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Self-Purification and Rainfall Events in a Tropical Rural Catchment, Nigeria

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Abstract: This paper studies self-cleansing processes in an urbanized stream in a Nigerian city. The stream under study took its source from a refuse heap in the Central open-place-city market and empties its water into a University Dam 15 kilometres away.

Twenty-seven water samples were taken from nine sample points, which were selected with distances downstreams and according to land use changes in the period before and after the 1st and the 2nd rainfall events. The results showed that some parameters decrease progressively with rain events while some equally increase progressively. The result of the Pearson moment product correlation showed that in the period before rainfall onsets five water parameters (Ca^+, P, total hardness, suspended particles, NO^-_3) significantly decreased in their concentration downstream; and after the first rainfall only NO^-_3 significantly decreased downstream from the source to the dam/site (downstream) while in the period after the 2nd rainfall event all the water parameters decreased in concentration downstream with seven parameters significantly decreasing (i.e. Na^+, Ca^+, K^+, Mg^+, P, NO^-_3 and pH). The overall results indicated that the processes of self-cleansing become more active with increasing rainfall events.

Key words: Sedimentation, contaminant, coagulation, precipitation.

Introduction

Self-purification of water bodies is the ability of water at purifying itself of sewage and other wastes. This is done in two main ways. First, through dilution of polluted water with influx of fresh surface and ground water and secondly by a complex hydrologic, biologic and chemical process. It entails some physical, chemical and biological sub-processes such as sedimentation, coagulation, precipitation and absorption of organic and inorganic dissolved substances. It also requires the life processes of aquatic organisms like reproduction, growth and processes of death organisms (Kalinin, 1971; Grava, 1969; Leclernc, 1964 and Dorfman et al., 1972). The nature of interactions between organisms within the food chain of aquatic environment lead to biological extraction and accumulation of wastes in streams and alteration in the available dissolved oxygen.

Sedimentation involves settling of sediments in streams as they agglomerate in transit by building-up in sizes and in density. These agglomerated sediments may eventually be deposited as excess sludge along shores, behind obstruction or in the eddy areas (Lenclerc, 1964). Meanwhile, as the stream moves along the bed, in most cases, such sludge are trapped by roots of vegetation. Coagulation on the other hand takes place when concentrations of metal hydroxide in streams coagulate particulate materials. The coagulated sediments are formed into balls and they become too heavy for stream transportation. Such balls are eventually deposited and trapped by roots of vegetation.

The factors affecting self-purification in streams include temperature (which controls biological and chemical activities in streams), stream topographical conditions (which control velocity, stream dilution, rates of re-suspension etc.) and death of organisms, which can outrightly discard the processes of self-purification.

Precipitation events, especially rainfall characteristics (amount, intensity, distribution and length of the time since the last rainfall) (Lazaro, 1979), play an important role in water chemistry. In the tropics, rainfall is about the main mechanism involved in washing of surface contaminants into water bodies. Indeed, falling precipitation are generally not pure in their natural state; they are usually saturated with oxygen, NO^-_3, dust, smoke particles, fumes. The earth's atmosphere is saturated with particles used up as condensation nuclei in rainfall or "washed-out" or "rained-out" to the earth. For example, Zverev (1971) reported that average proportion of dissolved load of rivers in USSR that may be attributed to precipitation is 14.4%. However, in Nigeria, Awani (1989) has reported that 23.8% of dissolved load of rivers in Ile-Ife, Nigeria is due to precipitation. Apart from the impact of overland flow in washing particles into rivers, rainwater is also capable of dissolving nutrients and causing underground seepage which may sometimes be highly polluted. For example, Ogunkoya (1986) reported that rivers draining areas of quartzite rocks and highly pressurized rocks in Nigeria have precipitation-dominated chemistry and that anywhere else the chemistry of rivers reflect rock dominance.

In addition, the longer the length of time since the last rainfall the poorer the water quality. Frequent rainfalls reduce the rate at which different contaminants such as organic wastes accumulate. They may easily be washed off as soon as they are produced. The higher the rainfall, the faster the velocity, the higher will be the rate of mixing, and the better the stream quality.

The processes of self-purification and the effects of rainfall are dependent on the basin land use. Out of the land use parameters urbanization has the most drastic effect on water self-purification. According to Grava (1960), in the earlier times there were few large cities; hence, raw sewage discharged from cities were absorbed by water environment. Today, such conditions are hard to come by in any part of the settled world.

Pereira (1973) has also reported the effects of forested land uses on river pollution. They include higher infiltration capacities, higher base flow and leaching of chemicals into adjacent streams. These suggest reasons for higher concentration of dissolved pollutants in streams of forested landscapes compared to suspended load. Hynes (1960) observed that in densely wooded regions, leaf and leaf fall usually add organic matter to water. Consequently, naturally flowing sluggish woodland streams are excellent examples of naturally polluted waters. Soil suspension has also been found in rivers draining newly cultivated arable lands, especially during time of cultivation and when they have weak abilities of absorbing heavy rainfall, immediate overland flow produces sharp peaks of stream flow which later results into floods.

Grazing management along watercourses also has significant impacts on water quality, where pollution by human and animal washes into streams. Forest fires show that a somewhat severe treatment involving forest clearance and vegetation could cause the total solute output from a small water shed to increase by as much as six times.

Research into natural cleaning processes of streams are sparse particularly in the tropics where they are most required simply because artificial purification system are not efficient since it is done by government agencies which are poorly funded. This is because provision of water is not cost recovery. Studies of water chemistry in Nigeria often mainly focus on assessing raw water quality and drinking water standard across; however, this present study will attempt to study self-purification along a polluted headwater stream in a tropical city of Nigeria.

The Study Area

The study area is Ile-Ife, Osun State, Nigeria. It is located on the intersections of longitude 4° 31′ East and latitude 7° 28′ N. It is located within the tropical rainforest belt of Nigeria.

Ile-Ife comprises five local government areas and it is having a population of about 50,000 people. The city is largely rural in its function with very few industries; most of which are cottage and small scale in nature. The city is poorly planned, with houses closely knitted together in disorderly manner. Refuse are disposed off openly in heaps and open sewers and streams. Ile-Ife is drained largely by River Opa, which forms a tributary of River Shasha, which eventually drains southwards into the Niger Delta. River Ogbe, the sampled stream in this study, is a tributary of river Opa (Figure 1).

River Ogbe takes its source from a refuse heap in the city centre, within an open space market known as Ogbe market in Ile-Ife area (see Figures 2 and 3). The city abattoir is located close to the source. This stream eventually flows into the Obafemi Awolowo University dam where it is stored for the university community about 15 km downstream. This influenced the choice of this stream in this study.

The flow pattern exhibited by this stream is closely patterned along the incidences of rainfall in the area. It has higher velocity and greater volume of water during

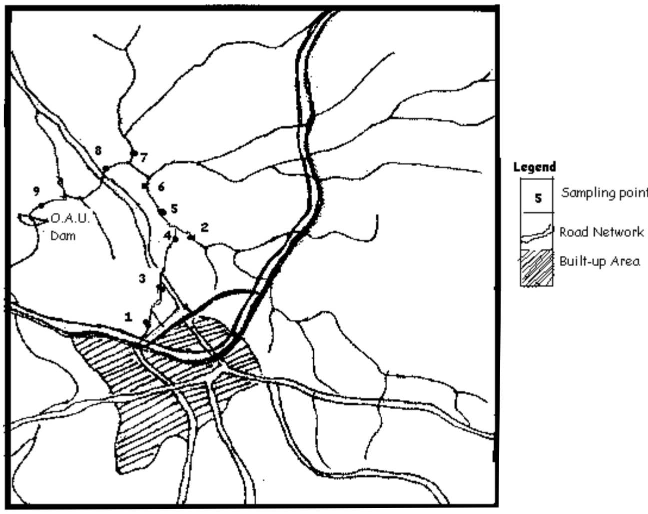

Figure 1: Ile-Ife showing the sampling points.

the rainy season; while during the dry season the flow is very low.

Different land use transverses the river channel. According to Adejuwon and Jeje (1979) four basic elements are discernable in the land use. These are township area, built-up area of the university campus, University Research Farm and the traditional farmland. Evidences from recent survey show that the percentage area covered by each of this land use is changing with the township area rapidly increasing in size. The land use can simply be categorised in two: urban and agricultural land use. The township area is used mainly for residential purposes within which patches of bushes are used for refuse dump. The University campus is well laid-out with residential houses situated on large plots

Figure 2: Open place market found in the headwaters of Ogbe river basin in Ile-Ife (note the open-place transaction of food items).

Figure 3: River Ogbe very close to the source area.

bounded by hedges with each house having its own soak-away pits. The greater part of the university research farm is used for field cropping. There are also plots planted with tree crops and sheds for keeping poultry, sheep, cattle and goats. The traditional farmlands consist of four main categories of land use types, which include tree crops, food crop plots, farm settlements and forests.

The climatic type of Ile-Ife is the humid tropical climate with an annual mean temperature of about 27° C and mean rainfall of about 1,500 – 2,000 mm (Nigerian Metrological Organisation Services). Rains are between the months of March and November; the other months are usually dry and rainless. The area is underlain by Pre-Cambrian Basement Complex rocks which comprises mainly fine grained biotite gneisses and schist. The rocks are strongly foliated and comprise mosaic plagioclase feldspar and quartz with abundant biotite and mica. They appear to be readily weathered and eroded to give rise to undulating topography with very few rock outcrops (Smyth and Montgomery, 1962). The soil and regolith in the basin may be classified as belonging to the ferallitic soils. The soil has an infiltration capacity of 81 cm/hr (Adubi, 1987).

Materials and Methods

Data Required

The data required in this study are:

(a) Rainfall data (incidences and amount)
(b) Stream flow pattern
(c) Distances downstream and distances between sampling points

Rainfall data were obtained from the University Research Farm through an automatic rain gauge installed in the basin by the OAU. Further information on the rainfall incidences were also taken by the author. Information on distances downstream was acquired from 1:50,000 topographical covering the area and coupled with ground truth information from pilot-field survey by the author. Information on physical and chemical compounds was obtained from the collected water samples through laboratory analysis conducted partly by the Department of Geography, Wet Laboratory and the Department of Zoology of the Obafemi Awolowo University.

Sampling Methods

A total of nine sample points were selected and established along River Ogbe to reflect the variation in land use and distances downstream from the source to the mouth of the stream, at the O.A.U. Dam (15 km away (Figure 1). For each of the sample points, three sets of water samples were collected. The first samples ware taken before the on set of the rains in Ile-Ife. The second samples were taken immediately after the 1st rainfall in Ile-Ife area and the third samples were taken after the second rainfall. On the whole 27 water samples were taken and analysed in this study.

Distances between each of the sample points were chosen after field pilot survey bearing in mind land use changes, and with other information from the topographical sheet of the area.

Laboratory Analysis

The details of the different laboratory methods are displayed in Table 1.

Table 1: Laboratory methods

S/N.	*Water parameters*	*Method of laboratory analyses*
i.	Water hardness	Volumetric methods using soap solution
ii.	pH	Glass electrode pH meter
iii.	NO^{-}_{3}	Chlorimetry with phenol disulphuric acid
iv.	P	Bray method
v.	Na^t, K^t, Mg^t, Ca^t	Flame analyzer, using atomic absorption spectrophotometer
vi.	Suspended particles	Filtration method

Data Analysis

Descriptive Statistics

Mean, standard deviation, coefficient of variation, tables and graphs were used in data summary and description of the data.

Correlation Analysis

The moment product correlation coefficient was used to measure the degree of association between water samples and distances downstream along the stream. This method was used to find the strength of association that exists between water quality and distances downstream. The answer ranges from –1.0 to + 1.0. For example –1.0 implies perfect negative correlation, 0 means no correlation while +1.0 refers to perfect positive correlation. Also, negative coefficient value indicates that there is a decrease in the concentration of water properties downstream while positive correlation indicates increases in concentration of chemical compound with distances downstream.

Results and Discussion

Descriptive Patterns of Water Chemistry

According to Table 2, out of the nine water parameters measured water hardness (WH) has the highest load with an average concentration of 347 mg/l. This was followed by Na^+ with 170 mg/l, while suspended particles has the lowest concentration of 0.02 mg/l. The high concentration of these compounds in the period before the rains is because of the fact that the processes of mixing and flushing are minimal at this time. Therefore chemical parameters are bound to increase in concentration; since they would have built up for months. Na^+ has the highest deviation from the mean suggesting that the values obtained vary significantly from the mean; however this is expected because of the effects of relatively long period of dryness. The lowest deviation was obtained in the suspended particles. This is because suspended particles have little relevance in the period of dry weather flow. The coefficient of variation showing relative deviation between one sample point and the other indicated that only four water parameters were homogeneous with values less than 33% (Table 2). These are Ca^t, P, pH and water hardness, while others are largely heterogeneous in their distribution, suggesting that unlike the first category they differ significantly in concentration from one sample point (or from land use types) to the other. This is reflecting details of the changes in land use.

In the samples after the 1st rainfall event, the highest was recorded also in water hardness (356 mg/l), and followed by Na^+ having a mean concentration of 129 mg/l. This trend was again after what was recorded in the period before rainfall incidences. The higher concentration of these values can be explained in the context of the high concentration of solute/dissolved

Table 2: Descriptive patterns of water samples of river Ogbe, Ile-Ife

Water compounds	*Samples before the rains*			*Samples after the first rain event*			*Samples after the second rain event*		
	X	*SD*	*CV%*	*X*	*SD*	*CV%*	*X*	*SD*	*CV%*
1. Sodium (Na^+)	170	57	92	129	164	78.0	32.0	13.7	42.8
2. Calcium (Ca^+)	1.04	2.00	19	0.67	0.50	83.0	1.50	2.80	215
3. Potassium (K^+)	3.40	3.20	94	6.60	1.83	3.56	3.56	7.50	214
4. Magnesium (Mg+)	0.18	0.19	105	0.16	0.12	75.0	0.10	0.01	10.0
5. Phosphorous (P)	2.10	0.70	33.1	2.20	0.72	32.0	2.00	0.50	25.0
6. pH	8.97	0.37	4.00	8.96	0.36	3.90	8.80	0.40	4.50
7. Water hardness (WH)	347	60.0	17.0	356	61.0	18.0	289.0	47.0	16.0
8. Suspended particles (SP)	0.02	0.10	60.8	0.04	0.01	25.0	0.06	0.04	66.6
9. Nitrate (NO^-_3)	14.0	11.0	78.0	16.3	8.00	49.0	14.1	6.00	42.0

materials coupled with refuse in the period of early rainfall events, when the impact of sewage, fertilizers and herbicides would have built up in concentration in adjacent streams. Suspended particles again remain the least in the concentration in the period after the first rains. Standard deviation was also highest in sodium concentration (4 mg/l) and least in concentration in suspended particles (0.04 mg/l). However, only four samples were homogeneous (P, 32%; pH, 3.90%; water hardness, 18% and suspended particles, 25%) in distribution. However, unlike what obtains in the period before rain, Ca^t and WH are now homogenous. This change in composition is simply because of the mixing and flushing due to the effects of first rain.

In the last category of samples, for example, after the second rainfall, water hardness has the highest concentration of 289 mg/l; followed by Na^+ with 32 mg/l and suspended particles remaining the least having a mean of 0.04 mg/l in concentration. Again, the above trend is also reflected in the samples collected after the first rainfall. On the whole, it is pertinent to note a progressive decrease in concentration of certain parameters, for example Na^+ was 170 mg/l before the rains, it went through 129 mg/l after the first rain to 32 mg/l after the second rain, while suspended particles depicts a progressive increase from 0.02 mg/l before rain, 0.04 mg/l after the first rain and 0.06 mg/l after the second rain. This clearly shows that water samples may change with increasing rainfall events. The results of the standard deviation from the mean are strongest on water hardness 47 mg/l and least on Mg^+ (0.01 mg/l). This has different trend from the two instances above, reflecting the impacts of increasing events of rains. The coefficient of variation in the period after the second rainfall showed that Mg^+ (10%), P (25%), pH (4.50%) and water hardness (16.0%) are the homogeneous parameters. All others were heterogeneous in their distribution. Indeed, the heterogeneous pattern of suspended particles and magnesium is at the instance of the increasing incidences of rainfall.

However, from the above analyses the patterns exhibited by the water compound vary from one instance to the other. For example, some parameters showed progressive increase with rainfall events, while others showed progressive decline in concentration with rainfall events. In addition, certain parameters became dispersed —both relatively and absolutely—with rainfall events while some others become closer to their means and also homogeneous with rainfall incidences.

Water Chemistry and Distances

According to Table 3 and Figures 4 to 12, the patterns exhibited by water compound with distances differ according to parameter and with rainfall characteristics.

In the period before the rains, Na^+ increases in concentration with distances downstream ($r = 0.30$) and after the first rain ($r = 0.23$) events but decreases in concentration with distances downstream in the second rainfall event ($r = –0.82$) (Figure 4) suggesting that the source of Na^+ may possibly be on the farmland due to fertilizers and farm inputs. Ca^+ on the other hand is reduced in concentration throughout, but significantly decreases in concentration before the rain events ($r = 0.60$) and after the second rainfall event ($r = –0.74$) (Figure 5). This is possible because the urban land use is a major source of Ca^+ along the channel. Potassium significantly increased in concentration in the period before rainfall onset ($r = 0.70$) and in the period after the first rainfall onset ($r = 0.74$) but reduced in concentration after the second rainfall (Figure 6). This change in

Table 3: Moment product correlation coefficient (*r*) between water compounds and distances downstream the river Ogbe channel

Water compounds	*Samples before the rains*	*Samples after the first rain event*	*Samples after the second rain event*
1. Sodium (Na^+)	0.30	0.23	-0.82**
2. Calcium (Ca^+)	-0.60*	-0.27	-0.74*
3. Potassium (K^+)	0.70*	0.74*	-0.74*
4. Magnesium (Mg^+)	0.91**	-0.52	-0.74*
5. Phosphorous (P)	-0.70*	-0.56	-0.68*
6. pH	-0.75	0.77*	-0.38
7. Water hardness (NH)	-0.66*	-0.10	-0.10
8. Suspended particles (SP)	0.66*	-0.69*	-0.83**
9. Nitrate (NO_3^-)	0.90*	0.30	-0.70*

*95% significant, ** 99% significant.

direction is due to the effect of flushing. Mg^+ on the other hand, also increased in concentration downstream before rain event but decreased in concentration with distances downstream. However, phosphorous, suspended particles and NO^-_3 decrease in concentration with distances downstream in all instances (Figures 9, 10 and 11). These suggest that the urban landscape that forms the headwaters of Ogbe stream is a source of these parameters within the study area. Consequently, there is a need to control land use within the urban area with a view to controlling the excess concentration of these parameters.

Moreover, Na^+, K^+ and pH (Figure 12) increase in their concentration with distances downstream in the samples before rain, and after the first rain events, but reduce in concentration or self purify with distances only after the second rainfall events. Also, Mg^+ alone is the only parameter which increased in concentration in both the periods after the first and second rainfall but increased with distances before rains suggesting that rainfall incidences play a sharp dominance on self cleansing of Mg^+. However only water hardness self purified before the rains and after the second rain events but did not increase in concentration with distances after the first rain.

On the whole, in the period before rains four parameters (Na^+, K^+, Mg^+ and pH) increased with distances downstream out of which Na^+ did not significantly increase with distance downstream. All other chemical compounds decreased in their concentration downstream; in other words, they self purify. In the period after the first rainfall event, out of the nine chemical parameters considered in this study, four parameters increased in concentration with distances downstream (i.e. Na^+, K^+, total hardness and pH), while all other parameters reduced in concentration downstream. However, only K^+ and total hardness have significant increase with distances.

Meanwhile, the phenomenon of self purification becomes most effective after the second rain event with all the chemical parameters decreasing in concentration downstream. All the nine chemical parameters have significant decreases with distances downstream suggesting that the processes of self purification involving coagulation, sedimentation, life processes of organism, mixing etc. are most important with rainfall events. Lernlerc (1964), Ifabiyi (1997) and Ajibade (2000) have equally reported the impacts of climate, particularly rainfall incidences, in the determination of water quality. For example, Ifabiyi (1997) reported that a significant proportion of the water parameters, he studied, reduced in their concentration with increasing rainfall incidences.

Conclusion and Implication of Study

Water purification efforts and aquaculture at the university dam and communities downstream should take the above findings into cognisance.

It is evidently clear from the analysis that before the rain events efforts at water treatment should focus on reducing solute materials (such as Na^+, pH, NO^-_3, P, Ca^+, Mg^+) in the dam but in the rainy season efforts at purification should focus on reducing water physical properties (i.e. suspended particles etc.). In other words, water treatment efforts in the water works should take rainfall events into cognisance, as it will directly dictate the extent of purification required at the dam site. Ifabiyi (1997) has equally pointed this out in a similar study.

In addition, the process of self-purification becomes more relevant and active with increasing rainfall events. Hence, there is a need to monitor water quality from time

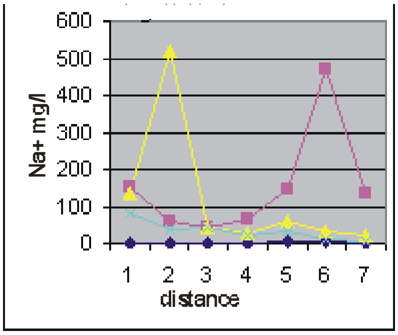

Figure 4: Sodium

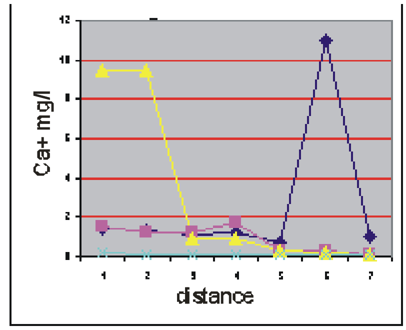

Figure 5: Calcium

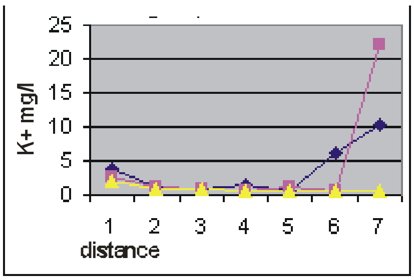

Figure 6: Potassium

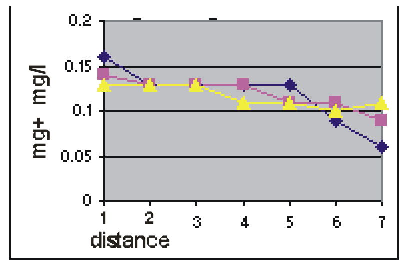

Figure 7: Magnesium

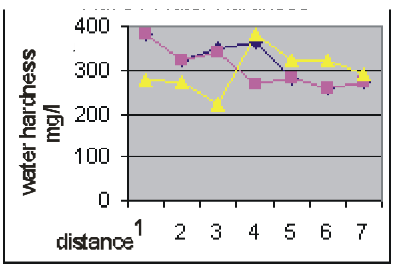

Figure 8: Water hardness

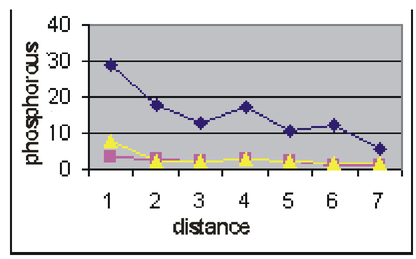

Figure 9: Phosphorous

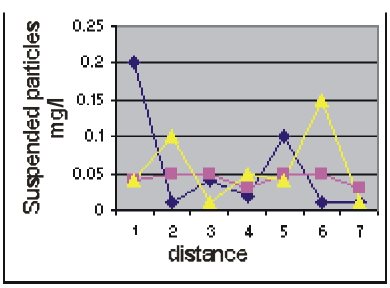

Figure 10: Suspended particles

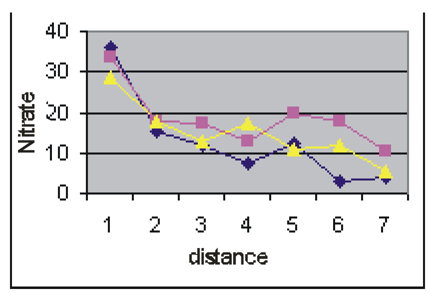

Figure 11: Nitrate

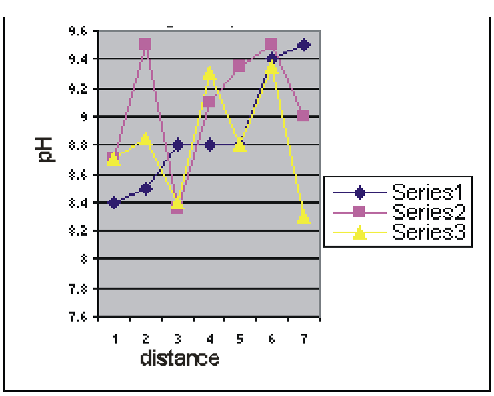

Figure 12: pH

Legends

Series 1: Samples before Rain Onset
Series 2 : Samples after the 1st Rain
Series 3: Samples after the 2nd Rain

Figures 4-12: Self-purification parameters of river Ogbe, Ile-Ife.

to time in order to determine the extent of purification that will be required in the places along the stream. For example excess addition of coagulant or even chlorine etc. can lead to pollution.

This study also allays the fear of environment managers that flowing streams even passing through urban landscapes may not necessary be of high danger to the adjoining communities.

However, there is a need to extend this present study beyond two rain events, with a view to elucidating extensively the input of rainfall events in the study.

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