

**SEDIMENT-YIELD MODEL FOR LARGE WATERSHED BY
USING THE AVHRR-NOAA SATELLITE DATA**

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ABSTRACT

The past drought in Ethiopia had resulted in a massive loss of vegetation as well as loss of soil within the watersheds of the Blue Nile and Atbara Rivers. The objective of this research is to develop sediment-yield model for the Blue Nile Basin by using the Advanced Very High Resolution Radiometer (AVHRR)-NOAA satellite Data. The Global Vegetation index (GVI), which determined from the Normalized Difference Vegetation Index (NDVI) using the AVHRR sensors, will be inserted as a major factor into the hydrologic regression sediment-yield model established for the Blue Nile Basin. This approach to predict sediment yield is very economical and gives a satisfactory results.

KEY WORDS: Hydrology, Image Analysis, Image Interpretation, Remote Sensing Application, Water Applications.

INTRODUCTION

The study area is located in the northeast region of the African continent and extends into two countries, Ethiopia and Sudan. This area covers most of the Ethiopian Plateau Highlands with an elevation of 2,000 to 3,000 meters above mean sea level. The area is west of longitude 40°E and extends west 32° 30' E to cover most of the region between the White and Blue Niles. The northern and southern borders of the study area are latitudes 15° N and 7° 50' N, respectively as shown in Figure 1.

Three main sub-watersheds were considered in this research. These sub-watersheds are: the Rahad, the Dinder, and the rest of the Blue Nile Coarse, started from lake tana and ended by sennar station. Different set of water discharges Q's (10³ m³/sec) were used as well as the regression sediment-yield model for the outlet station of the Blue Nile, which was established by Moussa (1987) and given as follows:

$$Q_{SK} = 387.736 \times 10^{-6} Q_K^{1.046} \quad \dots\dots (1)$$

where Q_{SK} is the suspended sediment (SS) discharge, in 10⁶ m³/sec, at the Khartoum station. Due to the absence of SS concentration measurements at or near the outlet stations of the three sub-watersheds, a minimum norm solution, which is based on the minimization of the unknowns rather than the residuals was used to determine the SS discharges at these stations.

This kind of solution was carried out on the basis of the prior information, relative water discharge, soil erodibility factors and slope classes, which were included in the relative weight matrix (P-Matrix) (Moussa, 1987). Vegetation coverage which can be represented by areal weighted values of the Global Vegetation Index (GVI) will be inserted as a major factor in the relative weight matrix. The resulted values of suspended sediment discharges at each outlet station will be regressed with their corresponding values of water discharges to construct the sediment yield models for both small and large sub-watersheds of the Blue Nile Basin.

SUSPENDED SEDIMENT DISCHARGE MODEL

There were no observations for SS concentration taken at or near the outlet stations of the three sub-watersheds. Therefore, the objective of this model was to determine SS discharge for Rahad and Dinder Rivers at their mouths and SS discharge for the Blue Nile River at the sennar station.

Historical water discharges, which were observed at or near the outlet station of the Rahad and Dinder Rivers and at Sennar and Khartoum stations during the flood period (Aug.-Oct.), as well as the relationship between water discharge and SS discharge

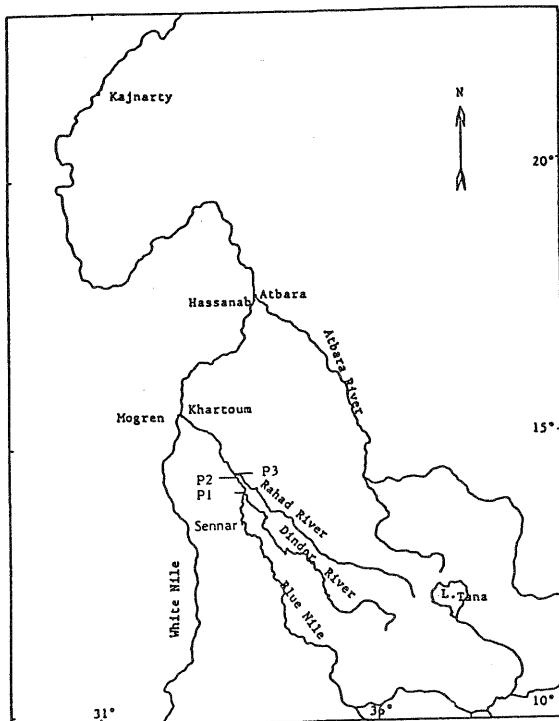


Fig.1. The Nile River and its Main Tributaries

at Khartoum station were used in formulating the SS discharge model. The historical water discharge observations for the years 1939 to 1953 were collected from the data given by Hurst et al. (1949, 1955, and 1959) and by Nile Control Staff (1962).

The time lag between one station and the other was considered. The time lags for the first reach (Sennar to Dinder) and for the second reach (Dinder to Rahad) were found to be 1 day, while the time lag for the third reach (Rahad to Khartoum) was found to be 2 days.

Model Assumptions

The following assumptions were made in developing the model:

- 1) Water and solid particles move with the same velocity, e.g.,

$$Q_{SS} = \bar{C}_{SS} \cdot Q \quad \dots\dots\dots (2)$$

where Q_{SS} is the SS discharge, \bar{C}_{SS} is the SS discharge concentration and Q is the total water discharge in the cross section (Graf, 1971 and Vanoni, 1975).

- 2) The SS load is equal to the total sediment load since bed load transport represents only about 1% of the total sediment transport of the river (Shahin, 1985).
- 3) There is no variation of the SS concentration along the Blue Nile Coarse.
- 4) Water discharges along the first and the second reaches are kept constant, then:

$$Q_{P2} = Q_S + Q_D \quad \dots\dots\dots (3)$$

- 5) There is no deposition of SS particles in both reservoirs, Sennar and Roseires (Shahin, 1985).

Model Derivation and Solution Procedure

The suspended sediment discharge model was derived by Moussa (1991). The resulted relationship between different sediment discharges Q_{SS} , Q_{SD} , Q_{SR} , and Q_{SK} was found to be:

$$Q_{SS} = Q_{SD} + Q_{SR} + [-(Q_{SK}/F)] = 0 \quad \dots\dots (4)$$

where Q_{SS} , Q_{SD} , Q_{SR} are sediment discharges at Sennar, Dinder, and Rahad outlet stations, respectively and F is given by:

$$F = Q_K / (Q_S + Q_D + Q_R) \quad \dots\dots\dots (5)$$

where Q_S , Q_D , and Q_R are water discharges at Sennar, Dinder, and Rahad outlet stations.

Assume that m is a number of observations of water discharge at each station. Then, there will be m number of equations of the form (4). The least squares method was carried out on the presence of prior informations which are represented by the P-Matrix elements. The form of the m equations can be written as:

$$[1 \quad 1 \quad 1] \begin{bmatrix} Q_{SS} \\ Q_{SD} \\ Q_{SR} \end{bmatrix} + \left[-\frac{Q_{SK}}{F} \right] = 0 \quad \dots (6)$$

or

$$B \cdot V + W = 0 \quad (7)$$

Equations 6 and 7 are called condition equation. By using the minimum norm solution, the vector of unknowns, V , can be determined using the equation:

$$V = -P^{-1} \cdot B^T (B \cdot P^{-1} \cdot B^T)^{-1} W \quad \dots\dots (8)$$

where P is the relative weight matrix, B is the coefficient matrix and W is the vector of constant values.

Assuming that the parameters Q_{SS} 's, Q_{SD} 's and Q_{SR} 's are independent then the relative weight values which correspond to each equation for each station can be written as:

$$P(I, I)_1 = \frac{Q_R(J) + Q_D(J)}{Q_S(J)} \cdot \frac{\sum_{i=1}^M A_i \cdot k_i^S \cdot s_i^S}{\sum_{i=1}^M A_i} \cdot GVBNS(I) \quad \dots\dots \text{for Sennar station} \dots (9)$$

$$P(I, I)_2 = \frac{Q_R(J)}{Q_D(J)} \cdot \frac{\sum_{i=1}^N A_i \cdot k_i^D \cdot s_i^D}{\sum_{i=1}^N A_i} \cdot GVBND(I) \quad \dots\dots \text{for Dinder outlet station,} \dots\dots (10)$$

$$P(I, I)_3 = \frac{Q_R(J)}{Q_R(J)} \cdot \frac{\sum_{i=1}^L A_i \cdot k_i^R \cdot s_i^R}{\sum_{i=1}^L A_i} \cdot GVBNR(I) \quad \dots\dots \text{for Rahad outlet station} \dots (11)$$

where $I_1 = 1, 4, 7, \dots, n-2$,
 $I_2 = 2, 5, 8, \dots, n-1$,
 $I_3 = 3, 6, 9, \dots, n$,
 $J = 1, 2, 3, \dots, m$, and

k is a soil erodibility factor determined by Murphy (1968), s is the slope class (UNESCO, 1977), A is the area of a specific type of soil, and M , N and L are the number of unique soil types in the Blue Nile, Dinder and Rahad sub-watersheds, respectively. $GVBNS$, $GVBND$ and $GVBNR$ are the areal weighted values of GVI for Sennar, Dinder, and Rahad respectively. The GVI values were given by 15-days composite mean values during the drought years (1981-1985).

Each value of areal weighted global vegetation index for different outlet station can be written as follows:

$$\begin{aligned} GVBNS \text{ for Sennar} &= A_S \cdot GVBIN \\ GVBND \text{ for Dinder} &= A_D \cdot GVBIN \\ GVBNR \text{ for Rahad} &= A_R \cdot GVBIN \end{aligned}$$

$$\text{where } GVBIN = (Q_{SK}(I) + 2891.04) / 10652.791 \quad \dots\dots (12)$$

and A_S , A_D and A_R are areal weighted values.

Equation 12 is the rearrange form of the following equation (given by Moussa, 1987):

$$Q_{SK} = 10652.791 GVBIN - 2891.04 \quad \dots\dots\dots (13)$$

SEDIMENT RATING MODEL

The main objective of this model was to determine the relationship between each set of the observed water discharges, Q_S 's, Q_D 's and Q_R 's and the corresponding SS discharge, Q_{SS} 's, Q_{SD} 's and Q_{SR} 's, that were determined by the minimum norm procedure and on the basis of AVHRR-NOAA Satellite Data, GVBIN, as one of the prior informations. The Linearized form of the equation given by:

$Q_s = a \cdot Q_f^b$, where Q_s is the SS discharge, Q_f is the water discharge, and a, b are constant values, can be written in the form:

$$\text{Log}(Q_s) = \text{Log}(a) + b \text{Log}(Q_f) \quad \dots\dots (14)$$

Assuming that Q_s and Q_f have the same units for the values Q_{SK} and Q_K , respectively, that were given in Equation (1). Equation (14) can be written in the form:

$$\text{Log}(a) + b \cdot \text{Log}(Q_f) - \text{Log}(Q_s) = V_r \quad \dots\dots (15)$$

where V_r is the residual value, e.g., the value by which the observation differs from the model value. Since a large number of observations of both water discharge and SS discharge exist, the method of least squares was used to determine constants a and b for each equation, e.g., for each outlet station and for the Sennar station.

RESULTS AND ANALYSES

About sixty observations of water discharge at each station, Sennar; Dinder; Rahad; and Khartoum, were used to carry out the SS discharge model.

The resulting sediment rating model for each station was found to be:

For Sennar station

$$Q_{SS} = 235.919 \times 10^{-6} Q_S^{0.531} \quad \dots\dots (16)$$

For Dinder outlet station

$$Q_{SD} = 2986.982 \times 10^{-6} \cdot Q_D^{0.873} \quad \dots\dots (17)$$

For Rahad outlet station

$$Q_{SR} = 1100.074 \times 10^{-6} \cdot Q_R^{0.528} \quad \dots\dots (18)$$

The correlation coefficient for the parameters were found to be -0.9923, +0.9197, and +0.9943 for Sennar, Dinder outlet, and Rahad outlet stations, respectively. While the correlation coefficient for the variables were found to be 0.263, 0.899, and 0.89 for Sennar, Dinder outlet, and Rahad outlet stations.

CONCLUSION AND RECOMMENDATIONS

The use of GVIBN to predict sediment yield is of vital importance to engineers and hydrologists. This approach to predict sediment yield for Large Basin is very economical since the satellite data has a large coverage area, easily available, and inexpensive.

It is recommended to use the variables, which inserted in the SS discharge model, at the same time during which the GVI data were collected.

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