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Modelling the Dynamics of a Hypereutrophication Process in Ruguma Ponds in Rumuosi-Akpor, Nigeria.

Kamalu C.I.O., Anusi M., Kamen F.L., Okwara C.A., Nwakaudu M.S., Nwakaudu A.A., *Obijiaku J.C.

Department of Chemical Engineering, Federal University of Technology,
Owerri P.M.B 1526, Nigeria.
*Phone:+234(0)07062810295, *Email:obijiakujudec@gmail.com

ABSTRACT

In this work, Experimental results were monitored for a period of eight months on certain variables parameter in great Ruguma eutrophication site with Fugro International Laboratory to observe the profiles of the simultaneous variations of these parameters with time. Some parameters show the approach or eminence of hypereutrophication. Cox et al (2009) model for recovering from hypereutrophication was modified to accommodate phosphate concentration variation in the great Ruguma hypereutrophication. Numerical values of constraints, initial and boundary conditions were culled in from the works of Cox et al (2009) in solving the system of ODEs modified.From the analysis made on the results obtained, the Great Ruguma Seasonal Ponds may be said to be recovering from hypereutrophication.The findings of this work can be applied in any trophic study especially when it is entering or recovering from hypereutrophication.

Keywords: Modeling, dynamics of hypereutrophication, Great Ruguma Seasonal Ponds, biomass, oxygen, ammonium, phosphate.

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

One of the foremost problems facing freshwater ecosystems in the 21st century is eutrophication. The term eutrophication means "well-nourished" and comes from the Greek words "eu" meaning "well" and "trophe" meaning "nourishment". However, the prefix "hyper" means "excessively" or"extremely". Hypereutrophication, is therefore a state of an excessively well-nourished aquatic system, but deficient of oxygen.

Eutrophication is defined as an enhancement of the natural process of biological production in water resources resulting from increased concentrations of nutrients, usually phosphorus and nitrogen compounds (Vollenweider, 1968). Eutrophication stimulates the rapid growth of algae and aquatic plants which leads to anoxia and fish kills, causes turbid water conditions with unpleasant tastes and odours, increases accumulation of organically rich sedimentation and promotes the dominance of certain algal. It is a natural process whereby lakes, estuaries and slow-moving streams receive excess nutrients as a consequence of weathery of rocks and soil from the surrounding water shed and anthropogenic activities (Val et al., 2006). Hypereutrophication however, is the ecosystem responsible for the addition of natural and artificial substances mainly phosphates through detergents, fertilizers or sewage to an aquatic system. Although phosphorus is naturally scarce, human activities can increase phosphorus in waters through human and animal waste, detergents, fertilizers and erosion (Chapra 1997). Nitrogen however, is more abundant than phosphorus and therefore is a less limiting factor to aquatic primary productivity (Chapra 1997). The increase in the level of these substances in water bodies may lead to harmful algal blooms of cyanobacteria (Cyano-HAB), which would result in the depletion of oxygen in the water (hypoxia) and will consequently cause death to aquatic animals.

One of the most critical and greatest challenges of the 21st century is meeting the world‘s growing demand for water while maintaining the health and functioning of aquatic systems (Postel, 2000).Water quality in almost all regions of the world has deteriorated through intensifying agriculture and the growth of urban and industrial areas (Revenga et al., 2000). Major problems related to hydromorphological alterations, eutrophication, turbidity, and the input of sewage are found in freshwater resources worldwide (Sondergaard & Jeppesen, 2007). Without water in sufficient quantity and acceptable quality, the future existence of both humankind and wildlife is threatened (Lozan et al., 2007).

Defined as an increase in the rate of organic matter addition to the ecosystem, eutrophication is one of the biggest coastal pollution problems the world faces today Smith and Bennett (1999) and Schindler, (2006).

Over the past decades, there have been washing of anthropogenic load into the standing water of Ruguma Seasonal Ponds. This has caused eutrophication through the sustained delivery of these anthropogenic nutrients to this surface water over time. When trophic state moves from oligotrophic through mesotrophic, eutrophic to hypereutrophic, the nutrients in such a soil is unnecessarily too much for agricultural activities to take place, since there is low oxygen concentration (hypoxia) in such place. The mechanism by which this happens has not been closely monitored and studied. The problem here is to develop a mechanism to monitor hypereutrophication using variable parameters like phosphorus, oxygen and organic matter (biomass), such that the trophic state of an aquatic system can easily be predicted (Revenga et al 2000). Below is a table showing the threshold of the various trophic states.

Table 1: Classification of lakes according to the extent of eutrophication

Parameter\Tropic state	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Average total phosphorus	8	26.7	84.4	>200
Average total nitrogen	661	753	1875	>2000
average chlorophyll a	1.7	4.7	14.3	>100
Chlorophyll a peak concentration	4.2	16.1	42.6	>500

Hypereutrophication can cause pH and dissolved oxygen variation due to changes in algal biomass, transparency and nutrient concentration. These variations may interfere with

recreational, aesthetic and fishery water usage. In addition, problems associated with algae can make the water less suitable for portable use and contact recreation (Novotny and Olem 1994).
The rationale for this study hinges on two major water resource problems faced in Nigeria and around the world. These are:

1) The deterioration in the quality of freshwater surface resources, including widespread eutrophication and cyanobacterial algal blooms, which present risks to human and animal health.
2) The need for more information concerning the state of freshwater resources, as this knowledge will be useful in agriculture and other activities.

Freshwater resources are in crisis as a consequence of major problems arising from global water scarcity, rising demand from population growth, the degradation of water quality through pollution, and the increasing destruction caused by water related disasters (UNESCO, 2003).
Water quality is a function of the physical, chemical and biological characteristics of water, such as its temperature, its chemical composition and concentration of nutrients, and the living organisms that reside in it (Jian & Sharma, 2005). Water quality is therefore, a 'human construct' defined as the suitability of water to sustain various uses or processes (Meybeck et al., 1996). It becomes unacceptable when it is unable to sustain the use for which it is intended, be it for human consumption or recreational purposes, or maintenance of ecosystems.
The objective of this research is to determine the applicability of sets of ordinary differential equations in monitoring the variable parameters of an aquatic ecosystem (the Ruguma Seasonal Ponds as a case study), in order to assess the water quality through analysis of these parameters and to predict its trophic status. The modified Cox et al (2009) model will be used to achieve this objective and the modification is to include phosphate as a variable parameter which was not used in the initial Cox et al model. This study will help to provide relevant information needed for agricultural practices based on the nutrient that is ruling the trophic state at any particular time.
In this study, the focus was on eutrophication process as a problem facing fresh water ecosystems. Greater emphasis was on the great Seasonal Rugwuma Ponds, an aquatic system in Rumuosi-Akpor, south-southern Nigeria. The work only focuses on the fitness of the experimental findings to the modified models and it relevance to the variable parameters behaviours in the metamorphosis of trophic states.

2.0 LITERATURE REVIEW

2.1 TROPHIC STATE INDICATORS

Trophic state terminology (ultraoligotrophic, oligotrophic, mesotrophic, eutrophic, hypereutrophic) and trophic status indices (TSI) describe the level of eutrophication with hypereutrophic being the most advanced stage of nutrient inputs and water quality Effects. According to Carlson's TSI the reservoirs are classified as eutrophic or hypereutrophic based upon prior chlorophyll-a and total phosphorus (TP) measurements (Carlson 1977).
The level of eutrophication can be classified by the trophic state index. Ultraoligotrophic lakes have low nutrient concentrations, low algae growth and high transparency. As nutrient concentrations and primary production increase, the water body classification can change from ultraoligotrophic to oligotrophic, mesotrophic, eutrophic and finally, hypereutrophic. An increase

in TP can be responsible for a shift in these trophic designations because TP is typically limiting in aquatic environments. Consequently, most TSI rely upon phosphorous concentrations to define trophic classification. Transparency (measured by Secchi depth), nitrogen and chlorophyll-a concentrations are also used in estimating trophic status (Novotny and Olem 1994).

In aquatic environments phosphorous is typically the nutrient in shortest supply (Novotny and Olem 1994) relative to nitrogen for several reasons. The atmosphere is not a source of phosphorous because phosphorous does not exist in gaseous phase as nitrogen does. Also, the phosphate in the Earth's crust is not very water soluble. Phosphorous sorbs strongly to soil particles making erosion and dry deposition one source of phosphorous in water. Sorption to soil particles also allows it to be removed by sedimentation (Chapra 1997). However, nitrogen differs from phosphorous in that it does not readily sorb to soil particles, it exists in the atmosphere and may be removed from the aquatic ecosystem through denitrification (Chapra 1997).

Chapra argues that the (N:P) ratios are useful in defining the nutrient in shortest supply that will limit algal growth. The use of N:P ratios to assess nutrient limitation assumes that algal growth is proportional to the quantity of either nitrogen or phosphorous in the water body (Ryding and Rast 1989).

Chlorophyll-a, another response variable, is used to assess the trophic status of a lake by estimating phytoplankton biomass. Algae, plants and cyanobacteria contain chlorophyll-a, a photosynthetic pigment that typically constitutes 1 - 2 % of the dry weight of planktonic algae (APHA 1995). The chlorophyll content of algae varies depending upon light availability, temperature and metabolism (Wetzel 1983).

Hypereutrophic lakes and reservoirs can have chlorophyll-a concentrations greater than 200 mg/L (Novotny and Olem 1994). One of the most important response factors of eutrophication is the accumulation of nuisance levels of algal biomass (Smith and Bennett 1999), making chlorophyll-a measurements important in eutrophication evaluation.

Lake habitat classification schemes have been based upon geography, physical factors, chemical factors, aquatic species and trophic status. Of the many options, trophic classification is currently the most widely used and accepted (Leach and Herron 1992)

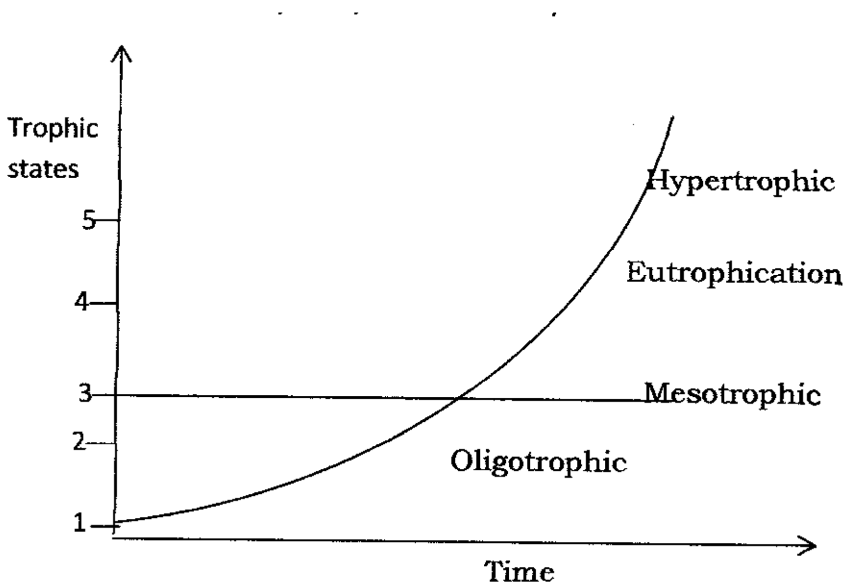

Fig 1: Trophic states over time

Conventionally, the parameters used to evaluate eutrophication and to construct models include nitrates, phosphates, carbon and chlorophyll (Rast et al 1983; Ryding and Rast, 1989;). Recent eutrophication models have been given by Adeyemo et al (2008), Anneville et al (2005), Ryan et al (2003).

The excessive overloading of soil with industrial fertilizers and uncontrolled discharges of nutrients (nitrogen and phosphorus) from municipal and industrial point sources have had serious worldwide consequences in water quality. The situation is troublesome as the water quality of a majority of impoundments deteriorate to the point that the basic uses of these water bodies for recreation and other uses are gone.

2.1.1 Importance of Phosphorus

The quality of the nation's surface water has become an increasing concern as the population has grown and the demand for clean water has increased. Many of man's activities such as land development for agriculture, industrial, or residential use increase the level of nutrients entering a water body from runoff. As excess nutrients enter a water body a process of enrichment known as eutrophication occurs, the results of which are increased productivity of plant life and water-quality degradation. Some common symptoms of a eutrophic lake or reservoir are anaerobic bottom water, algal blooms, prolific aquatic plants, increased populations of bottom-dwelling fish, and iron and manganese in the water column (Cooke, 1989), Codd et al (2005).

The trophic state describes the condition of a lake or reservoir in terms of its nutrient enrichment. Besides being eutrophic, a lake can be considered oligotrophic, mesotrophic, or hypertrophic. An oligotrophic lake is one with clear, pristine water and minimal plant life that would be an ideal drinking water source. Mesotrophic is the lake classification that falls between oligotrophic and eutrophic. Lakes overrun by aquatic plants and algae are considered hypereutrophic Conley et al (2009).

The influx of excess nutrients, especially nitrogen and phosphorus, to a water body starts a cycle of water-quality degradation that is difficult to break. Algae utilize the nutrients for growth, and when the algae die, they settle to the bottom of the lake or reservoir. The organisms that degrade the dead algae exert an oxygen demand that removes oxygen from the water, and if the bottom water becomes anaerobic, a reducing environment is created and phosphorus that is incorporated in the sediments can be released into the water column. Mixing of this released phosphorus with the entire lake volume starts the process over again, as algae can then use the phosphorus previously bound to the sediments. This process is called "internal loading" or "internal fertilization". If the water body is a drinking water supply, eutrophication can cause problems during the treatment process Elliott and May, (2008). Algae can cause taste-and-odor problems, clog filters, and their extracellular products, if chlorinated, can create trihalomethanes (THMs) and other disinfection by-products (DBPs). Iron and manganese are nuisances but not health threats in drinking water, however they will stain clothing and fixtures and clog pipes if allowed into a distribution system. Manganese is especially difficult and expensive to remove during the treatment process. These problems are most always worse during dry season when deep, eutrophic reservoirs are thermally stratified. Algae in most fresh water supplies are phosphorus limited. In other words, phosphorus is the nutrient that is usually in the shortest supply among the essential nutrients that algae need for growth. For this reason, the phosphorus concentration is crucial for water quality management.

One reason phosphorus is often limiting is that it is lost from the water column by sedimentation of both inorganic and organic forms (Cooke, 1989).

2.1.2 Sources of Phosphorus

Phosphorus entering a lake or reservoir can originate from both point and nonpoint sources. In regions where there is no phosphate detergent ban, effluents from laundering and other cleaning operations can be significant inorganic phosphorus sources, usually delivered to receiving streams in domestic wastewater effluents. Domestic wastewater, therefore, is a point source of inorganic phosphorus, and, organic phosphorus from human excreta and food wastes as nonpoint phosphorus sources often contribute the majority of the phosphorus load because they are not regulated as stringently as effluents from industries (Hofman et al, 2008).

Little is known about how these two factors may interact to control cyanobacterial growth. Modeling studies indicate that temperature and nutrients may interact synergistically to promote blooms (Elliott and May 2008), but it remains unknown as to how these two factors would interact in systems of different trophic state. Brookes and Carey (2011) proposed that nutrients ultimately control cyanobacterial biomass and composition, but at high nutrient concentrations, nutrients and temperature may synergistically interact to control blooms.

2.2 MERITS OF EUTROPHICATION

- Improved biodiversity: Biodiversity does not only entails the large animals and plants, but also the algae, fungi, bacteria and various types of invertebrates and insects. These smaller microorganisms are responsible for enriching the soil with nutrients needed for plant growth. Fungi and bacteria degrade organic matter, which break down into fertile soil.
- Boosts ecotourism: Since eutrophication leads to accelerated growth of forest tress and woodlands, tour companies promote ecotourism in locations like jungles and forests, where tourist enjoy natural aestheticity.

- Source of medicine: Most plants and microbes in these ecosystems are incorporated into modern medicine in the manufacture of antibiotics to treat an array of diseases.
- Source of food: Increase in the biodiversity of an ecosystem will provide a variety of foods for the aquatic inhabitants.(Carey et al 2012).

2.3 DEMERITS OF EUTROPHICATION

- The population of fish and other aquatic organisms decrease.
- The dissolved oxygen in the water decreases dramatically.
- Fishing and other recreational activities are hindered in such aquatic system.
- There is increased Biochemical Oxygen Demand (BOD)(Paerl et al 2001).

3.1 DEVELOPMENT OF MODELS

Several predictive techniques (models) have been developed to evaluate the effect of nutrient concentration in aquatic ecosystems. As noted earlier, if phosphorus is the limiting nutrient, the in-lake phosphorus concentration will control algal growth.

In developing this model, a new model was not started from first principle, instead, Cox et al. (2009) model was modified to accommodate phosphate as an algal controlling parameter present in the Ruguma Seasonal Ponds.

Cox et al. (2009) explored the consequences of the inhibition of algal growth by examining the steady state and transient behavior of a simple mathematical model (i.e systems of ordinary differential equations), designed to capture core features of the ecosystem behavior under over-enrichment with ammonium. The model consist of three state variables: algal biomass B, dissolved oxygen O_2 and ammonium NH_4 and can be considered as a one box model of the whole freshwater system. In the model, the following processes are taken into account and are given values based on Soetaert and Herman (1995b), Regnier et al. (1997) and Hofmann et al.(2008) process formulations: flushing, net primary production, difference between gross primary production and autotrophic respiration, nitrification and surface reaeration.

The phosphate parameter was not used in the original Cox et al. model. The Cox et al. (2009) model deals with systems of ordinary differential equations (ODEs). Each ODE represents the variation of a particular parameter and its interaction with other parameters. The parameters considered here are biomass, oxygen, ammonium and phosphates. In the modified Cox et al model, phosphate was added.

3.1 COX ET AL (2009) MODEL FOR BIOMASS, OXYGEN AND NITRATE

- For algal biomass

$$\frac{dB}{dt} = r_3(K_3 - B) + \mu \frac{O_2}{O_2 + K_1}\left(1 - \frac{B}{K}\right)B - r_2 B \text{..............................(1)}$$

- For Oxygen

$$\frac{dO_2}{dt} = r_4(K_4 - O_2) - \frac{M_1 O_2}{O_2 + K_1}.\frac{NH_4}{NH_4 + K_2} + \frac{M_2 O_2}{O_2 + K_1}\left(1 - \frac{B}{K}\right)B - r_2 B + r_0(a - O_2) \text{...........(2)}$$

- For ammonium

$$\frac{dNH_4}{dt} = r_2(K_5 - NH_4) - r_1 \frac{O_2}{O_2 + K_1} \cdot \frac{NH_4}{NH_4 + K_2} - \frac{M_2 O_2}{O_2 + K_1}\left(1 - \frac{B}{K}\right)B - r_2 B \ldots\ldots\ldots\ldots\ldots(3)$$

3.2 THE MODIFIED COX ET AL MODEL

The Modified Cox et al Model which includes phosphate is shown below

- For Algal biomass

$$\frac{dB}{dt} = r_3(K_3 - B) + \mu \frac{O_2}{O_2 + K_1}\left(1 - \frac{B}{K}\right)B - r_2 B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

- For Oxygen

$$\frac{dO_2}{dt} = r_4(K_4 - O_2) - M_1 \frac{O_2}{O_2 + K_1} \cdot \frac{NH_4}{NH_4 + K_2} - M_4 \frac{O_2}{O_2 + K_1} \cdot \frac{PO_4}{PO_4 + K_1} + M_2 \frac{O_2}{O_2 + K_1}\left(1 - \frac{B}{K}\right)B - r_2 B + r_0(a - O_2) \ldots\ldots.(5)$$

- For ammonium

$$\frac{dNH_4}{dt} = r_5(K_5 - NH_4) - r_1 \frac{O_2}{O_2 + K_1} \cdot \frac{NH_4}{NH_4 + K_2} - M_3 \frac{O_2}{O_2 + K_1}\left(1 - \frac{B}{K}\right)B - r_2 B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

- For Phosphate

$$\frac{dPO_4}{dt} = r_6(K_6 - PO_4) - r_1 \frac{O_2}{O_2 + K_1} \cdot \frac{PO_4}{PO_4 + K_8} - M_5 \frac{O_2}{O_2 + K_1}\left(1 - \frac{B}{K}\right)B - r_2 B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

If $O_2 = x_1$, $B = x_2$, $NH_4 = x_3$ and $PO_4 = x_4$; then the modified equation may be rewritten as;

$$\frac{dx_2}{dt} = r_3(K_3 - x_2) + \mu \frac{x_1}{K_1 + x_1}\left(1 - \frac{x_2}{K}\right)x_2 - r_2 x_2 \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$\frac{dx_1}{dt} = r_4(K_4 - x_1) - \frac{M_1 x_1}{K_1 + x_1} \cdot \frac{x_3}{K_2 + x_3} - \frac{M_4 x_1}{K_1 + x_1} \cdot \frac{x_4}{K_8 + x_4} + \frac{M_2 x_1}{K_1 + x_1}\left(1 - \frac{x_2}{K}\right)x_2 \ldots\ldots\ldots\ldots(9)$$

$$\frac{dx_3}{dt} = r_5(K_5 - x_3) - \frac{r_1 x_1}{K_1 + x_1} \cdot \frac{x_3}{K_2 + x_3} - \frac{M_3 x_1}{K_1 + x_1}\left(1 - \frac{x_2}{K}\right)x_2 - r_2 x_2 \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

$$\frac{dx_4}{dt} = r_6(K_6 - x_4) - \frac{r_1 x_1}{K_1 + x_1} \cdot \frac{x_4}{K_8 + x_3} - \frac{M_5 x_1}{K_1 + x_1}\left(1 - \frac{x_2}{K}\right)x_2 - r_2 x_2 \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

The lake is assumed to be well-mixed and the concentration of nutrients is assumed to be constant throughout. It is also assumed that any load is instantaneously mixed throughout the ecosystem but if the effluent from a point source discharges directly into the system, the "well-mixed" assumption may be violated.

3.3 EXPERIMENTATION

In this research, the variation of certain variable parameters of the Great Rugwuma Seasonal Ponds were monitored for a period of eight months at the Fugro International Laboratory Portharcourt, Nigeria. This was done to see the effect of their simultaneous action per month so as to determine the trophic state of the aquatic system. Four sets of ordinary differential equations (models) were developed and solved simultaneously using the MATLAB Package of 7.9 version to determine the concentration of biomass, oxygen, ammonium and phosphate with time.

3.4 DATA COLLECTION AND CURVE FITTING

Initial and boundary value constants of the ODE are collected from the Cox et al.(2009) research work, and, for the phosphate, deduced from text. These were employed in solving the systems of ODEs simultaneously using MATLAB 7.9 Version. This is to enable us see the behavior of the profile of the variables (Algal, Biomass, Ammonium and Phosphate) as against time of the hypereutrophication process. A programme (Appendix I) was written to solve the systems of ODE and to displace variable parameter profile as against time in months.

4.0 RESULT PRESENTATION AND DISCUSSION

4.1 Results for Systems of ODE

From figures 2, 3, 4, and 5, it is seen that only four variable parameters considered are oxygen concentration, Biomass and ammonium and phosphate concentration.

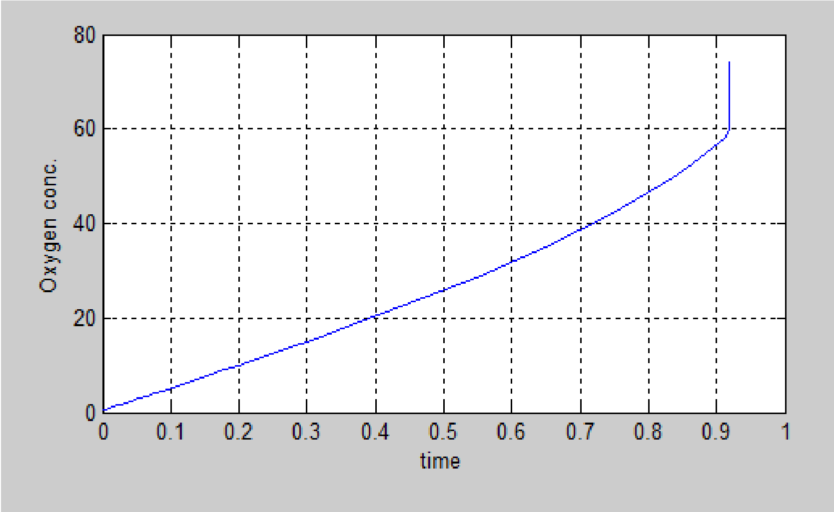

Fig 2: Graph of oxygen concentration versus time(yr) from the modified Cox et al model

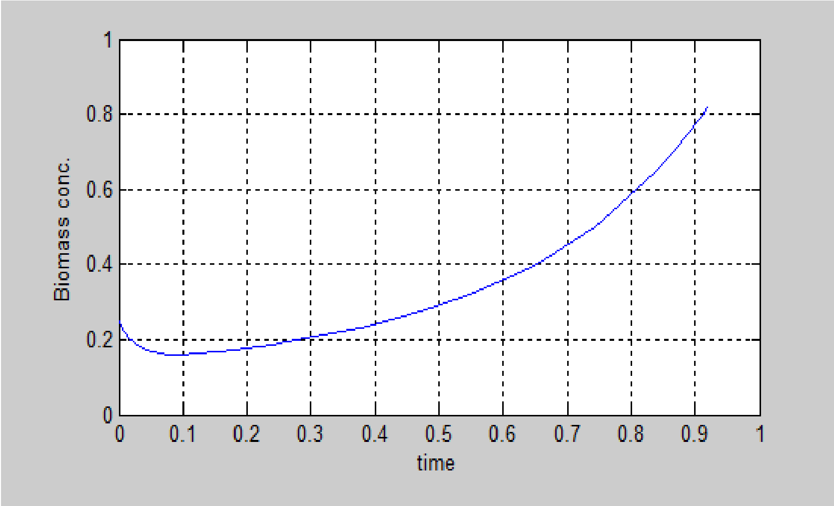

Fig 3: Graph of Biomass concentration versus time (yr) from the modified Cox et al. model

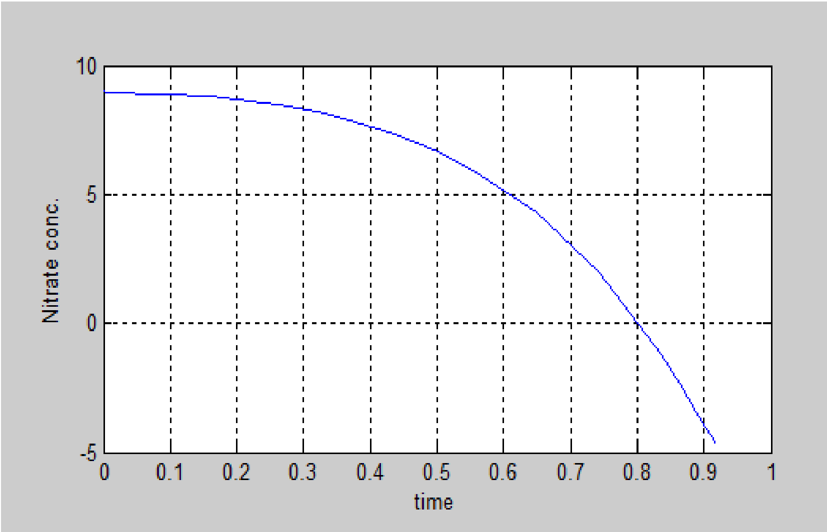

Fig 4: Graph of ammonium concentration versus time (yr) from the modified Cox et al. model

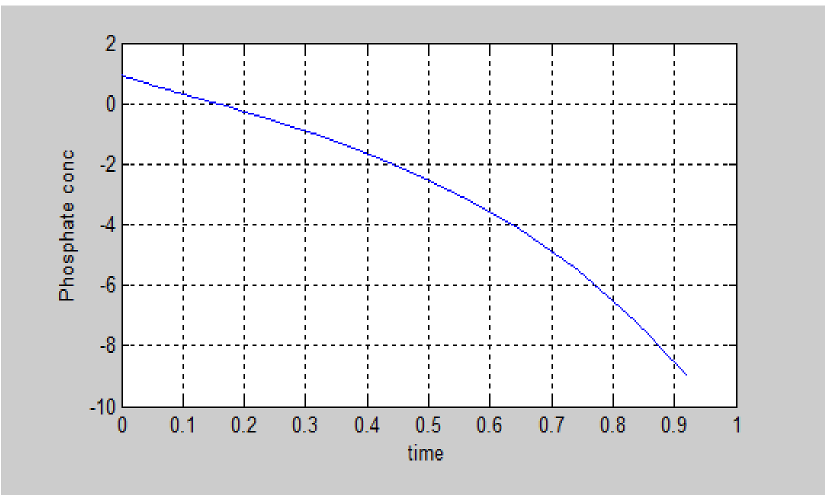

Fig 5: Graph of Phosphate concentration versus time (yr) from the modified Cox et al. model.

From the above graphs, oxygen (fig 2) progressively increases with time until after the 0.9 year (10 months 24 days) when it maintains a steady sky-short increase in concentration at a fixed time. The biomass concentration (fig.3) first decreased slightly up to 0.08 year (29 days) before increasing exponentially. However both ammonium nitrate (fig 4) and phosphate (fig 5) decreased exponentially but at different rates.

The algal biomass gradually increases towards the end of the year. The variation of these four parameters with time as compared with experimental data from the Great Ruguma Ponds may justify a claim that the Pond is Recovering from hypereutrophication. In the hypereutrophication process, nitrification reduced oxygen and ammonia concentration with no inhibition of algal growth. Steady State is attained when ammonia (nitrate) has disappeared from the system. However, at Steady State, oxygen and biomass concentration never gets to zero but nitrate concentration may be zero.

4.2 RESULTS OF FUGRO LABORATORY LAB TESTS ON GREAT RUGUMA PONDS SOIL SAMPLES

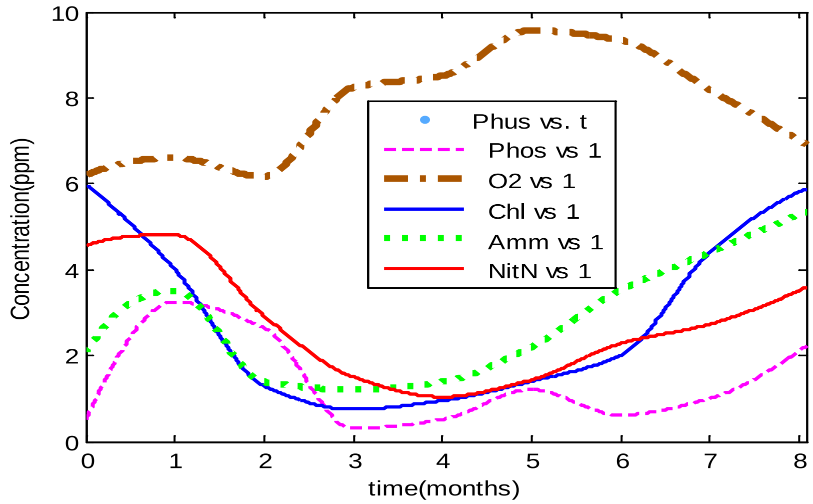

Fig 6: Nutrient concentrations versus time

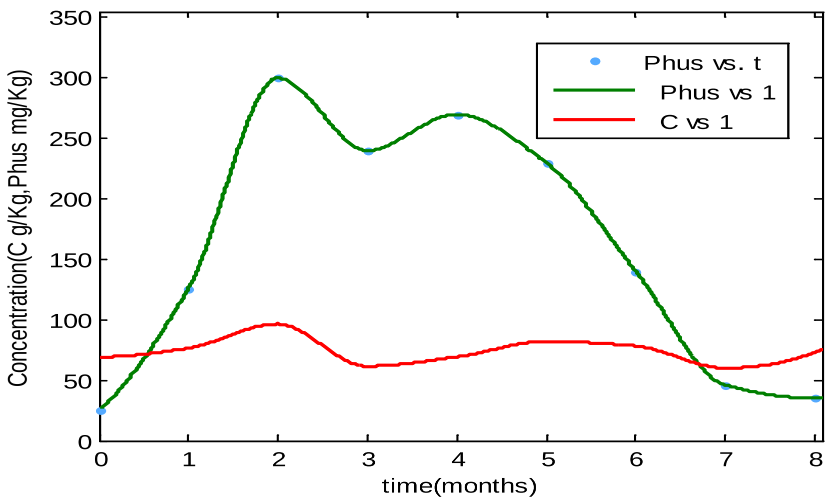

Fig 7: Nutrient concentrations versus time

In figure 6, from the curve fitting, it is seen that oxygen concentration profile has a slightly sinusoidal increase with time and attained a peak at the fifth month. It finally decreases progressively to the eighth month. The chlorophyll concentration profile has a drastic decrease in nutrient with time and gradually increases to the eighth month. The other nutrients concentration profiles made a trough in their various degrees with time and started rising from the sixth to the eighth month. In other words, they were working in opposite mechanism to that of dissolved oxygen profile. However in figure 7, carbon and phosphorus were isolated due to their higher concentration variation. Here it is seen that carbon made a low zig-zag rise and fall motion while the phosphorus profile produced two high peaks before falling. This also shows that phosphorus, oxygen and carbon play very important part as their concentrations are also high in trophic state analysis. Another look can be made of the nutrients concentration variations with time in fig 8 where the percentage concentration of the various nutrients is charted with time in months.

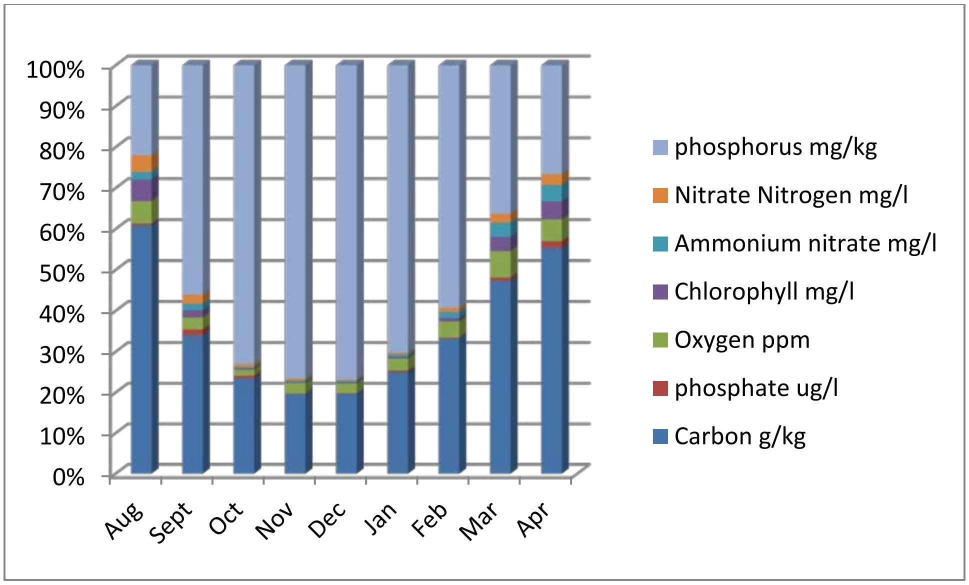

Fig 8: Chart to show nutrient concentration in eight months.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In this work, Experimental results were monitored for a period of eight months on certain variables parameter in great Ruguma eutrophication site with Fugro International Laboratory to observe the profiles of the simultaneous variations of these parameters with time. Some parameters show the approach or eminence of hypereutrophication. Cox et al (2009) model for recovering from hypereutrophication was modified to accommodate phosphate concentration variation in the great Ruguma hypereutrophication. Numerical values of constraints, initial and boundary conditions were culled in from the works of Cox et al (2009) in solving the system of ODEs modified. From the analysis made on the results obtained, the Great Ruguma Seasonal Ponds may be said to be recovering from hypereutrophication. The findings of this work can be applied in any trophic study especially when it is entering or recovering from hypereutrophication.

5.2 RECOMMENDATIONS

After thorough study of the above subject it is recommended that;

The government of the affected countries should take measures to reduce the required pollution load of surface water resulting in eutrophication then to hypereutrophication.

There should be measures like treatment of municipal sewage and industrial effluents including nutrient removal.

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APPENDIX I

Algorithm for the systems of ordinary differential equations

```
function [T,Y,K]=call_aqua()
clc
tspan = [0 3000];
y1_0 = 0.4;
y2_0 = 0.25;
y3_0=9;
y4_0=0.95;

[T,Y] = ode15s(@aqua,tspan,[y1_0 y2_0 y3_0 y4_0])
plot(T,Y(:,1),T,Y(:,2),T,Y(:,3),T,Y(:,4))

subplot(2,2,1)
plot(T,Y(:,1))
grid
subplot(2,2,2)
plot(T,Y(:,2))
grid
subplot(2,2,3)
plot(T,Y(:,3))
grid
subplot(2,2,4)
plot(T,Y(:,4))
grid
end
```

```
function dydt=aqua(t,y)
k1=1
k2=5
k3=20
k4=300
k5=50.55
k6=1.25;
k7=5;
k8=9;
r0=0.3;
r1=1.5;
r2=35;
r3=0.25;
r4=0.16;
r5=0.15;
r6=0.28;
r7=0.28;
M1=1.9;
M2=2.5;
M3=1.3;
M4=1.2;
M5=2;
k=250;
meu=1;
dydt=zeros(4,1);
dydt(2)=(r3*(k3-y(2)))+(meu*(y(1)/(k1+y(2))))*(1-y(2)/k)*y(2)-r2*y(2);
dydt(1)=(r4*(k4-y(1)))-(M1*(y(1)/(k1+y(1))))*(y(3)/(k2+y(3)))-(M4*(y(1)/(k1+y(1))))*(y(4)/(k8+y(4)))+(M2*(y(1)/(k1+y(2))))*(1-y(2)/k)*y(2);
dydt(3)=(r5*(k5-y(3)))-(r1*(y(1)/(k1+y(1))))*(y(3)/(k2+y(3)))-(M3*(y(1)/(k1+y(2))))*(1-y(2)/k)*y(2)-r2*y(2);
dydt(4)=(r6*(k6-y(4)))-(r1*(y(1)/(k1+y(1))))*(y(4)/(k8+y(3)))-(M5*(y(1)/(k1+y(1))))*(1-y(2)/k)*y(2)-r2*y(2);

end
```

APPENDIX II

RESULT DATA FROM FUGRO LABORATORY TESTS ON GREAT RUGUMA PONDS SOIL SAMPLES

Table 2: Experimental Data for Nutrient Concentration in Eight Months

Nutrient/month	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Carbon g/kg	69.02	76.36	96.48	61.56	69.15	82.1	78.36	60.01	72.95
phosphate ug/l	0.5	3.25	2.65	0.3	0.51	1.21	0.62	1	2.1
Oxygen ppm	6.2	6.61	6.17	8.24	8.51	9.57	9.35	8.2	7.02
Chlorophyll mg/l	6	4	1.3	0.75	0.95	1.4	2	4.4	5.8
Ammonium nitrate mg/l	2.09	3.52	1.39	1.21	1.39	2.2	3.52	4.4	5.28
Nitrate Nitrogen mg/l	4.55	4.81	2.93	1.51	1.04	1.43	2.28	2.73	3.51
phosphorus mg/kg	25	126	300	240	270	230	140	46	35