UNDERSTANDING THE MECHANISM OF SOIL EROSION FROM OUTDOOR MODEL STUDY

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ABSTRACT

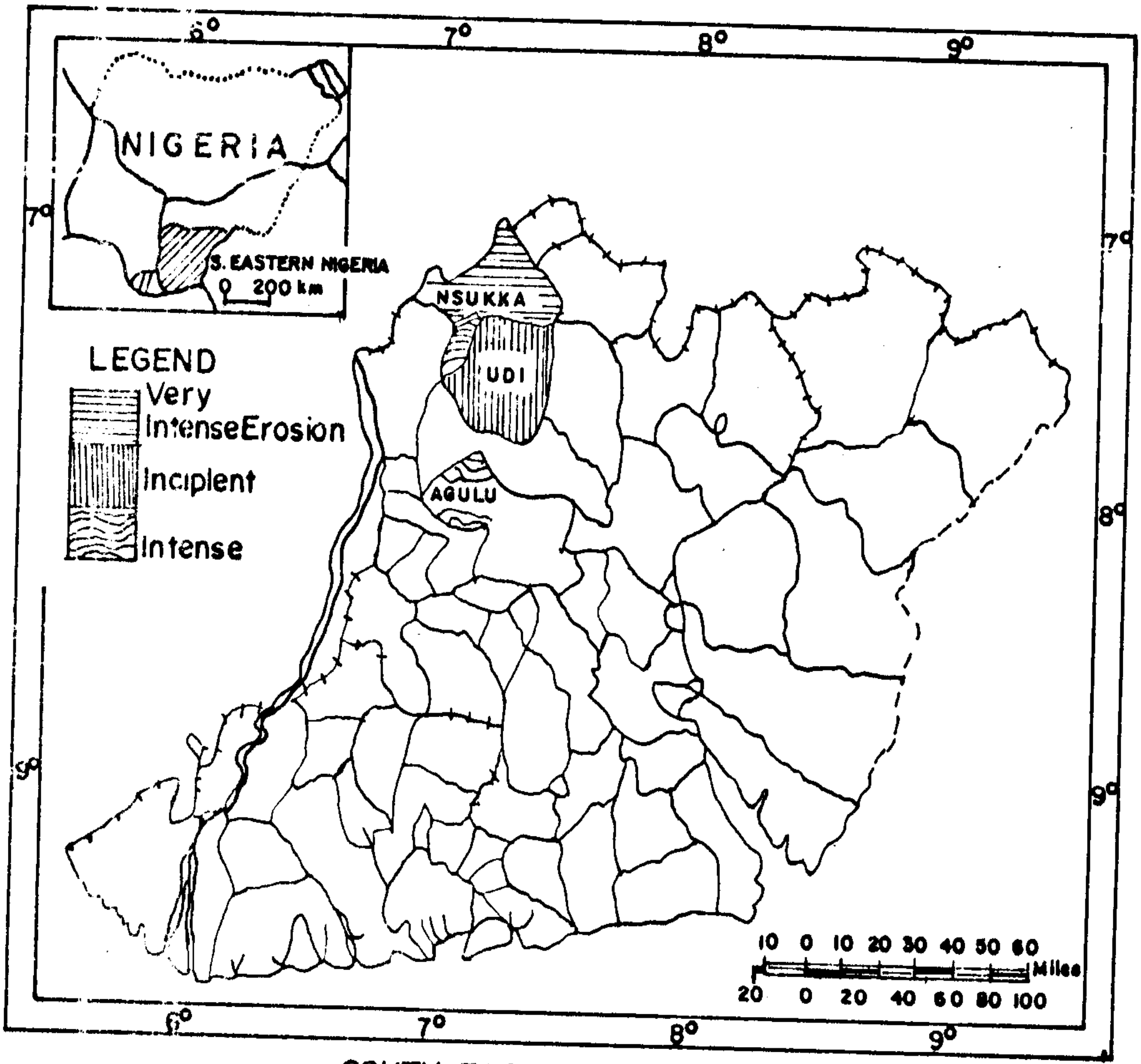
A method for obtaining important data on eroded soils, using a one eight experimental slope model is presented. The scope of the investigation herein described encompassed three locations in the south- eastern parts of Nigeria, which are belts of severe erosion, namely Opi-Nsukka, Agulu and Udi, [Fig. 1.] Soil samples were collected from several representative sites for each of these locations and composited into volumes sufficient to be compacted volumes into the fixed-bed flume to a depth of 12cm. mean sediment sizes for the belt soils were, in that order, 0. 326mm, 0.43mm and 0.56mm respectively. The basis of the experiments was an outdoor flume test on the Opi sample throughout the rainy season of June to early October 1996. With an existing mathematical modeling, the results of Opi were extended to the Agulu and Udi situations. Finally by distorted scale laws, data for the natural slopes were synthesised to produce the hydrologic quantities; slope erosion and average infiltration rates for the soils.

INTRODUCTION

In most parts of the world subject to heavy rain, erosion by overland flow is of common occurrence. This is particularly true of three belts in the southeastern part of Nigeria, Fig. 1. Severe gully erosion of undeveloped and road shoulders is a threat to agricultural and transportation progress. This phenomenon arises from the lack of proper control of storm water on the highway fight of way and tributary slopes. It is therefore a prerequisite in erosion control designs to secure accurate hydrological and soil data for the affected regions. The extent of the degradation of soil structure is such that in places roads have been cut across by gullies as deep as 0.8m and 0.5m wide. Besides the total destruction of agricultural resources, traffic between important towns has been impaired.

Extensive studies by some scholars [l, 4, 8] have been performed to prove that erosion is in addition to physical factors attributable to human factors such as the method of cultivation and excavation of soils, poor drainage and maintenance of road shoulders and cut slopes due to the lack of adequate and up-to-data design data for drainage works.

Laboratory research has been carried out intensively [5, 8] to develop relationship between erosion rate and the pertinent hydrologic parameters.



SOUTH EASTERN STATES OF NIGERIA

FIG. 1— LOCATION MAP OF THE EROSION BELTS STUDIED.

Saburo [8] came up with the equation of the form

$E = F(C_A, C_E, D, K, 1, L, S_o)$ (1)

of the seven independent variables in Eq. 1 three are amenable to elimination by way of silvicultural or agricultural management, namely:

i. bare-soil area: controlled by tree planting
ii. excessive slope: by avoiding excavations on such slopes
iii. Slope length: by keeping to short reaches of arable land.

For the other four parameters, laboratory, field and analytical investigations has shown clearer insight to the nature of these quantities.

It is the objective of this work therefore, to:

1. Determine the basic engineering soil properties of the samples collected from the erosion belts.

2. Procure hydrological data such as rainfall infiltration rate for the soil and erosion rate by applying the model result, and
3. present working data on the natural slopes.

GOVERNING EQUA EQUATIONS OF SLOPE EROSION

The theory of this work is based on open channel flow. For the over-land flow the following equation of continuity applies

$$q = q_0 + q_S x \qquad (2)$$

Considering total flows, Eq. 2 may be rewritten as follows:

$$\frac{Q}{B} = \frac{Q_0}{B} + q_s L \qquad (3)$$

As for the slope erosion rate the governing equation is

$$E = \frac{1}{L}\int_0^L aT_0^b dX \qquad (4)$$

in which a = a constant; t_0 = boundary shear stress of overland flow.

An important result achieved by Saburo showed that Equation 4 yields.

$$E = C_H q_s^{15/8} L^{3/8} S_0^{3/2} \qquad (5)$$

in which C_H = constant depending on the erodibility coefficient.

This constant was further reduced into $C_H = (N/D)C_A C_E$, where N = a whole number for a particular type of flow over rough surfaces, D - mean sediment size.

In an earlier laboratory work backed by mathematical analysis [61] the value of N for the Opi soil of specific gravity 2.66 was obtained as 658.

Pertinent erosion parameters are the runoff coefficient and the rainfall intensity which are linkable in the form [3]

$$W = I - KI \qquad (6)$$

The runoff coefficient, K, can be found from the expression,

$$q_s = \frac{KI}{3.6 \times 10^6} \qquad (7a)$$

$$q_2 = 2.778KI \times 10^{-7} \qquad (7b)$$

THE SLOPE MODEL

Figure 2 shows the layout of the one-eight slope model built as a fixed-bed flume. The model has a total length of 19m. and width of 45cm. It is located in an open field. Rainwater is channeled through a 7.6cm diameter pipe onto the upper end of the flume, the overland flow thus discharging ultimately into a 1m x 1m soakaway pit.

The following model laws apply [2]

Horizontal scale: $\times_r = 1/10$
Vertical scale: $y_r = 1/8$
Hence,
Velocity ratio: $v_r = y^{1/2} = 0.354$
Discharge ratio: $Q_r = X_r Y_r 3/2 = 4 \times 10^{-3}$
Slope ratio: $S_r = \frac{y_r}{\times_r} = 1.25$

Operation Details: The rainfall needed for the tests is allowed into the bed of soil through a 7. 6cm diameter pipe that is fitted by a short hose to a roof funnel which in turn is served from a 5m gutter. The catchment area is defined by this gutter and roof of length 9.8m giving an area of $49m^2$. At both ends of the flume are fixed two precalibrated linear proportional weir which read the rainfall and the overland flow respectively

The overspilling overland flow is diverted through a 15.24cm diameter asbestos cement pipe into a 1m x l m soakaway pit 1.22m deep located 2.59m away on one side of the flume. Overall length of the tested soil is 17.5m of depth 12cm.

EXPERIMENTAL PROCEDURE

Thirteen experiments were performed on the days in the months of June to October, 1986. Before the rains started, the inlet pipe was connected to the funnel, the time rain started was noted. Weir readings using point gauges were begun only after steady state was attained. Readings ended when the overland flow fell short of the weir sill. Time was then noted again. This was necessary for computation of rainfall intensity from the intensity - duration curve.

At the end of each day the flume was examined for eroded spots. These were patched by filling up and compacting with soils obtained from the identical samples in a nearby dump. The volume eroded was thus computed from the measuring can.

RESULTS

In figure 3 is shown the rainfall intensity - duration curve applicable to the study areas.

The natural slope erosion rate is described in that figure where the two categories of erosion are distinguishable: - sheet erosion, and gully erosion. Each section has different erodibility coefficients. Also it would be observed that gully erosion sets in for values of rainfall intensity near 60 mm/hr representing a duration of from 55 minutes downwards; that is to say shorter durations produce intense storm, capable of generating gully erosion. It is pertinent at this juncture to consider model law application to Eq. 5, from which a factor of 584 was obtained. Using this figure the model erosion rate was scaled up to the natural rate.

CONCLUSIONS

The principal conclusions to be drawn from the investigation herein described can be summarised as follows:

1. The natural phenomenon of erosion can be satisfactorily simulated in an outdoor experimental model, as shown in fig.2.
2. It is thus possible to obtain two fundamental soil hydraulic data namely erosion rate and the average infiltration rate respectively using Fig 4 and Eq. 6.

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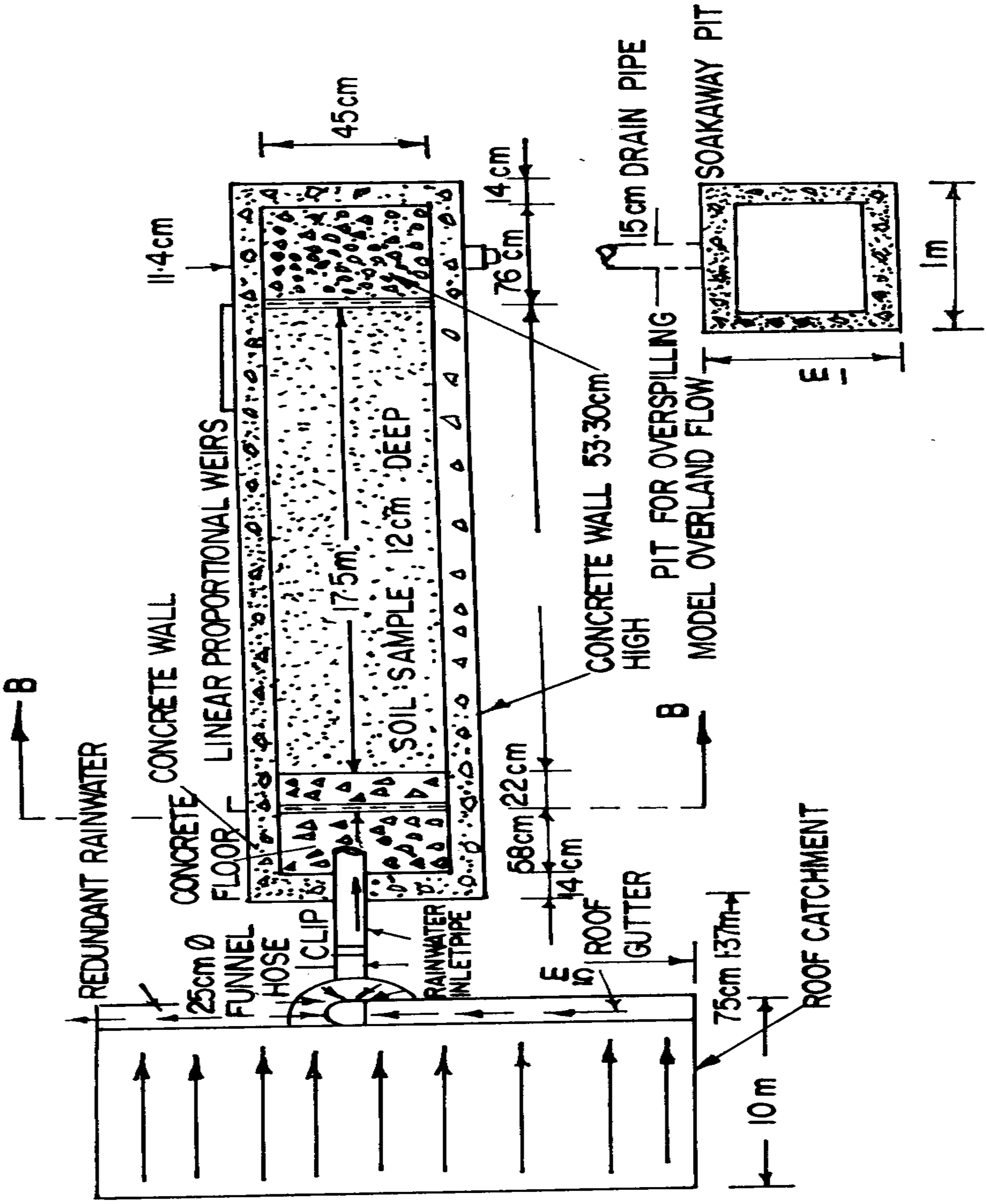

FIG. 2. PLAN OF THE SLOPE MODEL

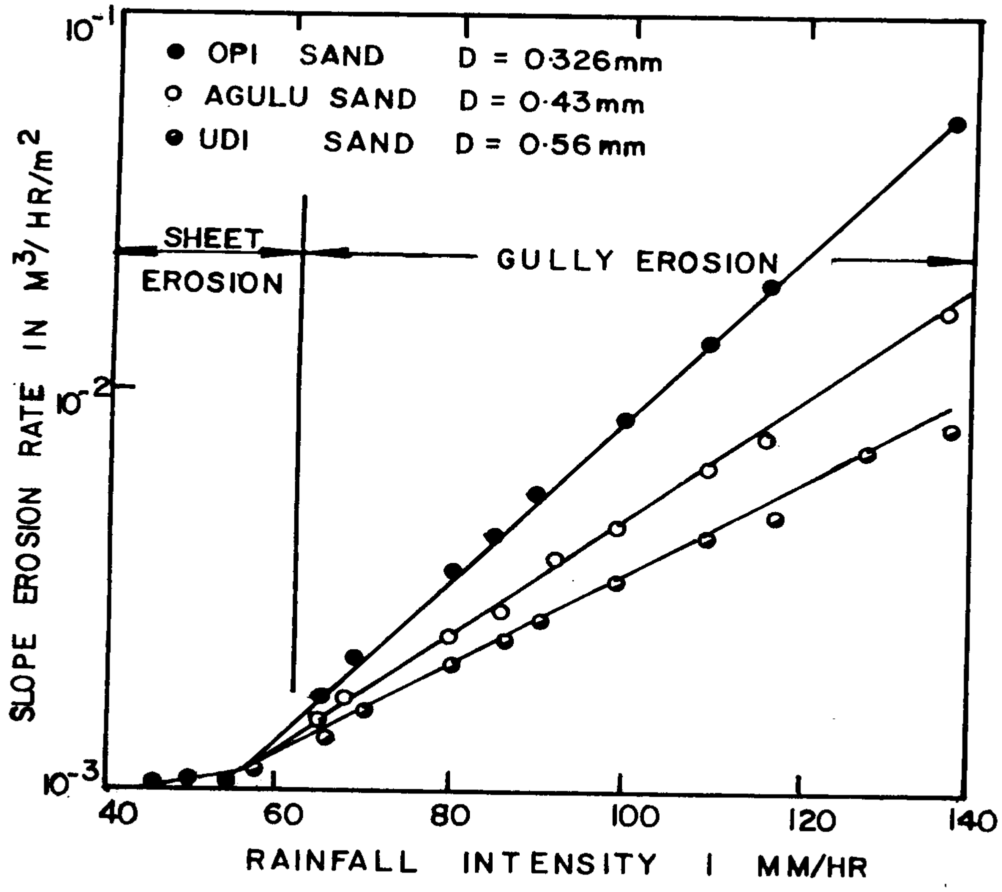

FIG 3 — VARIATION OF NATURAL — SLOPE EROSION RATE WITH RAINFALL INTENSITY

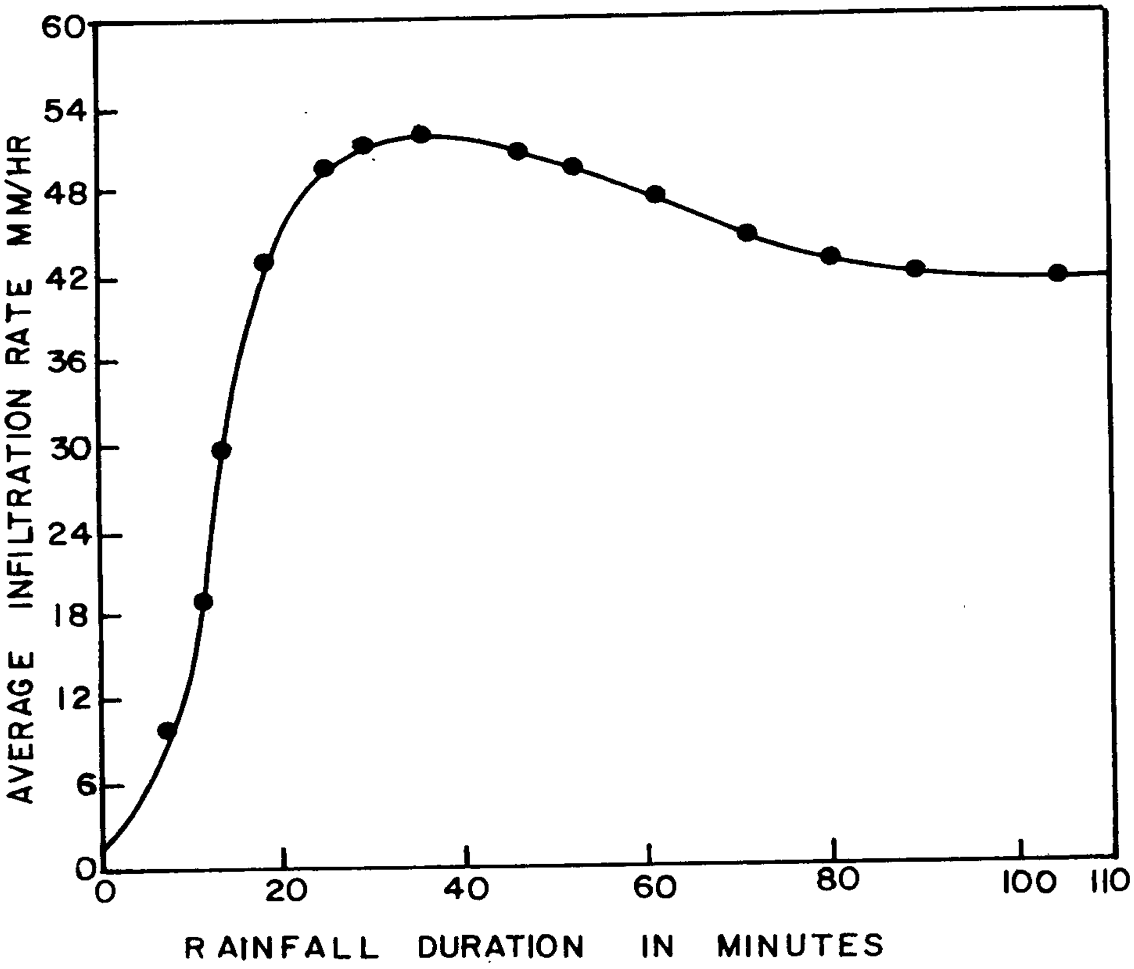

FIG. 4 – VARIATION OF AVERAGE INFILTRATION RATE WITH RAINFALL DURATION.

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NOTATION

The following symbols are used in this paper:

B = Width of model or the experimental flume

B = an exponent in fig. 4

C_A = Bare-soil area ratio, that is the ratio of vegetationless area to total slope area; for this model $C_A = 1$.

C_E = Erodibility coefficient (the constant incorporated in the slope erosion rate, Eq.5)

D = Mean sediment size of the slope material.

E = Slope erosion rate in cubic meters per second per square meter

F () = Functional notation

I = Rainfall intensity in millimeters per hour.

K = Runoff coefficient

L = Slope length in meters

N = Integer incorporated in Eq. 5: N is derived by experiment and analysis of flow over a particular soil or rough surfaces in general.

Q = Total overland (model) flow

Q_O = Total rainfall collected from feeder roof flowing into the upper end of slope

q = Overland flow per unit width of flume

q_o = Rainfall inflow rate per unit width at the upper end of slope

q_s = Rainfall inflow rate per unit area of slope.

S_o = Slope gradient as real number

S_r = Slope scale

T_o = Boundary shear stress of overland flow

W = Average infiltration rate of soil in millimeters per hour

x = Distance in downstream direction along slope surface

x_r = Horizontal scale = 1/10

y_r = Vertical scale = 1/8.