Soil Moisture Distribution Pattern and Yield of Jute Mallow *(corchorus olitorius)* under Three Different Soil Fertility Management

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Abstract

Field experiment was conducted to determine the soil moisture distribution pattern and yield of Jute mallow (*Corchorus olitorius)* in a sandy clay loam soil of the tropical rain forest of Akure, Nigeria, under three different soil fertility management. The treatments were: zero fertilizer application plus rain fed condition (control); 1.79 ton ha^{-1} of poultry manure plus rain fed condition; 0.54 ton ha^{-1} of urea fertilizer application plus rain fed condition. The three treatments were replicated three times in a completely randomized block design. During the period of the plant development, the moisture content of the soil increases with increase in the depth of the soil. The highest mean value for the depth of the water stored occurred in the plots under urea treatment with value 9.243 ± 2.96 cm. Measured plant parameters showed the best *Corchorus olitorius* yield components in plots under urea treatment. The mean plant height at 6 weeks after planting (WAP) was 106.13 ± 5.55 cm, mean number of leaves at 7WAP was 54.90 ± 6.71, while the mean leaf area and leaf area index at 6WAP were 572.26 ± 7.53 mm^2 and 0.16 ± 0.02, respectively. Biomass yield at 4 WAP was 1.99 ton ha^{-1} for plants in urea treated plots, 1.577 ton ha^{-1} under poultry manure and 1.445 ton ha^{-1} in the control experiment. There was no significant difference between the yields of the different treatment plots during the early stage of the plant development. The organic matter content was 2.1%, 2.15% and 2.25% in treatment plot under urea application, poultry manure and control experiment respectively. The nitrogen (N) content were 1.3%, 1.5% and 1.4% in treatment plots under urea, poultry manure plot and the control experiment respectively. Magnesium (Mg) content of treatment plots were 2.50 cmol kg^{-1}, 2.65 cmol kg^{-1} and 2.70 cmol kg^{-1} in plots under urea, poultry manure and the control experiment, respectively. At 7 WAP, the total biomass yields were 6.78 ton ha^{-1}, 5.58 ton ha^{-1} and 3.27 ton ha^{-1} for plants under urea and poultry manure application and control, respectively. The urea fertilizer and poultry manure applied, improved the chemical properties of the, soil which led to the significant increase in the biomass yield of the plant.

Keywords: *Corchorus olitorius,* soil moisture, soil fertility, urea fertilizer, biomass yield, poultry manure

Introduction

Jute Mallow (*Corchorus olitorius*) has been observed by scientists to be demulcent, emollient, diuretic, cleansing, and tonic in nature (Fasinmirin, 2009). It is a popular vegetable, grown in both dry and semi-arid regions and in the humid areas of Africa, because of its importance in giving the body good nutrients (Oladiran, 1986). *Corchorus olitorius* belongs to the Tiliaceae family and is an erect annual herb that varies from 60 cm to approximately 150 cm in height depending on the cultivar (Husselman and Sizane, 2006).

The most common of the Jute mallow family are *Corchorus capsularis* and *Corchorus olitorius* (Fasinmirin, 2001). *Corchorus olitorius* called "ayoyo" in Hausa and "ewedu" in Yoruba is a popular green vegetable plant (Musa et al, 2010). The vegetable is also known by several names in different countries, including Jews mallow or Jute mallow in English, Egyptian spinach, and bush okra in South Africa (Van Wyk and Gericke, 2000, Vorster et al, 2002). *Corchorus* seeds show a high degree of dormancy, which can be broken by means of hot water treatment (Schippers et al, 2002). The vegetable does well in acid, neutral and basic (alkaline) soils (Facciola, 1990). It tolerates soil pH of 4.5 to 8.0, but more extreme pH conditions will reduce the availability of iron in the soil and cause yellowing between leaf veins (Palada and Chang, 2003). *Corchorus* is mainly known for its fibre product, jute, and for its leafy vegetables (Schippers, 2000). The leaves are a rich source of iron, protein, calcium, thiamin, riboflavin, niacin, folate, and dietary fibre (Palada and Chang, 2003). Jute mallow responds well to added fertilizer, especially nitrogen.

A combination of both inorganic and organic fertilizers improves yield and maintains soil fertility. The rate of fertilizer application should be based on the initial soil fertility, soil type, fertilizer recovery rate, and soil organic matter (Palada and Chang, 2003). Nitrogen fertilizer application is effective in increasing the height of the plant and fibre length, thereby bringing about high fibre yield per acre (Fasinmirin, 2001).

Jute mallow is susceptible to moisture stress owing to its shallow rooting depth, which can be prevented by irrigation (Fasinmirin, 2009). Oguntunde (2004) showed that in the past, many land surface modelers do not consider the contribution of soil moisture portion of their models to be physically based but thought of the soil moisture as more of index used for evapo-transpiration and runoff calculations rather than representative of the actual mass of moisture in the soil. Sufficient knowledge of the distribution and linkage of soil moisture to evapo-transpiration is essential to predicting the land surface processes to weather and climate (Idso, 1982). Despite this importance, global measurement and analysis of soil moisture and temperature remains an outstanding scientific problem with far-reaching significance to agriculture (Wei, 1995). The objective of this paper therefore is to investigate the soil moisture distribution pattern, growth and yield in *C. olitorious* field under three different fertility treatments.

Study Area

The field experiment was carried out at the experimental farm of the Agricultural Engineering Department, Federal University of Technology, Akure (FUTA) between April and June 2011. The site is located on latitude $7^{0}16^{1}$ N and longitude $5^{0}13^{1}$ E. The soil on the site is sandy clay loam according to the United State Department of Agriculture (USDA) classification. Akure lies in the South western Tropical Rain forest zone of Nigeria and have a mean annual precipitation of 1300 to 1600 mm and with an average temperature of 27.5^{o}C (Fasinmirin, 2008).

Materials and Method

Field experiment was conducted between 6th April and 8th June, 2011. The field was divided into a block system. 3 blocks of system were used. A block was divided into three plots, which serves as replications for each treatment. Each block is of equal dimension of 10m x 1.4m. The land was tilled using the disc plough and further pulverized by using light implements like hoes, spade and cutlass to form seed beds. The plots were planted with Jute Mallow *(Corchorus olitorius)* with a spacing of 0.4 m inter row by 0.3 m intra row. The seed was soaked in ordinary water for three days to break its dormancy. Field plots were replicated thrice under different fertilizer application. Seeds were planted and thinning was first done two (2) weeks after planting. Fertilizer treatment was applied accordingly, after three weeks of planting. Manual weeding was carried out on weekly basis.

Irrigation was applied to compliment the rainfall during the early stage of the plant development. The water was delivered to the experimental field using hand watering can. The first treatment was application of irrigation water plus zero fertilizer (control), the second treatment was application of irrigation water plus poultry manure (1.79 ton ha^{-1}), the third treatment was application of irrigation water plus urea fertilizer (0.54 ton ha^{-1}). The three stages of the crop development which are; emergence, vegetative/flowering, and maturity were properly monitored.

Measurements of soil moisture distribution pattern and other growth parameters were carried out during the experimental period. Meteorological data such as solar radiation, Maximum and Minimum Air Temperature, Maximum and Minimum Relative Humidity, Rainfall, Wind Speed and Sunshine Hours during the growing season were obtained from a meteorology station located very close to the site of experiment. Rain gauges were installed within the experimental field to measure Precipitations during the experiment. Soil samples were collected from 0 – 15 cm depth from each of the experimental blocks to determine the soil physicochemical properties such as particle size distribution, organic matter, soil pH, bulk density, percentage composition of nitrogen, exchangeable phosphorus, extractable potassium, calcium and magnesium using standard procedures (Agyare, 2004). The Bouyoucos (1962) method was used to determine the particle size distribution on 2 – mm sieved air – dry soil. A method illustrated by Fasinmirin (2001) was used for the determination of organic carbon content. The organic carbon was oxidized by a known concentration of potassium dichromate (1.0 N or 0.166 M) solution added in excess. The percentage nitrogen content of the soil was determined using the digestion method described by Jackson (1962). Extractable potassium, calcium and magnesium were extracted using ammonium acetate as illustrated by Fasinmirin (2001) and the individual cations of Ca^{2+}, Mg^{2+}, K^{+} were measured by Atomic Absorption Spectrometer (AAS) and flame photometer. The soil pH was determined by suspending the soil in 0.01 M $CaCl_2$ solution a 1 - 2.5 soil to solution ratio. The suspension was stirred intermittently for 30 min. The pH was taken using a pH meter and a combined glass electrode (Thomas, 1996). Soil bulk density in gcm^{-3} was determined by the core method (Blake and Hartage, 1986) using a 9.0 cm long by 6.2 cm diameter cylindrical metal core. Samples were dried at 105^{o}C for 24 h in a forced air oven, while bulk density calculated as sample dry weight (g) divided by sample volume (cm^3). The soil moisture content at depths 5, 10, 15 and 20 cm from each plot was determined twice a week by using the soil moisture meter and the gravimetric method (Lascano, 2000) occasionally to serve as a regulator (control) for the soil moisture data. The collected samples were placed in different containers of known weight, with a lid on to prevent evaporation. The containers and soil are weighed and then placed in an oven at 105^{o}C, with the lid removed, until the sample dries. The containers, and dried soils were weighed again to estimate the loss in weight which is the weight of water in the original samples, and the weight of solids is final weight less the weight of the container. The formula below can be used to estimate the moisture content of the soil by using the gravimetric method:

$$\text{Soil Moisture content} = \frac{Weight\ of\ water}{Total\ weight\ of\ the\ sample} \quad \text{------} \quad 1$$

$$\text{Bulk density (BD)} = \frac{Mass\ of\ oven\ dried\ soil}{Volume\ of\ soil} \quad \text{------} \quad 2$$

Results and Discussion

Climatic Condition during Experiment

The mean solar radiation value was highest in May (270.17 W m^{-2}) comparatively with the months of April and June. The first modal rainfall of the study area (June – July) is usually preceded by increase in solar radiation and convectional movement of hot humid air. The highest rainfall (199.89 mm was observed in the month of June and the least (169.60 mm) occurred during the month of April. The rainfall recorded throughout the period of the plant development was enough for good seed germination and good stand establishment.

Soil Moisture Content

The soil moisture content in the various treatments from 0 – 56 DAP is presented in Figure 1, 2 and 3. The plants enjoyed good soil moisture during all the stages of its development, because the rain was abundant enough to keep the soil in a good condition. The highest mean value for the depth of the water stored occurred in the plots under urea treatment with value 9.243 ± 2.96 cm. This is in line with the Suggested Cultural Practices for Jute Mallow by Palada and Chang (2003). There was a sharp increase in volumetric soil moisture stored from 3.98 to 11.96 cm, 3.05 to 11.62 cm, and 3.44 to 13.38 cm under the control, poultry manure and urea treatments plots, respectively during crop development in May. This observation was preceded by heavy rainfall that accompanies the onset of raining season. Soil moisture content was highest in plots under urea fertilizer treatment, than in the other two treatments. This observation confirms the findings by previous researchers including Haynes and Swift (1990). The results from the Figures indicated that moisture content of the soil was highest at the 20 cm depth almost throughout the period of the plant development in all the three blocks.

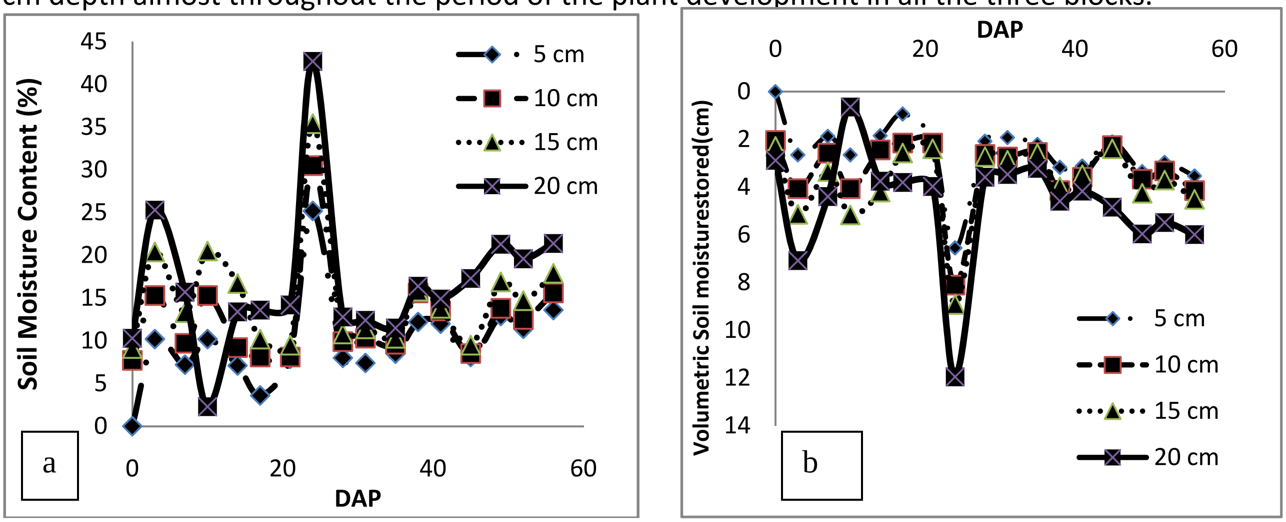

Figure 1: The moisture content and volumetric moisture stored in the soil at the control treatment (block one)

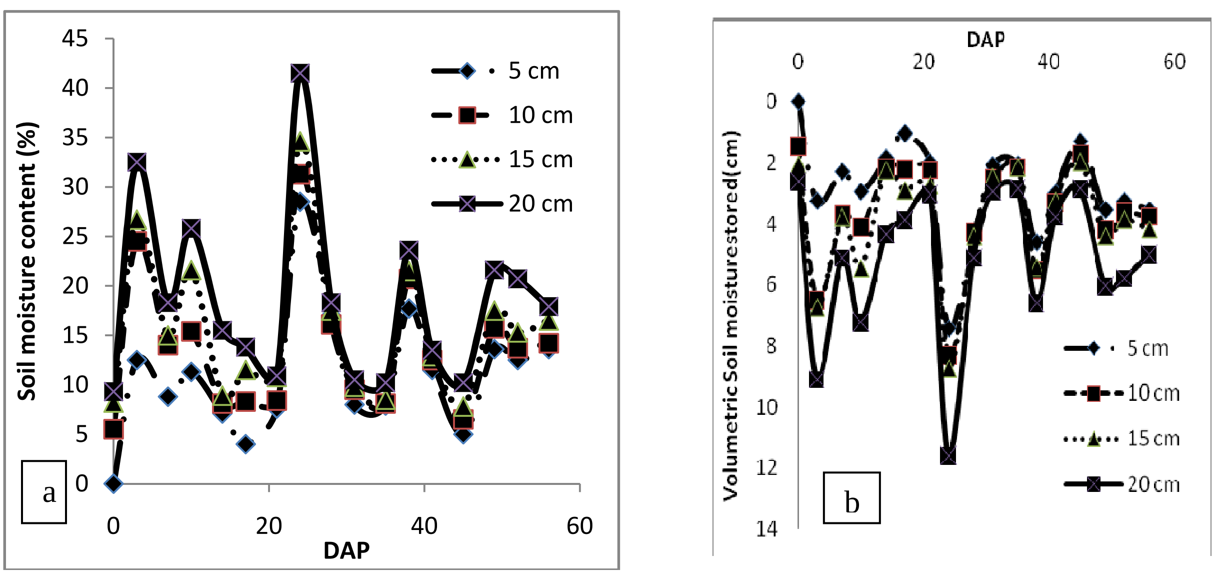

Figure 2: The moisture content and volumetric moisture stored in the soil at the poultry manure treatment (block two)

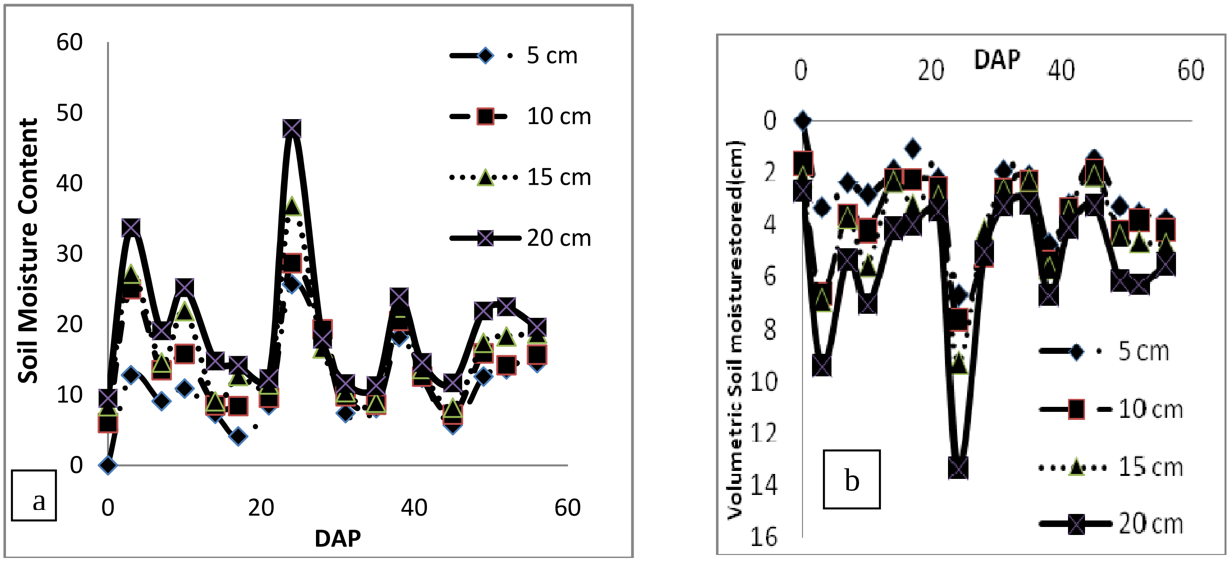

Figure 3: The moisture content and volumetric moisture stored in the soil at the urea fertilizer treatment (block three)

Plant Height

The plant height was not significantly higher in plots that received fertilizer treatments than under the control during the early stage of the plant development. The observed is because the properties of the soil were almost the same before the planting was done. Figure 3 showed the plant height at four weeks after plant (4WAP). The mean plant height under zero fertilizer (control), poultry manure and urea fertilizer treatments were 31.25 cm, 33.85 cm, and 35.68 cm at 4 WAP. Similarly, plant heights were 105.03 cm, 112.38 cm, and 113.67cm under control, poultry manure and urea fertilizer treatments respectively at the 7 WAP. There was no significant difference in the height of the crops during all the stages of its development, because, the soil fertility responsible for growth is available abundantly in the soil, and the availability of moisture in the soil is sufficient.

Number of Leaves

There are no significant differences in the number of leaves with respect to the fertilizer application as revealed in figure 4. Urea fertilizer treatment gave the highest leaf number from the 4^{th} to the 7^{th} WAP. The crop under this treatment benefited from increased soil moisture content. Plots under urea and poultry treatments produced more leaves and luxuriant growth when compared with the control treatment. The means of leaf number per sampled plot were 8.00, 8.48 and 9.15 at 4 WAP and 48.65, 50.21 and 54.90 at 7 WAP in control, poultry manure, and urea fertilizer treatments respectively. Sharma et al (1990) stated that crop growth and yield were improved when application of water can be controlled to what the plant actually need.

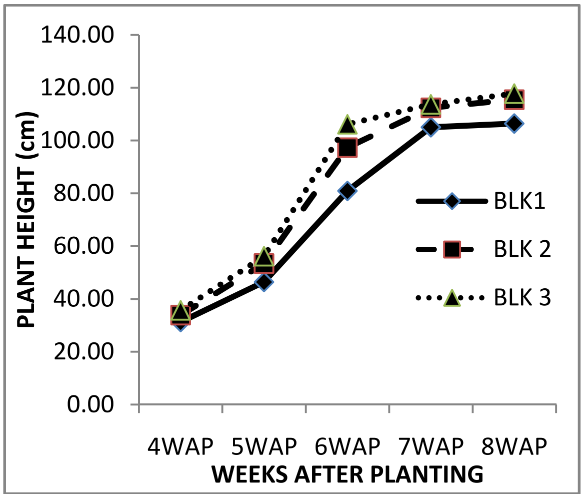

Figure 3: Mean plant height against WAP

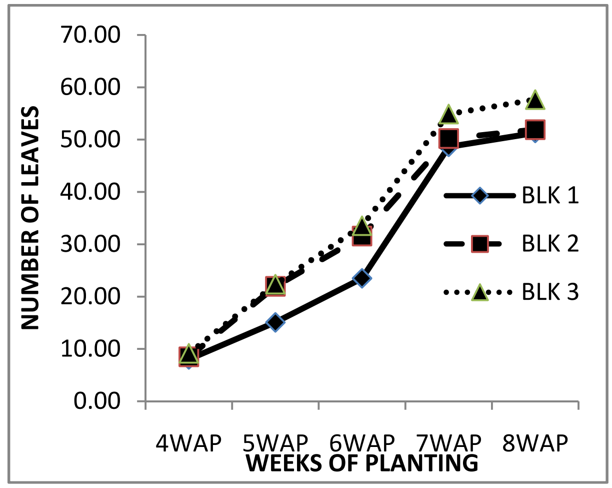

Figure 4: Mean number of leaves against WAP

Biomass Yield

The values of biomass yield in the various treatments are shown in Tables 1 and 2 for the 4th, 7th and 8th WAP. Biomass yield was increased as a result of the fertilizer applied. The total wet biomass yield for the treatments differed significantly at P = 0.05. However, no significant difference was observed between the yields of the different treatment plots during the early stage of the plant development. The total dry biomass yields at 4WAP are 0.72 ton ha^{-1} under the control treatment, 0.91 ton ha^{-1} under poultry manure treatment, and 1.05 ton ha^{-1} under urea fertilizer treatment. The total wet biomass yields at 7WAP are 5.96 ton ha^{-1}, 7.17 ton ha^{-1} and 7.98 ton ha^{-1} under the control, poultry manure and urea treatment plots respectively. At 8WAP, the total wet biomass yields are 8.04 ton ha^{-1} 10.68 ton ha^{-1} and 11.14 tonha^{-1} under the control, poultry manure, urea fertilizer treatment plots respectively. The result also revealed that the effect of the urea fertilizer and poultry dung manure was very significant to the soil fertility, despite the same application of water throughout the plant growth stages. The wet biomass yields for the 7th and 8th WAP were significantly higher under the urea and manure treated plots comparatively with the control treatment (Ansari and Ismail, 2008).

Table 1: Total biomass yield (wet) of *C. olitorius*

Treatments	Wet biomass yield in ton ha^{-1}		
	4WAP	7WAP	8WAP
Control	3.17	5.96	8.04
Poultry manure	3.73	7.17	10.68
Urea fertilizer	4.50	7.98	11.14

Table 2: Total biomass yield (dry) of *C. olitorius*

Treatments	Wet biomass yield in ton ha^{-1}		
	4WAP	7WAP	8WAP
Control	0.72	0.90	1.50
Poultry manure	0.91	1.19	1.83
Urea fertilizer	1.05	1.45	2.01

Conclusion

The performance of *C. olitorius* under three different fertility managements was evaluated. *Corchorus olitorius* was found to be very sensitive to good soil fertility condition. Total yield of *C. olitorius* (dry biomass) was highest in plots under urea treatment (2.01$tonha^{-1}$) at 8WAP. This was followed by the poultry treatment plots (1.83$tonha^{-1}$). The lowest value was recorded under the control treatment plots (1.50$tonha^{-1}$). *Corchorus olitorius* appear very sensitive to soil water and fertility treatment status because the higher the soil water content and good fertility management during the crop stages of development or growth, the greater the biomass yield observed. Excess of nitrate in the leaves of the plant can greatly affect the environment, and human health. Hence, further research is recommended to determine the influence of fertilizer quantity on nitrate accumulation in *C.olitorius*.

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Spatial Variation of Acid Rain and its Ecological Effect in Nigeria

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Abstract

The study is aimed at examining the spatial variation of acid rain and its ecological consequences in Nigeria. The study covers Nigeria. A total of two hundred and twenty eight rainwater samples were collected; an average of nineteen samples per month. The water samples were analysed in the laboratory and multiple regression analysis used to ascertain the level of variation and relationship with distance from the source of gas flare. Results of the Hydro chemical analysis revealed moderately low pH values of <4.99 for rainwater sources in Nigeria. The pH values however decrease from the north to the south. Also the pH value of rain water samples correlated significantly (r = 0.97) with latitudinal variation and is ascribed to the influence of gas flaring and other anthropogenic activities carried out in the Nigeria environment. There is the intrusion of acid rain into other sources of water, which led to mild acidity of these water sources in Nigeria. The need to extinguished gas flaring is recommended and Nigeria should embrace environmental laws and policies in order to adapt to the changing environment.

Keywords: Acid rain, gas flares, environment, degradation, Nigeria

Introduction

Human anthropogenic activities since 1800 have resulted in the emission of great volumes of gaseous materials into the atmosphere. Some of these gases - notably carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFC) nitrogen oxide – absorb earth's radiation. The radiation help to degrade the environment, leading potentially to warming of earth's surface and acid rain deposition, which in turn alter the world's climate (Intergovernmental Panel on Climate (IPCC), 2001 and 2007). At the molecular level, carbon dioxide has been emitted in greatest volume, largely from clearing forest, burning of coal, and oil and gas flaring. Carbon dioxide has the longest life span in the atmosphere, thus accumulating over time (Cooper, 2000). The accumulation has been observed in eastern United State of America (United States General Accounting Office (USGAO) 2000). For instance GAO (2000) opined that the combustion of coal and other fossil fuels produces, as by-products, a wide variety of chemicals, including gases like sulfur dioxide and nitrogen oxides. These gases, which are emitted into the atmosphere may be carried up to hundreds of miles by air currents, and are often transformed into acidic compounds, which are then returned to the earth. When the compounds are delivered by precipitation, such as rain and snow, the process is called wet deposition. When they are delivered as gases, aerosols, and particles, the process is called dry deposition. In addition, in high-elevation and coastal areas, they may be delivered through cloud or fog water, called cloud deposition.

However the concept of acid rain was first referred to by Robert Augus in 1872 during the industrial revolution to mean any acidic precipitation (such as rain and fog among others) or depositions that occur downwind of areas where major emission of SO_2, CO_2, and NO_x from human activities takes place (Oden, 1976; Botkin and Keller, 1998 and Efe, 2010b). Figure 1 shows the various atmospheric processes through which pollutants from gaseous emission react with water in the atmosphere to produce acid rain. It is evident that gaseous emissions of SO_2, CO_2, NO_x, and NH_3, from burning fossil fuels, and other anthropogenic activities form the major source of acid deposition in the region. Once airborne, these pollutants can travel for several thousand kilometres and this long atmospheric lifetime enables their oxidation into acidic species (Pickering and Owen, 1994 and Tripathy and Panda, 1999). Subsequent deposition of the acids onto land, leads to widespread soil and surface water acidification. Through infiltration processes, acid rain also leaches various heavy metals from the soil into subsurface water, which impacts aquatic life. Acid rain also affects the flora and fauna on land as well as causing damage to sculptures and buildings (Pickering and Owen, 1994 and Tripathy and Panda, 1999).

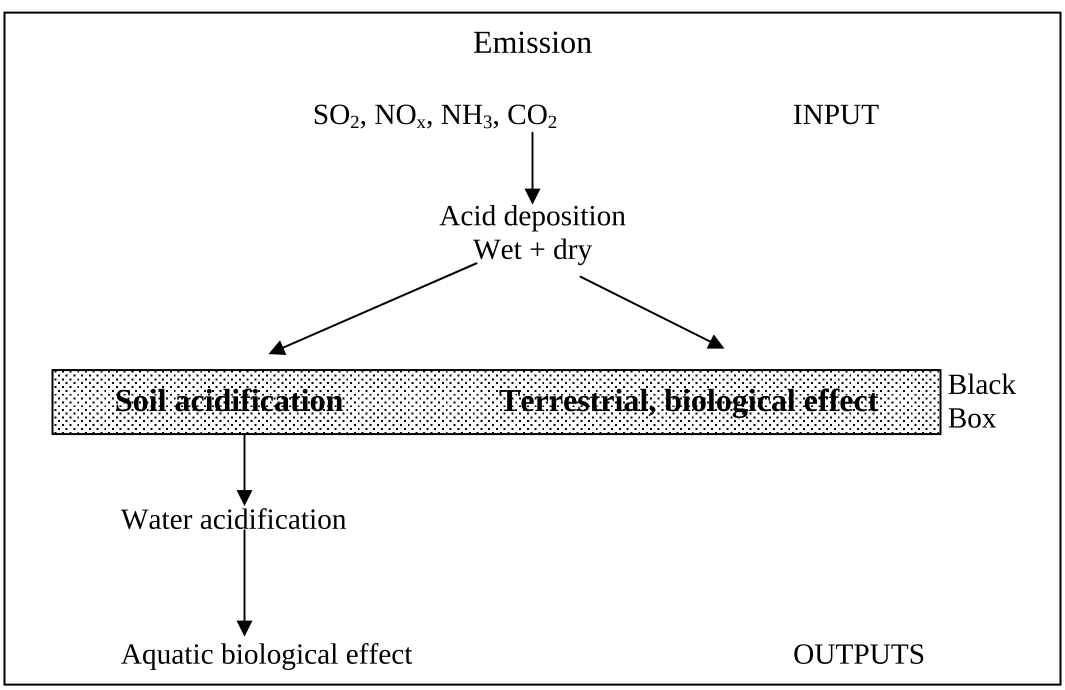

Figure 1: The chain linking some emitted gases (SO_2, NO_x and NH3) to soil and water acidification (modified after Last and Whathing, 1991; Efe, 2010b)

Similarly Likens, Bormann and Johnson (1972) give discussions of acid rain effects in North America, and Seip (2001) noted that around 1900 there were reports of fish deaths that could have been caused by poor water quality. In 1959 the Norwegian biologist Alf Dannevig suggested that long-range transported sulphur pollutants could cause acidification and kill fish in Norwegian bodies of water. Odén (1968, 1976) has earlier described the possible effects of acid deposition on soils and water in Norway, and opined that increasing number of lakes and streams in Norway were reported to be acidic in the 1960s, and there was concern about possible effects on forests. This resulted in a large interdisciplinary Norwegian research project, *Acid Deposition – Effects on Forest and Fish* (Sur nedbørs virkning på skog og fisk, SNSF) that lasted from 1972 to 1980. Originally the intention was to focus on effects on forests, but soon the interest in water acidification and the accompanying biological impacts was at least as great (Seip 2001). The occurrence of acid rain has also been reported in rains in Bangkok, Thailand (Somboon, 1997).

In Nigeria, acid rain has been observed in Warri, the rural areas of Delta State, Nigeria and the Niger Delta region of Nigeria (Efe, 2005, 2006, 2010b). There is however the need for the examination of its spread over the country. Efe (2006, 2010b) opined that gas flaring, waste incineration, bush burning, flumes from fairly used cars and other anthropogenic activities are the major causes of acid rain in Nigeria. Similarly the increased atmospheric concentration of carbon dioxide in recent years has also resulted in increased carbonic acid, which has been linked to the occurrence of acid rain in Nigeria (Efe, 2011).

However, studies on acid rain in Nigeria have been limited to the Niger Delta region of Nigeria, to the neglect of other part of Nigeria (Onianwa et al, 2002; Omoleomo et al; 2008 and Efe, 2010b). The reason for this perhaps, is that the Niger Delta area formed the foci of gas flares, and scholars felt that its ecological impact should be limited to the area (Efe, 2011). In recent times, the need for the extension of the investigation to the entire country is advocated. For instance Shell Petroleum Development Company SPDC (1995) argued that though there is the occurrence of acid rain in the Niger Delta region, acid rain is not restricted to the vicinity of the gas flares, but there is no evidence that gas flaring is the major factor. However Alakpodia (2000) asserted that gas flaring is the major cause of acid rain in the Niger Delta region of Nigeria and called for more studies to regularly assess the issue of acid rain and its causes not only in the region but over the Nigerian landscapes.

Leading credence to the above call, Efe (2006) further confirm the occurrence of acid rain in 18 rural coastal communities of Delta State. He observed a mean pH value of 6.4 in the open atmosphere, whereas lower pH values of 5.0 – 5.3 were seen in roof catchments of buildings in some coastal communities of Delta State, which he attributed to the proximity of the buildings to gas flare sites. Omoleomo et al (2008) also attributed the acidification of surface and ground water by acid rain in the Western Niger Delta to the flare rates, though he failed to correlate the gas flares with the pH values of the water sources. At the International Conference on Natural Resource, Security and Development in the Niger Delta held on March 8-11, 2010 at Niger Delta Wetlands Centre, Yenagoa, Bayelsa State, Nigeria, participants called for the examination of the spatial distribution of acid rain over Nigerian landscape as an impact of oil exploitation (Efe, 2010a). This study therefore addresses the identified gap by examining the spatial variation of acid rain and its ecological effects in Nigeria.

Methodology and Conceptual Issues

The data used for this study were collected through direct field survey that last from January to December for fourteen years (1997 – 2010). A total of 19 sterilized plastic rain gauges were randomly distributed on the basis of 19 rainwater samples a month, and the choice of these years is based on the time the researcher was able to secure the services of research assistants to undertake the collection of rainwater samples at the various sites. The spatial distribution of the 19 rainwater sample sites was determined with 2 by 2 latitudinal and longitudinal intersection (Figure 2). The rain gauges were positioned at the designated study sites at 1.5metres above the ground. To avoid dry precipitate on the gauges, they were removed immediately after the rain and returned to the sites when rain bearing cloud was observed. The rainwater samples were collected in line with Efe (2010b), where rainwater samples were collected from the first rain events for every month and for time lapse, experiment samples were taken at 5min, 10min, 15min and 20minutes from the start of the rain event with a final sample for any subsequent rain. All the rain events studied were collected as time lapse samples.

The volume of rain in each time interval was recorded and the samples were analysed for their physico-chemical parameters, the average values of the time lapse samples for each rain event were utilized for this study. This technique has been used by Somboon (1997) and Efe (2005, 2006, 2010b). A sub sample of the rain was used to measure pH and temperature immediately upon collection using a Teledo MC236 pH meter and digital mercury thermometer. The remaining rainwater collected was poured into sterilized plastic containers with and kept in a cooler containing ice to reduce the degradation of samples before analysis. Upon arrival at the laboratory, turbidity was estimated with a turbidity meter (APHA 214A). Nitrate-NO_3^- was determined by colorimetric spectro-photometry and SO_4^{2-} was determined with spectrometry via precipitation with $BaCl_2$. A digital MC 226 conductivity meter was used to determine the electrical conductivity and Total Dissolved Solid (TDS) of the water sample. Sodium ion (Na^+) and K^+ were determined with a flame Emission Analyser. Lead, cadmium, magnesium and iron were analyzed with an Atomic Absorption Spectrophotometer (AAS) 3200 Metler model. ANOVA and simple regression analysis were used to determine the latitudinal variation in pH and the effect of distance on acid rain intrusion on rainwater sample in Nigeria

The study adopts the concept of distance decay, which states that the quality and quantity of information decrease as distance increase from the source of information (Tobler 1970 and

Alber et al 1971). Distance decay is a geographical term, which describes the effect of distance on cultural or spatial interactions. The distance decay effect states that the interaction between two locales declines as the distance between them increases. Once the distance is outside of the two locales' activity space, their interactions begin to decrease. This model has been used extensively in human geography and ecology for several decades. For instance many ecological phenomena incorporate the pattern of decreasing community similarity with geographical distance (Nekola and White 1999). The above concept can be applied to this study because as distance increases from gas flares areas, the intensity of its influence decreases. That is, the intensity has inverse relationship with distance. In this study, the intensity of the occurrence of acid rain decreases as distance increases from gas flare areas, which could be ascribed to gas emission like ,So_2, and No_2 among others from the selected areas (Efe 2010b).

Results and Discussion

The spatial distributions of pH values of rainwater samples were generally lower than the WHO (2010) threshold of 6.5 for potable water. Apart from stations in the northern Nigeria (Potiskum, Maiduguri, Kano, Sokoto and others) that had higher pH values above 5.6 threshold of normal rainwater, the other rainwater samples collected from the coastal area (Port Harcourt, Warri, and Lagos among others) down to the middle belt area of Bida, Abuja, Lokoja, and Kaduna- Jos plateau areas had pH values that were generally lower than the 5.6 pH values for normal rainwater (Figure 2). During the period of investigation, Nigeria had 5.36 mean pH value, this however span 4.96 in the Niger Delta region to 5.69 in Sokoto - Nguru area (Figure 2 and Table 1). The result showed a reduction of 0.73 in acid rain from the coast to the northern extremities. Thus, indicating widespread acid rain over the entire country where rainwater samples were harvested for this study (Figure 2). The 5.69 mean pH recorded in northern Nigeria indicate that these area had pH that conform to 5.60 of a normal rainwater, but however did not conform to 6.5 pH threshold of World Health Organization (WHO 2010) for potable water. The result is corroborated by Somboon (1997), Onianwa (2002), Omoleomo *et al* (2008) and Efe (2010) who opined that the widespread acid rain experienced in Nigeria most especially in the Niger Delta region could be ascribed to the rate of gas flare in the coastal belt of Nigeria. Other factors are the increased anthropogenic activities, industrial and fumes from increased fairly used cars and motor cycles among others in Kano, Sokoto, Maiduguri, Abuja, Lokoja, Lagos, Warri, Benin city and Port Harcourt.

The distribution of pH in rainwater indicate 5.36 mean pH value, and an increase of 0.5 pH values from the coast to the northern extremities of Nigeria (Table 1). The observed indicates about 10% reduction in acid rain from latitude 4^0N to latitude 14^0N of the equator. The given result corroborated Somboon (1997) and Efe (2010b) who confirmed the spatial distribution pattern of acid rain in Bangkok and Nigeria respectively.

The spatial pH distribution in Nigeria also corroborated the concept of acid rain, which state that acid rain depositions occurs downwind of areas where major emission of SO_2, CO_2, and NO_x from human activities take place (Oden, 1976; Botkin and Keller, 1998 and Efe, 2010b). And the distance decay concept, which state that the spread of activities decreases with increasing distance from the centre of activities. Thus the level of rainwater acidity increases from northern extremities to the coastal belt of Nigeria (Figure 2).

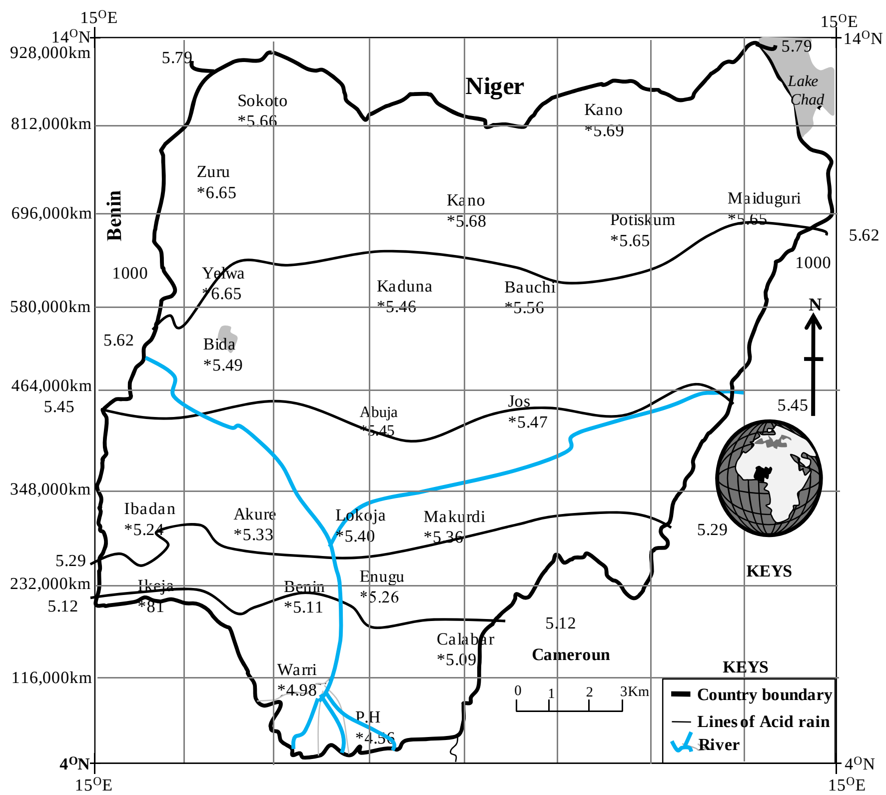

Figure 2: Map of Nigeria indicating rainwater collection points with corresponding recorded pH values

Table 1: Mean seasonal distribution of pH over latitudinal locations from flare sites

Months	**Lat 5.4**	**Lat 6.8**	**Lat 8.2**	**Lat 9.6**	**Lat 11**	**Lat 12.4**	**Lat 13.8**	**Mean**
January	4.95	4.97	5.23	5.45	5.49	5.65	5.46	5.31
February	5.01	5.09	5.56	5.46	5.49	5.65	5.54	5.4
March	4.98	5.06	5.33	5.4	5.56	5.65	5.34	5.33
April	4.98	5.09	5.36	5.36	5.53	5.68	5.5	5.36
May	5	5.11	5.47	5.46	5.47	5.47	5.67	5.38
June	5.08	5.14	5.5	5.51	5.5	5.6	5.6	5.42
July	5.12	5.19	5.22	5.23	5.22	5.22	5.62	5.26
August	5.06	5.16	5.32	5.35	5.36	5.36	5.56	5.31

September	5.33	5.39	5.4	5.4	5.42	5.46	5.69	5.44
October	5.25	5.33	5.35	5.4	5.41	5.35	5.64	5.39
November	4.99	5	5.08	5.35	5.55	5.65	5.6	5.32
December	4.9	4.91	5.02	5.31	5.52	5.67	5.46	5.26
Mean	5.05	5.12	5.32	5.39	5.46	5.53	5.55	5.35

Source: Fieldwork, 2011

The multiple regression analysis performed on latitudinal variation and pH level in rainwater samples revealed a standardized beta correlation (r) value of 0.97 (Table 2), indicating that latitudinal increase contributed 95% to the concentration of pH in rainwater. Such that as latitudes (distance) increases, pH concentration in rainwater increases, showing that acid rain decline with latitudinal increase in Nigeria, thus further confirming the concept of distance decay discussed earlier. The analysis of variance (F) value 914.975, which is greater than the critical F value 6.09 in Table 3, showed that acid concentration in rainwater resources from the coast to the north, varied significantly with latitudinal variation.

The seasonal variation of acid rain in Nigeria showed that the months of December had the lowest mean pH (5.29), while September had 5.44 pH values, indicating that rainwater in the months of December and September generally record the highest and lowest concentration of acid rain in Nigeria respectively (Table 1). The above corroborated (Efe 2006 and 2010) who observed higher pH values in rainwater samples collected during the wet months of September and July in the Niger Delta area of Nigeria.

Table 2: Regression Coefficients

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	4.757	0.066		72.415	0.000
	Lat	0.062	0.007	0.973	9.397	0.000

a, Dependent Variable: pH

Similarly, the acidic concentration in rainwater harvested also varied with the duration of rainfall. Higher acidic concentrations were generally recorded in the first 5 minutes of rainfall and lowest at the end of the rain (Table 4 and Figure 3). The observation showed a mean pH values of 5.13>5.24>5.33>5.42>5.46 for rainwater at 5minutes, 10 minutes, 15 minutes, 20 minutes and >20 minutes of rainfall (Table 4). The increase in rain pH throughout a rain event was reported previously in rains in Bangkok, Thailand and in Warri and rural areas of Delta State, Nigeria (Somboon, 1997; Efe, 2005, 2006, 2010b). Decrease in acidity is attributed to acidic species being washed out of the atmosphere during rain events (Efe 2010b).

Table 3: ANOVA explaining the Variation in acid rain over latitude

Model	Sum of Squares	Df	Mean Square	F	Critical F	Remark
Between	.032	7	.005	914.975	6.09	Significant variation exist
Within	.000	4	.000			
Total	.032	11				

a Predictors: (Constant), lat13.8, lat9.6, lat8.2, lat5.4, lat12.4, lat11, lat6.8; b Dependent Variable: Mean

Table 4: Temporal variation in mean acid rain and estimated gas flares rate (BCM)

Years	5mins	10mins	15mins	20mins	>20mins	Mean	*Gas Flare rates (BCM)
1997	4.99	5.01	5.25	5.39	5.48	5.224	29.41
1998	4.99	5.14	5.29	5.38	5.49	5.258	26.18
1999	5.01	5.15	5.29	5.38	5.43	5.252	24.61
2000	4.99	5.15	5.29	5.38	5.43	5.248	26.76
2001	5.03	5.18	5.31	5.37	5.45	5.268	27.01
2002	4.99	5.19	5.32	5.4	5.44	5.268	21.05
2003	5.12	5.19	5.35	5.4	5.45	5.302	24.26
2004	5.14	5.19	5.38	5.41	5.43	5.31	22.9
2005	5.16	5.22	5.38	5.42	5.43	5.322	21.56
2006	5.21	5.35	5.41	5.47	5.46	5.38	18.94
2007	5.21	5.36	5.41	5.43	5.46	5.374	18.6
2008	5.2	5.35	5.43	5.43	5.45	5.372	
2009	5.22	5.35	5.44	5.45	5.48	5.388	
2010	5.28	5.37	5.44	5.45	5.52	5.412	
2011	5.33	5.35	5.45	5.47	5.52	5.424	
Mean	**5.124667**	**5.236667**	**5.362667**	**5.415333**	**5.461333**	**5.320133**	

*The lower the pH value, the higher the acidity; Source: Authors' Fieldwork

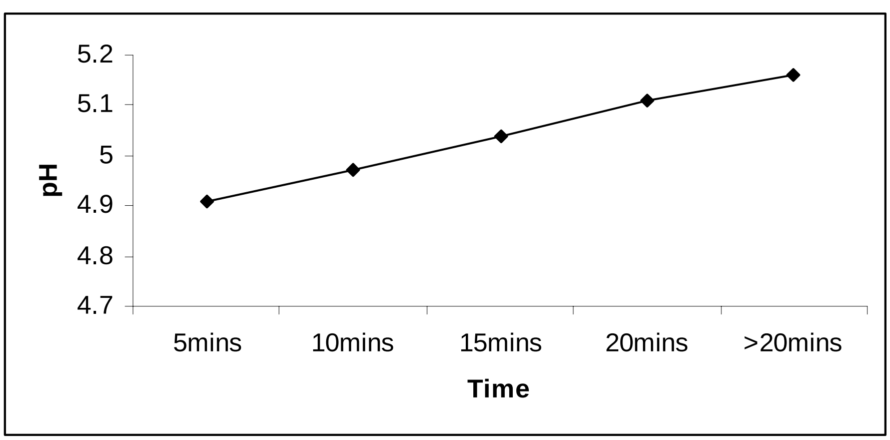

Figure 3: Temporal variation in acid rain, Nigeria

From Table 1 and Figure 4, the seasonal distribution of pH revealed a gradual decrease in acid rain from dry season to the peak of the wet season (September). This is evidence from mean pH values of 5.31 in January and 5.44 in September.

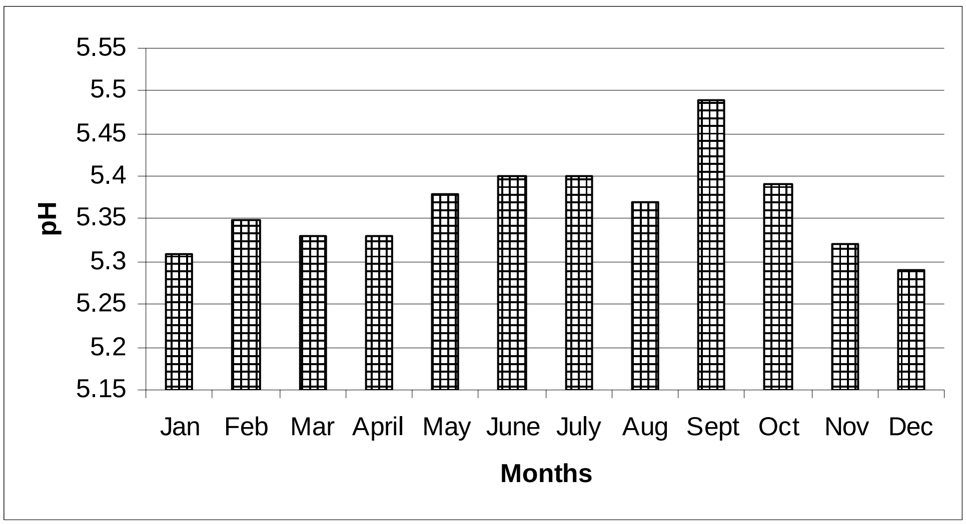

Figure 4: Seasonal variation in pH concentration in rainwater over Nigeria

The high level of acidity in rainwater could be ascribed to the influence of gas flares in Nigeria. This is because the years with high rate of flares had the lowest pH concentration in rainwater (Figure 5). For instance the highest gas flare (29.41BCM) was recorded in 1997, which also had the lowest pH 4.98 during the period of study. However with decline in flare rate over the years, there is a corresponding increase in pH over the country.

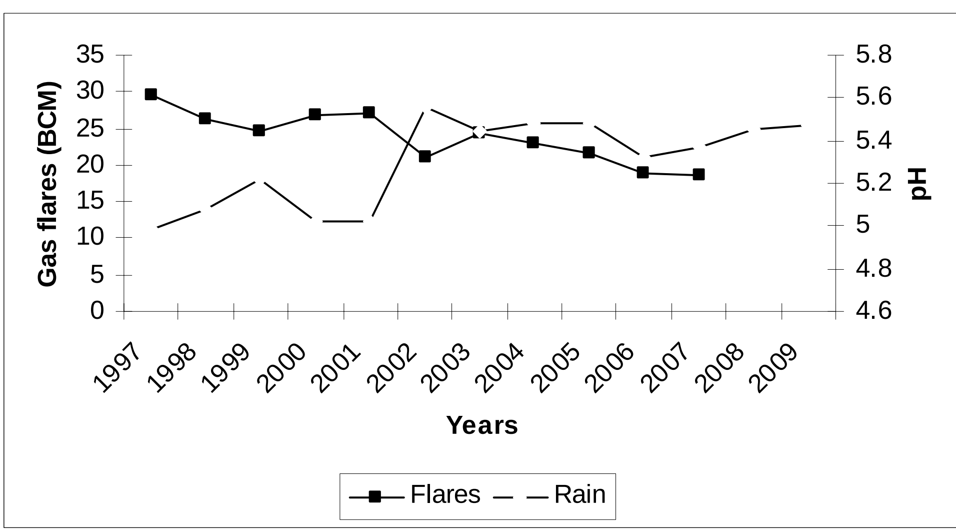

Figure 5: Mean distribution of gas flare and pH concentration in rainwater *BCM Billion cubic metres

Table 5 showed that acid rain has a strong inverse correlation with gas flaring (-0.80), indicating that as gas flaring increases, pH value decreases. And since lower pH indicate higher acid rain values, it showed that gas flaring is responsible for the occurrence of acid rain in Nigeria. Hence the higher the gas flare rate, the higher the occurrence of acid rain in Nigeria. This corroborated Somboon (1997) and Efe (2006, 2010b).

Table 5: Standardized Beta Coefficients (a) Explaining the relationship between acid rain and gas flares

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Correlations		
	B	Std. Error	Beta	Zero-order	Partial	Part	B	Std. Error
(Constant)	5.227	.044		117.674	.000			
Gas flares	-.007	.002	-.801	-4.007	.003	-.801	-.801	-.801

a Dependent Variable: pH

Ecological Implication of Acid Rain in Nigeria

The occurrence of acid rain in Nigeria has some implication on domestic water sources, vegetation and properties in Nigeria. The effects of acid rain on domestic water sources has been documented in Nigeria (Ogunkoya and Efi, 2003; Olobaniyi et al, 2007 and Efe and Mogborukor, 2008). For instance Efe and Mogborukor (2008) asserted that pH in rain, river, and open well water sources in Nigeria are generally low and there is low solute content in the region. Figure 6 showed the pH values in rain, river and open well water sources. The study revealed that pH values of rainwater, river water and open well water sources are 4.98 > 5.12 > 5.23, indicating mildly acidic rainwater, river water and open well water over Nigeria environment. And over 83% of 228 water samples for rain, well and river respectively had pH values below the lowest pH thresholds of 5.6 for rain water. It should be noted that The Target Water Quality Range (TWQR) for pH in water for domestic use is 6.5 (Efe and Mogborukor, 2008 and Efe, 2011). This made these water sources available to the residents of Niger Delta of Nigeria of low quality.

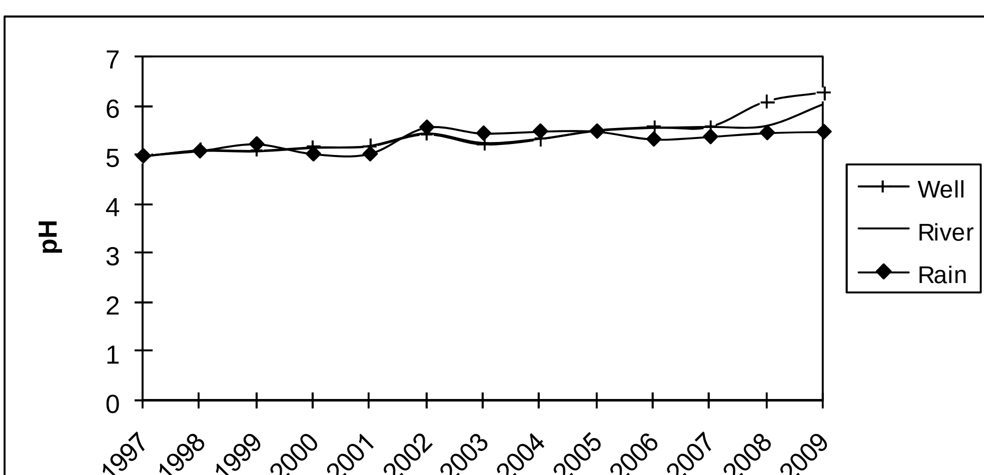

Figure 6: Mean distribution of pH in rain, hand dug wells and rivers in Nigeria

Similarly Ogunkoya and Efi (2003) and Olobaniyi et al (2007) opined that the acidic nature of rain, river and open well water sources in Nigeria causes corrosion of storage bowls, fetching bucket, tanks, borehole casing and plumbing fixtures in water distribution system. The acidic nature has also been associated with short life span of surface and submersible pumps used in the Niger Delta region. This corroborated the preliminary observation where over 75% of pumping equipment and hydro pneumatic tanks failed after 5 - 6 years of installation, thus reducing their useful age by 4 years (EPA, 2004), as well as failure of water distributing system i.e. pipes line, and hydro pneumatic tank valves. Also roofs are easily corroded, thereby impinging on the low quality of rainwater harvested in the region. As a result, demand for water is far greater than the supply. Similarly in spite of the alternative source of water supply via provision of boreholes made available by the oil companies in the oil rich Niger Delta, there is still acute shortage. The boreholes cannot go round the communities and apart, most of the boreholes and other water schemes are not functional and sustainable because of high level of acid, NO_4, Mg and Pb.

Similarly the acidification of the water sources led to productive failure in aquatic life. The eggs of fish species such as gold fish, salamonide, roach, and tilapia have reportedly been killed by high acidity. Amphibians that spawn in streams in the early wet season are unable to reproduce. Similarly, reduced Ca and increased Cd and Pb concentration in surface water as a result of acidification, result in deformed bone structures and poor growth in fish (Efe and Mogborukor, 2008 and Efe, 2010b). Consequently birds such as loons and osprey that predominate in the area and feed on fish are no longer found.

At the leaf surface, chlorosis and yellowing of leaves, wilting of the leaf tips, abscission of leaves and accelerated senescence was observed and, over the past thirteen years, more than 40% of tree and other plant species have been lost. The effects were most pronounced closest to the gas flaring sites where rain pH was lowest (pH 3.39) in most of the flare sites, Deleterious effects of acid rain on plants were reported previously (Jacobson, 1984, Neufeld et al 1985, Efe 2010b). Acid also damages roots and stems in addition to the leaves of plant. Such damage to plants is also an indirect threat to the microorganisms which decompose them, and subsequently the rest of the ecosystem. Jeffrey et al (1981) found application of simulated sulphuric acid to a number of crops resulted in decreased yield and growth and foliar injury. A decrease in the growth and yield of crops like cassava, sweet potatoes, maize, melon, plantain, rubber amongst others has also been reported in the area potentially due to effects from acid rain. The impact has invariably affected the socio economic life of the inhabitants of the oil producing communities in the agrarian communities (Jagtap, 2007). Acid rain has also affected soils by removal of essential nutrients leading to soil infertility in the region.

The cornea and mucous layer of the respiratory tracts are very sensitive to acid rain. Rates of acidosis, irritation of eye, conjunctivitis, bronchitis and prolonged coughing, and lung disease have been found around the gas flare sites, higher than in non oil producing regions of Nigeria (Asonye et al, 2004; Efe and Mogborokor, 2008). Health problems were previously linked to exposure to airborne acidity (Lippmannm 1985) and Keratoconjunctivitis was reported in a previous study among children in oil-producing industrial areas of Delta State, Nigeria where it was attributed to pollution in the area (Asonye et al., 2004). The high level of toxic heavy metals in fresh waters can also impact human health via consumption of birds and fish contaminated by exposure to the polluted waters.

According to Efe (2010b) the buildings and structures in Nigeria according to the residents have been decoloured and disfigured. Most landlords in the region asserted that they have to carry out routine repainting of their houses every two years because of decolouration by acid rain. Similarly, because of corrosion of the roofs most buildings in most of the area suffer leakages. Recent surveys found over 40% of houses in the region (especially those at the foci of the flare sites), leaking and roof repairs or replacement was carried out every three years (Alakpodia, 2000, and Efe, 2005). However, in the non oil producing region such repairs were required much less frequently. In addition most car owners in the region reported that their cars were regularly decoloured that they had to re-spray once every three to four years. The bottom plate and body of the car are usually affected by corrosion, leading to rust age, requiring annual body work on the car.

Based on the above environmental impacts of acid rain the study therefore recommends immediate enactment of legislation extinguishing gas flaring; alternatively it should be converted to industrial raw material for the production of domestic gases. There should be reduction of emission of acid gases. Acidified dug wells, rivers and other water bodies should be treated with lime to restore the pH to a level at which fish and other organism can survive. Rainwater harvested for domestic uses should be purified. All environmental laws for the protection of the environment should be implemented and periodic environmental impact assessment by both the oil company and the federal government of Nigeria should be carried out. The gas flaring operators should plough back part of their profits for the provision of social infrastructures in the region.

Conclusion

The study revealed a declining concentration in acid rain distribution from the coastal areas to northern Nigeria, with a mean pH of 5.36 in Nigeria. However 4.96 pH values were observed in the Niger Delta region where gases are being flared. Other southern states like Lagos, and

Akure among others had pH of 5.06 in rainwater and northern areas recorded pH of 5.56, which confirmed the presence of acid rain. The level of rainwater acidity increases from the northern extremities to the coastal belt of Nigeria. This has not only affected other water sources, but also impacted negatively on plant and animals, as well as buildings.

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