Journal of Urban and Environmental Engineering
E-ISSN: 1982-3932
celso@ct.ufpb.br
Universidade Federal da Paraíba
Brasil

Chizom Dike, Charles; Agunwamba, J. C.

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Journal of Urban and Environmental Engineering, vol. 7, núm. 2, 2013, pp. 330-339
Universidade Federal da Paraíba
Paraíba, Brasil

Journal of Urban and Environmental Engineering, v.7, n.2 p. 330-339, 2013

ISSN 1982-3932
doi: 10.4090/juee.2013.v7n2.330339

Journal of Urban and Environmental Engineering

www.journal-uee.org

MODELLING OF SEDIMENTS CONCENTRATION DISTRIBUTION IN DREDGED CANALS OF THE NIGER DELTA ESTUARINE REGION, NIGERIA

Charles Chizom Dike[**] and J. C. Agunwamba

Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria

Received 05 April 2013; received in revised form 6 September 2013; accepted 18 September 2013

Abstract: Previous sediments concentration distribution models used in the study of sediment characteristics of the dredged canals in the Niger-Delta estuarine region, Nigeria; did not take into consideration the lateral inflow due to tidal effects, which affects tremendously, the sediment intake into the estuarine waters. In the current research, existing models are modified by incorporating the missing lateral inflow parameters, which are peculiar to the Niger Delta environment, to obtain more accurate model results. Details are given herein, of the development and application of a 3-dimensional numerical model (EKU 2.8 Models) to predict sediment concentration distribution (total suspended sediment & bed sediment loads) in the Niger Delta estuarine canals, with Ekulama well 19 access canal as a case study. The approach in this paper involved coupling a sediment transport equation (with the inclusion of lateral inflow parameters), with an estuarine hydro-dynamics equation to generate a generic 3-dimensional sediment concentration distribution model, using deterministic approach. Predicted results using this model compared favorably with measured field results. Average sediment concentration of 29mg/l was obtained compared with 31mg/l measured in the field for bed sediment loads. Finally, the predicted sediment concentration distribution (TSS), when compared with field results, gave average correlation coefficient of 0.9.; hence, the present model will assist in generating adequate information /data on sediment characteristics and transport mechanism, required for effective design of canals to reduce rate of siltation. The application of the above knowledge/parameters generated from this model to effectively design canals to reduce siltation will be treated in subsequent articles.

Keywords: Dredged Canals, 3-D numerical model; sediments concentration modeling; Niger Delta –Nigeria; estuaries; siltation; mathematical modeling; sediment transport mechanism.

[*] Correspondence to: Charles Chizom Dike, Tel.:+234-8083581510, +234-7032849865.
E-mail:cchizod@hotmail.co.uk

INTRODUCTION

Dredged canals in the estuaries of Niger Delta-Nigeria are constantly threatened by siltation as a result of land based and river borne sediment loads, generated by tidal effects and human interference. The canal provides access to oil well slots, industrial field facilities, towns and fishing ports. As a result of incessant siltation of these canals, periodic maintenance dredging to ensure the serviceability of the canals are undertaken to provide the required draft level for operational vessels and swamp rigs and also to make them readily accessible for health, safety, security and environmental (HSSE) interventions. Currently, oil and gas industry operators' carries out maintenance dredging of canals and well slots at an average of 20 canals a year. This has been found to be a major cost item in the operating budget of the canal users, as a result, the maintenance dredging of several other inherently unsafe canals and well slots are regularly but regrettably foregone due to budget constraints. The inability of the canal users to achieve reduction in siltation rate through design can be attributed to lack of adequate understanding of the canal's flow regime/velocity distribution patterns, sources/characteristics of sediments as it affects the region. The present model dealt with the study of sediments characteristics of the region through mathematical model.

Sources of sediments in Niger Delta canals

Gradual sediment influx due to flooding, tidal currents and increasing human activities through dredging, oil and gas exploration and exploitation in the Niger Delta estuarine region accounts for a greater percentage of sediment source in the canals. River's Niger and Benue with a total drainage area of about 1100 km^2 transports approximately 25 mg/liter of sediment into the estuarine canals (Gibbs, 1987). Also, huge amount of organic materials generated by the mangrove forest which constitutes about 82% of the entire land cover (SPDC, 2005), together has potentially increased the rate of sediment in-put to the region. This has resulted in perennial siltation problems and increasing difficulty in maintaining the canals. Therefore, it has become quite imperative to formulate a good mathematical model to assist in understanding the hydro/geomorphology condition of the estuarine canals in order to proffer appropriate engineering solutions to the siltation problems.

Sediments and Sediment transport Mechanism

Sediment has been described generally as solid particles, which are being moved or have been moved by a fluid (Orji and Dike, 1991). The following discussion will be limited to particles moved by water. Sediment is in general classified according to size, specific weight, shape, mineralogical composition, color and other aspects. Sediment transport governs or influences many situations that are important to humanity; silt deposition reduces the capacity of reservoirs, interferes with harbor operation and closes or modifies the path of canals/watercourses (Orji & Dike, 1991). Erosion or scour may undermine marine structures, while in rivers and coastlines, sediment movement forms part of long-term pattern of geological processes. Sediment transport occurs only if there is an interface between moving fluid and an erodible boundary, this interface is extremely complex, and once sediment is being transported, flow is no longer a simple flow, since two materials are involved. Sediment transport may occur in one of the three modes:

a. By rolling or sliding along the floor (bed) of the river or sea – known as bed load
b. By suspension in the moving fluid, applicable to finer particles – usually Known as suspended load
c. By Saltation: The transport of sediment in short jumps and bounces above the stream bed or ground by a current that is not strong enough to hold the sediment in continuous suspension

Sediment transport is generally initiated by mobilizing (drag and lift) forces on the individual grain particles, caused by fluid moving over the sediments, while Stabilizing (Gravitational pull) forces tends to keep the particles at rest; this can also act as mobilizing force if the grain is located on a sloping bed.

Sediments movement begins if the mobilizing forces are larger than the stabilizing forces. The ability of the individual particles to move is determined using shield parameter, this parameter represents the ratio of shear stress (drag and lift forces) to normal stress (gravity). For a very small value of shields parameter (mobilizing force smaller than stabilizing force), there is no sediment motion. Therefore, sediments motion begins when a critical Shields parameter, between 0.03 and 0.06, occurs. When Shields values are above the critical value, particles start to roll, slide and jump over each other resulting in bed load transport. If the Shields parameter increases further, bed forms develop, ranging from small vortex ripples to large mega-ripples and dunes. (Dohmen-Janssen, 1999)

Sediments move over ripple beds either as bed load or as suspended load. Bed load may be used to designate either coarse material moving on or near the bed, or materials collected in or computed from samples collected in a bed-load sampler or trap. Bed-load transport is usually modeled with an empirical relation, depending on a certain power of the instantaneous flow velocity. Suspended load can be used for the materials either moving in suspension in a fluid being kept by the upwards components of the turbulent currents or by colloidal suspension or collected in or computed from samples collected with a suspended-load sampler. Suspended sediment transport can be described as the product of the sediment particle velocity and the sediment concentration, integrated over the water depth:

$$q_s\left(x,t\right)=\int_0^h u\left(x,z,t\right)*c\left(x,z,t\right)\partial z \tag{1}$$

where q_s = sediment transport rate; u = particle velocity and c = sediment concentration (Dohmen-Janssen, 1999).

The sediment transport rate is thus a function of the unsteady particle velocity and the unsteady concentration.

Sediment Transport Equation

The Ackers and white equation (1972) are amongst the most accurate sediment equations, although they are rather cumbersome. The simpler Engelund and Hansen equation, (Blake, 1988) yields similar levels of accuracy and can be expressed for bed material load as:

$$x=\frac{16000}{(S-1)^2}\frac{SVD^{\frac{1}{2}}S_o^{1.5}}{dD_{50}} \text{..........} \ (2)$$

where: X = Sediment Concentration in part per million (ppm); S = Sediment Specific gravity (usually 2.65); V = Average flow velocity in m/s; d= Average channel depth in meters; S_o = Channel slope and; D_{50} = Median sediment size of bed materials in meters.

Settling Velocity

When sediment grain moves through the water, it experiences considerable resistance, which is a function of the Reynolds number of this movement. When the particles moves downward, a settling velocity will be reached, at which the resistance equals the weight of the grain in water. For lamina and turbulent flows around the grain, the settling velocities for spherical grains are as follows (Blake, 1988):

Laminar flow:

$$s=\frac{D^2g\left(\rho_s-\rho\right)}{18\mu}=\frac{D^2g\left(G_s-1\right)}{18\nu} \tag{3}$$

Turbulent Flow:

$$V_s=\sqrt{\frac{4g\left(G_s-1\right)D}{3C_r}} \tag{4}$$

Where: G_s = specific gravity; υ = kinematics viscosity; ρs and ρ = density of water and particles; D = particle diameter; C_r = Coefficient of resistance depending on Reynolds number; (υ and ρs is assumed to be 8.98×10^{-1} mm^2/s and 2.40, respectively)

MATERIALS AND METHODS

The study area

This paper considered the modeling of sediments concentration distribution in the Niger Delta canals, with Ekulama well 19 access canal, as a case study. Ekulama the study area falls within the mangrove swamp environment of the Niger Delta; it is underlain by recent deltaic sediments and covered by medium dense to dense halophytic mangrove vegetation. It lies within coordinates, 460290E–479970E and 55246.734N–69750.484N of the oil rich Niger Delta coastal formation and covers approximately 285.43 square km², with about 81.12% (231.53 km²) of the total land mass made up of mangrove swamp (**Figs 3−4**).

Fig. 1 Map of Niger Delta (Southern Nigeria), showing Ekulama (Courtesy of Google earth).

Fig. 2 Map of Ekulama showing Well-19 Access canal- Study area (Courtesy of Google earth).

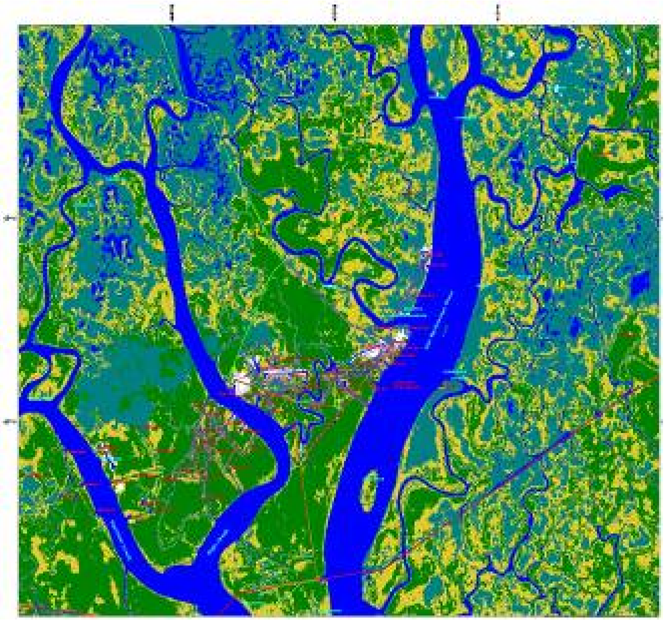

Fig. 3 Landcover types in Ekulama West and environ (Courtesy of SPDC Nigeria, 2004).

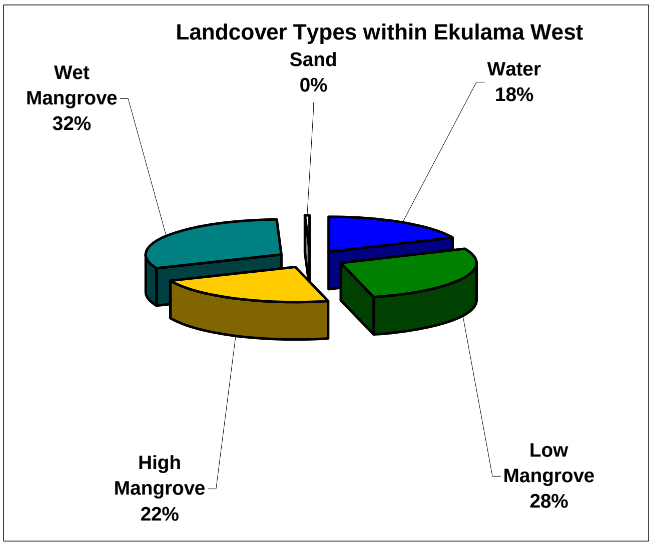

Fig. 4 Pie-chart representing the percentage land covers of Ekulama and environs.

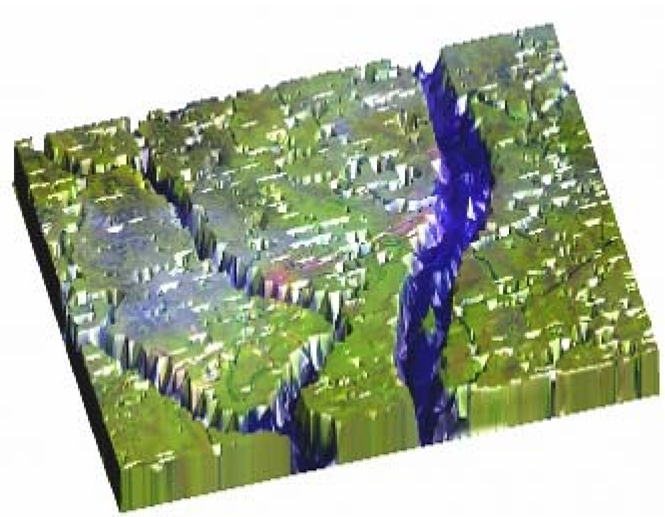

Fig. 5 Digital Elevation Model (3-D) of Ekulama terrain, the study area.

Water constitutes about 18.8% while Sand about 0.45%. The soils in the area are in essence, composed of peat, organic clays, silty clays and sand. Peat constitutes the dominant soil which is locally known as 'chikoko' with high compressibility and color ranging from dark brownish to dark grayish and texture from soft to firm. Typical bed material size (D_{50}) is approximately 0.2mm (SPDC, 2005).

Ekulama terrain is relatively flat (table land, see **Fig. 5**). Its deepest point is 26 m, while highest point is 8m above sea level. It is bathed by San Bartolommeo River and Sego creek, with majority of the landscape mostly under water.

MATERIALS AND METHODS

The field data collections were designed to ascertain the behavior of hydrographic, hydraulic and geologic processes occurring in the estuaries and to recover bank and riverbed sediments for laboratory analyses.

All the tests were carried out in accordance with the relevant BS methods of test for soil for civil engineering purposes. The soil investigation is in accordance with accepted geotechnical engineering practices; the conclusions and recommendations reached in this report is based on the data obtained from soil borings and tests performed. In addition, information gathered from previous pre and post dredging surveys were analyzed in other to reach the conclusions made in this report.

The following operations were carried out during the field investigation: Travers, Bathymetric and Hydrographic surveys, Current velocity and Tidal gauge measurement, Water column and riverbed sediment sampling, soil borings and sampling.

Bathymetric Survey

Bathymetric data were generated to determine the riverbed topography and bank slope angles using Raytheon Echo sounder. The echo sounder operates by sending acoustic signal to the riverbed through a transducer, which also receives a return signal from the riverbed. The time interval between these two actions is converted electronically to give the depth of the riverbed with reference to the water surface after corrections.

Traverse survey

Travers survey was carried out in order to establish geometry of the canals. The survey was carried out on existing survey points to provide controls along the access of the canal. These controls were used to detail the canal and all existing features within the area to be surveyed. Horizontal angles were measured using Wild

T2 while distance was measured using Wild d11660 electromagnetic distance measurement (EDM).

Current measurement

Andrea recording current meter (RCM 9) with Acoustic Doppler current sensor 3620 was used in water current measurements. The current meter is self-recording and intended to be moored to measure and record the vector-averaged velocity and direction of the tidal current. The instrument features a newly developed RCM Doppler current sensors as well as sensor for conductivity, turbidity, pressure and oxygen measurements. The data obtained are stored inside a removable and reusable solid stage data storage unit DSU 2990 and read in a computer with DSU reader 2995.

Water column samples

Hanna model H 1001300 multi parameter and data logger was used to determine in-situ, salinity, water temperature, pH value, conductivity and total dissolved solids (TDS) at three depths; surface, mid-depth and bottom levels. This involves the dipping of the probe of the meter directly into the sample in a 2-litre container. The reading for the parameter measured is displayed on the screen of the equipment and recorded.

Hydro graphic surveys

Tide gauges were installed close to the point of observation to measure the water surface elevations, and at the same time record the time of observation. The gauges were 4m staffs, painted and marked in a manner to cover the lowest and highest known depths of water within the study area. Readings were taken at intervals of 10 minutes.

Soil sampling methods

Disturbed and undisturbed soil samples were collected from the bank and bed of the Ekulama well 19 access canal (study area), through boring at a depth of 3m to 4m using hand auger at intervals of 0.5m and when necessary. The samples were fixed on to an adapter, which was screwed either on to the handle or onto extension rod of the auger. The large undisturbed samples were adequately protected against change of moisture content and damage in transit. The samples were placed in tins, tightly packed with sand dust to prevent damage, with the lid of the tins sealed with adhesive tape. A careful record of all the samples taken were kept, indicated on the lids were location position, depth and other relevant data.

Laboratory tests

Detailed laboratory investigations were carried out on representative disturbed samples obtained from the open boreholes for the classification tests and other tests by SPDC consultants, of which some of the results are used

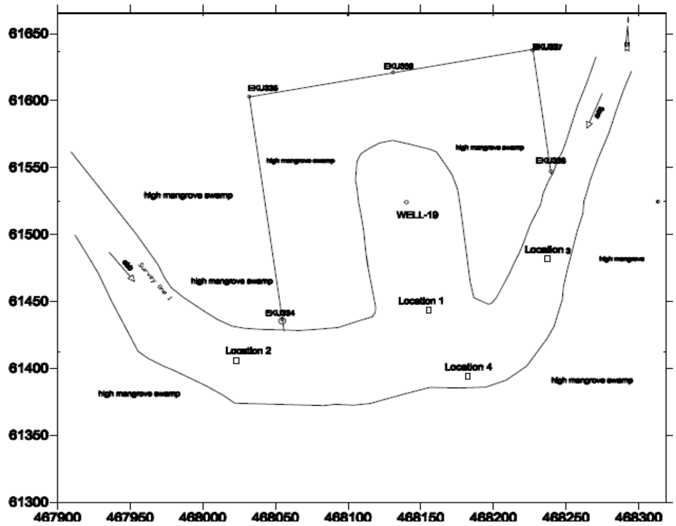

Fig. 6 Locations for current measurements.

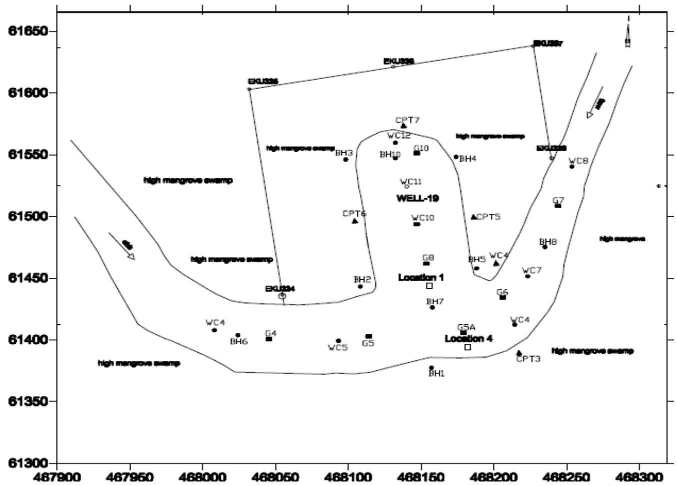

Fig.7 Positions of the boreholes, cone penetration test,water column test, and bottom sediment collection

in this report. The samples from the boreholes were described visually with respect to color and texture. In addition, information gathered from previous dredging, physical examination of the soil within the study reach/depth, geotechnical, tidal gauge recordings and topographical Situation/position of the study area in the Niger Delta coastal flood plain was considered.

Model Formulation

Basic Principles

Consider the figure below, where water flows through a length of river of variable cross-sectional area A in a controlled volume. There is a stream wise flow of fluid with mean velocity *u*, and lateral inflow from the banks due to seepage waters and occasionally runoff erosion floods.

The water fluid is considered as Newtonian, incompressible and taken to have constant physical properties. It is governed in the present investigation by a time-averaged formulation of the Reynolds-Averaged Navier-Stokes (RANS) equations as stated below.

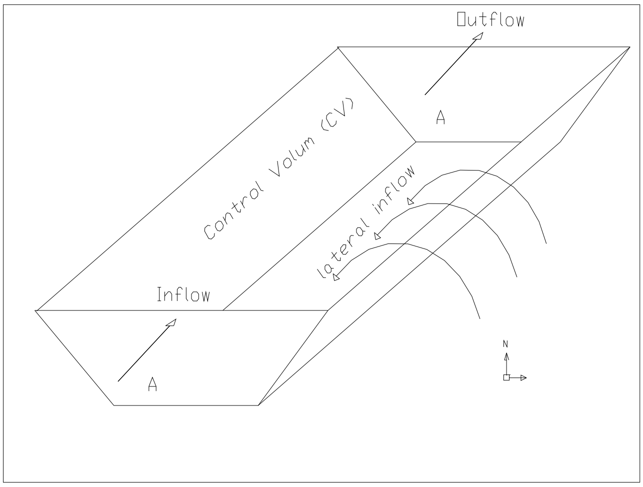

Fig. 8 River flow pattern.

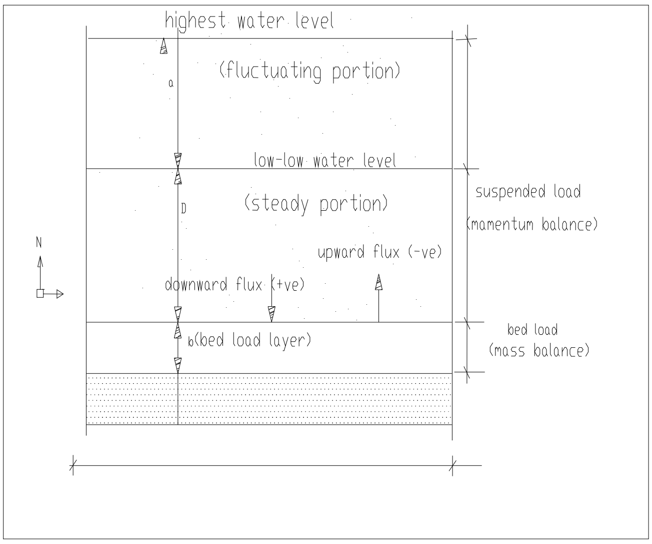

Fig. 9 Schematization of sediment exchange process.

The finite difference method proceeds by integrating the conservation laws, expressed in the Navier-Stokes equation for a control volume, over the entire domain, prior to the discretization phase. This ensures the exact conservation of the fluid physical properties in a control volume (CV) and yields a simple, physically-based, formulation of the form:

$$\begin{bmatrix} \textit{Rate of change of} \\ \textit{a property } \phi \textit{ in the} \\ \textit{CV with respect} \\ \textit{to time} \end{bmatrix} = \begin{bmatrix} \textit{Net flux of } \phi \\ \textit{due to convection} \\ \text{int}\ \textit{o the CV} \end{bmatrix} + \begin{bmatrix} \textit{Net flux of } \phi \\ \textit{due to diffusion} \\ \text{int}\ \textit{o the CV} \end{bmatrix} + \begin{bmatrix} \textit{Net rate of} \\ \textit{creation of } \phi \\ \textit{inside the CV} \end{bmatrix}$$

The space domain is subdivided into a set of non-overlapping cells, on which the fluid conservation properties are applied. This enables discrete fluid variables to be determined at cell nodes.

Basic equations

Consider figure 8 above, where water flows through a length of canal, of variable cross-sectional area A. There is a stream wise flow of fluid with mean velocity *u*, and lateral inflow from River banks due to tidal swelling and occasionally flood waters from the catchment area represented as follows.

$$U_r = \left[\rho q_x dx\right] nF \qquad (6)$$

Likewise, for sediment component, the lateral inflow sediment concentration can be related to river sediment concentration as follows:

$$C_{rl} = \left[C_l \frac{A_l}{A_r} \right] nF \qquad (7)$$

where: U_r = average lateral mass inflow, m^3/ms. C_r=sediment component of lateral inflow, mg/l, A_r = average river cross sectional area, A_l = average canal catchment Area, n = number of entry sides, *F = location specific* user defined dimensionless coefficient with default value of zero for no lateral inflow.

Equations of flow

The governing equation is a modification of equation previously used by Morteza and Roger in 2003 as shown below.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (8)$$

$$\begin{aligned} &\frac{\partial u}{\partial t} + \frac{u \partial u}{\partial x} + \frac{v \partial u}{\partial y} + \frac{w \partial u}{\partial z} = g S_{ox} \\ &- \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left(\mu_x \frac{\partial u}{\partial x} \right) \\ &+ \frac{\partial}{\partial y}\left(\mu_y \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z}\left(\mu_z \frac{\partial u}{\partial z} \right) \\ &+ U_{lx} \end{aligned} \qquad (9)$$

$$\begin{aligned} &\frac{\partial v}{\partial t} + \frac{u \partial v}{\partial x} + \frac{v \partial v}{\partial y} + \frac{w \partial v}{\partial z} = - g S_{oy} \\ &- \frac{1}{\rho}\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}\left(\mu_x \frac{\partial v}{\partial x} \right) \\ &+ \frac{\partial}{\partial y}\left(\mu_y \frac{\partial v}{\partial y} \right) + \frac{\partial}{\partial z}\left(\mu_z \frac{\partial v}{\partial z} \right) \\ &+ U_{ly} \end{aligned} \qquad (10)$$

With pressure term given as:

$$\partial p = \partial \frac{F_d}{A_r} = c_d \frac{\rho v^2}{2} \tag{11}$$

where: t = time; x, y, z = Cartesian co-ordinates; u, v, w = velocity component in the x, y and z direction respectively. C_d=co-efficient of drag =0.2 for Re>10^5 (Rajput, 2006), U_{lx} & U_{Ly} are lateral inflow from the banks due to tidal inundation in x and y directions respectively (see equations 6), P=pressure and A_r is as described above. S_{0x} and S_{0y} are x and y components of river slope. The model uses an implicit finite difference Scheme-Crank Nicolson procedure for solving the governing differential equations (a modification of equation used by Morteza and Roger in 2003) with central difference approximation in three dimensions for hydrodynamics

Equation of sediment transport

Under conditions of non-steady flow, the sediment flux can be taken as a sum of advective motion with the fluid and sediment entering the system from the river banks plus sediment particles falling under gravity and mixing by turbulent diffusion. The concentration c is governed by the adjective/diffusion equation:

$$\frac{\partial c}{\partial t} + \frac{u\partial c}{\partial x} + \frac{v\partial c}{\partial y} + \frac{w\partial c}{\partial z} - \frac{w_s\partial c}{\partial z} = \varepsilon_x \left(\frac{\partial^2 c}{\partial x^2} \right) + \varepsilon_y \left(\frac{\partial^2 c}{\partial y^2} \right) + \varepsilon_z \left(\frac{\partial^2 c}{\partial z^2} \right) + q_{Ly} \tag{12}$$

Where: c = sediment concentration; w_s = particle fall velocity; v, u and w are velocities in x, y and z directions, $\boldsymbol{\varepsilon_x}, \boldsymbol{\varepsilon_y}, \boldsymbol{\varepsilon_z}$ = Sediment mixing coefficient in x, y and z directions respectively, C_{rl} = Lateral sediment inflow given as $\left[C_l \frac{A_l}{A_r} \right] nF$, see equation 7 above, A_x = average cross sectional area of the river, A_l = average River catchment cross sectional area (breadth being average height of bank overflow above natural ground level due to tidal inundation), n = number of entry sides, *f* = user defined dimensionless coefficient with default value of zero for no lateral inflow.

MODEL SOLUTION

Sediment concentration equation in finite difference form:

Given Eq. (1) below,

$$\frac{\partial c}{\partial t} + \frac{u\partial c}{\partial x} + \frac{v\partial c}{\partial y} + \frac{w\partial c}{\partial z} - \frac{w_s\partial c}{\partial z} = \varepsilon_x \left(\frac{\partial^2 c}{\partial x^2} \right) + \varepsilon_y \left(\frac{\partial^2 c}{\partial y^2} \right) + \varepsilon_z \left(\frac{\partial^2 c}{\partial z^2} \right) + q_{Ly} \tag{13}$$

By applying finite difference method with central difference formula in 3-dimension, using Crank–Nicolson implicit method at points in time halfway between two nodes, results to the following:

$$\begin{aligned} &[0.33]^* \{i, j, k, \theta\} + [0.99]^* \{i+1, j, k, \theta\} \\ &-[0.99]^* \{i-1, j, k, \theta\} + [0.01]^* \{i, j+1, k, \theta\} \\ &-[0.01]^* \{i, j-1, k, \theta\} + [0.16]^* \{i, j, k+1, \theta\} \\ &-[0.48]^* \{i, j, k-1, \theta\} = \left[C_l \frac{A_l}{A_r} \right] nF \end{aligned} \tag{14}$$

The above equation is solved simultaneously to generate the values of sediment concentrations at the various nodes (Dike and Agunwamba 2010).

River Geometry/mesh

The river geometry was digitized using a series of 1:1000 maps provided by SPDC. Cross sections were taken at every 10 m. The reach is about 500 m long, between 70 m to 50 m wide and forms one C-bend at the apex of which a slot 70 m by 110m is dredged perpendicular to the main channel. The main channel depth varies between 2.0 m and 5.0m to 6.0 m. In the horizontal plane, the domain was covered with a square mesh, with *h* and k units in x and y directions respectively and time denoted by θ, while in vertical plane; the domain was divided into layers of 0.62 m intervals represented by L. Average bottom depth of 3.75 m was used, with low-low water level serving as the top layer.

The following boundary conditions were considered:

- At the free surface f(x,y,z,t)=0
- On the river bed f(x,y,z,t)=0
- At the coastal line, the velocity component perpendicular to the coastline is zero

Model Calibration

Model calibration is a system or procedure used in determining the values of the parameters that can fit the model in order for the model results to compare favorably with the real-world system or field measured values. This was carried out by plotting (with the aid of excel spreadsheet), solving (using excel solver); checking and adjusting the lateral inflow user defined coefficient (f) in the mathematical model until results, which best described the measured data were obtained. Other Computer packages for statistical analysis useful for curve fitting include STATGRAPHICS, SASS and SPSS (Agunwamba, 2007).

Assumptions

- No concentration gradient for lateral inflow components
- River density is assumed uniform across the river reach
- Flow velocity is assumed zero at coastal line, bed and surface levels.

RESULTS AND DISCUSSION

Bed and bank materials

Result of soil sample analysis on the bed and bank of the canal indicated that the soil samples are mostly peaty clay; sedimentation analysis using hydrometer tests showed that the typical bed material size (D_{50}) is approximately 0.2mm from which settling velocity of approximately 0.09mm/s was computed using Stokes equation.

Cohesive samples of the retrieved soil were subjected to Atterberg consistency limit test; the results showed that the samples are predominantly peaty clay of high plasticity only. Unconsolidated Un-drained triaxial compression tests were performed on relatively undisturbed samples obtained from the open, five numbers boreholes with depths ranging from1.5–6.45 m, with the objective of determining their un-drained strength parameters and the stability of the soil. The results show that the materials are relatively unstable, with 0^{o} angle of internal friction and cohesive strength ranging from 11 kN/m^2–20 kN/m^2.

Water Column Samples

Water column samples were collected from the water surface, mid-depth and bottom depth in order to analyze the water for temperature conditions, pH level, total suspended solids concentration (TSS), and total dissolved solids concentration (TDS), conductivity, turbidity and salinity. The results indicate average water temperature of 28.4°C, 28.3°C and 28.0°C for the surface, mid-depth and river bottom.

PREDICTED SEDIMENT DISTRIBUTION

Variation of sediment concentration along Vertical axis

Variation of Sediment concentration along vertical axis was examined by plotting sediment concentration against vertical distance, the results indicated that sediment concentration increases with increase in River depth i.e. Low sediment concentration at the River surface and high concentration at the bed level .This is due to particle settling out as a result of gravitational

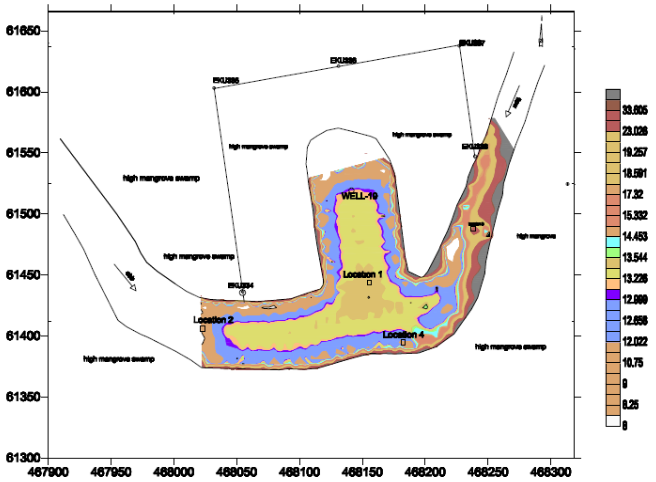

Fig. 10 Predicted Sediment concentration distribution (0.65m below LLWL) mg/l.

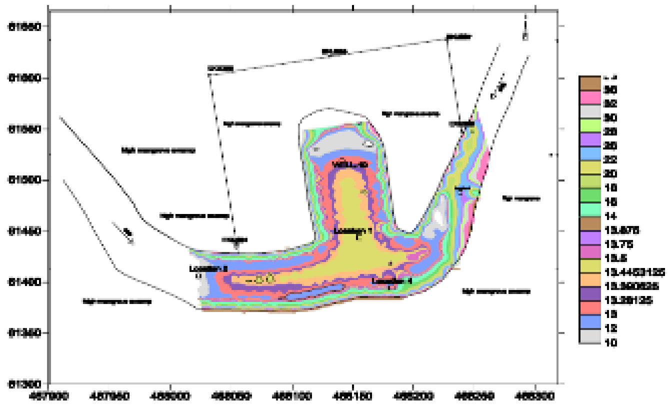

Fig. 11 Predicted Sediment concentration distribution (1.25m below LLWL) mg/l

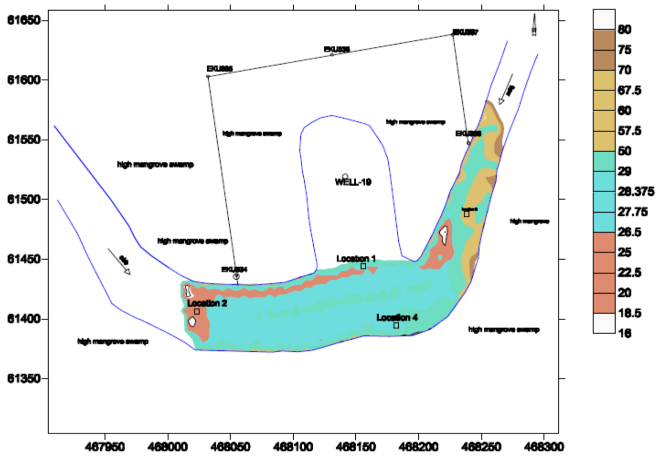

Fig. 12 Sediment concentration distribution for open River (Bed level-3.75m below LLWL) mg/l.

pull. Average Total suspended solids (TSS) of 10mg/l, 11mg/l and 31mg/l for surface, mid and bottom depths and Total dissolved solids (TDS) of 5599mg/l, 5839mg/l and 6786mg/l for surface, mid and bottom depths were obtained. In addition, the modeled result was verified by superimposing the result with the measured field data, the result showed a very good correlation with the field measurements (with average correlation coefficient of 0.95).

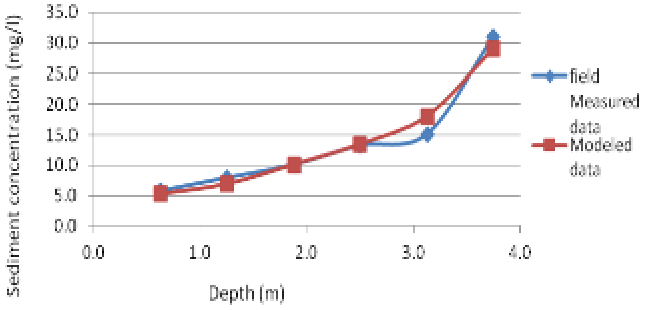

Fig. 13 Comparison of measured and modeled average bed level Sediment conc. distribution, 50m downstream of location 2

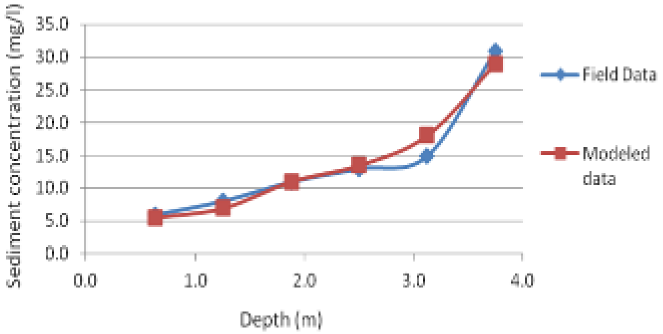

Fig. 14 Comparison of measured and modeled average bed level Sediment conc. distribution, 100m downstream of location 2

Variation of sediment concentration along longitudinal axis

Variation of sediment concentration along the horizontal profile (centre of the River) was plotted to verify the behavior of sediment concentration with the variation in bathymetric shapes and current velocity along the River stretch. The result as shown below indicates that sediment concentration increases with increase in current velocity. Reason being that River in motion is laden with sediment load under suspension, because of available driving forces and energy to keep the particles under suspension, unlike when the River is steady or having low current velocity, many suspended particles settles out leaving the river with a very low sediment load.

In addition, the shape of the River affects sediment concentration distribution as can be seen in the **Figs15 and 16**, at the upstream boundary, with a wider River width, the sediment concentration is very low, compared with downstream boundary with a very narrow width. This is as a result of the sudden decrease in river width (tapered River width) which resulted in turbulent flow and agitation of the river bank and beds accompanied by erosion, scouring and re-suspension, thus increasing the sediment load.

Variation of sediment concentration along transverse axis (bed level)

Sediment concentration characteristics was examined by plotting the sediment concentration versus distance

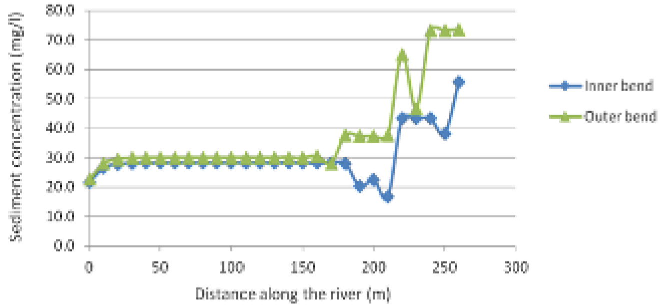

Fig. 15 Comparison of Sediment conc. distribution at the inner and outer bend of the river (mg/l)

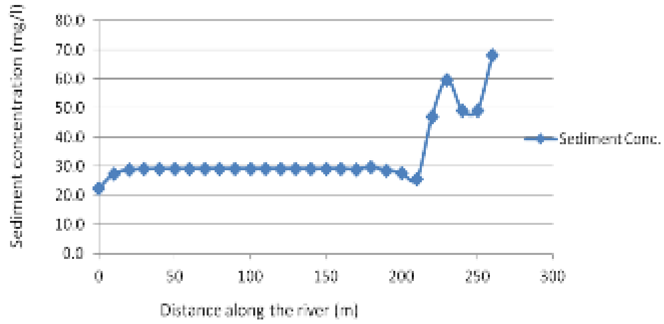

Fig. 16 Sediment conc. distribution along the river center profile (mg/l)

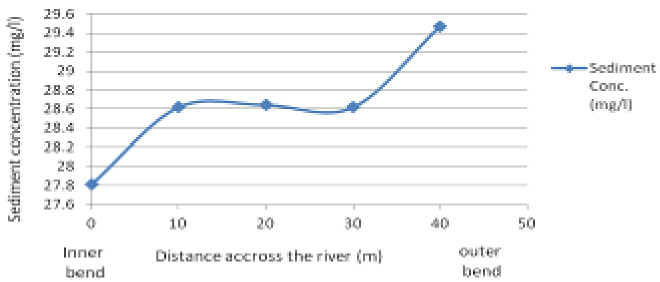

Fig. 17 Sediment conc. distribution across the river bed-upstream boundary (mg/l)

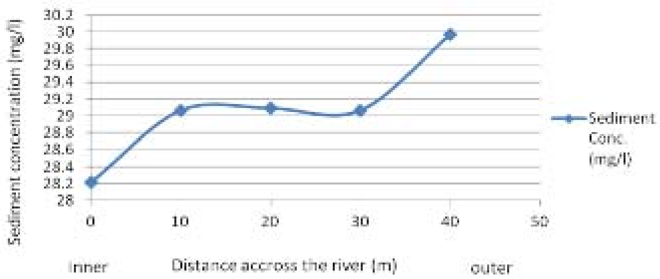

Fig. 18 Sediment conc. distribution across the river bed-midstream boundary (mg/l)

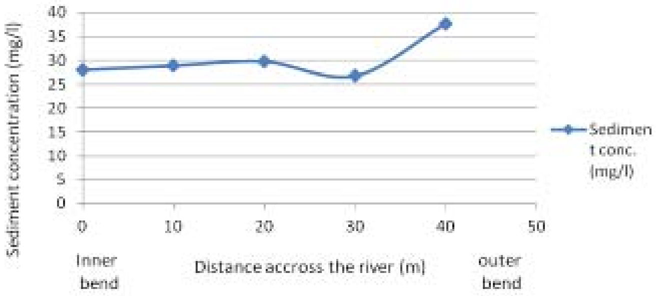

Fig. 19 Sediment conc. distributions across the river bed-at the river bend (mg/l) .

across the river transverse axis (Cross-section), the result of the plotting further explained the fact that sediment concentration increases with increase in river current and varies with the bathymetric shape of the River.

The results showed a high sediment concentration at the outer bend of the River, having very high current velocity, and low sediment concentration at the inner bends with a corresponding low velocity. The water current drifting towards the direction of the outer bend with its loads and particles settlement due to stillg water at the inner bend can best explain this phenomenon.

CONCLUSION

Equation of sediment transport, Equation 12 was modified by including lateral fluid inflow (sediments and water) due to tidal inundations, the resulting equation was solved implicitly in 3-D using finite difference method-crank Nicholson procedure to obtain the sediment concentrations (suspended sediments) at various nodes, which was authenticated by verifying using measured field data, see **Figs 13** and **14**.

The results of sediment concentration distribution at various nodes are as shown in the tables above. The result indicates that the river flow velocity and the bathymetric shape has some direct effects on the sediment concentration distribution and siltation pattern, a knowledge which is vital in designing canals to reduce siltation

Acknowledgements We acknowledge the supports of the following establishments in the course of this research works: (a) Frontline Systems Inc; Incline Village, NV 89450, P. O. Box 4288. United States. 775-831-0300- Owners of Premium Solver Platform release 8.0, and (b) The Shell Petroleum Development Company of Nigeria limited (SPDC), Port Harcourt Nigeria.

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