUSION

Laser scanning facilitates a comprehensive analysis of storage tanks. Scanning allows us to monitor the entire tank shell for deformation rather than by the conventional surveying approach with a limited number of discrete points. Traditionally, storage tank survey is carried out using a total station or a simple measuring tape. While these techniques provide the necessary position
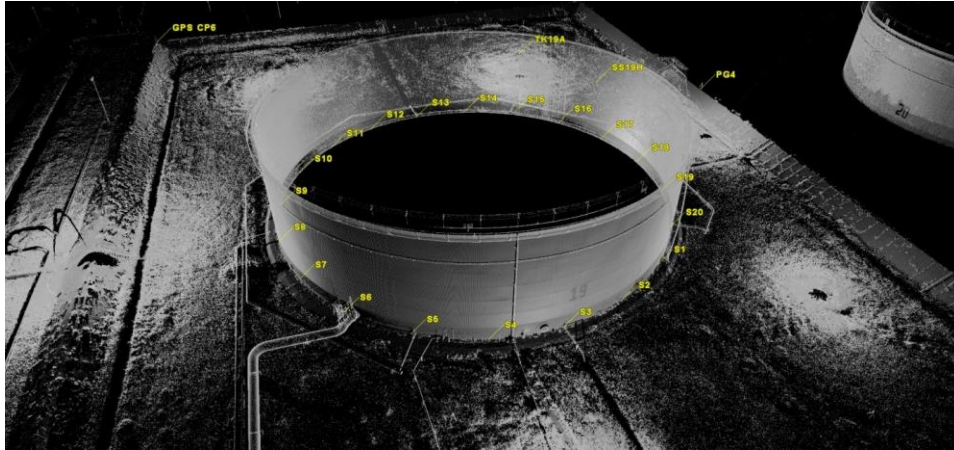
Figure 6. Greyscale Map showing Total Station Measurements (Yellow) and Laser Scan data.
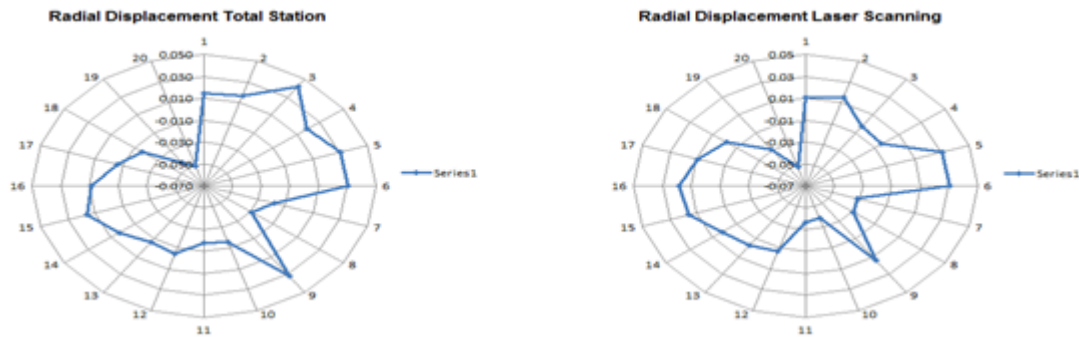
Figure 7. Comparison of Radial Displacement of Tank 18 using the Two Approaches.
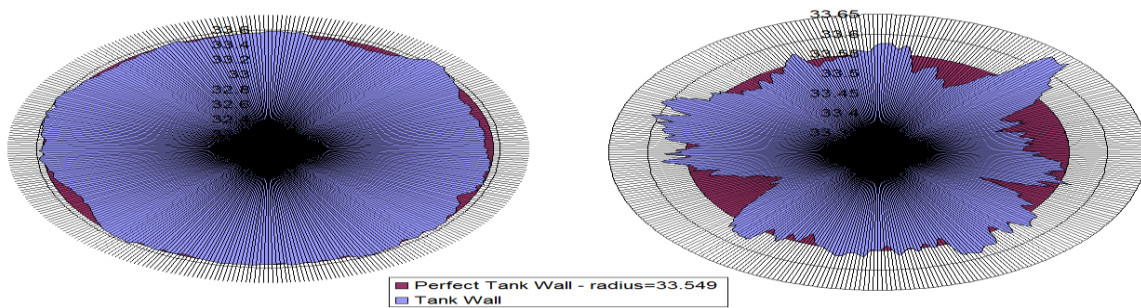
Figure 8. Radial Displacement Plots

information, they are generally time intensive when multiple measurements are required. When using a measuring tape, measurements are prone to errors. 3D scanning removes these deficiencies by capturing thousands of points in the same time it takes to capture few points with a total station. Comparisons of millions of points between two scans over an extended period can highlight areas where change has occurred. Closer inspection or repairs could then be undertaken on the specific areas of concern to avoid costly failures and potential loss of assets. 3D modelling of the storage tank and its surroundings allows us to create a comprehensive data set that can be used to obtain direct measurements and volumes to ensure that containment dikes for
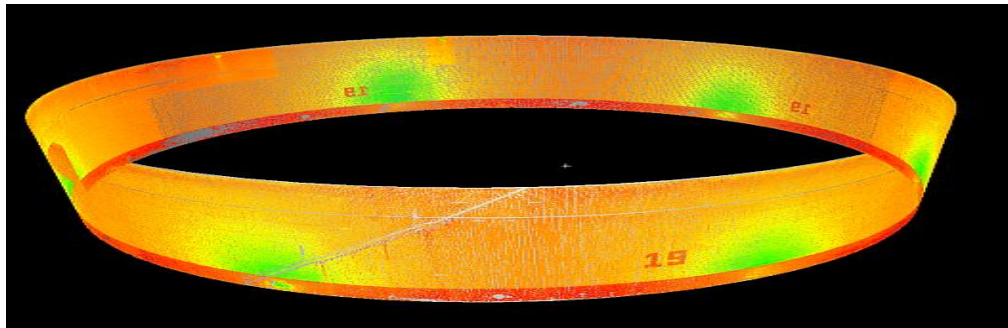
End Point 1 = (522743.432, 47543.056, 4.755) m

End Point 2 = (522743.431, 47543.061, 22.794) m

Origin = (522743.432, 47543.056, 4.755) m

Axis = (-0.0001, 0.0005, 0.0000)

Diameter = 67.098 m

Derived from cloud with 4265818 points

Figure 9. Image Cylinder fit through Laser Data.
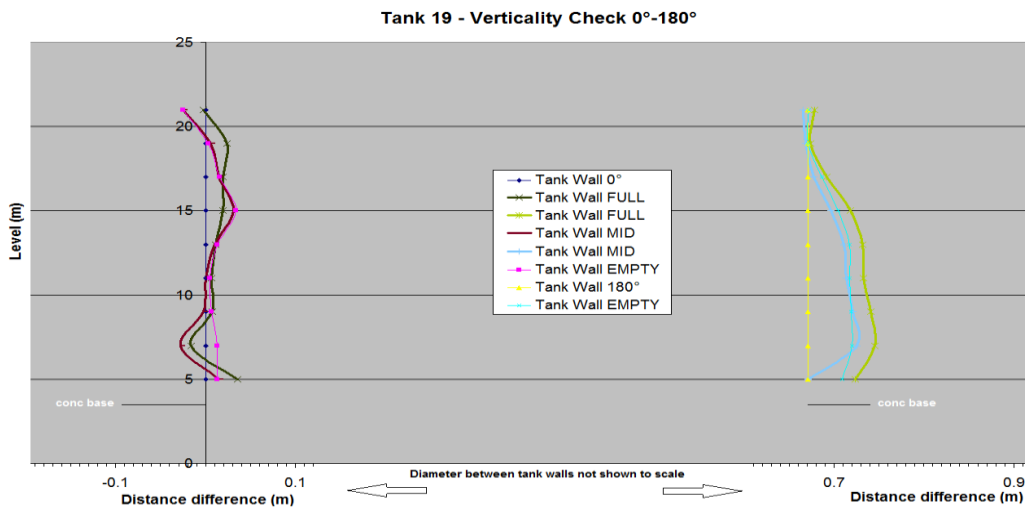
Figure 10. Verticality check for subsidence measurement.

example, satisfy regulatory requirements. Areas of potential concern or failure can be quickly identified and quantified to reduce repair time.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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African Journal of Environmental Science and Technology

Full Length Research Paper

Effect of agitation on the process of bi methanization of sludge from low-temperature wastewater treatment plants

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Wastewater treatment is a serious environmental problem, especially in developing countries such as Morocco. Their discharge into the natural environment has negative impacts on water resources and the environment. They are therefore purified to reduce the concentration of the main pollutants. Often biological remediation is used when wastewater contains biodegradable organic pollutants. This generally leads to treated water that can be discharged into the environment reused, or used as wastewater sludge. In the case of domestic or municipal water, this sludge has a fermentable character, which can have negative impacts on the environment especially when it is discharged directly into the environment. This sludge is subjected to various aerobic or anaerobic treatments to reduce the fermentable fraction. Anaerobic treatment seems more attractive because it gives the way to eliminate organic matter, produce biogas and manure compost both in one time. In this work, an experimental study was conducted on the ambient temperature anaerobic digestion of sewage sludge in two reactors, one operating without agitation and the other with agitation, to evaluate the impact of the latter on the biological process.

Key words: Bio-methanization, ambient temperature, agitation, methanogenic potential, sludge, wastewater treatment plant, COD, pH.

INTRODUCTION

Some solid wastes have a fermentable organic fraction which is an environmental problem. Their injection in the

environment could be a real threat. Nevertheless, this organic character can be used wisely, by valorizing its potential in value-added products when subjected to anaerobic biological treatment, which, in addition to reducing negative effects (emission of bad odors, methane, mercaptans, etc.), makes it possible to produce biogas and sludge mineralization for soil amendment. This solid waste includes sludge from wastewater treatment plants. They are often disposed of in landfills or dumped into the natural environment. In Morocco, their quantity is estimated at 435.600 tonnes /year (Afilal, 2013), and have a fermentable organic fraction between 50 and 70% (Eva, 2004); this is a good source for anaerobic biogas production, consisting mainly of methane 60 to 75% (Eva, 2004), the equivalent of 128,000 tonnes of CH_4 per year .

The anaerobic biological biomethanization treatment roceeds in four stages (Figure 1). The first step is the hydrolysis of organic matter, for example proteins, fats, cellulose and starch. These polymers such as amino acids, fatty acids and simple sugars are divided into monomers.

The second step is acidogenesis, during which the hydrolytes are oxidized to organic acids (for example lactates), alcohol (ethanol) or volatile fatty acids (propionate, butyrate and valerate).

In the third step, the resulting acidogenesis compounds are transformed into methane precursor products: acetic acid, carbon dioxide (CO_2) and hydrogen (H_2).

The fourth step biomethanization, which is done by two ways. One, it called hydrogenotrophic using hydrogenotrophic bacteria that draw their needs from the couple H_2/CO_2. These bacteria get their energy from the reduction of carbon dioxide by hydrogen to produce methane according to the following reaction.

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \qquad \text{(Reaction 1)}$$

The other way called acetoclast where the strict anaerobic bacteria known as acetates, which extract their needs from the acetates; use acetate as their only carbon source (Reaction 2).

$$CH_3COOH \rightarrow CH_4 + CO_2 \qquad \text{(Reaction 2)}$$

The anaerobic process is a complicated method controlled by physico-chemical conditions such as the nature of the substrate, temperature, pH, agitation, etc. for instance, psychophilic digestion is optimal between in a temperature range around 6 and 15°C, while mesophilic digestion in a range between 30 and 35°C; for

thermophilic anaerobic digestion, it is favored and most effective at temperatures above 45°C because the reaction is accelerated by heat. However, anaerobic digestion is often used in mesophilic conditions, a compromise between performance and energy costs due to heating and especially because of its greater stability (Laskri, 2016).

The anaerobic fermentation takes place in a pH range between 5.5 and 8 for all phases. For the acidogenesis phase, it is between 5.5 and 6.5 (Souza et al., 2012), for acetogenesis, it is near neutrality. For methanogens, the pH range is between 6 and 8 (Gourdon, 2002).

Agitation plays a significant function in the anaerobic metabolic process. It ensures a good mixture, which improves the contact between the purifying bacteria and the sludge (Borole et al., 2006). Many studies have shown the importance of agitation on the fermentation process ; in the first hand Johan Lindmark (Lindmark, 2014) evaluated the effect of mixing by comparing three régimes of mixing; 150 rpm, 25 rpm and continuous mixing; The results prove that the biogas production is better with a speed of 25 rpm which reaches 240 Nml , while the speed of 150 rpm gives a lower production of biogas; the author found that strong agitation inhibits the anaerobic fermentation process.

In the second hand, Hajji and Rhachi (2016) studied the influence of agitation on biogas production by comparing two reactors with and without agitation; he found a biogas production rate that reaches a value of about 0.61 m^3/for a reactor of 40 rpm, then in the reactor without agitation the final volume of the final biogas is reduced up to 62%, most of these methanisation plants operate at temperatures of 37 or 55°C, however Ukondalemba et al. (2016) studied an anaerobic digestion with recirculation (type of agitation) of juice in the hydrolysis phase and acidogens at an ambient temperature of 25°C; results showed that 83% of the COD is transformed into biogas.

This study aimed at studying the biomethanization of sludge from a wastewater treatment plant at ambient temperature. The objective is to evaluate the effect of agitation (agitated versus no agistated reactors) on the anaerobic biological process by comparing two identical reactors.

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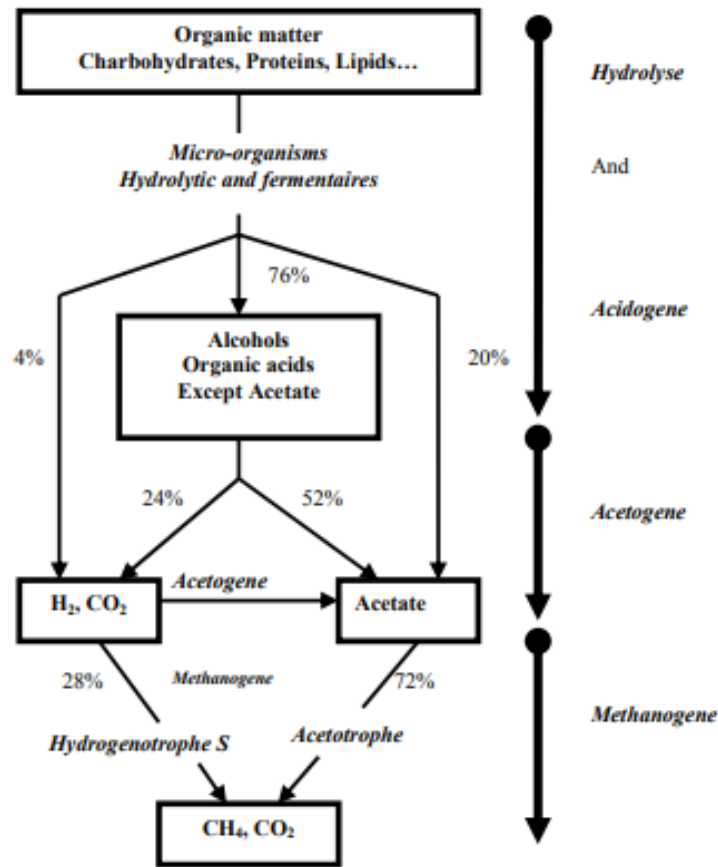
Figure 1. Diagram of the trophic chain of methanogenesis and its different stages (Moletta, 1993).

temperatures above 45°C because the reaction is accelerated by heat. However, anaerobic digestion is often used in mesophilic conditions, a compromise between performance and energy costs due to heating and especially because of its greater stability (Laskri, 2016).

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Dry sludge   Crushed sludge

Plate 1. Dry raw and crushed sludge.

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This study aimed at studying the biomethanization of sludge from a wastewater treatment plant at ambient temperature. The objective is to evaluate the effect of agitation (agitated versus no agistated reactors) on the anaerobic biological process by comparing two identical reactors.

MATERIALS AND METHODS

Origin and characterization of the substrate

The sludge samples collected from sludge wastewater treatment plant of the National Office of Water and Electricity (ONEE) of Bourereg in Rabat-Morocco. This station receives discharges at an average rate = 86.4 m^3/d, and a peak flow rate = 259.2 m^3/d; these discharges have the following characteristics: COD = 15.1 Kg/d, BOD_5 = 9.0 Kg/d, mean TSS = 16.2 Kg/d. It is a station that produces between 7 to 10 Kg/d of fresh liquid sludge in the open air on drying beds and then stocked.

Before their use, the dry sludge (Plate 1) was crushed and screened to generate small particles for better homogenization of the medium. To do this, the samples were spread on rectangular plates covered with filter paper, in the open air, then ground and sieved to obtain a homogeneous powder with a grain size of less than 2 mm.

Sludge characterization

Before use, the dry sludge (Plate 1) was crushed and sieved to

obtain a homogeneous powder with a grain size of less than 2 mm. Masses of 5 g of these sludge are added to 125 ml of distilled water. The mixture was then agitated every 15 min and then rested every 15 min for 1 h (Hamdani, 2008) .

The mixture was recovered to determine the following parameters:

1) The hydrogen potential (pH) is measured by using a multi-parameter probe.
2) The suspended matter has a centrifugation method.
3) The electrical conductivity.
4) Dissolved oxygen.

Organic matter

The chemical oxygen demand (COD) was determined according to the standard method (AFNOR T-101) (Kalloum et al., 2007)

Metal measurement: ICP-AES

Batch digester operation

The experimental system (Plate 2) used for the anaerobic digestion of sludge consists of two opaque plastic tanks each with a volume of 30 L. Each tank was filled with 1,350 kg of dry sludge at a rate of (50 g/L). The tests were conducted at an average ambient temperature of 18°C for 40 days. In the reactor, agitation is ensured by using a mechanically controlled agitation motor with a speed of 40 rpm (Kalloum et al., 2007).

The follow-up was made by daily samples of 50 ml from the reactors. The test was run during the month of February.

Plate   2. Reactor for methanogenic digestion.

Tables 1. Physical and chemical characteristics of the sludge from the Bouregregreg wastewater treatment plant

pH	Electrical conductivity (mS/cm)		Temperature (°C)		Dryness		COD (gO2/l)		Dry volatile matter (DVC)				Dissolved oxygen (O$_2$) mg/l		
6,82	2,74		18		89,03%		10,89		63%				8,72		
Elements	Cd	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Zn	Co	P	Pb	Ba	Al
Concentrations	3,023	71720	28,65	157,7	15470	1301	8808	252,4	1087	18,65	1652	4,077	--	138,5	518,6	7125
Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	mg/L	mg/L

RESULTS AND DISCUSSION

Physical and chemical characteristics of sludge

Table 1 presents the characteristics of the sludge from the Bouregregreg wastewater treatment plant.

These results show that the sludge has a COD of 10.89 g/l, and contains a number of metals of significant concentrations, in this case Ca (71720 mg/L), Fe (15470 mg/L), Mg (8808 mg/L), Al (7125 mg/L) and to a lesser extent K (1301 mg/L), Na (1087 mg/L) and Zn (1652 mg/L). The organic matter content is 63%. The typology of this sludge is similar to that of domestic or municipal wastewater treatment plants (Choo-Kun, 2015; Mehrez et al., 2017).
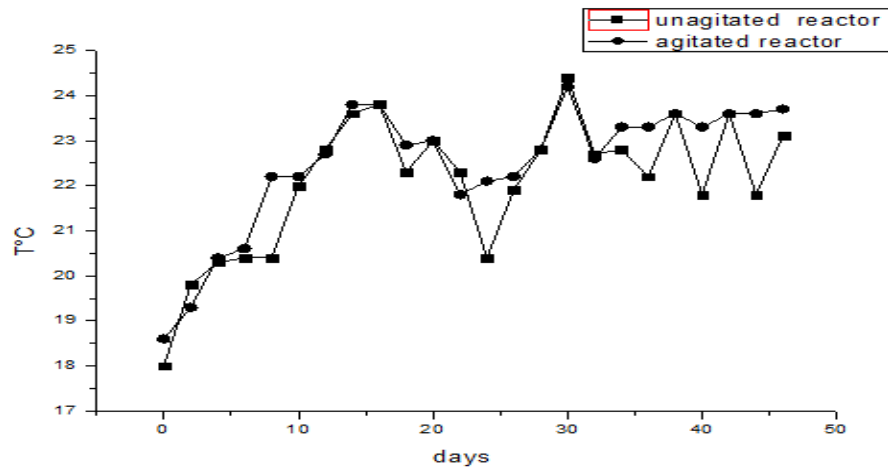
Figure 2 . Variation of the temperature.
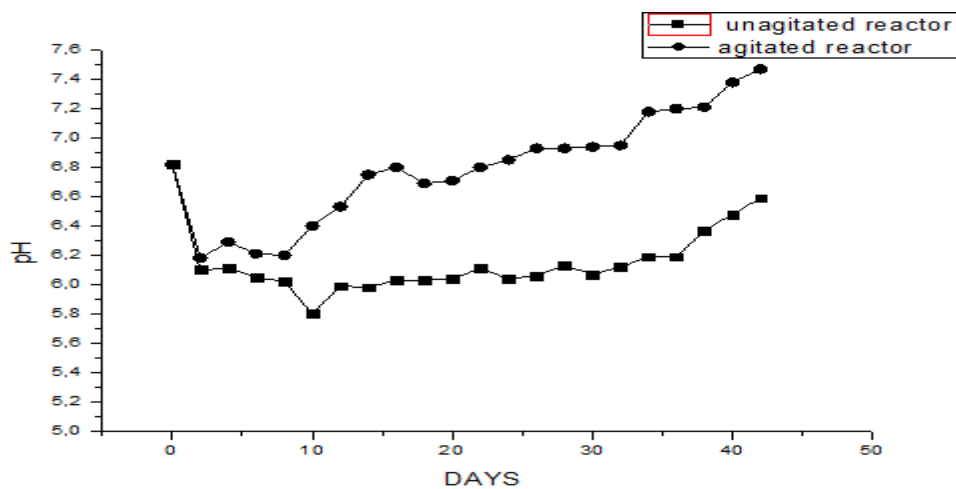
Figure 3. Variation of the pH.

The temperature variation

Figure 2 represents the evolution of temperature. The temperature data shows a same trend between the two samples (agitated reactor and unagitated reactor). The values vary between17 and 24°C. However, it is noted that temperature was higher in the agitated reactor.

The pH variation

Figure 3 represents the evolution of the pH; the profile shows two phases: the first probably corresponding to the hydrolysis and acetogenesis phase; the pH decreased from 6.82 to 5.8 in the unagitated bioreactor and from 6.82 to 6.2 in the agitated bioreactor (Zhai et al., 2015; Kalloum et al., 2007); the second corresponding to the biomethanization phase; the pH increased from 5.8 to 6.5 in the unagitated bioreactor and from 6.2 to 7.5 in the agitated bioreactor. The agitated bioreactor had good pH conditions. This can be explained by a better use of volatile fatty acids (VFAs) by heterotrophic bacteria following their contact with the substrate enhanced by agitation process, as was highlighted by many authors
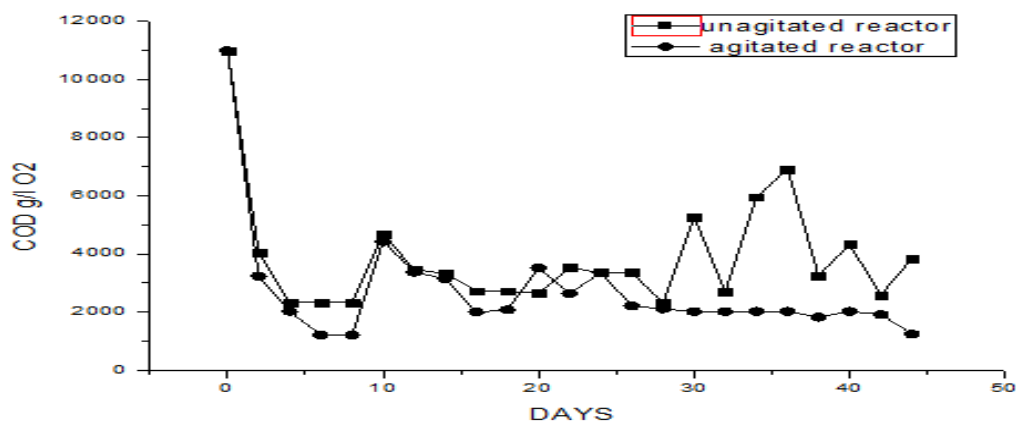
Figure 4. The COD variation.

(Mehrez et al., 2017 ; Monou et al., 2009). It can also be explained by the effects of agitation in favour of the emission of gases formed during the various stages of anaerobic fermentation, including in particular acidic materials: CO_2, volatile fatty acids, H_2S, etc. The partial hydrogen pressure is particularly important in the process. Excessively high hydrogen content prevents the conversion of intermediate products from being converted. As a result, organic acids accumulate and prevent the formation of methane (Wandrey and Aivasidis, 1983) ; hydrogen sulphide had an inhibiting effect on methane formation. The inhibition thresholds encountered in methanogenic bacteria vary according to the type of substrate and physicochemical conditions and ranged from 50 to 1000 mg/L.

The variation of COD

Figure 4 represents the evolution of COD; the COD decreased for both bioreactors. This decrease is relatively more significant for the agitated bioreactor. The abatement rates achieved after 40 days are 60 and 81% respectively for the unagitated and agitated bioreactors. This difference is probably due to agitation, which on the one hand allows the organic matter and the purifying microorganisms present in solution to be mixed, as pointed out Haoqin Zhou and Zhiyou (Zhou and Wen, 2019), and on the other hand to facilitate the liberation and disengagement that can remain trapped in the solid raw material Haoqin Zhou and Zhiyou (Zhou and Wen, 2019), such as hydrogen formed during the acetogenesis

step and H_2S which can be generated by sulfate-reducing bacteria, both inhibitors of bacterial activity and paricular for methanogenic bacteria with respect to hydrogen).

The work done by Kalloum (Kalloum et al., 2013) by using manual agitation showed a significant reduction in the COD of sludge to conclude that anaerobic digestion is an efficient method for the reduction of organic pollution and that most of the organic matter that is present in the digester is biodegradable. Pinho et al. (2004) confirmed that agitation rate plays an important role in the solubilization of suspended organic matter As well as the acceleration of the degradation of the COD in suspension. The same results were reported by Mehrez (Mehrez et al., 2017) and Ahmed et al. (2016) .

Variation of dissolved oxygen

The Figure 5 represents the evolution of the dissolved oxygen; the concentration values reflect the correct performance of anaerobic digestion in both bioreactors. By the third day, this concentration decreases below the value required for anaerobic conditions. It then reaches an average concentration of 0.3 mg/l. This value is comparable to what is being reported by other authors (Botheju and Bakke, 2011).

Variation in conductivity

Figure 6 represents the evolution of The Electrical conductivity; the data showed an increase throughout the
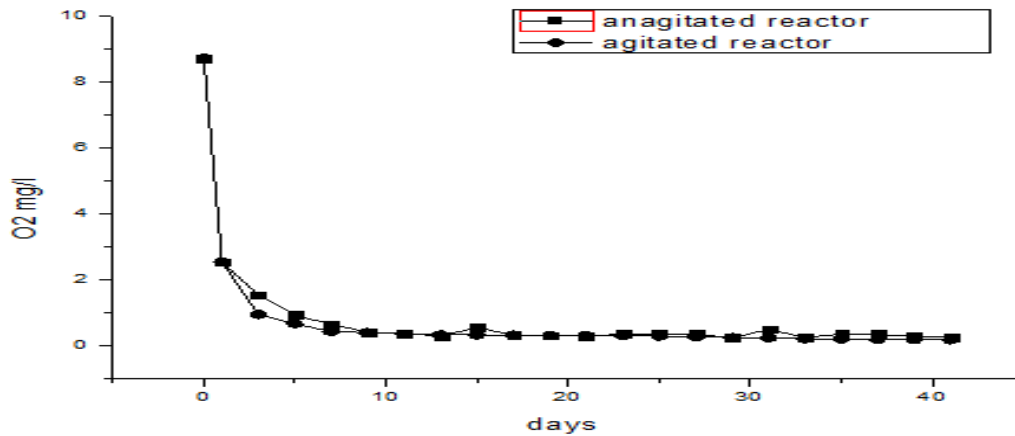
Figure 5. Variation of dissolved oxygen.
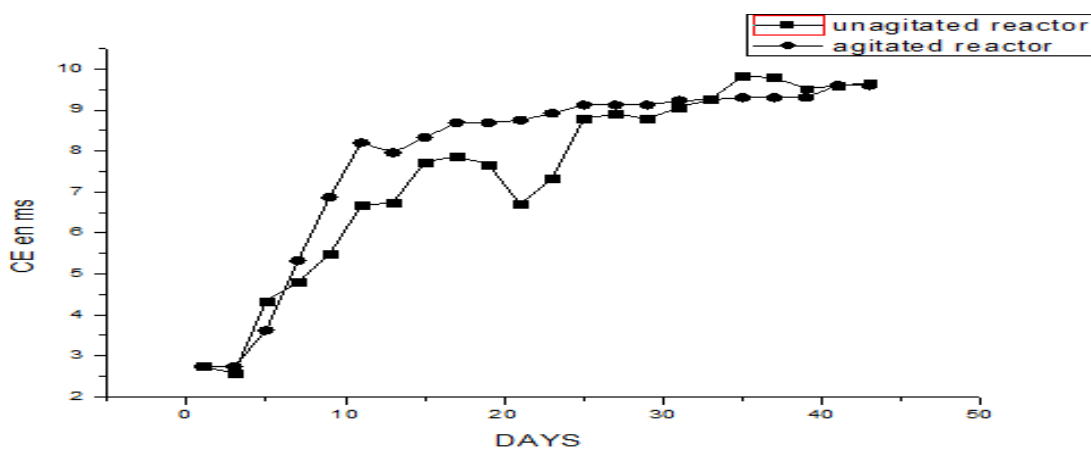
Figure 6. Variation of the conductivity.

anaerobic fermentation process. This could be due to the appearance of small species of high ionic mobility and/or mineralization of the environment. This is more pronounced in the case of the agitated bioreactor. (El Hafiane and El Hamouri, 2002) reported that conductivity increases from the inlet to the outlet of the reactor, indicating progressive mineralization of the medium.

Conclusion

The comparative psychrophilic anaerobic fermentation tests between two unagitated and agitated bioreactors have shown conclusive results regarding the role of agitation. Indeed, the monitoring parameters: pH, COD, temperature, conductivity highlighted the effect of agitation. The anaerobic fermentation processes are to the advantage of the agitated reactor. The agitation promotes the homogenization of the reactor and a good mixing between the substrate and the purifying bacteria. It also makes it possible to break the layer of solid products that can float on the surface of the solution and thus prevent the escape of certain gases such as AGV, CO_2, H_2, H_2S, which by their presence also make the medium acid and/or inhibit the activity of certain bacteria including methanogenic bacteria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Assessment of the health impacts of WASH interventions in disaster-prone communities in three regions of Northern Ghana

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This study evaluated the health impacts of WASH interventions in 9 intervention communities against 9 control communities in disaster-prone areas in northern Ghana. We extracted community-specific data on patient-reported cases of WASH-related diseases from health facilities in the study areas. Also, we used key informant interviews and household questionnaires to seek information for validation. The impact was measured using the before-after study with concurrent control (BAC) method of Health Impact Evaluation in WASH interventions. The findings indicate a substantial increase in the number of WASH facilities across the intervention communities. However, some respondents complained of access to inadequate quantities and increase downtime of water systems when there is a breakdown. Access to improved sanitation facilities was still a challenge, although a steady increase in the number of household access to latrines was observed. We extracted about 2,315 reported cases of WASH-related diseases, comprising diarrhoea (83%), dysentery (8%), typhoid fever (7%) and intestinal worms (2%). Impacts on diarrhoea prevalence were generally lower than reported figures, and varied across the intervention communities, ranging from 0 to 7% reduction. We recommend that greater attention be given to the sustainability of the intervention to ensure service delivery, rather than as a one-time investment, to achieve more significant impacts.

Key words: Disaster-prone communities, WASH, sanitation, public health.

INTRODUCTION

Typical environmental disasters in Ghana include droughts, epidemics, floods and wildfires. However, floods account for about one-third of all disaster-related deaths in the country (WHO, 2017). In the three (3) northern regions of Ghana, disasters significantly impact vulnerable populations in disaster-prone areas and may lead to unnecessary losses in social and economic capital. In particular, recurrent flooding events, which are the most

pervasive in terms of financial damages and the number of people affected, usually result in the disruption of services from water, sanitation and hygiene (WASH) facilities (Care Nederland, 2012). Such occurrences could lead to significant damages to property and trigger other emergencies such as the outbreaks of water-borne/related diseases (e.g. diarrhoea, cholera and malaria). Consequently, there is a reduction in productivity, economic losses and social pressures.

Ensuring quality of water supply (during collection, handling, storage, and use), and the maintenance of proper sanitation and hygiene practices after such flooding events also presents immense challenges to the health of these communities. Rehabilitation costs are usually high and unaffordable, leading to a drastic fall in the living conditions and opportunities for future development in the affected communities. The situation is exacerbated in communities where there is a lack of WASH facilities and services. In such circumstances, the challenges include the prevalence of water-borne, vector-borne and sanitation-related diseases as a result of poor drinking water quality, inadequate sanitation and poor hygiene and women, children and the youth are the most affected. Over the years, flooding and its devastating effects have been the narrative of the three (3) northern regions of Ghana.

Impact of WASH interventions on public health

The vital role of WASH in maintaining health has long been recognized, considering the critical role it plays in reducing illness and death from infectious diseases (McKeown and Record, 1962). Diarrhoea and selected parasitic diseases have been identified to be among the major diseases related to WASH. Infectious diarrhoea is probably the largest contributor to the disease burden from WASH (Prüss et al., 2002). The infection results from the ingestion of faecal contaminated fluids or foods, through various faecal-oral transmission pathways, as illustrated in Figure 1, is facilitated by poor WASH practices. Moreover, globally, diarrhoea is the second leading cause of mortality in children under the age of five (5), excluding pre-term birth complications (Liu et al., 2012). Diarrhoeal diseases, acute respiratory tract infections, cholera, *Shigella* dysentery, viral hepatitis A and diphtheria are the most common cause of death in emergencies associated with poor WASH services. However, all these causes of death are preventable. From the health perspective, improving access to safe water supply and sanitation services is a preventive intervention, whose primary outcome is a reduction in the number of episodes of diarrhoea and, accordingly, a proportionate decrease in the number of deaths (WHO, 2004). WASH interventions, such as the provision of clean piped drinking water, enhanced facilities for excreta disposal and the promotion of handwashing with soap at critical times, improve health and reduce infectious disease incidence (Burger and Esrey, 1995;

Dangour et al., 2013; Esrey et al., 1991; Laxminarayan et al., 2006; WHO, 2004; WHO and UNICEF, 2014).

Table 1 presents percentage reductions in diarrhoea incidence estimated from pooled analyses for water supply at source, water quality interventions, sanitation interventions and hygiene (handwashing with soap at critical times). Esrey et al. (1991) examined the impact of improved water supply and sanitation facilities. They reported significant reductions in morbidity for diarrhoea (26%), trachoma (27%), ascariasis (29%), schistosomiasis (77%) and dracunculiasis (78%). Similarly, by improving water supply and excreta disposal, the median reduction of 22% in diarrhoea morbidity rate has been reported (Burger and Esrey, 1995). The authors, however, stated that the magnitude of this reduction might vary depending on several factors such as age, type of service provided and the general living conditions of people. Furthermore, a systematic review and meta-analysis of WASH interventions to reduce diarrhoeal illness in less developed countries found a strong consistency in the effectiveness of the interventions (Fewtrell et al., 2005). Moreover, other scholars have maintained that sanitation and hygiene promotion are still the two most effective interventions for controlling endemic diarrhoea (Laxminarayan et al., 2006). A study conducted by the WHO found that using an improved water source reduces diarrhoeal disease risk by 24 to 73% (WHO, 2004). A meta-regression based on a single study by the WHO suggested that enormous health benefits could be gained by transitioning from basic on-site piped water to systematically managed water, with significant reductions in diarrhoea ranging from 73 to 79%, depending on baseline condition (WHO and UNICEF, 2014). A review by Mills and Cumming (2016) demonstrated that there is good evidence that poor WASH contributes to the majority of the burden of diarrhoea and related adverse health effects, and strong consensus around this point. The review further reported that there is suggestive evidence that increasing water quantity directly reduces the risk of diarrhoea and other WASH-related diseases. In spite of the aforementioned correlation between WASH interventions and public health, Care Nederland (2012) cautions that other factors may mask the expected outcome of WASH interventions (e.g. the provision of flood-resilient WASH facilities), especially in disaster-prone areas.

WASH intervention in disaster-prone communities in northern Ghana

In a bid to reduce the burden of the yearly flooding on improved WASH facilities in the northern part of Ghana, the WASH in Disaster Prone Communities (DPC) programme was designed to improve sustainable access to disaster-resilient WASH facilities in 265 communities in 24 districts. At the community level, the objectives of the programme included the provision of flood resilient
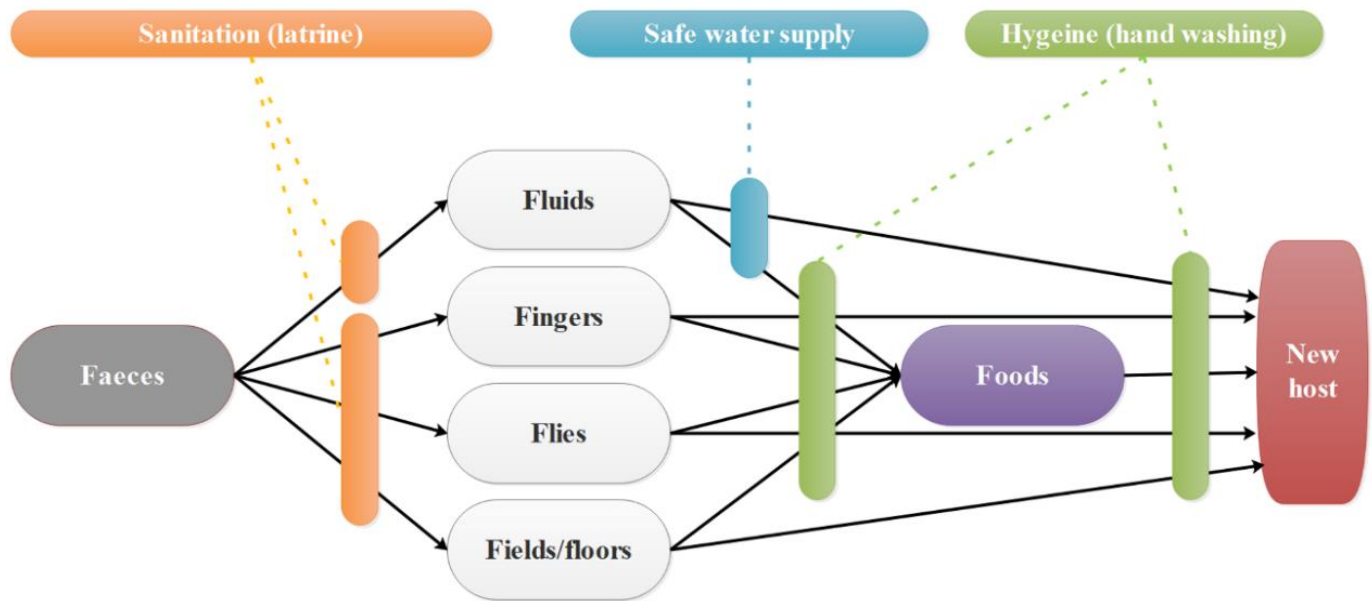
Figure 1. Faecal-oral transmission pathway.
Source: Adapted from OpenWASH (2016).

Table 1. Expected reductions in diarrhoeal disease morbidity from improvements in one or more components of water and sanitation.

Intervention	% reduction in diarrhoeal disease by 2004	% reduction in diarrhoeal disease by 2011
Water and sanitation	20 - 30	-
Sanitation	22 - 36	36
Hygiene	33	47
Water quality and quantity	16 - 17	19
Water supply at source	-	5

Source: Waddington et al. (2009).

improved water and sanitation facilities (for households and schools) and the promotion of behaviour change towards proper WASH practices through educational campaigns (UNDP, 2019). The programme covered 200,000 people, 25% of them being school children, in Disaster Prone Communities (DPC) in the Upper East, Upper West and Northern regions of Ghana. It was a collaboration between both international and local stakeholders, namely the UN-Habitat, UNDP, UNICEF and WHO, with support from Government partners in the WASH sector, as well as the private sector and non-governmental organizations. One of the expected outcomes of the programme was the reduced burden of WASH-related diseases among men, women, boys and girls in disaster-prone communities in the three (3) regions of northern Ghana.

According to WHO (2017), the WASH in DPC Programme had already achieved tangible results after more than two (2) years of implementation. It was on track to deliver the expected outcomes in terms of access to

resilient water and sanitation systems for the targeted population across the three regions of northern Ghana.

This study evaluated the health impact of the WASH intervention in the DPCs. Specifically, this research (1) assessed the impact of the WASH in DPC Programme by collating and analysing health data at the sub district; (2) gathered scientific evidence from previous and ongoing epidemiological studies to support the main objective of the assessment; and (3) highlighted recommendations for similar future programmes.

MATERIALS AND METHODS

Study design

This study used both qualitative and quantitative methodologies. The study encompassed nine (9) districts, comprising three (3) districts in each of the three (3) study regions. In each district, two (2) communities (1 intervention and 1 non-intervention) were selected. The study communities were chosen on the basis of the availability of

a community-based health facility (e.g. Community-based Health and Planning Services (CHPS) Compound or Health Centre). This was to help minimize the complexities associated with the evaluation of the outcomes of the interventions in these communities in relation to reported cases of WASH-related diseases.

The before-and-after study with concurrent control (BAC) method was used to evaluate the impact of the WASH intervention. In BAC studies, the pre- and post-intervention results of two groups (the experimental or intervention group and the control group) are compared to measure the effectiveness of an intervention (Mahajan, 2015; Robson et al., 2001; Schmidt et al., 2011). As noted by Robson et al. (2001), the intrinsic validity of the before-and-after method may be threatened by several factors (e.g. significant external influences other than the intervention, the Hawthorne effect, maturation effect, placebo threat, regression-to-the mean, etc.); however, it can be useful in providing preliminary evidence of the effectiveness of an intervention. Shadish et al. (2002) noted that the plausibility of results from the BAC method depends on (1) the similarity of the intervention and control cluster (a set of households), and (2) the observed disease trend. Thus, in this study, clusters in the intervention and control communities were randomly allocated to ensure similarity between the intervention and control communities. By a rigorous cluster randomized design, we selected both the intervention and control clusters for the study. In all, nine (9) each of the intervention and control clusters were chosen for the study. Once an intervention cluster was selected, a community from an enumerated list was selected randomly. To select control clusters, each intervention sub-district where a cluster was chosen, was then matched to a control cluster, considering the local geography, hydrogeology, infrastructure, agricultural productivity, and household construction. Once a control cluster was selected, a community from an enumerated list of the communities was selected randomly.

The changes in the prevalence of WASH-related diseases such as diarrhoea, cholera, diphtheria, dysentery, typhoid and worm infections (that is, helminths) are key indicators used to determine the impact of WASH intervention on health (Ramesh et al., 2015). Therefore, this study used data on reported cases of theses WASH-related diseases in the health facilities in the study communities.

Profile of study areas

Figure 2 shows the locations of the districts and communities selected for the study. Available data on the demographic and socioeconomic characteristics are aggregated at the district and regional levels. According to the district analytical reports of the 2010 population and housing census, the population of the study districts is dominated by females, averaging 51.5%, with the remainder being males. Generally, the majority (81.2-100%) of the population in the districts live in rural areas. Agriculture is the main economic activity in the study regions, serving as the source of livelihood for over 75% of the population. Among the economically active class, the unemployment rate is higher among females (3.0%) as compared to males (2.5%).

Though access to improved sources of drinking water is relatively good (60.4-96.6%), the case for sanitation is poor (3.9-24.5%), as presented in Table 2. This observation is similar to the national trend (Appiah-Effah et al., 2019). A large proportion (mostly > 80%) of the population across the districts practices open defecation due to the lack of access to toilet facilities. The three regions in northern Ghana lie in and are drained by the Volta River System (White Volta, Black Volta and the Oti rivers).

Data collection and analysis

Four (4) different methods were used in the collection of data:

document review, collation of data from health facilities, key informant interviews, and household survey. The document review involved a desktop review of all available project deliverables, reports and the literature on the WASH on the DPC programme. Pre- and post-intervention data on reported cases of the indicator diseases, for both the intervention and control populations, were collated for the analysis. Semi-structured questionnaires were used for the household surveys and key informant interviews. The key informants included opinion leaders, school officials, health officials and environmental health officers (EHOs). The information from the variety of stakeholders was to verify and improve the reliability of the findings from the medical records.

The collated data were organized and analyzed in Microsoft Excel. The health impact of the intervention was evaluated using the BAC method of Health Impact Evaluation in WASH interventions. In this study, we focussed on the first four indicator diseases with the most reported cases. The most prevalent indicator disease, among the four, was then selected for further analysis. By difference-in-difference (DID) analysis (Schmidt et al., 2011) of both the intervention and control communities, the effect of the intervention was estimated.

RESULTS

General disease trends and the basis for selection of outcome disease for impact analysis

From the data gathered from the various health facilities, diarrhoea, dysentery, intestinal worms, and typhoid diseases were the WASH-related diseases reported. A total of 2,315 reported cases of these diseases were recorded in the 3 study regions from the middle of 2014 till the time of visit (May 2017). Of the 2,315 reported cases, about 83% were diarrhoeal illness, 8% dysentery cases, 7% typhoid cases and 2% intestinal worm cases. Table 3 shows the percentage distribution of these diseases across the selected districts, regions and overall, the 3 regions put together. Diarrhoea was the most prevalent WASH-related disease among the four diseases. Therefore, in proceeding with further analysis of the impact of the interventions, diarrhoea disease was used as the outcome measure. This was to make the results more plausible as compared to using other disease outcomes.

Diarrhoea disease trend by age and sex

Of the 82% diarrhoea cases, children aged up to 5 years constituted 56% while those above 5 years accounted for 26%. Also, 64% of reported WASH-related diseases were children less or equal to 5 years, whereas 36% were above 5 years. Females had a higher prevalence of diarrhoea (54%) as compared to males (46%) from the study.

Health impact analysis of WASH interventions on a community by community basis

Here, compares the trends in disease prevalence between
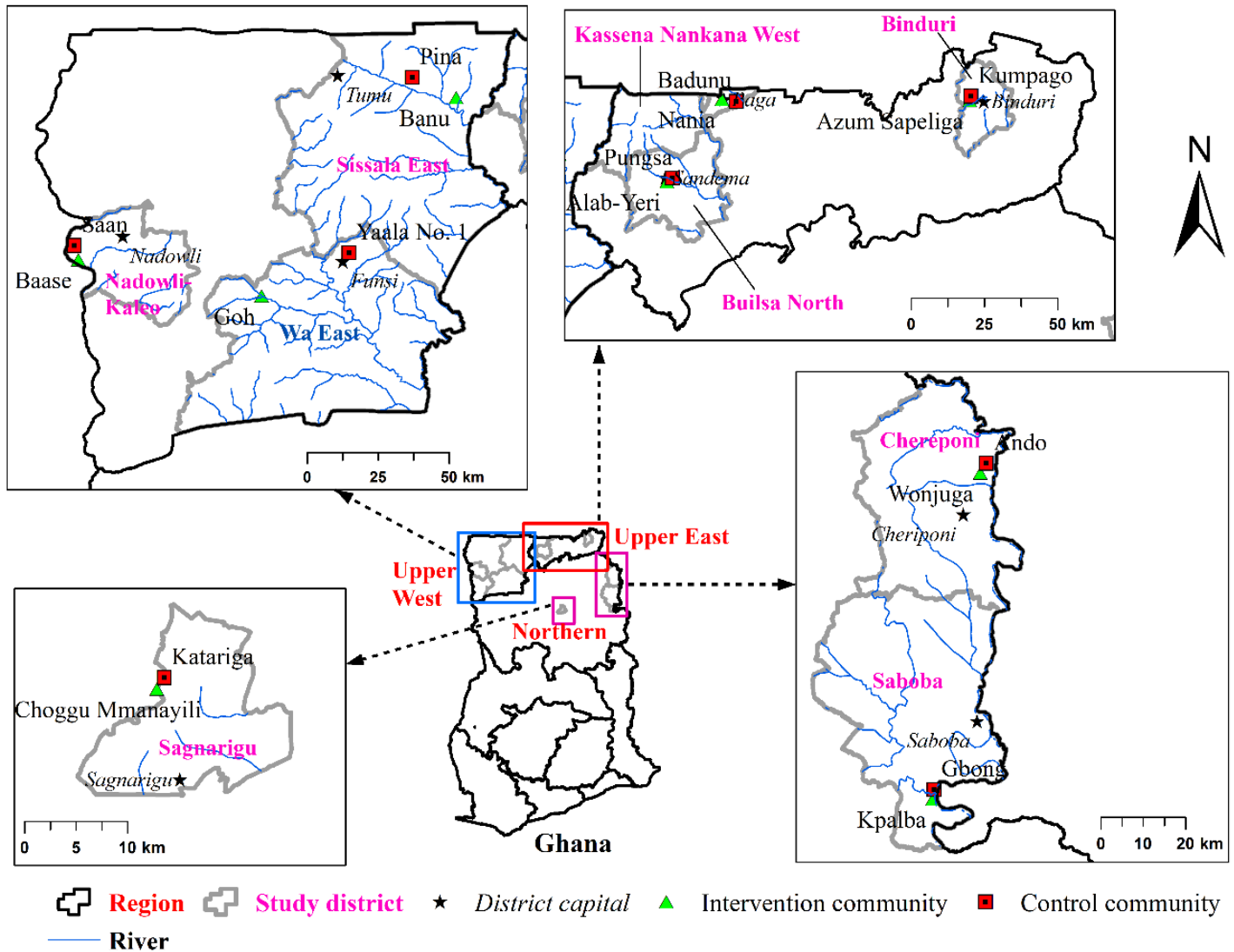
Figure 2. Map of study areas.

Table 2. Populations and proportions of the households with improved access to water and sanitation according to the 2010 population and housing census.

District	Population	Population density (cap/km²)	% of households with access to improved sanitation	% of households with access to improved drinking water
Wa East	72,074	31.2	5.4	72.9
Sissala East	56,528	11.1	11.2	96.6
Nadowli-Kaleo	60,813	54.4	12.2	94.3
Builsa North	56,477	61.2	8.8	81.1
Kassena-Nankana West	70,667	70.4	5.5	91.8
Binduri	61,576	151.1	9.5	85.2
Chereponi	53,394	38.8	3.9	94.9
Saboba	64,927	37.1	7.9	60.4
Sagnarigu	23,447	117.0	24.5	94.9

Source: GSS (2014 a-i).

Table 3. Percentage distribution of the most prevalent indicator diseases across selected districts, regions and overall the 3 regions of northern Ghana from mid-2014 to May 2017.

Disease	Upper West			Upper East			Northern			All 3 regions
	Selected district	% distribution		Selected district	% distribution		Selected district	% distribution		% distribution
		District	Regional		District	Regional		District	Regional	
Diarrhoea	Wa East	65.22		Builsa North	97.78		Cheriponi	93.24		
	Nadowli-Kaleo	97.50	74.54	Kasena Nankana West	100.00	90.39	Saboba	70.17	83.07	82.89
	Sissala East	91.4		Binduri	83.66		Sagnarigu	67.13		
Dysentry	Wa East	8.70		Builsa North	2.22		Cheriponi	0.31		
	Nadowli-Kaleo	0.0	6.24	Kasena Nankana West	0.00	9.61	Saboba	5.88	7.45	7.73
	Sissala East	1.85		Binduri	16.34		Sagnarigu	30.52		
Intestinal worms	Wa East	6.39		Builsa North	0.00		Cheriponi	5.19		
	Nadowli-Kaleo	0.00	4.38	Kasena Nankana West	0.00	0.00	Saboba	0.00	3.04	2.55
	Sissala East	0.62		Binduri	0.00		Sagnarigu	0.00		
Typhoid fever	Wa East	19.7		Builsa North	0.00		Cheriponi	1.26		
	Nadowli-Kaleo	2.50	14.8	Kasena Nankana West	0.00	0.00	Saboba	23.95	6.44	6.83
	Sissala East	6.17		Binduri	0.00		Sagnarigu	2.35		

The % distribution of disease for a selected district is based on only the two selected communities in the district.

the intervention community and the control community.

Wa East district (Goh and Yaala No. 1)

The Goh community had two boreholes fitted with hand pumps, which served as the only source of water for domestic use. Water from these boreholes was available all year round unless there was a mechanical breakdown, which does not take long to fix (usually within two weeks). Regarding sanitation and hygiene facilities, households had built traditional pit latrines with tippy-tap for hand washing (Figure 3). However, in

the control community, Yaala No. 1, households used water from unlined communal hand-dug wells, which were reported to have inadequate yield and usually dried up during the dry season. A nearby river served as an alternative source of water for domestic use. There was also the practice of open defecation in the community. The result from the study showed a decline in diarrhoea prevalence for Goh from 6 to 4% with no change in the prevalence (10%) for Yaala No.1 during the same period (Figure 4a). This gave a calculated DID of 4%, suggesting a 4% reduction in diarrhoea prevalence in Goh by the intervention (Figure 5). The reported positive impact could be as a result of the access to improved WASH facilities by

households. Also, as revealed by discussions with opinion leaders, the frequent and vigorous WASH education carried out by the EHOs assigned to the community gives credence to the observed trend. This was also confirmed by the EHO attached to the team, who indicated that Goh was soon to be declared ODF after the verification process.

Nadowli-Kaleo district (Baase and Saan)

Baase community had two boreholes that were constructed in 2016. Hitherto this, they used water from a nearby river for domestic activities. Households reported that the yield of the boreholes

Figure 3. Household latrine with tippy-tap.

was inadequate; hence, they resorted to a nearby river. With regards to sanitation facilities, households had constructed traditional pit latrines with tippy-tap after they were triggered under a Community-Led Total Sanitation (CLTS) programme undertaken in the community. Saan, on the other hand, had one borehole, which was reported to be unreliable. Moreover, households in Saan reported the use of a communal toilet facility, which has no handwashing facility.

In the case of Baase, there was a slight increase in the prevalence of diarrhoea from 1 to 2% over the period. For Saan, diarrhoea prevalence increased from 2 to 8% (Figure 4b). This gives a calculated DID of 5%, indicating that the impact of the intervention is a 5% reduction in diarrhoea prevalence in Baase (Figure 5). The vigorous implementation of the CLTS approach carried out in the community could have partly contributed to the positive impact observed in the Baase community. This was seen in the reported increased access to improved water (borehole) coupled with an increased number in the construction and use of household toilet facilities.

Sissala East district (Banu and Pina)

There were three boreholes constructed in Banu, but only one was functional at the time of the assessment, serving as the only improved source of water for domestic use. The respondents indicated that one borehole was highly inadequate, compelling them to resort to the River Kaalon as an alternative water source. Banu had also been declared as an ODF community. The majority of households have constructed their latrines. The Pina community has only one borehole located close to its

CHPS compound, and this was reported to be inadequate. This was evident by the long queues observed at the water point at the time of the visit. Households used a nearby river as an alternative source. In the case of sanitation, the majority of households in Pina did not have household latrines and practised open defecation.

In Banu, diarrhoea prevalence showed an almost steady scenario of 3% over the period. The results for Pina also showed an increase in diarrhoea prevalence from 2 to 6% (Figure 4c). This gives a calculated DID of 4%, suggesting that the impact of the intervention is a 4% reduction in diarrhoea prevalence in Banu (Figure 5). Efforts made at obtaining ODF status could be a major indicator of gains made in Banu. As expected, diarrhoea prevalence was lower in Banu as compared to Pina.

Builsa North district (Alab-Yeri and Pungsa)

Although Alab-Yeri was a DPC community, it was reported that no infrastructure had been provided under the project at the time of the visit. However, there existed two boreholes and one unprotected hand-dug well in the community. The two boreholes had been constructed for the school and CHPS facility, respectively. The community depends on the hand-dug well as a source of water for domestic use. The hand-dug well dries up during the dry season; hence, households compete with pupils for the use of the school's borehole. Moreover, households did not have latrines and resorted to open defecation. Pungsa, on the other hand, reported inadequate potable water and low sanitation coverage.

Diarrhoea prevalence in Alab-Yeri dropped slightly from 8 to 7% over the period. Pungsa, on the otherhand, had an
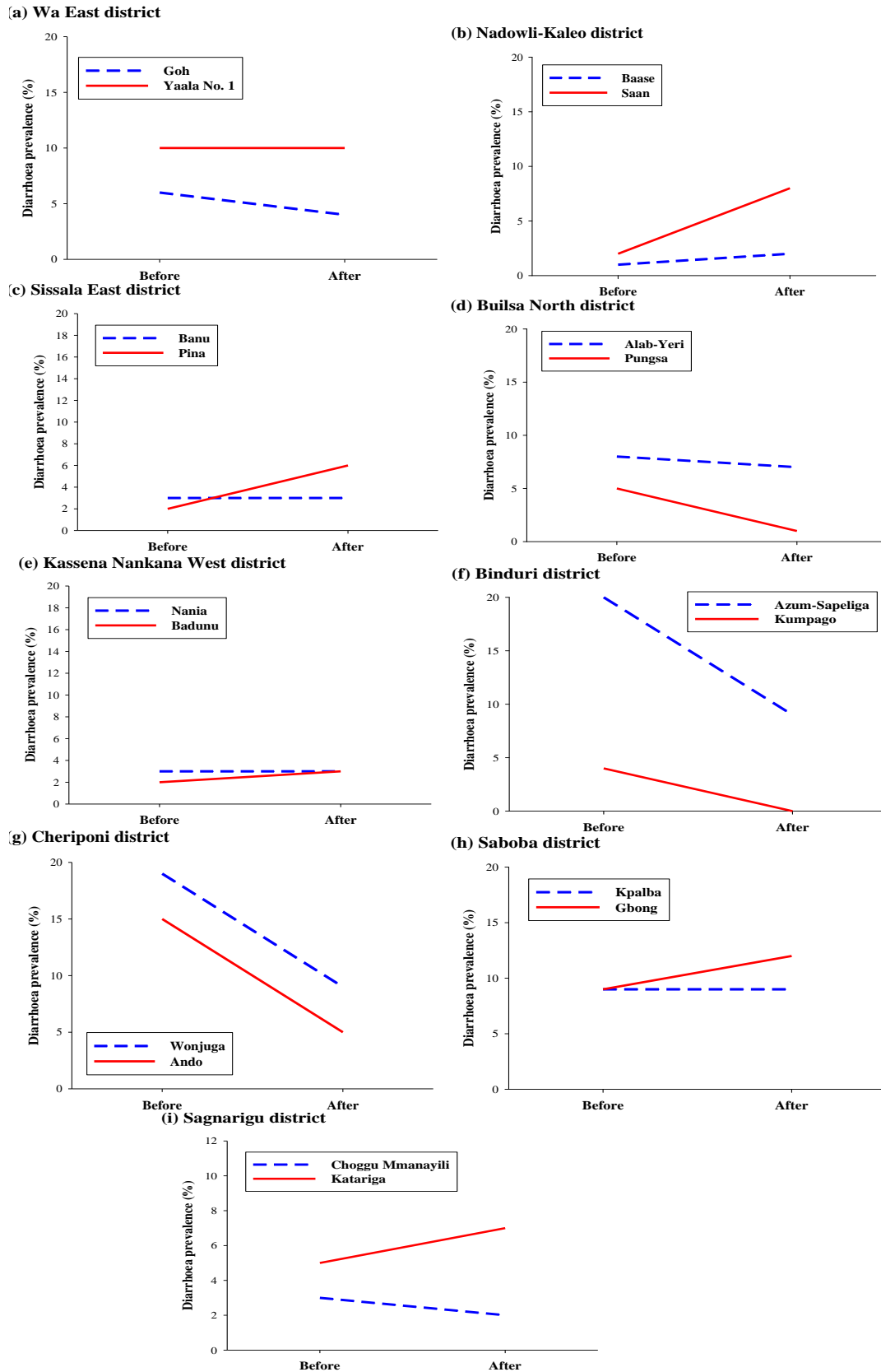
Figure 4. BAC on diarrhoea prevalence in the study communities. The dashed blue line and solid red line represent the intervention and control communities, respectively.
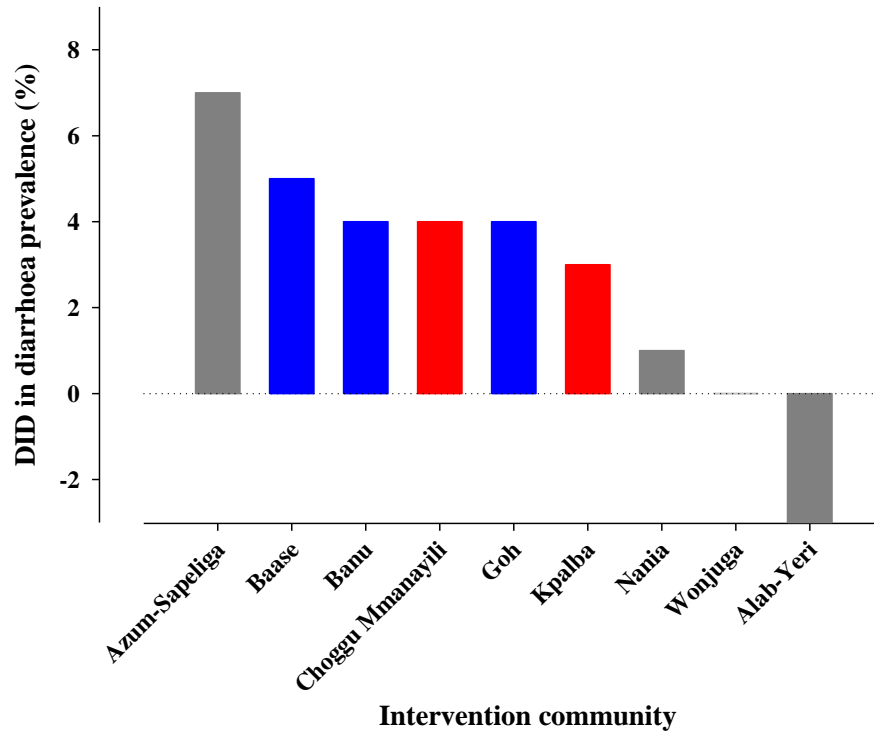
Figure 5. Difference-in-difference in diarrhoea prevalence in the intervention communities.

decrease in diarrhoea prevalence from 5 to 1% (Figure 4d). This gives a calculated DID of -3% (Figure 5), suggesting that there has been no impact (no effect) of the WASH in the DPC programme in Alab-Yeri. The negative impact (no effect) of the project in Alab-Yeri could be because the implementation of facilities had not begun as of the time of the assessment. Therefore, the downward trend observed could not be attributed to the WASH in DPC programme but other factors that may include other interventions.

Kassena Nankana West district (Nania and Badunu)

Nania has two boreholes that were reported to yield water all year round, but they experience mechanical breakdowns from time to time. There are also some hand-dug wells as alternatives. Households have also constructed latrines. Though households reported they practice handwashing after using the toilet, we observed no handwashing scheme attached to the latrines. Badunu, the non-intervention community, also had limited access to both improved water and household toilet facilities.

The diarrhoea prevalence for Nania showed a steady trend of 3% over the period. However, Badunu showed a slight increase from 2 to 3%. (Figure 4e). The calculated DID, therefore, 1% (Figure 5), inferring that the impact of the intervention was only a 1% reduction in diarrhoea prevalence in Nania. The relatively low impact of the programme, despite the availability of the boreholes, could

be attributed to the reported long walking distances to the water points and frequent breakdown of the boreholes. Due to this challenge, it was reported that households were unable to fetch adequate quantities for their daily use. Also, most households had no latrines, while those who had, had no handwashing facilities. Such conditions could result in faeco-oral transmission, hence the low impact.

Binduri district (Azum-Sapeliga and Kumpago)

Azum-Sapeliga has benefited from 3 boreholes from the programme; however, at the time of the visit, one of them was non-functional. Households reported that potable water was not adequate. Also, households had constructed latrines with tippy tap and ash for hand washing. Households indicated their preference for soap over ash, most of them had resorted to the latter due to financial reasons after a campaign was undertaken by UNICEF on handwashing with soap and water. The non-intervention community, Kumpago, also had limited access to improved water facilities, with the majority of households also not having access to improved household toilets.

The results showed a steady decrease in diarrhoea prevalence from 20 to 9% in Azum-Sapeliga over the period. Kumpago also showed a decline in diarrhoea prevalence from 4 to 0% (Figure 4f). The estimated impact

of the intervention based on the DID was relatively high in Azum-Sapeliga: diarrhoea prevalence reduced by 7%. It is worth mentioning that in this community, the chief was actively involved in rallying community members to improve upon the WASH situation in the community.

Cheriponi district (Wonjuga and Ando)

The results gathered showed an increase in the number of WASH facilities in Wonjuga after the intervention. At the time of the study, the community had three functional and two non-functional boreholes fitted with hand-pump, which are used by households for various domestic activities. The respondents indicated access to adequate improved water supply. A significant number of inhabitants had household latrines, which were mainly traditional pit latrines. On the other hand, Ando, the non-DPC, had only one functional borehole, which all households depended on for water for domestic use. Although some households have traditional pit latrines, the number observed was inadequate and hence, the majority of the population practised open defecation.

Although Wonjuga showed a decline in diarrhoea prevalence from 19% to 9% over the period, Ando also had the same percentage drop in prevalence (15 to 5%), as shown in Figure 4g. Thus, the calculated DID was 0%, indicating that the trend in Wonjuga would have remained the same without the intervention (the no effect situation). The trend observed in Wonjuga and Ando suggests that these two communities are quite homogeneous. The similar trend may also be attributed to the WASH interventions which took place in the control community (Ando) earlier. The community reported benefitting from hygiene education by environmental health officers. Hence, both communities have been sensitized on proper WASH practices and how to prevent diarrhoea diseases.

Saboba district (Kpalba and Gbong)

There were only two functional boreholes fitted with hand-pump in the Kpalba community, although it was an intervention community. Access to boreholes fitted with hand-pump was found to be limited according to the qualitative study from the households. Households, therefore, accessed surface water from the River Oti for their daily domestic chores. Prior to the installation of the boreholes with hand-pumps, residents in Kpalba relied on unimproved water sources. Although the community had benefitted from the CLTS approach in creating demand for household latrines, uptake was observed to be very low. Gbong, as the non-intervention community, also had limited access to improved water facilities, with the majority of households also not having access to improved household toilets.

Diarrhoea prevalence for Kpalba showed a steady trend of 9%, while Gbong showed an increase of 9 to 12%

(Figure 4h). The calculated DID was 3%, which inferred that the impact of the intervention reduced diarrhoea prevalence in Kpalba by 3%.

Sagnarigu district (Choggu Mmanayili and Katariga)

In Choggu Mmanayili, a small-town water supply scheme with standpipes has been constructed from which households access water for domestic activities. According to the households, the water is available all year round. Household use either self-constructed or communal latrines. Households also reported that WASH awareness campaigns had been organized by the UN-Habitat and World Vision, which, in their view, had brought improvement to their health status. Katariga, the non-intervention community, also had limited access to improved water facilities, with the majority of households also not having access to improved household toilets.

Over the period, diarrhoea prevalence in Choggu Mmanayili slightly decreased from 3 to 2%, whereas it increased from 5 to 7% (Figure 4i) in Katariga, resulting in a DID of 4%. Hence, the impact of the intervention in Choggu Mmanayili was a 4% reduction in diarrhoea prevalence. Choggu Mmanayili could be described as peri-urban and close the capital town of the region, Tamale. Therefore, the inhabitants of Choggu easily benefit from sensitization programmes on the benefits of proper WASH practices. Hence, the facilities provided are used, and the benefits derived as shown by the analysis.

DISCUSSION

Diarrhoea was the most prevalent WASH-related disease in the study communities, as it accounted for over 80% of the reported WASH-related cases. This finding agrees with the global level report by Prüss et al. (2002). Moreover, children less than five years were the most affected as they constituted the majority (56%) of the cases. Interviews with health officers confirmed these results. They indicated that children from early birth through age 5 were the most affected by diarrhoea. Further to this, the health officers acknowledged the relationship between the availability and use of improved WASH facilities and diarrhoea. However, they emphasized that it was not the sole cause of childhood diarrhoea. The result is consistent with the report by the Ghana Demographic and Health Survey (GSS et al., 2015), which indicated that diarrhoea prevalence is high among children below 5 years since they are at increased risk of contamination from the environment. Compared to age, the difference in diarrhoea prevalence by sex was relatively small. The study results, however, contradicted that of the GSS et al. (2015), which reported that diarrhoea prevalence was higher in males (52%) than in females (48%).

The reduction of diarrhoea prevalence as a result of the WASH intervention varied across the intervention communities, ranging from cases of no impact to a 7% reduction (Figure 5). The highest percentage reduction (7%) was observed in Azum-Sapeliga, a community in which the chief actively participated in promoting proper WASH practices. Due to the large difference in the diarrhoea prevalence at baseline, it could be argued that factors other than the intervention, such as maturation effect (socioeconomic development), might have significantly contributed to the observed difference (Schmidt et al., 2011; Shadish et al., 2002). However, we posit that the active participation of the chief of the community in promoting proper WASH practices cannot be overlooked and might have contributed significantly to the relatively high impact of the programme observed. Thus, we recommend that getting the active support of opinion leaders must be a priority to ensure the success of intervention programmes. Similarly, in Baase, the active involvement of the community members through the CLTS resulted in quite a substantial decrease in diarrhoea in the community.

Moreover, the 0-7% reductions in diarrhoea prevalence observed were low compared to what is reported in the literature. For instance, a review by Wolf et al. (2014), which included a meta-analysis 61 studies, suggests that water and sanitation interventions could reduce diarrhoea prevalence by 34 and 28%, respectively. The low levels of reductions in diarrhoea prevalence observed in this study could partly be because diarrhoea has many causes for which improved water, sanitation and hygiene only constitute some of the many sources of infection. Also, the neglect of the WASH interventions as a result of them not working, broken down or underused will probably result in a small impact. We argue that separating WASH as independent interventions in health impact analysis is not necessarily helpful, as they act upon interlinked transmission pathways, and often cannot be provided in isolation from each other. Care Nederland (2012) also noted that although ensuring WASH facilities are more flood-resilient can reduce how vulnerable communities, it is important to recognize that many other factors can limit the impact of the intervention.

Furthermore, behavioural factors play an essential role in determining the uptake and sustainable adoption of WASH technologies and practices. While WASH interventions are potentially highly efficient, their effectiveness in part depends on behaviour change and context. The installation and functioning of water and sanitation facilities need to be accompanied by the transfer of knowledge on how to use them, together with sustainable behaviour change (Waddington et al., 2009). Maintenance and periodic replacement of existing services/facilities and hygiene promotion are also necessary to achieve improvements (Bartram and Cairncross, 2010).

From the findings of the study, we recommend that more considerable attention should be given to the sustainability of the intervention (especially, the technical and financial aspects), rather than as a one-time investment, to ensure service delivery to achieve more significant impacts. Also, the CLTS approach should focus on triggering households to construct their latrines and hygiene facilities around the same time as the provision of the water facilities. Moreover, households should be encouraged to continue the use of WASH facilities at critical seasonal periods; for example, rainy seasons, where households use rainwater for most of their domestic activities, including cooking and drinking. In addition, since the provision of water, sanitation and hygiene facilities do not solely impact on diarrhoea, and other WASH-related diseases, the intervention should be packaged such that it incorporates other aspects of environmental sanitation such as wastewater, solid waste and faecal sludge management. Furthermore, the project should ensure the establishment of strong and coherent databases to enhance impact evaluation and sustainability analysis. Finally, rigorous studies should be conducted besides measuring coverage and prevalence of diarrhoeal and other WASH-related disease rates. Monitoring and evaluation of interventions should focus on other socio-cultural, economic and environmental conditions.

Conclusions

The qualitative and quantitative findings of the assessment agree that there has been a substantial increase in the number of water, sanitation and hygiene facilities across the intervention communities. The results indicate that interventions are needed to improve the quality of service delivery for water, sanitation and hygiene, particularly for deprived communities, including DPCs. Access to improved water sources increased considerably over the past two years of the intervention. Despite the increase in water facilities, a section of the respondents complained of poor water quality, access to inadequate quantities and increased downtime when there is a breakdown. Households, therefore, supplement water demand with unimproved sources such as river, stream, dams and rainwater, compromising the health benefits of the intervention. Access to improved household latrines was still a challenge, although the study acknowledges the steady increase in the number of household access to latrines. All this progress was noted with some level of satisfaction by many of the households and key informants interviewed.

Diarrhoea was the most prevalent WASH-related disease identified in the study communities. Evidence from this study also shows that the WASH interventions have made an impact on the reduction of diarrhoeal diseases. However, the extent of reduction (up to 7%) was low compared to that of other studies (over 20%). This indicates that some level of reduction in diarrhoeal

diseases can be expected from sustainable investments in water, sanitation and hygiene interventions. That notwithstanding, the study could not measure the extent to which water, sanitation and hygiene independently contributed to the reduction in diarrhoeal diseases since it could not gather detailed information on the quality of service delivered by either water, sanitation or hygiene.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEGDEMENT

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Assessment of chitosan – coated *Aspergillus–niger* as biosorbent for dye removal and its impact on the heavy metal and physicochemical parameters of textile wastewater

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Efficiency of biosorbent from chitosan coated dead fungal biomass of *Aspergillus niger* for dye removal with its impact on metals and physicochemical parameters of textile industry wastewater were assessed. Dye and metal concentrations of wastewater were determined using UV and Atomic Absorption Spectrophotometers respectively, before and after column biosorption using simulation optimized parameters with biosorbent. Physicochemical parameters were determined using standard methods. Simulated and industrial wastewaters data were analysed statistically with one way ANOVA and T-test. Biosorption of dye was classified with Langmuir and Freundlich isotherms. Results showed that at dye concentration of 100 mg/L, 6.90 mg/g of indigo dye adsorbed per mass (q_e); in 1.87 mg/L of wastewater, 0.07 mg/g of dye adsorbed per unit mass (q_e). Isotherm model fitted well to Freundlich with constant 0.04 and 8.45 mg/g in textile and simulated wastewater respectively. Metals in wastewater ranged from 0.071 to 1.102 mg/L. Acidity, COD Zn, Pb, Fe, Ni, Mn, Cu, Cd, Cr, Co, Mg ions were reduced by 32.94, 39.02, 84.95, 34.57, 44.19, 42.19, 49.09, 25.13, 43.66 and 32.03% respectively after treatment while TDS, conductivity, alkalinity, turbidity, pH increased. Chitosan coated *A. niger* could be effective in removing dyes and heavy metals from textile wastewater.

Key words: *Aspergillus niger,* biosorbent, physico-chemical, heavy metals, textile wastewater.

INTRODUCTION

The progress made in the development of Industries and technology has resulted in extra load of burden on the environment. This burden is linked to the large quantities

of hazardous waste, heavy metals (cadmium, chromium, and lead) and metalloids such as arsenic and antimony, and organic contaminant having deleterious effect on the

ecosystem (Ayangbenro et al., 2017). Heavy metal toxicity has proven to be a major threat and there are several health risks associated with it. The toxic effects of these metals interfere with the metabolic processes and sometimes get accumulated in the body and food chain and exhibit chronic nature (Jaishankar et al., 2014; Khan et al., 2015; Carolin et al., 2017). The textile industry being the largest dye stuff, water user and wastewater producer is not left out in inflicting this serious damage especially with the large volume of wastewater being discharged to the available water resources. The first modern textile industry in Nigeria, the Kaduna Textile Mill, started production in 1956. By the 70s and 80s, the Nigerian textile industry had grown to become the third largest in Africa. A report by the United Nations University (UNU) accounted for 37 textile firms in the country as of 1987, with operating 716,000 spindles and 17,541 looms. This was the golden period of Nigeria's textile industry. Environmental problems with used dyes baths are associated to the wide variety of different components added to the dye bath, often in relatively high concentrations. The dye itself is the greatest problem (Fersi et al., 2005). Textile wastewater is usually treated in an activated sludge plant not for reusing purposes but to meet regulatory standards for discharge, hence it is not surprising that an appreciable amount of physico-chemical contaminants such as Suspended Solids (SS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), high pH and strong colour still remain in biologically treated textile effluents. Colour removal by conventional treatment methods (e.g. ozonation, bleaching, hydrogen peroxide/UV, electrochemical techniques) was found to be unsatisfactory (Marmagne and Coste, 1996; Ciardelli et al., 2001; Baig and Liechti, 2001) because most textile dyes have complex aromatic molecular structures that resist degradation and are stable to light, oxidizing agents and aerobic digestion.

Metals, on the other hand, are used in a variety of processing techniques in the textile industry, including oxidizers for vat and sulphur dyes, after treatment of direct dyes, metal catalyst used for curing resins, finishes (that is, flame retardant, soil release, and water repellent), dye stripping agents, and various classes of dyes. Majority of the common dye classes, acid, basic, direct, disperse, fiber reactive and vat all contain toxic metals including Cr, As, Cd, Hg, Cu, Pb and Zn (Leonas and Leonas, 1994; Ahalya et al., 2005). Generally, heavy metals are present in low concentration in wastewaters and are difficult to remove from water. There are many methods being used to remove and recover the metals from metal bearing industrial effluents and our environment and many physico-chemical methods have been presented for their removal from wastewater (Iqbal et al., 2002). These methods differ in their effectiveness and cost. Some of the methods such as chemical precipitation, reverse osmosis, ultrafiltration, electrochemical deposition etc become inefficient when

contaminants are present in trace concentration (Muhammad et al., 1998). They are not environment friendly and do not seem to be economically feasible for such industries because of their relative high costs (Quek et al., 1998). During the 1970s, the increasing awareness and concern about the environment motivated research for new efficient and cost effective technologies that would be capable of removing metals and other organic contaminants such as dyes from polluted waste waters (Rao and Prabhakar, 2011). It was only in the 1990s that a new scientific area developed and helped to recover heavy metals and some other contaminants. The early reports described how abundant biological materials could be used to remove, at very low cost, even small amounts of toxic heavy metals from industrial effluents (Joshi, 2018). The main advantages of biological technologies for the removal of pollutants are that they can be carried out *in situ* at the contaminated site, usually environmentally benign (no secondary pollution) and they are cost effective. Biosorption is a simple technique that relies on the ability of living and nonliving biomass to remove metals or other organic contaminants from the matrix of interest (Ojima et al., 2019). Biosorption has been demonstrated to possess good potential to replace conventional methods for the removal of organic and inorganic contaminants (Malik, 2004; Di Piazza et al., 2017; Okoya et al., 2020a). This search brought biosorption/adsorption to the foreground of scientific interest as a potential basis for the design of novel wastewater treatment processes (Guendouz et al., 2016). Several adsorbents are currently used which are by-products from agriculture and industries, which include seaweeds, moulds, yeast., bacteria, fungi, crab shells, agricultural products such as wool, rice husk, cocoa husk, maize husks, straw, coconut husks, peat moss, exhausted coffee waste tea leaves, walnut skin, coconut fibre, Moringa oleifera husk etc. (Amuda et al., 2007; Okoya et al., 2014; Okoya et al., 2015; Okoya et al., 2020b). Therefore, the search for efficient, eco- friendly and low cost effective biosorbent for dye and heavy metals removal from wastewater is a continuous one. Hence this study seeks to assess the efficiency of the synergy of *Aspergillus niger* and chitosan from snail shell as biosorbent for the removal of heavy metals and indigo dye from textile industry wastewater.

MATERIALS AND METHODS

Collection and preparation of materials

The *A. niger* isolate used for this research was collected from the Department of Microbiology, Obafemi Awolowo University, Ile- Ife while the snail shells used for the extraction of chitosan were collected from households in Ile-Ife, Osun State. The snail shells samples were first washed, sun dried and ground into a powdery form after which it was sieved with 150 µm size mesh. The less than 150µm sized powdered snail shell was later stored and used for the extraction of chitosan according to the procedure (Okoya et

al., 2014). Analytically graded reagents were used for the extraction of chitosan, preparation of *A. niger* fungal biomass and all other experiments in this study.

Preparation of the powdered fungal biomass of *A. niger*

The *A. niger* isolate collected was inoculated into sterile petri-dishes of Potato Dextrose Agar (PDA) and incubated at 25°C for 5 days. After incubation, *A. niger* spores that had grown on the petri-dishes were harvested with distilled water in a 250 ml conical flask. Yeast extracts medium solution containing salts of KH_2PO_4; $(NH_4)_2$ $SO_4.7H_2O$; $ZnSO_4.7H_2O$ and $MgSO_4.7H_2O$ was later prepared and autoclaved at 121°C for 30 min. After allowing the autoclaved yeast medium salt solution to cool, the harvested *A. niger* spore solution was then inoculated into the yeast extract medium salt solution in different 250 ml conical flasks and mechanically agitated for 5 days to allow for maximum contact of the yeast medium and its content with the spores (del Rocío Urbina-Salazar et al., 2019). *A. niger* spores were later harvested by autoclaving the resultant contents of the conical flasks and filtering out the dead *A. niger* spores as the filtrate. The dead *A. niger* was pre-treated by washing with distilled water until the pH of the wash solution is close to neutral and then oven dried at about 70°C for 36 h. The dry biomass was ground to powder using a pestle and mortal. The powdered biomass was later sieved with a sieve opening of 150 μm and used as biosorbent.

Extraction of chitosan from snail shells

Chitosan was extracted from snail shell according to the method of Okoya et al. (2014) and Okoya, (2015). Snail shells samples were first washed, sun dried and ground into a powdery form after which it was sieved with 150 μm size mesh. The less than150 μm sized powdered snail shell was later deproteinised with 4% (w/v) KOH, the product demineralized with 3% (v/v) 1 M HCl, decolourised by refluxing in acetone for 3 h at 60°C to get chitin which was then deacetylated in 50% (w/v) NaOH solution on a magnetic stirrer at 30°C for 4 h to obtain the chitosan (2-acetamido-2-deoxy-β-D-glucose- (Nacetylglucosamine) shown in the following chemical reaction.

Chitin
(2-acetamido-2-deoxy-β-D-glucose- (Nacetylglucan)

Chitosan
(2-acetamido-2-deoxy-β-D-glucose-
(Nacetylglucosamine)

Deacetylation of Chitin
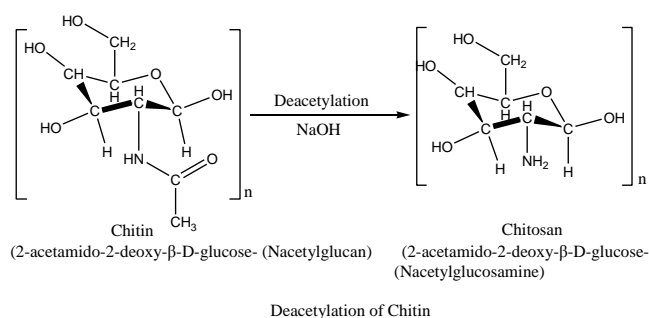
Characterization of chitosan

The chitosan powder was characterized using Fourier Transform Infra-red Spectroscopy (Perkin Elmer Spectrum BXl'l) to verify the structural modification upon extraction of chitosan from the snail shell (chitin).

Preparation of chitosan gel

About 5 g of chitosan was slowly added to 100 ml of 10% (w/ v) oxalic acid with constant stirring. The mixture was also heated to

40-50°C to facilitate mixing. A chitosan-oxalic acid mixture was formed with a whitish viscous gel.

Modification of biosorbent

The chitosan gel (100 ml) was diluted with water (~500 ml) and heated to 40 - 50°C. Ten grammes (10 g) of the sample of the adsorbent was slowly added to the diluted gel in separate container, and mechanically agitated using a shaker at 200 osc/min for 24 h. The gel coated adsorbents were then washed with distilled water and dried. It was then extensively rinsed with distilled water and dried in an oven at 102°C for 2 h, cooled at room temperature and stored in a desiccator.

Column biosorption experiment

Column biosorption study of the dye was carried out using the modified biosorbent in a column of 1.27 cm diameter and height of 40 cm, with simulated dye solutions of different initial concentrations (5, 25, 50 and 100 mg /L). Other parameters optimized include biosorbent dosage (0.1, 0.2, 0.3, 0.4 and 0.5 g) and contact time (10, 20, 30, 40, 50 and 60 min). For each of the investigations, the column was first loaded with the chitosan coated fungal biomass (biosorbent) and gravel in the ratio of 1 to 5 to create pressure for a better biosorption process. The simulated dye solution was later poured into the column setup in a down-flow direction. The effluents from the columns were then collected and residual dye concentrations determined with a UV/Visible spectrophotometer. The optimized conditions obtained from the simulated biosorption experiment were used to run the column biosorption of the textile industry waste water whose physicochemical properties have been determined using standard methods (Ademoroti, 1996; APHA, 2012) and heavy metal concentrations determined with Atomic Absorption Spectrophotometer (APHA, 2012).

Adsorption isotherms

Dye was sorbed from various initial concentrations (5 to 100 mg/L) of simulated dye solution. Langmuir and Freundlich models were applied to the adsorption isotherm and relevant constants were generated (Langmuir, 1916; Freundlich, 1906).

Statistical analysis

The various data obtained before and after treatment with chitosan coated fungal biomass of *A. niger* were analyzed using one way ANOVA to test if there are significant differences between the initial dye concentration before treatment and after treatment with the adsorbent in both simulated dye solution and industrial textile wastewater. Student T-test was used to check for significant differences between the initial concentration before treatment and final concentration after treatment of the physico-chemical parameters in the textile wastewater.

RESULTS AND DISCUSSION

Sample characterization

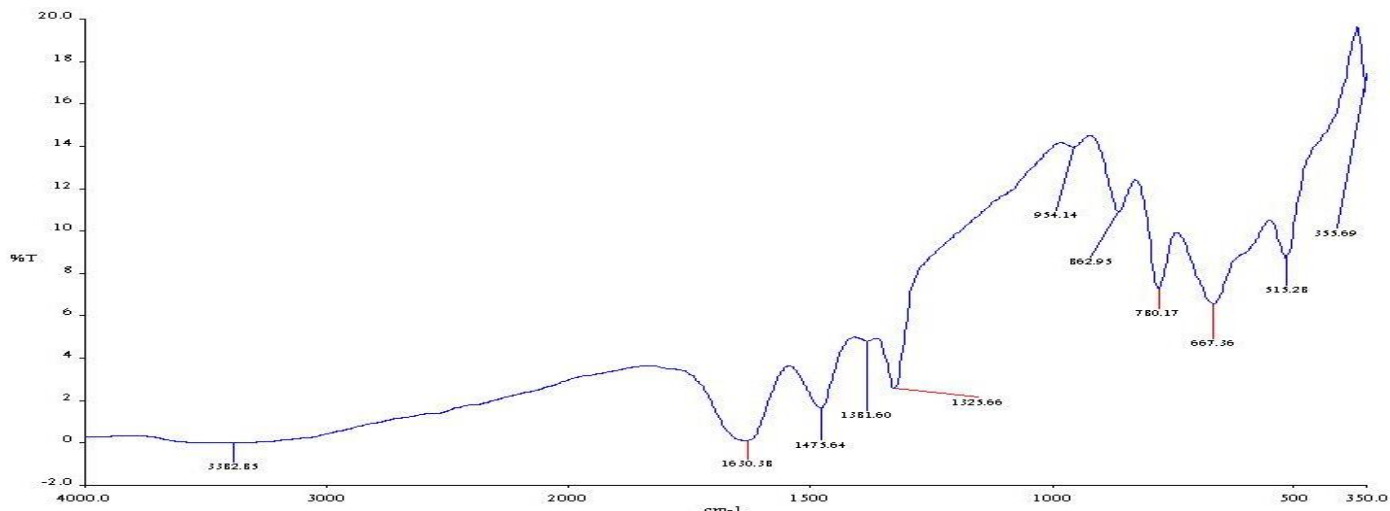The FTIR spectrum of the chitosan powder (Figure 1) showed a broad band at 3383 cm^{-1}due to O-H (hydroxyl)

Figure 1. FTIR spectrum of the chitosan powder extracted from snail shell.

Table 1. Effects of initial concentration on the amount of dye adsorbed.

Initial Conc. (mg/L)	Final Conc. (mg/L) ± SE	% Removal (This Study)	%Removal(**)	Q_e (mg/g) ± SE	F	P
5	4.08±0.15	18.40	N.A	0.11±0.04	35.82	0.00
25	3.58±0.54	85.68	93.05	1.76±0.49	1565.34	0.00
50	4.45±0.42	91.10	97.15	3.47±0.78	11509.14	0.00
100	9.02±0.86	90.98	98.62	6.90±0.98	11206.20	0.00
*1.87	0.81±0.45	56.68	N.A	0.07±0.02	553.05	0.00

SE = Standard Error, F= Degree of freedom, P = Probability and N.A = Not Applicable; p is significant when $p < 0.05$; Q_e is the amount adsorbed per unit mass of the biosorbent; *1.87 mg/L is industrial wastewater dye concentration.

and N-H (amine) stretching. The peak at 1630 cm^{-1} was assigned to C=O stretch. In addition to the peak at 1382 cm^{-1} assigned to amide I, there are also peaks at 1476 and 1353 cm^{-1} characteristic of chitin and chitosan which have been reported as amide I and III bands, respectively (Dragan et al., 2010).

Effect of initial concentration on the amount of dye adsorbed

Table 1 shows the effect of initial dye concentrations on the amount of dye adsorbed when the biosorbent was used for the treatment of both simulated dye solution and textile industry wastewater. As the initial concentration of the dye solution increased, the amount of dye uptake also increased in the simulated dye solution. This increase in the amount of dye adsorbed per unit mass of the adsorbent (Q_e) with increase in initial dye concentration of the simulated wastewater is due to an increased driving force between the aqueous and solid phases thereby increasing the number of collisions

between dye molecules and the adsorbent (Hubbe et al., 2011). In the textile wastewater, more dye uptake was observed than in the simulated dye solution. This is in agreement with Mohammed et al. (2009) who reported that in the application of adsorption for purification of wastewaters the solution will normally be a mixture of many compounds rather than a single one. The interactions of these compounds may mutually enhance adsorption.

Effect of biosorbent dosage on the amount of dye adsorbed

Effect of biosorbent dosage on biosorption of dye was studied by varying biosorbent dosage from 0.1 to 0.5 g when other parameters like initial dye concentration were kept constant. Tables 2 and 3 show increase in dye uptake by the biosorbent. This is because of the availability of more binding sites in the surface of the biosorbent as the dosage increased (Asubiojo et al., 2009; Choi et al., 2009; Okoya et al., 2020a) until the

Table 2. Effect of biosorbent dosage on the amount of dye adsorbed in 100 mg/L simulated dye solution.

Dosage (g)	Final concentration (mg/L)± SE	% Removal (This study)	% Removal (**)	Q_e (mg/g) ± SE	F	P
0.1	5.68±1.84	94.32	67.88	0.11±0.04	2.85	0.00
0.2	4.53±1.30	95.47	89.69	1.76±0.49	3.09	0.00
0.3	4.23±1.25	95.77	95.80	3.47±0.78	3.15	0.00
0.4	3.50±1.26	96.50	97.70	6.90±0.98	3.29	0.00
0.5	3.99± 1.01	96.01	97.62	0.07±0.02	3.20	0.00

SE= Standard Error; P= Probability, F= Degree of Freedom, p is significant when $p< 0.05$; Q_e = Amount adsorbed per unit mass of the biosorbent;
**_A. niger_ alone as the biosorbent   (del Rocío Urbina-Salazar et al., 2019)

Table 3. Effect of Biosorbent dosage on the amount of dye adsorbed from textile wastewater.

Dosage (g)	C_f (mg/L) ± SE	% Removal	Q_e (mg/g) ± SE	F	P
0.1	0.89±0.05	52.41	0.06±0.00	3.59	0.06
0.2	0.91±0.06	51.34	0.06±0.00	3.59	0.06
0.3	0.81±0.02	56.68	0.06±0.00	4.12	0.07
0.4	0.65±0.01	65.24	0.07±0.00	4.67	0.09
0.5	0.86± 0.04	54.01	0.07±0.00	3.56	0.06

SE= Standard Error; P= Probability, F= Degree of Freedom,p is significant when $p< 0.05$; Q_e = Amount adsorbed per unit mass of the biosorbent; Initial Textile Industry dye concentration = 1.87 mg/L.

Table 4. Effect of contact time on the amount of dye adsorbed from 100 mg/L simulated dye solution with 0.5 g Biosorbent Dosage.

Time (min)	Final Conc. (mg/L) ± SE	% Removal	Q_e (mg/g) ± SE	F	P
10	9.81±1.97	90.19	6.76±0.98	8.10	0.02
20	8.15±1.56	91.85	6.89±0.94	9.43	0.01
30	8.15±1.57	91.85	6.89±0.93	9.43	0.01
40	8.06±1.50	91.94	6.90±0.95	10.07	0.00
50	7.96±1.49	92.04	6.90±0.95	12.89	0.00
60	7.96±1.47	92.04	6.90±0.95	12.89	0.00

SE= Standard Error; P= Probability, F= Degree of Freedom,p is significant when $p< 0.05$; Q_e = Amount adsorbed per unit mass of the biosorbent.

surface was saturated leading to a decrease in the dye uptake by the biosorbent. Even though there were increases in the amounts of dye adsorbed with increase in biosorbent in the simulated dye solution and industrial wastewater, statistically there were no significant differences in the increases observed. This might be due to the fact that there is no commensurate increase in the adsorption resulting from lower adsorption of indigo dye per unit mass of adsorbent as reported by Etim et al. (2016).

Effect of contact time on biosorption of dye

Tables 4 and 5 show the uptake of dye as a function of contact time from both simulated dye solution and textile wastewater. The trend observed may be due to a very high continuous transfer rate of the dye to the surface of the biosorbent due to the availability of a large number of vacant sites initially for adsorption; later the adsorption capacity tailed off due to the saturation of vacant sites.

Adsorption isotherm

The applicability of sorption processes as a unit operation can be evaluated using isotherm models. The equilibrium sorption data obtained were analysed in terms of the Langmuir and Freundlich equations. The coefficients of

Table 5. Effects of contact time on the amount of dye adsorbed in the textile industry wastewater.

Time (min)	Final Conc. (mg/L) ± SE	% Removal	Q_e (mg/g) ± SE	F	P
10	1.52±0.08	18.72	0.02±0.00	6.97	0.03
20	1.50±0.06	19.79	0.02±0.00	7.04	0.03
30	1.44±0.03	23.00	0.03±0.01	8.13	0.02
40	0.67±0.00	64.17	0.07±0.02	9.56	0.01
50	0.65±0.01	65.24	0.07±0.03	10.42	0.01
60	0.65±0.01	65.24	0.07±0.03	10.42	0.01

± Standard Error; P= Probability, F= Degree of Freedom, p is significant when $p < 0.05$; Q_e = Amount adsorbed per unit mass of the biosorbent; Industrial dye wastewater = 1.87 mg/L.

Table 6. Langmuir and Freundlich constants for the biosorption of dye in the simulated and industrial wastewaters.

	Langmuir constants			Freundlich constants				
	b (L/mg)	**Q_{max}** (mg/g)	**Y (Equation of the line)**	**R^2**	**K_f**	**1/n**	**R2**	**Y (Equation of the line)**
100 mg/L simulated Dye solution	-1.2694	6.9027	-0.1159x+0.1957	0.9993	8.4528	-0.1607	0.9998	-0.0834x+0.817
Industrial Wastewater	-1.9153	0.0733	-35.274x+67.59	0.9804	0.0401	-1.3766	0.9960	-1.4145x-1.397

Where, R^2 is correlation coefficient; Q_{max} is biosorption; K_f Freundlich constant.

these isotherms for different systems are usually determined by experimental analysis (Enemose et al., 2014). Table 6 shows the co-efficient of the isotherm for both the simulated dye solution and textile industrial wastewaters. The coefficient of correlation (R^2) for both model falls within $0 < R^2 < 1$. This indicates that both models adequately describe the experimental data of the adsorption of dye studied. Freundlich isotherm had a better fitting for both simulated dye solution and the textile industrial wastewater.

In this study, Langmuir adsorption constant was both negative in the simulated dye solution and textile industrial wastewater; while the Freundlich isotherm model was positive in the simulated dye and industrial textile wastewater. This indicates that the amount of dye adsorbed when saturation is attained is higher with a strong electrostatic force of attraction when q_{max} is greater than unity (Alkan et al., 2008); but the reverse was the case in the industrial wastewater with a low Freundlich constant of 0.040 mg/g. The value of 1/n from Freundlich isotherm model indicates a constant related to intensity of adsorption. The 1/n from Table 6 shows a value that is less than a unit (1/n < 1) in both simulated and industrial wastewaters. A smaller value of 1/n indicates better adsorption mechanism and formation of a relatively stronger bond between adsorbate and adsorbent (Tellan et al., 2007).

Effect of biosorbent treatment on selected physico-chemical parameters and heavy metals in textile wastewater

The levels of heavy metals in the textile wastewater were quite higher than the tolerable limits set by Standard Organization of Nigeria (SON, 2007) which could have been possible through the various processes involved in textile producing factories as reported by Ohioma et al.

Table 7. Effect of the Biosorbent on the selected Heavy Metals and physicochemical parameters in Textile Industry Wastewater.

Physico chemical parameter	Before treatment	After treatment	Percentage difference	F	P
Chromium (mg/L)	0.131±0.000	0.070±0.012	45.565	25.126	0.001
Iron (mg/L)	0.465±0.000	0.070±0.048	84.946	19.566	0.002
Copper (mg/L)	1.102±0.000	0.637±0.093	42.196	25.141	0.001
Lead (mg/L)	0.082±0.000	0.050±0.010	39.024	10.811	0.011
Nickel (mg/L)	0.081±0.000	0.053±0.011	34.568	6.594	0.033
Zinc (mg/L)	0.255±0.000	0.171±0.021	32.942	17.031	0.003
Magnesium (mg/L)	0.281±0.000	0.191±0.004	32.028	14.369	0.005
Cobalt (mg/L)	0.071±0.000	0.040±0.008	43.662	15.177	0.005
Manganese (mg/L)	0.043±0.000	0.024±0.004	44.186	28.383	0.001
Cadmium (mg/L)	0.110±0.000	0.056±0.008	49.091	50.017	0.000
Conductivity(µs/cm)	342.000±1.000	503.000±1.000	47.076	12960.500	0.000
TDS(mg/L)	228.000±2.000	335.000±2.000	46.930	1431.125	0.001
pH	5.420±0.030	7.6900±0.010	41.882	5152.900	0.000
Acidity (mgCaCO$_3$/L)	100.000±3.500	38.500±1.600	61.500	255.385	0.004
Alkalinity (mgCaCO$_3$/L)	25.000±0.500	150.000±3.500	500.000	1250.000	0.001
COD (mg/L)	48.000±1.000	32.000±1.000	33.333	128.000	0.008
Turbidity (NTU)	1.530±0.020	19.710±0.100	92.237	661024.800	0.000

± Standard Error; P= Probability, F= Degree of Freedom, p is significant when p< 0.05 at 95% confidence level.

(2009). Huang et al. (1988) reported that the uptake of metals with biological materials may be possible due to physical sorption or the nature of the biosorbent by being heterogeneous as with this adsorbent. Chromium ion was 0.131±0.000 mg/L before treatment as against 0.050 mg/L permissible limit set by Standard Organisation of Nigeria (SON, 2007) but it was reduced to 0.070±0.012 mg/L after treatment with the biosorbent. The 46% removal of Cr metal ion recorded in this work from the textile industrial wastewater supports the finding of Chojnacka (2005), which investigated the sorption of Cr (III) ions with hen eggshells from aqueous solutions and postulated the remediation potential of wastewaters containing heavy metals with agricultural by-products as biosorbent. Odoemelam et al. (2009) removed about 90% of Pb (II) ions from aqueous solution with oyster and giant snail shells reported the possibility of using these materials to remediate wastewaters contaminated with heavy metals. This work supports his findings with a removal of about 40% Pb metal ion from textile industry wastewater. Cadmium metal ion in the textile wastewater was reduced by 49% which agrees with the report of Mapolelo and Torto (2004) that proved the biosorption of Cd (II), Cr (III), Cr (VI), Cu (II), Pb (II) and Zn (II) with *Saccharomyces cerevisiaeis* optimum when the pH value is above 5. The textile wastewater contained 0.255±0.000 mg/L of zinc metal ion before treatment with the biosorbent which was reduced to 0.171±0.021 mg/L after treatment. This is about 33 % removal of Zn metal ion from the textile wastewater which is still in accordance with the report of Mapolelo and Torto (2004)) as sited previously. Cobalt metal ion, copper (Cu) and iron (Fe)

were reduced by about 44, 42and 20% respectively. Magnesium (Mg) was 0.281±0.000 mg/L before treatment and 0.191±0.004 mg/L after treatment with the adsorbent while Manganese (Mn) was 0.043±0.000 mg/L before treatment and 0.024±0.004 mg/L after treatment with the adsorbent. Nickel (Ni) was 0.081±0.000 mg/L before treatment and 0.053±0.011mg/L after treatment with the adsorbent.

The conductivity of the wastewater increased from 342±1.000 µS/cm to 503.000±1.000 µS/cm after treatment with the biosorbent which could be as a result of the presence of salts which were used to cultivate *A. niger*. Total dissolved solids (TDS) was increased after treatment of the wastewater with the biosorbent, as against reduced TDS reported by Ramamurthy et al. (2011) in which live cultured isolate of *A. niger* was used. The increase in TDS observed in this work may be due to the use of dead *A. niger* fungal biomass. Alkalinity increased while acidity reduced from 100.000±3.50 to 38.500±1.600 mg/L, which is about 61.50% reduction. This may also be due to the alkaline nature as a result of the hydroxyl group present in the biosorbent used as evidenced in the FTIR spectrum of the chitosan used. Turbidity of the wastewater increased, which may be due to the dissolution of soluble organic compounds and other materials from the biosorbent into the wastewater as presented in Table 7.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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