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Lagrangian Model Framework: A Cutting Edge towards Predicting Pollutants Transport in River Benue of Greater City Yola, Nigeria.

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ABSTRACT *The purpose of this paper is to predict the fate and transport behaviour of pollutants discharged into the Benue River through point and non point sources using Lagrangian equations of fluid motion in MATLAB default environment. To achieve this, water samples were collected from the source of this river at Adamaoua Mountains of Cameroon and Yola, the study area in well preconditioned plastic bottles and analysed for the presence of heavy metals in the river. Findings of this study showed that only Zn, Cu, and Mn concentration levels were below the permissible limits of water quality standards while Fe, Cd, Cr, Ni, and Co values were by far above the threshold limits. The model predicted output indicated a one-dimensional non uniform linear graph of pollutants' movement due to advective forces and water current effects with average water velocity of 0.66m/s covering a travel distance of 1500 meters within 15 minutes.*

Key words : : Fluid motion, Transport, Pollution, Model, and River Benue

INTRODUCTION

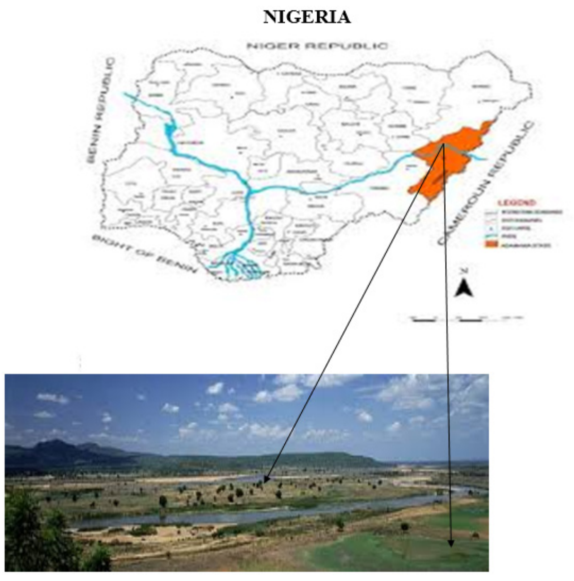
Pollution in Benue River at the Greater city of Jimeta-Yola can be attributed to many sources such as contaminants from agricultural fields, domestic sewage from the city, chemical wastes from industrial and commercial centers, waste dumpsites, atmospheric deposition, hospital wastes, abattoirs, and so on. This paper will introduce Lagrangian framework to model the travel time and distances of these pollutants in River Benue, located at about one and half kilometers down the slope of Gwari market vegetable waste dumpsites considered as one of the major sources of pollution whose heavy metals and leachates derived from them migrate through rainfall storm water runoff, seepage via soils and open drainages to contaminate the river. The insights gained from this study can be used to understand the unique realities of movement and degradation status of pollutants in surface water flows. Water pollution is the contamination of water bodies (e.g. lakes, rivers, streams, oceans, aquifers and groundwater). It occurs when pollutants are directly or indirectly discharged into water without adequate treatment to remove harmful compounds which affects plants and organisms living in these water bodies. The effect is damaging not only to individual species, but also to the natural biological communities [1]. West Larry [2] asserted that water pollution is a major global problem which requires on-going evaluation and revision of water resources policy at all levels. It has been suggested that it is the leading worldwide cause of deaths and diseases, and accounts for the death of more than 14,000 people daily. Estimates of 580 people in India die of diarrheal sickness every day [3]. Some 90% of China's cities suffer from some degree of water pollution, and nearly 500 million people lack access to safe drinking water. This problem is also peculiar in Nigeria and other developing countries; developed countries continue to struggle with pollution problems as well [4]. Most water pollutants are eventually carried by rivers into the oceans, some of which the influence can be traced hundred miles from the mouth by studies using hydrology transport models. Advanced computer models such as SWMM or the MODFLOW models have been used in many locations worldwide to examine the fate of pollutants in aquatic systems [5]. Many chemicals undergo reactive decay or chemical change especially over long periods of time in rivers. A noteworthy class of such chemicals is the chlorinated hydrocarbons such as trichloroethylene (used in industrial metal degreasing and electronic manufacturing); and tetrachloroethylene used in dry cleaning industry.

Heavy metals contamination in rivers is one of the major quality issues in many fast growing cities, because maintenance of water quality and sanitation infrastructure did not increase along with population and urbanization growth especially for the developing countries [6]. The main natural sources of metals in water are chemical weathering of minerals and soil leaching. The anthropogenic sources are associated with industrial and domestic effluents, urban storm, water runoff, and landfill leachate, mining of coal and ore, and atmospheric sources [7]. Some metals like Cu, Fe, Mn, Ni and Zn are essential as micronutrients for the life processes in animals and plants while many other metals such as Hg, Cd, Cr, Pb and Co have no biological role in the healthy organisms and can cause damage even at very low levels [8]. They are generally non- degradable and accumulate in the human body system, causing damage to nervous system and internal organs. Other adverse effects caused by chemical pollution are eye, nose and throat irritation, headache, allergic skin reaction, dizziness, nausea and difficult breathing. In worst cases long term exposure to chemical pollution can even lead to cancer. As such, in order to reduce the level of global chemical pollution, the world needs to reduce the generation of waste and ensure environmentally safe waste-disposal, ensure better monitoring and adequate laws as well as ensure improved level of care when using different chemicals for agriculture and industries [9]. During the decomposition process of organic compounds released into watercourse, the dissolved oxygen is reduced and it causes the oxygen depletion (anoxia), which have severe consequences for the stream biota. Surface water flow takes into account diffusion, convection, advection, dispersion, and chemical reactions where the pollutants at the upper water parcels mix with the lower water parcels to react with other materials or sediments on the river bed (Chris, 2004). Therefore, there is need to undertake this surface water transport modeling using acquired hydrology data integrated into Lagrangian equations and coded in MATLAB default environment in order to understand the fate and accumulation of pollutants in the Benue River through the following research objectives: (1) to analyze and characterize the presence of heavy metals and other conventional pollutants in the river, (2) develop Lagrangian model of fluid flow to simulate movement of pollutants, and (3) apply the model in MATLAB script file for the prediction of the transport pattern.

METHODS AND MATERIALS

Description of Study Site:

River Benue (French: la Bénoué) previously known as the Chadda River or Tchadda (Fig. 1) is the major tributary of the Niger River [10]. It traverses and drains Jimeta-Yola city and her environs. It is one of the 23 major rivers in Nigeria and passes through the north eastern part of the country. It rises in the Adamaoua Plateau of northern Republic of Cameroon at about 440 feet from where it flows westward; through the town of Garoua and Lagdo Reservoir with a 40m high Dam built across it. After exiting Cameroun, the Benue proceeds Westward, South of the Mandara Mountains, passing through Jimeta-Yola, Numan, Ibi and Makurdi, meeting the Niger River at Lokoja in Kogi State where they together flow through the lower Niger Delta basin and drains directly into the North Atlantic Ocean. Some of the Benue headwater tributaries are born in the South-eastern Chad. The Mayo Kébbi, one of the primary headwater tributaries to the Benue, connects it with the Logone River, an outlet of Lake Fianga (part of the Lake Chad system) forming part of the international boundary between Cameroon and Chad. Other major Benue tributaries in Nigeria are: River Gongola in Adamawa State, River Taraba in Taraba State and River Katsina Ala in Benue State. It flows a course of 1402 kilometers, through north western sub-Saharan Africa, chiefly northern Cameroon and eastern Nigeria. The river depth ranges from 1.0 to 7.0 meters at flood. The width of Benue River various from place to place due to different topographies and geological conditions of those areas as it passes through. The climatic conditions vary in the river and the annual amount of precipitation varies. These conditions have clear effects on alteration of wet and dry regimes and then on the variation of the capacity of the river being seasonally full during flood and rainy season but shrinks during dry period. The main discharge of the Benue is approximately 2450m^3/s, a level around 36% lower than that of five decades ago due to irrigation extraction [11]. It has other minor tributaries such as: Rivers Faro, Donga, Wase, Ankwe, Mada, Okwa, Mbilla, and Kilange in Nigeria.



NIGERIA
Fig.1: Map of Nigeria showing Locations of Adamawa State and River Benue as the Study Area

Method of Data Collection

Water Sampling and Laboratory Analysis:

The water sampling stretched over a distance of 6km covering the research area from under the bridge in Yola where the effect of pollution from the city and decayed vegetable waste dumpsites is greatly felt. Water samples were collected at three locations: upper stream, in the middle, and the lower stream at interval of 2km up to 6km mark. Water sample was also collected from the source of this river at Sassa Mbersi Mountains in the northern Cameroun. At each sampling point, water was collected at a depth of 5 – 10cm below the surface in separate pre-conditioned and acid rinsed clean polyethylene sampling bottles of 1 litre. The collected samples were digested with HNO_3 and filtered for determination of heavy metals in the samples after preparation of standard solutions as described in [12]. The metal concentrations were determined using atomic absorption spectrophotometer in the laboratory. The metals determined were: Zn, Cu, Mn, Fe, Cd, Pb, Ni, Cr, Co, Other conventional pollutants in the water samples were also determined such as Nitrate using nitrate testing equipment, pH of water using calibrated pH meter, Turbidity using turbidity meter.

Mathematical Model Development of Mass Transport in Rivers:

Mathematical representation of contaminants transported by water in River Benue can be achieved through basic equations of fluid motion. The equations were developed based on the following assumptions: constant discharge of water, uniform water temperature, uniform water dispersion, constant retardation factor, and uniform river slope; while the boundaries assigned were: constant head boundary, evapotranspiration boundary, recharges boundary, and river boundary. Parameters were coded in a computer based program of MATLAB script file. The equation representing this motion is:

$$T = \frac{1}{2} m \dot{z}^2 + \frac{1}{2} M \left(\dot{x}_G^2 + \dot{y}_G^2 \right) + \frac{1}{2} I_G \dot{\theta}^2 \qquad (1)$$

Where; $\dot{x}_G = \dot{z} + a\dot{\theta}\cos\theta, \quad \dot{y}_G = -a\dot{\theta}\sin\theta$

This was coded and programmed in MATLAB as:

```
Syms m M g L cvv cth K K IG a zg zgdot zgdotdot z zdot
Zdotdot v vdot vdotdot th thdot thdotdot real
Syms x1 x2 x3 x4 u real
% kinetic energy
Xgdot = zdot + a*cos(th)*thdot;
Ygdot = -a*sin(th)*thdot;

T = 0.5*m*zdot^2 + 0.5*M*(xgdot^2 + ygdot^2 + 0.5*IGthdot^2;
```

Equation (1) is extended by a typical Lagrangian mass balance equation to perform the appropriate calculation for the transport equations, which are given by:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right) - \frac{\partial T}{\partial z} + \frac{\partial V}{\partial z} = P_z \qquad (2)$$

and
$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}}\right) - \frac{\partial T}{\partial \theta} + \frac{\partial V}{\partial \theta} = P_\theta \qquad (3)$$

storage + advection - dispersion = source & sinks
The chain rule was used to evaluate the first integral in Lagrangian equations using Matlab, i.e.:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) = \sum_{i=1}^{N} \left\{ \frac{\partial}{\partial q_i}\left(\frac{\partial T}{\partial \dot{q}_i}\right)\frac{dq_i}{dt} + \frac{\partial}{\partial \dot{q}_i}\left(\frac{\partial T}{\partial \dot{q}_i}\right)\frac{d\dot{q}_i}{dt} \right\} \qquad (4)$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right) = \frac{\partial}{\partial z}\left(\frac{\partial T}{\partial \dot{z}}\right)\frac{dz}{dt} + \frac{\partial}{\partial \dot{z}}\left(\frac{\partial T}{\partial \dot{z}}\right)\frac{d\dot{z}}{dt} + \frac{\partial}{\partial \theta}\left(\frac{\partial T}{\partial \dot{z}}\right)\frac{d\theta}{dt} + \frac{\partial}{\partial \dot{\theta}}\left(\frac{\partial T}{\partial \dot{z}}\right)\frac{d\dot{\theta}}{dt} \qquad (5)$$

Each term in (2) and (3) was coded in MATLAB as follows:

$\frac{\partial T}{\partial \dot{z}}$	pTpzdot = diff(T, zdot);
$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right)$	ddtpTpzdot = diff(pTpzdot, z)*zdot + ... diff(pTpzdot, zdot)*zdotdot + ... diff(pTpzdot, th)*thdot + ... diff(pTpzdot, thdot)*thdotdot;
$\frac{\partial T}{\partial z}$	pTpz = diff(T, z);
$\frac{\partial V}{\partial z}$	pVpz diff(V, z);
$\frac{\partial T}{\partial \dot{\theta}}$	pTpthdot = diff(T,thdot);
$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\theta}}\right)$	ddtpTpthdot = diff(pTpthdot,z)*zdot + ... diff(pTpthdot,zdot)*zdotdot + ... diff(pTpthdot,th)*thdot + ... diff(pTpthdot,thdot)*thdotdot;
$\frac{\partial T}{\partial \theta}$	pTpth = diff(T,th);
$\frac{\partial V}{\partial \theta}$	pVpth = diff (V, th);

Combining these terms together yields the two equations of motion:

```
% the equation of motion for "z" (eqz = 0)
eqz = simple (ddtpTpzdot – pTpz + pVpz – pz);
% the equation of motion for "th" (eqth) = 0)
eqth = simple (ddtpTpthdot – pTpth + pVpth – pth);
```

Input data were entered with a command of plot and a graph was plotted by MATLAB predicting the transport route of pollutants in the river.

RESULTS AND DISCUSSIONS

Analysis of Heavy Metals and other Pollution Parameters in Water Samples:

The results of heavy metals analysis in water samples collected from River Benue in Yola and Cameroun Mountains where the river takes its source are presented in Table 1.

Table 1: Results of Analysis of Water Samples from River Benue at Yola and Cameroun Parameters (mg/litre)

Samples	Zn	Cu	Mn	Fe	Cd	Pb	Ni	Cr	Co	NO^-3	pH	Turb. (NTU)
A	0.46	0.21	0.023	24.60	0.000	0.00	0.052	0.253	0.049	10.50	8.29	315.00
B	0.31	0.23	0.066	19.33	0.000	0.00	0.061	0.096	0.048	10.50	7.80	158.00
C	0.00	0.09	0.000	1.78	0.009	0.00	0.082	0.071	0.039	7.00	6.46	7.5300
D	1.107	0.77	0.023	13.06	0.004	0.00	0.053	0.081	0.044	7.00	7.84	171.00
WHO, 2007	3.0	1.0	0.5	1.0	0.003	0.01	0.02	0.05	0.1	50.0	6.5-8.5	5.00

A – Water sample collected from Cameroun Mountains, the source of River Benue; B – Water sample collected directly under the bridge at Yola; C – Water sample collected at 2km away from the bridge (middle stream); D – Water sample collected at 4km from the bridge (downstream) All results obtained were compared with the World Health Organisation [13] Drinking Water Quality Standard indicated in Table 1.

From the results, all Zn, Cu and Mn values fall below the maximum permitted limits of 3.0mg/l, 1.0mg/l, and 0.5mg/l. But all Fe concentration levels exceeded the stipulated limit of 1.0mg/l by far; Cd was not detected in samples A and B while samples C and D were above the reference level of 0.003mg/l. Pb was not detected in all the samples, but sadly all values of Ni were above the permissible standard value of 0.02mg/l which can lead to possible carcinogenic cases in the environment. Cr concentration values were all above the desired limit of 0.05mg/l, while Co levels in the four samples fall below the threshold reference value of 0.1mg/l. The presence of NO^-_3 values in the river was also below the permitted limit of 50mg/l and pH values recorded were within the tolerance limit of 6.5 - 8.5; only sample C was acidic. This implies that for now, the levels of Co and pH in the river do not post any public health risk. However, all the turbidity values ranging from 7.53 – 513.00mg/l obtained exceeded the desired limit of 5NTU which renders the water unfit for consumption.

Model Implementation:

Let f(c, x) represent f(T,z) as above; where: c = concentration of pollutants (mg/l), and x = distance travelled in water(m).

The values of the model parameters are shown below as:

c = [1 2 5 6] in mg/l; x = [200 500 1000 1500] in meters; S = 0.03, slope of area; t = [5 10 20 30] in minutes; Dx = 0.5, coefficient of dispersion; Water discharge = 450m^3/s; Width of river = 930m Depth of rive = 5m at time of study;

In the Lagrangian equation of motion, differentiation is given by:

```
i=2;
y = diff(c, x (i));
y(abs(p) < 10 * eps) = 0;
ddxdcdx = diff(y, x(i));
ddxdcdx(abs(ddxdcdx) < 10 * eps) = 0;
meshgrid(c ,x);
title('movement');
xlable('distance (m)');
ylabel('concentration (mg/l)');
plot(x,c);
```

When the above code was complied and executed with the command of plot, MATLAB runs the file and displayed the output as a two-dimensional model graph predicting the movement of pollutants in water. The graph indicated a non uniform linear flow curve due to advective forces and water current which made it to change directions of flow down the river (Fig. 2). The model provides a method for calculating transport losses due to reaction with particles and sediments of the river bed along the movement route.

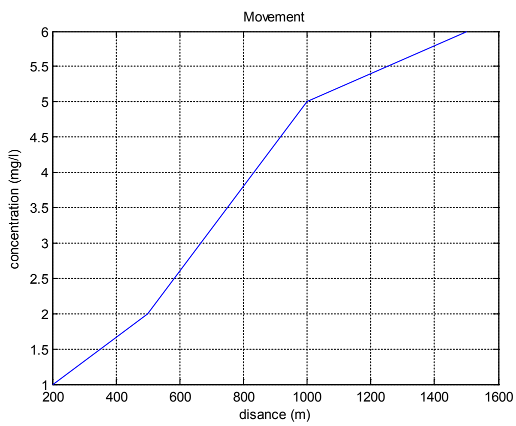


Figure 2: Two-Dimensional Flow Model Predicting the Transport of Pollutants in River Benue

From the model, the pollutants changed direction of flow at 500m, 1000m, and 1500m marks. It took contaminants 5 minutes to travel a distance of 500m and 15 minutes to travel a distance of 1.5 km down the river with a velocity of 0.66m/s. The simulation shows pollutants' concentration levels at different distances with respect to time.

CONCLUSIONS

Based on the laboratory measured data and predicted results of pollutants' movement in the river, it can be concluded that in most cases, heavy metal concentration levels in the river exceeded the maximum permissible limits of [13] standards. Mathematical Lagrangian equation of fluid motion was developed and solved in Matlab which simulated transport route of pollutants in the river. The predicted output indicated a 2-D non uniform linear graph which suggests the effect of advective forces and water current on the movement with an average velocity of 0.66m/s. the model predicted a travel distance of 1.5km within 15 minutes. There appears to be a good agreement between values of heavy metals tested and the previous results on the same river.

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