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Application of Harmonic Analysis in the Preliminary Prediction of Air Temperature over Lagos and Abuja, Nigeria

[*]B.C, Isikue, [1]P.O. Agada, and [2]E.U. Uta

Abstract
Harmonic Analysis technique has been employed in predicting the hourly air temperature variations over Lagos and Abuja, Nigeria. The variations in hourly air temperatures over the two stations are periodic and thus have strong tendency of being repeated the next day, if all other atmospheric variables are constant. It was observed that the variation in hourly air temperature in the two stations is dominated by the first harmonic, thus it fluctuates by one cycle with a period of 24 hours. The maximum hourly air temperature occurred 2 hours on the average after the maximum solar irradiance has occurred in each station. The degree of hotness or coldness of the air at a later hour depends on that of the previous hours for each station.

Key words: *Harmonic analysis, air temperature, prediction, solar irradiance and Nigeria.*

*B.C, Isikue, [1]P.O. Agada, and [2]E.U. Uta
[1]Department of Physics, Federal University of Agriculture, Makurdi, Benue State. Nigeria
[2]Department of Physics, University of Jos, Nigeria
*Corresponding Author

Introduction

The climate system adjusts when one or more of external factors change, for example, global average temperatures would be expected to increase with an increase in solar output. Climatic predictions are made using climate system models as the Atmosphere-Ocean general circulation models (AOGCMs). These are mathematical expressions of the thermodynamics; fluid motions; chemical reactions; and radiative transfer of the complete climate system that are as comprehensive as allowed by computational feasibility and scientific understanding of their formulation. The ultimate aim is to model as much as possible the climate system, especially the complex feedbacks among the various components. A number of models are in operation in various research institutes and universities Worldwide. Although the models are based on the same laws of physics, each has different ways of dealing with processes that cannot be represented explicitly by physical laws, such as formation of clouds and precipitation. Variations in these parameterizations lead to different regional projection of climate change, particularly for precipitation.

AOGCMs as well as many other climatic models cannot simulate all aspects of climate. The AOGCMs in particular have large uncertainties associated with clouds, it has difficulty portraying accurately precipitation patterns in mountainous regions and resolving important synoptic weather features (such as Mesoscale Convective Systems) that strongly influence precipitation patterns and amounts in many agricultural regions (Ebi and Means, 2002). Since the challenges of climate change persist globally, the need for climatic models and better statistical methods for analyzing climatic variables will continue to grow. This study in its own way of improving on existing methods of analyzing climatic variables, did not stop at the use of descriptive statistics (e.g. mean) in the analysis, but proceeds to developing a computer program for predicting the average hourly temperature over Lagos and Abuja, Nigeria.

Purpose of Study

The identification and implementation of methods that will effectively enhance the study of atmospheric variables has posed a challenge over time. Thus the aim of this work is to employ the use of harmonic analysis technique in fitting a periodic function or model to carry out a preliminary prediction of hour to hour air temperature over Lagos and Abuja, Nigeria.

Lagos is in the south western part of Nigeria and lies approximately on Longitude 2^0 42" and 3^0 22" East and between Latitude 6^0 22" and 6^0 42" North. It stretches over along the Guinea Coast of the Bight of Benin on the Atlantic Ocean. On the other hand, Abuja is in the northern part of Nigeria at Latitude 8.9 and Longitude 7.09. So the locations of these two cities make them liable to climatic variations due to ocean and desert effects respectively. Hence the work will help in providing useful information that will improve human and agricultural activities in these areas especially in this era of global erratic climatic change.

According to Weather fundamentals (2007), the amount of solar energy received by any region of the earth varies with time of day, with seasons, and with latitude. These differences in solar energy create temperature variations. These temperature variations create forces that drive the atmosphere in its endless motions.

Review of related works

In the past, some researchers have actually used harmonic analysis in studying temperature variations but none has been known to be carried out in Nigeria, especially with the Nigerian Environmental Climatic Observing Program (NECOP), real time data.

Lidija (2007) used harmonic analysis to investigate the seasonal cycle in temperature at five locations over the Mount Biokovo region (Croatia), Makarska, Opuzen, Sestanovac, Imotski, and Vigorac. The monthly averages of temperature as well as monthly means of minimum and maximum temperatures from 1961 to 1980 were subjected to harmonic analysis. The results were reported to have a good implication for botanical investigations.

Aisu and David (2000), used mean monthly average daily values of global irradiation for seven stations in Oman to develop harmonic models. Pertinent amplitudes and phase angles were obtained for each station. The results show the dominance of the first two harmonics in the southern stations, Salalah and Marmul and the dominance of only the first harmonic in the north, Buraimi and Seeb.

The mean annual variations of the air temperature over European and Mediterranean area have been studied using Harmonic Analysis. Basic data consist of the mean monthly values of air temperature from 1961-1990. It was found that the first 2 harmonic terms contribute, altogether, to the total variance of over 95% (Makrogiannis and Balafoutis, 2001).

Harmonic analysis along side with other statistical methods has also been applied to study seasonal variability of the air temperature at Mlynany using mean hourly, monthly and annual values of the air temperature during the period of 1962-2002. The results showed that the air temperature trend at Mlynany has an increasing tendency and that the mean annual air temperature increased by about 1.4 during the investigated period, i.e., approximately by 0.34^0 per decade.

Air-water temperature relationship in the Illinois River (Peoria) was studied using Harmonic analysis. It's application to daily mean air, water temperature records for this location, indicates that the first harmonic accounts for a major portion of the total variance in the records. It was discovered that water temperature residuals are well correlated with air temperature residuals. This result enabled the development of a mathematical model whose parametric values were used for predicting water temperatures from air temperature records and this was seen to be stable from year to year (Kethandaraman, 2007).

However in this work, the harmonic analysis technique is used in analyzing and predicting hourly air temperature data for a few days over Lagos and Abuja, Nigeria.

Source of data

The air temperature and solar irradiance data used for this work was obtained from Nigerian Environmental Climatic Observing Program (NECOP), NECOP is a new programme about three years old, designed to establish a network of meteorological and climatological observing stations spatially located across Nigeria. NECOP's main objectives among other things is to make real time data available for meteorological and climatological research which will serve as a warning tool for decision makers involved in emergency management, natural resources management, transportation and agriculture. The size of the NECOP real time data obtained in these stations is small. Hence Abuja and Lagos have 8 and 2 months data respectively. This does not allow for a long time climatic prediction of the area. Hence, this research serves as a preliminary investigation to the climatic prediction in these areas.

This work was carried out based on series equation adapted from Panofsky and Brier, 1960:

$$X_t = \bar{X} + \sum_{i=l}^{N/2}\left[A_i \sin\left(\frac{360}{p} it\right) + B_i \cos\left(\frac{360}{p} it\right)\right] \quad (1)$$

Where N is the number of observations, X1 = the time series, X = arithmetic mean, P= period of observation.

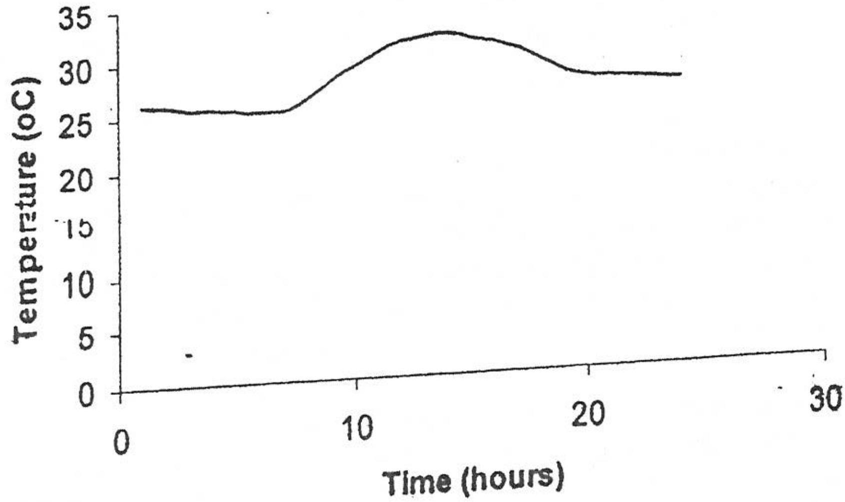
$$A = \frac{2}{N}\sum_{i=l}^{N/2}\left[X \sin\left(\frac{360}{p} it\right)\right],\ B = \frac{2}{N}\sum_{i=l}^{N/2}\left[X \cos\frac{360}{p} it\right] \quad (2)$$

A and B are coefficients
X = Observed value, t = time and i = number of harmonies.
In other words the time series equals the mean plus the sum of all N/2 harmonies.

The first harmonic (or fundamental) has a period equal to the total period studied. The second harmonic has a period equal to half the fundamental period, the third harmonic a period of one = third of the fundamental and so on. It is not always required to determine all the N/2 harmonies, usually the first two, or at most three, harmonies describe the variation of the periodic sufficiently well. The equation (1) can be re-written as:

$$X_t = \bar{X} + \sum_{i=l}^{N/2} C_i \cos\left[\frac{360}{p} i\,(t - t_i)\right] \quad (3)$$

Where $C_i = \sqrt{A^2 + B^2}$ is the amplitude of the i^{th} harmonic and



The result of the run of the harmonic analysis program on the hourly average air temperature data is summarised in Table 1.

Table 1: Result extracts from the run of harmonic analysis program on the hourly average air of temperature of Lagos

Harmonics	Since Coefficients (A_i)			Cosine Coefficients (B_i)			Amplitude	Time Harmonic is Maximum (h)	Percentage contribution
	A1	A2	A3	B1	B2	B3			
1st	-1.7720	0	0	-2.2585	0	0	2.87	14.54	86.72
2nd	0	0.6593	0	0	0.8699	0	1.09	13.24	12.54
3rd	0	0	0.0746	0	0	0-.1017	0.13	13.07	0.17

Using the average daily air temperature of 27.810C, the period of 24 hours and the sine and cosine coefficients of Table 1, the fitted periodic function X1 for the hourly average temperature of Lagos station is obtained using extracts from equation 1 as:

$$X_i = 27.81 + \sum_{i=1}^{3}[A_i \sin(15it) + B_i \cos(15it)] \quad (4)$$

Where A_1 and B_1 are the coefficients of the sine and cosine respectively and the I's are integers ranging from 1 to 3 as given in Table 1.

Equation 4 was employed in the harmonic analysis program so as to make a six days forecast of hourly average air temperature measurements for Lagos station. The result of this forecast is displayed with the corresponding actual and estimates of hourly average air temperature measurements in Table 2.

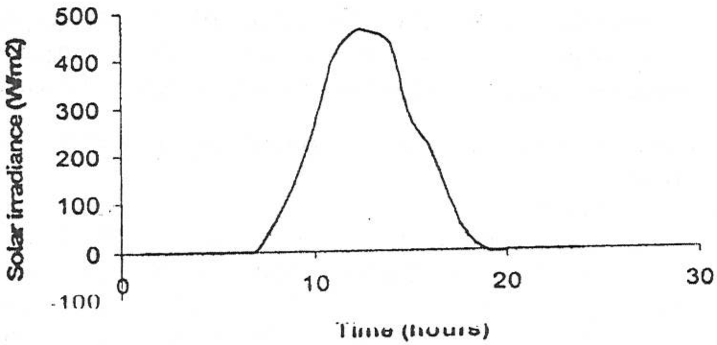
Table 2: A display of six day forecasts of hourly average air temperature for Lagos station against corresponding actual and model estimate values

Time (hours)	Actual values	Model estimate	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1	26.12	26.23	26.23	26.23	26.23	26.23	26.23	26.23
2	25.91	26.05	26.05	26.05	26.05	26.04	26.05	26.05
3	25.68	25.74	25.74	25.74	25.74	25.74	25.74	25.74
4	25.53	25.38	25.38	25.38	25.38	25.38	25.38	25.38
5	25.32	25.11	25.11	25.11	25.11	25.11	25.11	25.11
6	25.19	25.09	25.09	25.09	25.93	25.09	25.09	25.09
7	25.13	25.48	25.48	25.48	25.48	25.48	25.48	25.48
8	26.11	26.30	26.30	26.30	26.30	26.30	26.30	26.30
9	27.67	27.48	27.48	27.48	27.48	27.48	27.48	27.48
10	28.96	28.89	28.82	28.82	28.82	28.82	28.83	28.83
11	30.15	30.08	30.08	30.08	30.09	30.09	30.09	30.09
12	30.97	31.04	31.04	31.04	31.04	31.04	31.04	31.05
13	31.46	31.55	31.55	31.55	31.55	31.55	31.55	31.55
14	31.54	31.58	31.58	31.58	31.58	31.58	31.58	31.58
15	31.09	31.19	31.19	31.19	31.19	31.19	31.19	31.19
16	30.61	30.51	30.51	30.51	30.50	30.50	30.50	30.50
17	29.90	29.66	29.66	29.66	29.66	29.66	29.66	29.66
18	28.82	28.78	28.78	28.78	28.78	28.78	28.78	28.78
19	27.69	27.98	27.98	27.98	27.97	27.97	27.97	27.97
20	27.19	27.31	27.31	27.31	27.31	27.31	27.31	27.31
21	26.91	26.82	26.82	26.82	26.82	26.82	26.82	26.82
22	26.66	26.52	26.53	26.53	26.53	26.53	26.53	26.53
23	26.49	26.38	26.38	26.38	26.38	26.38	26.38	26.38
24	26.29	26.32	26.32	26.32	26.32	26.32	26.32	26.32

Daily average	27.81	27.81
Standard deviation	2.18	2.17

Analyses and results for Abuja Station

The same process was used to carry out the analysis for Abuja and the results for the time series plots of air temperature and solar irradiance measurements are given in Figures 4 and 5 respectively.



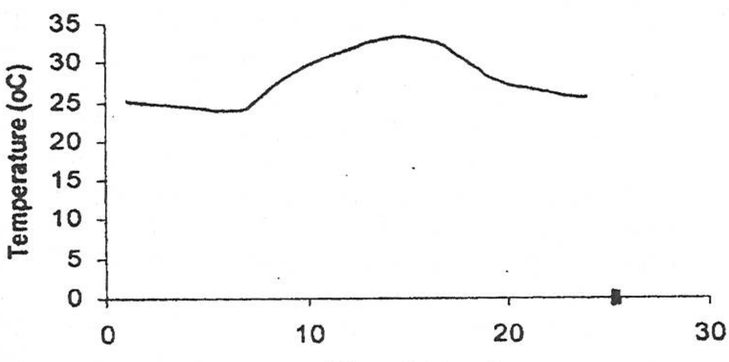


Figure 5: Time series plot of hourly average solar irradiance for Abuja Station. The fitted periodic function X_1 for the hourly average temperature of Abuja Station is given as:

$$X_t = 27.89 + \sum_{i-i}^{i}[A_i \sin(15it) + B_i \cos(15it)] \quad (5)$$

Where A1 and B1 are the coefficients of the sine and cosine respectively and the I's are integers ranging from 1 to 3 as given in Table 3.

Table 3: Result extracts from the run of harmonic analysis program on the hourly average air of temperature of Abuja Station

Harmonics	Since Coefficients (A_i)			Cosine Coefficients (B_i)			Amplitude	Time Harmonic is Maximum (h)	Percentage contribution
	A1	A2	A3	B1	B2	B3			
1st	-2.8	0	0	-3.34	0	0	4.37	15.07	91.69
2nd	0	0.89	0	0	0.79	0	1.19	14.02	6.83
3rd	0	0	0.30	0	0	0.22	0.37	13.17	0.65

The result of six days forecast of hourly average air temperature measurements for Abuja is displayed with the corresponding actual and model estimates of hourly average air temperature measurements in Table 4.

Table 4: A Time distribution of Maximum air temperature and Maximum Solar irradiance across Stations

Station	Maximum Air Temperature (°C)	Time (hours)	Maximum Solar Irradiance (W/m²)	Time (hours)
Lagos	31.53841	14h (2P.M)	457.2712	12h (Noon)
Abuja	33.17894	15h (3 P.M)	511.1827	12h (Noon)

Discussions

Observations show that the equation (1) – (6) exhibit a good fit to the hourly average temperature of Lagos and Abuja, as thy produced very close estimates of the actual hourly average air temperatures, yield the same mean (average daily air temperature) as that of the actual data and very close standard deviation of the actual data and that of the model estimates as shown in Table 2 and 4 respectively. It can also be observed from Tables 1 and 3 that the first harmonic dominates the periodic components in the hourly average air temperature of all the Stations since it has the highest contribution of 86.72% and 91.69% for Lagos and Abuja stations respectively, showing that the hourly air temperature of each station fluctuates by one cycle. This implies that the contributions of the second and third harmonies for each Station is negligible thus, the information about them is discarded.

The six days forecasts of hourly average temperatures for each Station as shown in Tables 3, 2 and 4 respectively, show a strong indication that the hourly air temperatures across the two stations have the tendency of being repeated in every twenty four hours provided all other intervening atmospheric variables are kept constant. The results in Tables 1 and 3, show that the first harmonic is maximum at time; 14.54^{th} and 15.07^{th} for Lagos and Abuja respectively, which give close estimate of the time at which the actual value of the maximum hourly average air temperature occurred for each station as shown in Table 5. This result further validates the fitted periodic function to the data for each Station.

Figure 2 and 5 show that the solar irradiance for each station is low in the morning hours, highest in the afternoon and again low towards the evening hours. For the Lagos station, solar heating starts increasing from 7^{th} (7a.m), peak at 12^{th} (12 noon), and reduces from 13h (1p.m) while in Abuja Station, solar heating also starts increasing from 6h (6a.m), peak at 12h (12 noon), and reduces from 13h (1p.m). Figures 1 and 4 show the fluctuation in average hourly air temperatures for each station. For the Lagos the air temperature starts increasing at 8h (8a.m), peaks at 14h (2p.m) and reduces from 15h (3 p.m). The air temperature of the Abuja station starts increasing at 7h (7a.m), peaks at time 15h (3p.m) reduces from 14h (2p.m).

It can be observed from Table 5 that the maximum air temperatures is not the same across the two stations and neither did it occur at the time for which the solar irradiance is maximum for each station. The maximum average hourly temperature occurs 2hrs after the maximum average hourly solar heating had occurred in Lagos, while after 3hrs in Abuja. This could be attributed to the fact that the stations differ in the nature of geophysical features they are endowed with. These physical features such as water bodies, hills and mountains differ in their specific heat capacities.

The rate of radiation loss at the different locations could be explained by the Stefan-Boltzman law, which states that: "the total energy radiated per unit surface area of a black body in unit time is directly proportional to the fourth power of its thermodynamic or surface temperature". Thus, since these surfaces differ in their surface temperatures, their respective radiation loses cannot be equal to the solar irradiance at the same time, affirming the reason why maximum air temperatures did not occur at the same time of the day across all stations and neither did it occur at the time for which the solar irradiance is maximum for each station. This could also be explained by a phenomenon known as solar and terrestrial balance which asserts that the maximum air temperature occurs at the time when the solar heating and the energy lost by these surfaces (terrestrial radiation) are equal. In addition, amount of solar energy received by any region varies with the time of the day, season and latitude and these difference in solar energy create temperature variations (Weather fundamentals, 2007).

Conclusion

From the results of the analyses made for each station, the following conclusion can be drawn:

(i) The variations in hourly air temperatures across Lagos and Abuja, Nigeria are periodic and thus have strong tendency of being repeated the next day, if all other atmospheric variables are constant.

(ii) The hourly air temperatures and solar irradiance vary across each station, and that their respective maximum air temperatures never occurred at the time when the solar irradiance is maximum.

(iii) The maximum hourly air temperature occurs 2hrs on the average after the maximum solar irradiance has occurred in each station.

(iv) The degree of hotness or coldness of the air at a later hour depends on that of the previous hours for each station.

(v) The Nature of substances (hills, water bodies, mountains, etc) could have effects in variations in the average hourly temperature across stations.

(vi) The harmonic equations exhibit a good fit to the hourly average temperature of Lagos and Abuja and hence can be applied for hourly temperature prediction irrespective of the length of the data.

Acknowledgement

We are thankful to the Centre for Basic Space Science, University of Nigeria, Nsukka, Nigeria in conjunction with the National Space Research and Development Agency (NARSDA) for establishing this NECOP programme in most of the University campuses in the country thereby providing the data set for studying of the variations in climatic variables in real time.

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Effect of Different Vadose Zone Depths on the Purification Quality of an Aggregate Laden Soil Infiltration System

M.O. Isikwe[1], S.B. Onoja[1] and A.F. Onyilo[2]

Abstract

This study investigated wastewater effluent quality from a soil purification system, considering the influence of the vadose depth. A wastewater soil infiltration system was designed and fabricated with two vadose zone depths of 60cm and 90cm. It consisted of 10 compartments, each with 12 x 12 cm² surface area. Loamy sand soil was used as the infiltration medium. The system was dosed 4 times daily with raw wastewater for 24 weeks. The trend indicated that purification quality improved gradually over the 24-week period. The results for the two vadose depths of 60 and 90cm were: BOD (69.86 and 76.82mg/I). COD (71.28 and 71 79mg/I); TSS (65.34 and 66.22mg/I). TBC (78.7units/100 and 83.60units/100ml) respectively. These results were within the FAO standard for irrigation, but TSS and TBC exceeded the WHO water quality standard for consumption. NO_3^- (14.36 and 7.85mg/I). PO_4^- (8.48 and 3.50mg/I), C (83.07 and 92.42 mg/I) and K (66.27 and 88.22mg/I) were within the limits for both domestic and irrigation purposes. Soil vadose depth of 90cm had

M.O. Isikwe[1], S.B. Onoja[1] and A.F. Onyilo[2]
1: Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria
2: Council for Regulation of Engineering Practice in Nigeria. Abuja
e-mail of Corresponding author: moisikwue@yahoo.com
Phone. +234-8060204939

better purification efficiency on TDS with the filtrate concentrate of 283.2mg/I being within both WHO and FAO standards, while soil vadose zone depth of 60cm had a range of 560.3mg/I. There was significant difference ($p<0.05$) in purification performance attributable to the soil vadose zone depth. The 90cm depth had a higher effect on the purification quality than that of 60cm.

Kaywords: *wastewater, purification, infiltration, soil, fitration, quality.*

Introduction

Domestic wastewater can be treated using soil infiltration system and recycled for domestic and agricultural usage. Wastewater in this study refers to all the water used in the home that goes down the drain or into the sewage collection system, such as water from baths, showers, sinks, dish washers and water closets. In and semi-arid areas, where surface water is scarce and rainfall distribution poor, recycling wastewater will go a long way in ameliorating the problems caused by clean water scarcity and also improves hygienic standard of the people. Nature has provided a means of treating wastewater as it percolates through the soil. Therefore, wastewater can be recycled with minimum treatment for both domestic and agricultural usage where good water is scarce.

Wastewater systems for onsite and small-scale applications are commonly designed for application of primary treated wastewater into natural soil where it infiltrates and percolates through the vadose zone before it recharges the underlying groundwater. Such systems are widely used because of their high purification performance with respect to organics, solids and nutrients, with relatively low cost and limited operation and maintenance requirements (Siegrist and Cuyk, 2001). A system's physical features, operational parameters and environmental conditions can determine its hydraulic and purification behaviours. The infiltration surface character and the soil vadose zone depth are two system features that are commonly determined during design (Cuyk et al, 1999).

Long time contact between wastewater constituents, the soil matrix and associated biofilms occur during unsaturated flow. This can be achieved by intermittent dosing (e.g. 4-24 times per day) of daily loadings, limited to a small fraction of the soil's saturated hydraulic conductivity (Cuyk *et al.*, 2000). The infiltration rate in these systems is critical to system design and the resulting performance achieved in terms of both hydraulic and purification aspects. The infiltration behaviour experienced during treatment of wastewater effluents in soil is extremely complex and even after decades of studies, it is still not fully understood. While it is clear that wastewater effluent composition and loading characteristic can impact infiltration rate during wastewater purification, the underlying phenomena have not been fully elucidated for different designs and environmental conditions (Siegrist and McCray, 2006). Performance data related to the extent of soil clogging in systems with gravel on the infiltrative surface (Aggregate-laden) led to infiltration system design that has an open surface (Aggregate-free), the most common of which is the chamber system (May, 1996). Gravel on an infiltrative surface can reduce infiltration zone permeability by becoming embedded in the soil matrix, yielding fines that are deposited in pore entries thereby blocking them and by attracting wastewater constituents to itself as a result of the reduced permeability due to the effects of the factors above (Jenssen and Siegrist, 1990).

Vinten *et al.* (1983) who worked on the effect of suspended solids in wastewater on soil hydraulic conductivity and vertical distribution of suspended solids discovered that clogging was influenced by the amount of suspended matter and pore size distribution. This resulted in decrease in hydraulic conductivity for finer textured porous media. Siegrist and McCray (2002) worked on principles and behaviour of infiltration process during onsite wastewater treatment in soil systems. They found that long-term decrease in infiltration rate is due to the deterioration of soil structure, partial sealing of profile, particle relocation, and air entrapment within the soil structure.

According to Siegrist et al (2000), an estimate of the time required for effluent to infiltrate and percolate to a given depth based on the daily flow, area of infiltrative surface, and an effective porosity for the soil (loamy sand soil) is based on the following relationship.

$$T_r = \frac{(A_{is})\ (D/N_g)}{Q} \qquad (1)$$

Where T_r = travel time required for effluent to reach the depth of interest (days)

D= depth of interest (m), A_{IS} = infiltrative surface area (m^2). Q = daily flow (m^3/day)

N_g= effective porosity (v/v)

This relationship assumes uniform application and infiltration into the absorption system. Unsaturated zone thickness beneath a soil infiltration system and the depth to ground water can affect hydraulic function and in turn purification by influencing the soil water content, aeration status, media surface area, and hydraulic retention time. Usually, the thickness of the unsaturated zone for the soil infiltration system ranges from 0.6 to 1.2m and for intermittent sand filters, from 0.6 to 0.9m (US EPA, 1980, Anderson *et al.*, 1985, Crites and Tchobanoglous, 1998). A high degree of treatment normally occurs in the infiltration zone as soil clogging develops. However, at high hydraulic loading rates and with non-uniform distribution methods, constituents of concern that would normally be treated can be transported through the vadose zone to groundwater.

The objective of this study was to determine the effect of two vadose zone depths on the purification quality of wastewater through an infiltration system using loamy sand soil as the filtration media.

Methodology

Study Area

The study was carried out in the Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria. Makurdi lies between latitudes $7^0\,45^1$ and $7^0\,52^1$N and longitude 8^035^1 and 8^04^1E. The physical characteristics of loamy sand soil sample used as the filtration media are water content

(18.8%), bulk density (2.51g/cm^2) and saturated hydraulic conductivity (0.051cm/s).

The Purification Chamber

A soil purification system made of fibre glass was designed and fabricated consisting of 10 compartments, each with 144 cm^2 surface area (figure 1). The filtration media was loamy sand and the chamber comprised of two vadose depths of 60 and 90cm of five compartments each. The choice of two depths was informed by the fact that the thickness of the unsaturated zone for the soil infiltration system for intermittent sand filters range from 0.6m – 0.9m. So the lower (0.6m) and higher (0.9m) limits were chosen. Washed gravel (2 to 4mm diameter) was used both as envelope material over a screen (1mm^2) at the bottom of all the compartments and as aggregates over the surface of the compartments.

Dosing

The study which was in three replications was run for 24 weeks. During the 24 weeks of continuous operation, each compartment of the system was dosed 4 times daily with wastewater from same source. Physical and biochemical analyses were carried out weekly on the potable water (control) and wastewater before dosing. Wastewater effluents were collected in one-litre cans and stored in a refrigerator until the analyses were completed. Filtrate was collected over a 24-hour period at the end of every seven days (and stored in a refrigerator) for laboratory analysis. The essence of this was to keep the filtrate in a stable state pending completion of the laboratory analyses.

Analysis

Soil and Water Quality laboratory of the Abubakar Tafawa Balewa University, Bauchi, Nigeria was used for water and wastewater analyses while Soil and Water Laboratory of the Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria was used for soil analysis. The GenStat 7.2 (2007) software package was used for the statistical analyses of the raw data generated. Percentage removal of the wastewater constituents was adopted as the measurement of the filtrate quality and the index of purification efficiency.

The percentage removal was computed by using the following equation:

$$\%\ removal_r = \frac{(Wr - Wf)}{Wr} \times 100 \qquad (2)$$

where w_r = Concentration of constituent in the raw wastewater before dosing

w_f = Concentration of constituent in the filtrate after dosing.

Results and Discussions

Physical Parameters

Removal of the key constituents from the wastewater is shown in Table 1. Summary of the treatment means, Coefficient of Variation (CV) and the Least Significant Difference (LSD 0.05) of the parameters are given in Table 2 while Table 3 shows the comparison of the values obtained from the existing standards. The CV being less than 10% indicates a good degree of precision in the study (Gomez and Gomez, 1984). At the end of the study (i.e. 24 weeks), the depths of 60cm (VD60) and 90cm (VD90), had mean percentage removal of total suspended solids (TSS) as 65.91% and 64.98% respectively (Table 1). This shows that 60cm depth (though shorter distance of travel) performed better in the filtration process throughout the 24 weeks with respect to TSS. The filtration medium might have introduced some solids in the 90cm vadose zone depth. Vadose depth of 60cm had a treatment mean of 65.34mg/1 while 90cm depth had 66.22mg/1 (Table 2). There was a significant effect of the depth on the filtrate quality. This meant that in this chamber the shorter the travel distance of the wastewater produced a more acceptable quality of the filtrate with respect to the TSS (though subject to verification with still shorter distances of travel). The TSS values exceeded the WHO Standard of 30mg/1 and FAO value of 18mg/1 for domestic uses, but are within the limits of 50-150mg/1 for reuse in irrigation as recommended by the Jordan Ministry of Water and Irrigation Standard, as well as Nigerian National Agency for Food and Drug Administration and Control (NAFDAC) acceptable concentration of 100mg/1 (Table 3). The variation trend of TSS for the period of study is shown in Figure 1.

Table 1: Means of the parameters monitored over a 24-week period of the study

Para-meter	Before Dosing		Filtrate Quality			
	PW* (mg/1)	WW** (mg/1)	Retained (mg/1)		% Removal	
			60cm Depth	90cm Depth	60cm Depth	90cm Depth
TSS	28.49	288.03	98.20	100.88	65.91	64.98
TDS	139.78	1130.91	734.49	380.00	35.13	66.44
BOD	8.07	79.33	21.15	18.69	73.32	76.42
COD	33.94	305.55	87.83	84.48	71.24	72.34
NO	4.06	27.08	15.68	8.61	41.91	68.10
PO	0.05	14.93	11.61	4.80	22.23	67.88
C	5.92	178.51	35.54	14.92	80.10	91.65
K	0.76	21.05	6.90	3.81	67.17	81.85
TBC	125	8627	1789	1413	79.25	83.6
EC	1.78	4.16	2.29	2.26	45.10	45.64

**PW=potable water (control); **WW=wastewater*

Table 2: Treatment Means of the Analysed parameters

Para-meter		TSS	TDS	BOD	COD	NO_3	PO_4	C	K	TBC
Treat-ment	60cm	65.34	560.3	69.86	71.28	14.36	8.48	83.07	66.27	78.70
Means	90cm	66.22	283.2	76.82	71.79	7.85	3.50	92.42	82.22	83.60
$LSD_{(0.05)}$		0.0997	1.140	0.725	0.1404	0.434	1.451	1.228	1.692	0.724
CV%		0.4	5.7	2.4	0.5	2.1	8.0	3.4	5.6	2.2

Table 3: Comparing Values of Monitored Parameters with Water Quality Standards

S/N	Parameter	60cm	90cm	W.H.O. Max. Acceptable Conc.[1]	NAFDAC Max. Acceptable Conc.[2]	FAO[3] reuse in	Allowable limit for irrigation[4]
1.	Colour	-	-	5TCU	-	-	-
2.	pH range (units)	7.6	7.6	7.0-8.5	6.5-8.5	6.5-8.4	6-9
3.	BOD (mg/1)	69.86	76.82	-	500	<100	30-300
4.	TSS (mg/1)	65.34	66.22	30	100	18	50-150
5.	TDS (mg/1)	560.3	283.2	1000	500	450-2000	1500
6.	Potassium (K) mg/1	1.82	0.98	1-2	10	12	-
7.	Nitrates (NO_3) mg/1	14.36	7.85	50	-	50	30-45
8.	COD (mg/1)	71.28	71.79	-	-	65	100-500
9.	TBC (MPN/ 100ml)	165	130	Must not be detectable in any 100ml per sample	1 (max)	1 (max)	100-100
10.	Phosphate (PO4) mg/1	8.48	3.50		10	-	30
11.	Carbon (C) mg/1	8.11	3.39	100	-	-	-
12.	EC (dS/m)	2.1	2.08	-	120	0.7-3	-
13.	Temp(^{0}C)	30	30	25	-	-	-

[1]WHO, 1988 Guidelines for drinking water

[2]NAFAC, 2004: Water quality standard for consumption

[3]FAO, 1985 Standard for irrigation

[4]Ministry of Water & Irrigation, Jordan, 2006

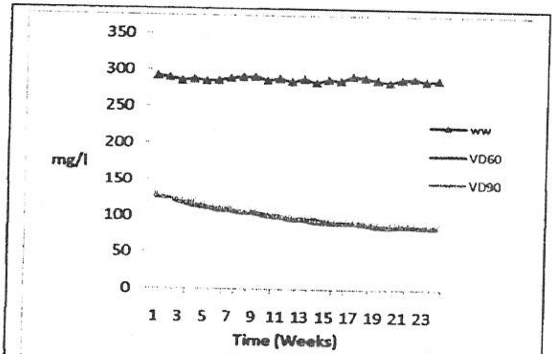

Fig 1: Trend of TSS

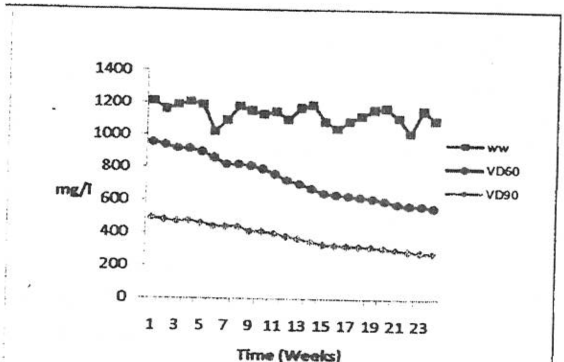

Fig 2: Trend of TDS

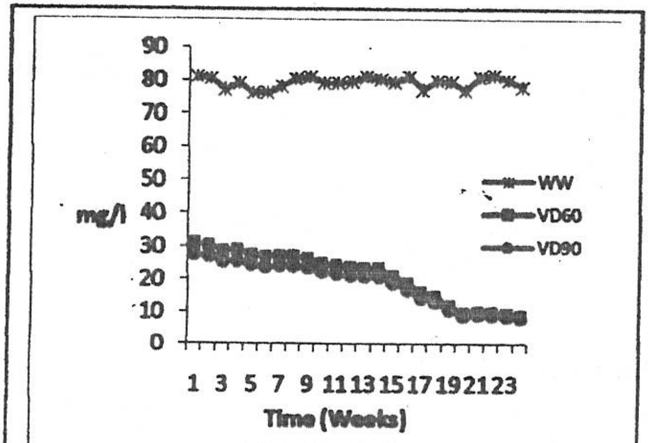

Fig 3: Trend of BOD

Based on the Total Suspended Solid (TSS) data and the guidelines, the effluent is suitable for irrigation and consumption under Jordan and Nigerian contexts (Table 3). The mean percentage removal of the Total Disolved Solid (TDS) in the 60cm vadose depth was 35.13% and in the 90cm vadose depth the mean percentage removal was 66.4% (Table 1). Figure 2 shows the variation for the 24 weeks of study. The TDS varied significantly with depths (Table 2). The value obtained from 90cm depth (283.2mg/1) is within WHO and FAO standards for domestic and irrigation purposes (Table 3). However, the value of 60cm depth (560.3mg/1) is above the 500mg/1 value of NAFDAC (Nigeria) for water consumption. TDS removal is achieved more when the wastewater travelled over a longer distance in the filtration chamber (contrary to that of TSS). The lower TDS value at 90cm indicates that the deeper the filtration chamber (vadose zone) the more time for the particles to attach to surfaces by electrostatic forces and chemical absorption and the better the filtrate quality.

The average temperature of the filtrate was 30°C. The temperature varied from 34-38°C in the wastewater and this could be as result of the biochemical reactions resulting from the high level of population. The temperature later decreased due to reduction of reaction within the water medium and also due o the effect of the environment. From the water quality standard used, temperature of treated effluent is suitable for both domestic and irrigation purposes.

NAFDAC water quality guidelines recommend that the target pH range is 6.5 – 8.5. The mean values of 7.6 in both depths falls within the recommended range for both domestic and irrigation purposes. If pH values are below 6.5 or over 8.4 (FAO, 1985), there can be damage to crop leaves, reduced production, unavailability of some nutrients and corrosion and encrustation to the irrigation equipments.

Chemical parameters

The mean percentage removal of Biochemical Oxygen Demand (BOD) constituent is 73.32% and 76.42% for 60cm and 90cm respectively (Table 1). There was a general gradual increase in purification from the onset of first week (Figure 3). It was observed that in both depths the values were tending towards constancy. There was significant difference in the depths (Table 2). The values of BOD_5 from both 60cm and 90cm vadose depths were 69.86mg/1 and 76.82mg/1 respectively. These are within the Nigerian NAFDAC value of 500mg/1, FAO value of (<100mg/1) and Jordan allowable limit for reuse in irrigation of (30-3000mg/1) as shown in Table 3. This shows that the filtrate from this filtration media can be used for domestic purposes and irrigation comfortably. The value of BOD_5 in the 90cm vadose depth was higher than that of 60cm showing that purification efficiency increased with vadose depth in the whole process.

Chemical Oxygen Demand (COD) test is said to be an alternative test to that of BOD_5. It is used to measure content of organic water of wastewater as well as natural waters. The measurement of COD level is used to determine the treatment efficiency and effluent quality. It also indicates the suitability of water for non-potable uses. The mean percentage removals of the COD were 71.24% and 72.34% respectively in the 60cm and 90cm depths. Figure 4 shows the variation trend. There was not much variation in the raw values with respect to vadose zone (depth of filtration) as in the case of BOD5. In the 60cm and 90cm depths, the mean values were 71.28mg/1 and 71.79mg/1, respectively (Table 2). The higher values of the COD compared to that of the BOD5 could be as a result of the oxidizing materials such as fats and lignins which are only slowly biodegradable in the waste water (Punmia *et al.*, 2005). Depth had a significant effect on the purification efficiency and a CV of 0.5% indicating a very good research result (Table 2). The COD filtrate quality of 71.28mg/1 (60cm) and 71.79mg/1) (90cm) falls above the FAO maximum limit of 65mg/1 and below Jordan Ministry of Water and Irrigation range of 100-500mg/1 allowable limit for range in irrigation (Table 3).

Nitrates (NO_3) indicate the presence of fully oxidized organic matter; they indicate the most stable form of nitrogenous matter contained in wastewater. The mean percentage removal of the constituents was 41.91% for 60cm and 68.10% for 90cm (Table 3) showing that the removal of fully oxidized organic matter was more

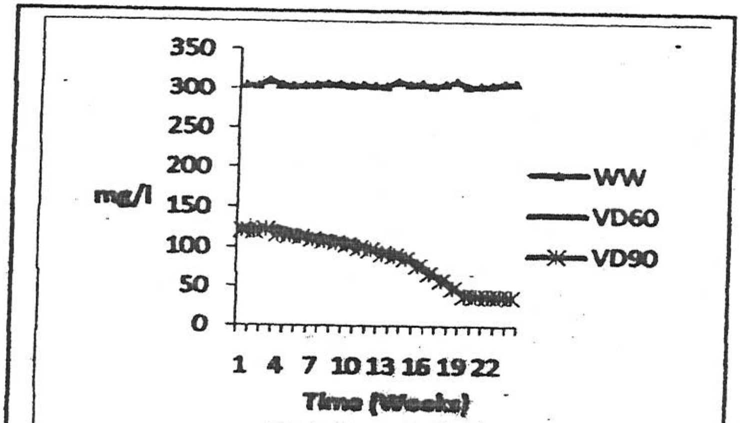

Fig 4: Trend of COD

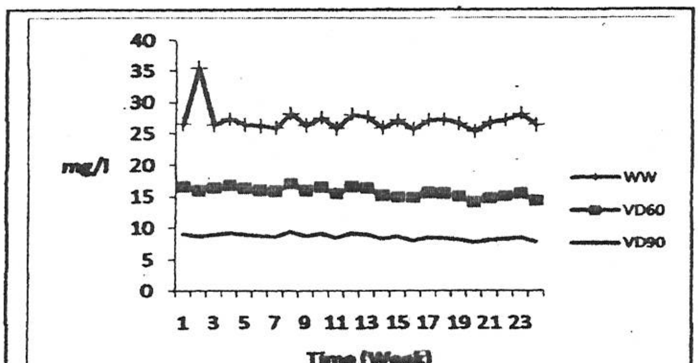

Fig 5: Trend of NO3

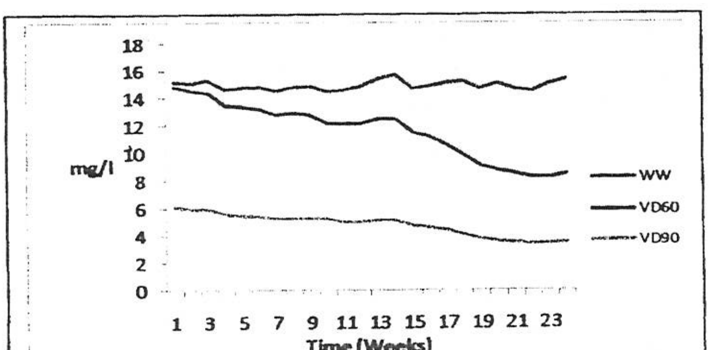

Fig 6: Trend of P04

in a longer travel distance. Significant variation exists due to the depth factor (Figure 5). Based on the WHO (1988) and FAO (2005) standards value of 50mg/1 and the Jordan (2006) allowable limit for irrigation of 30-45mg/1, the NO_3 value range of (14.36mg/1) for 60cm depth and (7.85 mg/1) for 90cm depth is suitable for both domestic and irrigation purposes (Table 3).

The 90cm vadose depth performed better than the 60cm depth in the removal of Phosphate (PO43) from the wastewater as presented in Table 1. The mean percentage removal of the constituent in the 90cm (67.88%) is higher than three times the value (22.23%) in the 60cm depth. This was also evident in the significant effect of depth on the quality of the filtrate (Table 2). The mean values of 8.48mg/1 and 3.50mg/1 for 60 and 90cm respectively fit in with Monwuba (2004). Agbejimi (2004), and Monwuba and Agbejimi (2004) NAFDAC value of 10mg/1 for water consumption and Jordan Ministry of Water and Irrigation (2006) value of 30mg/1 for allowable limit for reuse in irrigation (Table 3). The trend of variation is shown in Figure 6 to 8

Biological parameters

The Total Bacterial Count (TBC) is the most common bacterial indicator that is used to assess the microbial quality of irrigation water. Values of the parameter (Figure 9), with respect to the depth of infiltration showed significant difference as shown in table 2. The 60cm depth had a mean percentage removal of 79.25% and in the 90cm depth, the mean percentage removal was 83.6%. The values of TBC at the end of the period studied was 130 and 165 counts/100ml. The WHO, FAO and NAFDAC Standards recommended that there must not be any detectable trace (or at most 1 unit) in any 100ml per sample for drinking purposes while it should not exceed 1000 counts/ 100 ml for irrigation purposes (Jordan Ministry of Water and Irrigation). Although, the quality in terms of TBC is allowable for re-use in irrigation. It is definitely not suitable for domestic use. The concentrations of a number of parameters studied in the filtrate meet the standards for domestic purposes, the data for TBC, which is an overriding parameter for domestic purpose, rules out the possibility of ever using the filtrate for domestic purposes.

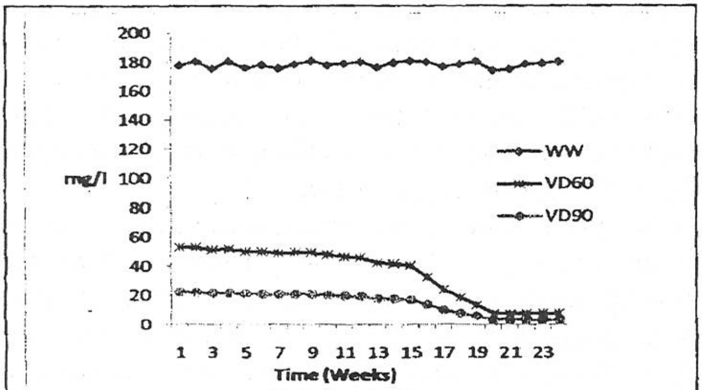

Fig 7: Trend of C

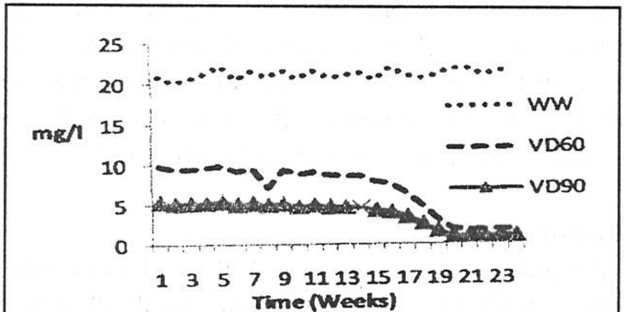

Fig 8:Trend of K

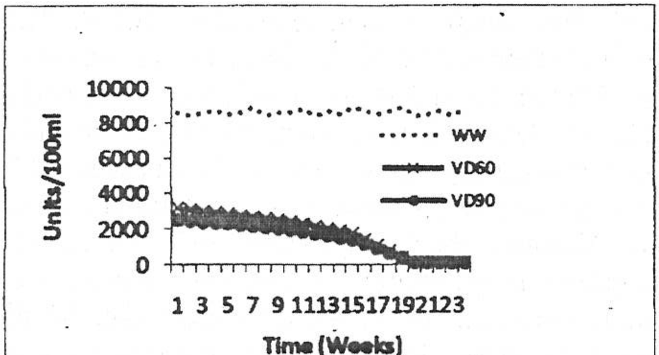

Fig 9: Trend of TBC

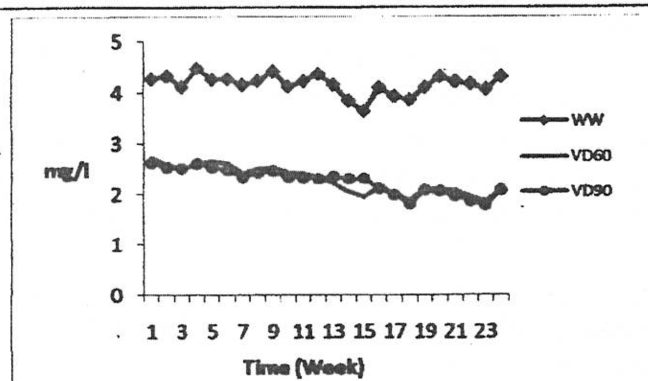

Fig 10: Trend of EC

Conclusion

This work has shown that:

(i) The 90cm (0.9m) vadose depth gave better wastewater purification quality than the 60cm (0.6m) depth.

(ii) The filtrate quality (purification quality) increased/improved with time.

(iii) Though the results of many of the parameters were within NAFDAC and WHO recommended guidelines, the results of TBC which are higher than both guidelines disqualifies the use of the filtrate for domestic purposes.

(iv) The filtrate however can be used for irrigation of crops that are not eaten raw.

(v) This simple infiltration system can be used to treat domestic wastewater and the filtrate can be used for irrigation or disposed into the environment more safely.

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