MODELS FOR FLOODING AND EROSION CONTROL IN PARTS OF NIGERIA

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ABSTRACT:
Flooding and erosion phenomenon is a major environmental problem prevalent in the rainforest region of Nigeria. The need to develop appropriate models to control the menace of the phenomenon is informed by the high demand for land and the increasing incidents of flooding and erosion in some parts of the country. Whatever model is to be adopted, its effectiveness depends on the contributions from geodetic measurement data. Once relevant data from geodetic and other sources have been obtained, the desired model can be developed using least squares approximation technique.

1. INTRODUCTION.

Flooding and erosion phenomenon is a major environmental problem prevalent in the rain forest region of Nigeria. It causes ecological havocs: destroying lives and property as well as agricultural land and social infrastructure. The phenomenon arises as a result of the following: when rain falls on unsaturated soil, it infiltrates, increasing the moisture content until the soil becomes saturated, after which additional rainfall becomes surface runoff. The runoff accumulates into a big flood as it flows down slopes and erodes the soil. It uses the heavy particles and other objects it gathers to erode the bed and walls of the flood path, causing big gullies to be created. The gullies continue to grow bigger and multiply, if adequate measures are not taken to control them.

With the increasing value and high demand for land, due to rapid urbanization and population growth, there is a compelling need to halt every occurrence of flooding and erosion. Satisfactory progress in this direction has remained illusive, due to insufficient data on the parameters that influence the occurrence of this phenomenon, and the unpredictable variableness of such parameters, as well as man´s adverse impact on the environment.

The extent of damages, and the suggested models for controlling this phenomenon in the Niger Delta and Anambra State of Nigeria, are discussed in details in Fubara(1986) and Uzodinma(1991), respectively. So far, little success has been achieved in most cases in combating this manace.

This paper reviews the various parameters that influence the occurrence of flooding and erosion in Nigeria. It discusses the various techniques of controlling flooding and erosion menace, their strength and weakness, as well as appropriate physical and mathematical models to control the phenomenon. The contributions of geodetic principles and techniques to the design and implementation of these models are singled out for special consideration.

2. FACTORS THAT AID FLOODING AND EROSION.

The degree of flooding and erosion depends largely on the soil type, topography, vegetation cover, the velocity of the runoff, amount and frequency of rainfall, as well as drainage system in the area. A great deal of flooding and erosion in this region equally emanates from man's adverse activities on the environment. The problem took a dramatic turn when uncontrolled developmental activities; such as the construction of highways, runways, concrete floors, massive structures in the cities, extraction of oil and other minerals; channelization, as well as irrigation and large scale mechanized farming, became widespread in the region. These activities cause either the ground levels to be lowered, water infiltration to be impared or natural drainage to be obstructed. Each of these activities leads subsequently to flooding and erosion.

3. METHODS OF CONTROLLING FLOODING AND EROSION.

Flooding and erosion in this region can be controlled in two major ways:

(a) By controlling the activities that aid flooding and erosion.

(b) By predicting the occurrence and magnitude of flooding and erosion; and designing models and adequate structures that will control the adverse impact of such phenomenon.

3.1 Limiting the Activities that Aid Flooding and Erosion.

Flooding and erosion in this region often emanates from runoffs after heavy rainfalls. It is better to prevent the occurrence of flooding and erosion than to fight it after it has started. The strategy is to limit the volume and velocity of the runoff and hence reduce its erosive potential. One of those stategies is the construction of drainages. Drainages assist in the control of soil erosion by improving the conditions for vegetation growth, which can dramatically reduce erosion rate through the effect of canopy, stems, and roots. They can also be used to enhance infiltration into the soil, and hence reduce runoff velocity and volume. Erosion(E) in this area is essentially a geomorphological process associated with runoff speed (V) over a slope (S) of the topography, subjected to the gravity acceleration (g). This can be expressed in the following equation:

$$E = f(V, S, g) \tag{3.1}$$

A more definite form of (3.1) is given by Fookes and Vaughan (1986):

$$F = \int_{t_1}^{t_2} PM\,dt \tag{3.2}$$

Where F is the landform (extent of erosion)
P(=V) is the process forming the landform
M(=S.g) is the material contributing to the landform. The operational forms of equations 3.1 and 3.2 are obtained by means of regression models. The various measures for controlling the velocity of the flood and hence the erosion include: massive afforestation, construction of dams, catch-pits, ridges, good drainage systems and other models adequate for anti-erosion processes, such as designing optimum infiltration model for the region(Smart and Herbertson,1992).

3.2 Prediction of Flooding and Erosion.

Flood prediction still remains one of the unsolved problems of operational hydrology (Garrote and Bras, 1995). Hydrology is the study of the occurrence, circulation and distribution of water over the earth's surface. It is concerned with the quantitative relationship between rainfall and runoff; and with the magnitude and time variation of runoff (Chadwick and Morfett, 1993). That is, rainfall and runoff records are needed for flood prediction scheme. There are imprecise connections between data and modelling strategies. The data needed for the prediction include: area (A) of the watershed;

P = intensity of rainfall (precipitation in a duration, D).

g = acceleration due to gravity

S = the land slope

C_f = forest cover fraction

T = return period of the flood

L = soil type

There are three types of prediction techniques in use. They are Statistical method, Unit Hydrography method, and Soil Conservation Service(SCS) method. The most successful schemes are usually those based on statistical approach (Chadwick and Morfett, 1993).

3.2.1 Statistical model.

(a) The use of mean annual flood

The mean annual flood (MAF) is the mean of annual series of the highest discharge occurring in each year of record.

Suppose Q = amount of discharge

g = acceleration due to gravity

A = area of watershed

S = the land slope

P = intensity of rainfall (precipitation in a duration, D)

C_f= forest cover fraction

T = return of period,

then the amount of discharge Q_* (dimensionless) is given by Swamee et al (1995):

$$Q_* = a_0 \, D_*^{a_1} \, T_*^{a_2} \, P_*^{a_3} \, (S_0 + a_6)^{a_4} \, (C_f + a_7)^{-a_5} (3.5) \qquad (3.3)$$

Where the following non-dimensional parameters have been determined, and are given by:

$$
\begin{aligned}
Q_* &= g^{-0.5} A^{-1.25} Q \\
D_* &= g^{0.5} A^{-0.25} D \\
P_* &= A^{-0.5} P \\
T_* &= g^{0.5} A^{-0.25} T
\end{aligned}
\qquad (3.3)
$$

and a_0 - a_7 are positive empirical constants. These constants will be determined for a given locality by means of regression analysis or any other curve fitting techniques. Equation (3.3) is applicable to locations where gauges for measuring the precipitation are installed. Flood prediction in ungauged areas is accomplished by finding quantitative relationships between catchment characteristics and flood magnitudes for large numbers of gauged catchments, and the application of these results to ungauged catchments by the use of multiple regression technique. The equation for ungauged catchment is given by Chadwick and Morfett (1993):

$$Q = a_0\, Area^{0.94}\, StmFrq^{0.27}\, S1085^{0.16}\, Soil^{1.23}\, RSmd^{1.03}\, (1 + ReSV)^{-0.85} \qquad (3.5)$$

where Q = the mean annual flood

a_0 = constant depending on the given location

Area = the catchment area

StmFrq = flood frequency

S1085 = the slope of the topography

Soil = number depending on the soil type

RSmd = 1 day rainfall of 5 year period minus the mean soil moisture deficit

ReSV = the area of reservoirs

3.2.2 **Unit hydrograph method.**

A unit hydrograph is a simple model of the response of a catchment to rainfall. It is the hydrograph of a surface runoff produced by P mm of net rainfall in D hours, provided the net rainfall is uniform over the catchment in both space and time (usually, P = 10mm and D = 1hr are used). It is based on the following assumptions (Chadwick and Morfett, 1993):

(a) Any uniform net rainfall, having a given duration, will produce runoff of specific duration, regardless of its intensity.

(b) The ratios of runoff equal the ratios of net rainfall intensities, provided that the rainfalls are of equal duration.

(c) The hydrograph representing a combination of several runoff events is the sum of the individual runoffs.

Once a unit hydrograph has been derived for a catchment, it can be used to produce the surface runoff for any storm event by the process of convolution (Chadwick and Morfett, 1993):

$$P.U = q \tag{3.6}$$

Where **P** is the matrix of net rainfall,
U is the matrix of unit hydrograph ordinates, and
q is the matrix of surface runoff ordinates.
The details of equation (3.6) are presented in equation (3.7) below:

$$\begin{bmatrix} p_1 & 0 & 0 & 0 \\ p_2 & p_1 & 0 & 0 \\ 0 & p_2 & p_1 & 0 \\ & & p_2 & p_1 \\ & & & \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ .. \\ .. \\ u_m \end{bmatrix} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ .. \\ q_n \end{bmatrix} \tag{3.7}$$

where $p_i = P_i/P$ for a P mm, D hour hydrograph. That is, if P_i = 30mm and the unit hydrograph is a 10mm, D hr unit hydrograph, then $p_i = 30/10 = 3$.

To obtain unit hydrograph **U**, we pre-multiply (3.6) by P^T.
Hence we obtain:

$$\therefore U = (P^T P)^{-1} P^T q \tag{3.8}$$

3.2.3 Soil conservation service method.

The soil conservation service (SCS) model is about the earliest model used in runoff prediction.

Suppose P is the precipitation for a given period,

Pe is the effective rainfall, that is, the amount of precipitation after runoff starts,

S is the potential maximum storage available, and

Ia = 0.2S is the initial abstraction an arbitrary constant for a given location based on experience. The amount of runoff Q, can be predicted by (Tammo, et al, 1995):

$$Q = \frac{(P-Ia)^2}{P+S-Ia} = \frac{Pe^2}{Pe+S} \qquad (3.9)$$

The accuracy of any of this prediction model will depend greatly on the quality of data available for such prediction. Each one of them will also need geodetic data in the modelling exercise. It is evident that the success of any of the models will be achieved after a series of experimentation, using data collected over many years in a given location. Other models can be tried using least squares approximation technique. By this approach an optimal prediction model can be obtained.

4. GEODETIC TECHNIQUES.

Many processes, for example, flooding and erosion, whose impact on the environment have far reaching adverse consequences can be attributed to position-related data. Such data will include the topography of the area; land cover, number, size and location of drainage basins; existing stream network with stream gauge records and data on existing dams and reservoirs; and records of past rainfall intensity and duration. Given these data, together with an appropriate model such as equation (3.3) or (3.5), a regression analysis procedure will be adopted to obtain the constants of these equations. Once the constants are obtained, they could be used in appropriate situations and places to predict flooding and erosion. Because of the vast potentials and capabilities of the modern digital computers, integrated data, including digital terrain models, for a large area, such as the entire country can be analyzed in a single modelling exercise.

Geographic information system (GIS), a sophisticated software for storing, manipulating and analyzing large volumes of spatially related data, is very handy in this modelling. Having done that, it becomes a simple matter to predict locations of potential floods and their severity. Experiments can be conducted in such a way that certain input data on parameters are varied to obtain optimum prediction model. It is however pertinent to note that the success in modelling vertical motion depends on the regularity of measurements in both time and space. Our ability to rid the levelling data of systematic errors, so that the actual variations in heights can be detected amid random measurement errors is also very crucial. Some of the geodetic data relevant to this modelling and the procedures for obtaining them are discussed in the next section.

4.1 The Slope of the Topography.

The information on the slope of the topography for a large area, such as an entire country, can be obtained from topographic map of the country. However, for areas with high flooding and erosion risk, geodetic levelling techniques will be required. These requirements re-echo the persistent call by the surveyors for comprehensive program to provide adequate control networks, and to map the entire country.

4.2 Ground Subsidence.

Ground subsidence is a phenomenon that causes the affected part of the earth's surface to drop in height relative to the surrounding areas. The consequence of this is that flood water will flow from other areas to the subsided area. The data on this can be obtained by designing and implementing monitoring scheme for the areas with potential subsidence risk. Possible subsidence risk areas are the mining sites, oil exploitation zone, areas where underground waters are being withdrawn. The information on the subsidence rate will contribute to effective modelling of flooding and erosion menace in the affected areas.

4.3 Variations in the Values of Gravity.

The force of gravity is largely responsible for runoff water on slopes after rainfalls. Therefore the knowledge of the magnitude of gravity in a particular area will be needed when modelling flooding and erosion phenomenon. It is possible for the flooding and erosion problem to start in an area where it had never occurred before. This could be due to variation of gravity values in the area. Such variations may be due to mining activities or other underground resources withdrawal activities within the neighbourhood. For a topography with gentle slope, repeated precise gravity measurements can be used to infer elevation changes and hence put some bounds on vertical movements determined by other types of measurement.

4.4 Variation in Tidal Heights.

Variations in tidal heights along the sea coasts or along river courses are needed to model flooding and erosion phenomenon in these areas. The rise of tidal water above the general level of the coasts results in sea or river flooding. It is therefore necessary to install tide gauges at reasonable intervals along our sea coasts and river courses, in order to monitor these variations. This will not only provide early warning signal on any impending danger but will also provide the data for monitoring its exact impact on the environment.

Sea-level rise is a world-wide phenomenon that is of great concern to mankind. The occurrence of such phenomenon portends great danger to the people living in and around the coastal areas of our country. Records of tide gauge readings along the coasts will no doubt provide direct estimates of the elevation changes with time. The much needed information on the sea-level rise will be easily derived from these tide gauge readings. By analyzing the tidal data covering many tidal circles, any systematic changes in sea-level will be detected and appropriate measures taken to prevent or limit the emergence of flooding and erosion menace in the areas.

5. SUMMARY AND CONCLUSIONS.

Flooding and erosion phenomenon is a major environmental problem prevalent in the rainforest region of Nigeria. The country is in dare need of effective method of checking the occurrence of this phenomenon. This need stems from the rapid urbanization and population growth which place high demand on the available land resources. Success in modelling the occurrence of flooding and erosion has not been realised because of paurcity of data, and the unpredictable variableness of the parameters which influence flooding and erosion.

Various factors that affect the occurrence and the degree of flooding and erosion were identified. The different methods of modelling the phenomenon have also been discussed. It was observed that whatever method of modelling is adopted, geodetic data and techniques, as well as data from other sources are needed to obtain the desired model.

The general approach to modelling process is to propose a functional relationship between the flooding and erosion parameters and the amount of runoff water, based on perceived physical relationship between the parameters and the amount of runoff. The coefficients of the parameters in the functional model are determined, using least squares approximation technique. Once the coefficients have been determined for a particular locality, it is assumed that flooding and erosion of any degree and duration can be readily predicted using such a model.

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