Rainfall Runoff Model for River Sosiani's Catchment

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ABSTRACT
Rainfall runoff from a river catchment is essential for hydrologic analysis for the purpose of water resources management, including water quality assessment. Rainfall runoff estimations from River Sosiani catchment were carried out using MIKE 11 NAM model which was subsequently used to develop a hydrodynamic model for the river. The river's catchment was delineated using topographic maps and digital elevation model (DEM) derived using ArcView GIS 3.3 software. The runoff discharges were simulated using rainfall and evaporation data collected over a period of 25 years (1965-1990) and then filtered using a Water Engineering Time Series Processing tool (WETSPRO) software. The simulated peak flow occurred in 1967, 1973, 1978, and 1982 with approximate values of 39, 38, 39, 39m^3/s respectively. The peak filtered interflows and baseflows for 1967, 1973, 1978 and 1982 were 5 & 2, 6 & 3, 7 & 4, and 5 & 2 m^3/s respectively. The optimum values of the model parameters obtained during the calibration procedures were presented. The reliability of the MIKE 11 NAM was evaluated based on the Efficiency Index (EI) and Root Mean Square Error (RMSE). The EI and RMSE obtained are 0.80 and 0.070 respectively.

Key words: Catchment, Flow filtration, Rainfall runoff, River Sosiani, Simulation

1.0 INTRODUCTION

Rainfall runoff estimation from a catchment is essential for the purpose of water resources planning, including water quality and pollution control applications. A number of models have been developed to correlate rainfall and runoff relationship in engineering research and practices. The notable ones include the Rational Method (McPherson, 1969), Soil conservation service – Curve Number Method (Maidment, 1993), and Green and Ampt method (Green, 1911). The more advanced models which should provide better runoff estimation are continuously being researched and developed. Some of the advanced models identified include the Generic Danish MIKE 11 NAM. The choice and validity of the model depends on the purpose of the study, the data availability, and the decision requirement.

The objective of this study was to model the rainfall runoff discharges of River Sosiani's catchment using MIKE 11 NAM. The long term simulation (1965 – 1990) was carried out based on the available rainfall and evaporation data. To support the time series processing tasks as well as the application of the multi-criteria model evaluation protocol, a time series tool (WETSPRO: Water Engineering Time Series Processing tool) has been developed (Willems, 2000). It is based on the assessment of graphical displays, which complement traditional goodness-of-fit statistics. The simulation results were subsequently filtered using WETSPRO, and the calibration and validation procedures of the model performed to provide a satisfactory estimation. River Sosiani's catchment MIKE NAM model was necessary for the subsequent development of the river's hydrodynamic model, for further application in River Sosiani's water quality model.

2.0 CATCHMENT DESCRIPTION

River Sosiani's catchment lies between latitudes 00^0 03'S and 00^0 55' N, and longitudes 34^0 50' E and 35^0 37 E. It occupies 225 sq km and has 21 sub-catchments (Figure 1). It is bound in the South-East by the Elgeyo escarpment and in the North-west by Uasin-Gishu plateau in the Rift Valley province of Kenya. There are two major water reservoirs in the catchment: the Elligerin dam and the Two-river dam. The catchment was divided into three zones, namely the Forested zone (Fz.shp), Agricultural zone (Az.shp) and Urban zone (Uz.shp) (Figure 1). Presented in Table 1 are some of the pertinent characteristics of the catchment.

Table 1: Geo-morphological Parameters of the Sosiani Catchment

S. No	Parameters	Unit	Value
1	Basin length	km	34
2	Area	Sq km	225
3	Perimeter	km	88
4	Total no. of streams	No.	15
5	Total length of streams	km	20
6	Total length of main stream	km	44
7	Stream order		2
8	Form factor		0.20
9	Circulatory ratio		0.36

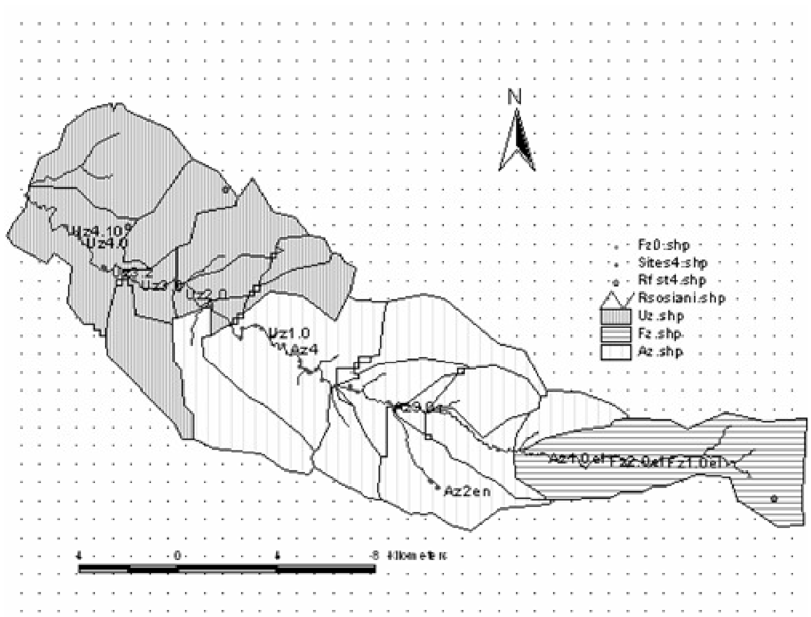

Figure 1: The study area

3.0 MATERIALS AND METHODS

3.1 ArcView GIS 3.3

River Sosiani's catchment was delineated using topographical maps. The maps were digitized and digital elevation model (DEM) derived. The catchment was subsequently delineated using DEM (Figure 1).

3.2 MIKE 11 NAM

Data requirements for MIKE 11 NAM model consists of: setup parameters: catchment area, model parameters: time constants and threshold values for routing of overland flow, interflow and base flow, meteorological data: precipitation and potential evaporation, and stream-flow data for model calibration. The reliability of the MIKE 11 NAM was evaluated based on the Efficiency Index (EI) as described by Nash and Sutcliffe (1970). There are several related studies available for model performance evaluation such as by Aitken (1973) and Fleming (1975). The procedure by Nash and Sutcliffe (1970) had been widely used for detection of systematic errors with respect to long term simulation. The EI was developed to evaluate the percentage of accuracy or goodness-of-fit of the simulated values with respect to their observed values. The EI as described by Nash and Sutcliffe (1970) summarized in Equation 1.

$$EI = \frac{\sum_{i=1}^{n}(q_o - \bar{q})^2 - \sum_{i=1}^{n}(q_o - q_s)^2}{\sum_{i=1}^{n}(q_o - \bar{q})^2} \quad (1)$$

Where; q_o = observed flow at time *i* number of data points, $\bar{q}$ = mean value for observed flow $= \frac{1}{n}\sum_{i=1}^{n} q_o$, q_s is simulated flow at time, *i*, and *n* is number of data points. The efficiency index (EI) equal to 1 indicates the best (perfect) performance of the model. The reliability of MIKE 11 was also evaluated using Root Mean Square Error (RMSE) used by Fleming (1975). This method provides a measure of absolute error between the computed and observed flows. RMSE values tend to be zero for perfect agreement between observed and simulated values. RMSE is defined as in Equation 2.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_o - Q_s)^2} \quad (2)$$

Where; Q_o = observed flow at time *i* number of data points, Q_s = simulated flow at time *i*, and *n* = number of data points.

3.3 Water Engineering Time Series Processing tool (WETSPRO)

A time series total rainfall-runoff discharge was filtered using a numerical digital filter technique by WETSPRO tool into overland flow, interflow and base flow (Willems, 2000).

3.3.1 Discharge splitting

On the basis of the filter, the series of the total runoff discharges can be split up into the series of its subcomponents: overland flow, interflow and base-flow. The splitting procedure is based on the clear difference in the order of magnitude of the recession constants of the runoff sub-flows. The base-flow is initially separated from the total rainfall-runoff discharge. Interflow is subsequently separated from the combined surface runoff and interflow. The recession constants of the sub-flows can be calibrated as the average value of the inverse of the slope, *k*, of the linear path in the recession periods of ln (q). When s is a number of time steps considered during the recession period *t*, the recession constant can be calculated using Equation 3.

$$[illegible] \quad (3)$$

3.3.2 Input Data

The rainfall and evaporation data were collected from the three gauging stations (Rf st4.Shp) (Figure 1), operated and maintained by the relevant authorities in Kenya, in Uasin-Gishu district (Table 2).

Table 2: Rainfall Gauging Stations

Station	Location	Authority	Latitude	Longitude
Maji Rf st	Mlimani	Min. of Water	59551	750835
Kapsoya Rf st	Kapsoya	Meteorological dept.	61045	754792
Kaptagat Rf st	Kaptagat forest	Forest dept.	48535	776984

The areal precipitation was required for the MIKE 11 NAM computation. The areal precipitation was computed from the three point precipitation data by Theissen polygon method.

4.0 RESULTS AND DISCUSSION

The application of MIKE 11 model for rainfall runoff estimation was divided into two phases. The first phase involved the calibration process to ascertain optimum values of the model parameters. The second phase was the stream flow simulation using the estimated model parameters during the calibration process. Some parameters were highly sensitive to changes as shown in Table 4. This is probably due to varied relief and vegetation cover in the catchment. The calibration was effected using records of daily rainfall for a period of 25 years between 1965 and 1990. The NAM parameters were adjusted to match the geo-morphological and vegetation characteristics of the catchment (Table 3). Figure 2 represents the results of simulated and observed flow in the MIKE 11 model calibration. It is evident that MIKE 11 model cannot incorporate the peak discharges in the model optimization. Some of the factors that contribute to the calibration inaccuracy are system uncertainties including the nature of rainfall pattern, flood problems and land-use. The nature of rainfall pattern, due to varying catchment relief, is spatial resulting in uneven rainfall distribution within the catchment area. This factor directly affects rainfall runoff model calibration.

The reliability of the MIKE – NAM was evaluated based on the Efficiency Index (EI) as described by Nash and Sutcliffe (1970). The EI was developed to evaluate the percentage of the accuracy or goodness-of –fit of the simulated values with respect to their observed values. The IE obtained was 0.70. The Root Mean Square Error (RMSE) method (Fleming, 1975) was also applied to evaluate the reliability of MIKE 11 during this study. RMSE method can be regarded as a measure of absolute error between the computed and the observed discharge values. The RMSE values tend zero for the perfect agreement between observed and simulated values. The RMSE value obtained during this study was 0.08. Satisfactory and reliable results were obtained with their EI and RMSE of 0.70 and 0.08 respectively.

Table 3: NAM model parameters after calibration

Parameter	Units	Value	Lower bound	Upper bound
Area of catchment	km^2	225		
Maximum water content in surface storage	mm	20	0	100
Maximum water content in root zone storage	mm	200	0	1000
Overland flow runoff coefficient	Dimensionless factor	0.3	0	1
Time constant for routing interflow	hr	700	100	10000
Time constant for routing overland flow	hr	20		100
Root zone threshold value for overland flow	Dimensionless factor	0.1	0	0.9

Observed Q

Simulated Q

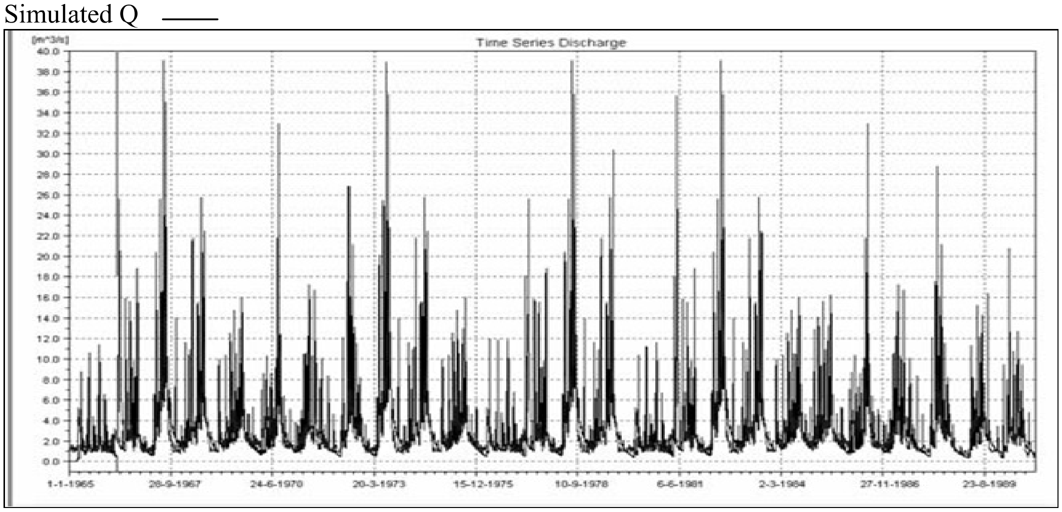

Figure 2: Catchment rainfall runoff simulation for period 1965 - 1990

Table 4: Effect of changing different NAM Parameters on Runoff

Parameter	Change	Effect
U_{max}	Increase	Peak runoff decreased, Runoff volume reduced
L_{max}	Increase	Peak runoff decreased, Runoff volume reduced
CQOF	Increase	Peak runoff increased, Runoff volume increased
CKIF	Increase	Peak runoff decreased, Runoff volume reduced
$CK_{1,2}$	Increase	Peak runoff decreased, The triangular shape expand horizontally
TOF	Increase	Peak runoff decreased, Runoff volume reduced

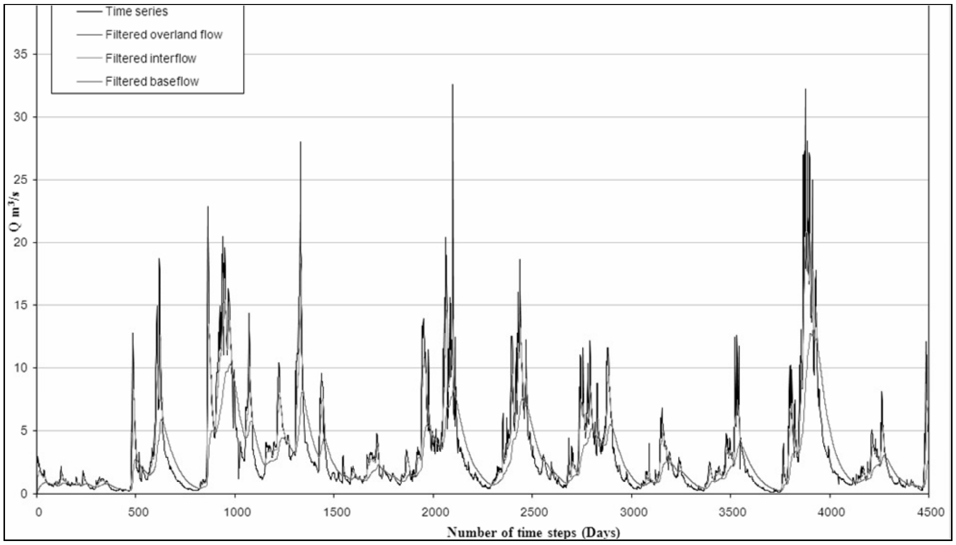

Figure 3: Part of the Filtered daily discharges in the Sosiani catchment for a period of 25 years

5.0 CONCLUSION

River Sosiani's catchment rainfall runoff discharge was successfully modeled using MIKE 11-NAM during this study. The simulated peak flow occurred in 1967, 1973, 1978, and 1982 with approximate values of 39, 38, 39, 39m^3/s respectively. The corresponding peak filtered interflows and baseflows were 5 & 2, 6 & 3, 7 & 4, and 5 & 2 m^3/s respectively. The optimum values of the model parameters obtained during the calibration procedures were presented. The reliability of the MIKE 11 NAM was evaluated based on the Efficiency Index (EI) and Root Mean Square Error (RMSE). The EI and RMSE obtained are 0.80 and 0.070 respectively. The discharge estimations will be used as input for the MIKE 11 Hydrodynamic model for river Sosiani.

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