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Modeling and Modification of the Effect of Self Purification of Kwa River Pollution

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Abstract

River pollution is a complex physical, biochemical and ecological process, which pose a global threat and challenge to environmental issues. The problem of reducing pollution and improving water quality can be solved by using the appropriate mathematical models and their implementation in software. Waste is considered a grave threat to our urban environments, especially our streams and rivers. From the study, it has been observed that improper practices of solid waste management carried out at the Lemina landfills site and the inappropriateness of leachate collection system and its treatment or recycling exert a tremendous impact on the surface and groundwater quality. This paper examines the main sources of pollution in the river and presents a mathematical modification of the river pollution. It addresses the problem of mathematical modelling of river pollution and pollutant dispersion in rivers. It summarizes the mathematical formulation in the field of river water quality modelling. Using mathematical modelling helps to predict the behaviour of self-purifying systems and to determine the results of actions of different processes on river systems.

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Modeling, Modification, Pollution, purification, Kwa River, Wastes

Introduction

The Kwa river is one of the major tributaries of Cross River estuary. It takes its rise from the Oban Hills in Akamkpa of Cross River State, flows Southwards and discharges into the Cross River around the latitude of $4^0 45^1$N and longitudes 8^0 20^1 E. The lower reaches of the River drains the eastern coast of the Calabar municipality the capital of Cross River State of Nigeria.

The lower Kwa river is characterised by semi-diurnal tides and extensive muds flats. Apart from artisanal fisheries which target mainly the macro brachium, human activities within the Kwa river catchment is limited to small-scale farming and aquaculture. With the increase in population in the area and associated with the Export Free Zone status of Calabar the river is constantly polluted.

Presently, the State has no waste treatment plant, human settlement and industrial layouts are expanding rapidly into the freshwater and mangrove swamps, cottage industries are disposed of as well as the scattered surface dump in the river. Expected future developments will put increasing pressure on the self-purification capacity of the river with attended negative consequences on most water users in that area. One of the critical problems of developing countries like Nigeria is the improper management of vast anthropogenic activities.

The more, challenging is the unsafe disposal of these wastes into the ambient environment.

Consequently, most of the wastes, especially the solid ones, are carried to our rivers and streams through surface runoff which contributed a major pollution, comprising 90% of heavy metals.

According to Aderemi *et al.*, (2011), they discussed municipal solid waste disposal as a global concern, especially in developing countries across the World; as poverty, population growth and high urbanization rates combine with ineffectual and under-funded by the government to prevent the efficient management of wastes.

A number of Scholars, Longe and Balogun., 2010, Kumar., *et al.*, 2012, Looser, 1999, Moo_ Young *et al.*, 2004, have examined the causes of river and groundwater pollution as mainly due to the process of industrialization and urbanization that has progressively developed over time without any regard for environmental consequences, and that the dumped solid wastes gradually release its initial interstitial water and some of its decomposition by-products get into the water flowing through the waste deposit and empty into the river.

Problems of environmental pollution requires swift action to prevent lowering water quality. Choosing pollution control methods and determining quality is an important step in improving water quality. An effective method of controlling and predicting water pollution is the use of information systems consisting of two main components: mathematical models and software, which are generated by numerical models Gages *et al.*, 2011.

Furthermore, Abu-Rukah and Al-Kofahi, 2001; Abid and Jamil, 2005 have equally examined the possible river contamination around municipal landfills by using the microbiological examination and physio-chemical analysis of leachate and groundwater and the focus of these scholars has been to find out the impact of landfills on groundwater quality, quantitative analysis of level of water contamination and the identification of possible threats to the local environments and residents as well.

Accordingly, Barrett and Lawlor, 1995 concluded in their work, that landfilling is the simplest, cheapest and most cost effective method of disposing of waste in both developed and developing nations of the World and they added that municipal landfill leachate is highly concentrated with complex effluents which contain dissolved organic matters, inorganic compounds such as ammonium, calcium, magnesium, sodium, potassium, Iron, Sulphates, Chloride and heavy metals such as Cadmium, Chromium, copper, lead Zinc, Nickel and xenobiotic organic substances.

Noye and Hayman (1994) discussed to useof ADI to solve the two dimensional time-dependent heat equations subject to a constant coefficient. Dehghan (2002) used ADI methods for solving elliptic problems. Alias and Islam (2010) used Alternating Group Explicit (AGE) method and iterative Alternating Decomposition Explicit (IADE) method to solve a two- dimensional and three-dimensional in PDE problems. A discrete mathematical model was obtained where border nodes have the same order of approximation as the interior, G. Manina, 2011. A deterministic mathematical model was developed to determine the dispersion of petroleum products for a sector of Prut River from Costesti in the Republic of Moldova. Similarly, Antar and Mokheimer (2011) used spreadsheet programs to solve a three dimensional equation for numerical solutions by using finite difference solutions which are the most appropriate. Taha and Ablowwitz (1984) solved a generalized Korrteweg-De varies equation.

According to Ciufudeen *et al.*, 2008, mentioned that, modeling processes through probabilistic models, the method of Monte Carlo is used. In surface waters area the mathematical models are used for solving wastewater treatment, industrial pollution, agricultural pollution, protection of potable water sources and others. The models are used in dispersion the transport of pollutants, control and analysis of the processes.

In the research of Tsegaye and Koya (2016) they explained that Advection –Diffusion- Reaction (ADR) equations are partial differential equations PDEs that dependent on temporal and spatial coordinates, that ADR equations can be used to model mathematically, a wide range of natural phenomenon and explain their dynamics range with respect to time.

They developed a discrete dynamical model as an example of a mathematical model that describes the pollution problem more clearly.

Further, stresses that dynamical system is about the evolution of some quantities over time and that this evolution can be as continuous over time or in discrete time steps. He maintained that, river flowing has an effective quality of getting purify as it moves forward with distance and this process is referred to self – purification.

Similarly, Agunwamba (2001), discussed waste engineering and management tools in pollution control. The consistence indiscriminate discharges of industrial effluents in receiving water bodies is an improper way of disposal of domestic wastes, particularly in urban centres of the most developing countries and result in the outbreaks of water-borne diseases like cholera and hepatitis.

Research method

From the case study area, water samples were carefully collected in three different locations in a clean one-litre plastic polythene bottle from the river which includes the upstream, downstream and mid-stream.

These samples were collected at a depth of 1.5 m, the bottles were labelled accurately by date and time of collection. The river samples were collected from equidistance of 100, 200, 300, 400 and 500 m, from the river within a 3km radius of the landfill close to the river. The collected samples were taken to Cross River State water board laboratory for both physio-chemical and bacteriological analyses.

In this research paper, we adopt the one-dimensional Streeter-Phelps equation which described the river self-purification model as a concrete approach. This approach model describes the level of pollutant upstream and downstream as the pollutants travel with the stream velocity in the direction of the river flow.

Now the introduction of the diffusion-reaction systems is interesting on many levels, displaying phenomena, such as pattern formation far from equilibrium. The diffusion reaction systems are mathematical models that are used to illustrate how concentrations of one or more substances are distributed in space and how these concentrations vary under the influence of the processes namely, diffusion and reaction.

Diffusion causes the pollutant substances to spread out in the river water and during the local chemical reactions the pollutant substances are transformed into each river, Craster and Sassi 2006, Gerisha and Chaplain (2004).

The representation of the analyst materials obtained fromKwa river at each point of up-stream, mid-stream and down- stream, are depicted in the Table below.

Mathematical Description

Several physical problems in engineering when modelled mathematically leads to a partial differential equation (PDE).

Consider the coupled equations for the pollutant and dissolved oxygen concentrations. The coupling occurs because the oxygen reacts with concentration P. We consider cases with and without dispersion k negligible ($0 \approx k$) and k non- zero. To simplify the equations, we set the values A, v, q, α and S to be constant. We assume that the polluted Kwa river contains, N contaminants with concentrations U_i, where i =1, 2,…, N. let us restrict the independent variables to the regions $0 \leq x \leq 1$ and $t \geq 0$. The boundary conditions are considered as 0,= 1,=1 and 0,= 1,=0.

The initial conditions are considered as $U_1(0,t) = U_1(1,t) = 1$ and $U_2(0,t) = U_2(1,t) = 0$. The initial conditions are considered as $U_1(x,0) = 1$ and $U_2(x,0)$ 6. Also, the parameter values are chosen as λ-=3, $\omega = 1$ and $K_2=1$.

To model the Kwa river pollution to each of the chemical contaminants is given by Brain *et al.*, (2002) and Gibbons (2007).

$$(\partial U_i/\partial t) + [\partial(wui/\partial z)] - [D_i (\partial^2 u_i/\partial z^2)] = [(q_i/A) + K_i U_i + C_i], \forall_i=1,2,\ldots, N \quad (4.1)$$

Modification of equation 1, here we assumed that $[\partial(wu_i/\partial z)]$, which is the advection along the river is ignored because, when w=0, the pollution in the mid-stream (MS) does have much effect due tohigh flow from the upstream (UP) and the downstream (DS). Again we assumed that pollution input has ceased and BOD can decay by combining the DO of the following downstream, because the contaminants or the pollutants will not evaporate, so equation (1) will be reduced to.

$$(\partial U_i/\partial t) + [\partial(wu_i/\partial z)] - [D_i (\partial^2 ui/\partial z^2)] = [(qi/A) - K_i U_i \quad (4.2)$$

Hence, equation 2 becomes modified equation

$$(\partial U_2/\partial t)=D_2 (\partial^2 U_2/\partial z^2) - K_2 U_2 \quad (4.3)$$

Let assume that the oxygen diffuses into the river from the air,then the flux of oxygen into the river per unit area is given by this expression($[K_0(w\text{-}U1)]/h$], when the h represent effective depth of the imagining membrane,

$K_0$is permeability to oxygen, and w is the concentration of oxygen in the air above the river surface. Multiplying the flux ($K_0[w-U_i]$)/h, here b is the width of the river in obtaining the rate at which oxygen enters the river per time duration and is given in the equation below.

$(q1/A) = ([b\ k_0 (w-U_1)]/Ah = \lambda(w-U_1)$ (4.4)

$-K_1U_1 = - YU_1U_2 =-K_2U_2$ (4.5)

Let $(\partial U_1/\partial t) =D_1 (\partial^2U_2/\partial x^2) + \lambda(w-U_1) - K (U_1, U2)$ (4.6)

$(\partial U_2/\partial t) = D_2 (\partial^2U^2/\partial x^2) - K (U_1, U2)$ (4.7)

$K (U_1, U_2) = K_IU_1$, first order kinetics

$K_2U_1U_2$, second order kinetics (4.8)

Solving the system of equations

Solving the system of equations in (4.6) and (4.7) with second order kinetics, we make use of the system of equations given in (4.9) and (4.10).

$(\partial U_1/\partial t) =D_1 (\partial^2U_1/\partial X^2) + \lambda(w- U_1) - K_2U_1U_2$ (4.9)
$(\partial U_2/\partial t) = D_2(\partial^2U_2/\partial X^2) - K_2U_1U_2$ (4.10)
$(dU_1/dt) =\lambda(w-U_1) - K_2U_1U_2$ (4.11)
$(dU_2/dt) = K_2U_1U_2$ (4.12)

Applying the method of central difference in space;

$U_{1,I}= (D_1/\Delta x^2)(U_{1,\ I+1}-2U_{1,\ I} +U_{1,I-1}) +\lambda(w-U_{1,I}) -K_2U_{1,I}$ (4.13)

Now to have non zero diffusion, when the municipal solid waste react with the oxygen in the flowing river causing the dissolved oxygen concentration to drop and also the BOD concentration. However, after successive interval the self- purification of the river becomes active, and the BOD concentration decreases to zero and dissolved of Oxygen concentration goes to normal value 1.

In general, the interval of the step is given by [a + (i-UΔx, a +I Δx].

Using the method of central difference in space, the system of equation (4.9) and (4.10) after discretising the spatial 0≤ x ≤1 into N = 20 number of steps, is given by (4.13) and (4.14)

$U_{2,i}= (D_2/Dx^2)(U_2,i+1- 2U_{2,i}+U_2,i-1)$ (4.14)

Now equation (4.13) and (4.14) we use the notation

$U_{1,i}=[\partial U_{1,i}/\partial t]$ and $U_{2,i}=[\partial_2,i/\partial t]$ also, $U_{l,i}^{(t)}$, l = 1,2 is a function of time.

Let $Ul =[U_{l,I},\ldots,U_{l\ N-1}]$ for l = 1, 2. Now the system of equations (4.13) and (4.14) can be in a matrix form.

$U_i = (D_1/\Delta x^2) AU_1+ \lambda(w1_i- U_i) + \lambda(w-U_{1-i}) -K_2U_{1,\ I}\ U_{2,\ I}$ (4.15)

$U_{2,1} = (D_2/\Delta x^2) (U_{2,\ i+1} - 2u_{2,i}+U_{2,\ i-1}) - K_2U_{1,i}U_{2,I}$ (4.16)

Now, equation 4.15 and (4.16), the A represents a tri-diagonal matrix of order
[N-1 x N-1].

To discretize the time coordinate, let assume that the step size of time coordinate be given by $\Delta t = [(t_{end} - t_o)/m] = 0.1$.

By splitting the diffusion equation from the reaction equation from the system of equation given by (4.15) and (4.10) we obtain a system of equations in (4.17) and (4.18) respectively.

$U_2 = (D_{1/}\Delta x^2) AU_1+ (D_1/\Delta x^2) b_1$ (4.17)

$U_2 =(D_2/\Delta x^2) AU_2+ (D_2/\Delta x^2) b_2$ (4.18)

Where l= 1, 2 is an index for diffusion equation (4.11) and (4.12) equations.

approach Finally, equation (4.16) and (4.17) the step size Δt in solving the problem are given by trapezoidal rule or Crank- Nicolson method and equation (4.12) reaction equation was solved by Runge- Kutta method of four order.

Results and Discussion

Waste are considered a grave threat to our urban environments, especially our streams and rivers. From the study it has been observed that improper practices of solid waste management carried out at the Lemina landfills site and the inappropriateness of leachate collection system and its treatment or recycling exert tremendous impact on the surface and ground water quality.

Table.1 Water analysis of Kwa river

S/N	Parameter/Unit	Up-Stream A	Mid-Stream B	Down-Stream C	WHO'S STDS
1.	Tempt. (^{0}C)	28.6	28.9	28.9	Ambient
2.	PH	5.83	5.80	4.82	6.5-8.5
3.	Turbidity (NTU)	5.75	5.53	5.49	< 5
4.	Total solids	0.005	0.01	0.01	500mg/l
5.	Sulphate (SO4)	16.0	18.6	14.2	250mg/l
6.	Alkalinity	7.60	7.59	7.09	200mg/l
7.	Total dissolve solids	3.45	3.318	3.294	1000mg/l
8.	Nitrate (NO3)	5.7	3.318	4.000	50mg/l
9.	Total hardness	17.1	17.5	17.4	500 mg/l
10.	Phosphorous	5.63	5.12	4.50	-mg/l
11.	Dissolve Oxygen	7.0	7.0	7.0	5mg/l
12.	BOD5	6.06	5.41	6.00	-
13.	Acidity	0.416	0.144	0.344	250 mg/l
14.	Chlorine (mhl)	4.80	4.50	3.00	250mg/l

River has its self-cleansing ability which allows assimilation and treatment of industrial waste in the river but if releasing of waste in Kwa remains unstopped then self-cleansing process will not remain effective. Where withdrawal from the river is much higher than the discharge of waste, pollution is inevitable. Actually Discharge of untreated sewage is beyond the self-purification capacity of Kwa river that's why pollution is continuously going on increasing. All sewage lines from the area and surroundings areas should be connected to sewage treatment plants so that pouring sewage in the Kwa river can be stopped. The carrying capacity of dissolved oxygen is considered to be one unit, i.e. Less than one. When the self-purification system of the water is not active it means that the self-purification is equal to one. But, for any reason if at any time <1 then the self-purification system of the water becomes active and helps the dissolved oxygen to boost up to reach its carrying capacity for example when it is one. As long as the dissolved oxygen does not reach its carrying capacity the self – purification system does not become inactive. But, when the dissolved oxygen reaches its carrying capacity, the self – purification system becomes inactive. Thus, the responsibility of the self – purification system of the water is to see always that the amount of dissolved oxygen be at or reach its carrying capacity or saturation level.

The issue of water quality is a difficult problem because water is a complex physical, biochemical and ecological system. The consistence indiscriminate discharges of industrial effluents in receiving water bodies is an improper way of disposal of domestic wastes, particularly in urban centres of the most developing countries and result in the outbreaks of water-borne diseases like cholera and hepatitis. The future work will be software packages analysis that are used in the implementation of mathematical models in numerical models, highlighting the best software packages in addressing river pollution. An effective solution for analysing and solving various problems in water systems are methods based on mathematical modeling of such systems. River self-purification is a complex process, which presents a turbulent flow. The problem of reducing pollution and improving water self-purification can be solved by using the appropriate mathematical models and their implementation in software. In the list of current problems, which are solved by using mathematical modeling, environmental issues play a distinct role. The issue of water quality is a difficult problem because water is a complex physical, biochemical and ecological system. An effective solution for analysing and solving various problems in water systems are methods based on mathematical modeling of such systems. Using mathematical modeling helps to predict the behaviour of aquatic systems and to determine the results of actions of different processes on aquatic systems

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