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Long-term-discharge Analysis Using the EPA Method for the Tana River in Kenya

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Abstract: The Tana River is Kenya's largest river, with a length of 1,000 km and a catchment area of 95,000 km^2, and that has one of the famous drainage basins in the country. This study aims to clarify the trends in the long-term-discharge based on hydrological records of the Tana River for the past 52 years. The long-term-discharge data of the Tana River show that the discharge of the river has been increasing every year since 1988. The annual maximum discharge of the Tana River has been increasing since 1983, and the maximum discharge during the wet season (October to December) has been increasing. In recent years, it is probable that the occurrence cycle of heavy rainfall has shortened, and it is estimated that flooding will become more frequent.

Keywords: Basin, Discharge, Long-term-trend analysis, Precipitation, River

1. Introduction

The Tana River is Kenya's largest river, with a length of 1,000 km and a catchment area of 95,000 km^2. It flows past the foot of Mt. Kenya and into the Indian Ocean. The Tana delta that locates in the lowest reaches of Tana River consists of 2,000 km^2 of alluvial land. To utilize the rich land and water resources of the delta, large-scale agricultural land development has been conducted since 1980s, under the Tana Delta Irrigation Development Project (Agwata, 2005). Agriculture in the delta suffered catastrophic damage from abnormal weather and floods caused by *El Niño* in December 1997 and December 2006. Because climate change has been an obstacle for water use and flood control projects in the basin, it is necessary to clarify the long-term hydrologic changes of the Tana River and to devise responses. This study aims to clarify the trends in the long-term hydrological environment (*i.e.*, changes in precipitation and discharge) based on hydrological records of the Tana River for the past 52 years.

2. Survey site and analysis method

The Tana River flows past the foot of Mt. Kenya before emptying into the Indian Ocean. It has the largest catchment area (95,000 km^2) of any river in Kenya. Alluvial land measuring 2,000 km^2 lies at the river mouth. Because the Tana River is an unimproved river with a gentle gradient, it has flooded repeatedly and its main course has changed many times over the ages. The survey site is Garissa (0˚29'S, 39˚38'E), a city at the middle reaches of the river.

We used discharge data of the Tana River observed by the Kenya Meteorological Department for 1944 to 1995 (52 years). The data were monthly average discharge, maximum discharge and minimum discharge. For analysis of precipitation, we used the monthly total precipitation observed by the Kenya Meteorological Department for 1959 to 2006 (47 years).

Fig.1. Investigated point.

To clarify the long-term changes in the Tana River's discharge, we used the method of the Economic Planning Agency of Japan (the EPA Method). Long-term-trend analysis is a method to qualitatively clarify a given trend. In this paper, we assume that changes in long-term-discharge are the combined result of four components (*T*, *C*, *S*, and *I*), and we statistically separate the *TCSI* components to understand the trend of each component. The details of the *TCSI* components are discussed below. The EPA method was used in separating the *TCSI* components.

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In the EPA Method, a trend in the time-series data of discharge is classified into four categories of variation for use in the following equation.

Discharge = $T \cdot C \cdot S \cdot I$

Where, *T* (Trend) is long-term variation, which usually shows gradual increase or decrease; *C* (Cyclical component) is mid-term cyclical variation (*i.e.*, over 12 months), *S* (Seasonal variation) is 12-month variation, in which the variation for a given certain season tends to be similar from year to year; and *I* (Irregular variation) is other variation.

3. Results and Discussion

3.1 Long-term-change in river discharge

The changes in the annual minimum, maximum and average discharges of the Tana River for the years 1944 to 1995 are shown in **Figure 2**. The long-term-change in each of the three discharges is shown in the 10-year moving average.

The change in the minimum discharge is small, and the discharge is stable for a long period. The average discharge fluctuates in the range from 57 m^3/s to 423 m^3/s. The changes in the moving average show that even though there is a gentle peak around 1970, the average discharge has been roughly stable. The range of fluctuation in the maximum discharge is 245 m^3/s to 2,111 m^3/s. The largest value is 8.6 times the smallest value. The 10-year fluctuations in the moving average of the maximum discharge show that the maximum discharge peaks in the first half of 1970's and starts to increase again in 1983.

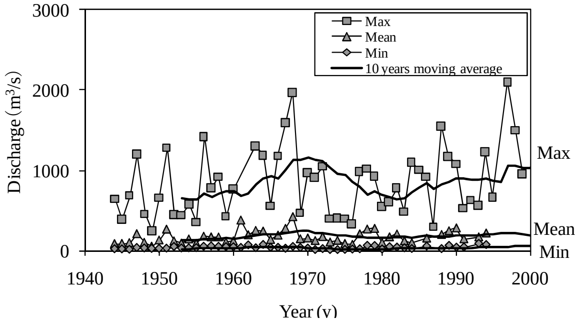

Fig. 2. Time Series data of discharge (Max, Mean Min).

3.2 Annual changes in discharge

The fluctuation in annual discharge of the Tana River obtained from the data for the analyzed periods is shown in **Figure 3**. The monthly average discharge shows two major changes in discharge in each year in this region: one change during the rainy seasons and another during the dry seasons. We divided one year into four quarters: the first quarter is from January to March, the second quarter is from April to June, the third quarter is from July to September, and the fourth quarter is from October to December. We defined the first and third quarters as dry seasons, and the second and fourth quarters as rainy seasons. The discharge for each quarter was calculated by obtaining the average discharge from the three-month discharge data for each quarter.

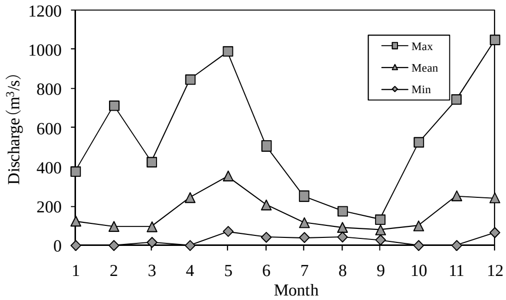

Fig. 3. Annual changes in discharges (Max, Mean, Min).

3.3 Discharge changes in each quarter

Long-term changes in the discharge of each quarter are shown in **Figure 4**. **Figure 5** shows the ten-year moving average for each quarter that was calculated using the data in Figure 4. From Figure 5, it is known that the rate of change for the third quarter is relatively stable. The rates of change in discharge for the first, second, and fourth quarters show that there are peaks around 1970. The rates of change in discharge for the second quarter are relatively stable after the peak, but the discharges for the first and fourth quarters start to increase again in 1988. The increase in the discharge for the first quarter is particularly steep. The discharges for the first quarter showed a marked increase, which we hypothesized was caused by the wet season in the forth term extending into the first quarter due to recent climate change.

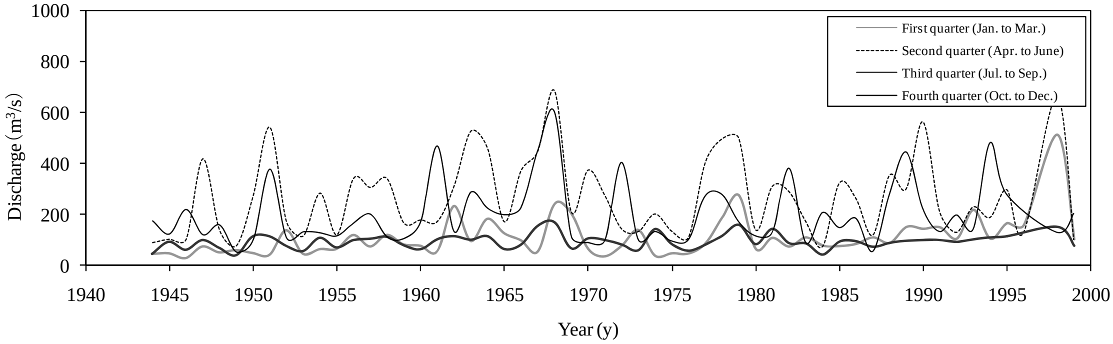

Fig. 4. Discharge fluctuation for each quarter.

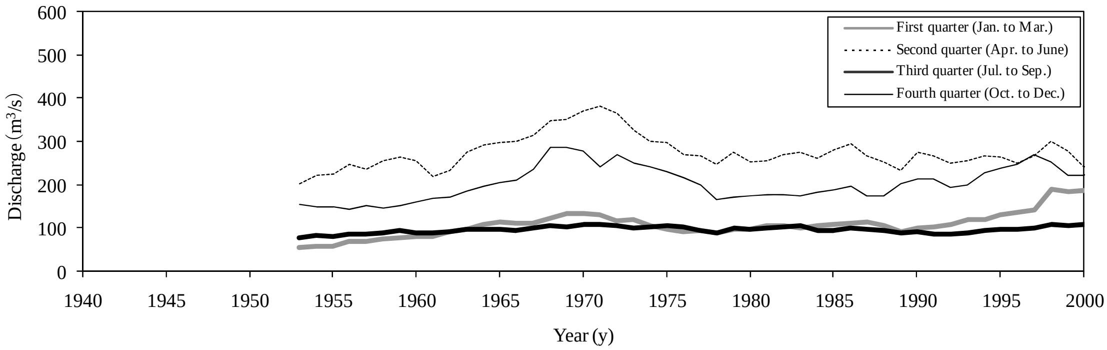

Fig. 5. Ten-year moving average of discharge for each quarter.

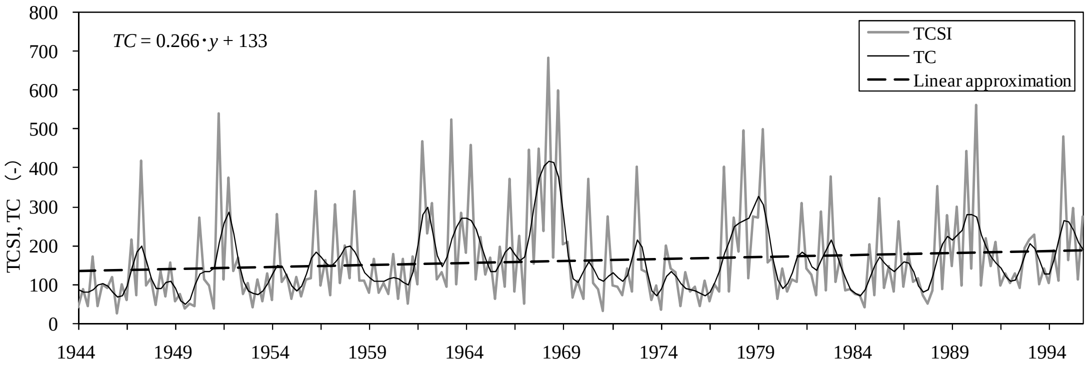

Fig. 6. Results of TCSI separation (EPA method).

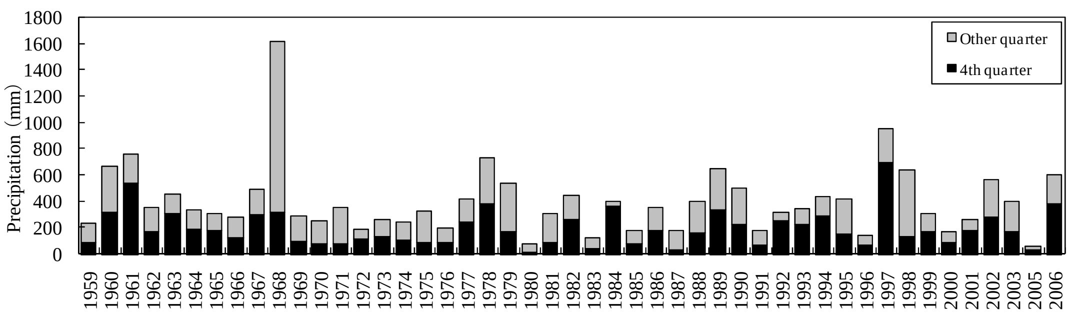

Fig. 7. Annual precipitation and precipiration for the fourth quarter (Oct. to Dec.).

3.4 Long-term-trend analysis for discharge

The measured discharge and the result of Trend and Cycle (*TC*) are shown in **Figure 6**. The approximation curve for *TC* is shown in the same figure. The approximation curve for *TC* is the curve that shows long-term variation in discharge. The approximation curve shows that the values are increasing year by year.

3.5 Long-term change in annual precipitation

The annual precipitation observed in Garissa for the 47 years from 1959 to 2006 and the total precipitation for the fourth quarter of each year is shown in **Figure 7**. The average annual precipitation during the observed years is 392 mm/y. Yearly precipitation exceeded 500 mm/y ten times during the observed period: in 1960 (661 mm/y), 1961 (757 mm/y), 1968 (1612 mm/y), 1978 (724 mm/y), 1979 (531 mm/y), 1989 (640 mm/y), 1997 (950 mm/y), 1998 (639 mm/y), 2002 (560 mm/y) and 2006 (600 mm/y). Two successive years saw precipitation exceeding 500 mm/y, and the cycle of occurrence of heavy precipitation was 7 to 10 years. In recent years, however, the cycle may have become shorter; heavy precipitation occurred in 2002, only four years after the previous heavy precipitation. It is conjectured that abnormal weather caused by *El Niño*, which has surfaced globally, has affected the interval between heavy rainfalls to some degree.

The average for total precipitation in the fourth quarter (October to December) is 187 mm. The average precipitation for the 10 years from 1997 to 2006 is 231 mm, which is 44 mm greater than the average for total precipitation. The precipitation in the October to December quarter in recent years has been greater than that for previous years.

The precipitation during the fourth quarter in 1997 and 2006, in which the observed area experienced flood damage, was 690 mm and 378 mm, respectively. These two are the greatest and third greatest values in the observed period (The second greatest is 529 mm, for 1961). It is understood that heavy precipitation, whose probability of occurrence was once low, has become more frequent in recent years.

4. Conclusions

To clarify the hydrological changes in the Tana Delta region, we examined the long-term- changes in the discharge of the Tana River and precipitation in the catchment area observed in Garissa. The followings are the findings.

(1) The maximum discharge of the Tana River has tended to increase every year since about 1983.

(2) The discharge in the quarter from October to December (one of the two rainy seasons) has been increasing.

(3) As results of EPA analysis, long-term variation (*T*) and mid-term cyclical variation (*C*) are increasing year by year.

(4) In recent years, the event cycle for large-scale precipitation, which had been 7 to 10 years, has become shorter.

(5) A comparison of the average precipitation during fourth quarter for the observed period (1959 to 2006) to that for the most recent 10-year period (1997 to 2006) finds that the precipitation in the October to December quarter in recent years has been greater than that for previous years.

The precipitation findings were obtained using the data for the years before 1997 in which flood damage occurred. The discharge and precipitation data revealed that the precipitation and discharge have tended to increase in recent years. Precipitation in the rainy season of October to December has tended to show particularly great increases, to which can be attributed the increasing discharge of the Tana River in this quarter. It is probable that the cycle of heavy rainfall occurrence has shortened in recent years, and it is estimated that flooding will become more frequent.

Reference

Agwata J.F. (2005): Water Management in the Tana Basin of Kenya: Potential Conflicts and Interventions. *Asia Journal of Water, Environment and Pollution*, **2**(2): 69-74.