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WLRC - Research Report - 1

Long-term Agro-climatic & Hydro-sedimentology Monitoring

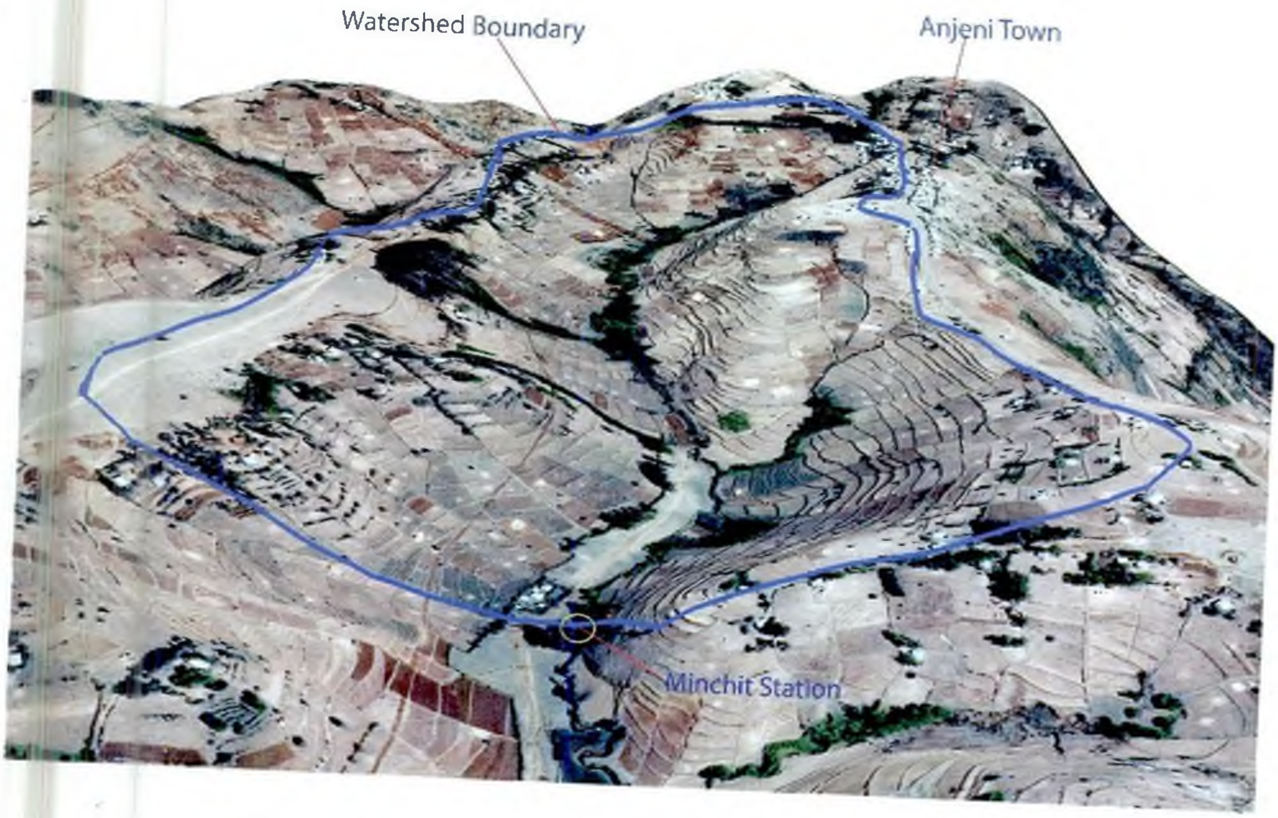
The Synthesis Report for Anjeni Observatory Micro-watershed, Blue Nile Basin, Ethiopia

Water and Land Resource Centre

May 2015
Addis Abeba, Ethiopia

Long-term Agro-climatic and Hydro-sedimentological Monitoring

The Case of Anjeni Micro-watershed, Blue Nile Basin, Ethiopia



Water and Land Resource Centre, Addis Abeba
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Title Page	3D view of Anjeni Watershed
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Preface

One of the challenges of effective development and management of water and land resources is lack of systematically collected and organised data, particularly at watershed scale. Ethiopia is an agro-ecologically and hydrologically diverse country; the rainfall pattern and the farming systems differ significantly in short distances. Recognising these challenges, the Department of Natural Resources of the Ministry of Agriculture, in collaboration with the University of Bern, launched the Soil Conservation Research Programme, widely known as SCRP, in 1981. The objectives of the research programme were to (1) generate baseline data for subsequent intervention; (2) evaluate the impact of soil conservation interventions, and (3) provide long-term climate, and hydro-sedimentology monitoring. Through its activities, seven watershed observatories were established in different agro-ecological zones in the country. One of these watersheds is Anjeni Observatory, which was established in 1984.

Data has been collected at Anjeni since March 1984 though not all data collections started at the same time, and observations for few years were either incomplete or missing. Recently, the temporal and spatial resolutions and the number of variables being monitored in the observatories have been improved because of the installation of automatic/digital weather and river gauging stations. The data from 1984-1994 has been compiled and reported earlier (SCRP, 2000). In the present report, we have compiled the data until 2014. One added feature of this report is that the data collected using automatic digital instruments at finer temporal resolution is provided, which makes event-based comparisons of hydrological processes possible.

There are large datasets collected for the last 31 years, creating tremendous opportunities for different kinds of data analyses and modelling. In this report, only the annual and mean monthly data are presented and described. This report covers rainfall, air and soil temperature, runoff and drainage coefficient, suspended sediment loss at watershed scale, and runoff and sediment losses from four standard test plots. All daily and event-based data are archived in the Water and Land Information System (WALRIS) of the Water and Land Resource Centre (WLRC). WLRC, in collaboration with SDC, CDE and ARARI, will further refine the data measurement systems, thereby improving the data resolution so that hydro-sedimentological processes can be precisely modelled using newly-developed hydrological process models for enhanced calibration, validation and extrapolation of the information generated.

We would like to take this opportunity to acknowledge the financial support we received from Swiss Development Cooperation (SDC) to equip the stations with the latest climate and river hydrology monitoring instruments. We strongly believe that these stations will continue to generate useful primary data, which is scarce and limited in this country and the region. The data will be instrumental in managing water and land resources in the Abay Basin in particular and the country at large. The efforts of Amhara Region Agricultural Research Institutes (ARARI) to maintain and continue data collection in Anjeni, in two other similar watersheds (Maybar and Andit Tid) and in a new set-up in the Simen Mountains in the face of severe financial constraints is highly commended. We hope it will continue to maintain and monitor data collection to the extent that longer time-series data will be available.

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Abbreviations and Acronyms

ARARI	Amhara Region Agricultural Research Institute
CDE	Centre for Development and Environment
CV	Coefficient of variation
id	incomplete data (data for some months are missing)
MOA	Ministry of Agriculture
nd	no data
PI	Precipitation Index
SCRP	Soil Conservation Research Programme
SDC	Swiss Agency for Development and Cooperation
sdv	Standard deviation
WALRIS	Water and Land Resource Information System
WLRC	Water and Land Resource Centre

1. Introduction

Anjeni micro-watershed observatory was established in March 1984 as one of seven long-term Soil Conservation Research Programme (SCRP) sites implemented jointly by the then Soil and Water Conservation Department (SWCD) of the Ministry of Agriculture (MoA) and the University of Bern, and financed by both Switzerland and Ethiopian governments.

The goal of establishing these watersheds was 'to develop and promote ecologically sound, economically viable and socially acceptable conservation measures.' Before the interventions, farmers used to face serious soil erosion problems, which affected the water holding capacity, soil fertility and productivity status of the farmland. The construction of the terraces has brought relative improvement in the land productivity and socio-economic wellbeing of the watershed communities (SCRP 2000; Bosshart, 1997a,b).

Long term monitoring of climate, runoff from small catchments and multi-runoff plots, soil loss, catchment suspended sediment, seasonal land use and crop production, land cover changes in demographic and social-economic features, as well as soil conservation experiments at various scales have been done. Data generated have been extensively used by local and international researchers and students. The information has been used for capacity building on sustainable land management and policy formulation. The lessons learned from these watersheds have been instrumental in building the trust on soil and water conservation investment.

Data collection started in April 1, 1984. The 10-year data were analysed and reported by SCRP (2000) under the title 'Area of Anjeni, Gojjam, Ethiopia: Long term monitoring of the Agricultural Environment 1984-1994.' A number of research articles and master theses and doctorate dissertations have been produced based on these data. The intent of this report is to compile the data from 1995 to 2014, and when necessary to combine it with the data processed from 1984 – 1994 so that data since 1984 is available for analysis requiring longer time series data. Summary of monthly and annual data are presented in figures or/and tables, while daily and event-based data are uploaded in the Water and Land Information System (WALRIS) (www.wlrc-eth.org) database.

Though there were some interruptions of data collection, the report is the first of its kind in presenting systematically collected and processed data to establish rainfall-runoff relationship, hydro-sedimentological analysis, climate trend, etc. at watershed scale. Moreover, new field measuring instruments with high temporal resolution have recently been installed since May 2013 to develop event-based rainfall runoff relationships for advanced hydrological process studies.

2. Description of Anjeni Micro-watershed Observatory

Anjeni Observatory is located in the Abay (Blue Nile) Basin in Amhara National Regional State, West Gojjam Zone, near Debre Markos at 10° 40' north latitude, 37° 31' east longitude, 370 km northwest of Addis Abeba to the South of the Choke Mountains, 15 km from Dembech on the road to Feres Bet (Figure 1). The site is named Anjeni after the name of the small village in the watershed, while the hydrometric station is located in Minchet River. The watershed covers topographic area of 108.2 ha but the size of the hydrologic catchment is about 113.4 ha (Bosshart, 1996, 1997a, 1997b) due to the diversion from the road that goes to Feres Bet from Dembecha. The elevation of the watershed ranges 2405 and 2507 m a.s.l. Anjeni watershed is sub-watershed of Gerda River meso-scale sub-watershed in the centre of the Blue Nile Basin established in May 2013 to investigate scale effect in the rainfall – runoff relationship at Meso-scale level.

Figure 1.
Location map of Anjeni watershed

The watershed is intensively cultivated. About 67.8% of the area is cultivated land, about 14.7% is woodland, and 9.6% is grassland (Appendix 6). The agro-ecology of Anjeni, with altitude ranging from 2407-2507 m asl, annual rainfall of 1696.4 mm, and length of growing period of 151 days is classified as Wet Dega Agro-Ecology. As per the revised agro-ecological classification of MOA, the agro-ecology is classified Tepid to cool moist high altitude (M2-9).

Table 1.
Summary of Anjeni micro-watershed characteristics

Location	Lat. 10° 40' N and Long. 37° 31' E
Year of establishment	March 1984
Altitude	2405 -2507 m asl
Catchment size	113.4 ha hydrological catchment 108.2 ha topographic catchment
Geology	Tertiary olivine basalt and tuff
Major soils	Alisols, Nitosols, Cambisols (Appendix 1)
Mean annual rainfall (1985-2014) Mean *Kiremt* rainfall (1985-2014)	1742.3 mm 1551 mm
Air temperature	
Minimum (1984 – 2014)	9.4 °C
Maximum (1984 -2014)	26.6 °C
Mean (1984 – 2014)	18 °C
Soil temperature	
Minimum (1985 – 2014)	9.1 °C
Maximum (1985 -2014)	28.5 °C
Mean (1984 – 2014)	18.9 °C
Length of growing period	151 days
Rainfall pattern	Unimodal
Mean erosivity (1985-2014)	630.9 J/m hr
Mean annual runoff (1985-2014)	854 000 m^3
Mean annual runoff depth (1985-2014)	755.3 mm
Mean runoff coefficient	44.4 (%)
Mean annual suspended sediment yield	23.4 t/ha/yr
Land Use Land Cover	Appendix 1
Soil Map	Appendix 2

3. Data Collection Tools and Methods

The instruments installed for data collection have been described earlier (Bosshart, 1997). Recently, new set of automatic weather stations and pluviometer have been installed. Table 2 provides the list of instruments installed and brief description of the data type collected in the watershed. Data on crop production and soil has also been collected. This report, however, focuses on climate and hydro-sedimentological data only. Data on socio-economic and soil health impact of long term soil conservation activities will be presented separately.

Table 2. Measuring instruments and methods of data collection at Anjeni

Parameter	Device, methods and data availability
Rainfall amount	Ordinary rain gauges (since 1984) Chart-roll recording rain gauges (Lamprecht type 1509-20) since April 1984
	Three manual rain gauges distributed with in the watershed (since 1985)
	Digital HOBO rain gauges (every 15 min (since May 2013)
Intensity of rainfall	Calculated from pluviograph (since 1984) Calculated from HOBO rain gauge readings (since 2013)
Erosivity	Calculated from rainfall intensity using "Testmain" Program (since 1984)
Direction of rainfall	Inclinometer (inclined catch cans) (since 1986)
Air temperature (min. and max.)	Thermometer, 1.5 m above ground (since January 1986)
	HOBO weather station, U30 readout temperature, relative humidity, solar radiation, wind speed and direction (since May 2013)
Soil surface temperature (min. and max.)	Thermometer, 0.1 m above soil surface.(since 1989)
Evaporation	Piche tube evaporimter (since 1986)
	Class A Pan (since 1991)
River runoff	Limnigraph, type Ott R16 (Float-actuated recorders) since 1984
	Otto thalimedas since May 2013
	Otto ecolog 500 pressure gauge since 2014
Wind strength and direction	Observation using thread (since 1986)
	Hobo wind vane (both wind direction and wind speed) (since May 2013)
Solar radiation	HOBO weather station since May 2013
Sediment	One litre grab samples every 10 minutes when the river stage is increasing and 30 minutes interval when it is falling until no more change in the water colour and stage of the river since June 1984

4. Agro-Climate Monitoring

4.1. Rainfall

Rainfall has been collected using ordinary rain gauges since May 1984, autographic chart recorder *(Pluviometer) since April 1984, and HOBO digital data logging rain gauge since May 2013.* Data from pluviometer is primarily used for different rainfall-related data analysis including rainfall intensity and erosivity. Rainfall data collected using ordinary rain gauges are also provided for recording rain gauge (pluviometer) data validation. The 2014 complete data from digital rain gauges are also provided with the premise that future data collection will shift towards digital automatic rain gauges.

4.1.1. Inter-annual rainfall variability

The long term mean average annual rainfall at Anjeni is 1742.3 mm (Table 3). The annual rainfall from 1985 to 2014 excluding missing and incomplete data is shown in Figure 3. It should be noted that the 1984, 1991, 1999, 2001- 2005, 2010, and 2011 data are either missing or incomplete.) Rainfall data for nearby stations, i.e., Debre Markos, Finote Selam, and Dembecha weather stations (Appendix 7) are provided to estimate the data for the missing years at Anjeni. The long term rainfall trend (Figure 3) is generated excluding missing observations. However, statistical analysis of rainfall data using Mann-Kendal test did not show a statistically significant rainfall trend. Among the years with complete data record, the lowest annual rainfall (1371 mm) was recorded in 1986 while the highest rainfall (2146 mm) was measured in 2013. The inter-annual rainfall coefficient of variation (CV) (9.6%) is regarded as modest.

Table 3.
Long term basic rainfall descriptive statistics of Minchet at Anjeni.

Parameter	Values	
Mean	1742	mm
Standard Error	38	mm
Median	1739	mm
Standard Deviation	165	mm
Kurtosis	2	
Skewness	0	
Range	775	mm
Minimum	1371	mm
Maximum	2146	mm

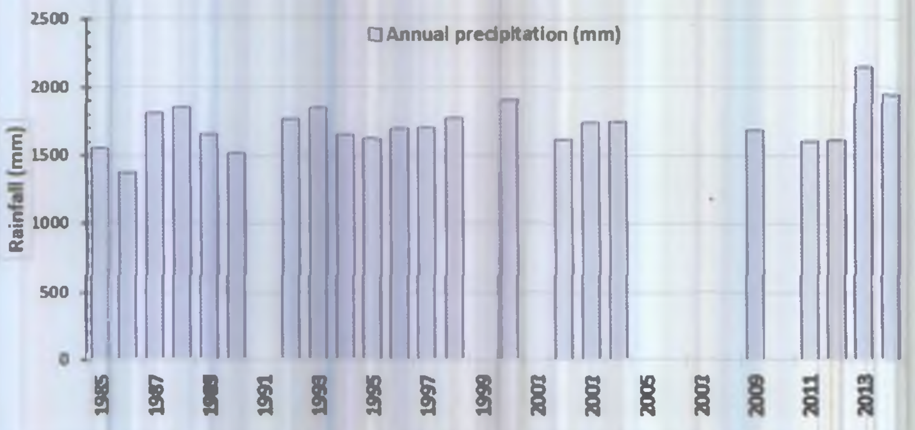


Figure 2.
Annual rainfall (mm) (1985-2014) at Anjeni

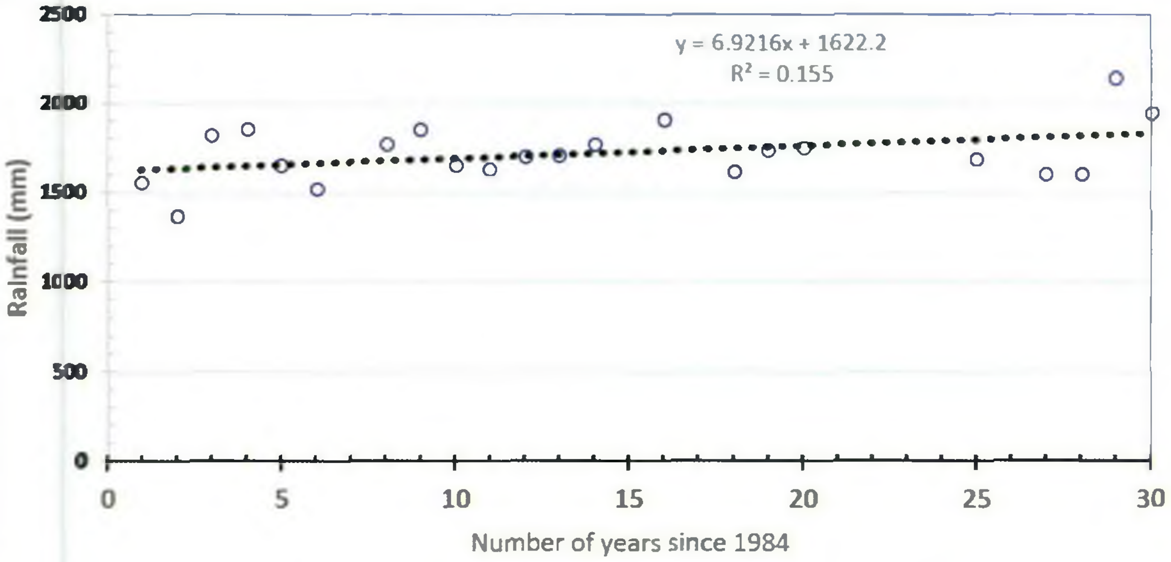


Figure 3. Long term rainfall trend at Anjeni

Table 4 shows annual rainfall amount, rainfall start and end, and growing period relations. Missing data are filled using INSTAT software. The growing period start and end dates are provided based on the Julian calendar (1 for January 1, 2 for January 2, etc.). Hence, growing period starts end of May/ beginning of June while the end of the growing season extends up to end of October, and about 90% of the rain fall is in the growing period.

Table 4. Annual rainfall (mm), start and end of growing period

	Rainfall			Growing Period				CV	
Years	Amount (mm)t	Start	End	Length (days)	Rainfall (mm)	Percent	Total (mm)	Growing period	SAI
1984	1427.5	139	289	150	1347.6	94.4	119.5	9.8	8.5
1985	1560.0	136	295	159	1417.3	90.9	106.6	8.5	9.8
1986	1372.7	149	294	145	1282.9	93.5	112.1	8.6	9.6
1987	1612.3	139	294	155	1582.1	87.3	96.6	8.0	10.5
1988	1853.2	155	309	154	1734.4	93.6	118.7	10.0	8.3
1989	1671.0	139	291	152	1445.9	86.5	104.5	9.8	8.5
1990	1668.4	158	292	134	1481.3	88.8	114.1	11.1	7.5
1991	1158.6	184	294	110	1109.4	95.8	150.2	14.9	5.6
1992	1770.2	160	310	150	1498.8	84.7	89.5	7.0	11.9
1993	1839.3	137	317	180	1613.3	87.7	95.9	7.2	11.6
1994	1651.9	155	289	134	1529.0	92.6	115.3	9.7	8.6
1995	1622.5	152	302	150	1456.5	89.8	101.4	7.8	10.7
1996	1696.9	137	290	153	1378.3	81.2	96.7	10.4	8.0
1997	1708.2	138	290	152	1457.3	85.3	83.1	5.1	16.5
1998	1772.7	136	311	175	1610.3	90.8	105.0	8.1	10.3
1999	1258.3	173	309	136	1167.8	92.8	102.4	6.6	12.7
2000	1910.1	151	323	172	1713.5	89.7	97.4	6.6	12.7
2001	836.9	139	289	150	741.2	88.6	159.4	19.0	4.4
2002	1635.8	162	289	127	1601.9	97.9	133.8	11.2	7.5
2003	1739.3	158	295	137	1588.7	91.3	124.4	12.0	6.9
2004	1746.4	153	302	149	1547.5	88.6	111.1	10.5	7.9
2005	1907.5	144	295	151	1745.1	91.5	109.2	8.9	9.4
2006	1787.9	149	300	151	1565.4	87.6	93.2	6.6	12.6
2007	1566.1	156	307	151	1361.6	86.9	101.3	9.1	9.2
2008	1757.1	136	322	186	1504.5	85.6	93.8	7.9	10.5
2009	1687.0	170	313	143	1482.6	87.9	111.8	10.8	7.7
2010	1463.4	146	298	152	1284.2	87.8	108.7	10.1	8.3
2011	1598.4	157	295	138	1476.5	92.4	129.1	12.1	6.9
2012	1608.2	136	290	154	1442.3	89.7	117.6	11.2	7.4
2013	2145.6	136	308	172	1976.0	92.1	107.8	8.2	10.2
2014	1946.5	144	305	161	1623.6	83.4	79.7	4.7	17.6
Mean		149.2	300.2	151.1	1476.4	89.6	109.3	9.4	9.6

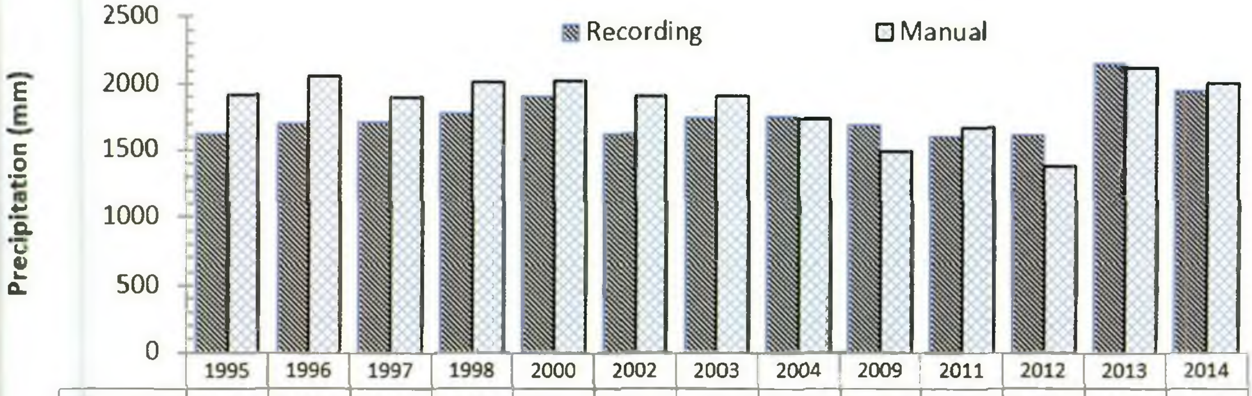
Table 5 shows the coefficient of variation and precipitation concentration index, used as statistical descriptors of rainfall variability for rainfall means of the annual, Kermit and Bega rainfall. Annual and Kiremt rainfall variability at Anjeni are generally low while Bega rainfall is more variable. Moreover, the high rainfall concentration index (PCI), calculated as the ratio of square of the rainfall amount of the specific month to the square of the total rainfall shows that monthly rainfall distribution at Anjeni is not uniform.

Table 5. Annual, Kiremt and Bega rainfall variability

Year	Annual			Kiremt			Bega			PCI(%)
	Total	Mean	CV%	Mean	CV	%	Mean	Cv	%	
1985	1556.2	129.7	107.5	269.3	37.6	86.5	30	104.4	13.5	17.2
1986	1370.7	114.2	112.0	234.6	46.3	85.6	28.2	134	14.4	17.9
1987	1811.4	151.0	96.0	298.1	33.1	82.3	45.8	71.4	17.7	15.4
1988	1853.5	154.5	118.5	305	61.6	82.3	46.9	157.9	17.7	19.1
1989	1654.1	137.8	105.5	269.9	49.6	81.6	43.5	99.4	18.4	16.8
1992	1768.3	147.4	89.5	256.8	45.3	72.6	69.2	110.1	27.4	14.5
1993	1847.6	154.0	95.5	296.3	35.7	80.2	52.3	107.9	19.8	15.3
1994	1651.9	137.7	115.9	298.6	39.5	90.4	22.7	84.4	9.6	18.6
1995	1623.6	142.0	102.6	291.8	32.3	89.8	35	86.4	15.1	18,0
1996	1696.9	141.4	97.2	269.0	44.6	79.3	50.3	84.0	20.7	15.6
1997	1708.2	142.4	82.6	254.1	28.8	74.4	62.5	100.4	25.6	13.5
1998	1772.9	147.7	106.2	292.3	46.5	82.4	44.5	121.8	17.6	16.9
2000	1907.1	150.7	107.5	290.8	44.8	76.2	50.6	184.4	18.6	15.4
2002	1618.7	134.9	133.9	293.8	61.7	90.7	21.4	199.4	9.3	22.0
2003	1739.3	144.9	125.3	302.7	62.6	87.0	32.3	98.1	13.0	20.3
2004	1747.2	145.6	111.4	287.8	57.0	82.4	44.0	84.5	17.6	17.8
2009	1687.0	140.6	109.1	257.4	65.1	76.3	57.1	121.9	23.7	17.4
2011	1598.4	228.3	73.6	357.6	13.1	89.5	56.0	106.2	10.5	20.9
2012	1608.2	134.0	119.9	283.1	52.7	88.0	27.5	100.9	12.0	19.3
2013	2145.6	178.8	105.3	362.7	38.7	84.5	47.4	125.7	15.5	16.8
2014	1946.5	162.2	80.0	270.6	29	83.4	53.8	96.5	16.6	13.2
Mean	1742.4	148.6	11.6	260.9	4.2	89.8	31.4	116.8	10.2	

According to Oliver (1980), the PCI value of less than 10 represents a uniform rainfall distribution (i.e. low rainfall concentration); PCI values between 11-15 denote a moderate rainfall concentration; values from 16 to 20 denote an irregular rainfall distribution, and values above 20 represent strong irregularity (i.e. high rainfall concentration) of rainfall distribution (De Luis, et al, 2011). Nearly all values fall under irregular rainfall distribution.

Rainfall at Anjeni has been measured using different types of rain gauges simultaneously There are three manual (ordinary) rain gauges distributed at different locations in the catchment. These manual rain gauges in addition to monitoring the spatial rainfall variability are used to cross-check the proper functioning of recording and automatic rain gauges. The annual records of rainfall obtained using recording pluviometer and manual rain gauges are shown in Figure 4. The difference in amount of rainfall is random, i.e. neither of the instruments is under or over estimating. The variability in the annual rainfall amount from different rain gauges might be associated to the interpolation of rainfall charts. When the data is to be used for hydrological simulation, it is advisable to consider the daily data from both sources as both are available.



	1995	1996	1997	1998	2000	2002	2003	2004	2009	2011	2012	2013	2014
▨ Recording	1,623.6	1,696.9	1,708.2	1,772.9	1,907.1	1,618.7	1,739.3	1,747.2	1,687.0	1,598.4	1,608.2	2,145.6	1,946.5
☐ Manual	1,909.0	2,054.6	1,887.3	2,012.3	2,020.3	1,899.2	1,899.2	1,728.3	1,489.4	1,663.9	1,377.7	2,114.6	1,999.1

Figure 4. Comparison of rainfall measured using recording and ordinary raingauges

4.1.2. Mean monthly rainfall variability

Figure 5 exhibits a unimodal, i.e. an intra-annual distribution with one peak, rainfall pattern. The mean maximum monthly rainfall occurs in July (414.5 mm) and it contributes to 24.4% of the annual rainfall followed by August (20.9%), June (16.5%), and September (14.9%). Rainfall is low in January (0.6%), February (0.7%) and December (1.6%). The coefficient of variation of monthly rainfall is high during the dry season. It ranges from 141% in January to 49% in May. This shows that months with low rainfall are doubly worse off, because they tend to additionally suffer from high deviations around already low average mean of monthly rainfall. The wet season rainfall variability is relatively low and it ranges from 17.6% in July to 26% in August (Table 6).

Precipitation coefficient (PC) is calculated as the ratio between the mean monthly rainfall and one-twelfth of the mean annual rainfall. PC greater than one shows wet month contributing more than one-twelfth of the mean annual total, and 'dry' months contribute less than one twelfth of the mean annual rainfall. A month is "rainy" if the rainfall coefficient is greater than 0.6. The expression "small rains" is used to refer to months with rainfall coefficient of 0.6 to 0.9; and the expression "big rains" refers to months with rainfall coefficient of 1 and above. Big rainy months are further classified into three groups: months with "moderate concentration" (coefficient of 1.0 to 1.9); months with "high concentration" (coefficient of 2.0 to 2.9); and months with "very high concentration" (coefficient of 3.0 and above). In July, rainfall coefficient is about 3 which is a 'very high concentration" while August with rainfall coefficient of 2.5 is regarded as moderate concentration. The May, June and September precipitation concentrations are regarded as small.

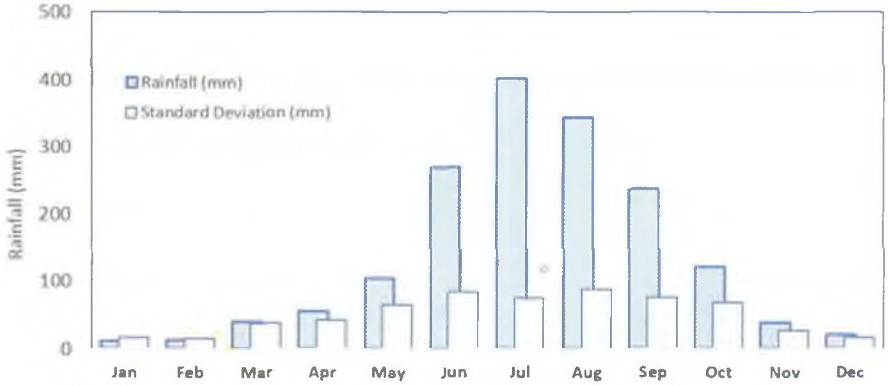


Figure 5. Mean monthly rainfall amount and variability (1985-2014)

Monthly rainfall, potential evapotranspiration and temperature distribution are shown in Figure 6

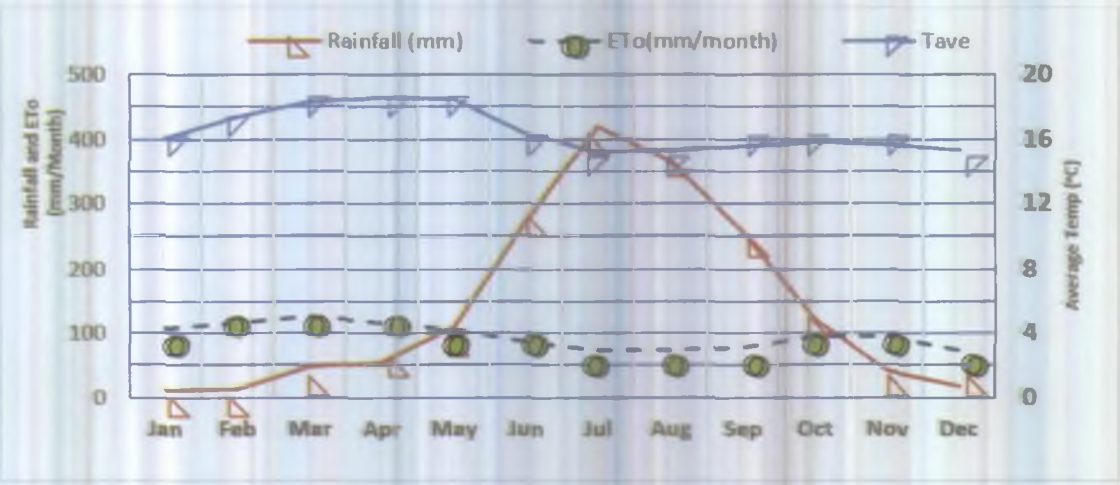


Figure 6. Mean Monthly rainfall, potential evapotranspiration, and mean temperature relationships.

Table 6. Annual and Monthly rainfall from 1984 to 2014 (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1984	nd	nd	nd	11.2	142.6	358	370.4	265.9	193.2	20.3	45.5	24.8	id
1985	3.1	1.9	13.9	71.6	135.3	233.8	379.6	361.4	236.3	77	20.8	21.5	1556.2
1986	0.4	7.2	33.6	10.7	56.5	269.8	336.1	294.5	216.3	109	30.5	6.1	1370.7
1987	5.8	32.6	75	50.6	215.4	304.1	405.2	383.1	182.8	100.3	18.5	38	1811.4
1988	36.5	44.2	4.9	6.2	72.3	320.2	583.3	335.9	213.4	211.3	15.8	9.5	1853.5
1989	0	4.3	86.1	85.6	121.8	163.7	457.7	326.7	279.4	95.5	23.2	10.1	1654.1
1990	nd	nd	nd	nd	90.5	182.6	433.6	432.4	312.3	33.7	33.1	3.3	id
1991	nd	nd	nd	nd	nd	nd	403.8	344.3	240.4	83.7	24.1	6.9	id
1992	3.2	0	49.3	123.2	92	302.9	279.6	403.9	205.4	215	39	54.8	1768.3
1993	1.9	23.1	48	119.4	153.5	226.8	370.3	413.3	317.7	142.2	30.2	1.2	1847.6
1994	11	6.1	7.6	45.1	134.4	388.3	395.7	361.5	213.2	35.5	47.5	6	1651.9
1995	0.0	11.8	11.5	60.2	155.0	250.2	352.7	303.0	397.9	77.8	24.4	59.1	1623.6
1996	*29.4*	*10.7*	*124.8*	*82.3*	*177.6*	*298.7*	*454.7*	*262.7*	*151.1*	*32.9*	*62.6*	*9.4*	*1696.9*
1997	6.4	4.5	47.5	82.0	152.3	251.2	346.2	225.6	295.3	187.8	73.5	35.9	1708.2
1998	32.0	12.0	88.6	12.6	121.2	258.2	375.8	473.8	232.6	148.2	17.9	0.0	1772.9
1999	42.2	0.9	6.2	32.0	112.2	238.9	391.7	nd	nd	nd	nd	nd	id
2000	0.0	1.3	10.0	11.1	120.7	351.6	460.8	307.6	213.3	258.8	46.6	26.1	1907.1
2001	0.0	25.4	29.8	40.5	121.6	273.6	329.7	16.3	nd	nd	nd	nd	id
2002	*nd*	*nd*	*nd*	*nd*	*nd*	402.7	470.4	329.3	266.4	116.0	9.2	24.7	id
2003	0.8	45.8	71.7	5.6	16.4	371.0	520.3	371.4	234.2	74.9	7.7	19.5	1739.3
2004	0.9	4.6	43.2	91.1	47.8	241.4	485.2	383.1	281.7	93.6	44.6	30.0	1747.2
2008	nd	nd	nd	nd	nd	nd	nd	356.3	165.8	177.2	60.4	21.5	id
2009	1.4	17.2	105.9	33.2	22.1	231.7	407.4	430.8	195.2	195.4	21.1	25.6	1687.0
2010	21.7	0.6	17.5	34.1	153.6	nd	nd	334.9	314.6	37.2	6.9	0.0	id
2011	*nd*	*nd*	*nd*	*nd*	nd	308.9	420.4	360.5	340.6	49.6	118.4	0.0	id
2012	4.4	0.0	55.3	0.0	107.2	175.3	492.1	316.6	324.2	63.7	48.8	20.6	1608.2
2013	2.7	2.4	38.6	37.7	213.1	306.5	539.5	480.8	273.6	162.5	88.2	0.0	2145.6
2014	25.8	43.8	138.2	94	288	275	315.3	355.1	260.8	129.4	18.7	2.4	1946.5
MEAN	9.6	13.1	48.1	47.5	126.0	279.4	414.5	341.9	252.2	112.6	37.6	17.6	1742.0
Std	13.5	15.3	39.8	38.2	61.7	63.8	73.0	88.8	59.5	65.7	26.4	16.5	163.5
CV(%)	141.1	117.1	82.7	80.4	49.0	22.8	17.6	26.0	23.6	58.3	70.2	93.9	9.6
Max.	42.2	45.8	138.2	123.2	288.0	402.7	583.3	480.8	397.9	258.8	118.4	59.1	2145.6
Min.	0.0	0.0	0.0	0.0	16.4	163.7	279.6	225.6	151.1	20.3	6.9	0.0	1370.7
PC[†]	0.1	0.1	0.3	0.3	0.8	2.0	2.9	2.5	1.8	0.8	0.3	0.1	12.0
P (%)[††]	0.6	0.7	2.6	2.6	6.9	16.5	24.4	20.9	14.9	6.6	2.2	1.1	100.0

[†] Precipitation Concentration

[††] *Annual percentage of monthly rainfall from the mean annual rainfall*

4.1.3. Daily rainfall variability

Figure 7 shows long term average daily rainfall pattern at Anjeni together with the 10 year moving average. The long-term mean daily rainfall data is presented in Appendix 1, while the one-day extreme rainfall events are shown n Figure 8. The highest one-day rainfall of 87 mm occurred on June 9, 1995 and the minimum one-day maximum rainfall of 38.7 mm occurred in 1986. Daily rainfall data from different rain gauges is available in WALRIS database.

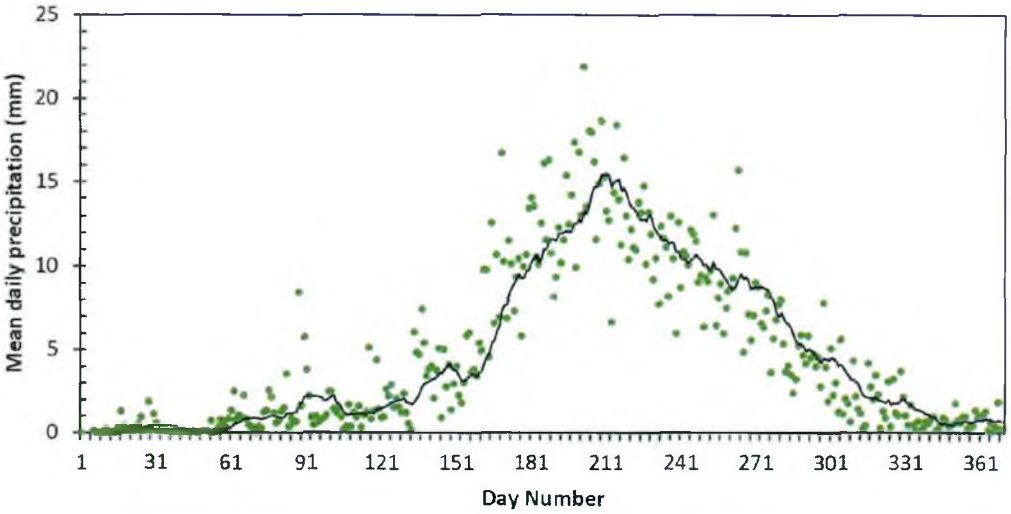


Figure 7. Mean daily rainfall (1984-2014) along with 10 year moving average

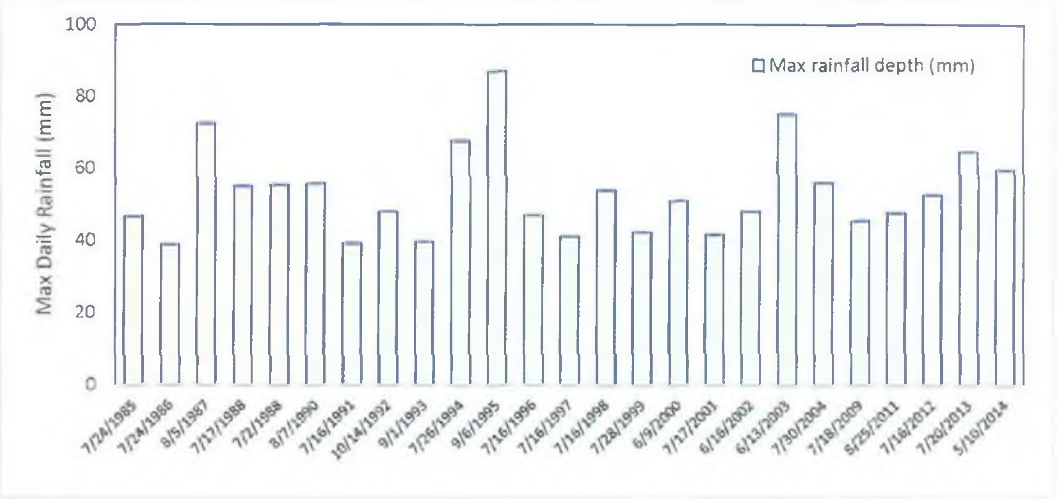


Figure 8. One day maximum rainfall at Anjeni

4.1.4. Rainfall intensity

The rainfall intensity calculated from pluviograph for each rainfall storm and up to one hour duration is shown in Figure 9 while Figure 10 was generated taking the three most intensive storms for the specific time duration. Rainfall break point data used to generate the figures is available in WALRIS database.

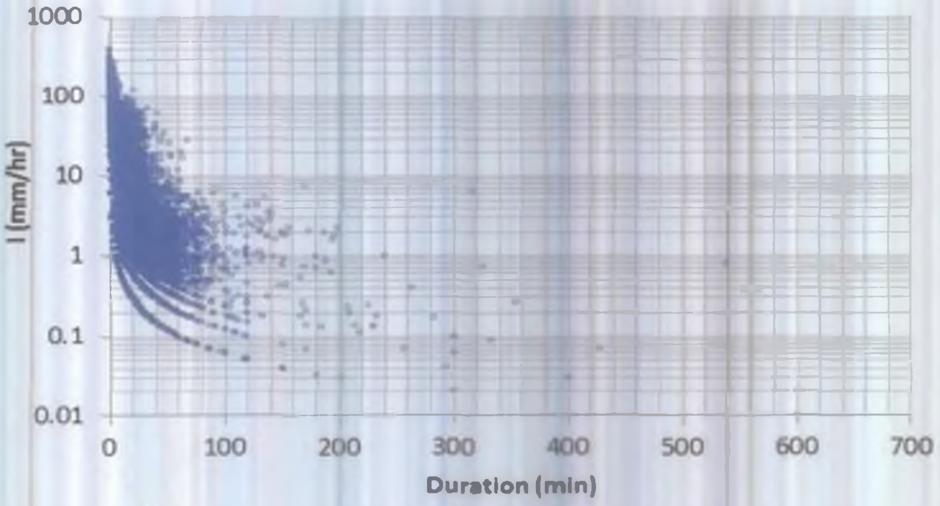


Figure 9. Event based rainfall intensity- duration relationships (1984-2014)

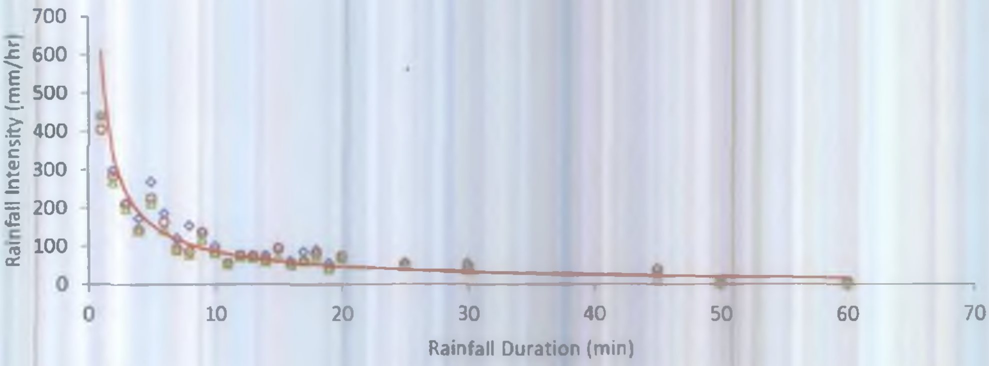


Figure 10. Extreme rainfall intensity duration curve (1984-2014)

The rainfall intensity and duration relationship generated from Figure 10 has the following power relation (equation 1)

$$i = \frac{612}{t^{0.834}} \quad (R^2 = 0.84)$$

Where 'i' is rainfall intensity in mm/hr, t is rainfall duration in minutes and R2 is the coefficient of determination.

4.1.5. Annual and monthly rainfall erosivity

Rainfall erosivity (R) is one of the six factors in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978; Renard, et al, 1997). It quantifies the ability of rainfall to detach soil from hillslopes. It is obtained as the product of total storm kinetic energy (E, MJ/ha) and the maximum 30-minute rainfall intensity in the storm (I30, mm/hr). R is the average of annual summations of storm (EI30) values, excluding storms of less than 12.5 mm total rainfall depth. Unless land is bare, rainfall amount less than

12.5 mm is considered non-erosive. The 'E' portion of these values represents the rainfall energy, and the 'I30' portion represents the maximum 30-min rainfall intensity during the storm. The index has been widely tested, adopted, and used in countries where moderate to high intensity rainfall prevails, and runoff to be primary infiltration excess (Krauer, 1988; Yin et al, 2007).

The calculation of EI30 uses breakpoint rainfall intensity data derived from recording rain gauges. The breakpoint data are read manually from graphical charts that are generated by continuously recording rain gauges. Breakpoint data are recorded as pairs of values representing time and cumulative depth of rainfall as measured from the charts. Time intervals between the recorded data pairs represent portion of the storm that exhibit constant or near constant rainfall intensity. Thus the recoded points represent times of discernible 'breaks' or changes in the rainfall intensity of the storm.

Table 8 shows rainfall intensity I30 and rainfall amount of storms from 1995-2014. On average, there are 16 erosive storms for which I30 is more than 25 mm/h and 46 erosive rainfall events as storm with a total rainfall exceeding 12.5 mm for the period 1995 to 2014. The mean annual rainfall depth and I30 of storms are 8.2 mm and 8.6 mm/h respectively. Figure 11 shows long term annual rainfall and erosivity for the period 1984-2013 while Figure 12 shows mean monthly rainfall and erosivity for the period 1984 to 2014. The maximum (902.5 J/m.hr) and minimum(394 J/m.hr) values of rainfall erosivity were obtained from higher and lower annual rainfall depth of 2145.6 mm and 1370.7 mm respectively. The mean annual rainfall erosivity for the period 1995 to 2014 was 628.4 J/m.hr and the long term (1984-2014) value was about 630.4 J/m hr. The coefficient variation of the mean annual rainfall erosivity ranges between 34% and 364%. The lowest coefficient of variation is found in the major rainy seasons. The highest rainfall erosivity is recorded in July which is 177.1 J/m hr.

Table 8 also shows monthly erosivity and other associated key values such as mean, standard deviation, maximum and minimum Coefficient of Variation (CV), Erosivity Coefficient (RC) and the mean monthly rainfall erosivity as percentage of the annual total (%) for the period 1984-2014. Rainfall erosivity coefficient is calculated as ratio between the mean monthly rainfall erosivity and one-twelfth of the mean annual rainfall erosivity. Rainfall erosivity coefficient of 1 or above is considered to be the threshold distinguishing between "erosive" months contributing more than one twelfth of the mean annual erosive rainfall, and "less erosive" months that contribute less than one twelfth of the mean annual rainfall erosivity. Months of June to September have greater than one erosivity coefficient and the others have less than one erosivity coefficient.

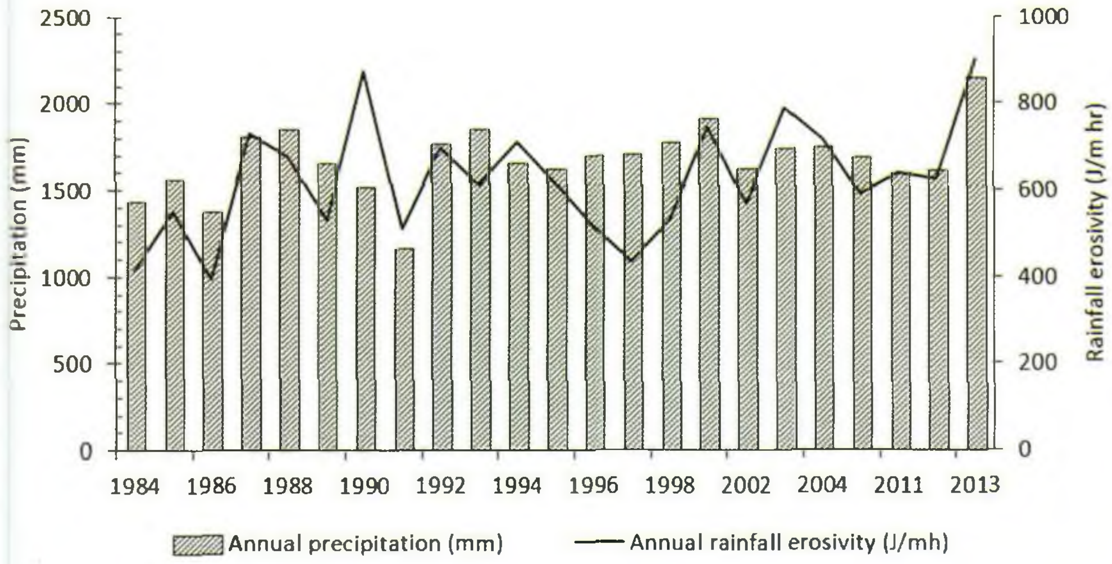


Figure 11. Trend in rainfall and rainfall erosivity

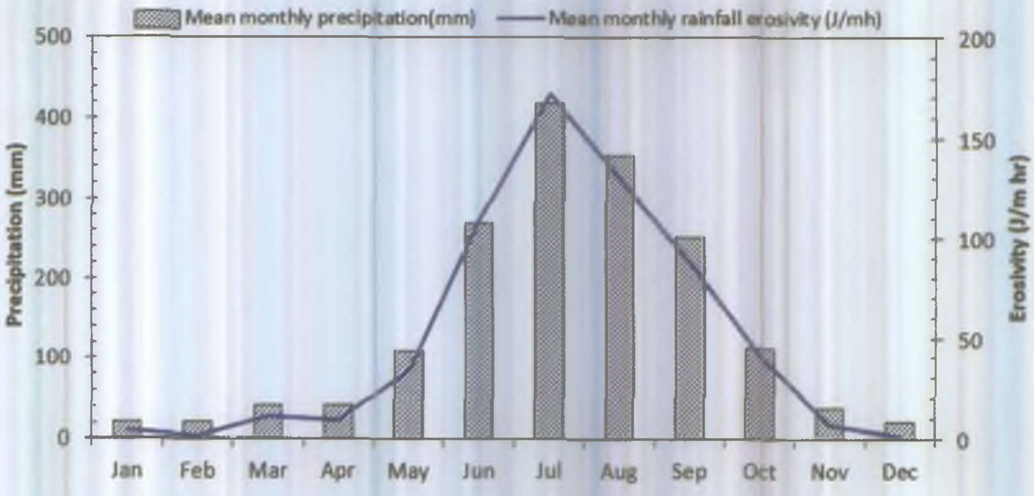


Figure 12. Mean monthly rainfall and erosivity for the period 1984-2014

Table 7. Rainfall intensity, I30 (≥25 mm/h) and rainfall amount (≥12.5 mm) of storms from 1995 to 2014.

Year	Total no. events	Total storm	**Rainfall Intensity (mm/hr.)(I_{30})**				**Rainfall amount (mm)**				Percent	
			No. of storms with I_{30} ≥25 mm/hr.	max	min	Mean	No. of storms with I ≥12.5 mm	Max	Min	Mean	No. of storms I_{30}≥25 mm/hr	No. of storms ≥12.5 mm
1995	1583	218	14	71.8	0.2	8.6	41	84.7	0.1	7.5	6.4	18.8
1996	2295	237	13	47.3	0.2	7.2	41	79.1	0.1	7.2	5.5	17.3
1997	1943	263	10	49.6	0.2	7.4	42	42.5	0.1	6.5	3.8	16
1998	1676	220	13	46.2	0.1	8.2	43	61	0.2	8.1	5.9	19.5
2000	3480	266	19	52.6	0.1	6.7	51	79	0.1	7.2	7.1	19.2
2002	1361	164	15	46.8	0.2	9.8	49	56.3	0.1	9.9	9.1	29.9
2003	1604	207	10	104.2	0.2	7.9	47	86.7	0.1	8.4	4.8	22.7
2004	1165	242	21	60.6	0.2	9.3	46	56	0.1	7.2	8.7	19
2009	1378	209	17	45.9	0.2	8.7	46	77.3	0.1	8.1	8.1	22
2011	1765	161	20	67.5	0.2	10.6	45	47.9	0.1	9.9	12.4	28
2012	1406	197	13	69.1	0.2	8.2	40	61.1	0.1	8.2	6.6	20.3
2013	2150	217	22	61.6	0.2	10	62	89	0.1	9.9	10.1	28.6
2014	2155	250	19	85.4	0.2	8.9	48	67.9	0.1	7.8	7.6	19.2
Ave	1843.2	219.3	15.8	62.2	0.2	8.6	46.2	68.3	0.1	8.1	7.4	21.6
Stdv	601.6	33.0	4.1	17.6	0.0	1.1	5.8	15.4	0.0	1.1	2.3	4.5
CV	32.6	15.1	25.7	28.2	20.3	13.4	12.6	22.5	25.8	13.8	31.4	20.8
Max	3480	266	22	104.2	0.2	10.6	62	89	0.2	9.9	12.4	29.9
Min	1165	161	10	45.9	0.1	6.7	40	42.5	0.1	6.5	3.8	16

Table 8. Annual and Monthly rainfall erosivity (J/mh) (1985-2014)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1984	nd'	nd	nd	0.0	47.2	138.1	176.5	32.0	21.7	0.0	0.0	0.0	id"
1985	0.0	0.0	0.0	24.1	20.4	122.6	129.7	155.4	83.0	16.9	0.0	0.0	552.1
1986	0.0	0.0	6.2	0.0	56.0	43.7	67.1	99.4	64.8	45.4	11.4	0.0	394.0
1987	0.0	17.0	21.3	23.2	83.3	116.7	197.5	195.5	35.0	34.1	0.0	7.8	731.2
1988	4.7	9.9	0.0	0.0	5.8	132.6	241.4	107.6	63.9	105.6	3.9	0.0	675.3
1989	0.0	0.0	23.5	16.0	47.1	26.4	226.5	84.2	77.4	30.1	0.0	0.0	531.1
1990	82.9	0.0	0.0	0.0	105.3	62.3	247.7	312.1	60.7	0.0	3.3	0.0	874.3
1991	nd	nd	nd	nd	nd	nd	175.8	115.4	171.6	46.9	0.0	0.0	id
1992	0.0	0.0	0.0	50.3	18.4	173.2	123.7	119.4	74.7	129.4	7.8	0.0	696.4
1993	0.0	0.0	2.7	22.5	18.7	100.8	183.7	129.1	112.4	42.4	0.0	0.0	612.2
1994	0.0	0.0	0.0	17.8	14.8	212.6	259.0	114.1	69.3	3.6	19.1	0.0	710.3
1995	0.0	0.0	0.0	19.1	44.4	122.9	95.3	108.4	195.7	17.3	0.0	13.2	616.2
1996	0.0	0.0	59.3	8.7	77.3	108.4	186.3	50.5	9.6	7.9	5.8	0.0	513.7
1997	0.0	0.0	0.0	9.4	51.1	51.1	96.1	40.6	132.8	43.1	5.3	5.0	434.4
1998	8.8	0.0	37.4	0.0	45.2	81.7	125.8	187.8	34.5	8.8	0.0	0.0	530.0
1999	3.3	0.0	0.0	0.0	5.2	106.6	129.3	nd	nd	nd	nd	nd	id
2000	0.0	0.0	0.0	2.6	48.5	148.3	252.4	83.7	69.1	129.6	7.5	4.1	745.8
2001	0.0	0.0	9.8	15.4	30.0	109.8	93.9	13.6	0.0	0.0	0.0	0.0	id
2002	nd	nd	nd	nd	nd	171.7	168.1	85.6	74.4	67.1	0.0	0.0	id
2003	0.0	10.6	37.5	0.0	0.0	322.1	215.1	107.8	54.3	35.2	0.0	7.0	789.5
2004	0.0	0.0	0.0	7.7	5.9	54.4	201.7	203.1	212.8	15.7	18.3	0.0	719.5
2008	nd	nd	nd	nd	nd	nd	nd	129.5	23.4	91.5	21.3	0.0	id
2009	0.0	0.0	26.3	0.0	0.0	122.6	131.0	150.9	65.4	96.5	0.0	0.0	592.7
2010	3.6	0.0	0.0	0.0	39.9	nd	nd	199.4	108.9	0.0	0.0	0.0	id
2011	nd	nd	nd	nd	nd	132.7	201.4	155.9	105.2	8.5	36.7	0.0	id
2012	0.0	0.0	34.9	0.0	27.6	18.5	284.2	127.3	109.2	22.9	0.0	0.0	624.5
2013	0.0	0.0	0.0	13.3	66.2	161.1	267.7	160.1	181.3	25.1	27.6	0.0	902.5
2014	5.3	22.1	55.9	11.5	222.6	116.3	137.4	134.8	58.4	77.9	0.0	0.0	842.2
Mean	4.7	2.6	13.7	10.1	45.0	118.3	177.5	126.0	84.1	40.8	6.2	1.4	630.4
STD	17.2	6.2	19.3	12.2	46.9	63.8	60.9	62.0	55.5	39.9	9.9	3.3	140.0
CV (%)	364.5	237.6	141.0	121.4	104.0	53.9	34.3	49.2	66.0	97.9	159.2	236.6	22.2
MAX	82.9	22.1	59.3	50.3	222.6	322.1	284.2	312.1	212.8	129.6	36.7	13.2	902.5
MIN	0.0	0.0	0.0	0.0	0.0	18.5	67.1	32.0	9.6	0.0	0.0	0.0	394.0
RC	0.1	0.0	0.3	0.2	0.9	2.3	3.4	2.4	1.6	0.8	0.1	0.0	12.0
%	0.7	0.4	2.2	1.6	7.1	18.8	28.2	20.0	13.3	6.5	1.0	0.2	100.0

'nd no data in the specific month.

"id – incomplete data

NB. Source of data from 1984 to 1994 is Bosshart (1997b)

4.1.6. Rainfall and wind direction

Knowing the direction of rainfall is important to know the source and magnitude of rainfall and to assess its impact on rate of soil erosion. Rainfall inclinometer - an instrument consisting of four compass directions inclined catch-cans (Hurni, 1989), were used to capture rainfall and compute the average weighted rainfall direction, measured at 8 a.m. daily. Table 8 shows the annual observation recorded in each direction for the years 1995 to 2014 while Figure 13 shows the corresponding rainfall received from each direction. The dominant direction of rainfall is westerly, which is similar to the dominant wind direction in the afternoon (Figure 14). Rainfall in Anjeni dominantly occurs in the afternoon. Daily rainfall and wind direction data is available in the WALRIS website.

Table 9. Annual rainfall (mm) received from different directions (1995-2014)

Year	N	NE	E	SE	S	SW	W	NW	All
1995	91.7	376.0	378.7	142.0	101.0	222.3	392.0	126.2	1829.9
1996	197.5	420.8	146.6	49.5	90.6	450.5	357.2	237.7	1950.3
1999	164.2	256.5	64.8	76.3	69.0	368.3	490.3	334.8	1824.3
2000	269.2	430.9	218.6	98.5	157.2	235.8	390.2	174.9	1975.2
2002	215.3	349.5	313.0	229.9	226.0	151.9	221.2	105.9	1812.7
2003	194.5	204.5	307.8	325.8	75.5	126.8	141.9	412.0	1788.7
2004	302.4	293.5	95.0	141.6	109.5	270.9	131.9	126.0	1470.7
2005	55.4	95.5	309.2	362.5	278.6	103.9	166.3	479.4	1850.7
2006	73.2	260.3	93.0	120.6	829.5	156.6	85.7	229.8	1848.6
2007	106.9	123.8	80.8	103.9	583.8	107.1	369.1	212.1	1687.4
2008	106.9	123.8	80.8	103.9	583.8	107.1	369.1	212.1	1687.4
2009	222.8	395.3	203.5	91.0	79.7	159.3	288.2	246.4	1686.4
2010	192.0	412.2	270.7	78.7	222.0	162.3	202.0	303.6	1843.4
2011	75.2	492.0	215.7	289.5	119.9	264.6	253.1	216.0	1925.9
2012	74.7	212.7	266.3	123.8	231.2	386.2	2586.0	113.4	1667.2
2013	175.3	342.0	238.6	160.1	231.5	324.1	494.4	221.6	2187.7
2014	219.0	305.7	279.2	168.1	75.9	114.9	292.9	305.8	1939.5
Mean	161.0	299.7	209.6	156.8	239.1	218.4	425.4	238.7	1822.1
p(%)	8.8	16.4	11.5	8.6	13.1	12.0	23.3	13.1	100.0
SD	74.9	118.4	98.9	91.6	220.1	109.8	569.9	103.4	158.8

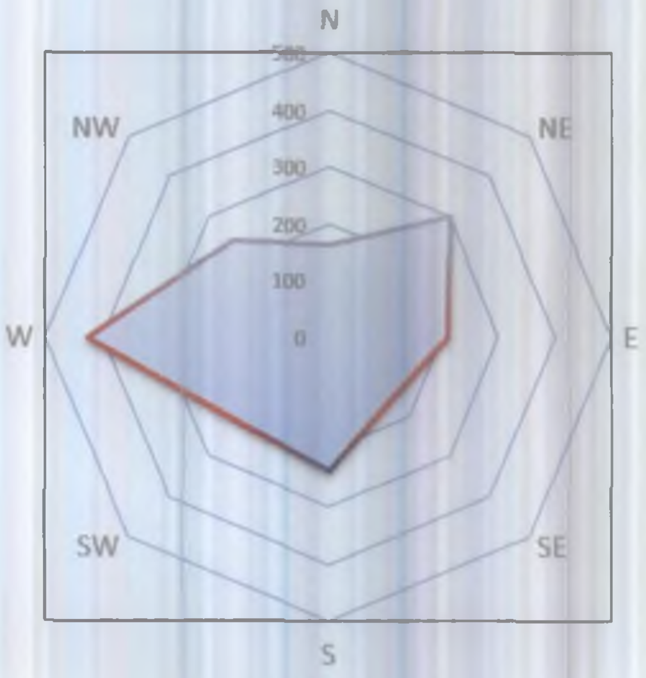


Figure 13. Mean (1995-2014) rainfall (m) direction

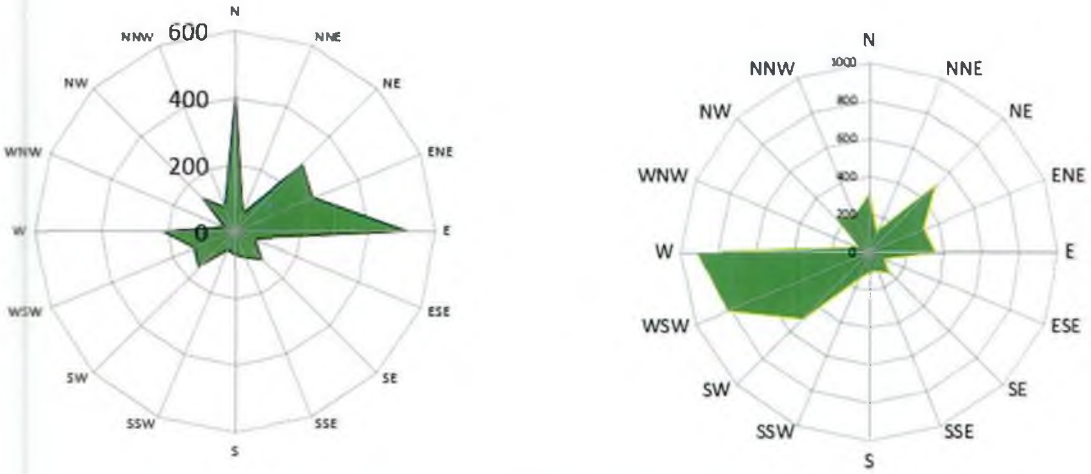


Figure 14. Mean daily wind direction from 1994-2014

The wind direction is measured using simple thread in the morning (8:00 am) and during the afternoon (6:00 pm). Figure 14 shows that the morning wind in easterly while the afternoon wind is westerly. The original daily wind direction data monitored in the morning and afternoon is available in the WLRC database.

4.2. Air and Soil Temperatures

4.2.1. Annual temperature

The mean daily annual minimum, average and maximum temperatures at Anjeni are 9.4 °C, 18 °C, and 26.6 °C, respectively (Table 10). Figure 15 shows the long term daily mean annual maximum, average and minimum air temperature trends for Anjeni. The statistical analysis shows that there is a statistically significant increasing trend for both maximum and minimum temperatures (Figure 16). The mean temperature is increasing at the rate of 0.05°C/yr. The maximum and minimum temperatures are increasing at rates 0.07°C/yr and 0.025°C/yr. respectively.

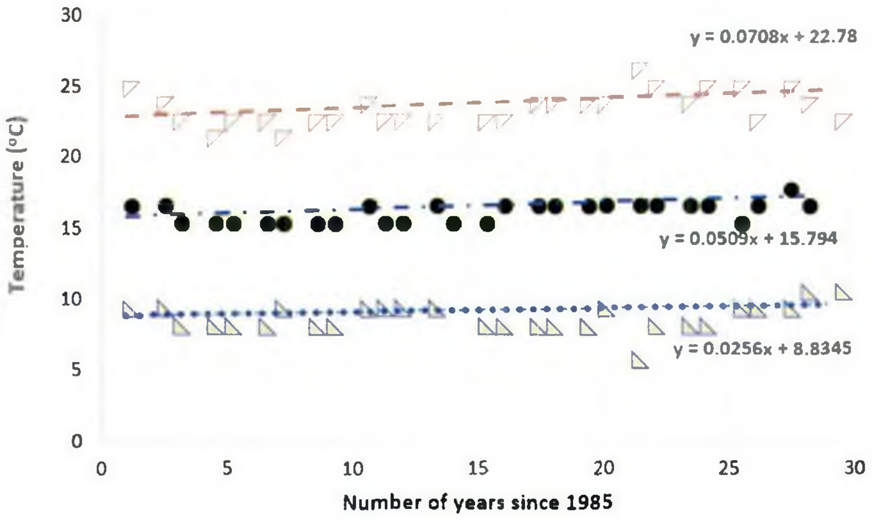
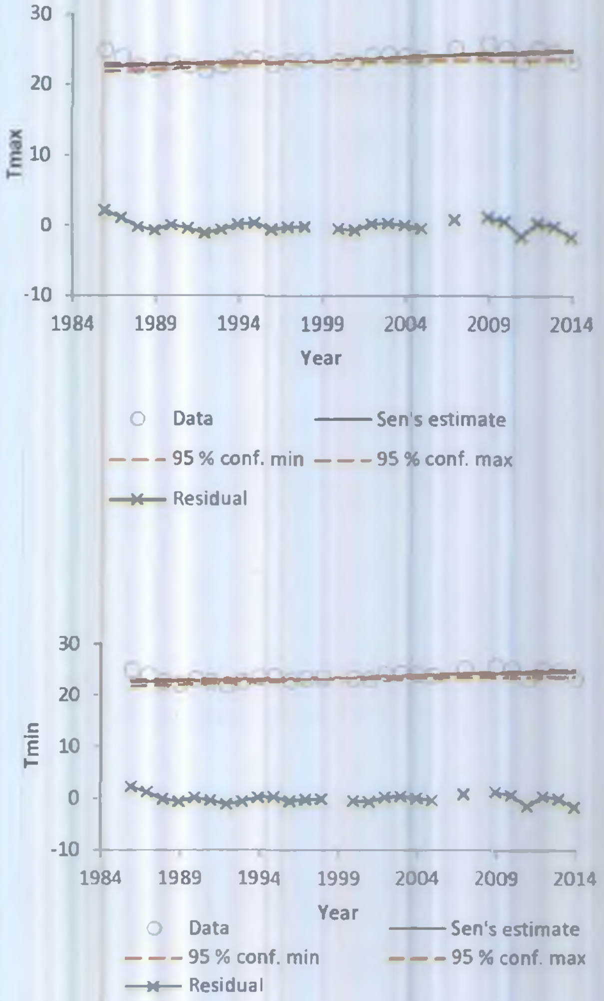


Figure 15. Daily mean annual maximum, average and minimum temperature trends



	Tmin	Tmax
Years	1986 - 2014	1986 - 2014
n- no. of years	26	26
Z-test	2.73	2.78
Significance	**	**
Q	0.034	0.079
Q_{min99}	0.002	0.005
Q_{max99}	0.071	0.133
Q_{min95}	0.010	0.023
Q_{max95}	0.061	0.120
B	8.8	22.6
B_{min99}	9.3	23.4
B_{max99}	8.3	21.9
B_{min95}	9.2	23.2
B_{max95}	8.4	22.0

Where Q is slope and B is the intercept

Figure 16. Mann Kendall and Sens's maximum and minimum annual trend test

4.2.2. Mean monthly temperature

The long term mean monthly variability in the maximum, average and minimum temperature are shown in Figure 17. Mean monthly temperature is low during the rainy season (June, July and August). December and January have low night temperature; due to this, the mean air temperature is also low.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
T_{Min}	6.1	7.4	9.0	10.3	11.2	11.2	11.4	11.4	10.6	9.5	8.0	6.6	9.4
T_{Max}	28.4	30.5	30.4	30.5	28.9	25.2	21.9	21.7	23.2	25.3	26.8	26.3	26.6
T_{Mean}	17.3	19.0	19.7	20.4	20.0	18.2	16.7	16.6	16.9	17.4	17.4	16.5	18.0
SD-Min	1.3	1.2	1.0	1.3	1.3	1.2	1.3	1.2	1.2	1.4	1.6	1.6	0.7
SD-max	3.8	4.8	4.1	5.2	4.6	3.9	2.5	2.6	2.5	3.1	3.2	6.9	3.3
SD-mean	1.9	2.5	2.1	2.4	2.2	2.2	1.8	1.8	1.7	2.0	2.2	3.9	1.9

Table 10.Mean monthly minimum, maximum and average temperatures (oC) from 1986-2014

Figure 17. Mean monthly air temperature variability at Anjeni (1986-2014)

4.2.3. Daily temperature

The daily temperature variability from 1986 to 2014 is shown in Figure 18. The mean maximum, average, and minimum temperatures were 23.7, 16.5, and 9.2 °C respectively. The lowest temperatures recorded were 0 °C; it occurs in the last week of December and early January. The highest temperature ever recorded was 39 °C on 14 March 2010. The daily data is provided in WALRIS/WLRC database.

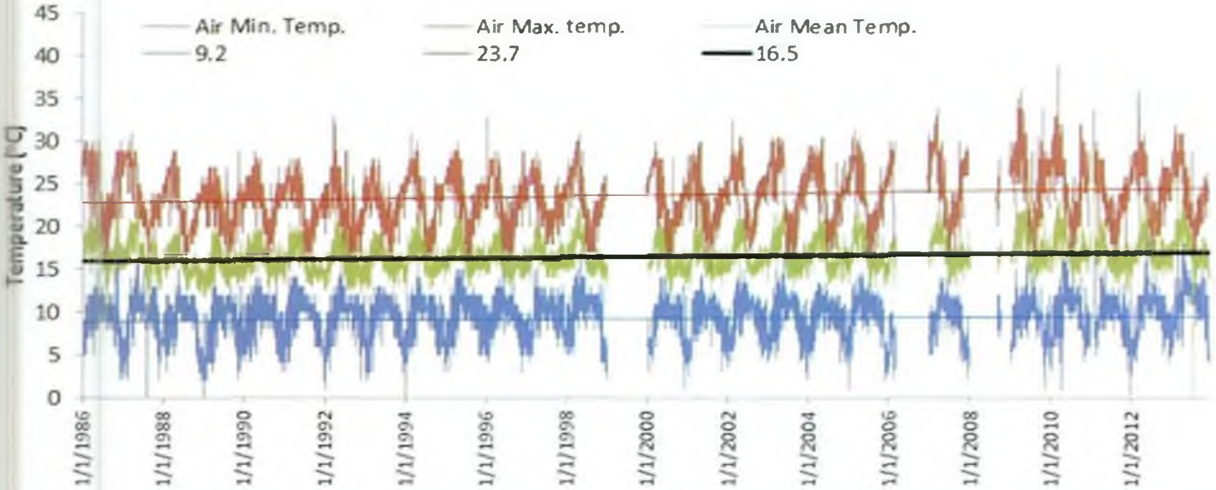


Figure 18. Daily maximum, average and minimum air temperatures from 1986 to 2014

The probability plot of the maximum and minimum temperature are shown in Figure 19 and Figure 20 respectively. The Shapiro-Wilk normal distribution test (W=0.969, p<0.0001) shows, the daily minimum temperature is not normally distributed about the mean. Skewness test also shows that minimum temperature is skewed to the left – most values are concentrated to the right of the mean, with extreme values to the left. On the other hand, maximum temperature is symmetrical around the mean.

The kurtosis values for the two distributions are less than three, indicating distribution is flatter than a normal distribution with a wider peak; i.e., the probability of extreme values is less than for a normal distribution and the values are wide spread around the mean.

Table 11. Air temperature descriptive statistics

	Temperature		
	Max	Mean	Min
Mean	23.6	16.5	9.2
Standard Error	0.03	0.02	0.03
Median	24	16	10
Mode	24	15.5	11
Standard Deviation	3.3	1.8	2.5
Sample Variance	11.0	3.4	6.4
Kurtosis	-0.4	1.0	0.1
Scenes	0.0	0.5	-0.4
Range	27	29	24
Minimum	12	0	0
Maximum	39	29	24

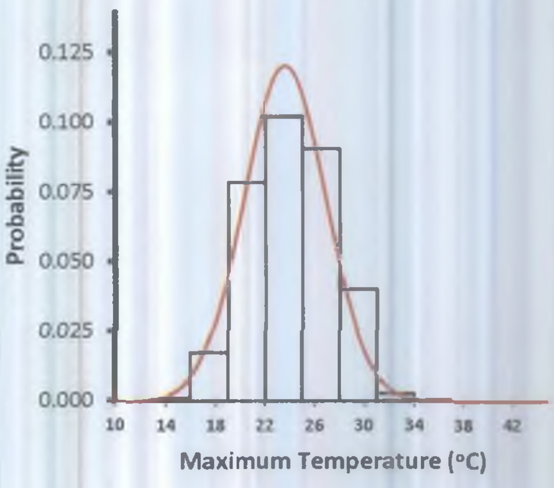


Figure 19. Maximum daily temperature distributions

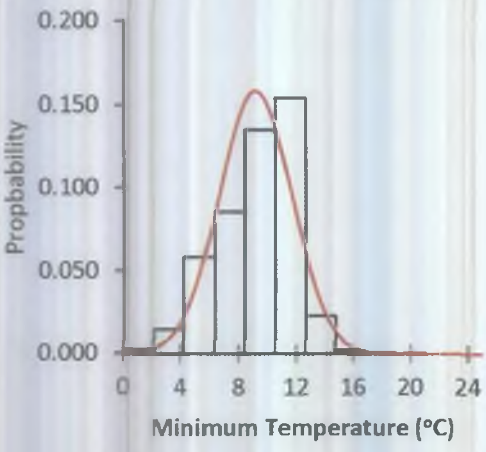


Figure 20. Minimum daily temperature distribution

4.2.4. Soil surface Temprature

The daily mean annual soil surface minimum, avearge, and maximum temperatures are 9.1 °C and 18.9 °C, and 28.5 °C (Table 12). The trend in the mean annual maximum, average, and minimum temperature values is shown in Figure 21. The trend is visiablly increasing specifically for the lower and mean temperatures and it is in agreement with the air temperature observations described under 4.2.3.

The mean monthly soil surface temprature ranged from 17.4 °C in December to 20.8 °C April. Figure 22 shows that mean monthly maximum and mean average monthly soil surface tempratures are higher than the corresponding air tempratures. On the other hand, the minimum air temperature is close to the minimum soil surface temperature. From January to May, minimum air temperature tends to be lower than the air temperature, and from June to November, the minimum soil temperature tends to be modestly higher.

Table 12. Mean monthly soil temperature distribution (°C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
T_{Min}	5.5	6.8	8.5	9.7	10.7	11.1	11.6	11.6	10.7	9.4	8.0	6.4	9.1
T_{Max}	31.2	33.3	33.2	31.9	30.0	26.8	23.3	23.3	24.9	27.3	28.7	28.2	28.5
T_{Mean}	18.3	20.1	20.9	20.8	20.4	19.0	17.5	17.5	17.9	18.4	18.4	17.4	18.9
SD-min	1.60	1.49	1.16	1.75	1.55	1.33	1.27	1.27	1.33	1.66	1.75	2.16	0.96
SD-Max	2.32	2.31	1.51	4.94	4.39	3.30	1.83	1.56	1.74	1.78	1.49	7.21	1.71
SD-mean	1.22	1.61	1.15	2.85	2.44	1.92	1.37	1.24	1.33	1.11	1.30	3.83	1.17

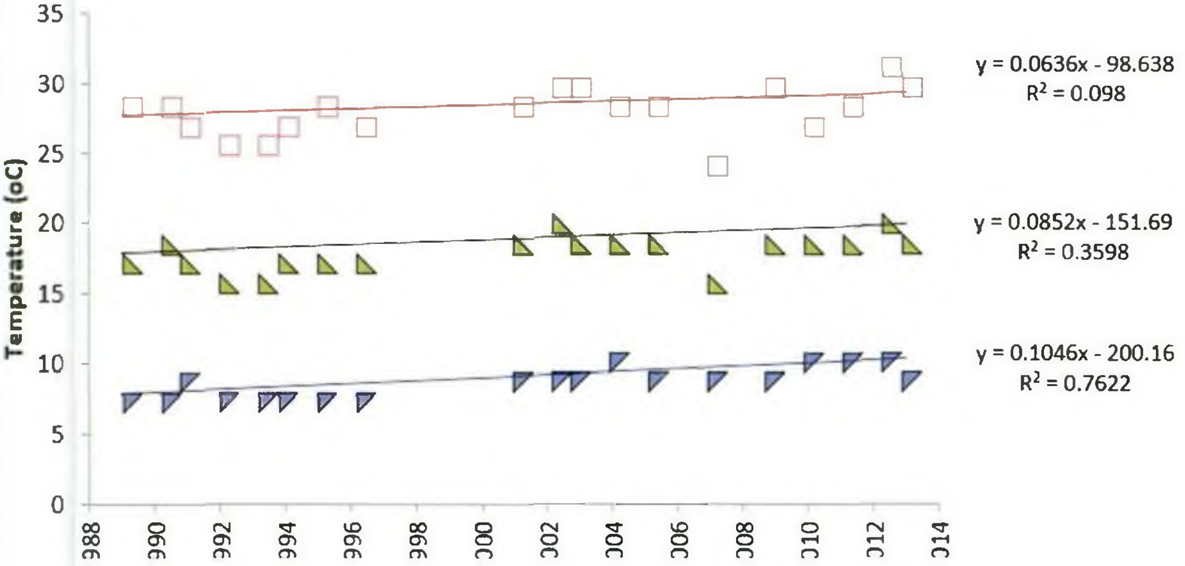


Figure 21. Mean annual soil surface maximum, average and minimum soil surface temperatures

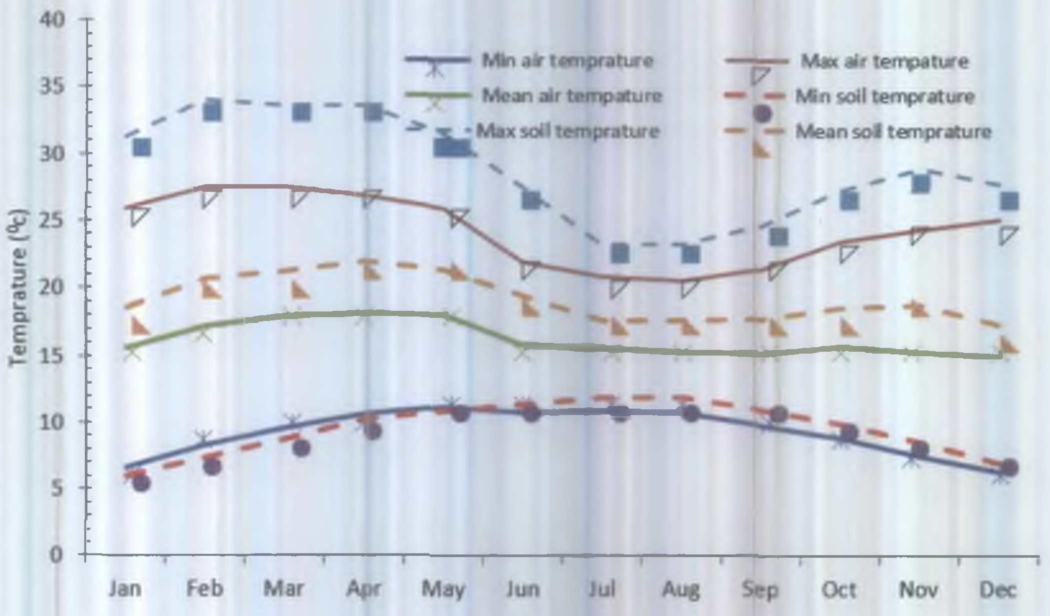


Figure 22. Variability in mean monthly maximum, average and minimum air and soil temperatures (1995-2014)

4.3. Piche Tube Evaporation

Evaporation from Piche Tube Evaporimeter has been observed since 1988. The annual mean daily evaporation computed is 4.2 ml/day. The mean daily and mean monthly evaporation values are presented in Figure 23 and Figure 24 respectively. The highest mean monthly evaporation measured by Piche tube evaporimeter occurred during the dry season especially from March to April. The readings during the rainy season are expectedly low due to cold and humid weather condition prevailing in the season. It is to be seen later that this has a substantial bearing on rainfall-runoff relations.

Figure 23. Mean daily evaporation from Piche tube (1986-2014)

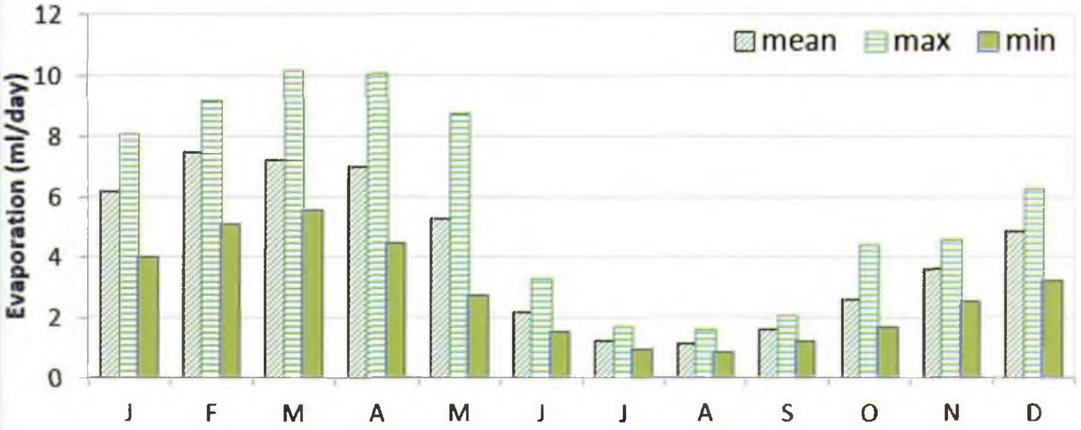


Figure 24. Mean monthly evaporation from Piche tube evaporimeter

5. Hydrometric Data

The total size of Minchit stream hydrological catchment is 113.4 ha. The gauging station represents the standard SCRP set-up. The artificial cross-section consists of stones dressed in mortar with a thin concrete layer on the horizontal planes. The stilling wells generally consist of a float chamber with a simple inlet opening directly into the river channel. The core construction consists of a concrete chamber housing the float. Since May 2013, additional Otto Thalimeda Pressure gauges for continuous automatic recording of the water level have been in place. It is believed that this will be useful for the analysis of rainfall-runoff relations at finer temporal resolution (event based) than daily time scale.

5.1. Annual river runoff

There are 17 years complete river runoff data shown in Table 14 and Figure 25. Table 13 shows the summary statistics of the runoff depth. The mean (1984-2014) annual volume of runoff is about 850307.5 m^3. The corresponding mean annual catchment runoff in depth units is 755.3 mm. This is about 45% of the mean annual rainfall. The mean annual runoff is 26.6 l/s (23.7 $l/s/km^2$). The annual depth of runoff varied from 610 mm to 918 mm with a mean annual runoff depth of 755.3 mm. The runoff coefficient of variation is 10%.

Table 13. Anjeni watershed runoff summary statistics

Descriptive Variable	Value
Mean	755.3 mm
Standard Error	18.8 mm
Median	755.1 mm
Standard Deviation	77.4 mm
Kurtosis	0.5
Skewness	0.3
Range	307.4 mm
Minimum	610.7 mm
Maximum	918.1 mm

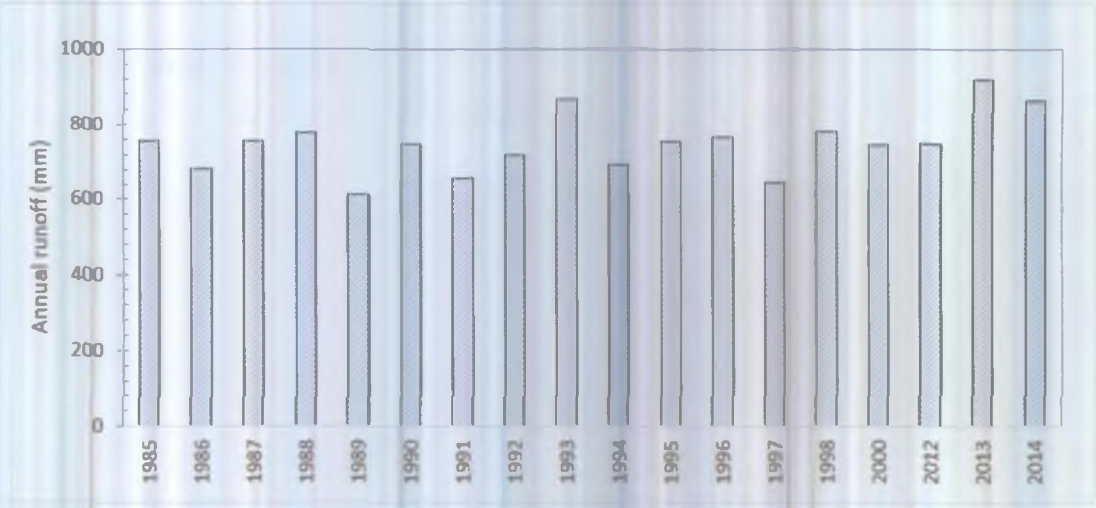


Figure 25. Mean annual runoff for the period of 1985-2014

5.2. Monthly river runoff

Table 14 shows the mean monthly runoff of the watershed. The highest mean monthly runoff values are recorded between July and September which contributes 70% of the total mean annual runoff with coefficient of variation between 23% and 28%. The mean monthly runoff ranges from 10323.9 m^3 in April to 235379.6 m^3 in August, which corresponds to the mean monthly discharge ranging from 4.1 l/sec in April to 87.1 l/sec in August. In depth units, results of the mean monthly runoff measurements are presented in Figure 26. The daily runoff data is available in the WLRC website.

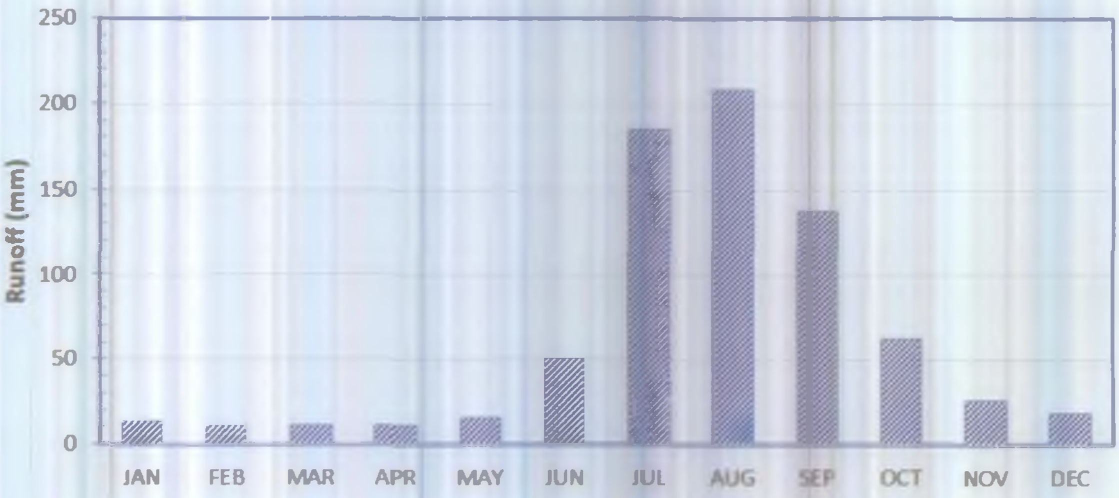


Figure 26. Mean Monthly runoff (mm)

Table 14. Monthly runoff (mm) of Anjeni watershed (1984-2014)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1984	nd	nd	nd	nd	nd	74.3	244.0	163.7	113.7	26.3	18.4	16.3	id
1985	14.7	10.3	8.0	9.3	10.5	27.6	142.0	275.8	165.9	52.5	23.8	14.7	755.1
1986	14.7	7.2	8.1	7.8	13.2	41.8	148.3	187.6	123.1	83.4	25.4	21.4	682.0
1987	14.5	7.2	12.1	10.8	15.1	93.3	183.4	247.4	91.2	44.5	22.0	14.7	756.4
1988	14.7	13.8	9.3	7.8	8.0	21.8	269.4	196.9	91.5	95.5	28.1	22.2	779.0
1989	14.7	7.2	11.3	13.6	12.1	9.3	159.5	164.3	134.7	42.4	22.9	22.2	610.7
1990	22.8	11.6	8.0	7.8	10.9	12.7	141.5	277.2	170.7	47.9	21.9	17.5	750.4
1991	11.7	9.0	8.0	7.8	8.9	12.3	183.5	202.1	139.9	37.9	21.5	14.7	id
1992	14.7	12.5	8.4	12.5	10.0	40.0	123.3	229.1	109.8	114.6	27.2	18.6	720.7
1993	14.7	11.8	8.0	8.0	8.6	61.5	177.0	260.4	208.4	68.0	25.7	14.7	867.0
1994	8.0	7.2	8.0	7.8	9.5	75.2	198.5	195.3	112.4	35.3	21.6	14.7	693.5
1995	14.7	10.5	8.0	8.4	12.5	75.1	192.2	182.8	168.9	46.4	18.9	18.2	756.7
1996	12.0	10.2	24.6	24.3	49.9	100.3	222.3	151.8	89.9	44.8	22.2	15.0	767.2
1997	14.7	7.2	8.0	8.2	12.6	47.3	146.9	115.9	124.5	73.4	51.7	33.5	644.0
1998	23.7	16.7	14.3	8.0	11.6	37.1	148.1	239.6	146.2	78.2	36.9	20.9	781.3
2000	19.1	13.8	14.7	10.8	10.4	80.1	184.3	156.0	87.7	76.7	57.1	33.6	744.3
2012	8.0	7.6	7.2	2.1	3.2	16.0	200.0	209.0	215.8	60.6	11.9	8.7	750.1
2013	2.8	0.0	0.0	0.1	21.6	55.5	276.3	296.9	163.9	63.8	15.0	22.1	918.1
2014	14.7	11.2	14.1	11.5	57.9	83.6	170.7	209.8	160.1	84.0	25.1	20.1	862.8
Mean	14.2	9.7	10.0	9.2	15.9	50.8	184.8	208.5	137.8	61.9	26.2	19.2	755.3
Stdv	4.9	3.7	5.0	4.9	14.3	29.5	43.1	48.7	38.5	23.1	11.3	6.2	77.4
Max	23.7	16.7	24.6	24.3	57.9	100.3	276.3	296.9	215.8	114.6	57.1	33.6	918.1
Min	2.8	0.0	0.0	0.1	3.2	9.3	123.3	115.9	87.7	35.3	11.9	8.7	610.7
CV (%)	34.6	37.9	49.5	53.5	90.2	58.2	23.3	23.3	27.9	37.2	43.0	32.3	10.2

6. Suspended Sediment Yield

6.1. Methods of data collection and instrumentation

The term "sediment yield" here refers to the suspended sediment passing the gauging station at the outlet of the catchment to determine sediment concentration during the storm. One-liter grab samples were taken from the river at the gauging station. Sampling starts once the water color at the gauging station looked brown, and the sampling continued at 10 min intervals. When runoff became clearer, the sampling interval was extended to thirty minutes, and sampling continued until the runoff was visibly sediment-free. The collected water samples were filtered using filter paper, air dried until it was transported to Adet Research Centre for oven drying and weighing (Bosshart, 1996).

6.2. Annual and monthly suspended sediment rates

Table 15 and Figure 27 show the annual mean suspended sediment yield for the period 1984-2014. The annual average soil loss is about 2652 ton. This is equivalent to 23.4 t/ha with coefficient of variation of 56.6%. According to Hurni (1983), the maximum tolerable soil loss for Wet Weyna Dega agro-ecology zone is 16 t/h/yr and 10 t/ha/yr for Wet Dega agro-ecology zones.

The annual sediment load varied between 5.9 t/ha and 61.5 t/ha. The highest sediment yield was recorded in 1985 which is 6979 t (61.5 t/ha). In 1988 and 1989, sediment concentration was low compared to other years. This may be explained by the fact that the soil conservation work was completed in 1986. For the following years (1987-89), the structures were still effective in trapping the soil hence reduced soil loss. In 1990 and 1991, the maintenance of these structures might have not been effectively made due to the war. Afterwards, though there is a modest decline in the annual soil loss, it has not been possible to bring to where it was in 1988 and 1989. The probable reasons for higher soil loss than where it was 1988 and 1989 may be the following: (1) trenches in the farmland might have been filled-up and no maintenance has been made; and (2) there might have been growing number and size of gullies, particularly the one upstream in the Minchet headwater, which might have contributed to the total annual soil loss.

The mean monthly suspended sediment yield is shown in Figure 28 and Table 15. During the main rain season, average monthly sediment concentration was highest in June; then; it decrease with time. There is no suspended sediment concentration in January, February, November and December since rains are either scarce or antecedent soil moisture conditions are low. June to September contributes about 75% of the mean annual loss.

Figure 27. Annual suspended sediment yield for the period 1985-2014

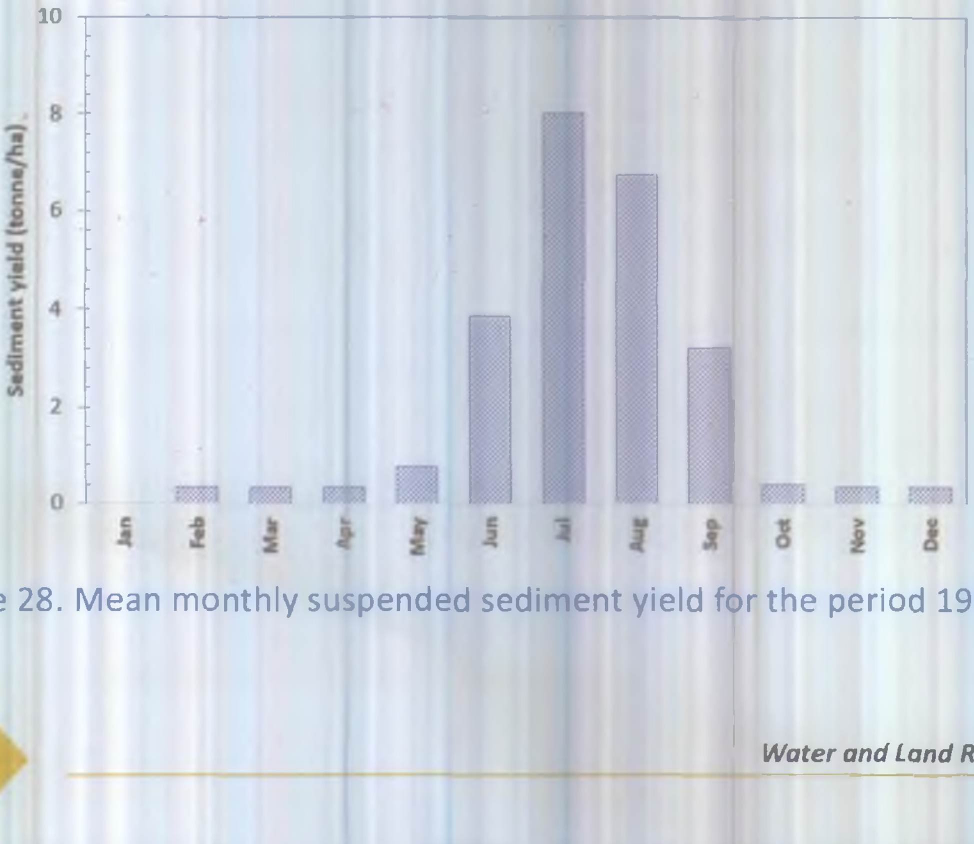


Figure 28. Mean monthly suspended sediment yield for the period 1984-2014

Table 15. Monthly and annual suspended sediment (tonnes) rates (1984- 2014)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
1984.0	nd	nd	nd	nd	nd	944.5	1682.9	487.3	425.5	0.0	0.0		id
1985.0	0.0	0.0	0.0	15.0	61.2	515.0	2036.8	3317.1	966.3	68.5	0.0	0.0	6979.9
1986.0	0.0	0.0	0.0	0.0	289.8	540.2	605.5	726.2	319.1	187.2	1.2	0.0	2669.2
1987.0	0.0	0.0	0.0	17.9	72.7	425.9	566.9	693.1	78.9	13.0	0.0	0.0	1868.4
1988.0	0.0	0.0	0.0	0.0	0.0	63.6	273.5	186.5	88.1	105.1	0.0	0.0	716.9
1989.0	0.0	0.0	0.0	0.0	0.0	2.4	337.2	186.8	131.5	0.0	0.0	5.6	663.4
1990.0	0.0	0.0	0.0	0.0	52.2	72.6	1021.9	1947.5	642.2	0.0	0.0	0.0	3736.4
1991.0	0.0	0.0	0.0	0.0	3.5	0.0	1224.6	917.9	479.9	6.7	0.8	0.0	2633.4
1992.0	0.0	0.0	0.0	99.1	27.3	501.7	598.3	483.6	197.9	232.6	0.0	0.0	2140.4
1993.0	0.0	0.0	0.0	0.3	0.4	587.6	978.7	986.9	1028.5	77.7	0.0	0.0	3660.1
1994.0	0.0	0.0	0.0	0.0	16.3	793.8	834.9	665.2	273.9	0.0	1.9	0.0	2586.0
1995.0	0.0	0.0	0.0	12.1	50.9	986.0	758.4	598.6	576.0	0.0	0.0	0.0	2982.0
1996.0	0.0	0.0	413.9	57.5	314.0	473.2	1200.1	486.8	165.5	20.7	0.0	0.0	3131.7
1997.0	0.0	0.0	0.0	0.0	85.1	325.5	554.1	265.0	325.3	29.1	5.9	0.0	1590.0
1998.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2000.0	0.0	0.0	0.0	0.0	0.0	886.1	910.1	544.1	198.7	0.0	0.0	0.0	2539.0
2012.0	0.0	0.0	0.0	0.0	0.0	141.4	1421.6	243.5	215.7	0.2	0.0	0.0	2023.0
2013.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2014.0	0.0	11.1	31.9	1.5	388.2	192.5	437.4	289.1	122.6	23.0	0.0	0.0	1497.3
Mean	0.0	0.7	27.9	12.7	85.1	438.4	908.4	766.2	366.8	44.9	0.6	0.4	2652.0
t/ha	0.0	0.0	0.2	0.1	0.8	3.9	8.0	6.8	3.2	0.4	0.0	0.0	23.4
Std.	0.0	0.0	110.6	29.0	102.8	335.6	482.8	808.9	298.6	73.6	1.6	1.5	1502.1
CV (%)	0.0	0.0	397.0	227.8	120.9	76.5	53.1	105.6	81.4	163.8	270.7	427.6	56.6
Max	0.0	0.0	413.9	99.1	314.0	986.0	2036.8	3317.1	1028.5	232.6	5.9	5.6	6979.9
Min	0.0	0.0	0.0	0.0	0.0	0.0	273.5	186.5	78.9	0.0	0.0	0.0	663.4
SC[I]	0.0	0.0	0.1	0.1	0.4	2.0	4.1	3.5	1.7	0.2	0.0	0.0	
%	0.0	0.0	1.1	0.5	3.2	16.5	34.3	28.9	13.8	1.7	0.0	0.0	
q[II]	0.0	0.0	0.2	0.1	0.8	3.9	8.0	6.8	3.2	0.4	0.0	0.0	23.4

[I] - SC - Sediment concentration (g/l)

[II] - q – sediment yield (t/ha)

7. Rainfall, Runoff, Suspended Sediment and Erosivity Relations

7.1. Drainage ratio, rainfall and runoff relations

Figure 29 shows the long term rainfall, runoff and drainage ratio relations. Drainage ratio, i.e. the ratio of runoff to rainfall, is not only dependent on the amount of runoff but it is also significantly affected by the rainfall pattern which intern affects the antecedent soil moisture condition and the land practices. Though there have been significant changes in the landscape as a result of the soil and water conservation structures, the drainage ratio reduction did not show a significant change. The fundamental reason why flow did not show a substantive reduction as a result of the soil conservation work may be attributed to the fact that much of the runoff occurs in July and August. During this periode temperature is low, and air is humid high; hence, potential evapotranspiration is low and antecedent soil moisture conditions are wet during much of the rainy season is very low at Anjeni. Hence, whatever is retained is lost through deep percolation recharging the groundwater. The groundwater later leaves the watershed as base flow. This might be attributed to subsequent improvement in the base flow as a result of the soil and water conservation efforts. Figure 29 and Table 16 do not show a substantive reduction in the runoff coefficient as a result of the soil conservation structures.

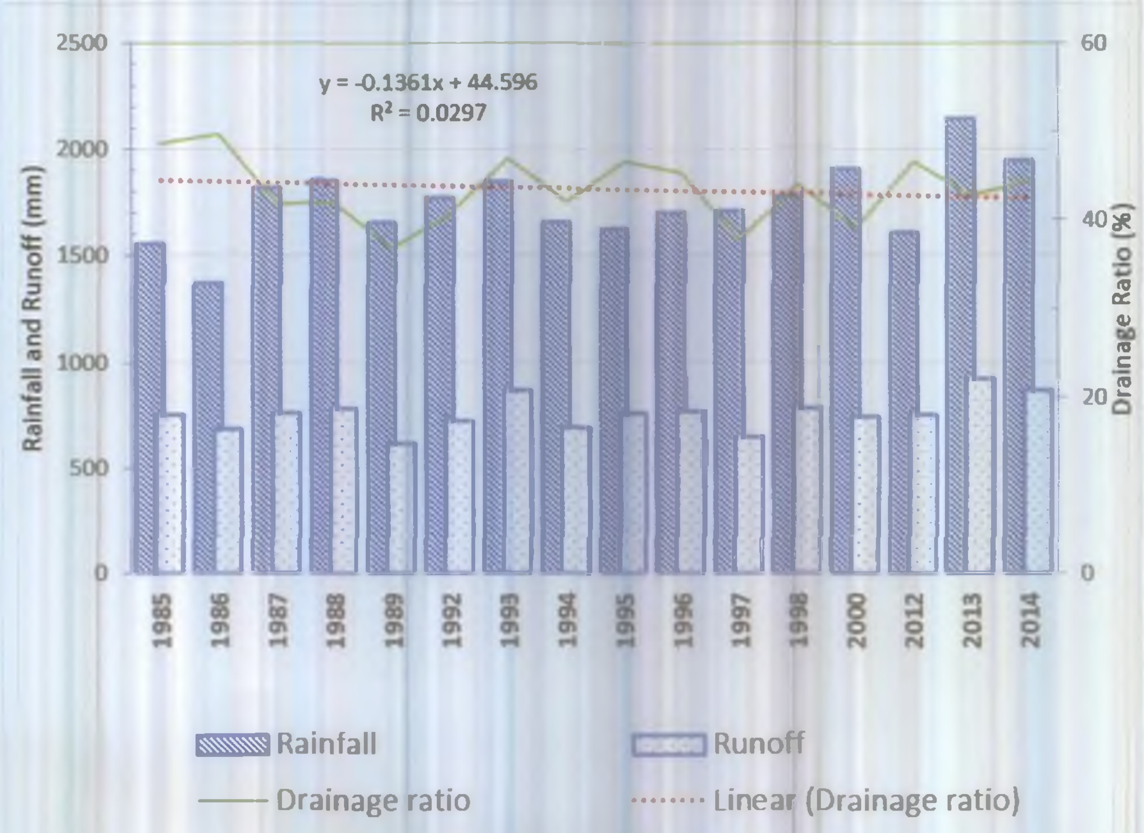


Figure 29. Long term annual rainfall, runoff and drainage ratio relationships

The mean monthly rainfall, runoff and drainage ratio relationships are shown in Figure 30. The fact that there are little rains during the dry season while base-flow continues explains why the drainage ratio during the dry season is high. During the Kiremt season, drainage ratio is highest; during July (44.6%), August (58.6%) and September (56.8%) but it is low during May and June. This may be explained by (1) the frequency of rainfall events (rainfall pattern) and drier antecedent soil moisture condition; (2) land surface roughness after ploughing, and (3) the high atmospheric evapotranspiration demand during May and June.

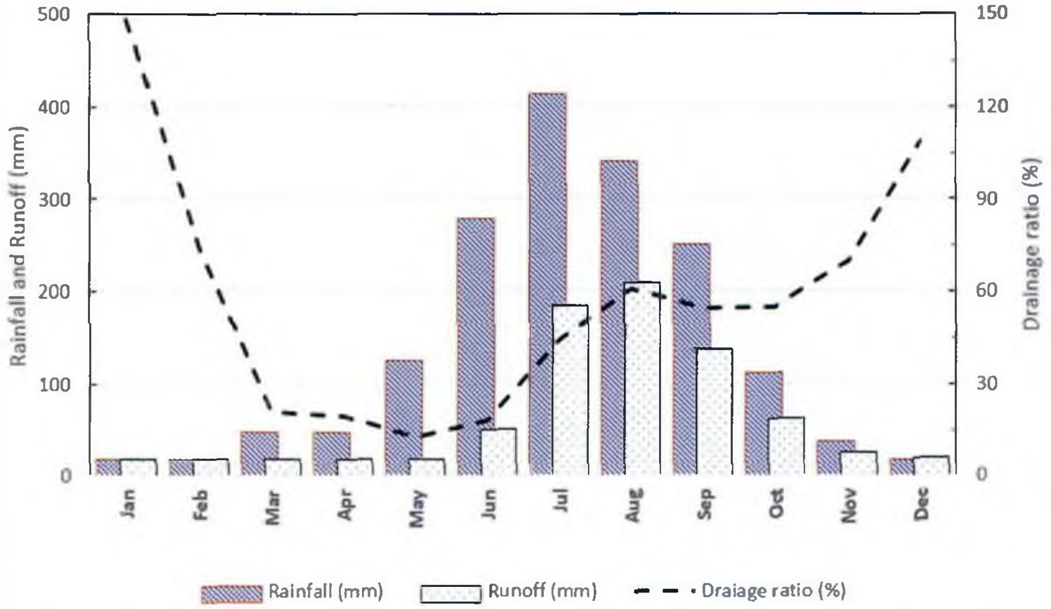


Figure 30. Long term mean monthly rainfall, runoff and drainage ratio relations

Table 16. Long term annual rainfall, runoff and suspended sediment relations

	Climatic Data			River station data			Suspended Sediment		
	Precipitation		Erosivity	Runoff			Suspended sediment		
	Pluivometric	Rain gauges		Volume	Depth	Drainage	Rate	Yield	Concentration
	mm	mm	(J/mh)	(m3)	mm	(%)	(tonne)	(t/ha)	(g/l)
1984	id	nd	id	id	id	id	3540.2	31.2	id
1985	1556.2	id	522.1	856278	755.1	48.5	6979.9	61.6	8.2
1986	1370.7	1557.1	393.9	773368	682.0	49.8	2669.2	23.5	3.5
1987	1811.4	1975.3	731.2	857791	756.4	41.8	1868.4	16.5	2.2
1988	1853.5	id	675.2	883431	779.0	42.0	716.9	6.3	0.8
1989	1654.1	1835.6	531.2	692539	610.7	36.9	663.4	5.9	1.0
1990	id	1855.9	874.3	851005	750.4	49.3	3736.4	33.0	4.4
1991	id	1703.4	509.8	745400	657.3	56.7	2633.4	23.2	3.5
1992	1768.3	1775.4	696.9	817317	720.7	40.8	2140.4	18.9	2.6
1993	1847.6	1583.8	612.2	983139	867.0	46.9	3660.1	32.3	3.7
1994	1651.9	1803.9	710.3	786475	693.5	42.0	2586.0	22.8	3.3
1995	1623.6	1909.0	616.2	858143	756.7	46.6	2981.9	26.3	3.5
1996	1696.9	2054.6	513.7	869969	767.2	45.2	3131.6	27.6	3.6
1997	1708.2	1887.3	434.4	730280	644.0	37.7	2152.1	14.0	2.9
1998	1772.9	2012.3	530.0	886011	781.3	44.1	nd	nd	nd
1999	id	1904.7	id	nd	nd	nd	nd	nd	nd
2000	1907.1	2020.3	745.8	844074	744.3	39.0	2539.0	22.4	3.0
2001	id	1873.6	id	nd	nd	nd	nd	nd	nd
2002	id	1899.2	566.9	nd	nd	nd	nd	nd	nd
2003	1739.3	1899.2	789.5	nd	nd	nd	nd	nd	nd
2004	1747.2	1728.3	719.3	nd	nd	nd	nd	nd	nd
2005	nd	1,832.2	nd	nd	nd	nd	nd	nd	nd
2006	nd	1,922.5	nd	nd	nd	nd	nd	nd	nd
2007	nd	1,355.7	nd	nd	nd	nd	nd	nd	nd
2008	id	id	id	nd	nd	nd	nd	nd	nd
2009	1687.0	1,489.4	592.7	nd	nd	nd	nd	nd	nd
2010	id	1,631.8	351.9	nd	nd	nd	nd	nd	nd
2011	id	1,663.9	640.4	nd	nd	nd	nd	nd	nd
2012	1608.2	1377.7	623.6	850659	750.1	46.6	2022.0	17.8	2
2013	2145.6	2114.6	902.5	1041090	918.1	42.8	nd	nd	nd
2014	1946.5	1991.1	842.2	978460	862.8	44.3	1497.3	13.2	2
Mean	1741.9	1802.1	630.3	850302	749.8	44.5	2677.5	23.3	3
Std	165	200	145	89048	78.5	4.9	1427.7	12.8	2
CV(%)	9.5	11.1	23.1	10.5	10.5	10.9	53.3	54.8	53.6
Max.	2145.6	2,114.6	902.5	1,041,090.0	918.1	56.7	6,979.9	61.6	8.2
Min.	1,370.7	1,355.7	351.9	692,539.0	610.7	36.9	663.4	5.9	0.8

7.2. Rainfall –runoff and suspended sediment relations

The long term rainfall - runoff –suspended sediment relations are also shown in Table 16 and Figure 31. Despite a steady river discharge, the suspended sediment load in the river is highly variable. The soil loss values were very high before and immediately after the construction of soil conservation structures. The sediment yield is relatively steady lately but the values are higher than the tolerable limit (Hurni, 1983).

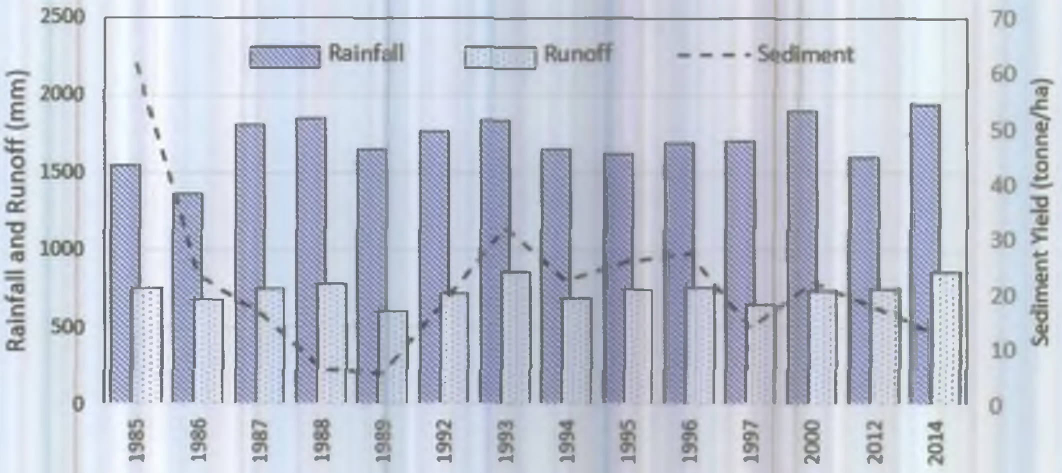


Figure 31. Annual rainfall, catchment runoff and suspended sediment yield for the period 1985 to 2014

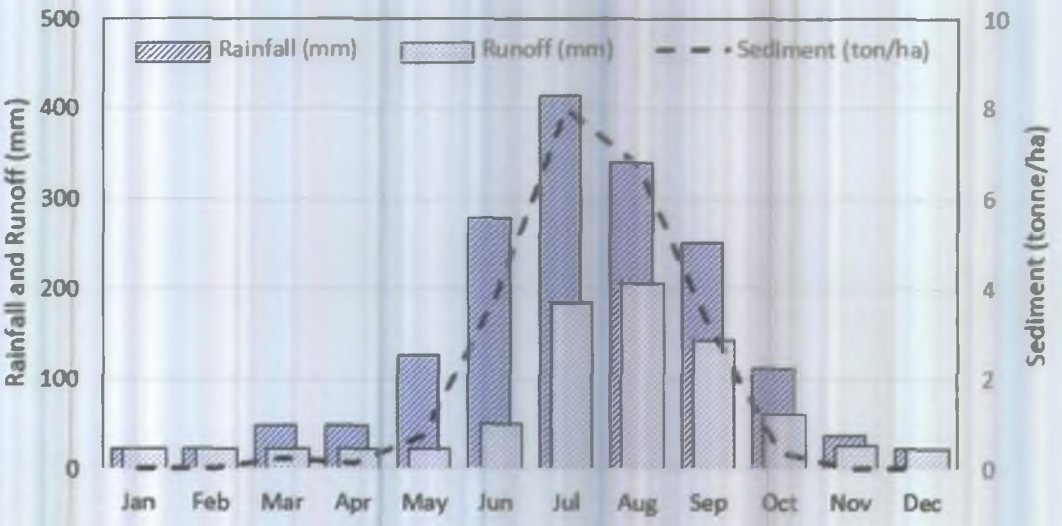


Figure 32. Mean monthly rainfall, catchment runoff and suspended sediment yield for the period 1985-2014

Table 17. Monthly rainfall, catchment runoff and suspended sediment yield reltionships (1985-2014.

	Climatic data		River Station Data						
	Rainfall	Erosivity	Runoff			Drainage ratio	Suspended sediment		
	(mm)	(J/m h.)	(l/sec)	(m³)	(mm)	(%)	Rate (tonne)	Yield (tonne/ha)	Concentration. (g/l)
Jan	9.6	4.3	5.9	16069	14.2	149.3	0	0.0	0.0
Feb	13.1	2.4	4.5	11025	9.7	80.2	0.7	0.0	0.1
Mar	48.1	12.6	4.2	11362	10	22.1	27.8	0.2	2.4
Apr	47.5	9.3	4.1	10477	9.2	21	12.7	0.1	1.2
May	126.0	41.6	6.7	18035	15.9	13.6	85.1	0.8	4.7
Jun	279.4	109.5	22.5	57588	50.8	18.2	438.4	3.9	7.6
Jul	414.5	170.9	77.5	209565	184.8	44.6	908.4	8.0	4.3
Aug	341.9	130.4	87.1	235504	207.7	58.6	766.2	6.8	3.3
Sep	252.2	87.3	63.4	162516	143.3	56.8	366.8	3.2	2.3
Oct	112.6	42.4	25.9	70000	61.7	54.8	44.9	0.4	0.6
Nov	37.6	6.5	11.8	30184	26.6	70.8	0.6	0.0	0.0
Dec	17.6	1.4	8.1	21903	19.3	101.4	0.4	0	0.0

The rainfall, runoff and suspended sediment yield for three typical years, 1985 before the construction of the Fanya juu, 1994 and 2012 with the latest data presented in Figure 34. The 1985 rainfall, runoff, and sediment yield values were 1156.2 mm, 755.1 mm, and 6979.9 ton respectively. In 1994, the corresponding values were 1651.9 mm, 693.5 mm, and 2585.9 ton. And in 2012, the values were 1608.2 mm, 750.1 mm, and 2022.5 ton respectively. The figures clearly demonstrate the impact of the soil and water conservation work on the amount of sediment loss. The months when the peak sediment loss occurs seems to shift from August (in 1985), to June and July (in 2012). This requires detail investigation on the source of sediment (farmland, communal grazing land, or gullies/wasteland) in different seasons along with the crop cover in the specific years.

7.3. Daily rainfall, runoff and sediment yield relations

The long term mean daily rainfall and runoff and soil loss relations together with the respective 10 year moving average is shown in Figure 33. Unlike both rainfall and runoff which show the clear seasonality, the sediment loss tends to have two peaks during the rainy season. This may have to be explained in relation to the farming practice in the watershed.

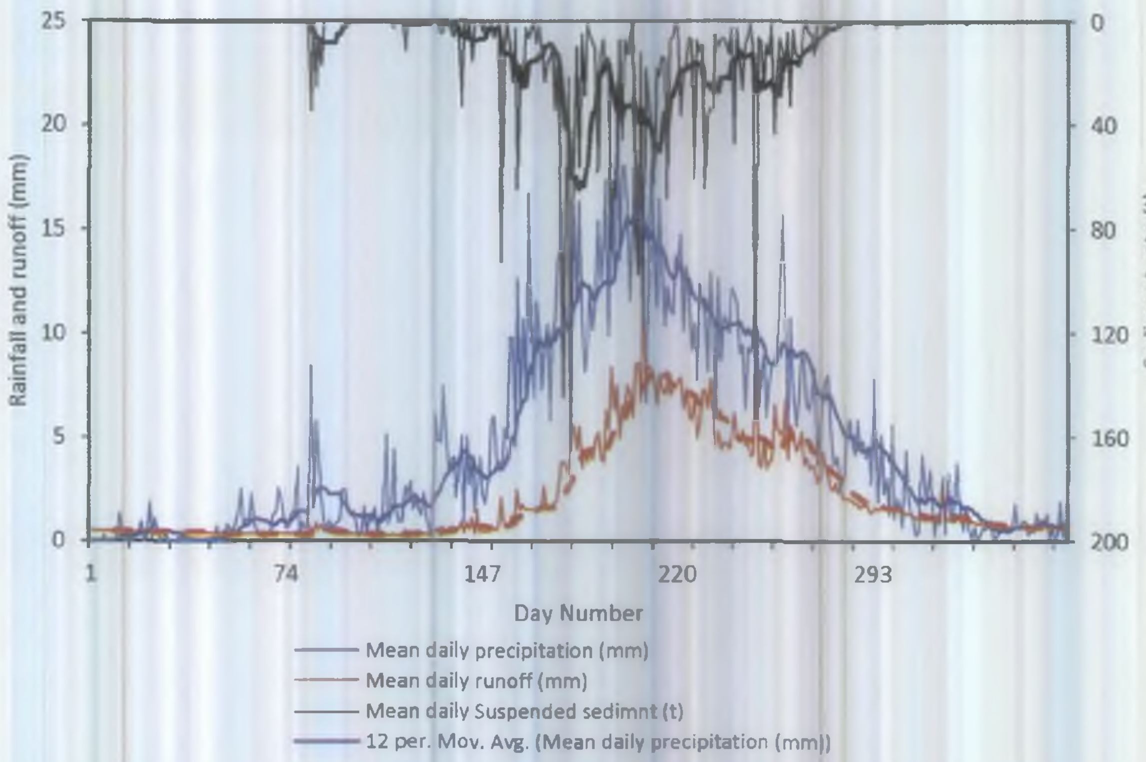


Figure 33. Mean daily rainfall, runoff, suspended sediment relationship

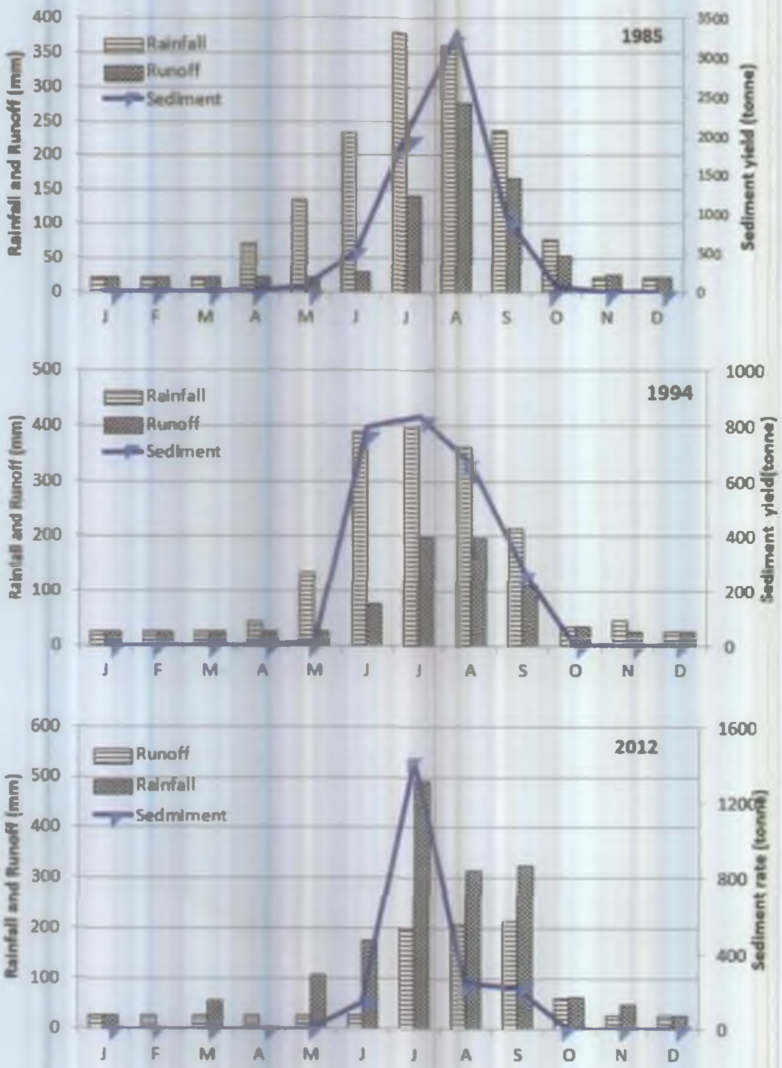
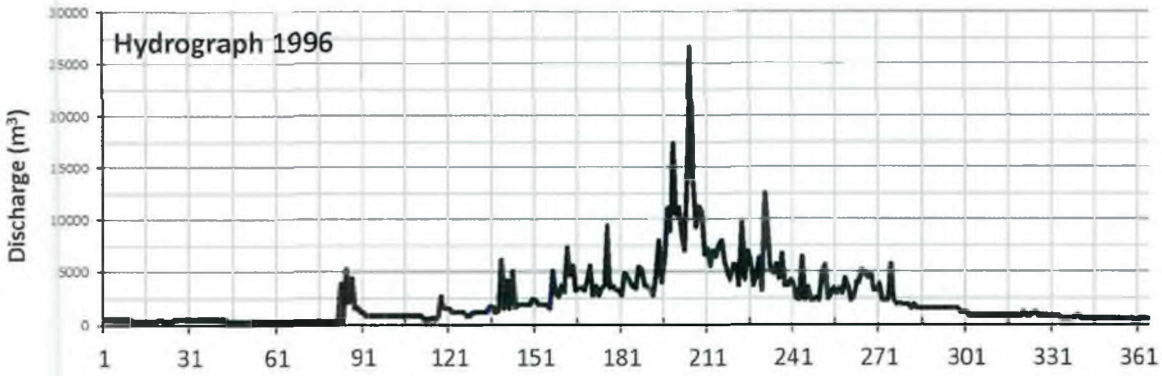
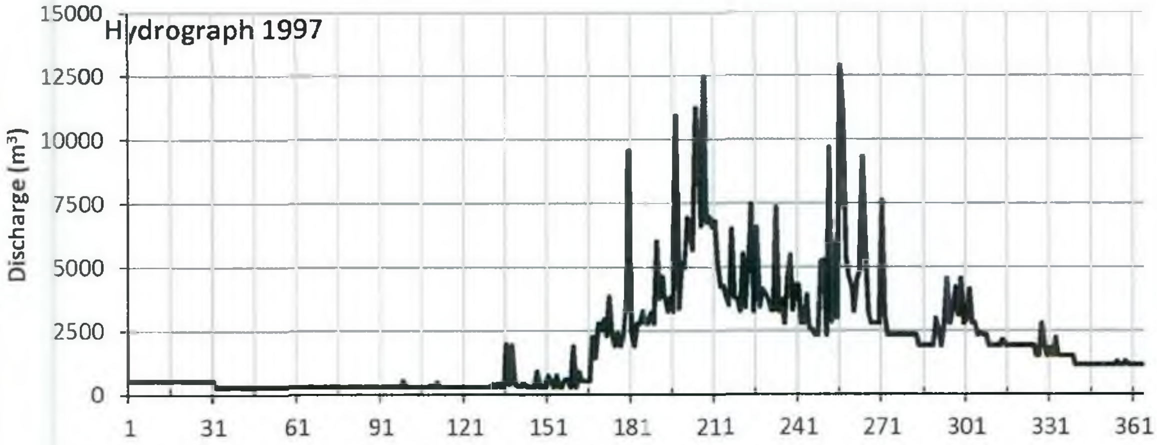
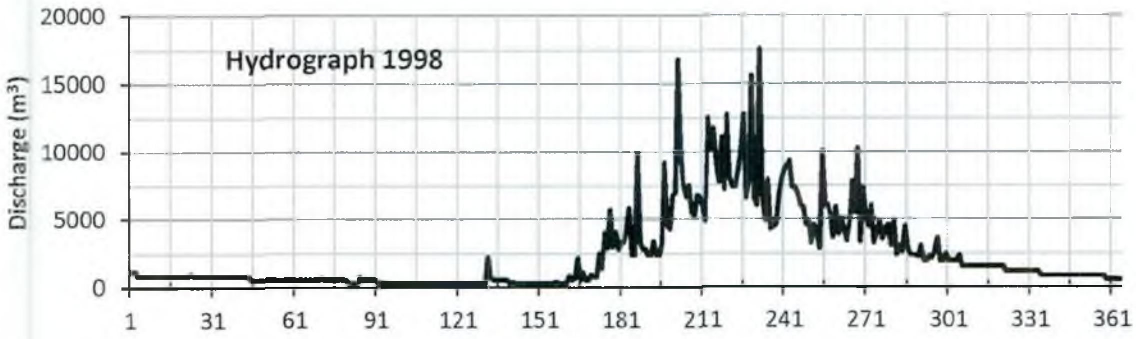


Figure 34. Selected years rainfall, runoff and suspended sediment yield relations

Figure 35 shows the variability of daily runoff of Minchit river at the gauging station for selected years from 1995 to 2014. The peak discahrge ever recorded was 26, 589 m3, i.e. 7.3 m3/sec, which is (6.4 m3/s/km2), and it occurred on July 23,1996.







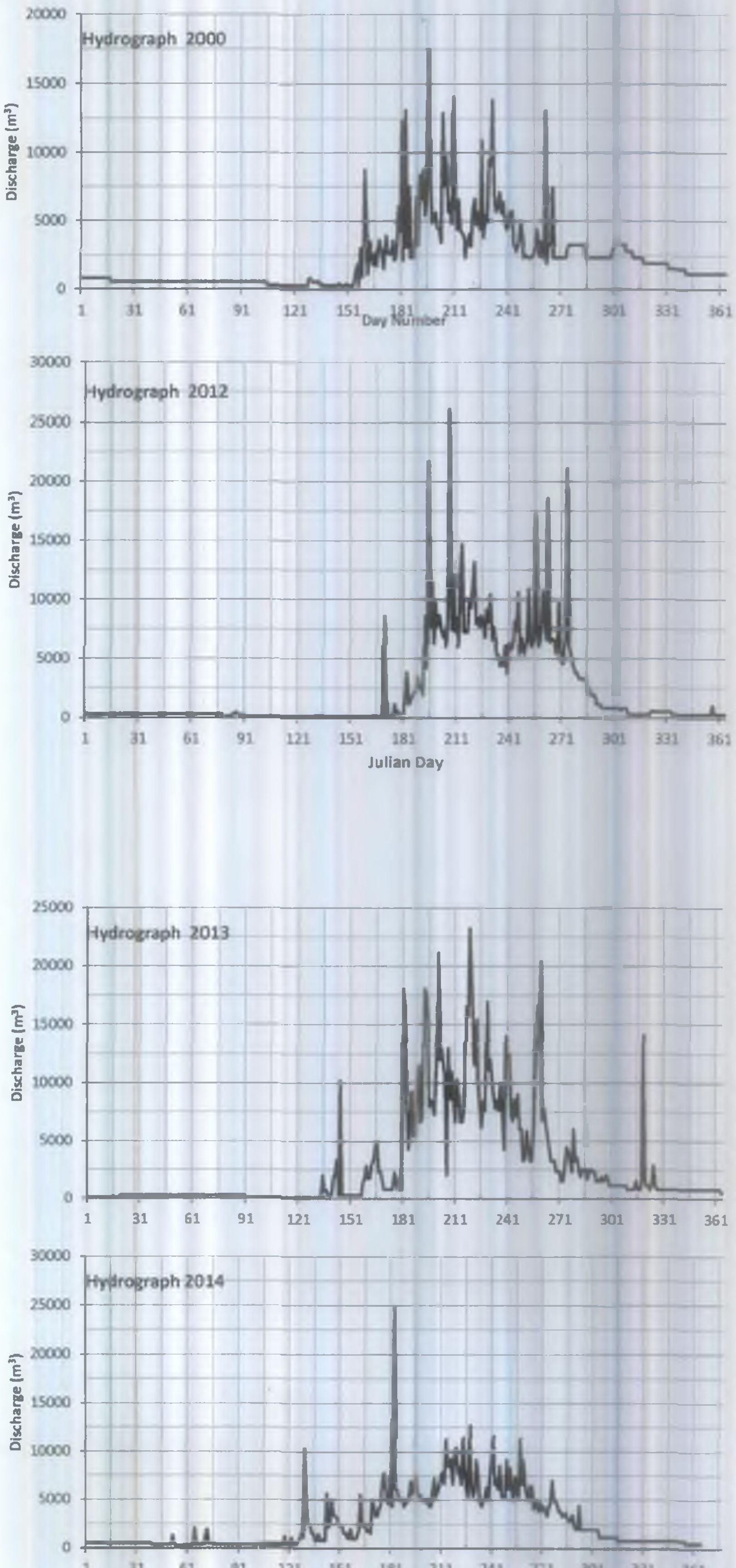
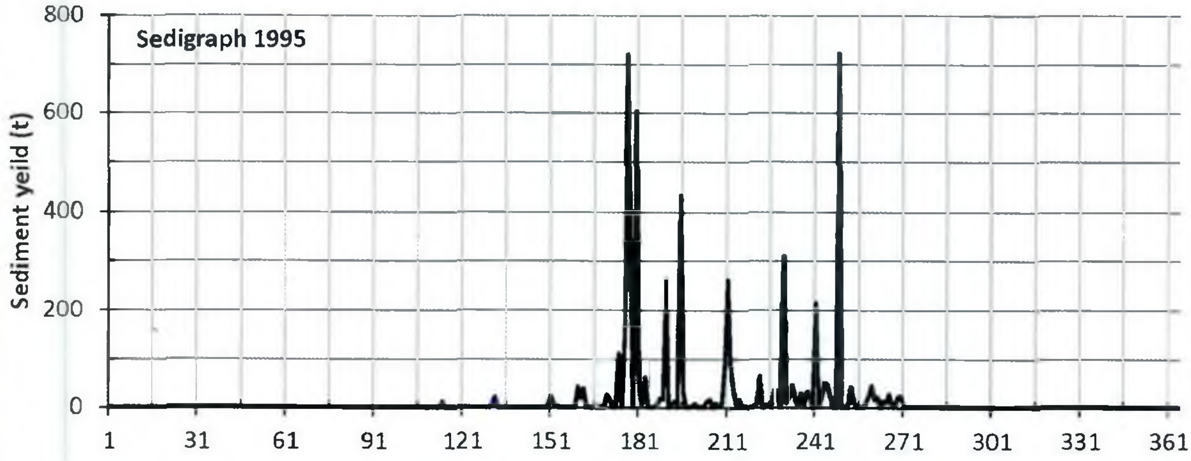
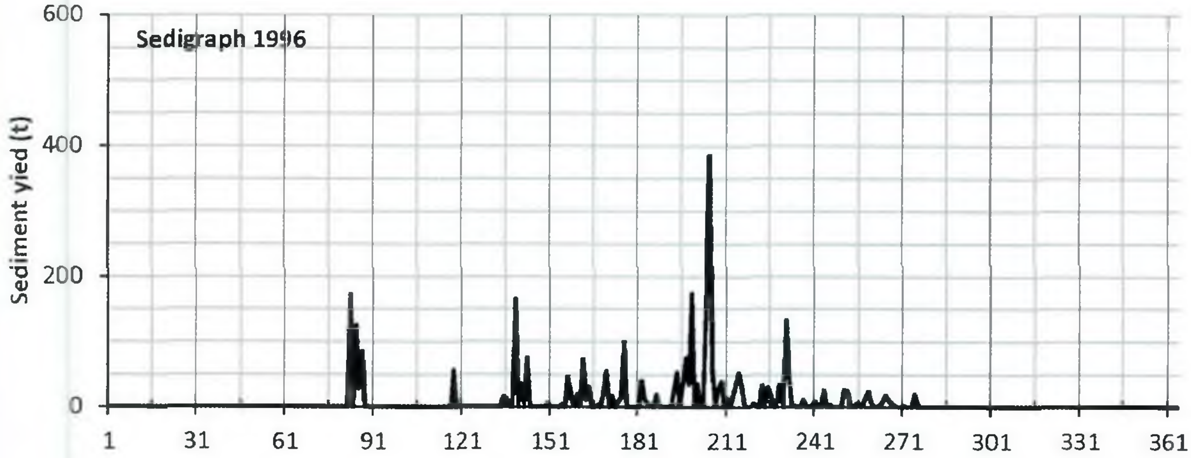
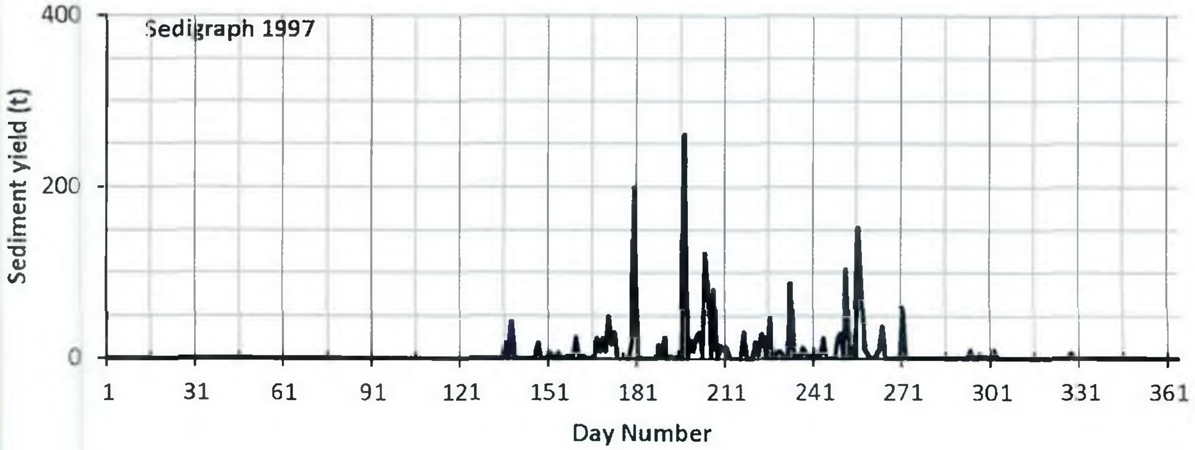


Figure 35. Daily runoff variability of Minchet for selected years

Suspended sediment variability for selected years is shown in Figure 36. The highest one-day suspended sediment rate was 722.51 t (6.4 t/ha) that was recorded on September 6, 1995. The fugures show how the few torential rains are resposble in causing soil loss from the catchment. The figures clearly show that there are few rainfall events causing a significant amount of soil loss.







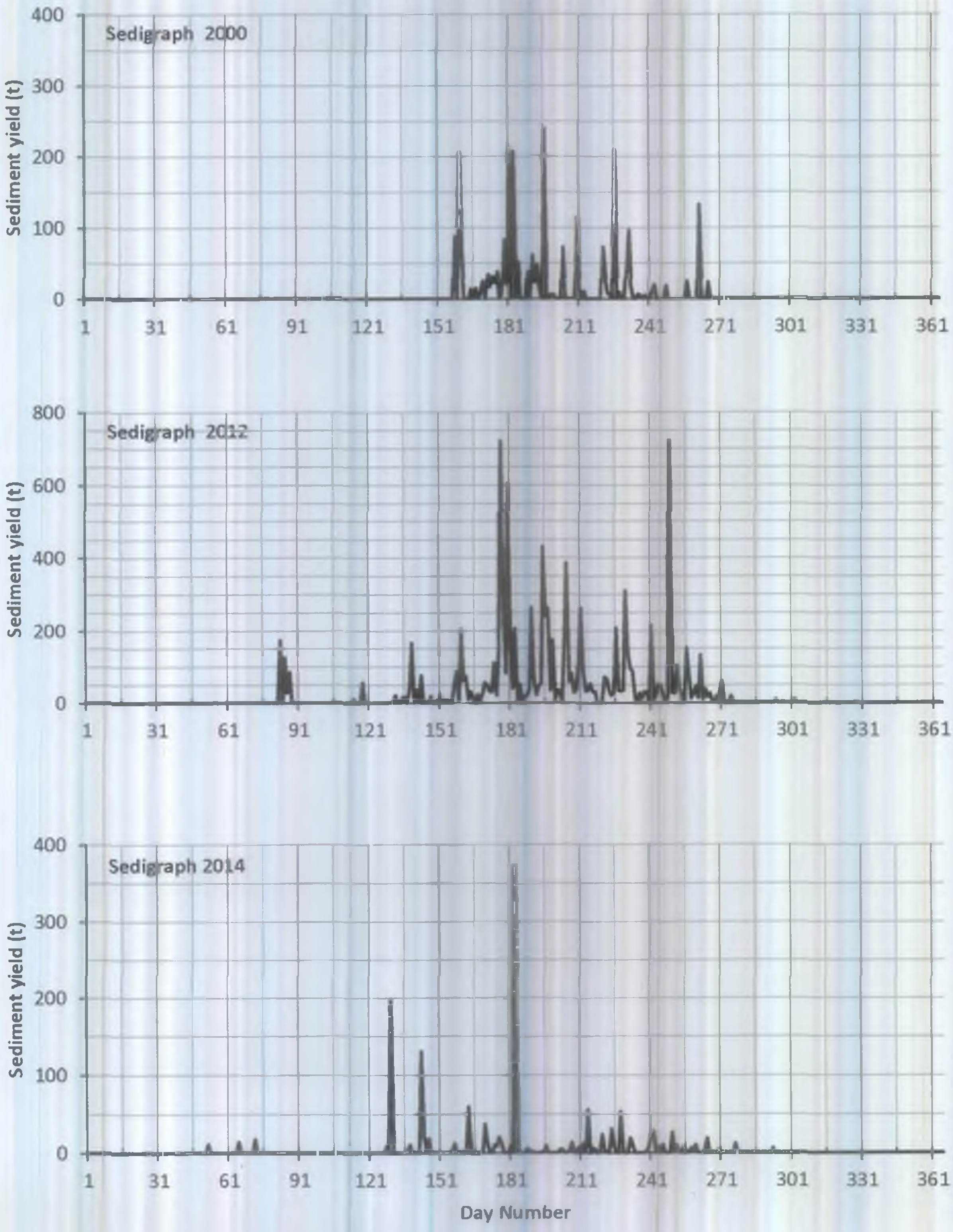


Figure 36. Daily suspended sediment load of Minchet for selected years

8. Climate Data from Automatic Weather Station

HOBO U30 _NRC fully digital weather station has been installed since May 2013. The set up makes reading at finer time resolutions possible. Moreover, the data collected can enable the use of FAO Modified Penman monteith equaiton to estimate potential evapotranpiration. The mean monthly data collected in 2014 is sumarized in Table 18. The variability in the daily values of temperature, relative humidity, solar radiation, wind speed ad rainfall are presented in Figure 38 to Figure 42.

Table 18. Mean monthly climate data for 2014 from automatic weather station

2014	Rainfall (mm)	Temprature (°C)			Relative Humidity RH(%)			Solar radation	Wind speed	ET_o
		Max	Min	Ave	Max	Min	Ave	(MJ/m²/day)	(km/day)	mm/day
Jan	23.6	24.6	6.6	15.5	88.6	30.8	59.9	19.1	79.7	3.4
Feb	40.8	25.5	6.9	16.4	77.0	25.8	48.1	21.6	48.5	3.56
Mar	138.2	24.9	10.4	17.1	87.6	38.2	63.5	21.7	84.2	3.69
Apr	76.1	24.5	10.8	17.2	92.2	43.7	69.2	20.1	81.6	4.19
May	257.0	22.6	11.4	16.3	98.0	61.4	83.6	18.1	52.0	3.43
Jun	247.6	21.4	10.9	15.6	98.5	64.8	85.8	15.7	55.8	2.96
Jul	256.2	19.6	11.6	14.5	99.9	79.2	93.7	12.1	42.3	2.47
Aug	295.1	19.3	10.2	13.8	100.0	77.7	94.6	12.8	40.8	2.40
Sep	213.0	20.3	9.8	14.2	100.0	74.2	92.8	14.4	43.2	2.96
Oct	109.6	21.7	10.1	15.0	99.9	63.5	87.6	17.7	42.3	3.32
Nov	15.9	23.6	7.2	14.6	99.3	46.3	78.0	19.5	61.0	3.25
Dec	2.3	23.4	4.3	13.3	95.8	32.6	67.9	20.2	28.5	2.91
Annual	1675.2	22.6	9.2	15.3	94.8	53.4	77.2	16.0	55.0	3.21

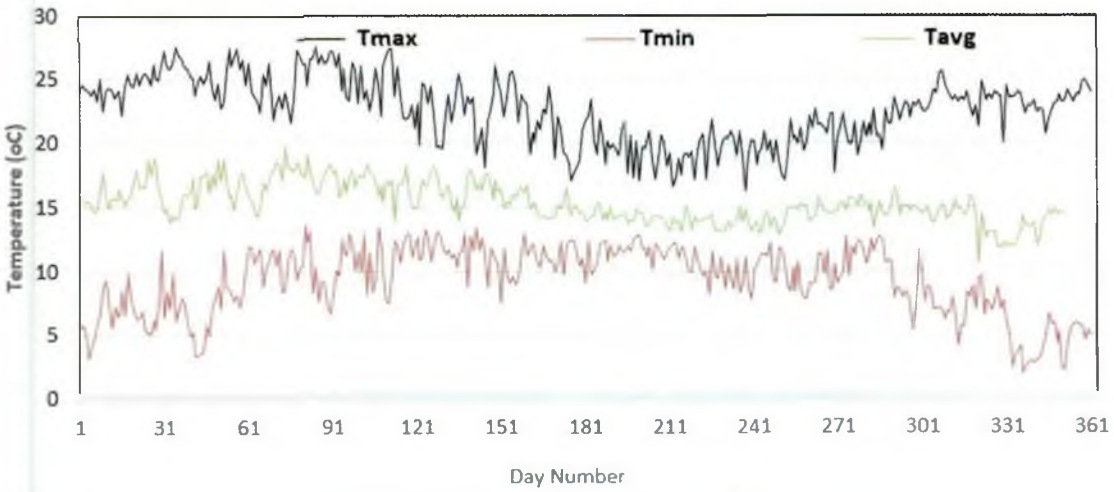


Figure 37. 2014 Daily temperature variability

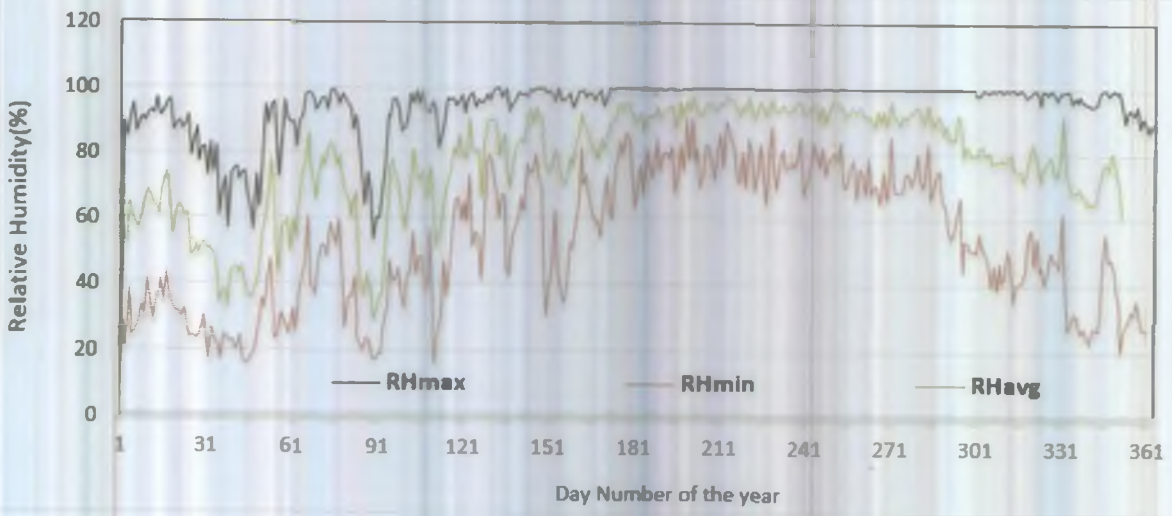


Figure 38. 2014 Daily relative humidity variability

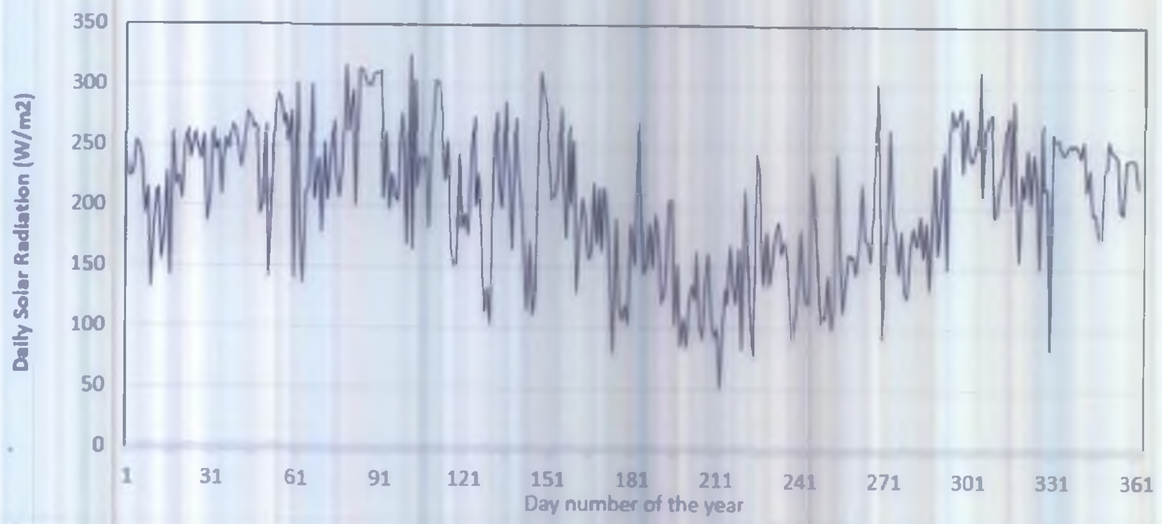


Figure 39. 2014 daily solar radiation variability

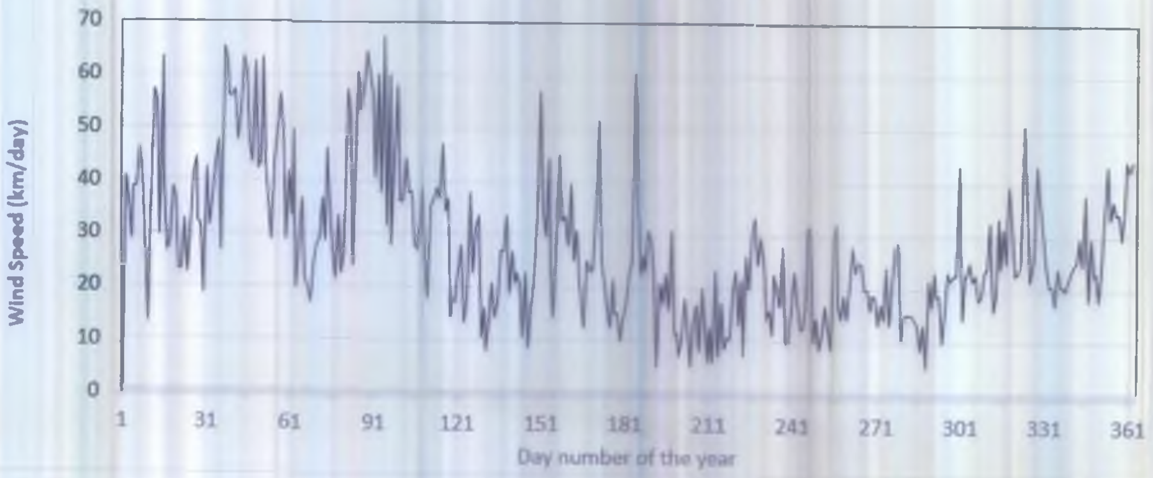


Figure 40. 2014 Daily average wind speed

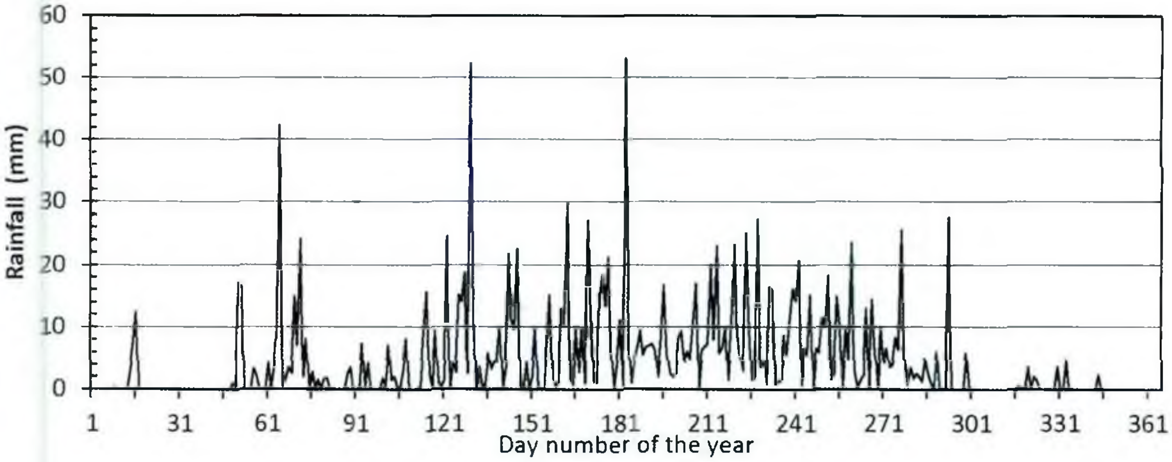


Figure 41. 2014 Average daily rainfall variability

The relation between rainfall measured using HOBO digital rain gague and recording rain gagues is shown in Figure 43. The figure clearly shows that there is about 14.4% differene in rainfall amount measured using the two methods. Until the digital rain gague is recaliberated once agin, one has to be catious in using the HOBO rainfall data.

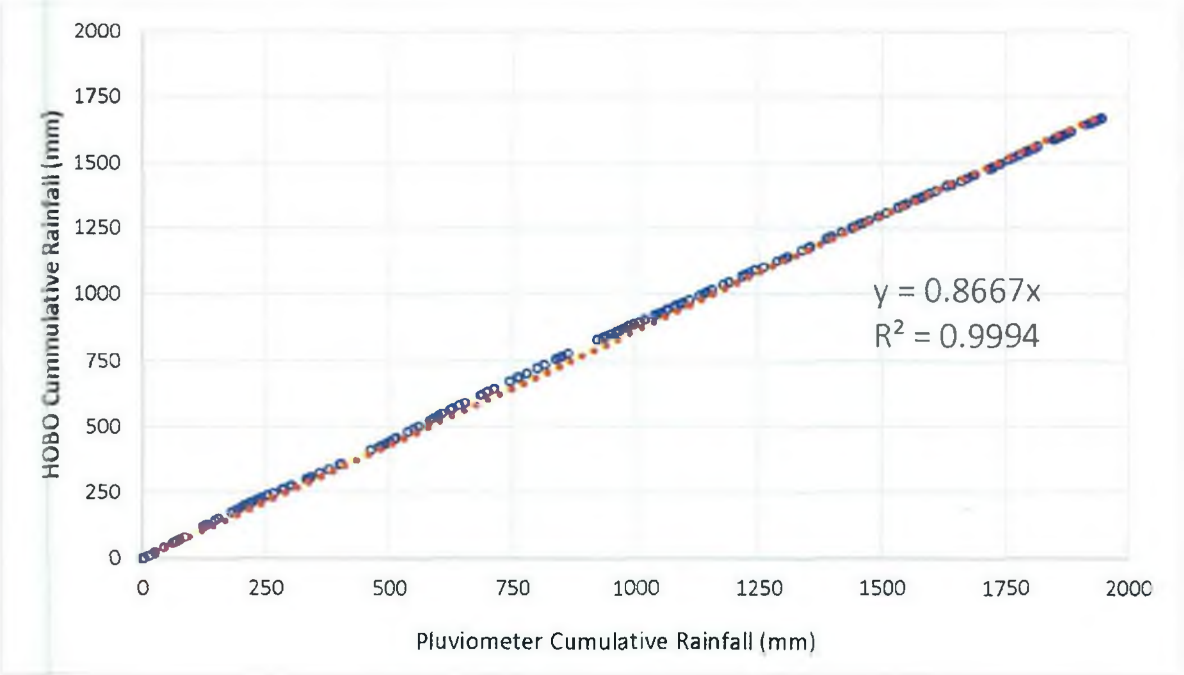


Figure 42. Relation in rainfall measured using pluviometer and HOBO raingauges

9. Runoff and Soil Loss Rates from Test Plots

Run-off and soil loss from four different land use-land cover, soil, and relief on 2 m wide by 15 m long Test Plots enclosed with corrugated iron sheet borders have been collected since 1985. The detail description of the setup is explained in Bosshart (1996). The major characteristics of each test plots and the long term mean runoff and soil loss rate are the following:

Test Plot 1 (TP1): The test plot has 28% slope; the soil is vertic Luvisol and plots are cultivated. The mean annual soil loss is 135.6 t/ha while the mean runoff was 718.6 mm resulting 42.2 runoff coefficient.

Test Plot 2 (TP2): The test plot slope is 12%; the soil is eutric Nitosol and the field is cultivated. The mean annual soil loss was 104 t/ha and mean annual runoff was 795.3 mm resulting with 46.7% runoff ratio.

Test Plot 3 (TP3): The test plot has 16% slope; The soil is eutric Regosol soil and land use is grassland. The mean annual sediment loss is 2.4 t/ha while the mean annual runoff was 495 mm resulting 29% runoff coefficient.

Test Plot 4 (TP4): The test plot slope is 22%; The soil is eutric Nitosol and field is cultivated. The mean annual soil loss was 89.8 t/ha while the mean annual runoff was 534.7 mm resulting 31.36% runoff ratio

One would expect for runoff coefficient to be high when the slope is steep. This was, however, not observed as seen in Figure 43 and Table 19. There are research reports arguing that this is due to the fact that the saturation excess is driving the runoff process in the watershed (Haenggi, 1997; Elias Sime Legesse, 2009; Easton et al., 2010 Guzman, et al., Tegenu, et al., 2012; Tilahun, et al., 2013). This is perhaps another research area that requires further investigation using additional instrumentation. (Yakob, 2009; Woubet, et al, 2013).

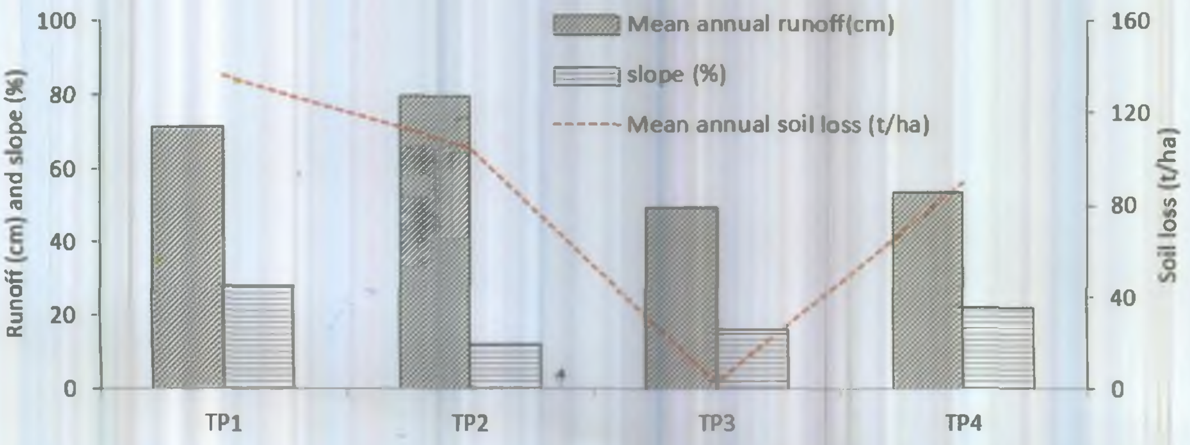


Figure 43. Long term mean plot level runoff, slope and sediment relations (1985-2012)

Table 19. Annual rainfall, erosivity, runoff & soil loss on Test Plots from 1985-2013

	Rainfall (mm)	Erosivity (J/ m.h.)	Test Plot 1		Test Plot 2		Test Plot 3		Test Plot 4	
			Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)
1985	1556	552.1	798.0	148.0	1159	187.5	758	11.9	734.4	263.2
1986	1372	393.9	646.0	182.9	595.8	66.4	571	11.4	502.1	159.4
1987	1811	731.2	863.1	202.5	857.9	176.6	579	12.8	535.5	166.0
1988	1855	675.2	728.0	191.0	718.3	38.2	563	0.9	535.6	69.3
1989	1648	531.2	595.2	102.7	518.1	41.7	306	0	357.8	41.3
1990	1668	874.3	736.6	175.1	1002	238.9	387	0.6	551.6	131.5
1992	1770	696.9	744.1	223.6	874.4	154.5	361	0.1	548.4	156.3
1993	1839	612.2	629.8	134.4	898.4	147.5	419	0	498.6	87.7
1995	1624	616.2	1109	225.0	808.2	245.2	439	0.6	768.4	166.2
1996	1697	513.7	598.8	114.6	633.5	57.2	480	1.4	621.2	67.4
1997	1708	434.4	526.8	109.2	860.3	167.2	469	0.6	527.2	21.9
1998	1773	530	451.4	39.6	443.9	42.4	376	0.5	355.7	1.9
2000	1866	745.8	917.0	101.3	965.4	61.2	635	0	701.9	23.2
2002	1573	566.9	583.7	15.0	948.7	28.6	751	0	381.3	3.7
2003	1656	789.5	678.9	nd	948.7	28.6	491	0	472.1	4.6
2004	1523	719.3	835.8	113.3	482.9	15.1	482	0	534.9	136.9
2012	1593	623.6	774	90.8	805.2	77.5	349	0	458.4	26.7
2013	2146	902.5	nd	nd	nd	nd	nd	nd	nd	nd
Mean	1704	639.38	718.6	135.6	795.3	104.4	495	2.4	534.4	89.8
SD	170	140	160	61.6	201	77.6	133	4.6	120	76.5
Max	2146	903	1109	225	1159	245	758	13	768	263
Min	1372	393.9	451.4	39.6	443.9	15.1	306	0	355.7	1.9
CV(%)	10	21.9	22.2	45.4	25.3	74.3	26.8	191.7	22.4	85.2

Test Plot data in 2013 has not been included in this repot because of collection barrel defects and data quality problems.

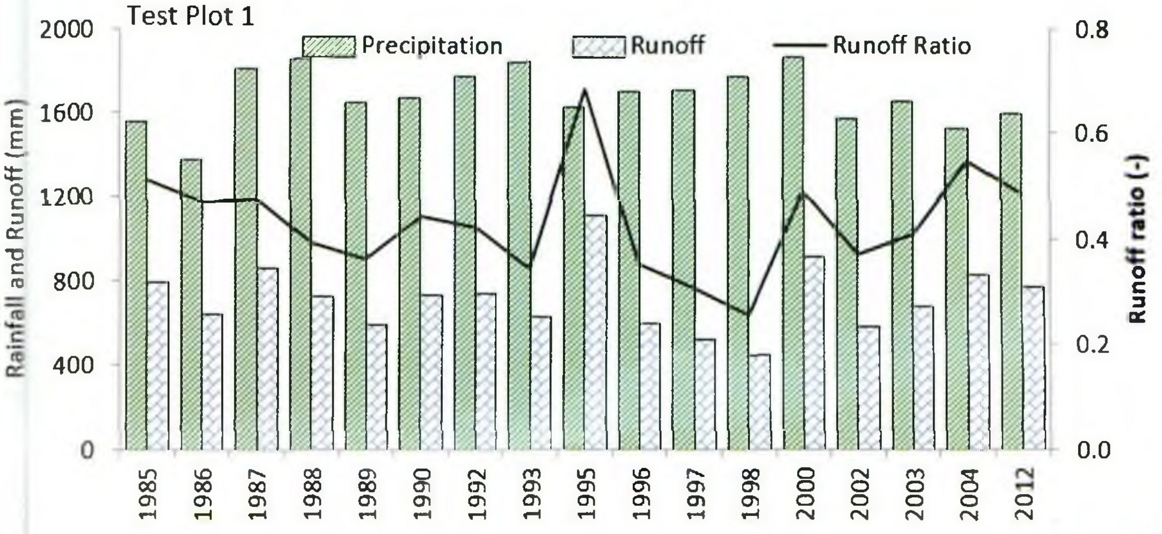


Figure 44. Annual rainfall, runoff and runoff ratio on Test Plot 1

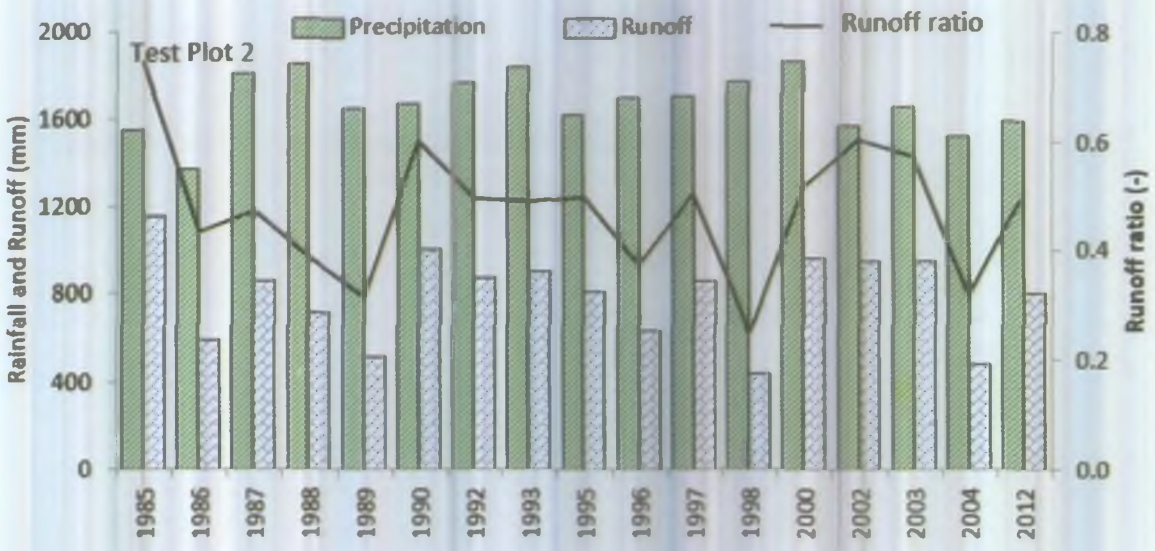


Figure 45. Annual rainfall, runoff and runoff ratio for Test Plot 2

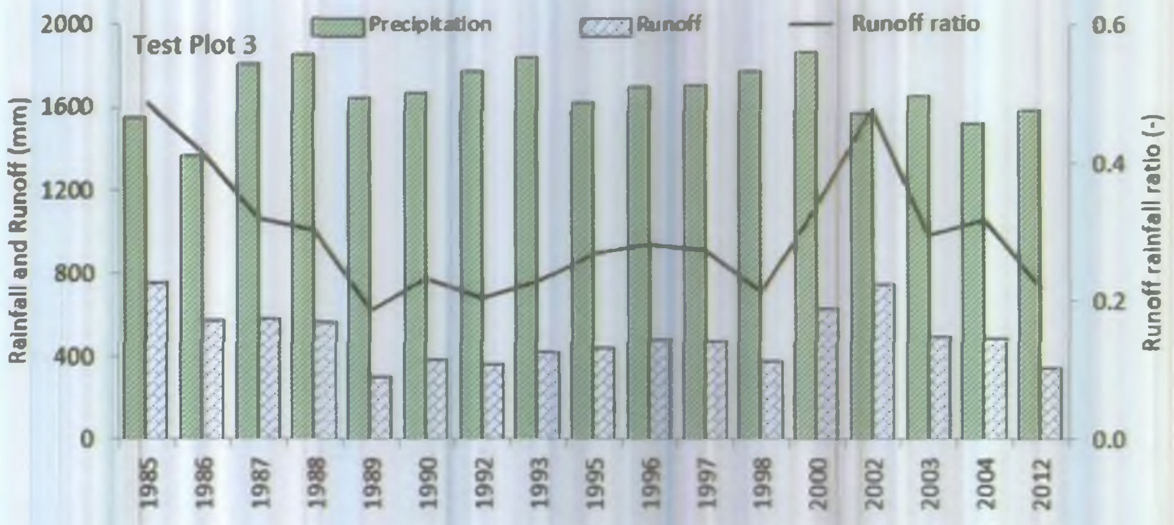


Figure 46. Annual rainfall, runoff and runoff ratio on Test Plot 3

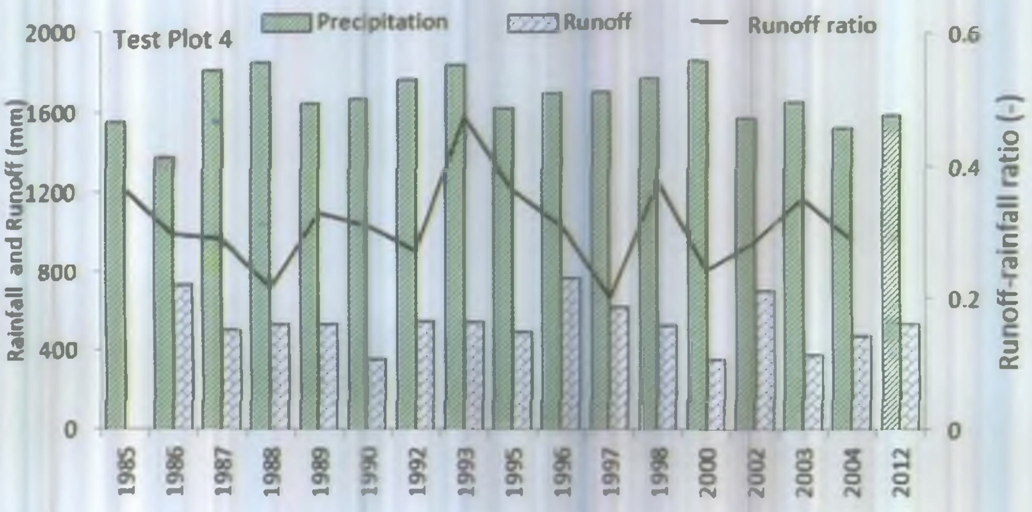


Figure 47. Annual rainfall, runoff and runoff ratio on Test Plot 4

The long term rainfall erosivity and annual soil loss relations are shown in Figure 49 and Table 19. As the land cover in each year is different, trend evaluation will be inappropriate unless the land use is considered as one variable. A closer scrutiny into the data is suggested to evaluate the impact of different land covers. This is suggested by taking into consideration the different land cover types for the specific year.

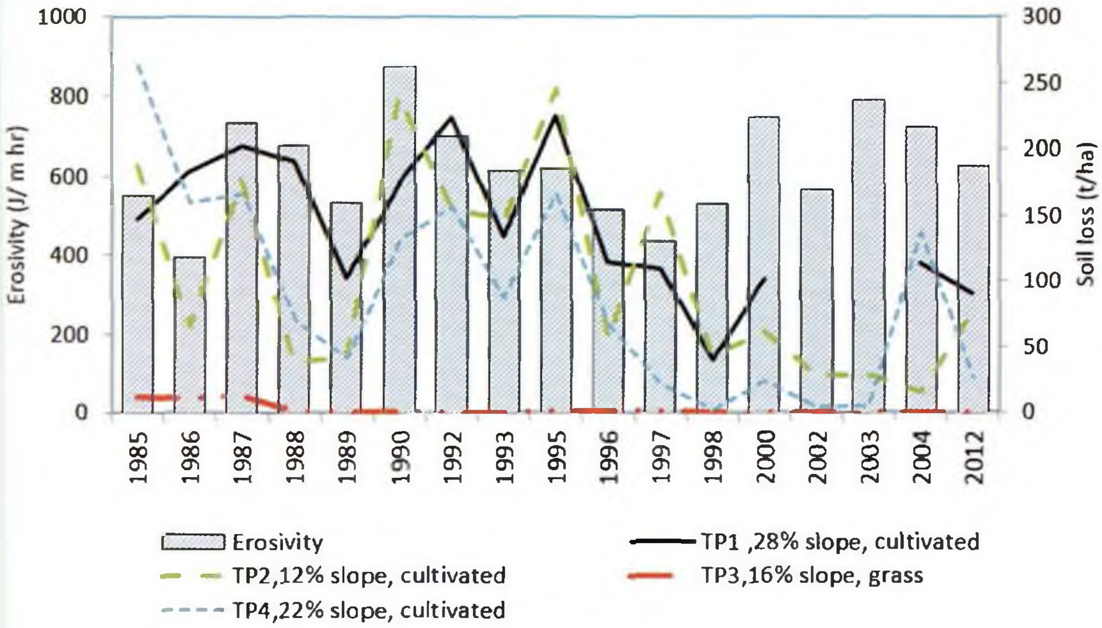


Figure 48. Test plots long term rainfall erosivity and annual soil loss relations

Table 20. Test plot characteristics, long term mean runoff coefficient

Test plot	Slope (%)	Mean annual runoff(cm)	Runoff coefficient (%)	Mean annual soil loss (t/ha)	Soil type	Land use type
TP1	28	71.9	42.9	135.6	Veric Luvisol	Cultivated
TP2	12	79.6	47.4	104.4	Eutric Nitsol	Cultivated
TP3	16	49.5	29.5	2.4	Eutric Regosol	Grass
TP4	22	53.4	31.9	89.8	Stony eutric Nitosol	Cultivated

7.3 Mean monthly rainfall, erosivity, runoff and soil loss from test plots

Table 21 shows the long term mean monthly rainfall amount, erosivity, runoff, and soil loss values. Figures 50 shows the mean monthly rainfall and runoff relations at test plot level.

Table 21. Mean Monthly rainfall, erosivity, and runoff and soil loss on test plots for the period 1985-2013

Month	Rainfall (mm)	Erosivity (J/ m hr	TP1, (Slope 28%)		TP2, (Slope 12%)		TP3, (Slope 16%)		TP4, (Slope 22%)	
			Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)
Jan	13.9	6.0	6.8	0.8	5.2	0.4	1.9	0.0	1.9	0.1
Feb	14.3	2.1	2.6	0.4	3.3	0.3	1.5	0.0	1.4	0.1
Mar	45.7	10.7	0.6	0.1	0.8	0.1	0.8	0.0	0.9	0.3
Apr	53.6	11.2	0.4	0.2	1.4	0.7	1.7	0.0	0.5	0.1
May	115.6	36.8	12.4	4.9	17.3	5.6	9.1	0.3	9.5	5.4
Jun	273.3	109.0	86.0	26.6	108.5	22.4	70.6	1.7	75.9	23.0
Jul	414.8	168.3	221.8	47.9	232.4	28.1	152.4	1.2	167.0	34.0
Aug	354.8	130.2	208.7	31.5	226.4	29.9	124.6	0.4	154.3	24.9
Sep	253.1	79.0	142.5	16.7	134.1	10.7	87.7	0.1	92.4	8.3
Oct	114.8	41.8	47.6	4.3	53.8	1.3	33.3	0.1	31.4	1.1
Nov	36.5	5.4	4.2	0.0	2.7	0.0	1.3	0.0	1.0	0.0
Dec	18.6	1.4	2.9	0.2	2.7	0.5	0.8	0.0	0.5	0.1

Establishing a linear relation between slope steepness and runoff and sediment may not be straight forward (Table 21, Figures 46). The runoff from Test plot 1 with a slope of 28% is lower than the runoff from Test plot 2 with a slope of 12%. On the other hand, sediment yield tends to follow the same relationship.

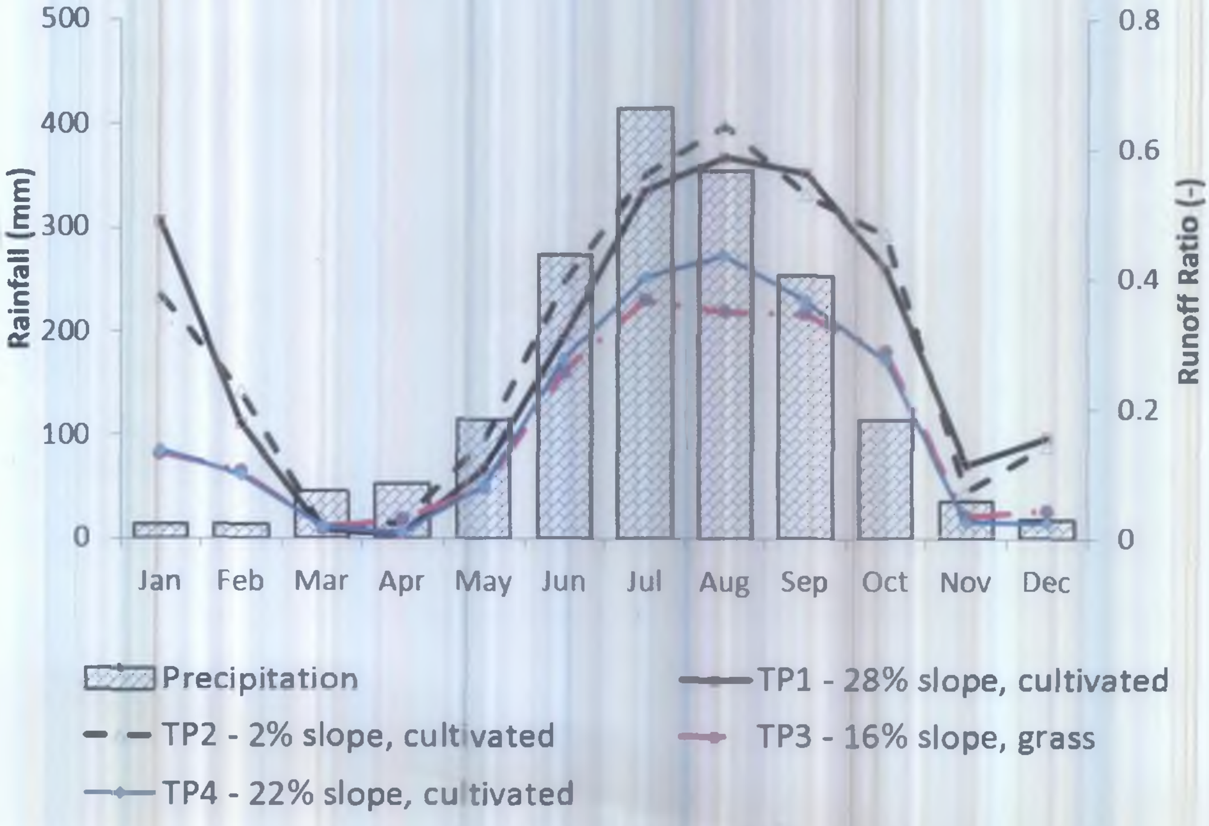


Figure 49. Test Plots mean (1985-2012) monthly rainfall and runoff ratio relationships

10. Final Remarks and Recommendation on the Way forward

The objectives of establishing and maintaining Anjeni and other observatories have been (1) to generate primary data on agro-climate, hydrology, hydro-sedimentology at watershed level; (2) to evaluate the impact of soil conservation works on the hydrology and hydro-sedimentology , and (3) to monitor long term trends in climate change, specifically temperature and rainfall characteristics.

Data collection at Anjeni has been going on for the last 30 years. Notwithstanding the missing and incomplete data for some years, the data generated provides useful information on a number of variables. In this report annual and monthly rainfall amount, rainfall erosivity, rainfall intensity, temperature, suspended sediment yield, both at watershed and Test Plot level are provided. The daily data have been cleaned, organised and archived in the WALRIS database at WLRC website (www.wlrc-eth.org) so that it is readily available to researchers.

Rainfall-Runoff – Rainfall at Anjeni is long unimodal concentrated from mid-May to mid-October. The long term mean annual rainfall at Anjeni is 1742 mm. The long term mean annual runoff is about 753 mm (0.239 l/s/ha), resulting in 43.2% average runoff coefficient. The trend in the annual rainfall is increasing but not statistically significant. The monthly rainfall trend has not also been statistically significant. The rainfall erosivity is 630.4 J/m h. Though the erosivity trend is positive, it was also not statistically significant. The high inter-annual variability may explain why the statistical test is not able to detect trends despite the modest visible trend.

Soil loss – The long term average annual sediment loss of the micro-watershed is 2652 tonnes, resulting in the annual average sediment loss of 24 t/ha. This is higher than the soil formation rate for the prevailing climate (10-16 t/ha). Despite the impressive landscape transformation , the amount of soil loss on average is much higher than the allowable level. Hence, further research is required to identify possible suspended sediment loss other than farmlands – specifically the contribution of gullies and river banks.

Temperature –The mean daily maximum, mean and minimum temperatures are 9.4, 18, and 26.6 oC respectively. However, there has been statistically significant positive trend in the minimum and maximum temperatures. Climate change impact exhibited through temperature increase is obvious.

Test plots – The highest mean annual soil loss of 135.6 ton/ha was observed from vertic Luvisol cultivated land on a slope of 28%. Expectedly, the loss from grasslands was the lowest (2.4 t/ha). Except on grasslands, plot level rates of soil losses are much higher than the watershed level, reinforcing the importance of erosion and deposition at scale.

Finally, based on the observations noted in the process of cleaning, organizing and summarizing the data, we have come to the following recommendations on the way forward:

Use of daily data – The daily data collected is now carefully cleaned, and systematically archived and uploaded in the WLRC's website. Hence, researchers and development practitioner can now freely use this long term data for analysis and modelling.

Data collection – For many of hydrological process investigations, refining the data collection from daily to event-based using the state-of-the-art instruments can help to accurately predict the hydrological process (blue-green water balance) in the watershed and evaluate the impacts of soil and water conservation intervention. Moreover, further data collection with the existing set-up should continue to investigate climate change trends at a longer time-scale and higher time resolution.

Strengthening soil conservation intervention – The amount of soil loss in the watershed has not been brought down to the tolerable level. This can be partly attributed to a big gully on Minchet River towards its headwater. Nevertheless, rehabilitation of the physical structures, reinforcing them with biological and agronomic soil conservation measures is required. Anjeni watershed has been used as a showcase to demonstrate the benefits of soil conservation for a long time. Hence, the continued maintenance of the watershed physical structures, reinforcing them with biological interventions, should continue unabated so that the observatory can continue to be used as sustainable land and water management field school.

Investigating scale effect - The Anjeni micro-watershed is a sub-watershed of Gerda meso-scale watershed established in mid-2013. Hence, the data collection between the two watersheds needs to be harmonised so that it is possible to see the scale effect.

Establishing other observatories – Rainfall runoff relation is expected to vary from one agro-ecology to the other. Hence, monitoring-runoff relation at different agro-ecological conditions in the basin is expected to improve rainfall runoff relations at basin-scale.

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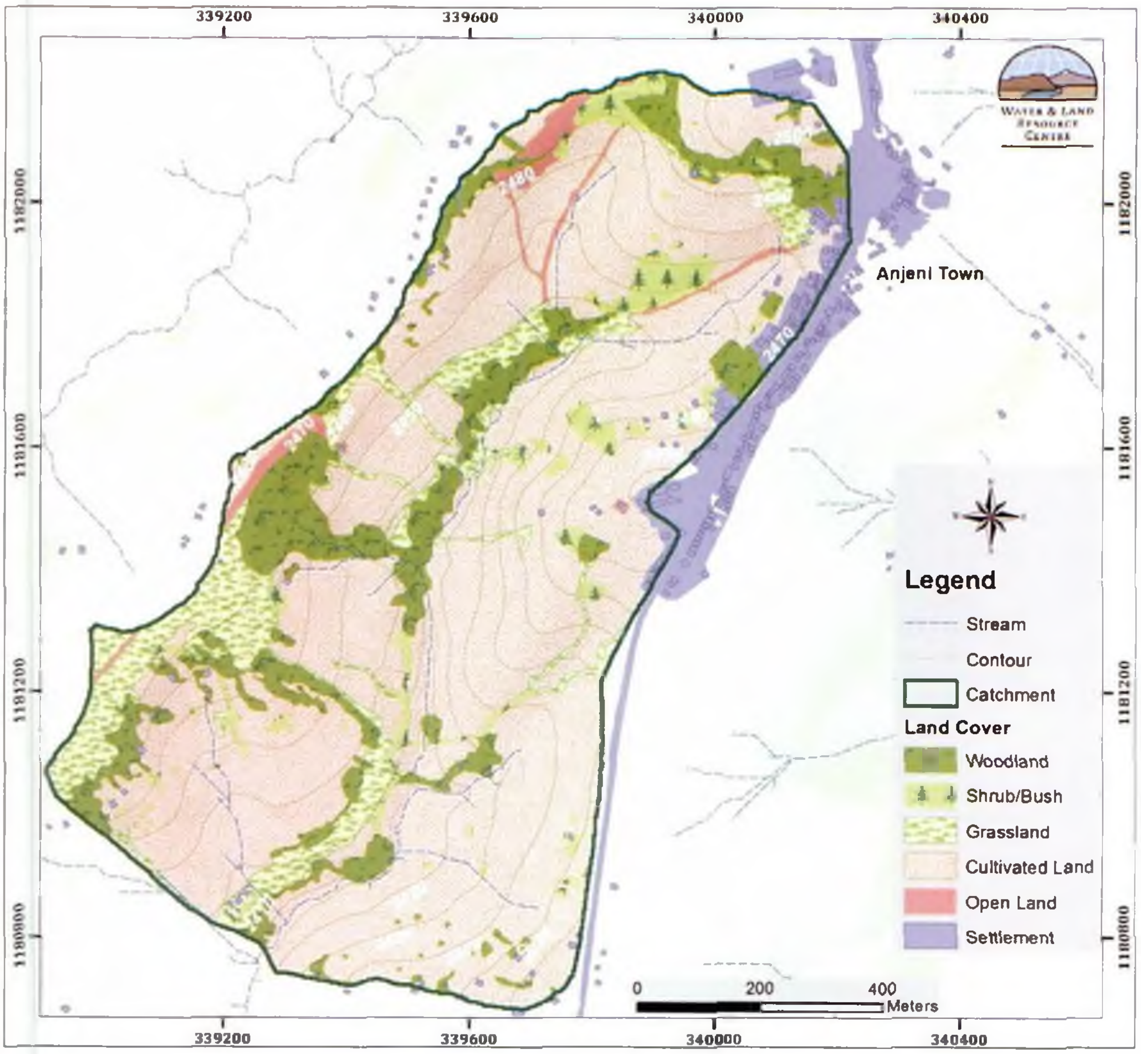
Appendix 1. Land use/Land Cover Map of Anjeni Watershed (2014)



Land Use/Land Cover

Type	*ha*	*(%)*	*Type*	*ha*	*%*
Cultivated	*71.8*	*67.8*	*Shrub/Bush*	*4.3*	*4.1*
Woodland	*15.6*	*14.7*	*Open Land*	*3.2*	*3.0*
Grassland	*10.2*	*9.6*	*Settlement*	*0.8*	*0.8*

Appendix 2. Soil Map of Anjeni Watershed

Soil Type	Area(Ha)	Percent
Eutric Regosols	0.2	0.1
Haplic Cambisols	22.6	21.5
Haplic Leptosols	3.4	3.2
Haplic Lixisols	20.0	19.0
Haplic Nitisols	8.6	8.2
Haplic Phaeozems	11.3	10.8
Haplic Regosols	21.0	19.9
Lithic Leptosols	1.5	1.4
Molic Nitisols	15.2	14.5
Rock Outcrop	0.1	0.1
Vertic Luvisols	1.4	1.3
Settlement	1.0	1.0
Total	105.2	100.0

Appendix 3. Mean Daily Rainfall from 1984-2014

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.2	0.2	0.6	0.8	1.3	6.0	14.2	15.8	10.4	5.5	2.5	0.7
2	0.2	0.2	2.8	1.8	1.3	6.5	13.8	13.6	6.4	8.3	1.2	1.1
3	0.2	0.3	0.5	0.8	1.8	5.3	11.1	9.1	10.8	8.1	0.8	0.6
4	2.1	0.1	0.2	0.9	1.0	5.3	10.3	11.4	9.5	4.7	0.8	0.1
5	0.0	0.0	0.3	0.8	2.6	5.7	10.1	14.2	8.1	3.5	1.2	1.0
6	0.1	0.0	0.5	1.6	1.2	9.5	13.9	9.5	10.6	3.5	1.2	0.6
7	0.0	0.0	0.9	0.5	2.0	10.5	12.8	12.3	6.4	3.7	3.1	0.9
8	0.0	0.0	1.1	1.8	0.5	7.9	11.5	11.0	7.9	3.0	1.5	1.0
9	0.3	0.1	0.5	1.6	5.6	10.4	14.6	13.9	7.2	2.8	1.8	0.3
10	0.6	0.1	0.7	1.8	5.7	6.2	12.1	13.1	5.7	4.2	1.9	0.3
11	0.2	0.0	1.3	0.9	5.2	10.0	11.1	13.2	5.9	4.7	1.7	0.3
12	0.7	0.3	1.7	0.4	4.8	7.8	13.4	11.6	8.1	2.4	0.7	1.0
13	0.9	0.2	1.5	1.3	3.9	12.1	10.7	10.9	10.8	3.1	0.8	0.8
14	0.3	0.3	1.3	0.4	3.1	9.7	14.3	10.7	7.3	6.4	0.7	0.4
15	0.2	0.3	0.7	1.8	3.8	5.8	12.2	6.3	12.0	3.5	4.2	0.6
16	0.3	0.1	0.8	1.8	3.5	9.3	19.4	9.5	11.1	4.2	0.6	0.5
17	0.0	0.4	1.7	2.5	3.8	9.8	13.0	11.3	10.1	4.3	2.5	0.5
18	0.1	0.0	1.1	0.6	5.1	6.4	15.9	10.3	6.1	4.3	0.8	0.6
19	0.2	0.0	1.6	2.3	4.4	9.8	17.4	9.2	9.8	3.5	1.2	0.7
20	0.8	0.2	1.0	1.2	1.9	8.0	13.4	11.3	7.2	6.8	2.1	0.5
21	0.4	1.8	0.5	3.7	4.1	8.6	12.8	11.0	6.5	2.9	1.2	0.8
22	0.2	0.8	0.8	1.7	2.8	7.7	12.3	9.6	7.4	1.3	0.6	0.3
23	1.0	0.6	0.7	2.0	4.3	8.7	15.1	11.7	8.7	4.9	0.2	0.8
24	0.3	0.5	4.6	4.0	1.8	10.9	12.8	9.8	6.6	1.4	0.8	0.8
25	0.6	1.4	1.3	1.6	2.8	12.6	13.8	10.4	6.9	2.8	0.6	0.1
26	0.3	2.7	3.9	2.0	3.1	10.1	13.8	9.3	5.9	1.2	0.2	0.5
27	0.0	0.8	2.4	1.4	4.1	9.9	10.4	10.1	6.8	4.6	1.7	0.0
28	0.3	0.7	2.7	1.6	3.0	10.7	16.7	11.7	6.0	1.3	0.3	0.4
29	0.2		0.8	1.2	2.7	12.2	14.6	11.1	6.1	3.1	0.7	1.1
30	0.0		1.5	0.8	4.3	13.3	14.0	10.1	4.7	1.9	0.4	0.6
31	0.0		1.3		3.9		12.6	8.1		1.1		0.2
Mean	0.3	0.4	1.3	1.5	3.2	8.9	13.4	11.0	7.9	3.8	1.3	0.6
Std	0.4	0.6	1.0	0.8	1.4	2.3	2.1	1.9	2.0	1.9	0.9	0.3
min	0.0	0.0	0.2	0.4	0.5	5.3	10.1	6.3	4.7	1.1	0.2	0.0
max	2.1	2.7	4.6	4.0	5.7	13.3	19.4	15.8	12.0	8.3	4.2	1.1

Appendix 4. Mean daily runoff for the period of 1984 to 2013

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.29	0.24	0.19	0.22	0.20	0.40	2.65	8.40	4.23	2.00	0.85	0.42
2	0.29	0.24	0.18	0.18	0.18	0.29	4.11	7.25	5.28	3.12	0.80	0.43
3	0.29	0.24	0.20	0.17	0.18	1.11	3.01	6.45	4.21	2.73	0.79	0.44
4	0.32	0.24	0.19	0.22	0.18	0.48	3.06	6.38	5.85	2.55	0.75	0.44
5	0.28	0.24	0.18	0.18	0.18	0.33	2.44	8.22	3.94	1.94	0.73	0.45
6	0.28	0.24	0.18	0.18	0.22	0.52	3.05	6.49	3.64	2.04	0.69	0.44
7	0.28	0.24	0.19	0.20	0.19	0.65	3.10	5.91	5.59	1.72	0.69	0.42
8	0.28	0.24	0.18	0.17	0.16	0.61	3.23	7.48	3.32	1.94	0.66	0.40
9	0.28	0.24	0.20	0.19	0.20	1.27	3.40	6.54	3.79	1.52	0.64	0.44
10	0.28	0.24	0.18	0.17	0.33	0.81	3.58	5.62	3.08	1.51	0.66	0.40
11	0.27	0.24	0.18	0.18	0.34	1.00	4.13	6.88	3.24	1.51	0.67	0.40
12	0.27	0.24	0.19	0.18	0.33	1.16	3.96	5.31	3.52	1.44	0.62	0.40
13	0.27	0.23	0.18	0.17	0.33	0.85	4.23	5.30	3.72	1.22	0.62	0.40
14	0.27	0.21	0.18	0.18	0.24	0.87	3.96	6.83	4.38	1.16	0.60	0.38
15	0.27	0.21	0.18	0.19	0.39	0.87	6.11	4.79	3.40	1.46	1.27	0.38
16	0.27	0.19	0.18	0.16	0.35	0.88	5.44	4.74	3.46	1.14	0.62	0.38
17	0.27	0.19	0.18	0.17	0.28	1.37	5.31	5.31	4.04	1.45	0.61	0.38
18	0.25	0.19	0.18	0.20	0.33	1.20	4.74	4.56	4.16	1.36	0.56	0.38
19	0.25	0.19	0.19	0.16	0.48	1.35	4.81	6.05	3.67	1.34	0.56	0.38
20	0.27	0.19	0.18	0.23	0.24	1.88	7.12	5.79	4.06	1.13	0.59	0.38
21	0.27	0.20	0.17	0.21	0.43	1.09	5.49	4.39	3.96	1.46	0.66	0.38
22	0.26	0.19	0.16	0.16	0.38	1.27	4.67	4.67	3.16	1.12	0.53	0.37
23	0.27	0.19	0.16	0.16	0.57	0.99	5.67	5.03	3.53	1.09	0.52	0.37
24	0.26	0.19	0.39	0.15	0.29	1.41	6.81	4.11	3.95	1.18	0.58	0.42
25	0.26	0.18	0.21	0.28	0.75	1.72	4.65	5.24	3.35	1.02	0.54	0.36
26	0.28	0.19	0.45	0.18	0.24	1.99	7.13	4.42	2.26	1.05	0.52	0.35
27	0.27	0.19	0.28	0.27	0.26	2.46	6.57	4.43	2.81	1.17	0.51	0.36
28	0.27	0.19	0.40	0.26	0.28	2.16	5.65	4.75	2.88	0.92	0.47	0.35
29	0.27		0.29	0.20	0.48	3.26	7.43	4.84	2.19	0.98	0.50	0.35
30	0.27		0.25	0.20	0.31	4.23	6.87	5.28	2.21	0.93	0.46	0.36
31	0.27		0.24	0.00	0.29		7.11	4.55		0.86		0.33
Mean	0.27	0.22	0.21	0.19	0.31	1.28	4.82	5.68	3.70	1.49	0.64	0.39
stdev	0.01	0.03	0.07	0.05	0.13	0.87	1.53	1.16	0.87	0.55	0.15	0.03
min	0.25	0.18	0.16	0.15	0.16	0.29	2.44	4.11	2.19	0.86	0.46	0.33
max	0.32	0.24	0.45	0.28	0.75	4.23	7.43	8.40	5.85	3.12	1.27	0.45

Appendix 5. Daily mean suspended sediment (tones) for the period 1984 to 2014

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	0.6	26.9	37.3	30.3	3.3	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	2.8	37.5	19.0	15.6	7.8	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	31.0	15.0	15.4	38.2	3.7	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	3.8	10.4	107.7	8.5	1.1	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	1.9	10.9	24.8	11.3	2.0	0.0	0.0
6	0.0	0.0	0.0	0.4	0.6	5.1	15.1	11.5	54.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	8.4	11.0	48.9	6.6	3.2	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	4.2	10.9	30.8	9.2	0.6	0.0	0.3
9	0.0	0.0	0.0	0.0	1.8	22.5	27.0	24.0	11.9	0.1	0.0	0.0
10	0.0	0.0	0.0	0.0	1.4	9.9	10.5	30.8	5.3	0.7	0.0	0.0
11	0.0	0.0	0.0	0.0	1.5	15.4	34.5	19.1	9.4	0.7	0.0	0.0
12	0.0	0.0	0.0	0.0	1.5	1.0	9.5	14.3	6.3	0.4	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	5.9	16.7	22.8	23.9	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	1.7	1.1	36.4	31.7	8.9	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	1.4	3.8	36.1	6.5	10.3	2.4	0.1	0.0
16	0.0	0.0	0.0	0.0	3.1	16.9	76.9	12.5	5.8	0.1	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	2.5	3.5	10.4	26.4	1.7	0.0	0.0
18	0.0	0.0	0.0	0.2	2.9	27.0	17.5	38.6	3.3	0.9	0.0	0.0
19	0.0	0.0	0.0	0.7	11.0	16.5	31.6	30.9	26.2	1.3	0.1	0.0
20	0.0	0.0	0.0	0.2	0.3	16.6	16.6	14.4	9.1	0.1	0.0	0.0
21	0.0	0.0	0.0	0.0	3.8	10.6	8.8	21.2	5.9	5.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	5.4	7.0	14.2	9.3	0.0	0.0	0.0
23	0.0	0.0	0.0	0.3	5.7	12.0	65.5	9.8	19.6	0.5	0.0	0.0
24	0.0	0.0	11.6	0.8	0.7	9.3	35.2	30.2	6.7	0.3	0.4	0.0
25	0.0	0.0	0.0	1.9	0.0	39.7	22.4	9.8	1.3	0.0	0.0	0.0
26	0.0	0.0	8.4	0.0	0.0	48.8	43.3	8.3	5.5	0.2	0.0	0.0
27	0.0	0.0	1.9	3.1	2.2	40.5	12.4	21.0	2.8	4.5	0.0	0.0
28	0.0	0.0	5.7	3.8	12.5	32.0	24.6	14.7	8.4	0.0	0.0	0.0
29	0.0		0.0	0.0	0.2	68.4	56.6	25.3	1.4	1.1	0.0	0.0
30	0.0		0.0	0.0	0.4	37.5	39.9	18.1	0.7	0.0	0.0	0.0
31	0.0		0.0		3.2		77.6	11.8		0.0		0.0
mean	0.0	0.0	0.9	0.4	1.8	16.7	27.4	23.7	12.7	1.3	0.0	0.0
stdev	0.0	0.0	2.7	0.9	3.0	16.9	20.0	18.6	12.1	1.9	0.1	0.1
Max	0.0	0.0	11.6	3.8	12.5	68.4	77.6	107.7	54.0	7.8	0.4	0.3
Min	0.0	0.0	0.0	0.0	0.0	0.6	3.5	6.5	0.7	0.0	0.0	0.0

Appendix 6. Daily mean Temperature (mm) for the period 1984 to 2014

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	15.0	16.8	17.4	18.1	18.5	16.9	15.2	14.7	15.3	15.4	15.6	15.1
2	15.0	16.6	17.6	18.3	19.0	17.3	15.2	14.7	15.0	15.4	15.3	15.2
3	15.4	16.4	17.5	18.3	19.1	16.8	15.3	14.9	15.0	15.4	15.7	15.0
4	15.2	16.3	17.4	18.1	18.9	17.0	14.8	14.8	15.1	15.6	15.3	15.3
5	15.2	16.6	17.7	18.1	18.5	16.9	15.3	14.9	15.2	15.9	15.4	15.0
6	15.1	16.4	17.7	17.9	18.6	16.7	15.3	14.8	15.1	15.9	15.2	14.8
7	15.2	16.7	18.0	18.2	18.5	16.7	15.2	15.1	15.2	15.9	15.5	15.0
8	15.3	16.8	17.8	17.8	18.4	16.6	15.2	15.1	15.2	15.8	15.4	15.1
9	15.6	17.0	18.0	18.1	18.1	16.3	15.1	15.0	15.3	15.9	15.5	14.9
10	15.8	16.7	18.2	17.8	18.3	16.4	15.2	14.7	15.1	16.0	15.2	15.0
11	16.0	16.9	17.8	18.3	18.6	16.2	14.7	15.0	14.9	15.8	15.5	15.0
12	15.8	16.9	18.0	18.7	18.0	16.3	15.2	14.9	15.1	15.6	15.0	15.0
13	15.5	16.6	18.4	18.6	18.3	16.3	15.3	15.0	15.2	15.5	15.2	15.0
14	15.7	17.0	17.9	18.5	18.1	16.3	15.0	14.9	15.3	15.6	15.6	14.7
15	15.6	16.6	18.0	18.4	18.0	16.2	15.2	15.1	15.4	15.5	15.3	14.9
16	15.5	17.0	18.3	18.6	22.5	16.3	15.0	14.7	15.3	15.8	15.5	14.8
17	15.6	16.5	18.5	18.1	18.4	15.9	15.1	14.9	15.2	15.4	15.6	14.7
18	15.6	16.9	17.9	18.4	18.3	16.0	14.6	15.1	15.2	15.5	15.4	14.9
19	15.6	17.3	17.5	18.6	18.2	15.9	14.5	15.1	15.2	15.4	15.2	15.4
20	15.6	17.4	17.5	18.5	17.9	15.8	14.9	15.3	15.4	15.3	15.3	15.1
21	15.6	17.6	18.0	18.4	17.8	15.9	15.2	14.8	15.5	15.7	15.8	14.9
22	15.6	17.5	18.1	18.7	17.7	15.9	14.7	15.1	15.2	15.6	15.4	15.0
23	15.8	17.5	18.3	18.1	18.2	16.0	15.1	15.1	15.5	15.3	15.3	14.9
24	16.0	17.8	18.2	17.9	17.5	15.5	15.0	15.1	15.3	15.2	15.2	14.6
25	15.8	19.0	18.3	18.0	17.7	15.3	14.6	14.8	15.6	15.2	15.1	14.9
26	15.9	17.6	18.2	18.0	17.6	15.3	14.6	15.2	15.8	15.1	15.2	14.9
27	16.1	17.4	18.0	18.5	17.9	15.4	15.1	15.2	15.9	15.1	15.1	15.0
28	16.7	17.7	18.1	18.3	17.6	15.6	14.9	15.0	15.8	14.9	15.1	15.1
29	16.4		17.8	18.3	17.6	15.2	14.7	14.8	15.5	15.3	15.1	15.1
30	16.4		18.0	18.4	17.6	15.2	14.9	19.1	15.7	15.2	15.2	14.8
31	16.7		17.6		17.3			15.2		15.2		15.0
mean	15.7	17.0	17.9	18.3	18.3	16.1	15.0	15.1	15.3	15.5	15.3	15.0
stdev	0.4	0.6	0.3	0.3	0.9	0.6	0.2	0.8	0.3	0.3	0.2	0.2
Min	16.7	19.0	18.5	18.7	22.5	17.3	15.3	19.1	15.9	16.0	15.8	15.4
max	0.4	0.6	0.3	0.3	0.9	0.6	0.2	0.8	0.3	0.3	0.2	0.2

ppendix 7. Rainfall Observation from Adjacent Meteorological stations

Year	Anjeni	Yechereka	Dembecha	Debra Markos	Fintoselam
1985	1556				904.9
1986	1371		1309.4		838.5
1987	1811		1870		1093.9
1988	1854		1268.8		1403.6
1989	1654	1402.7	725.7		1062.8
1990	1522	1189.7	1278.2		1037.7
1991	1315	1029.9	1065		927.1
1992	1768	1348.2	1286.8		id
1993	1848	1167.7	1614.3		1276.2
1994	1652	1179.9	1440.4		1192.1
1995	1624	2017	1292.2	1248.9	1208.1
1996	1697	1309	1563.4	1590.4	1243.5
1997	1708	1486.3	1639.6	1517.7	1608.4
1998	1773	1716.6	1469.6	id	id
1999	1766	1609.6	1549.9	1344.1	nd
2000	1907	1764.5	1325.6	id	nd
2001	1690	1275.9	1391.4	1374.2	nd
2002	1619	1237.7	1111.3	1305.5	nd
2003	1739	1429	1320.2	1210.8	nd
2004	1747	1666	1144.8	id	nd
2005	1623	1416.2	1197.8	1209.1	nd
2006	1429	2810.6	1402.9	1521.6	1347.7
2007	1412	2003.8	30.9	1400.5	1174.8
2008	1647	1830	1464.4	1315.2	1393.2
2009	1687	id	1283.1	id	1332.5
2010	1631	id	935.2	id	225.2
2011	1598			1512.2	
2012	1608				
2013	2146				

Water & Land
Resource
Centre

The Water and Land Resource Center (WLRC) is an autonomous research for development center established in 2011 and affiliated to Addis Ababa University (AAU), Ethiopia and Center for Development and Environment (CDE) of University of Bern. The WLRC is basically a reorganization of the previous Soil Conservation Research Programme (SCRP), which was initiated by CDE in collaboration with MoA in 1981, and WLRC builds itself on SCRP's research database and set-ups. Both SCRP and the core functions of WLRC has been supported by the Swiss Development Cooperation (SDC). The Center is governed by a Steering Committee constituted from four state ministers of MoA, MoWIE, MoFED, MoST, and co-chaired by AAU and SDC. The Center has been instrumental in generating pertinent information that helps in supporting and informing the current Integrated Water and Land Resource Management (IWLRM) activities in the country both in highlands and pastoral areas and the Eastern Nile Region. The core mandate of WLRC is research for development in sustainable water and land management which it delivers through three functions: i) Knowledge Generation of hydro-sedimentology, climate, land use and IWLRM, ii) Knowledge Management for cross-sector and cross-scale policy and development actions and iii) Capacity Development of key partners on IWLRM and geo-information technologies and techniques. WLRC has established a web-based and the state of the art Water and Land Resources Information System (WALRIS) (www.wlrc-eth.org; walris.wlrc-eth.org).

WLRC aims at contributing to the reduction of land degradation and its impacts (both on-site and off-site impacts) in transboundary river basins and improving livelihoods and resilience through generating and managing cross-sectoral and cross-scale knowledge on sustainable water and land resources management in Ethiopia, Eastern Africa and Eastern Nile region.

WLRC adheres to the values of inter-disciplinarily, scientific evidence, partnership, equity, and environmental integrity while performing its functions.

ARARI

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