wjert, 2019, Vol. 5, Issue 2, 405-424. *Review Article* ISSN 2454-695X

World Journal of Engineering Research and Technology
WJERT
www.wjert.org SJIF Impact Factor: 5.218

WATER BALANCE ANALYSIS IN MAKERA MARSHLAND, MUHANGA DISTRICT – RWANDA

BINYEBEBE Maurice*

Department of Civil, Environmental and Geomatics Engineering - College of Science and Technology - University of Rwanda P. O. Box 57 Nyagatare, Rwanda.

Article Received on 02/02/2019 **Article Revised on 23/02/2019** **Article Accepted on 14/03/2019**

***Corresponding Author**
BINYEBEBE Maurice
Department of Civil, Environmental and Geomatics Engineering - College of Science and Technology - University of Rwanda P. O. Box 57 Nyagatare, Rwanda.

ABSTRACT

Makera marshland is located in the southern Province, Muhanga District. Seasonal rainfall is characterized by two rain seasons from September to January and March to May whereby monthly rainfall vary from 99 mm to127 mm declining to 19 mm in July. Only 11% of the annual rainfall was observed during the dry season. The average annual rainfall for the catchment was 1269 mm/year. The statistical analysis shown that was no statistical dependency correlation between the annual data while a medium statistical dependency observed between the monthly data of Kigali and stations closed to Makera. The results have been verified with the river flow measured in August, November 2016 and February 2017 while groundwater observation was done from taps and wells. The total gross water requirements are of 4,086m3/ha/ year. It was observed that available water resources can be used to irrigate 109ha as supplementary irrigation and 40ha for complete irrigation.

KEYWORDS: Rainfall, runoff, river flow, probability function, Crop water requirement, Crop watt, command area, irrigation frequency.

1. INTRODUCTION

Hydrological components and their interrelation is one of the major needed requirements for any planned investigations concerning Water Resources Management.[1]

The quality to achieve knowledge about the water balance mainly depends on monitored data of the area. Additional general related information and knowledge gained from others and their findings will complement the analysis of acquired data and brings the results into a context of the entire neighboring area.[2]

The Makera project area is located part of Nyabarongo basin. The seasonal rainfall is characterized by one wet season from October to May whereby monthly rainfall figures vary from 99 mm in November, 127 mm in April declining to 19 mm in July. Only 11% of the annual rainfall can be observed during the dry season from June to August. The average annual rainfall for the Makera catchment is 1269 mm/year.

1.1 Statement of problem

Knowledge and understanding of different hydrological processes and their interactions with climatic variables are essential for the present and future assessment of water resources availability. These are also pre-requisites for improved planning and sustainable management of water resources.[3] Unfortunately, there are some critical issues that many African catchments are facing, which include poor water resources management and planning, climate variability and change, water scarcity because of rapid riparian population growth and urbanization, and lack of adequate hydro-climatic data.

In Rwanda, the main problems include: (i) lack of sufficient studies in this area; (ii) lack of sufficient data particularly in the post 1994 period because of destruction of hydro-meteorological stations together with many missing historical data sets; and (iii) lack of human resources with skills in hydrology and water resources management.

1.2 Limitation of the study

Due to the times constraint it was not possible to conduct an annual observation and record of river flow as well as ground water observation as Makera is not gauged watershed.

1.3 Objective of the study

Keeping all the above constraints in mind, the study's objective aimed at assessment of available water resources, choice of water uses as well available irrigable land in Makera marshland, Muhanga District using hydrological analysis and modelling

2. MATERIALS AND METHODS

2.1 Materials

Hydrological data were obtained from Rwanda Meteorology Agency, which is an institution affiliated to the Ministry of Natural resources in Kigali. Data is available for several rainfall gauge stations in Rwanda. The received data show distinctive inconsistencies and gaps of several years. Rainfall stations were mostly not comparable as their gaps and state of data vary widely. For Makera Site, closed stations were used for generating rainfalls and evaporation rates. They are compared with other stations in Rwanda and verified in terms of homogeneity and consistency.

Data from the stations Byimana, Kanyanza, Muramba, Kibangu and Kigali has been investigated and analyzed for the present study

2.1.1 Rainfalls

For the long-term simulation of the Makera a non-gauged catchment on a daily basis, a rainfall time series had to be generated from the surrounding stations. All assumptions and statistical evaluations will be presented in the following sections. Cautious treatment of the available data was herein necessary for limiting inconsistencies.

The four closest stations around Makera site were selected for calculation of the catchment rainfall because of their proximity. Due to the large data gaps in the nearby stations, Kigali Aero was added to the dataset despite the greater distance to the site. As the rainfall station in Kigali generally registers lower annual precipitation values as the ones closely surrounding the Makera site, this slightly lowers the total rainfall and increases the reliability of the calculated value. The utilized stations as well as the available data and the location are presented in the table below.

Table 1 Distance of used weather station from Makera marshland.

Station name	Distance to Makera	Available Complete Years
Byimana	23	7
Kanyanza	12	3
Muramba Parish	33	19
Kibangu	21	4
Kigali-Aero	41	43

2.1.2 Software for Statistical Analysis

The following statistical analysis of the precipitation data was done using the software Hydrognomon 4.1.0, a hydrological time series software.[4] Hydrognomon belongs to the Openmeteo.org project which is devoted to the development of free hydrological and meteorological software.

1.2 Methodology

2.2.1 Statistical Data Analysis

The precipitation data (rainfall series, probability density function for annual data, return period (T) and exceedance probability of annual precipitation) for the stations at

- Kigali
- Muramba
- Kibangu
- Kanyanza
- Byimana

The monitored data of the Kigali-station represents one of the major data-sets in Rwanda. This station is well maintained and offers reliable data for a period of about 41 years, the longest data set to be found in Rwanda. The data series was used to support the hydrological analysis and to achieve a more reliable general hydrological view.

2.2.2 Flow measurement

For operation of the system, especially in the dry season, it was important to determine the base flow of Makera Stream in order to size the irrigation system and weir structure. Usually the base flow was determined by measuring the flow along the river in dry season after 6month of dry season. As Makera River was not gaged; therefore this method cannot be used.

An alternative method was to do a simulation using various properties of the catchment, most importantly runoff coefficient. As there is no existing reliable input data for such a model, this solution is also no practicable. Therefore the existing measurements have to be utilized to estimate a value for the base flow.

Figure 1: Stream flow measurement.

Figure 2: Spring flow.

Figure 3: Water ponded near the existing weir.

Figure 4: Water in the river.

2.2.3 Crop water requirement analysis

Cropping pattern

Usually, the annual crops are grown in wet seasons A and B. Irrigation must allow not only for increase the agriculture produce but also to extend the growing season over the dry season C and would also allow for changing the crop structure from subsistence type crops to high value crops which can be sold to the market in Muhanga and Kigali and other cities.

Site suitability for high value crop production

The area is suitable for high value cropping as seen from the variety of crops growing. Under irrigation, the potential of area to produce high value crops can dramatically increase.

Proposed crops and cropping pattern

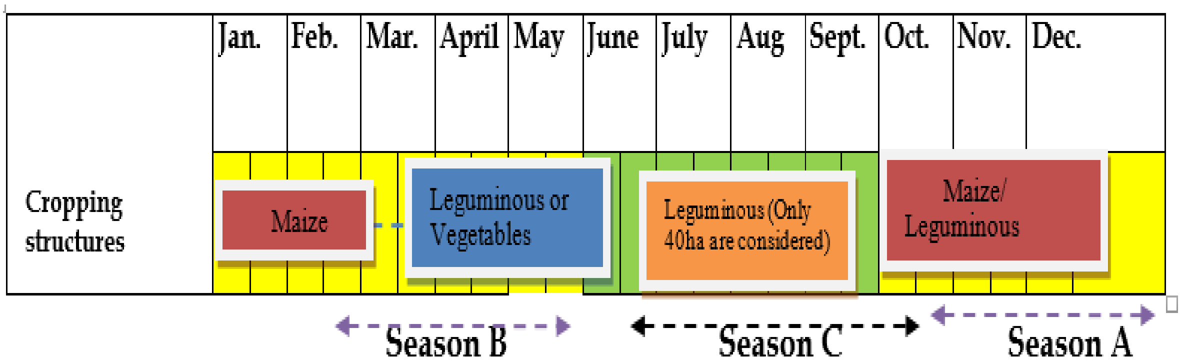

Figure 5: Proposed cropping patterns on the areas.

Figure 5 represented the anticipated cropping pattern in the valley of the stream where maize and legumes are used as rotational crops though they are major food crops for the communities. They may receive supplemental irrigation just as well as the vegetables are planted in season C.

2.2.4 Sizing of the command area

To determine the size of command i.e the potential area to be irrigated the following formula has been used:

$$Area\ (ha) = \frac{Estimated\ flow\ or\ measured\ \left(\frac{lit}{sec}\right)}{Crop\ water\ demand\ \left(\frac{\frac{Liter}{sec}}{ha}\right)}$$

2. RESULTS AND DISCUSSION

Table 2 Rainfall at Kigali weather station

	KIGALI												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Annual*
1971	35.4	66.3	84.9	165.4	129	0	17.9	56.1	79.4	56.6	125.3	92.8	*909*
1972	62.2	193.7	110.8	92.5	111.7	58.8	0.7	35.7	88.7	111.2	219.7	69.2	*1155*
1973	22.2	127.9	98.6	162.4	111.9	0.5	0	31.8	127.6	111.8	126.9	91.1	*1013*
1974	20	76.8	139.5	115.1	81	102.4	20.1	1.9	67.6	49.3	101.1	80.5	*855*
1975	33.1	45.3	67	120.6	79	1.7	54.6	4.7	149.8	162.9	53.6	117.2	*890*
1976	31.7	89.6	77.5	102.6	56.9	29.1	0.4	60.8	82.2	29.8	79.8	153.9	*794*
1977	59.4	67.5	115.4	189.8	91.4	17	3.2	29.4	82.6	45.1	158.6	148.3	*1008*
1978	84.1	151	182.2	168.3	97	11.2	0	23.3	57.2	86.6	82.8	137	*1081*
1979	135.1	93	107.6	234.7	314.9	24.7	0.4	31.1	25.4	96.9	168.9	123.9	*1357*
1980	68	133.4	96.9	130.7	132.7	14.1	1.2	5.7	193.7	74.9	151.9	71.9	*1075*
1981	115.8	136.6	142.2	220.1	63.9	0.3	0	135.5	86.3	100	93.7	75	*1169*
1982	63.9	47.2	47.9	211.9	132.5	17.5	3.3	3.9	101.4	126.4	111.9	125.9	*994*
1983	30.5	78.7	60.1	202.3	25.4	60.3	1.3	27.8	45.5	145.3	142.6	104.5	*924*
1984	59.8	110.1	97.3	201.3	28.6	0.4	59.1	55.6	39.1	131.3	130.8	82.7	*996*
1985	60.7	61	98.2	317.1	48.4	1.6	1	4.4	101.5	113.3	192.1	37.7	*1037*
1986	66.6	103.6	90.2	273.5	81.3	8.7	0	0	12.1	87.6	109	120.8	*953*
1987	75.5	103.8	98.7	158.9	213.9	25	0	11.3	101.5	98.5	212	33.5	*1133*
1988	120.3	117.4	187.5	107.8	149.2	0	15.1	97.1	77	126.5	127	70.9	*1196*
1989	68.8	62.4	91.9	272.8	77.3	21.4	1.7	43.6	49	91.2	90.5	133.2	*1004*
1990	74.6	139.3	136.3	190.9	39.1	0	0	13.7	155.4	108.3	80.3	121.1	*1059*
1991	67	95.2	82.5	139.8	180.1	18.4	10.5	27	51.6	146	67.2	52.5	*938*
1992	46.4	48.9	94.1	140.6	43.2	28.7	1.3	1	57.8	86.7	53.7	84.8	*687*
1993	128	89.2	65.5	88.6	119.9	8.7	0	67.1	22.7	34.4	121.3	28.8	*774*
1995	76.4	57.7	119.8	155.2	114	63.9	0	1.1	74.7	131.1	139.7	46	*980*
1996	42.2	97.1	136.4	124.9	42.4	45.6	36.5	95	80.3	52	67.6	28.3	*848*
1997	116.3	45.4	98.8	171.1	59.8	67.3	6.2	40.6	11.7	166.8	147	134.1	*1065*
1998	141.9	200	161.3	93.3	222.7	35.8	8.7	41.7	85.1	107.1	122.1	54.6	*1274*
1999	64.4	18.3	218.2	121.8	43.9	0	0	64.4	77.8	48.9	106	104.3	*868*
2000	22.1	58.2	100.7	84.1	51.3	0	0	5.4	32.6	129.2	144.2	76.3	*704*
2001	80.3	60.8	257.3	84.3	61.4	0.2	120.8	21.8	86.1	225.9	185	98.9	*1283*
2002	155	65.7	98.9	156	145.6	0	0	0.2	34.6	99.7	116.5	131.7	*1004*
2003	60.3	29.8	74.6	121.7	49.9	0	0	65.1	147.5	106.7	101.1	49.5	*806*
2004	67	71.8	114.3	201.4	23.1	4	0	15.1	74.6	70.7	75.8	82.8	*801*
2005	64.6	41.8	134.3	91.6	88	10.3	0	41.6	112.4	128.2	55.3	30	*798*
2006	22.7	90.6	112.2	218	117.8	5.3	14.5	25.1	35.4	57.4	210.2	141.4	*1051*
2007	53.1	161	40.6	134.7	124.5	39.5	65	21.2	68	163.9	125.3	50.9	*1048*
2008	76.7	73.5	154.8	115	63	58.9	7.4	13.3	34.5	64.8	55.5	39	*756*
2009	103.6	183.5	97.4	116.9	99.4	0	0.8	14	21.1	132.1	122.7	69.1	*961*
2010	133.3	315.7	120.6	135.1	88.6	40.8	0	4.3	87	128.1	79.6	87.7	*1221*
2011	71.5	60.4	115.8	123.8	55.3	50.7	1.8	61.7	83.9	137.1	112.6	51.6	*926*
2012	28.3	70	109.7	184.4	222.3	13.9	0	47.2	61.3	97.9	170.6	74.3	*1080*
Average	*70.95*	*96.08*	*113.13*	*157.10*	*99.54*	*21.63*	*11.06*	*32.86*	*74.72*	*104.10*	*120.43*	*85.55*	***987***
Percentage of total	7%	10%	11%	16%	10%	2%	1%	3%	8%	11%	12%	9%	100%
20% Risk	**61.0**	**82.6**	**97.2**	**135.0**	**85.5**	**18.6**	**9.5**	**28.2**	**64.2**	**89.5**	**103.5**	**73.5**	***848***

Table 3: Rainfall at Byimana weather station.

Byimana													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Annual*
1971	103.7	132.3	80.8	193.3	197.6	0.0	16.8	126.6	51.6	42.9	115.2	121.2	*1182*
1972	63.3	225.2	68.3	84.0	103.2	111.5	0.0		52.2	106.9	223.4	83.3	*1121*
1973	85.5	104.2	84.0	258.9	232.7	4.7	0.0	36.4	204.8	105.3	189.5	73.1	*1379*
1974	76.5	32.6	276.5	173.3	202.4	105.9	87.9	7.8	84.7	34.5	121.7	55.4	*1259*
1975	136.0	82.6	73.9	231.8	142.7	3.4	52.4	14.6	135.2	151.1	92.0	160.5	*1276*
1976	65.1	99.6	113.9	118.5	143.6	31.5	0.0	82.6	90.0	94.6	74.3	82.5	*996*
1977	116.3	87.2	105.4	237.4	93.6	7.2	5.5	66.3	119.3	121.7	161.6	109.2	*1231*
1978	85.1	125.2	243.1	173.0	127.8	22.0	0.0	39.5	37.1	55.4	106.1	106.9	*1121*
1979	210.1	150.3	36.3	185.6	234.7	52.3	0.0	21.5	5.5	28.8	140.9	129.9	*1196*
1980	81.9	96.9	86.2	204.5	160.1	3.8	0.0	8.9	154.2	110.4	182.9	122.5	*1212*
1981	62.2	69.7	150.7	186.9	174.2	0.2	0.0	148.8	107.5	79.7	62.9	83.4	*1126*
1982	68.2	83.3	45.3	247.5	224.6	41.3	0.0	6.1	112.2	135.8	131.2	154.2	*1250*
1989	118.8	76.9	117.5	220.4	96.7	37.7	21.1	61.5	54.2	75.2	59.1	104.0	*1043*
1991	140.1	140.0	125.1	120.3	152.9	53.0	14.5	31.2	37.9	99.6	64.9	135.5	*1115*
1992	107.8	86.5	178.5	161.1	119.0	89.4	1.9	1.7	83.2	169.3	103.3	149.9	*1252*
1998	210.8	274.9	150.4	198.9	135.6	55.1	11.5	25.0	41.9	94.9	117.8	66.9	*1384*
2010	230.3	389.2	154.2	129.4	181.3	34.4	0.0	0.3	92.7	113.1	126.5	165.5	*1617*
2011	157.5	85.3	69.8	76.2	57.2	193.7	13.0	31.0	75.2	114.1	240.4	120.5	*1234*
2012	11.7	74.8	70.2	281.3	168.9	16.6	6.5	54.4	63.0	123.1	138.5	108.1	*1117*
Average	**112.2**	**127.2**	**117.4**	**183.3**	**155.2**	**45.5**	**12.2**	**42.5**	**84.3**	**97.7**	**129.1**	**112.2**	***1216***
	9.2%	**10.5%**	**9.6%**	**15.1%**	**12.8%**	**3.7%**	**1.0%**	**3.5%**	**6.9%**	**8.0%**	**10.6%**	**9.2%**	**100%**
20% Risk	**103.2**	**117.1**	**108.0**	**168.7**	**142.8**	**41.8**	**11.2**	**39.1**	**77.6**	**89.9**	**118.8**	**103.3**	***1120***

Table 4: Rainfall at Muramba weather station.

Muramba													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Annual*
1971	59.4	61.2	122.0	239.0	122.6	35.4	15.7	40.2	120.2	92.2	208.2	131.6	*1248*
1972	98.5	187.7	165.7	221.7	136.3	80.7	0.0	72.4	38.7	154.6	157.6	59.7	*1374*
1973	141.3	141.4	96.6	299.6	229.9	0.0	0.0	32.4	190.0	128.8	238.4	104.9	*1603*
1975	118.8	63.6	109.4	173.0	137.4	104.8	72.3	20.2	23.0	188.9	121.0	117.2	*1250*
1976	131.8	178.8	126.4	164.5	143.8	39.3	4.7	71.3	119.4	141.5	113.0	167.5	*1402*
1977	113.6	65.4	166.1	263.3	62.1	69.0	12.2	134.7	79.2	125.2	218.0	107.6	*1416*
1978	59.2	115.0	233.2	168.3	102.6	105.9	22.6	24.1	77.8	150.5	152.1	127.6	*1339*
1979	163.8	121.7	114.0	137.3	256.0	62.7	2.8	62.4	20.3	140.1	129.1	165.9	*1376*
1980	140.8	151.1	90.7	145.4	249.9	30.7	45.6	3.7	173.1	286.3	194.3	123.0	*1635*
1981	111.7	62.0	201.4	240.5	63.4	0.0	0.0	131.9	83.5	126.9	102.2	76.2	*1200*
1983	24.0	61.9	115.1	205.8	108.1	5.8	15.5	97.8	72.7	292.7	241.2	60.5	*1301*
1984	85.8	79.8	128.4	147.8	0.0	0.0	49.0	97.9	38.7	156.1	149.0	80.5	*1013*
1985	71.8	92.7	114.2	180.0	140.2	18.2	10.4	2.5	118.0	156.9	154.7	30.8	*1090*
1986	151.0	111.2	94.1	190.5	99.8	51.4	0.0	5.9	58.7	223.6	113.5	126.8	*1227*
1987	128.3	89.2	215.5	214.5	232.8	38.4	8.7	80.9	154.9	134.1	232.0	76.1	*1605*
1988	95.0	150.5	239.3	344.3	130.2	3.0	49.5	146.3	172.7	173.4	160.1	102.7	*1767*
1989	53.8	96.1	195.4	111.7	142.5	99.8	3.4	37.5	141.9	146.3	191.1	138.5	*1358*
1990	149.8	121.3	187.0	269.3	172.2	0.0	0.0	73.2	102.0	130.7	150.9	148.9	*1505*
1991	108.0	100.8	125.5	169.4	158.3	111.6	28.1	6.6	126.2	193.3	87.1	113.3	*1328*
1992	81.4	90.8	192.5	193.4	125.1	75.1	0.0	2.8	153.5	164.3	108.7	135.1	*1323*
1993	96.3	47.6	148.6	180.7	166.2	14.3	0.0	60.5	18.2	102.5	175.8	142.1	*1153*
2011	79.7	128.0	222.6	138.2	92.3	85.3	18.4	108.4	221.0	136.0	182.8	215.4	*1628*
Average	**102.9**	**105.4**	**154.7**	**199.9**	**139.6**	**46.9**	**16.3**	**59.7**	**104.7**	**161.1**	**162.8**	**116.0**	***1370***
	7.5%	**7.7%**	**11.3%**	**14.6%**	**10.2%**	**3.4%**	**1.2%**	**4.4%**	**7.6%**	**11.8%**	**11.9%**	**8.5%**	**100%**
20% Risk	**92.4**	**94.6**	**139.0**	**179.6**	**125.4**	**42.1**	**14.7**	**53.6**	**94.1**	**144.8**	**146.2**	**104.2**	***1231***

Table 5: Kanyanza Rainfall data corrected.

Kanyanza													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	***Annual***
1981	124.1	79.6	142.6	293.0	123.1	7.6	7.0	91.1	70.8	130.7	169.0	91.2	*1330*
1983	63.9	100.4	223.6	255.6	86.6	18.9	11.5	12.1	97.9	225.6	348.7	81.8	*1527*
1984	85.6	96.5	132.3	157.1	33.7	3.3	89.3	49.5	7.1	177.6	178.0	53.0	*1063*
1985	91.0	55.9	108.7	225.5	70.4	6.6	2.0	5.3	125.1	144.2	130.5	110.6	*1076*
1986	155.2	107.0	159.3	428.6	130.9	11.2	0.0	2.1	33.9	204.6	136.2	122.3	*1491*
1987	97.4	76.6	81.3	161.4	160.6	108.0	5.2	1.0	173.6	78.8	277.1	43.9	*1265*
1988	90.2	84.2	178.3	350.2	183.1	0.0	63.7	149.8	89.4	77.7	129.9	133.6	*1530*
1989	194.5	91.1	127.8	149.1	149.0	117.7	10.4	87.0	123.9	121.9	133.4	180.4	*1486*
1990	95.4	207.6	138.7	348.0	138.8	0.0	0.0	45.3	265.8	87.2	143.5	121.5	*1592*
1991	109.3	95.7	173.2	133.3	248.1		29.2	6.0	77.1	133.7	80.4	121.6	*1208*
1992	50.7	119.1	149.0	180.2	131.7	125.0	2.6	1.2	158.5	196.8	112.6	119.3	*1347*
1993	96.9	74.5	95.6	119.8	165.8	36.1	0.0	54.0	9.0	38.5	194.4	103.5	*988*
Average	**104.5**	**99.0**	**142.5**	**233.5**	**135.2**	**39.5**	**18.4**	**42.0**	**102.7**	**134.8**	**169.5**	**106.9**	***1325***
	7.9%	**7.5%**	**10.8%**	**17.6%**	**10.2%**	**3.0%**	**1.4%**	**3.2%**	**7.7%**	**10.2%**	**12.8%**	**8.1%**	**100%**
20% Risk	**86.9**	**82.4**	**118.6**	**194.2**	**112.4**	**32.8**	**15.3**	**35.0**	**85.4**	**112.1**	**141.0**	**88.9**	***1102***

Table 6: Muramba – Corrected monthly precipitation Data.

Muramba													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	***Annual***
1971	59.4	61.2	122.0	239.0	122.6	35.4	15.7	40.2	120.2	92.2	208.2	131.6	*1248*
1972	98.5	187.7	165.7	221.7	136.3	80.7	0.0	72.4	38.7	154.6	157.6	59.7	*1374*
1973	141.3	141.4	96.6	299.6	229.9	0.0	0.0	32.4	190.0	128.8	238.4	104.9	*1603*
1975	118.8	63.6	109.4	173.0	137.4	104.8	72.3	20.2	23.0	188.9	121.0	117.2	*1250*
1976	131.8	178.8	126.4	164.5	143.8	39.3	4.7	71.3	119.4	141.5	113.0	167.5	*1402*
1977	113.6	65.4	166.1	263.3	62.1	69.0	12.2	134.7	79.2	125.2	218.0	107.6	*1416*
1978	59.2	115.0	233.2	168.3	102.6	105.9	22.6	24.1	77.8	150.5	152.1	127.6	*1339*
1979	163.8	121.7	114.0	137.3	256.0	62.7	2.8	62.4	20.3	140.1	129.1	165.9	*1376*
1980	140.8	151.1	90.7	145.4	249.9	30.7	45.6	3.7	173.1	286.3	194.3	123.0	*1635*
1981	111.7	62.0	201.4	240.5	63.4	0.0	0.0	131.9	83.5	126.9	102.2	76.2	*1200*
1983	24.0	61.9	115.1	205.8	108.1	5.8	15.5	97.8	72.7	292.7	241.2	60.5	*1301*
1984	85.8	79.8	128.4	147.8	0.0	0.0	49.0	97.9	38.7	156.1	149.0	80.5	*1013*
1985	71.8	92.7	114.2	180.0	140.2	18.2	10.4	2.5	118.0	156.9	154.7	30.8	*1090*
1986	151.0	111.2	94.1	190.5	99.8	51.4	0.0	5.9	58.7	223.6	113.5	126.8	*1227*
1987	128.3	89.2	215.5	214.5	232.8	38.4	8.7	80.9	154.9	134.1	232.0	76.1	*1605*
1988	95.0	150.5	239.3	344.3	130.2	3.0	49.5	146.3	172.7	173.4	160.1	102.7	*1767*
1989	53.8	96.1	195.4	111.7	142.5	99.8	3.4	37.5	141.9	146.3	191.1	138.5	*1358*
1990	149.8	121.3	187.0	269.3	172.2	0.0	0.0	73.2	102.0	130.7	150.9	148.9	*1505*
1991	108.0	100.8	125.5	169.4	158.3	111.6	28.1	6.6	126.2	193.3	87.1	113.3	*1328*
1992	81.4	90.8	192.5	193.4	125.1	75.1	0.0	2.8	153.5	164.3	108.7	135.1	*1323*
1993	96.3	47.6	148.6	180.7	166.2	14.3	0.0	60.5	18.2	102.5	175.8	142.1	*1153*
2011	79.7	128.0	222.6	138.2	92.3	85.3	18.4	108.4	221.0	136.0	182.8	215.4	*1628*
Average	**102.9**	**105.4**	**154.7**	**199.9**	**139.6**	**46.9**	**16.3**	**59.7**	**104.7**	**161.1**	**162.8**	**116.0**	***1370***
	7.5%	**7.7%**	**11.3%**	**14.6%**	**10.2%**	**3.4%**	**1.2%**	**4.4%**	**7.6%**	**11.8%**	**11.9%**	**8.5%**	**100%**
20% Risk	**92.4**	**94.6**	**139.0**	**179.6**	**125.4**	**42.1**	**14.7**	**53.6**	**94.1**	**144.8**	**146.2**	**104.2**	***1231***

3.1 Probability function distribution

The appropriate probability distributions to match the observed rainfall for all stations was carried out based on goodness-of-fit tests. The quantiles (1, 2, 3, 10, 25, 50, 75, 90, 91, 92, and 99 percent) were determined for the selected probability distribution; more for the two extremes of the distribution compared to central part of the distribution. This focuses the statistical assessment at the two extremes where more variations occur between the observed, annual-maximum rainfall and the selected frequency distributions.

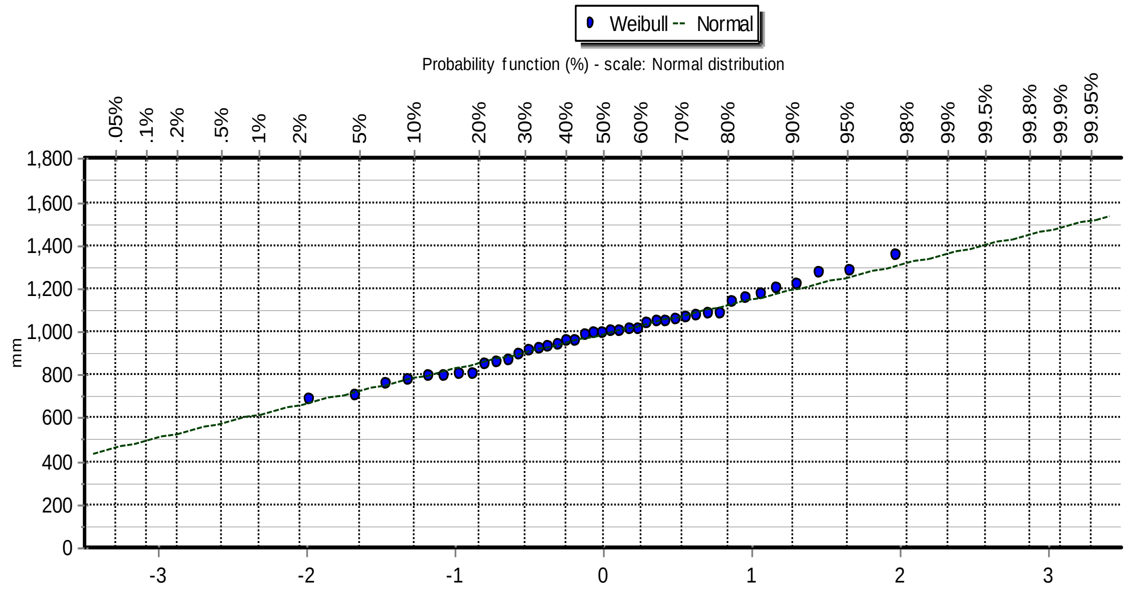

Figure 6: Rainfall probability function Distribution at Kigali.

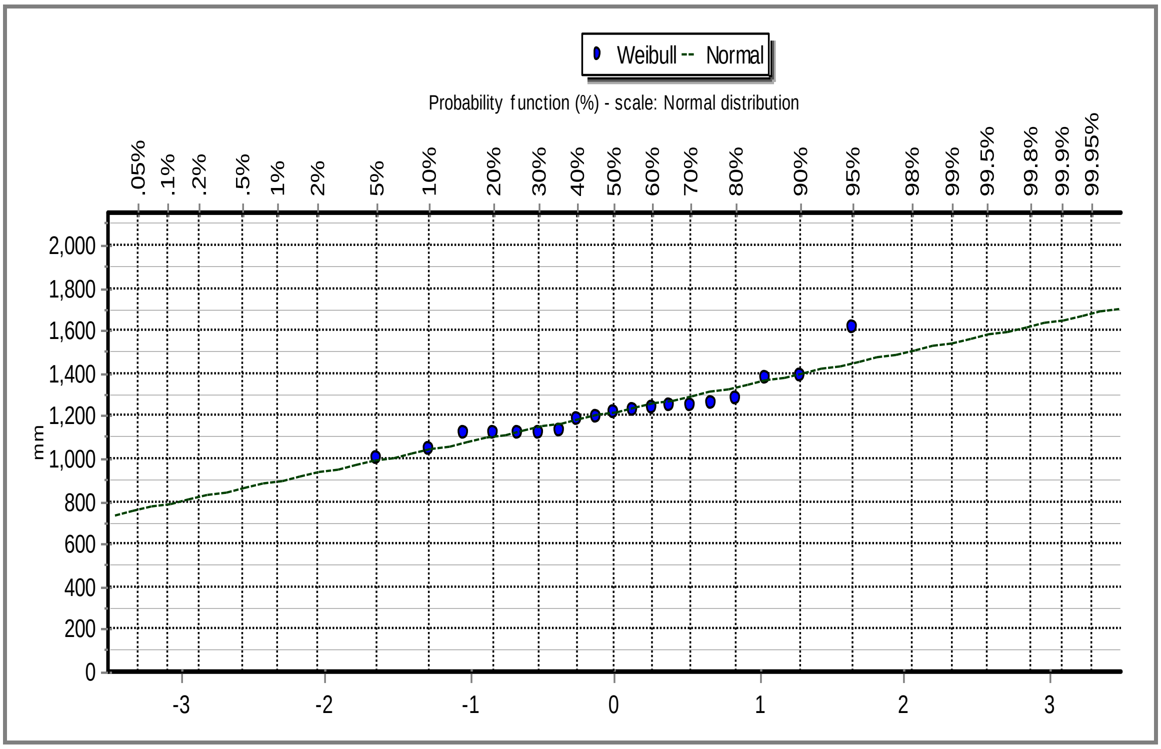

Figure 7: Rainfall data probability function distribution at Byimana.

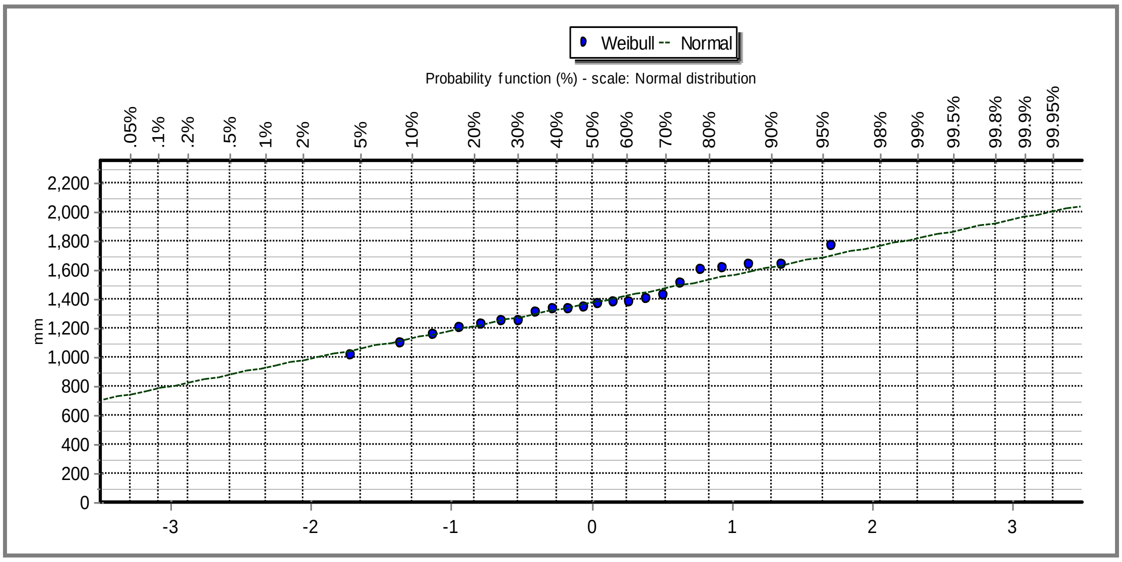

Figure 8: Rainfall probability function distribution at Muramba.

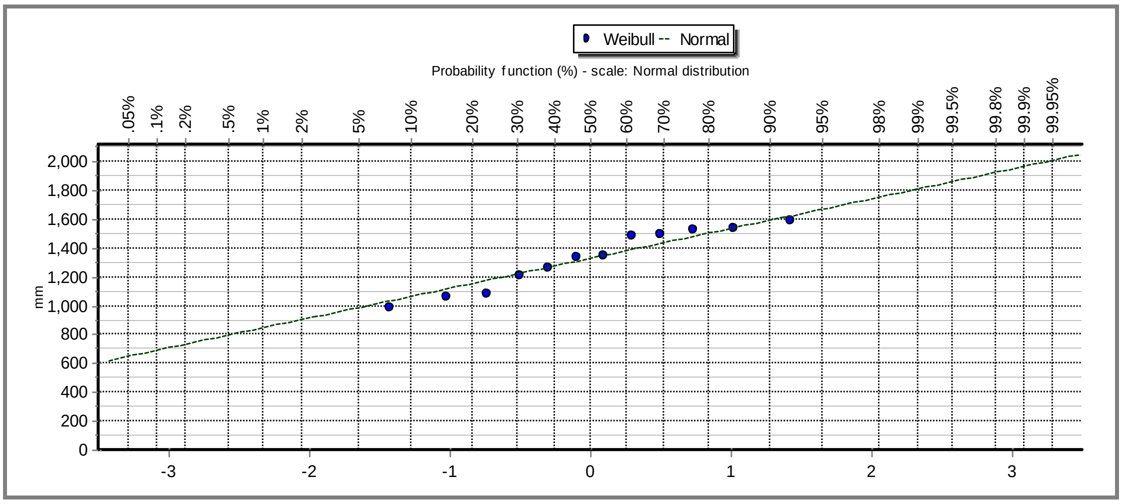

Figure 9: Rainfall data probability Distribution at Kanyanza.

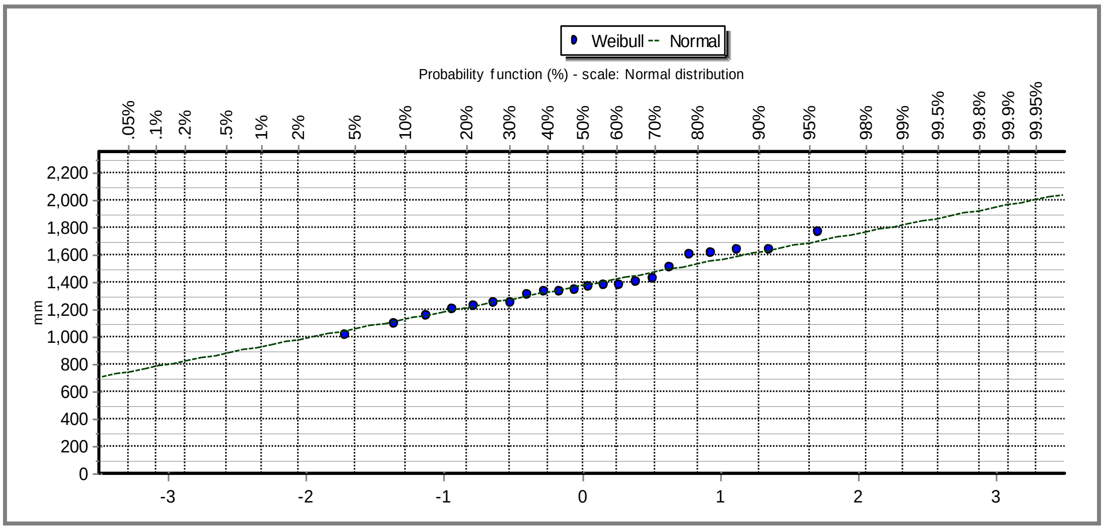

Figure 10: Muramba corrected rainfall data probability distribution.

3.2 Homogeneity Check / Analysis of double mass plots

Displaying the double mass plots was the most common way of investigating the homogeneity of rainfall time series. The method is applied on annual samples of two or more time series, where the first time series was used for investigating the homogeneity, while the others are considered to be homogenous. According to the methodology, graphs are plotted with the points of coordinates of the cumulative rainfall of the dependent station on the X axis and the cumulative rainfall for the independent time series on the Y axis. A "break" in the line formed by these points would indicate possible unevenness of the samples.

The rainfall data from Kigali was used as a reference (plotted on all of the following graphs on the x-axis) since Kigali has the longest record of precipitation data.

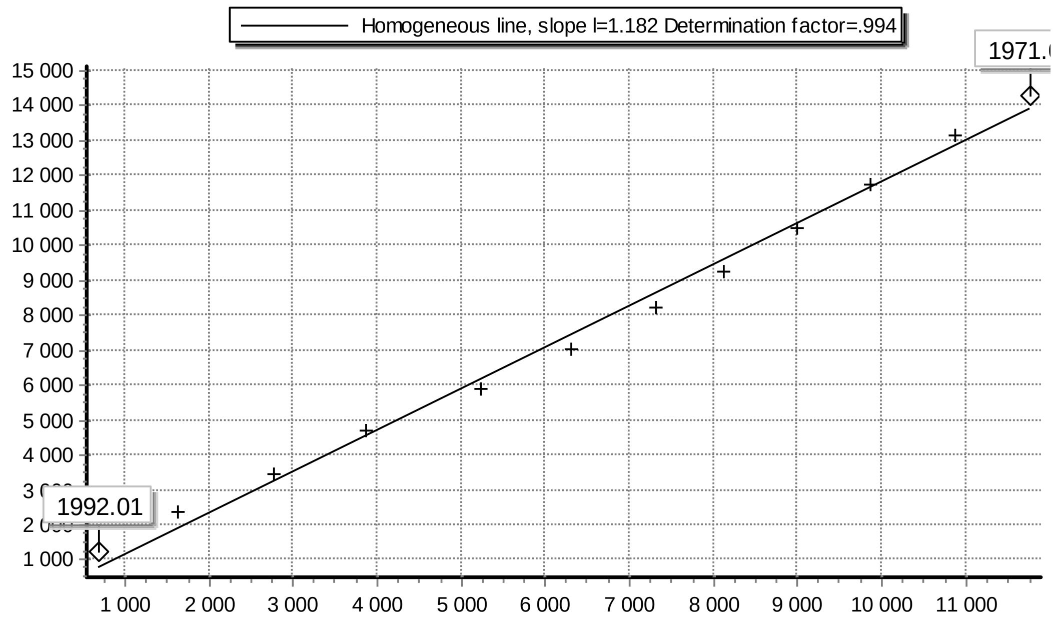

Figure 11: Double mass curve Kigali (x-Axis) – Byimana (y-Axis).

In the figure 11 (determination factor 0.974 – 1) it was observed that the data from the four different stations was homogenous and had been used. The less precise data station is Kibangu with a determination factor of 0.974.

3.4 Annual Rainfall linear relationship

Annual data were shown in the following figure with correlation of the rainfall data for the 4 meteorological stations in the near surrounding of Makera compared with the station in Kigali.

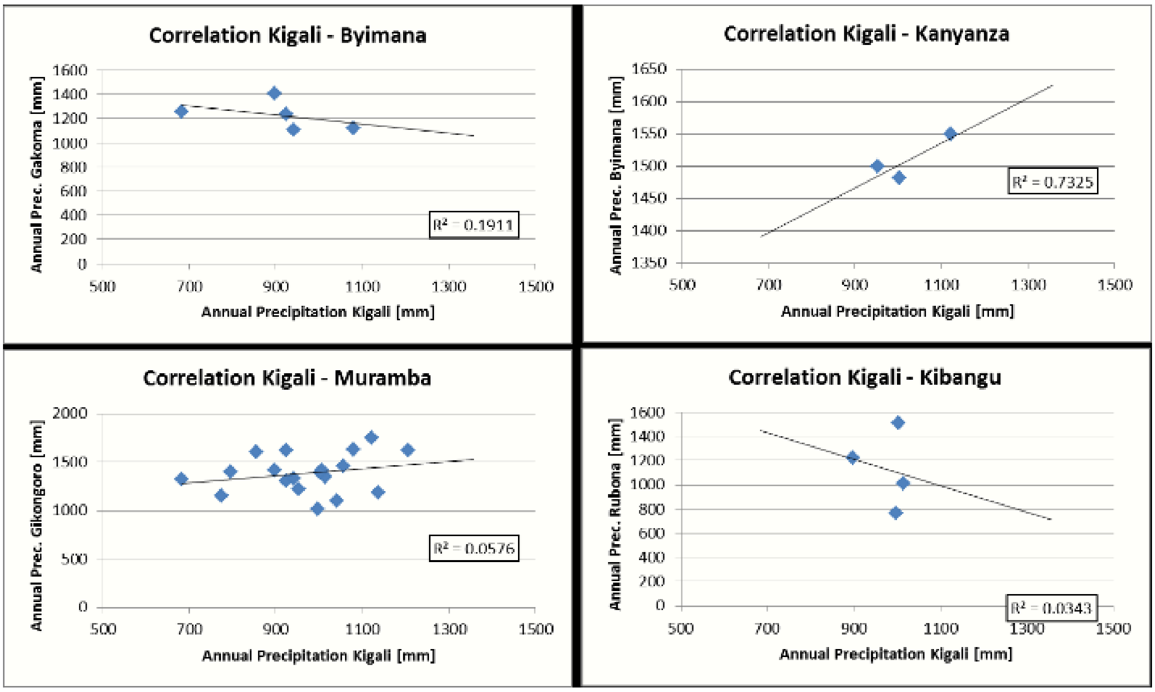

Figure 12: Coefficient of determination R^2 of annual data Byimana, Kanyanza, Muramba and Kibangu with Kigali.

As it has been shown, the correlation between 4 stations compared to the station in Kigali did not suit properly and could be recommended in terms of linear regression. The most distinctive exists between Kigali and Kanyanza with a coefficient of determination of 0.73 which was classified as strong dependency.

In general no correlations identified between the 4 surrounding stations at Makera due to the small amount of annual values available for 3 of 4 stations

Table 7: annual rainfall relationship.

Stations	R^2	r	Remarks
Kigali - Byimana	0.1911	0.44	Not accepted
Kigali - Kanyanza	0.7325	0.86	Accepted
Kigali- Muramba	0.0576	0.24	Not accepted
Kigali - Kibangu	0.0343	0.19	Not accepted

Except for Kanyanza station the correlation coefficient was not accepted, as it was less than 0.5.

3.5 Monthly Rainfall linear relationship

The statistical dependencies (coefficient of determination) for monthly data were additionally compared with the data from Kigali station.

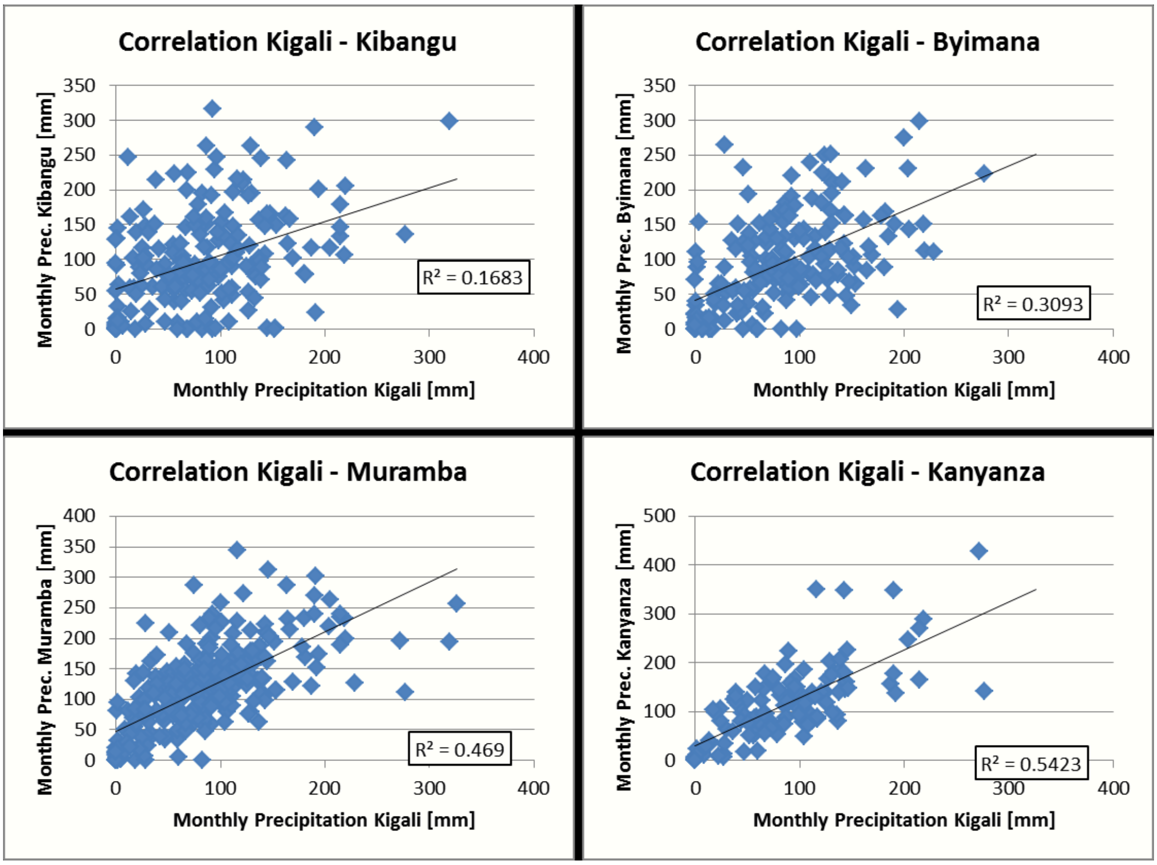

Figure 13: Monthly data relationship at Kibangu, Byimana, Muramba and Kanyanza with Kigali.

The correlation based on monthly data was slightly stronger than the correlation on annual data. However, the coefficient of determination R^2 range from 0.17 to 0.54 is not very distinctive due to the very limited amount of complete annual records from surrounding stations, Kigali has been included in the calculations despite the rather weak correlation. This assumption is on the safe side, as the recorded precipitation values in Kigali are generally lower than for the stations nearby Makera site.

Table 8: Annual Rainfall Relationship.

Stations	R^2	r	Remarks
Kigali - Byimana	0.1683	0.41	Not accepted
Kigali - Kanyanza	0.3093	0.56	Accepted
Kigali- Muramba	0.469	0.68	Accepted
Kigali - Kibangu	0.5423	0.74	Accepted

Except Byimana Station the observed were positively correlated as it was great than 0.5.[5]

3.6 Makera River Flow analysis

The observed Makera river Flow was shown in the table below:

Table 9: Flow measurements.

Months	Flow(m3/s)	Flow(liter/s)
August,2016	0.01	10lit/sec
September,2016	0.013	13lit/sec
November,2016	0.090	9lit/sec
February,2017	0.019	19lit/sec

The lowest value Q = 10 l/s was observed in August 2016. The analysis shown that the flow of 10 l/s has been recorded after a very dry period and could resemble the base flow. Additionally the theoretical runoff has been analyzed using a runoff coefficient of 12.8 % adopted by MINAGRI in dry land. The theoretical curve, derived from the precipitation data, shows no flow in June. As this distribution calculates the river flow according to the rainfall distribution with 80 % exceedance probability, no measured rainfall results in no flow in the distribution, as the base flow cannot be considered.

Therefore the Nakano Curve should be utilized for further investigations, as it is based on measurements and is well documented.

Based on Nakano Curve the lowest expected flow in August was 7liter/second (MINAGRI, 2012). The sample measured loosely grouped around the runoff curve. The measured sample was too small to draw any conclusions regarding the validity of the utilized runoff coefficient or distribution. Nakano states: “Sharp flood by surface flow happens around 2 or 3 hours after peak rain.” Within the “severe flood disasters” if have been delayed, therefore indicating a large base flow, where the study was conducted. The base flow was heavily depending on the sub-surface conditions in the catchment and therefore highly site-specific. Without detailed data (rainfall, stream flow) the effect could not be considered in a satisfactory way. Therefore assumptions regarding the storm runoff have to be made. The Soil Conservation Services-Model which used for several studies in East Africa and Rwanda has been applied.

The calculated storm runoff of ~25-30% is in line with other studies (for similar projects) in Rwanda and was therefore not be seen as unreasonable. Considering different approaches and Models it was observed that a coefficient range from 10%-15% depending on the input parameters, in between all values could be justified, however using the Nakano value of 12.8 is seen to be on safe side.

Table 10: Estimated and observed stream flow in Makera River.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Run Coeff	5%	4%	4%	18%	23%	8%	6%	3%	5%	7%	7%	7%	97%
Theoretical	0.011	0.010	0.009	0.042	0.052	0.019	0.013	0.007	0.012	0.016	0.016	0.016	0.018
Observed		0.019				0.011	0.010	0.01					

3.7 Ground recharge estimation

In order to fulfill the satisfaction of crop water demand other resources of water rather than surface water (river and direct runoff) were evaluated. In Makera marshland five permanent water tap were found i.e their location and recorded discharge was shown in the following table:

Table 11: Location of water tabs and their discharge.

#	X (m)	Y (m)	Discharge (L/sec)	Discharge (12hours)
1	473770	4771516	0.5	43.2
2	473091	4772512	0.7	60.48
3	472304	4771909	0.8	69.12
4	472742	4772930	0.6	51.84
5	474033	4771556	0.5	43.2
Total (m3/day)				**267.84**

The second option was to measure discharge of the river from inlet and measure the discharge at downstream, with reference to this different measurements were made as it was shown in the figure below:

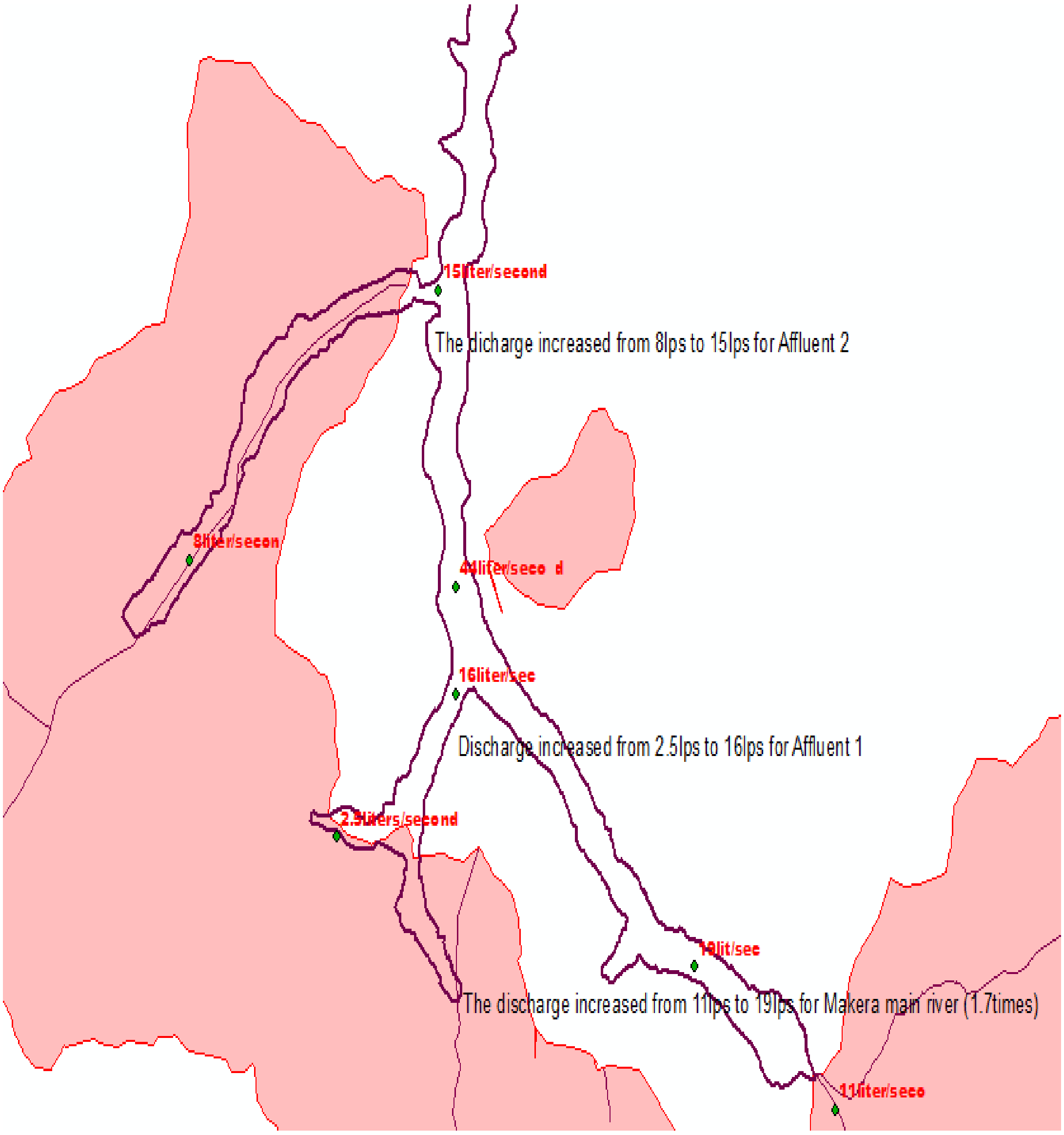

Figure 14: stream flow measurement made on February 2017.

The third option to evaluate ground water was to consider the recharge in the open well, which excavated in November and the ground recharge assessment figure below, it was observed that recharge was 3.5lit/day, considering the targeted to use ground whole basin the volume of recharge per day will 246m3/day.

3.8 Irrigation water requirement

Considering the crop coefficient and ETO determined using CropWat software, and considering effective rainfall determined by considering 80% of 20% risk failure rainfall, net water requirement was determined.

Table 12: Eto Calculation.

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo	Eto
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day	mm/Month
January	15.3	26.7	77	207	4.6	16.2	3.65	109.5
February	15.5	27.1	75	225	4.7	16.8	3.91	117.3
March	15.5	26.7	79	225	4.5	16.6	3.7	111
April	15.8	26	83	199	4.4	15.8	3.32	99.6
May	15.9	25.7	80	216	4.7	15.3	3.3	99
June	15	26.2	68	225	7.3	18.3	4.08	122.4
July	14.8	26.9	60	233	7.4	18.7	4.51	135.3
August	15.7	27.8	60	259	6.4	18.3	4.79	143.7
September	15.6	27.9	69	268	5.6	17.9	4.49	134.7
October	15.6	27	75	251	5.2	17.5	4.07	122.1
November	15.3	25.9	81	225	4.6	16.3	3.49	104.7
December	15.3	26.2	79	259	5	16.6	3.67	110.1
Average	15.4	26.7	73.8	232.7	5.4	17.0	3.9	117.5

3.9 Crop Water Requirements and Net and Gross

Based on the above presented crop structure and cropping pattern, the crop water requirements have been calculated using the FAO - CROPWAT specialized software. The results are presented in table below. For estimating the gross irrigation water requirements following efficiencies were assumed.

Field irrigation application efficiency and conveyance efficiency = 74%

As per observation in dry season available cannot afford the crop demand per season C hence it is planned to cultivate 100% in rainy season and 37% in dry season. The water demand was shown in the following sections:

Table 13: Gross Irrigation Water Requirements.

Crops	Area Occupation (% of total)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL or PEAK
Maize, Leguminous & Vegetables	50%	Maize		Vegetables			Leguminous (Grean beans)			Maize				50%
Leguminous, and Maize	50%		Maize				None			Leguminous (green beans)				50%
Percent of Cultivated Area	100%	100%	100%	100%	100%	100%	50%	50%	50%	100%	100%	100%	100%	100%
Total Net Crop Water Requirements (mm/month)		5.06	8.36	20.39	19.00	30.09	50.17	48.61	40.50	12.12	46.11	20.15	26.34	326.89 mm/year
Total Gross Crop Water Requirements (mm/month)		6.32	10.45	25.49	23.75	37.61	62.71	60.76	50.63	15.15	57.64	25.18	32.93	408.61 mm/year
Total Gross Crop Water Requirements (m³/ha/month)		100	100	100	100	100	68	68	68	68	68	68	68	976 m3/ha/year
Total irrigated area (ha/month)		109	109	109	109	109	109	109	109	109	109	109	109	100 / 50 **
Total Irrigation Water Demand (m³/ha)		63.19	104.50	254.88	237.50	376.13	627.10	607.56	506.26	151.50	576.38	251.83	329.29	4086 m3/ha/year
Irigation Duty for 24 hours/day (l/s/ha)														0.381 l/s//ha
Irigation Duty for 12 hours/day (l/s/ha)														0.762 l/s//ha

The peak gross irrigation water requirements also known as Gross Peak Water Demand is recorded in June, and amounts 627 m3/ha. This value is used further for designing of the water conveyance and distribution irrigation infrastructure. The total yearly gross water requirements are of 4086m3/year. The table above shows that only in June, July and August the entire water requirement is met by irrigation. Outside the period June - August only a fraction varying from 15% to 95% of the water requirement is met by irrigation because rain is supplying part of the crop water requirements.

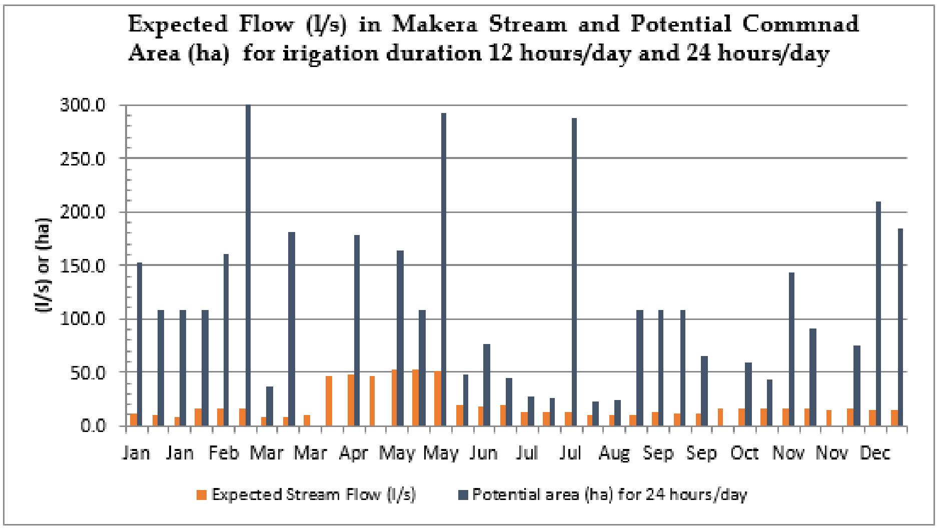

Figure 15: Gross irrigation demand with respective to the irrigated land.

3.10 Sizing of the command area

From the figure above can be seen that most of irrigation water is needed in June, July and August and it amounts 1721 m3/ha representing 42% (irrigating 22ha or 20.2% of the total) of the yearly water demand (4086 m3/ha). Such distribution is common for Supplementary Irrigation.

Considering existing of water taps in the command area and river fluctuation as shown in figure 14 and table 11; it was observed that recharge was 3.5lit/day, considering the targeted to use ground whole basin the volume of recharge per day will 246m3/day which can irrigate which can contribute up to 18ha in dry season hence the possible irrigable land in dry season is 22ha + 18ha = 40ha.

3.11 Choice of the land to irrigate in dry season

This was based on availability of water in the river and water cumulative, the most potential zone was found in the downstream of the marshland where all water are drained to. It was observed that at this section water was increased up 29% which shows the contribution of ground water. The following figure was shown the distribution of the command area. The calculation shown that at the weir no 2 located at downstream the flow vary from 13.1l/sec to 24.1liter/ second in June, July and August. Considering the above flow the minimum area to irrigate was 42.5ha hence the consultant decided to irrigate 40ha in dry season located at downstream of weir number 2.

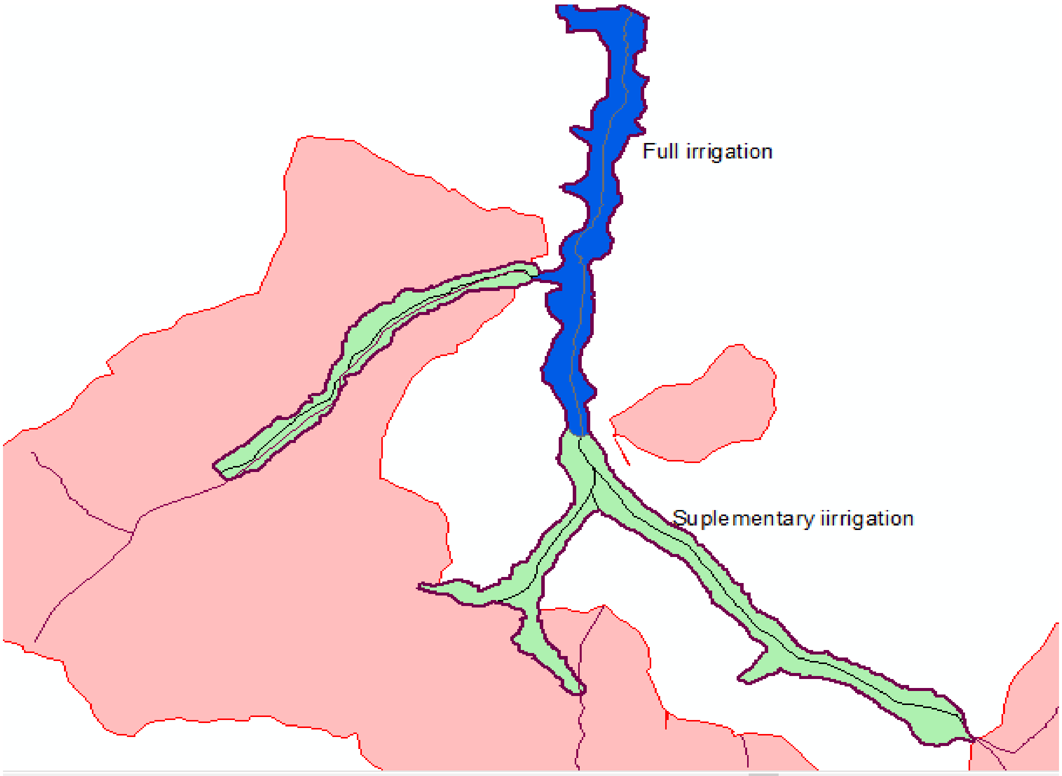

Figure 16: Planned land to be cultivated in dry season.

4 CONCLUSION

The statistical analysis of the rainfall data leads into the following conclusion

- The daily time series from the four stations were not complete. Only 56 % of the possible values have been recorded in a total period of 44 years, 1971 – 2014.
- No statistical dependency up to a medium correlation observed between the annual data of Kigali and the four stations close to Makera
- A medium statistical dependency was observed between the monthly data of Kigali and the four stations close to Makera
- Due to the lack of recorded data, the statistical dependency in between the stations surrounding Makera site cannot be analysed reliably.
- The rainfall in Rwanda is locally restricted and varies extremely within a few kilometers.

Consider three cropping seasons (A, B and C) the total growth water demand was 4086m3/year and 627m3/ha/year. Based on effective rainfall, river flow in the river and ground water resources; available size of command area was 109ha as supplementary irrigation in rain season and 40ha for complete irrigation in dry season.

5 REFERENCE

1. Mockus V, National engineering handbook section 4 hydrology, United State (2.85), 1972.
2. Pimpale, A.R., S.S. Hiwase and P.G. Patil. Probability analysis of rainfall at Akola, Maharashtra. Journal of Soil and Water Conservation, India, 2001; 45: 129-132.
3. B Mutreja K. N., Applied hydrology; New Delhi (668-794), 1990.
4. WaterNet, Water and Sustainable Development for Improved Livelihoods. WaterNet/ WARFSA/GWP-SA, International conference on 9th WaterNet Symposium, 29-31 October 2008, Johannesburg, South Africa, 2008.
5. Zarris, D., Analysis of the environmental flow requirement incorporating the effective discharge concept, Proceedings of the 6th International Symposium on Environmental Hydraulics, Athens, 1125–1130, International Association of Hydraulic Research, National Technical University of Athens, 2010.