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The influence of areal rainfall variability on surface flow regimes in the central highlands of Ethiopia

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Abstract
Rainfall variability affect the water resource management of Ethiopia. The influence of rainfall variability on flow regimes was investigated using five gauging stations with data availability from 1982-1997. It was confirmed that the variability in rainfall has a direct implication for surface runoff. Surface runoff declined at most of the gauging stations investigated. Therefore, effective water resource management is recommended for the study area. Future research should focus on watershed management level which includes land-use and land cover.

Introduction
Rainfall variability and its impact on the hydrologic regimes is highly affecting the water resource management in the central highlands of Ethiopia. The impact of climate variability on surface hydrology and water resources was investigated by several authors (e.g., Kundzewicz and Somlyódy, 1997; Wood et al., 1997; Kiely, 1999). Farquharson and Sutcliffe (1998) noted that temporal variability and occasional periodicity of sub-saharan African river flows are primarily induced by temporal and inter-temporal rainfall variability. Seleshi and Demarée (1995) found out that rainfall variability in the Ethiopian and Eritrean highlands significantly affected the flow regimes of the Blue Nile. Moreda and Bauwens (1998) reported that rainfall time series of the Addis Ababa weather station was significantly correlated with discharge measurement of the Awash River at its upper watershed. Studies on the impact of long-term mean rainfall variability on surface flow in the central highlands of Ethiopia are scarce. A little consideration was given to these subjects in land and water resources management research. This study aims: (1) To analyse the relationship between seasonal and long-term areal mean rainfall and surface flow regime, (2) to assess the temporal variability of surface flow regime, and (3) compare and contrast the long-term trend of surface hydrologic regime and long-term areal mean rainfall in the central highlands of Ethiopia.

Methods and Materials
The study focuses on the Awash River Basin in the central highlands of Ethiopia which plays an important role in the economy of the country and is the largest and most representative for the study area. Especially it is highly exploited for agricultural and

industrial development. Hydrometric data ranging from 1982-1997 of five gauging stations were statistically analysed (Tab. 1).

Tab. 1: Selected gauging stations in the central highlands of Ethiopia

Gauging station	Latitude	Longitude	Elevation (m)	Drainage area (km^2)	Years of observation
Hombole	8°23´	38°47´	2300	7722.50	1986-1997
Kessem	9°10´	39°04´	2800	50.00	1986-1997
Melka Kunture	8°42´	38°36´	2332	4456.00	1986-1997
Modjo	8°36´	39°05´	2175	1264.40	1989-1998
Teji	8°51´	38°25´	2569	662.50	1982-1988

Results and Discussion

The magnitude of the surface runoff at various gauging stations in the central highlands of Ethiopia varies considerably. It can be best explained by spatial variability of rainfall, terrain characteristics, soil physical properties, soil depth, soil water storage capacity and land-use practices in the area. The results are shown in Tab. 2 and 3.

Tab. 2: Statistical characteristics of annual hydrometric records at the selected gauging stations

Gauging stations	N	Mean (mill. m^3)	Stand. dev.	Coefficients		
				CV (%)	Skewness	Kurtosis
Hombole	12	583.69	614.44	105	0.75	-1.39
Kessem	12	33.07	13.04	39	0.01	0.33
Melka Kunture	12	499.58	159.50	32	1.79	3.44
Modjo	10	150.94	121.56	81	1.89	3.28
Teji	7	113.85	41.81	37	0.76	-0.44

Tab. 3: Statistical characteristics of summer hydrometric records at the selected gauging stations

Gauging stations	N	Mean (mill. m^3)	Stand. dev.	Coefficients		
				CV (%)	Skewness	Kurtosis
Hombole	12	908.10	371.18	41	1.74	1.23
Kessem	12	26.65	10.96	41	0.63	1.33
Melka Kunture	12	726.17	200.52	28	0.16	-0.31
Modjo	10	111.90	106.92	96	1.96	3.48
Teji	7	89.84	39.17	44	1.09	1.72

The variability coefficient of long-term mean annual surface runoff varies from 32% (Melka Kunture) to 105% (Hombole); in the summer period from 28% (Melka Kunture) to 96% (Modjo). Generally, the surface runoff is the highest at Hombole and the lowest at Kessem. Moreover, Hombole is characterised by the highest relative variability in annual runoff and Modjo by the highest summer relative variability. The annual and summer runoff records shows the least variability at Melka Kunture. Annual and summer runoff measurements for the studied gauging stations are approximately normally distributed.

The fluctuation of theareal mean annual and summer rainfall in the central highlands of Ethiopia had clear consequence on surface runoff at the gauging stations examined (see Figs. 1 to 10).

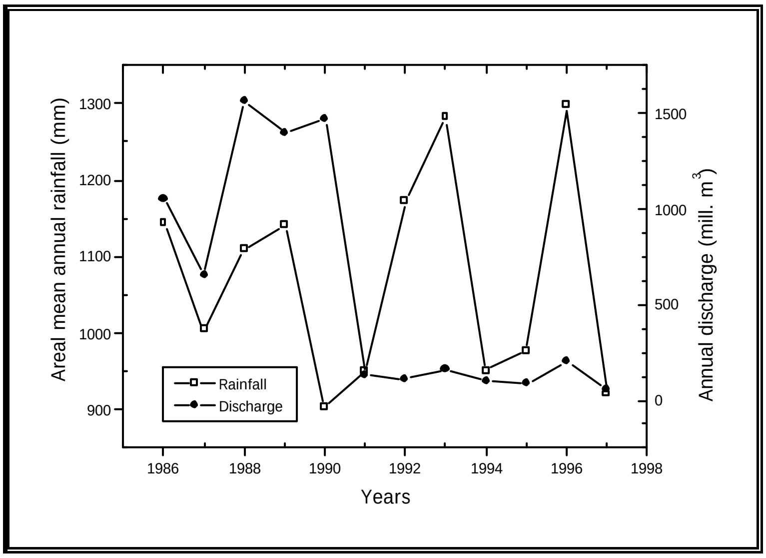

Fig. 1: Comparison of mean annual rainfall and surface runoff at the Hombole gauging station

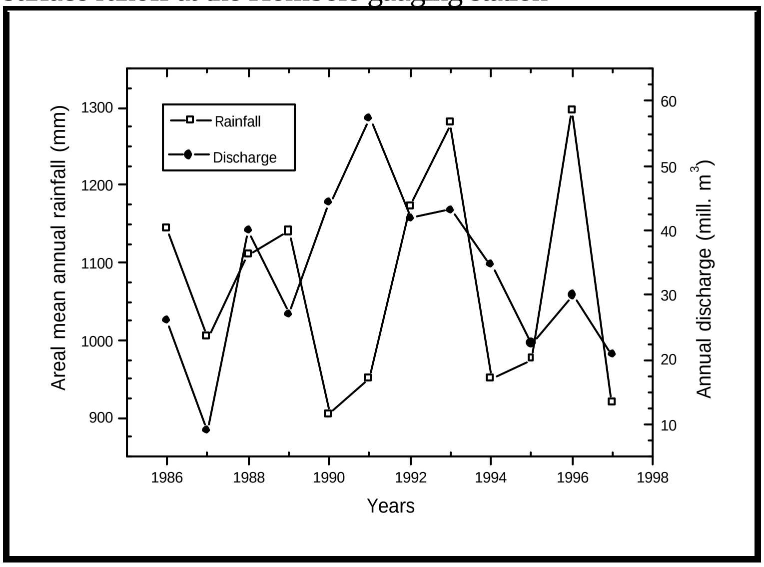

Fig. 2: Comparison of mean summer rainfall and surface runoff at the Hombole gauging station

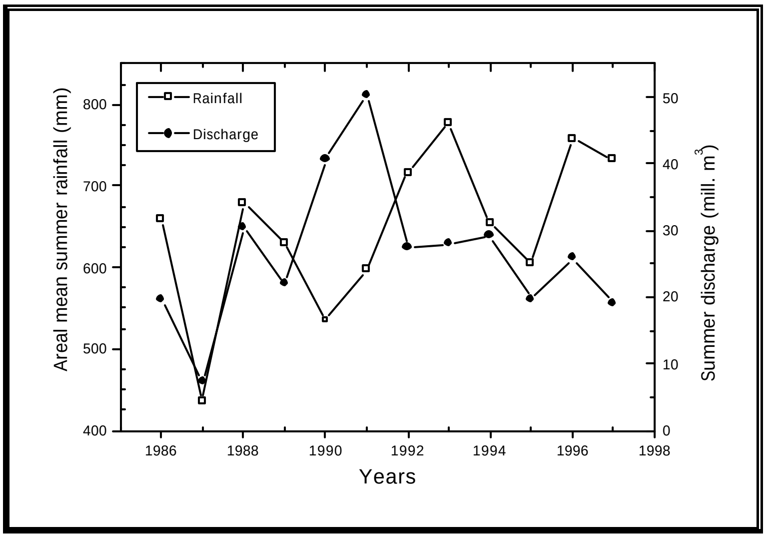

Fig. 3: Comparison of mean annual rainfall and surface runoff at the Kessem gauging station

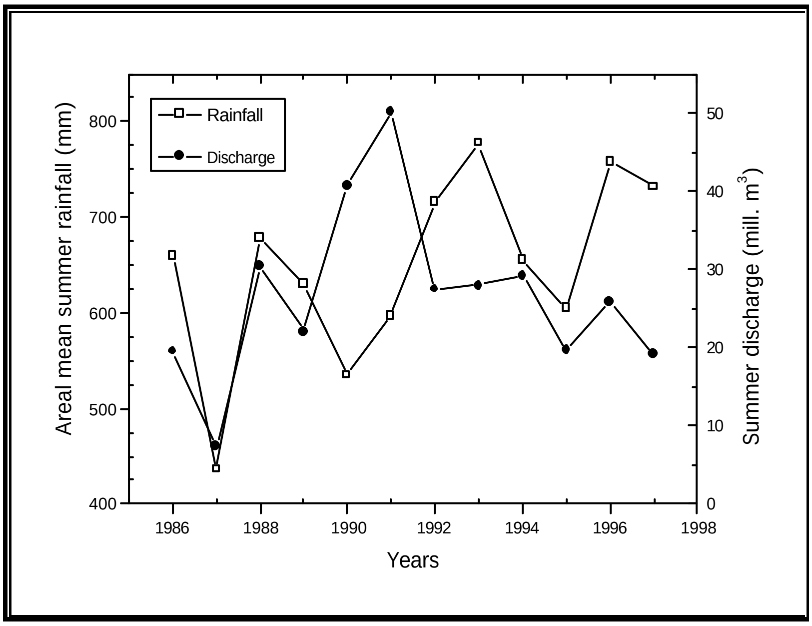

Fig. 4: Comparison of mean summer rainfall
and surface runoff at the Kessem gauging station

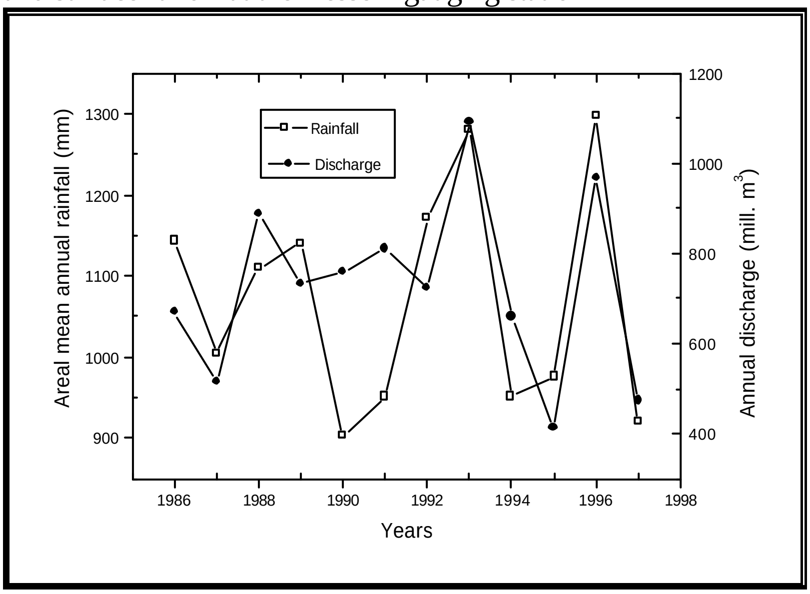

Fig. 5: Comparison of mean annual rainfall and
surface runoff at the Melka Kunture gauging station

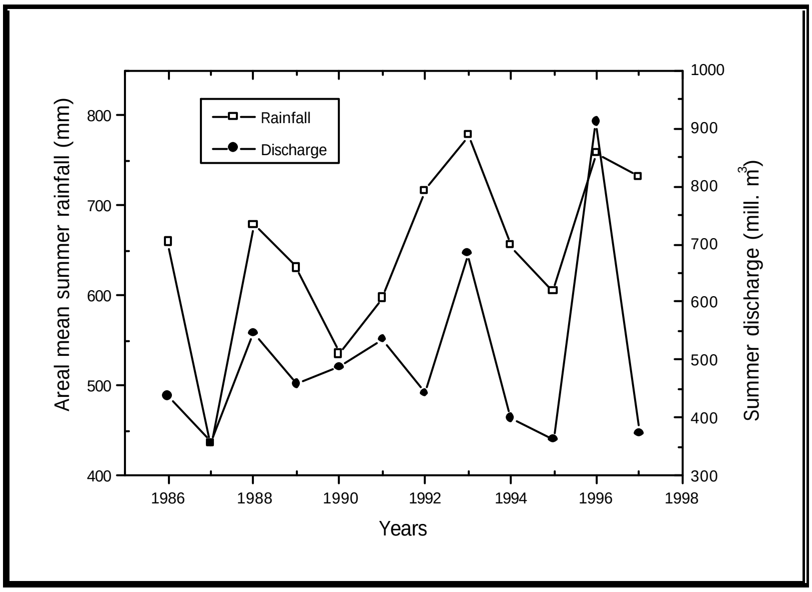

Fig. 6: Comparison of mean summer rainfall and surface runoff at the Melka Kunture gauging station

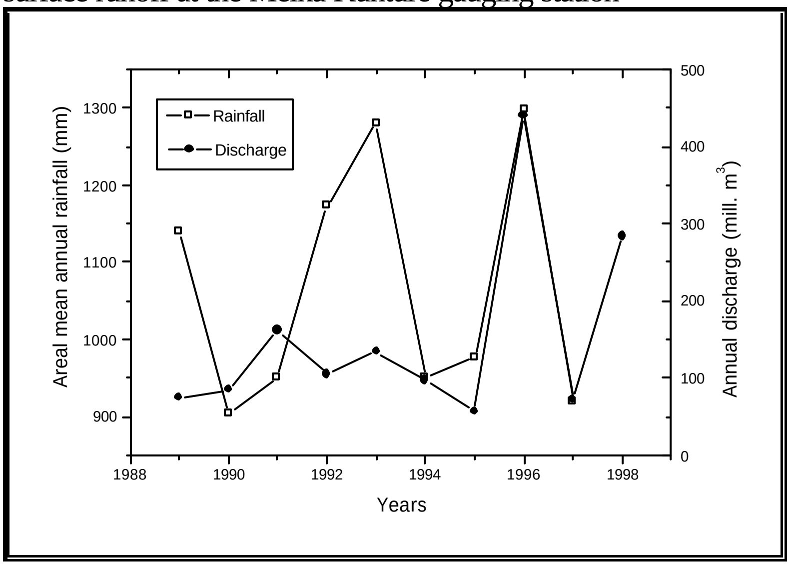

Fig. 7: Comparison of mean annual rainfall and surface runoff at the Modjo gauging station

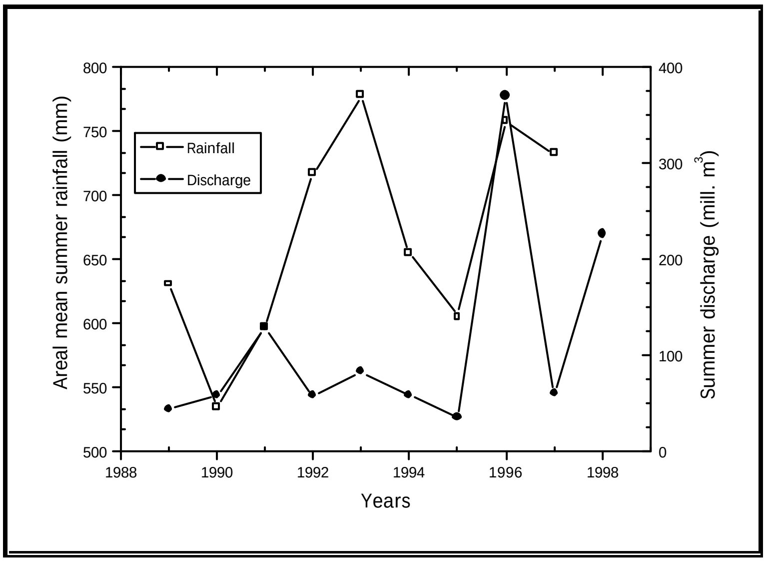

Fig. 8: Comparison of mean summer rainfall and surface runoff at the Modjo gauging station

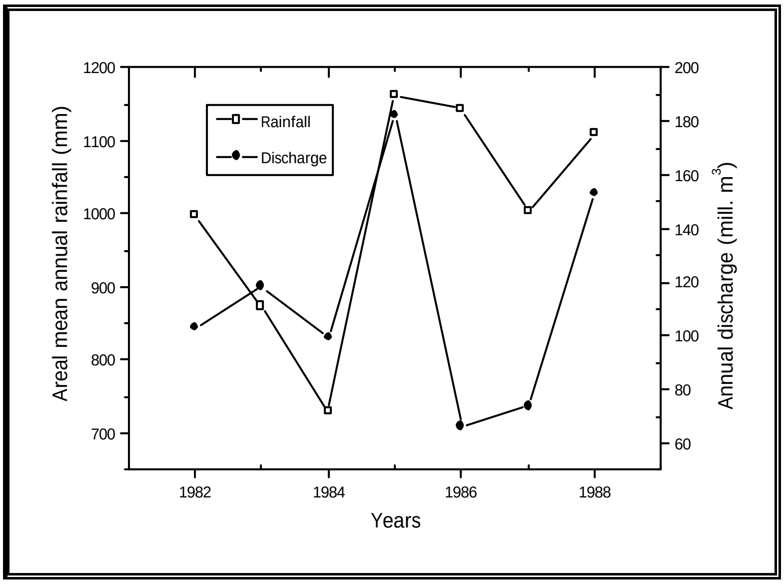

Fig. 9: Comparison of mean annual rainfall and surface runoff at the Teji gauging station

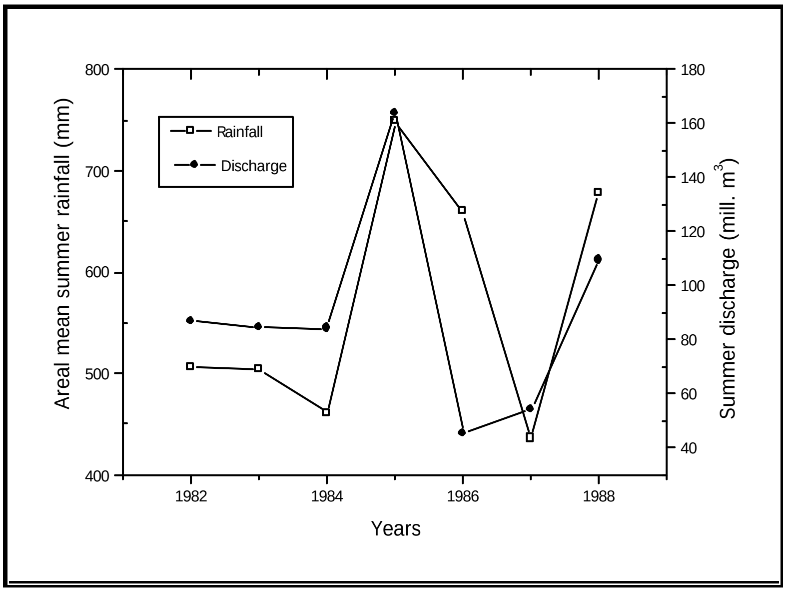

Fig. 10: Comparison of mean summer rainfall and surface runoff at the Teji gauging station

The trend of precipitation was directly reflected on surface runoff for Kessem (Figs. 3 and 4), Melka Kunture (Figs. 5 and 6) and Teji (Figs. 9 and 10). Irregular characteristics were noted for Modjo, where the surface runoff only slightly fluctuated (1991-1995), as compared with marked rise and fall in the long-term mean annual and summer rainfall data series (Figs. 7 and 8). Annual runoff series for Hombole exhibited a constant trend (1991 and 1998), where surface runoff showed only a small change. The trend of summer rainfall series at Hombole was directly reflected on the surface runoff (Figs. 1 and 2). In order to support the results of visual inspection with quantitative facts, trend correlation analysis between hydrometric records and rainfall for the selected gauging stations was made (Tab. 4).

Tab. 4: Non-parametric trend correlation coefficients of surface runoff and rainfall

Gauging stations	N	Annual				Summer			
		Runoff		Rainfall		Runoff		Rainfall	
		Cor. coef.	P value	Cor. coef.	P value	Cor. coef.	P value	Cor. coef.	P value
Hombole	12	-0.76	0.004	-0.09	0.78	0.350	0.27	0.48	0.12
Kessem	12	-0.03	0.930	-0.09	0.78	-0.007	0.98	0.48	0.12
Melka Kunture	12	-0.11	0.750	-0.09	0.78	0.040	0.89	0.48	0.12
Modjo	10	0.20	0.580	0.10	0.79	0.430	0.21	0.57	0.11
Teji	7	-0.07	0.880	0.54	0.22	-0.110	0.82	0.18	0.70

A concurrent decline in long-term areal mean annual rainfall and the corresponding mean surface runoff was noted for Hombole, Kessem and Melka Kunture (Tab. 4). The declining trend in surface runoff was statistically significant (1%) only for Hombole it was different (P value of 0.004). The trends for all the other gauging stations are not statistically significant. The data of Teji has experienced contradicting trends in rainfall and surface runoff. The decline in surface runoff, as opposed to increase in rainfall, might be due to the diversion of runoff from the measuring point or retention in the watershed area. The trends are statistically not significant. Further investigation is required to find out the reasons for this behaviour. Concurrently the increasing trend in long-term areal mean annual precipitation and surface runoff was observed for Modjo.

Nevertheless, the trend was statistically not significant. For the summer period, a declining trend in long-term mean surface runoff was found only for Kessem and Teji. The trend does not seem to be a result of decline in long-term areal mean summer rainfall. For all the remaining gauging stations, a concurrently increasing trend in long-term areal average summer rainfall and the corresponding mean surface runoff was noted. The increasing trend was, found to be not statistically significant.
Generally the trend in long-term surface runoff can not be fully explained only by the long-term areal mean rainfall variability. Subsequently, it is postulated that change in surface runoff at each gauging station can be more explained by local precipitation characteristics, soil physical properties, mainly soil water storage capacity, land-use and cover of the area than the areal precipitation.

Conclusion and recommendations

The rainfall variability in the central highlands of Ethiopia has clear implication on the surface flow regime. the consequence is not uniform and it varies for the annual and summer period. A decline in annual surface runoff was noted at most of the stations. The increasing trends in summer surface runoff at the majority of the gauging stations are not statistically significant. Water management be seriously practised to use the water resources of the country effectively. Areal precipitation does not give full explanation of the variability in flow regime in the study area. Increased gauging station density with reasonable spatial distribution can substantially improve the assessment results of the (inter)-temporal variability of the surface flow regime. So more precise decision regarding sustainable land and water management is necessary. Detailed assessment should be conducted on watershed hydrology and meteorology, soils, land-use and cover for careful land and water management planning.

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