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Acid Rain in Niger Delta Region: Implication on Water Resources Quality and Crisis

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Abstract

This research focused on the effect of acid rain on the water quality of the Niger Delta region of Nigeria. Three hundred water samples were collected: 100 water samples from rain, 100 from open wells and 100 from rivers. The water samples were analysed using the paired t-test and multiple correlation analysis to ascertain their level of variation and relationship. Hydrochemical analysis revealed moderately low pH values of 4.98 > 5.12 >

5.23 for rain, river and well water resources in the Niger Delta region. The anions, cations and microbiological characteristics in river and well water sources before rain events were generally greater after down pours. This indicates that the pH values of rain water resources correlated significantly (r = 0.80) with gas flaring, an activity connected with petroleum exploration activities in the Niger Delta region. The acid content in the rainwater not only lowers the quality of rainwater sources for domestic use, but also the quality of well and river water sources in the region. This has led to acute drinking water shortages in the region and has exacerbated struggles for the few existing clean water sources. The cessation of gas flaring as well as the provision of adequate potable water supply to locals is highly recommended. Additionally liming of the water resources and other methods of cleansing acidic water may be employed in the interim.

Key Words: Acid rain, well, river and water crisis

Introduction

Acid precipitation, which is the deposition of wet acid solution or dry acidic particles from the atmosphere, is one of the major environmental hazards currently ravaging the Niger Delta landscapes (Okecha, 2000; Alakpodia, 2000 and Efe, 2006). But the concept of acid rain has been recognised since 1850 and it is described in terms of 5.6 pH, below pH 7. Normal unpolluted rainwater generally has a pH of about 5.6 due to carbonic acid created when rainwater reacts with CO_2 in the air. Downwind of industrial areas, rainfall acidity can reach levels below pH 4.3, more than ten times the acidity of normal rain (Cunningham and Cunningham, 2003).

The occurrence and consequences of acid rain on the environment have been widely documented but are limited to research carried out in developed countries (Oden, 1976, Miller, 1994; Pickering and Owen, 1994; Botkin and Keller, 1998; United States Global Change Research Programme, 2002 and Cunningham and Cunningham, 2003). Other studies such as Oguejiefor (1998), Okecha, (2000), Alakpodia (2000) and Efe (2006) confirmed the occurrence of acid rain and its environmental effects in the Niger Delta region. While these studies did not address the effect of acid rain on the region's water quality they all attributed the occurrence of acid rain in this region to gas flaring. For instance Alakpodia (2000) and Efe (2006) opined that gas flaring is the major factor that precipitates acid rain in the region, and the Alakpodia (2000) and Efe (2006) studies revealed pH values of 4.9 – 5.3

up to 500meters away from flare sites. However, the effects of flaring on water quality were not empirically validated.

Be that as it may, there have been some politics over the cessation of gas flaring in the region.The politics of gas flaring are behind the Nigeria National Petroleum Corporation and the Federal Government of Nigeria's ever changing deadlines for the cessation of this harmful practice. As the players and umpires, these government entities, can freely shift the goalposts as they please (Bassey, 2008). According to Bassey (2008, p5), the government's staggering of the gas flaring issue commenced in 1969. That was when the first major move was made by the Nigerian state to halt gas flaring in the country. At that time the General Yakubu Gowon oil ordered that corporations should set up infrastructure to utilize associated gas within five years of their commencement of operations. When the oil companies paid scant attention to this order the government then moved the goal post to 1979 but could not enforce this new deadline before it was overthrown in 1975. The Associated Gas Re-Injection Act Number 99 of 1979 required that oil corporations operating in Nigeria produce detailed plans for gas utilization as well as guarantee zero flares by January 1, 1984. The only way by which they could continue flaring after that date would be by the express permission of the responsible Minister on a case-by-case basis. Since these deadlines are never honored, government has resorted to shifting them according to the pleasure of the corporations through executive orders embedded in speeches/remarks and without any backing by law. It was in response to local and international pressure that the Federal Government of Nigeria through President Umaru Yar'Adua's speech at an International Gas Stakeholders Forum held in Abuja in November 2007, about a month to the end of a subsisting deadline, simply moved the deadline for gas flaring from January 2008 to December 2008 (The Guardian, 2008), despite the clamour of Nigerians and citizens of the world that gas flaring should be stopped at the close of 2007, because of its environmental consequences. After that announcement there has been a lot of muddling that renders it virtually impossible to know what target date the government is pursuing. This is why Nigerians believe that the Senate is on the right track when they embarked on the drafting of a Bill to end illegal gas flaring by December 31, 2008. An enactment of such a law was the only measure by which Nigerians could say there is a modicum of the rule of law with regard to gas flaring in Nigeria. Otherwise, it is clear that the acclaimed rule of law claims of the government may well be nothing beyond political posturing (Bassey, 2008).

Efforts have been made in the past to penalize oil corporations for flaring gas beyond set deadlines. These fines however, have been so paltry that it is still cheaper for the corporations to *pay* the fines than to act to halt the obnoxious act. By the Associated Gas Re-injection Act 1979, the fee charged for flaring was first fixed at 0.50 Naira per million cubic feet (mcf) but was from January 1998 increased to 10 Naira per mcf (World Bank, 2004). In fact, those involved in the gas flaring (oil industries and the Nigeria government) argue that it is cheaper to flare gas than to channel it to useful ventures. So, the flaring of gas continued unabated in the oil rich Niger Delta region despite its environmental consequences.

Similarly the residents of the Niger Delta region are faced with an acute problem of drinking water shortage that forces them to get their domestic water supply from rivers, hand dug wells, and rainwater harvesting. However, the quality of these water sources according to the residents is unreliable. There have been complaints of high amounts of particulate matter in their sources of water soon after every down-pour even as claims have been made that the high acidity of the region's rain water is negatively impacting its river and well water sources (Efe, 2010). This according to Efe (2010) is linked to the intrusion of acid rain which is precipitated by the influence of the unabated gas flares in the region over the years. This has earlier be reported (see Smith, 1872, Somboon 1997, Olobaniyi and Efe 2007, and Munton 2007), who opined that the emission of SO_2, NO_4, NH_3, CO_2 into the atmosphere produces acid deposition. The longer these deposits stay in the atmosphere, the more likely they are oxidised into acid. These are then washed down through rainfall. Some of the acid rainwater are deposited directly on surface water (river) and open wells. Despite these consequences, the problem of acid rain in the Niger Delta region has been neglected. Therefore, this study is aimed at investigating the occurrence of acid in rainwater harvesting, with a focus on the relationship between acid rain and water quality in the region.

Study area

The Niger Delta region is located between latitudes $5^0$31N and $5^0$33N and longitudes $5^0$30E and $5^0$32E. One third of the region is made of wetlands and houses the third largest wetland forest in the world (Efe, 2002, 2010). The area is being endangered by gas faring and oil pollution (Alakpodia, 2000). As such, most of the plant and animal species have gone into extinction.

The region experiences subequatorial climate that is now influenced by gas flaring. For instance, mean temperature generally ranges between 35^0C and 37^0C. Rainfall amount is over 300cm without a distinctive dry season, with monthly rainfall (January – December) averaging 2.5cm. The rainwater according to Alakpodia (2000) is acidic in nature and the quality is being threatened because of high level of impurities (Efe, 2006). This has resulted in struggles, quarrelling/fighting amongst children and women at few existing bore holes and water dispensing spots as well as trekking far distances to the river to get water for domestic use in Delta, Bayelsa and River States. Pressure has been mounting on the various local government councils and traditional rulers in the region over the need for the government and all the stakeholders in the oil industry to provide potable water to the inhabitants of the affected areas.

The region has been described as a gas province that had over 75% of the gas flared. The routine gas flaring over the years has led to: thermal pollution, climatic anomalies, extinction of vegetation and animal species in the region (Ndukwe, 1998; Oguejiofor, 1998 and Alakpodia, 2000).

Methodology and conceptual issues

The study adopted a field survey of the Niger Delta region that lasted from January to December for eleven years (1997 – 2007). The base map of the region where the oil fields and gas flare sites are located were obtained and used as a basis for the choice of the gauge stations, well and river water samples obtained (fig. 3). A total of 300 water samples were collected on the basis of 100 each for rain, well and river water resources. One hundred (100) sterilized rain gauges were distributed on the basis of 50 gauges in the western division and 50 in the eastern division of the SPDC areas of operation. Another 200 samples of well and river water each were collected from the neighbouring communities where the rainwater were collected making a total of 300 water samples collected. In order to control for nitrate and sulphate, other industrial and agricultural areas (where fertilizer application are practised) were avoided for rain, well and river water samples collection. These water samples were collected into sterilized cans, put into a cooler and taken to the laboratory for analysis. The river and well water samples were collected soon after every down pour, while rain water samples were collected at 500m, 4km, 8km and 12km from gas flare sites at 1.5metres above the ground to ascertain the influence of gas flares on the pH of rainwater in the region. To avoid deposition of dry precipitation 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 at these intervals in order to ascertain the influence of the gas flares on the rainwater quality. The rainwater samples were collected from the first rain events for every month and for time lapse, experimental 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 distance and time lapse samples for each rain event were utilized for this study. This technique has been used by Somboon (1997) and Efe (2005, 2006, and 2010) who asserted that time lapse samples are used to determine the variation in pH of rainwater over time of rain event. And Efe (2006) opined that the effect of gas flare on acid rain may vary with distance from the flares, which Efe (2010) later confirmed. 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 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). NO_3^- was determined by colorimetric spectrophotometry and SO_4^{2-} was determined with spectrometry via precipitation with $BalCl_2$. A digital MC 226 conductivity meter was used to determine the electrical conductivity and Total Dissolved Solid (TDS) of the water sample. 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. The details of the analytical methods are listed in table 1.

Table 1: Standards and methods of analysis

Test Parameter	Units	Standard test method	Description of methods
pH	pH	ASTM D1293B	pH meter
Temperature	^oC		Thermometer
Turbidity	NTU	APHA 214A	Turbidity meter
TSS	mg/l	Gravimetric	Gravimetric
TDS	mg/l	APHA 2080	TDS meter
Conductivity	$\mu s/cm^{-1}$	APHA 145	Conductivity meter
DO	mg/l	APHA4500C	Iodometric
Cl_2	mg/l	Titration	Titration
Nitrate (NO_3^-)	mg/l	APHA 419C	Diazotization
Sulphate (SO_4^{2-}	mg/l	APHA 427C	Colorimetric
Ca^{2+}	mg/l	ASTM93-77	AAS
K^+	mg/l	ASTM D93-77	AAS
Na^+	mg/l	ASTM D93-77	AAS
Pb^{2+}	mg/l	ASTM D3559	FAAS
Cd^{2+}	mg/l	ASTM D511	AAS
Fe^{2+}	mg/l	ASTM D106C	FAAS
Mg^{2+}	mg/l	ASTM D 511	AAS

The pH and temperature of the water samples were taken immediately with pH meter (Toledo, MC236) and mercury thermometer in the field before taking them to the laboratory. The heavy metals were analysed with Atomic Absorption Spectrophotometer [ASS) 3200 Metter model] and their result were read from the screen (see table 1 for detail methods of analysis).

To determine the priority needs of the residents, 500 questionnaires were administered in each community. The communities were stratified based on existing quarters, thereafter questionnaires were administered through systematic sampling technique of interviewing the head of every 5^{th} household in each street. Respondents were asked to rank their needs in order of priority. The questionnaires returned by respondents were used for the study. This became imperative because Okafor (1985) opined that the views of the residents of an area should be sought for their priority needs in order for government/company not to be investing on developmental projects that least meet the needs of the inhabitants of such region or area.

The paired t test statistical technique was used to test the level of the difference with distance. Multiple correlations were used to ascertain the relationship between the acid in rain water and those of river and well water samples.

The major focus of this study is acid rain and environmental interaction, and it was first used by Smith Robert Augus in 1872, where he referred to acid rain as any acidic precipitation (dry and wet such as rain, fog and dust particulate) or deposition near the downwind of areas where major emission of SO_2, NO_4 activities take place; when it occurs the pH is lower than those of normal rainwater (5.6 pH) (See fig 1).

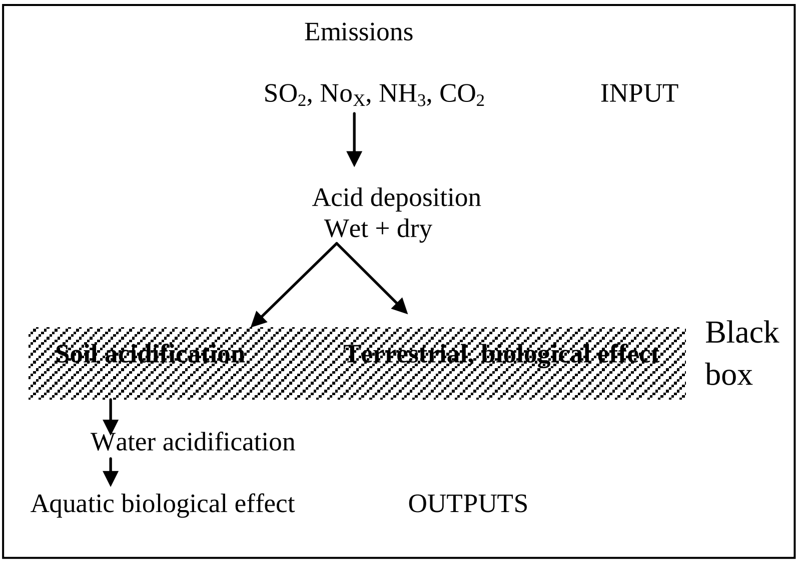


Fig 1: Linking emissions of SO_2, No_X etc to soil and water acidification modified

Source: Adapted from Last and Whathing (1991)

Figure 1 shows that the emission of SO_2, NO_4, NH_3, CO_2 into the atmosphere which produce acid deposition. These pollutants once air borne, can stay and travel for several thousand kilometres. The longer they stay in the atmosphere, the more likely they are oxidised into acid. These are then washed down through rainfall. Some of the acid rainwater are deposited directly on surface water (river) and open wells. Through infiltration processes, the acid rain leaches various heavy metals from the soil into the subsurface water bodies to produce infiltration effect on biological lives (See Fig 1).

Results and discussion

The data collected are presented in tables 2 and 3, figure redundant sentence as the title says the same thing.

The result of the preliminary investigation indicates that before the advent of oil exploration and exploitation, the three dominant sources of water supply were; rain, river and open wells. According to the residents, over 30% and 15% of the water supplies before now were gotten from rain and river water respectively. But this has been reduced to 20% and 10% for rain and river water supply respectively and 40% for hand dug wells. But with the advent of oil exploration and extraction this harvesting of water from both sources of water has gradually given way to boreholes and well water supply at 40% and 30% for well and bores water resources respectively (See Table 2).

Currently rainwater is used for washing toilets. River water is used for bathing and washing clothes, etc. This has placed greater demand on boreholes and well water for drinking. But the supply from existing boreholes is limited and sometime dispenses only water twice a week, except where there is electricity, it runs throughout the week. As a result, women and school children usually huddle around the few existing bores holes waiting for 2 – 4 hours to fetch water. Occasionally, fighting breaks out especially at boreholes that dispense water free of charge.

Those who cannot wait opt for well water and rain water. According to the residents in the oil producing region, none of the water collected from these sources are treated before consumption. Distributing systems are frequently corroded because of acid deposition thus reducing the life span of the distributing system, and bowls (containers) where the water is stored.

Table 2: Preliminary field surveys' report 1997

Predominant source of water	Uses	Age of water project	State of distributing system	State of water in the area	Perceived effects	Causes of water problem	Treatment	Regular of crisis
Rainwater 20%	Drinking, washing bathing, Toilet		Corrosion of roofs, gutters	Not treated occasional ash in colour	Mildly acidic and water borne diseases	Gas flaring and burning of industrial waste	Nil	Regular and acute
Well 40%	Same as above	10% below 10years; 25% is 10years. 15% is 15years and 50% Is above 25years	Collected plastic cans iron bucket and stored in basins	Not treated and inadequate with sediment whitish in colour, individually managed	Parent material/rain deposition	Rainfall, erosion action wash water into 10% of the wells	Nil but occasional introduction of alum	Regular and acute
Boreholes 30%	Drinking	+15years and +25years 35%	Pipes line are faulty with occasional leakages	Few boreholes not treated and in equate supply	Lack of fund and pollution by oil spillage	Acid infiltration and corrosion of the distributing system	Not treated	Regular
River 10%	Bathing, washing of clothes	The river was since the first settler		Not treat, use reduced	Oil spillage and acid deposition	Acid deposition oil spillage discharges of waste	Nil	Regular and acute

Source: Authors' field Report, 1997

Physical characteristics of water resources

The results of the rain, river, and open well water sources in the areas indicated a generally low pH and low solute content in the region. The mean pH values of rainwater, river water and open well water sources are 4.98, 5.12 and 5.23. This showed mildly acidic rainwater, river water and open well water in the Niger Delta region. In fact, of the total 300 samples measured, 85% had values (See Table 3 and Fig. 2) below the lowest pH limit of 5.6 for rain water. The Target Water Quality Range (TWQR) for pH in water for domestic use is 6.5. This made the water sources available to the residents of this region of low quality. This acidic nature of rainwater, river and open well water sources may cause corrosion of storage bowls, fetching bucket, tanks, boreholes casing and plumbing fixtures in water distribution system. This acidic nature has also been associated with short life span of surface and submersible pumps used in this region (Ogunkoya and Efi, 2003 and Olobaniyi et al, 2007). This confirmed 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, that is pipelines, hydro pneumatic tank valves etc. Similarly, roofs are easily corroded, thereby impinging on the low quality of rainwater harvested in the region.

Comparing these sources of water available to the residents of the region, significant difference in pH exists amongst them in this order $4.98 \leq 5.12 \leq 5.23$ for rainwater, river and open-well water resources ($p \leq 0.05$) (see fig. 2). Similarly, the pH of intermittent rainwater, well and river water of the drier months of November to February is significantly lower than those at the peak of rainy events (see fig 2). For instance, pH values ranged from 4.80 in December to 4.94 in February, while the rainy months had 5.00 to 5.47 in March to September (see fig 2). This corroborated the earlier view of Efe et al (2005) and Efe (2006) that rainwater quality appreciates as rain fall gets to its peak. Similarly, the acid concentration in rainewater reduces with the duration of rainfall.

Table 3: Mean physicochemical and microbiological characteristics of water resources in Niger Delta region

Parameters	**Rainwater (RW)**		**Well water (WW)**		**River water**	
Physical characteristics	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
pH	4.98	± 4.94 – 5.45*	5.23	± 4.98 – 5.57*	5.12	± 4.98 – 5.56*
Temperature, -^{0}C	31.2	± 27.6 – 33.9*	30.5	± 28.33*	30.3	± 27.6 – 32*
Turbidity, NTU	4.05	± 4.00 – 5.80*	14.56	±12.22– 6.23*	20.52	±20.08 – 22.78*
TSS, mg/l	41.08	± 32- 45*	408	± 400 – 415*	408	± 400 – 415*
TDS, mg/l	12.65	±12.21 – 23.5*	129	±28.2 – 136.5*	133.6	± 26.5 – 138*
DO, mg/l	5.6	± 4.44 – 5.88*	5.0	± 5.44 – 5.70*	5.7	± 5.44 – 5.70
Chemical Characteristics	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Electrical conductivity, Scm^{-1}	70.2	± 65.9 – 69.3*	267	±46.5 – 278.1*	370.2	± 65.9 – 289*
Cl_2 mg/l	26.3	± 25 – 27.3*	27.1	± 25 – 31.3*	27.3	± 26 – 30.3
Nitrate, mg/l NO_3	31	± 10.5 – 32.6*	13.7	±10.5 – 16.15*	12.5	± 10.2 – 16*
Sulphate, mg/l SO_4	30.5	± 28 – 32.6*	0.6	± 0.5 – 1.39*	0.5	± 1 – 37*
Pb^{2+}, mg/l	0.98	± 0.88 – 1.03*	0.6	± 0.02 – 0.08*	0.08	± 0.07 – 0.09*
Cd^{2+}, mg/l	0.002	±0.00 – 0.001*	0.001	±0.00 – 0.001*	0.001	± 0.00 – 0.001*
Fe^{2+}, mg/l	0.03	± 0.02 – 0.03*	3.50	± 0.09 – 0.43*	4.3	± 0.06 – 4.8*
Mg^{2+}, mg/l	0.7	± 0.6 – 0.8*	10.39	±10.09 – 11.8*	10.40	± 10.06 – 10.8*
Bacterial characteristics	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Total coliform	0.0	± 0.00	1.89	± 0.2 – 2.8*	3.1	± 0.02 – 3.8*
Faecal coliform	0.0	± 0.00	0.66	± 0.2 – 2.9	0.78	± 0.2 – 3.0*

*Significant difference exists at P > 0.05

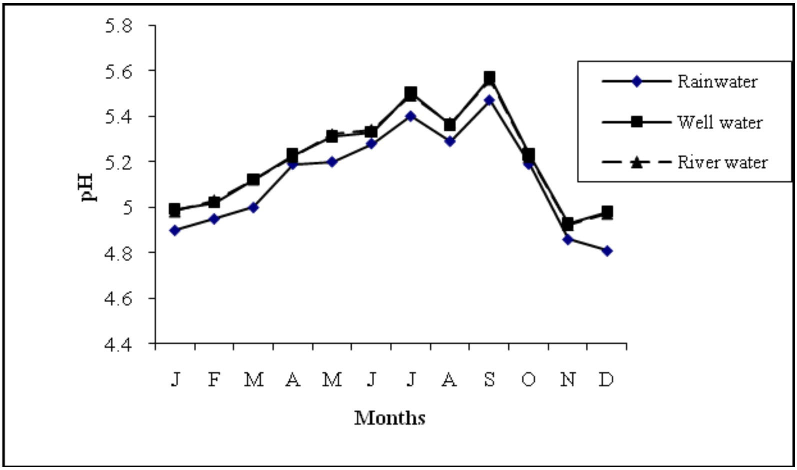


Fig. 2: Monthly distribution of acid rain in the Niger Delta region of Nigeria

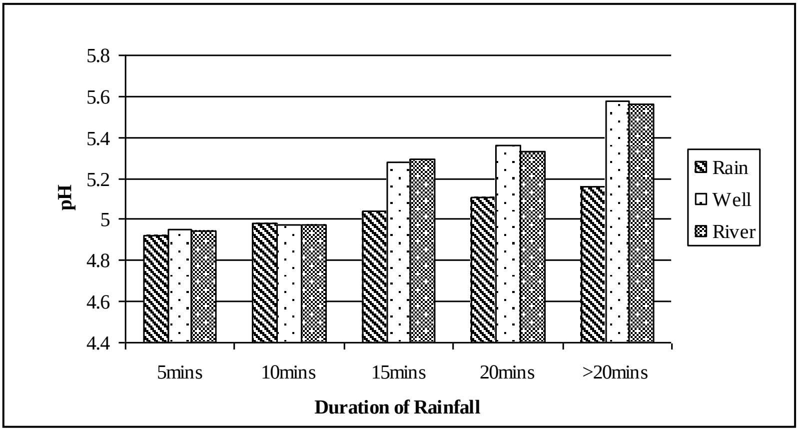


Fig 3: Temporal variation in acid rain

For instance lower pH values of 4.92<4.94<4.95 for rain, river and well water respectively were observed within the first five minutes of rainfall, and higher values of 5.16< 5.56<5.58 were observed in rain, river and well water sources respectively at >20 minutes of rainfall in the region(see fig. 3).

The result of the pH values indicates a spatial spread of acid rain over the entire region (see fig. 4). The pH values range from 4.98 to 5.15 with 5.07 mean values (table 2), indicating the occurrence of acid rain in the oil producing region of Nigeria. Acid rain was wide spread over the entire region where rainwater samples were harvested for this study as illustrated by figure 3 which shows the spatial distribution of acid rain in the Niger Delta. Low pH values of 4.89-4.97 were observed in rains in a number of oil fields in both western and eastern regions. The mean rain pH was slightly lower in the eastern region (pH 5.14 ± 4.89-5.39) (fig.4). This, according to Olobaniyi et al (2007) is aggravated by the enormous volumes of gas flared by the petroleum upstream industries operational in the region. They further stressed that the water soluble portions of these gases eventually dissolve in rainwater and recharged the aquifer and surface water as acid rain whenever there is a down pour. The higher acidity in rainwater in the region is attributed to the dissolution in rainwater of acidic gases, including CO_2, NO_2 and SO_2, which originated from gas flaring (Ogunkaya and Efi, 2003). For instance, areas like Ugborikoko in Sapele, Olomoro, Uzere, Utorogu in western division and Krakami, Kaiyama, Sagbama, Bonny, Enwhe, Adibawa, Belema, Otamini and Ubie had pH values that span 4.89 - 4.98 for rainwater <4.98 – 5.23 for open-wells and < 4.98 – 5.56 for river water (See Fig 2 and 4). These pH values correlated significantly with SO_4^{2+} and NO_3 values. For example sulphate indicated 28 – 32.6mg/l for rainwater, $>$ 1-37mg/l for river water 0.5 – 1.39mg/l for open well water, while nitrate showed 10.5 – 32.6mg/l for rainwater, $>$ 10.5 – 16.15mg/l for open well and $>$ 10.2 – 16mg/l for river water sources respectively. However, nitrate and sulphate correlated significantly with low pH ($r = 0.68$ and 0.86) which is significant at $p > 0.05$, with sites where the rain pH was lowest. For example, Egwa, Sapele, Kokori, Uzere, Adibawe, Ahia, Soku, Bonny, Afam, and Ogula have the highest SO_4^{2-} and NO_3^- concentration. This showed that the NO_2 and SO_2 that are emitted from the flare sites are the major determinant factors of the low pH values experienced in the Niger Delta region. Fig. 4 illustrates that in addition to an increase in pH, sulphate and nitrate in rain concentrations increase with increasing distance from gas flare sites. The high concentration of SO_4^{2-} and NO_3^- reflected in rainfall acidity has been linked to emission of SO_2 and NO_2 gases that subsequently dissolve in rainwater (Smith 1872, Longhurst et al, 1987, Last and Whathing 1991, Efe 2005, 2010; Olobaniyi and Efe 2007, and Munton 2007). The natural gas flared in the region at an average rate of 42.5 million m^3 day^{-1} is rich in oxides of sulphur and nitrogen and is likely to be a source of acid rain (Olobaniyi and Efe 2007).

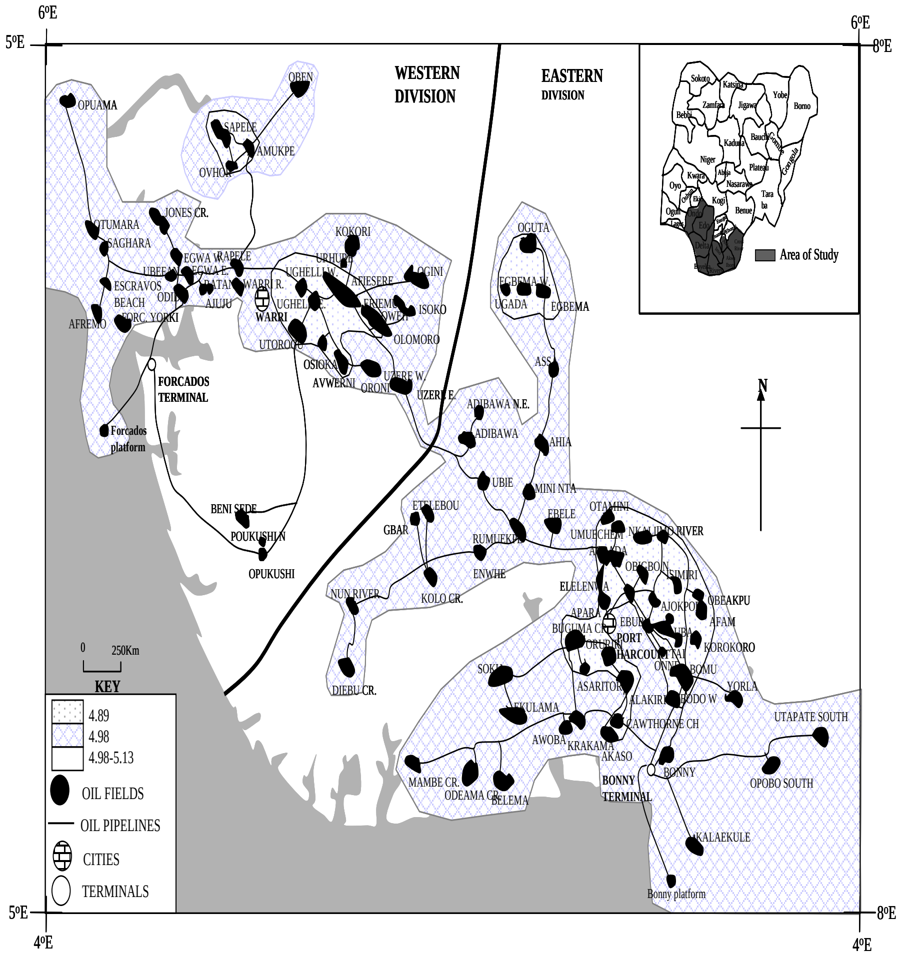


Fig 4: Spatial distribution of acid rain in Niger Delta

There are some industries in the area, but increased sulphate and nitrate content in wells and rivers could be their intrusion from agricultural landuse. However the linkage of acidity of rainwater, to well and river water has earlier be observed by Smith 1872, Longhurst et al, 1987, Last and

Whathing 1991, Efe 2005, 2010; Olobaniyi and Efe 2007, and Munton 2007 to emission of SO_2 and NO_2 gases from industrial operation. The result of this study therefore corroborated those of these scholars. The cluster analysis adopted by Efe(2010) revealed that study sites close to gas flaring had contributed 94% to acidity recorded in the region. Most of the sites had coefficient > 11.45 which is significant at p>0.05. The concentrations of SO_4^{2-}, Ca^{2+}, Cl^- and NO_3^-, ions correlated significantly to moderately (r = 0.86, 0.72, 0.58 and 0.51 respectively) with low pH values in the sites that are close to flare sites, and had combined cluster > 10.34 in the region. However, while a significant relationship exists between SO_4^{2-}, Ca^{2+} and Cl^- (r = 0.78), poor correlation exists between H^+ and SO_4^{2-} (r = 0.12). The relationship amongst SO_4^{2-}, Ca^{2+}, K^+ and Cl^-, NO_3^- suggests an excess acidic anion, and the poor relationship between SO_4^{2-} and H^+ shows that the inorganic acid anion present in rain water was not only associated with free acidity. This is consistent with a previous study of rain in Warri region which found SO_4^{2-} and NO_3- contributed 74 % and 26 %, respectively, to free acidity when they were at their highest (Ogunkoya and Efi 2003, Efe et al 2005).

The lowest pH in rain was recorded in 2000, when sulphate and nitrate concentrations were also at their highest with mean values of pH values of 4.90, SO_4^{2-} 28.9mg/l and NO_3^- 10.3mg/l respectively (see fig. 5). Throughout the study, pH values span 4.93 in 2006 to 5.20 in 1998. Sulphate rain concentration ranged from 30mg/l in 2007 to 31.5mg/l in 2005 and NO_3^- ranged from 10.7mg/l in 1997 to 16.9mg/l in 2005 (see fig. 5). These variations in the pH, sulphate and nitrate concentration of rainwater, are not significant (P>0.05) over the years of study.

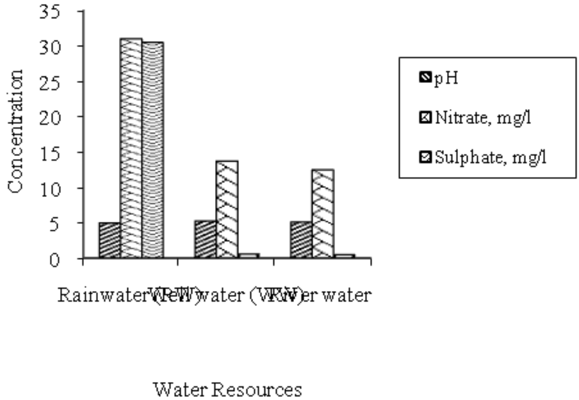


Fig 5: Mean Distribution of pH, Nitrate and Sulphate in Rainwater, Well and River water Resource

The in-site temperatures for water samples generally ranges from 27.6^0C to 33.9^0C, with mean temperature of 31.2^0C, 30.5^0C and 30.3^0C, for rainwater, open well and river water sources respectively. The temperatures were generally lower than those of the atmosphere that range from 29.2 to 35.4^0C for the period of data collection. However, significant temperature differences showed amongst these water sources; with rainwater > open well, while open well water > river water ($p > 0.05$).

Dissolved oxygen however showed no significant variation at $p < 0.05$) (see table 1). On the other hand, other physical parameters of water sources also showed significant difference in terms of turbidity, TSS and TDS. Generally turbidity, TDS and TSS showed that river water sources is > open well water sources which is > rain water sources ($p > 0.05$) (see table 2). Mean turbidity is 20.52 NTU > 14.56NTU > 4.05NTU for river, open well and rainwater respectively. While TSS and TDS showed 408mg/l and 133mg/l > 408mg/l > 129mg/l > 41.08mg/l and 12.65mg/l for river, open well and rain water respectively. This indicates that the river and well water resources are characterised by low solute content. The level of TSS and TDS in rainwater harvested could be attributed to dissolved PM10 and pollutant loads in the area from industrial emission and transportation system (Efe, 2005). The

TDS in well and river water is an indication of the degree of dissolved substances such as metal ions in the water. Also the enhanced conductivity and TDS values in river and open well water resources compared with rainwater showed significant water soil interaction resulting in the dissolution of the geological medium and solubility and toxicity of metals in the aquatic system. Similarly, significant variations exists in term of electrical conductivity (70.2 to 370.2μS/cm > 267μS/cm >70.2μs/cm) for river, well and rainwater resources in this region.

Chemical characteristics

The mean sulphate and nitrate concentration in rainwater tend to be higher generally than those of open well and river water resources, for instance while nitrate indicates 31mg/l > 27.1mg/l < 27.3mg/l for rainwater, open well water and river water resources; sulphate showed 30.5mg/l > 13.7mg/l > 12.5mg/l for rainwater, well and river water respectively. Significant differences ($p \geq 0.05$) exist in nitrate and sulphate level observed amongst these water resources. The high concentration of nitrate and sulphate could be attributed to high level combustion in sulphur containing hydrocarbon fuel in the region. The oxidation of sulphur containing compounds after rainwater has been discharged to ground water resources may increase the acidity and toxicity of river and open well water sources in the region (Efe et al, 2005).

The mean chloride both in the eastern and western region of Niger Delta had a high level of 27.3mg/l, 27.1mg/l and 26.3mg/l resources (see table 2). This however, spans 2.5mg/l to 31.3mg/l for water resources in the Niger Delta region. These values correlated significantly with distance from flare site $p \geq 0.05$ and significant variation exists amongst the three sources: 27.3mg/l > 27.1mg/l > 26.3mg/l for river, open well and rain water sources respectively. The high chloride concentration in these water sources is explained by the intrusion of salt water from the sea via streams and creeks (Offodile, 1992 and Olobanyi and Owoyemi, 2004). This confirmed the reason why areas such as Abraka, Oguta, Agbor, Ugbowo, Sagbama, Egbema, Akure, and Olomoro have chloride level of 27 – 27.6 due to distal location compared to Awoba, Onne, Afm, Nun, Forcados, Escravos beach, etc; that had 28.93 to 33mg/l in the surface and well water sources which are proximal.

The mean content of Pb^{2+} and Fe^{2+} are above the limit acceptable for drinking water for the three sources of water (see table 3). Pb^{2+} showed 0.98mg/l > 0.08mg/l > 0.08mg/l for rainwater, river and open well water resources respectively, these values are above the 0.07mg/l minimum acceptable limit for domestic water. This indicates that Pb in rainwater is markedly higher than those of river and open well in the region. High rate of Pb in water is attributed to the deposition of pollutant from gaseous emission on water bodies (Kapp et al, 1988), and this could be attributed to the gas flaring and iron smelting/iron and steel industrial waste in the area.

On the other hand, Fe^{2+} in river and well water indicate higher content than that of rainwater (4.3mg/l > 3.5mg/l >0.03mg/l see table 3). This shows some dissolution of Fe from some scraps, metallic wastes and lateritic Fe within the soil particles which are leached or washed by erosion action into water bodies, which recorded markedly high level in rivers, and wells compared to rainwater. This occurs in this order 10.40mg/l > 10.39mg/l > 0.7mg/l for river, open well and rainwater sources. The high mg^{2+} content in river and well is expected because of the release into the sea water bodies as a result of the dissolution of Micas and Feldspars (Freeze and Cherry, 1979), which are vital features of the deltaic plain sand aquifer (Olobaniyi and Owoyemi, 2004). Generally, the physicochemical characteristics of these water sources, with the exception of pH were significantly higher ($p > 0.05$) during the peak of rainy season than the drier months of November through February.

Microbiological quality

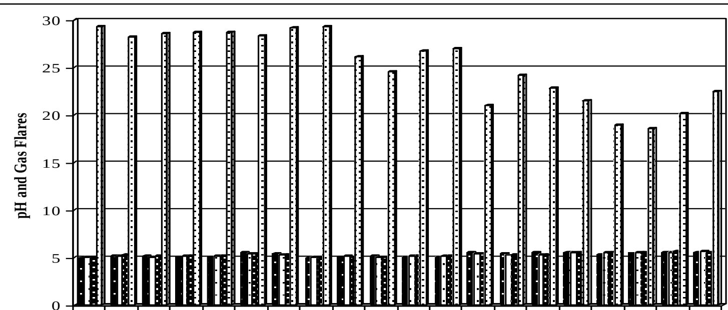
Total coliform bacteria and faecal coliform had the highest mean values in river > open well and not in rainwater. This indicates mean indicator of bacteria 3.1log > 1.89log > 0.00 for river, open well and rainwater respectively in all the water samples (see table 3). These values are markedly higher during the peak of rainfall in river and well water because of the high rate of sediment load of decaying plant materials. E.faecalis were detected in all the river and well water samples. While *clostridium perfringens* were detected in 30% of the well, they were found in all the river water samples though the number were fewer. This corroborated the result of Olobaniyi et al (2007). This occurrence according to AI – Jebouro and Trollope (1984) is that the contamination of the river and well water sources are not mainly of faecal origin, but the faecal coliform are always present in faeces and in higher numbers than the enteric pathogens (Moringo et al, 1990). Hence their presence in open wells and river water resources in the region makes the water vulnerable to pathogenic organisms, and makes these water sources of low quality for domestic uses. Their concentration is enhanced at the peak of the rains than the drier months, thus indicating the influence of the rainfall on quality of water. The result of the multiple regression analysis indicated that the physicochemical and microbiological quality of rainwater harvesting corrected significantly with those of open-wells and river water sources with correlation values of 0.80, indicating that a corresponding change in the quality of rainwater will lead to a corresponding decrease in the qualities of open-wells and river water sources in the Niger Delta region ($p > 0.05$). This corresponds to the finding of Ogunkoya and Efi (2004) and the earlier discussion that rainwater quality impinges negatively on other sources of water in the region.

Water pollution from acid rain and its attendant crisis in the region

Prior to the discovery of oil in the Niger Delta area, all rivers, streams, ponds, well and rain water which served as a source of domestic water supply to the residents were free from pollution. However, this state was changed with the advent of oil exploration, exploitation and the consequent flaring of natural gas into the environment (Alakpodia, 2000). The result of this is the production of acid rain which eventually increased the level of acidity in most of the water bodies rendering them to be turbid and toxic(see table 3 and fig. 6).

The increase in rain pH throughout a rain event has been reported previously in rains in Bangkok, Thailand and in Warri and rural areas of the Delta State, Nigeria (Somboon, 1997; Efe, 2005, 2006). This decrease in acidity is attributed to acidic species being washed out of the atmosphere during rain events, and the fluctuating pattern of acidity in rainwater, well water and river water sources in the region is a reflection of the fluctuating gas flaring rate, the higher the flaring rates the more the occurrence of acid rain in the region (See fig 6).

Rain in the non oil producing region was less acidic than those in the oil producing belts of Nigeria, but still showed some acidity. According to Somboon (1997) and Efe (2005, 2006) once the gas is released through flaring into the atmosphere, it can be carried and spread to several thousands of kilometres, thereby degrading the atmospheric environment where it is spread. For instance this study revealed that pH values increases as distance increases away from the flare sites (see fig 7). Though, there is widespread acid rain in the region, higher concentration of acid rain were observed at distance close to the gas flare sites (fig 7)



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Rain	5	5.2	5.2	5	5	5.6	5.5	5	5.1	5.2	5	5	5.6	5.4	5.5	5.5	5.3	5.5	5.5	5.5
Well	5	5.2	5.1	5.2	5.2	5.4	5.2	5	5.1	5.1	5.2	5.2	5.4	5.2	5.3	5.5	5.6	5.6	5.6	5.6
River	5	5.3	5.1	5.2	5.2	5.5	5.3	5	5.1	5.1	5.2	5.2	5.5	5.3	5.3	5.5	5.6	5.6	5.6	5.6
Gas	29	28	29	29	29	28	29	29	26	25	27	27	21	24	23	22	19	19	20	23

Years

Fig. 6: Annual distribution of gas flare and pH of rain, river and well

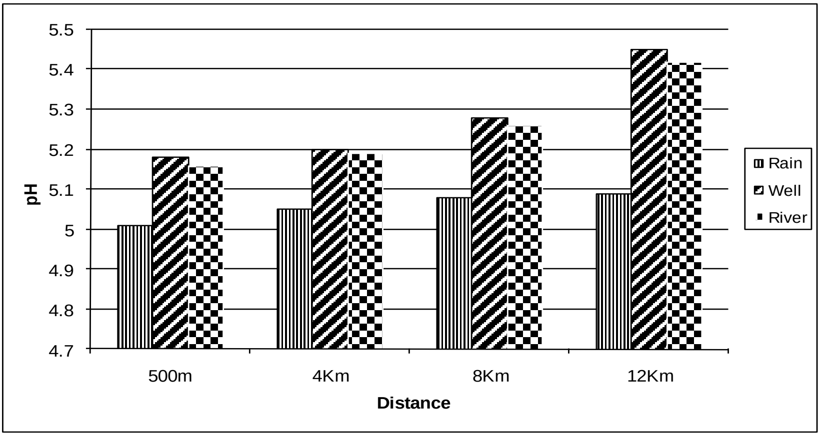


Fig 7: Variation in pH over distance from gas flares

In recent times, acid rain in the Niger Delta area has adversely affected the ecosystem. Fish that were once in abundance and used for food and recreation have disappeared. Most of the residents were fishermen but their incomes have declined significantly.

As a result of the coastal location and the environmental condition in the region, most of the residents have limited livelihood opportunities hence increased incidents of crime and hostage taking. Omuta (1985) studied the impact of the petroleum industry on the land use system and the general economy of all the 16 clans in Isoko land of Nigeria. He reported that the petroleum industry degraded the physical and economic base of the region through remarkable land modification such as destruction of vegetal cover, soil and water pollution and disruption of farming, fishing and hunting. The ultimate manifestation of these externalities according Omuta (1985) was that, 89 percent of the farmers and 93 percent of the fishermen were negatively affected with actual loss or reduction of farmland and fishing grounds respectively.

The worst effect of this pollution is on the quality of domestic water supply which has been drastically reduced. As a result, demand for water is far greater than the supply. In spite of the alternative source of drinking water made available by the oil companies, there is still acute shortage because boreholes are inadequate. Besides, most of the boreholes and other water schemes are not functional and sustainable because of high level of acid, NO_4, mg and pb. In a study of residents' basic needs in Nigeria, drawn from a representative sample of cultural and ethnic diversity of rural settlements (Okafor, 1985), it was found that most rural communities have domestic water supply in top priority of needs. The results from this study corroborated Okafor's (1985) view of basic needs in Nigeria (see table 4). This is not surprising because the availability of safe drinking water tends to reduce health hazards, and this contributes both directly and indirectly towards better health, higher productivity and increased life expectancy and wealth for the community. The reverse is the case in Niger Delta due to water pollution and other act of environmental degradation.

Research has shown that pollution caused by acid rain from gas flaring does not only end with sanitizing the water bodies, but it is now known that health risk is not averted by abstinence from meat and fishes killed by this pollutant but fishes and animals that escape instant death from pollution are known to have taken in some of the toxic substances, which in turn get into human beings that eat them (Oden, 1976; Alakpodia, 2000 and Olobaniyi et al, 2007). This will in turn cause infections such as bronchitis, coupled with other "side effects in the form of genetic mutations" (Olusi, 1981).

The study revealed that all the communities in the Niger-Delta region had need for social infrastructural development such as pipe borne and borehole water supply, electricity, roads, primary and secondary schools, health centres and community town halls. But the top priority of most of the communities among these infrastructures is the provision of potable water supply (boreholes and pipe borne) which was ranked highest in demand in these communities (see table); Community town hall ranked least in most of the communities.

The struggle for compensation

Understandably, the oil producing communities have responded to the destruction of the of their natural resources as well as alleged marginalisation in the area which represent "a kind of socio-economic paradox in that it is the poorest and the most industrialised region in Nigeria" (Naanen, 1995).

The pattern of response by the people residing in the Niger Delta communities has brought significant pressure on the Federal Government and the oil industry through protests/civil disobedience. The struggle was enacted through protests carried out in 1993 by a cross section of Ogoni people numbering 300,000 in a march to protest their negligence.

In July 1987, Iko residents demonstrated against environmental pollution and the negligence of their village in spite of the environs wealth from oil. In the ensuring fracas, protesters burnt down thirty-eight houses, looted Shell properties, forcing the government to intervene and address their grievances. The same pattern of struggle for compensation through protests and civil disobedience took place at Olomoro in Isokoland between 1980 and 1985. Residents wanted shell to help construct roads, pay compensation for crops destroyed and extend the water project in Olomoro to Okpe, Angodo, Ujevwe and Ikietutu villages (Agbon, 1995).

Table 4: Priority needs of some communities in Niger-Delta region

Community/location	Facilities in need	No of respondents	%
Ugborikoko	Pipe borne water, electricity	250	50
Lat.5°31’ 23.3”	Tarred Roads	75	15
Long. 6°00’ 46.8”	Primary School	50	10
	Secondary School	40	08
	Health Centres	50	10
		35	07
		500	100%
Olomoro	Electric transformer	60	12
Lat.5°27’ 04.8”	Health Centre	40	08
Long. 6°11’ 35.1”	Pipe borne water	225	45
	Tarred Roads	75	15
	Primary School	35	07
	Secondary School	30	06
	Town hall	35	07
		500	100%
Uzere	Electricity	92	23
Lat.5°21’ 01.4”	Health Centre	48	12
Long. 6°13’ 32.6”	Pipe borne water	140	35
	Tarred Roads	40	10
	Primary School	12	03
	Secondary School	48	12
	Town hall	20	05
		400	100%
Utorogun	Electricity transformer	90	20
Lat.5°39’ 4.1”	Health Centre	54	12
Long. 6°10’ 16.0”	Pipe borne and bore hole water	189	42
	Tarred Roads	45	10
	Primary School	32	07
	Secondary School	32	07
	Town hall	18	18
		460	100%
Bonny	Electricity	70	20
Lat.5°21’ 01.4”	Health Centre	53	15
Long. 6°13’ 32.6”	Pipe borne and bore hole water	88	25
	Tarred Roads	60	17
	Market	21	06
	Secondary School	42	12
	Town hall	18	05
		352	100%

Belema Lat.5°37'26.7" Long. 6°01' 28.3"	Electricity Health Centre Pipe borne and bore hole water Tarred Roads Market Primary School Secondary School Town hall	54 50 153 40 36 45 59 23	12 11 34 08 07 10 13 05
		452	100%
Krakami Lat.5°30' 55.0" Long. 6°08'23.3"	Electricity transformer Health Centre Pipe borne and borehole water Tarred Roads Primary School Secondary School Markets	47 70 233 33 33 28 24	10 15 50 07 07 06 05
		468	100%
Sagbama Lat.6°26' 14.2" Long. 7°12' 37.4"	Electricity supply Health Centre Pipe borne water Tarred Roads Primary School Secondary School Town hall Markets	80 35 200 40 15 22 30 20	18.1 7.9 45.2 9.1 3.4 5.0 6.8 4.5
		442	100%
Otamine Lat.5°36' 25.7" Long. 6°02' 24.4"	Electricity Health Centre Pipe borne and bore hole water Tarred Roads Primary School Secondary School Markets	55 40 250 35 15 18 17	12.8 9.3 58.1 8.1 3.5 4.2 4.0
		430	100%
Kokori Lat.5°37' 26.7" Long. 6°06' 40.6"	Electricity Health Centre Pipe borne and bore hole water Tarred Roads Primary School Secondary School Markets Town Hall	80 50 255 20 15 10 10 10	17.8 11.2 56.7 4.4 3.3 2.2 2.2 2.2
		450	100%

Ubie Lat.5°33' 13.7" Long. 6°01' 39.8"	Electricity Health Centre Pipe borne and bore hole water Tarred Roads Primary School Secondary School Markets Town Hall	60 15 160 12 15 18 10 10	20.0 5.0 53.4 4.0 5.0 6.0 3.3 3.3
		300	100%
Udibawa Lat.5°31' 22.6" Long. 6°04' 13.1"	Electricity Health Centre Pipe borne and bore hole water Tarred Roads Primary School Secondary School Markets Town Halls	80 50 200 40 20 25 20 15	17.8 11.1 44.5 8.9 4.4 5.6 4.4 3.3
		430	100

The paradox of "poverty in wealth" associated with the status of the socio-economic conditions of the residents of the Niger Delta, in spite of the huge oil revenue generation capacity of the region to Nigeria, and the people's poor quality of life is revealed in the poverty threshold of their incomes, unemployment, poor housing structures, constrained lifestyle, inadequate and non functional infrastructures and degraded environment.

The imperative is that, although the region studied here constitutes a major domain of vast oil reserves, the benefits of oil revenue and resource distribution have not significantly impacted on the residents. This study has shown that the provision and sustenance of functional potable water is the most highly desired need of the residents in the Niger Delta.

Conclusion

This study revealed wide spread occurrence of acid rain in the entire Niger Delta region, and this could be related to gas flaring associated with petroleum exploitation activities in the region. This acid rain has further polluted the river/streams and open well water sources in the region. Our overall observation of the implication of rainwater, showed rapid deterioration of the quality of water resources available for domestic purpose, and this has led to acute shortages in drinkable water, resulting in struggling and fighting amongst children and women. It is therefore, recommended that gas flaring should be extinguished. Alternatively, it should be converted to the production of domestic gas. Government and all stake-holders in the oil industries should provide potable water supply to inhabitants in the entire region as well as provision of regular electric power supply. Regular liming of the open-wells and surface water should be carried out with the assistance of the federal and state Ministries of Environment working in collaboration with the oil companies operating in the area.

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