Spatio-Temporal Rainfall and Runoff Variability of The Runde Catchment, Zimbabwe, and Implications on Surface Water Resources

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Abstract

The variability of the rainfall and runoff of the Runde catchment is considered both temporarily and spatially and its implications on surface water resources explored. Data from six rain gauge stations and 12 stream flow gauging stations of the Runde catchment (41 000 km^2) were used to study this variability and to determine whether any useful relationships could be established between. The mean annual rainfall of the six rain gauge stations Chiredzi, Chendebvu, Chivi, Masvingo, Zvishavane and Gweru are 562, 591, 544, 582, 576 and 676 mm with coefficient of variation of 39, 43, 37, 44, 38 and 30% respectively, showing strong inter-annual and spatial variability in the catchments. Cycles of variation of annual rainfall were observed and the long-term trends in runoff and surface water resources reflect the effect of such rainfall cycles. Significant correlations between rainfall and runoff were observed for some of the sub-catchments.

Keywords: rainfall, runoff, variability, and surface water resources.

Introduction

Zimbabwe has been divided into 7 catchments (ZINWA, 1995) each defined by a major river system and its associated tributaries. Catchment delineation was done in order to effectively manage water resources with the participation of all stakeholders (ZINWA, 1999). Of these catchments, Runde (41 000 km^2) is one of the three catchments that lie in the driest parts of the country covering Natural Regions III, IV and V and major districts and towns. It constitutes of 22% of the area (Figure 1) of the country and 40% of this catchment is in communal lands (Anderson, et al., 1993). Its mean annual rainfall is about 684 mm and droughts are frequent.

The catchment contains 45 large dams that are used by communal, resettled and commercial farmers for irrigation and water supply. Some are also used for mining purposes. The Lowveld sugar industry is the major user of water in the catchment. The main estates are Triangle, Hippo Valley and Mkwasine, which obtain their irrigation water from Mutirikwi, Bangala, Manjirenji and Siya dams. There are also a number of small-scale irrigation schemes including Mushandike, Banga, Zananda, Mavhaire, Mabwematema, Musaverema, Mhende, Muchigwe and Musvuvugwa, which obtain their water from some of the dams in the catchment. The six major municipal areas that obtain raw water from Runde catchment are Gweru, Masvingo, Zvishavane, Shurugwi, Chiredzi and Gutu. The ZIMASCO mine in Shurugwi, the Shabani and the Mimosa mines, the Gaths mine and the Renco mine use water from Impali, Palawani, Muzhwi and Nyajena dams respectively.

It is therefore apparent that rainfall and runoff has an impact on the socio-economy of the people living in the Runde catchment and Zimbabwe as a whole, hence the need to understand the temporal and spatial variability of both rainfall and runoff and how it determines the reliability of surface water resources. The objective of this study is to determine how rainfall and runoff varies both temporarily and spatially and the implications on surface water resources in the Runde catchment and also to determine whether any useful relationships exist between rainfall and runoff.

Study Sites and Methods

Runde catchment is located in Southwest Zimbabwe and stretches from Gweru to Gonarezhou (Figure 1). The Department of Water Development has divided Zimbabwe into 6 hydrological zones, A to F, and the Runde catchment falls within the Hydrological zone E, which comprises areas drained by Runde, Tokwe, Mutirikwi and Chiredzi rivers and finally draining into the Limpopo river.

Rainfall data for Chibi Office, Masvingo, Chiredzi, Zvishavane, Gweru and Chendebvu stations was obtained from the Department of Meteorology. Rainfall recording started in different years, but for purposes of uniformity data used for this analysis starts in 1960. The rain gauge stations are fairly well distributed within the catchment (Figure 2). Data from 13 stream flow gauging stations were used (Figure 2) to determine both its spatial and temporal variability. The runoff gauging stations were installed in the 1960s and early 1970s and all of these stations have been in continuous operation since then. Dam water level changes for three dams (Mtirikwi, Gwenhoro and Bangala) were obtained from the Data and Research Unit of ZINWA.

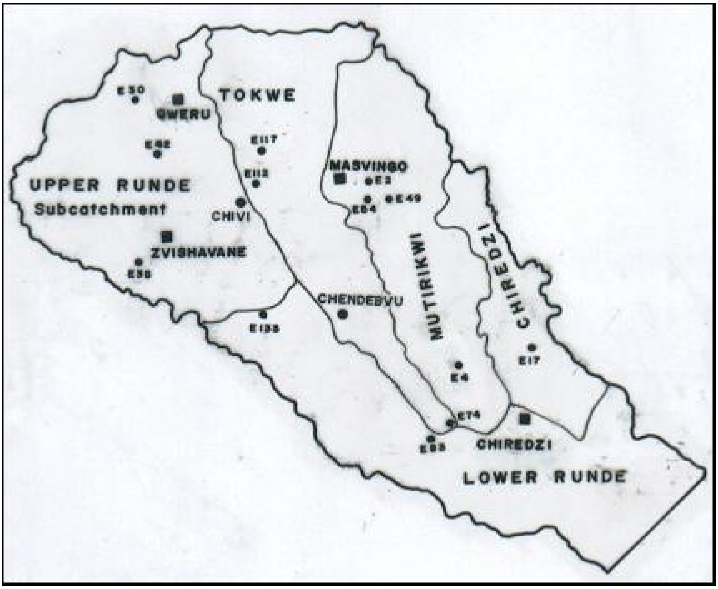

Figure 2:Distribution of rainfall

Results

Table 1 shows that the annual rainfall average for Chendebvu, Chiredzi, Chivi, Gweru, Masvingo and Zvishavane are 590, 562, 544, 676, 582 and 576 mm with coefficient of variations of 43, 39, 37, 30, 44 and 38 % respectively.

Table 1: Statistical parameters of annual rainfall for some of the rainfall stations in the Runde catchment.

Station	Period of record	Mean rainfall (mm)	Std dev	CV (%)	Max (mm)	Min (mm)
Chendebvu	1953 – 1998	591	253	43	1191	83
Chivi	1914 – 1998	544	203	37	1123	143
Chiredzi	1965 – 2000	562	219	39	1120	127

Gweru	1952 - 1999	676	203	30	1229	344
Masvingo	1953 – 1998	582	255	44	1037	102
Zvishavane	1952 - 1999	576	217	38	1042	176

Figure 3 illustrates the 5-year running means of annual rainfall totals for the six stations. Each of the six sites displays a broadly similar characteristic except the magnitude for most of the period. Masvingo differed a lot with the other stations during the period 1960 to 1965 in that it displayed very low rainfall. Gweru had the highest rainfall in most years while Chivi had the least. A cyclic trend is displayed; rainfall was above average in the 1960s and 1980s and below average in the 1970s and the 1990s.

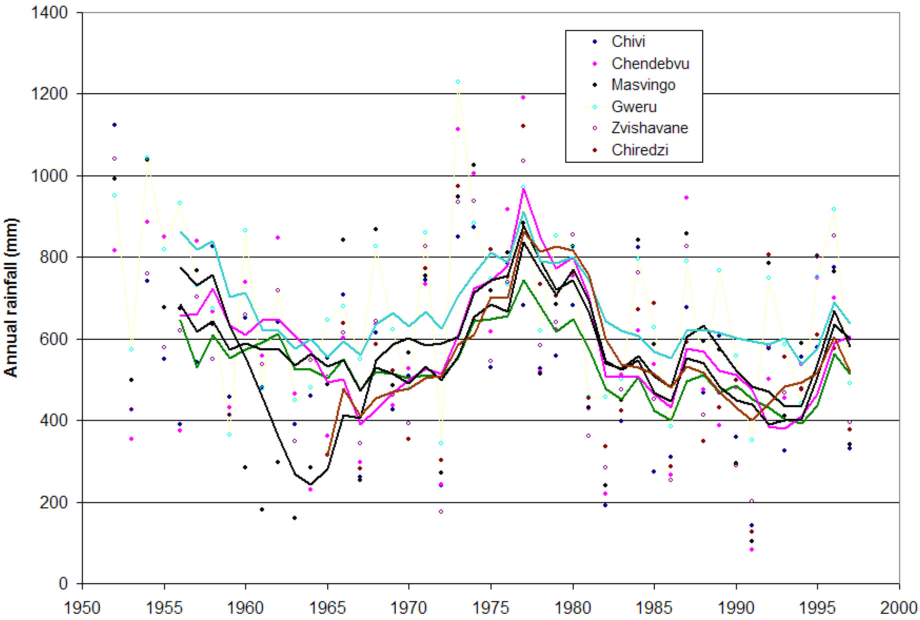

Figure 3: 5-year running averages of annual rainfall totals at Chendebvu, Chiredzi, Chivi, Gweru, Masvingo and Zvishavane.

A long-term trend at Chibi Office from 1914 shows a similar cyclic nature (Figure 4) when (using a 10 year running average) rainfall was below average in the mid 1940s to mid 1950s and the 1990s and above average in the mid 1950s to 1980. Just like the Chivi rainfall station (Figure 4) the long-term rainfall data at all of the six stations displayed an insignificant decline over the study period. All the 13 runoff gauging stations display the same general runoff pattern (Figure 5) with the highest runoff being recorded in 1977 at all the sites. However, there is much spatial variation, even for gauging stations that are in the same subcatchment.

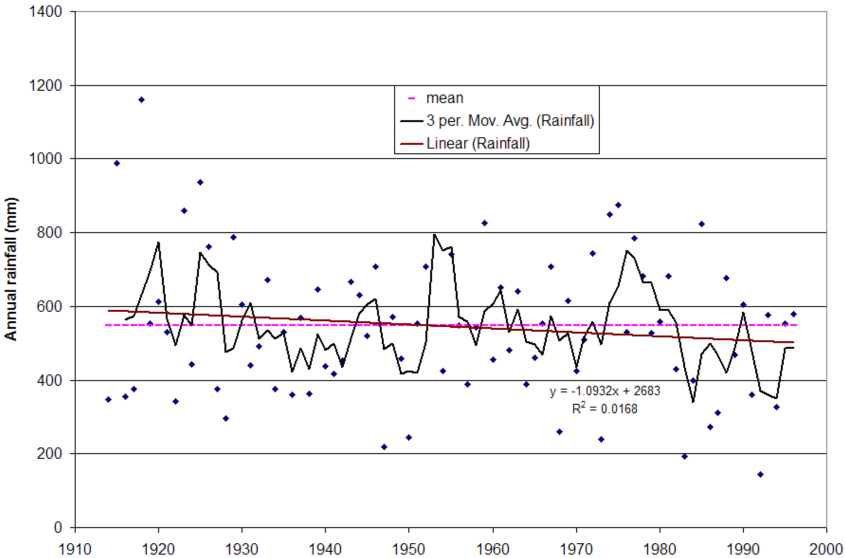

Figure 4: 10-year running average of annual rainfall totals at Chivi (1914-1998).

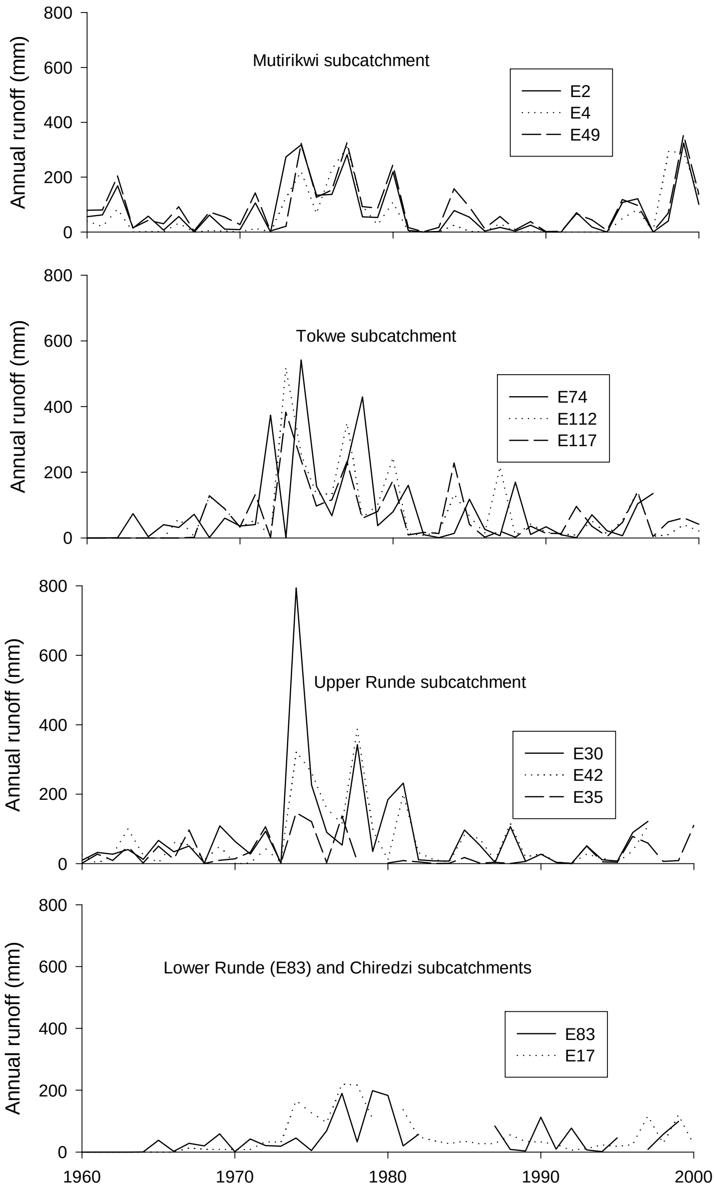

Figure 5: Annual runoff for selected gauging stations in the Runde catchment. **The Es are gauging stations.**

The Tokwe subcatchment produced the most runoff in most of the years, while the least runoff was recorded at Chiredzi and Lower Runde subcatchment (Table 2).

Table 2: Statistical parameters of runoff at the different gauging stations

Sub-catchment	Gauging stations	Area (km^2)	Mean runoff (mm)	CV (%)	Max runoff (mm)	Min runoff (mm)
Mutirikwi	E2	541	78.6	104	385	0.0
	E4	7058	59.2	161	309	0.0
	E49	1010	85.8	107	358	1
	E54	212	52	105	215	0.0
Tokwe	E74	23000	88	142	542	0.7
	E112	1200	87.3	129	519	4
	E117	1090	76.5	113	383	2
Upper Runde	E133	5390	54	111	259	0.7
	E30	254	92.2	170	794	0.3
	E42	648	72.7	137	387	0
	E35	1630	30.3	140	146	0.0
Lower Runde	E83	17100	50	112	199	0.3
Chiredzi	E17	1700	57.6	104	220	6

E2, E4, E49, E54, E112 and E117 showed significant relationships between runoff and rainfall (Table 3), while E74, E133, E30, E42, E35, E83 and E17 were not significant.

Table 3: Linear equations of rainfall-runoff relation.

Sub-catchment	Rain-gauge station	Stream gauging station	Equations (P = rainfall; R = runoff	R^2
Mutirikwi	Masvingo	E2	R = 0.2209P – 60.07	0.413*
	Masvingo	E4	R = 0.1846P – 58.04	0.305*
	Masvingo	E49	R= 0.2032P – 40.25	0.361*
	Masvingo	E54	R = 0.1491P – 32.77	0.435*
Tokwe	Chivi	E74	R = 0.0585P + 63.90	0.008

	Chivi	E112	R = 0.3395P – 89.80	0.361*
	Chivi	E117	R = 0.3118P – 86.27	0.493*
Upper Runde	Chivi	E133	R = 0.0678P + 17.06	0.057
	Gweru	E30	R = 0.0747P + 32.94	0.012
	Gweru	E42	R = 0.0108P + 59.30	0.0005
	Zvishavane	E35	R = 0.0271P + 14.09	0.0201
Lower Runde	Chivi	E83	R = 0.0019R + 48.966	$4x\ 10^{-5}$
Chiredzi	Masvingo	E17	R = 0.0426P + 31.211	0.0293

* Significant at the 0.05 level.

All the four gauging stations from Mutirikwi subcatchment show significant relationship, while two are significant in the Tokwe sub catchments and non at all in the Upper Runde, Lower Runde and Chiredzi sub catchments. The coefficient of determination from the relationships between rainfall and runoff decreases with increase in catchment area (Figure 6).

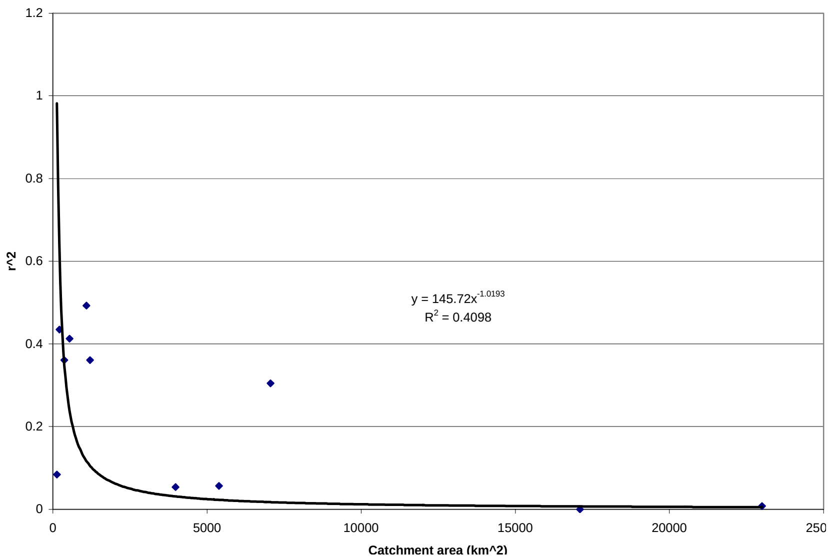

Figure 6: The relationship between catchment area and the coefficient of determination

Changes in the Mutirikwi dam water storage reflect the temporal variability in runoff of the Mutirikwi catchment that is measured at E2 above the dam (Figure 7). The cyclic nature of rainfall and runoff is displayed in all the three dams (Mutirikwi, Gwenhoro and Manjirenji). The droughts of the early eighties and early nineties are clearly reflected in the dam water storage while the wet periods of the seventies and the Cyclone Eline of the late nineties are also reflected in the dams though they are in different sub catchments (Figure 7).

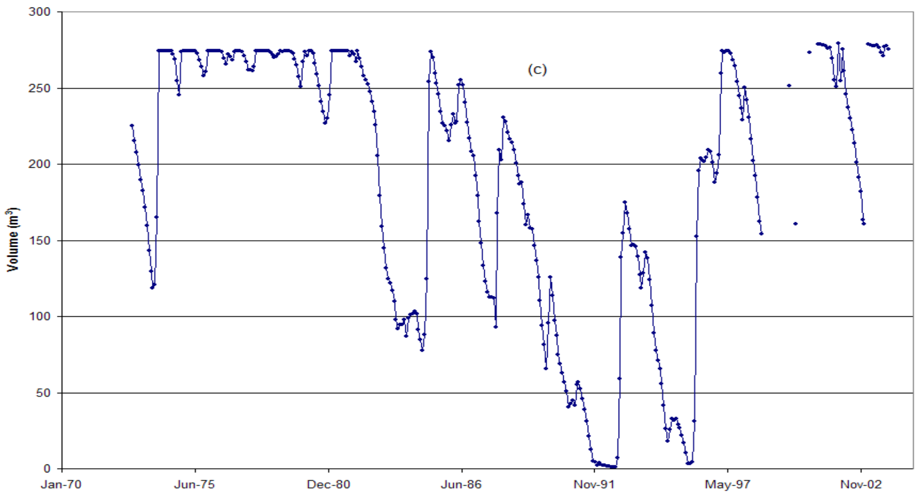

Figure 7: Monthly dam water levels and at (a) Mutirikwi, (b) Gwenhoro and (c) Manjirenji dams that are in Mutirikwi, Upper Runde and Chiredzi sub catchments.

Discussion

Though the general pattern of rainfall at the rainfall stations was similar over the whole period, the annual totals were different indicating both spatio-temporal variability in rainfall over the Runde catchment as was observed by Nicolson (1980) and Lebel et al. (1996). Makarau (1999) observed inter-annual and inter-monthly variabilities in the climate of Zimbabwe over the past century. A cyclic nature of the rainfall in the Runde catchment is observed just like the Zimbabwean rainfall that was observed by Makarau (1999), July et al. (1992) and Tyson, (1987). Runoff from all the gauging stations display a similar general pattern to rainfall which both show an increase that had a peak in 1977 and then declined.

Gauging stations in Upper Runde and Tokwe sub catchments have less runoff than the other sub catchments because rainfall increases from Southwest to Southeast in the Runde catchment. The lack of similarity in the pattern of the runoff from the same subcatchment is an indication of high spatial variability in runoff. The 13 gauging stations show differences in runoff that might be emanating from differences in the average rainfall received, land use type or soil type.

There were both significant and insignificant relationships between rainfall and runoff, with those from the drier Upper and Lower Runde and Chiredzi showing insignificant relationships. Thiam and Singh (2002) observed relationships between rainfall and runoff that had coefficient of determination that were above 0.5 in Southern Senegal. The low values of the coefficients of determination might be due to the large variability in rainfall, land use, soil and vegetation cover in the Runde catchment (Whitlow, 1979) like most areas in Zimbabwe (Anderson, 1993). Rainfall distribution is often more important in runoff generation mechanisms in semi-arid areas than rainfall totals (Sandstrom, 1977; Mugabe, 2004). Runoff normally occurs in a few months (February and March) of the year, when there are closely spaced rainfall events (Mugabe, 2004). The lack of good relationship between rainfall and runoff is due to a considerable temporal and spatial variability exhibited by rainfall-runoff process (Sivakumar et al., 2000). The considerable spatial and temporal variability exhibited by the rainfall-runoff process is due to the various physical mechanisms that govern the dynamics of the process (Sivakumar et al., 2000).

One of the characteristics feature of the rainfall within the semi-arid areas of Zimbabwe is that it comes mostly in the form of convective thunderstorms that are highly isolated resulting in a high spatial variability. For example, Lebel, et al. (1996) observed a seasonal difference of 275 mm (39%) for two rain gauges just 9 km apart in the Sahel during the 1992 season. More representative catchment rainfall values could have been obtained if there was a network of rain gauges in each catchment, thereby enabling application of the Thiessen Polygon method.

The change in land use might also affect the relationship between rainfall and land use. For example the Lundi E83 catchment stretches from Gweru to Ngundu and there are a number of soil types and land use types (communal use, natural vegetation and commercial use). Whitlow (1979) observed an increase of over 36%

of cultivated land area between 1963 and 1977 in Communal lands in Zimbabwe. Lorup, et al. (1998) observed a decrease in the annual runoff with time in catchments that were located in communal land, which they attributed to increases in population and agricultural intensity.

The factors that affect runoff are more uniform for smaller catchments and we would have expected the coefficients of determination to increase with decrease in area. This resuls in smaller catchments having the highest coefficients of determination while bigger catchments have smaller coefficients determination. A similar trend was observed by Lacobellis et al. (2002), which they ascribed to the limited spatial extent of extreme events, which leads to a decrease of CV of areal rainfall intensity.

The same trend as rainfall and runoff is reflected in the dam water storage changes of the three dams that are in three distinct sub catchments. This is in agreement with several studies that show that most of the variability in catchment hydrology is attributed to rainfall variability (Thiam and Singh, 2002; Farmer, et al. 2003; Rodda, 1967; Dawdy and Bergman, 1969) hence renewable water resources are directly related to rainfall. Peel et al. (2001) demonstrates that rainfall variance (Equation 1) is the same as runoff variance since the variability of actual evapotranspiration is small relative to the variability of annual precipitation and runoff.

$$Cvr = Cvp \frac{MAP}{[MAP - AET]} \qquad \text{Equation 1}$$

where: Cvr is coefficient of variation of annual runoff, Cvp is coefficient of variation of annual precipitation, MAP is mean annual precipitation and AET is actual annual evapotranspiration.

The wet period between 1974-1980 and 1985-88 are reflected in both the runoff and dam water level while the dry periods of 1981-1984 and 1988-1992 are also shown in both parameters indicating that both rainfall and runoff have a bearing on surface water resources. Gwenhoro is not affected much during these dry periods because it is a smaller dam that has a relatively larger catchment area as shown by a dam capacity/catchment area ratio of 0.076 compared to 0.346 mm and 0.179 for Mutirikwi and Manjirenji respectively.

The dry periods during the study period had a serious impact on the agricultural productivity of the sugar cane industry especially in the 1991/2 season when irrigation demands could not be met (Lecler, N; Scoones et al. 1996). This resulted in some sugar cane fields being neglected or planted to dryland crops and it took four years for the sugar industry to recover to full capacity.

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