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A strategy for organizing a sediment data collection network based on the available hydrological records for a catchment in Kenya

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Abstract The sediment loads of rivers can give rise to many problems in terms of water resource development and there is an important need for sediment data in many areas. A network of stations must be established for regular data collection and, since resources will frequently be limited, a strategy must be developed to ensure adequate data collection for the purpose. The Tana catchment in Kenya is employed to demonstrate how such a strategy could be developed. Available rainfall and streamflow data are analysed to obtain seasonal patterns of flow and rainfall. Sediment yields are calculated and further analysis is used to confirm that sufficient information will be obtained through limited data collection.

Stratégie d'organisation d'un réseau de collecte d'information sur les transports solides à partir de rélevés hydrologiques disponibles de courte durée pour un bassin versant du Kénya

Résumé Les sédiments transportés par les fleuves peuvent poser de nombreux problèmes pour l'aménagement des ressources en eau et le besoin de données concernant ces transports solides s'impose absolument dans de nombreuses régions. Par suite de ressources financières plutôt limitées, une planification et une stratégie sont nécessaires pour assurer une collecte d'informations suffisante pour les besoins. Le bassin de la rivière Tana est choisi pour mettre au point cette stratégie. L'information sur les précipitations et l'écoulement fluvial est analysée pour arriver à connaître la répartition saisonnière des débits et des précipitations. La quantité de sédiments transportés est déterminée et une analyse plus poussée est faite avec en plus d'autres informations pour confirmer que des informations suffisantes peuvent être obtenues facilement avec une collecte limitée de données.

MEASUREMENT OF SEDIMENT

It is important to measure the quantities of sediment in rivers as they cause many problems in water resources development. These measurements must be undertaken in a specific manner. Because the sediment transport process is dynamic, i.e. varying from one point to another and changing with time, measurements are required on a routine basis. Measurements normally undertaken for the assessment of sediment include:

(a) sampling of suspended sediment,
(b) sampling of bed load,
(c) flow determination.

These measurements can be undertaken by wading in a river during dry weather flows, but at higher flows boats and cableways are required. If measurements are made from a bridge, a bridge crane will be necessary. The instruments required for this purpose are suspended load and bed load samplers and sample bottles. The requirement of logistic support is inevitable. This involves manpower and financial commitment, both for the field sampling and for the laboratory analysis. These requirements are dependent on the number of sediment data collection stations to be employed and the number of samples to be taken and flow measurements to be made. Assuming that the number of stations is constant (i.e. use of an optimum network of stations for the purpose), it is clear that the requirements would be reduced by a decrease in the number of samples taken.

PURPOSE AND SCOPE

A strategy must be developed, whereby, the number of stations available is considered to be reasonably adequate, and an accurate assessment of sediment loads is possible using a limited number of samples from the available stations in the network.

THE STUDY BASIN

The drainage basin selected for the purpose of the study is the Tana River basin in Kenya and the study area is indicated in Fig. 1. The Tana River is the largest river of the Republic of Kenya. It originates in the highlands of the Nyandarua Range and Mount Kenya and flows eastwards and then southwards into the Indian Ocean. The Tana River basin has an area of 132 000 km^2 (22.6% of the area of the country). The minimum daily dry weather flow of the river is 25 $m^3 s^{-1}$ and the maximum daily flood flow is 2418 $m^3 s^{-1}$ (the instantaneous peak value being estimated at 3000 $m^3 s^{-1}$). The mean daily flow is estimated at 229 $m^3 s^{-1}$, and the total annual flow at approximately 7232 million m^3.

The upstream area has both agriculture and hydropower potential and the downstream area has a great potential for irrigation. Due to the good climate and soil conditions, the upstream project area has a high population density and is considered to be one of the most developed areas of Kenya. Unfortunately this area experiences high rates of soil erosion leading to high sediment loads in the rivers. Sediment yields in the project area are in places in excess of 4000 t km^{-2} $year^{-1}$.

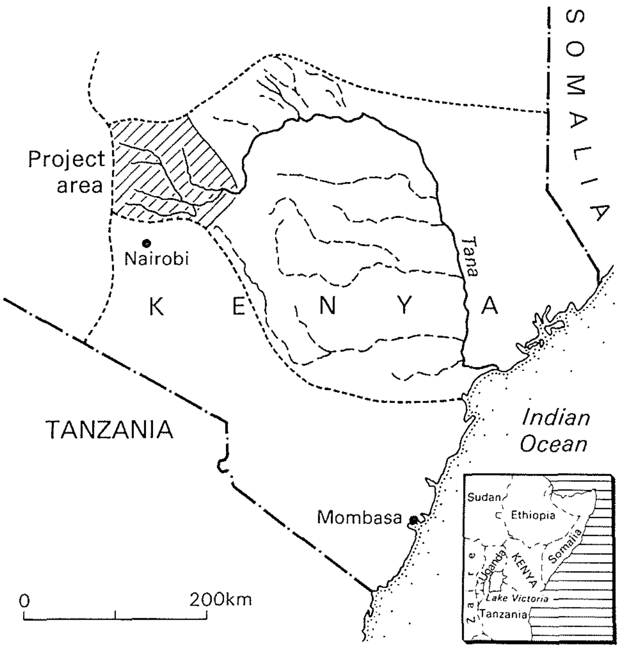

Fig. 1 The Tana River basin, Kenya and the project area.

THE EXISTING NETWORK AND RECORDS

An extensive network of hydrometeorological stations exists in the Tana River basin. These are considered to be adequate when checked against the World Meteorological Organization requirements (WMO, 1974).

The network is operated by the Ministry of Water Development of Kenya in coordination with the Meteorological Department of Kenya. The headquarters of both organizations are in Nairobi. The work is undertaken by staff from the headquarters together with staff from five field offices and local field staff. The staff involved are professionals, technicians and locally trained semi-technicians. The normal means of transport are Landrovers, pick-ups and sometimes lorries. The staff gauges and raingauges are read manually on a daily basis by local staff in the vicinity of the gauges. Maintenance and security of the instruments is the responsibility of local staff in the area. Rivers are gauged by staff from the field offices twice a month along with the changing of rainfall and runoff recorder charts. Data processing is carried out by field staff, whilst the final analysis for any development project and for regional analysis and policy planning is undertaken by the headquarter's staff.

The important rivers in the Upper Tana basin are shown in Fig. 2. The Chania, Thika, Tana (Sagana), and Thiba rivers all contribute to major reservoirs. The stations selected for study in this paper are also shown in Fig. 2.

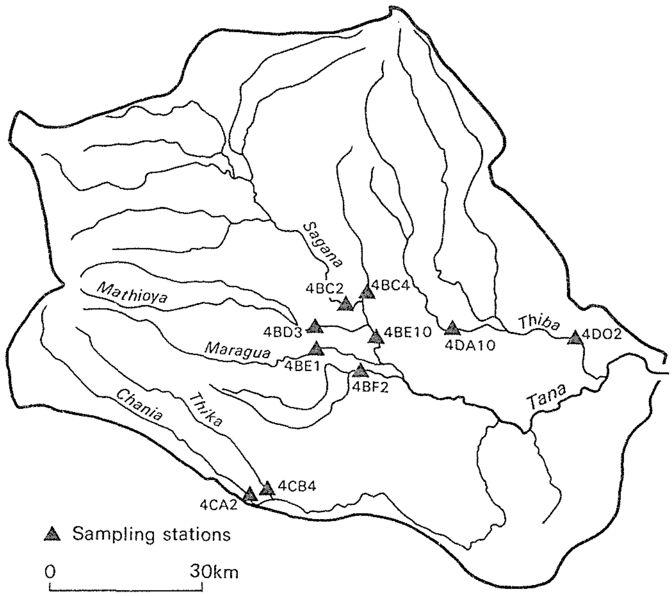

Fig. 2 Major rivers of the Upper Tana basin and the sediment sampling stations.

DATA ANALYSIS AND ASSESSMENT

The data required for the analysis for the paper are:

(a) summary of gaugings at all stations;
(b) gauge height records at all stations;
(c) mean suspended sediment concentration values and corresponding flow values at all stations.

All these data were compiled for processing and further analysis. The stations were calibrated and the available gauge heights converted to discharge. Flow duration analysis was carried out for each station using the daily flows and the total year method of analysis. The flows were sorted into classes and the relative frequencies and probabilities of flow were obtained. The flow duration curves were plotted on normal arithmetic paper.

Sediment yields were obtained using the formula:

$$S_y = k \times C_s \times Q_w$$

or

$$S_y = 0.0864 \times C_s \times Q_w$$

where

C_s = sediment concentration (mg l^{-1}),
Q_w = flow ($m^3\ s^{-1}$),
S_y = sediment yield (t day^{-1}).

The equation of the sediment rating curve for each station was obtained by plotting the sediment yields against the corresponding water flows on loglog paper. Examples of a flow duration curve and a sediment rating curve are given in Fig. 3. These curves for each station were used to convert the daily discharges into daily sediment yields. The annual sediment yields at each station was determined by two different methods.

The first method of determining the annual sediment yield used the flow duration curve and the sediment rating curve for a given station. The example of R.G.S. 4CA2 is given in Table 1.

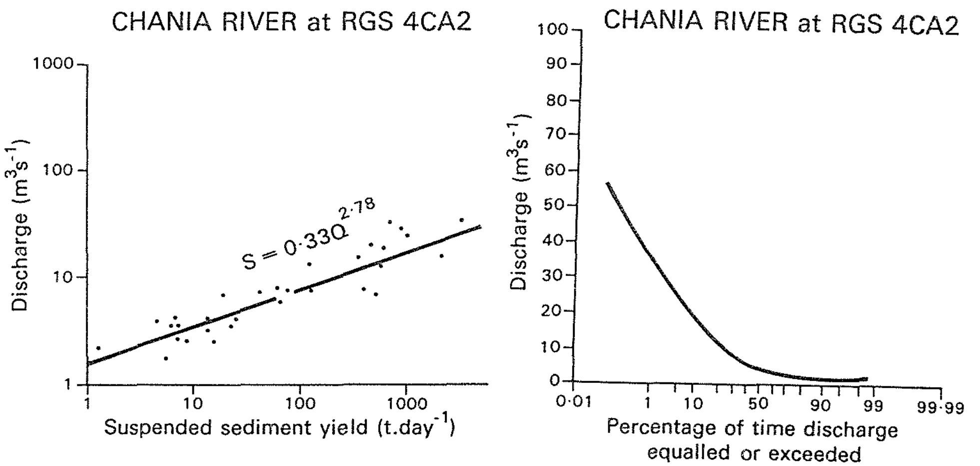

Fig. 3 The sediment rating curve and flow duration curve established for the Chania River at R.G.S. 4CA2.

Table 1 Calculation of annual sediment yield for R.G.S. 4CA2

Class	*Int*	*Mid-pt.*	*Q* $(m^{-3}s^{-1})$	*Sed. yield* $(t\ day^{-1})$	*Weighted Sed. yield*	*flow*
0-5	5	2.5	32	5040	252.25	1.6
5-10	5	7.5	23	2014	100.70	1.15
10-15	5	12.5	18	1018	50.90	0.90
15-20	5	17.5	15	614	30.70	0.75
20-30	10	25.0	12	330	33.00	1.20
30-40	10	35.0	8	107	10.70	0.80
45-60	20	50.0	4	16	3.20	0.80
60-80	20	70.0	2.5	4.2	0.84	0.50
80-90	10	85.0	2	2.3	0.23	0.20
90-100	10	95.0	1	0.33	0.033	0.10
					482.553	8.00

Annual Sediment Yield $= 482.55 \times 365\ t\ year^{-1}$

$= 176\ 130\ t\ year^{-1}$

Annual Water discharge $= 8.0 \times 31.6 \times 10^{6}$

$= 252.8 \times 10^{6}\ m^{3} year^{-1}$

Table 2 *Cumulative Sediment quantities associated with given flow values for R.G.S. 4CB4*

Flow	*Total sediment amount (t)*	*% of annual yield*
1	*3.59*	*0.003*
2	*68.69*	*0.060*
3	*456.42*	*0.430*
4	*811.17*	*0.756*
5	*1132.17*	*1.056*
8	*2041.38*	*1.903*
10	*3753.97*	*3.500*
15	*10434.37*	*9.720*
20	*26074.10*	*24.300*
30	*84590.80*	*78.840*

The second method used to determine the annual sediment yield used the sediment rating curve and the daily discharge series for the station. The daily flow values were converted to daily sediment yields, using the sediment rating curve for that station. These sediment yields were then totalled to give the annual sediment yield for the station. The ratio of the two sediment yield values was used as a correction factor for the daily sediment yield values in the final analysis.

Further analysis was undertaken to determine the relationship between flow magnitude and the corresponding proportion of the total sediment yield (%). This was done by arbitrarily selecting a flow value and obtaining the total value of all daily sediment yields corresponding to flow values less than the selected flow value for a given year as a percentage of the annual sediment yield. The following flow values were selected for all the stations under scrutiny in the paper: 1, 2, 3, 4, 5, 8, 10, 15, 20, 30 and 40 $m^3\ s^{-1}$. The above exercise was repeated with the data from all the selected stations with available records to produce Table 3.

Table 3 *Cumulative Percentage sediment yield associated with given flows at selected stations*

Flow	*Sediment quantity (% of annual yield)*							
	4BE10	*4CA2*	*4CB4*	*4BF2*	*4BC2*	*4BC4*	*4DD2*	*4DA10*
1	-	-	*0.003*	*0.5*	-	*0.72*	-	-
2	-	-	*0.06*	*1.73*	-	*7.12*	-	-
3	-	*0.22*	*0.43*	*3.21*	-	*17,.80*	*0.03*	*0.01*
4	-	*0.40*	*0.75*	*4.39*	-	*23.75*	*0.21*	*0.11*
5	-	*0.71*	*1.05*	*5.75*	-	*27.80*	*0.33*	*0.44*
8	-	*1.39*	*1.90*	*14.85*	*0.01*	*44.1*	*0.59*	*1.31*
10	-	*2.18*	*3.50*	*20.26*	*0.04*	*52.1*	*1.29*	*2.28*
15	*0.04*	*7.03*	*9.72*	*27.78*	*0.14*	*100*	*5.46*	*10.0*
20	*0.10*	*19.72*	*24.3*	*31.28*	*0.64*	-	*12.61*	*20.0*
30	*0.82*	*46.45*	*78.8*	*53.10*	*1.49*	-	*23.16*	*39.7*
40	*1.37*	*79.39*	*96.0*	*55.00*	*2.48*	-	*4045*	*59.1*
50	-	*91.05*	*100*	-	*3.93*		*54.70*	*66.8*

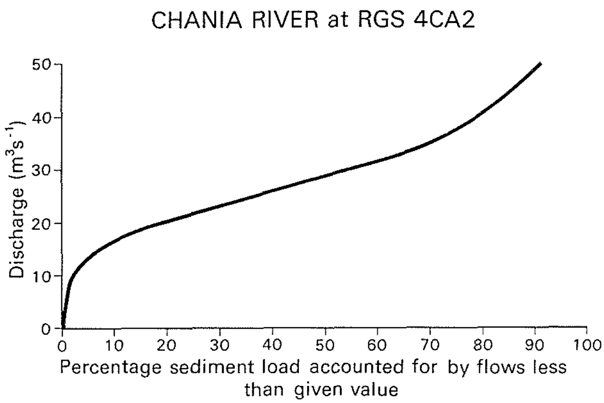

Fig. 4 *The flow vs. cumulative sediment yield plot developed for the Chania River at R.G.S. 4CA2.*

Table 4 *Limit of flow for given proportion of measured sediment load*

Proportion of measured sediment load (%)	*Lower limit of low (m^3 s^{-1})*							
	4BE10	*4CA2*	*4CB4*	*4BF2*	*4BC2*	*4BC4*	*4DD2*	*4DA10*
99	*40*	*6.5*	*4.8*	*1.2*	*24.5*	*1.1*	*9.0*	*8.0*
98	*60*	*9.5*	*8.1*	*2.0*	*35.3*	*1.2*	*11.0*	*9.0*
95	*105*	*13.0*	*11.2*	*4.7*	*54.5*	*1.9*	*14.5*	*12.0*
90	*140*	*16.5*	*15.0*	*6.5*	*70.0*	*2.3*	*18.0*	*15.0*

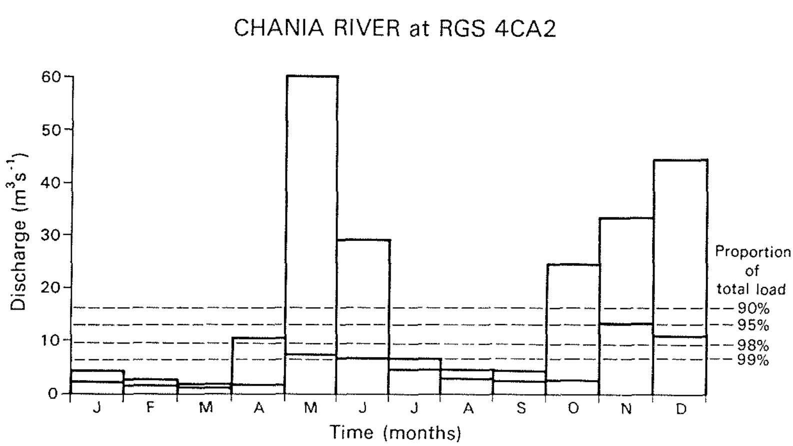

Fig. 5 *The annual flow pattern of the Chania River at R.G.S. 4CA2 in relation to the threshold levels for sediment sampling.*

These values are used to obtain the flow *vs.* percentage sediment yield plots for each station (e.g. Fig. 4). Table 4 was developed from the plots for each station to guide decisions as to the lower limit of flow at which sediment sampling needs to be undertaken to ensure availability of adequate information for assessment of sediment loads.

Knowing the flow limit for sediment sampling (e.g. 6.5 m^3 s^{-1} for measurement of 99% of the sediment yield at R.G.S. 4CA2) the final analysis of flows was undertaken to approximate the times of sampling. Figure 5, based on R.G.S. 4CA2 provides a general indication of the pattern of flows at stations in the Tana area.

CONCLUSION

It is clear that there is no need to undertake sediment sampling all times during the year. If a reasonable error of say 5% was permitted, sampling at the stations in the Upper Tana could be reduced by at least 40%, leading to significant reductions in costs of sampling and more effective use of the few instruments available for the purpose, without any significant reduction in the accuracy of the results.

REFERENCE

WMO (1974) *Guide to Hydrological Practices.*WMO no. 168.