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The Evaluation of the Rainfall-Runoff Effects to the Variation of Hydrology of Migina Catchment in Rwanda

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Abstract

The basic implementation of agricultural development and crop production increase in marshland of Migina catchment (ca: 257.4 km^2) requires strong and technical analysis of the effect and change of hydro-meteorological aspects from rainfall-runoff parameters. This paper focuses on the effect of rainfall and runoff in Migina catchment and describes in details the study of rainfall and runoff availability in Migina catchment. The study was limited to the analysis of hydrological aspects of the catchment including the water balance. Specifically the paper specifies the seasonally hydrologic variation, evaluates the performance of the catchment area on the environmental activities and studies the rainfall-runoff effect on the variation of hydrology of the catchment. The required data were collected from the thirteen (13) meteorological stations located in the catchment (Meteo-Rwanda, 2008) and historical data from other institutions like: Center of GIS of the University of Rwanda, Ministry of Agriculture (MINAGRI), Ministry of Environment and Ministry of Infrastructure (MININFRA). Arithmetic mean method was used for the determination of annual rainfall. The annual evapotranspiration has been calculated through evaporation pan at Rwasave and Gisunzu stations for data recorded from 2010 to 2012. Annual discharge was determined using rating curve method at Munyazi, Mukura and Cyihene rivers for discharge data of 2010 to 2012. Simple formulas were used in calculations, and the adjusted crop coefficient was found to be 0.66, and the annual rainfall varies with respect to weather or Climate events like Temperature increase.

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This can have major effects on society, economy and the environment and was found to be 1569.5mm. The results show that the Migina catchment land use is dominated by the agricultural at 70% (rice, maize and beans) and livestock activities. It is recommended to contribute to the amelioration of Agricultural activities to increase the Rwandan primary sector production and sensitize the population on Rwanda seasonal changes and good governmental catchment protection plan.

Key words: Migina catchment; Rainfall analysis; Runoff analysis; Rwanda; Variation.

1. Introduction

The variation of hydrology is the situation changing the almost physical and environmental aspect of the region in our living land. This change is enhanced by hydro-meteorological factors like sun rays increase, temperature difference in different earth's area, seasonal variation based on the loss and /or the precipitation abundance, [1].

The Migina catchment is the water reservoir (storage) located in the southern province of Rwanda where it recovers three districts including: Huye, Gisagara and Nyaruguru district. From many years ago, this catchment constitutes the principal water resource and contributes to the alimentation of water to several people accommodating the area.

Villages in which the catchment is located; get water from several rivers within Migina catchment. Rivers:Mukura,Musizi,Akaremera,Ruvuzo,Kidobogo,Kadahokwa,Munyazi,Migina,Rwimbogo,Cyenzubuhoro,etc are of the paramount importance for agricultural domain[1].. The precipitation of water vapor from the atmosphere occurs in many forms all over the world depending to the geographical location, the most important of which are rain and snow. The drainage in most urban communities is designed primarily to protect/control runoff from rainfall.

The runoff, amount of water which is recovering the surface hydrology produced by the abundance of the rainfall, is the most important part of surface water hydrology in the determination of the hydrological and the topographical parameters of the region [2].

The land area that can contribute to the runoff at any particular location is determined by the shape and topography of the surrounding region. The potential contributing area is known as the watershed and the area within over which the rainfall occurs is called the catchment area characterized by the quantity, quality, timing and distribution of run-off [3].

1.1 Limitation

The Evaluation of the Rainfall-Runoff Effects to the Variation of Hydrology of Migina Catchment in Rwanda

Covers the study of rainfall and runoff availability in Migina catchment, it specify the hydrological variation based on seasonal periodic change, evaluates the performance of the catchment area on the environmental activities and studies the rainfall-runoff effect on the variation of hydrology of the catchment.

1.2 Description of study area

Migina catchment is meso-scale catchment of approximately 260 km^2 and coordinates ranging from 2^{o}32" to 2^{o}48" latitude south and from 29^{o}40" to 29^{o}48" longitude East, contains approximately 103,000 inhabitants [4].Migina catchment, located in early southern part of our country, as shown above, is covered by three district in which (64.12 Km^2) are in eastern part of Gisagara, (52.62 Km^2) in southern -western of Nyaruguru and (140.52 Km^2) in north-west of Huye district. Migina catchment is divided into 5 sub-catchments according to the main rivers draining area (Munyazi-Rwabuye, Mukura, Cyihene-Kansi, Akagera and Migina). The delineation of this catchment has been done by using GIS-software, Digital Elevation Model (DM) and the Topographic Map for determination of catchment area and identifying catchment characteristics [5]. Fig.1 shows Migina catchment boundaries:

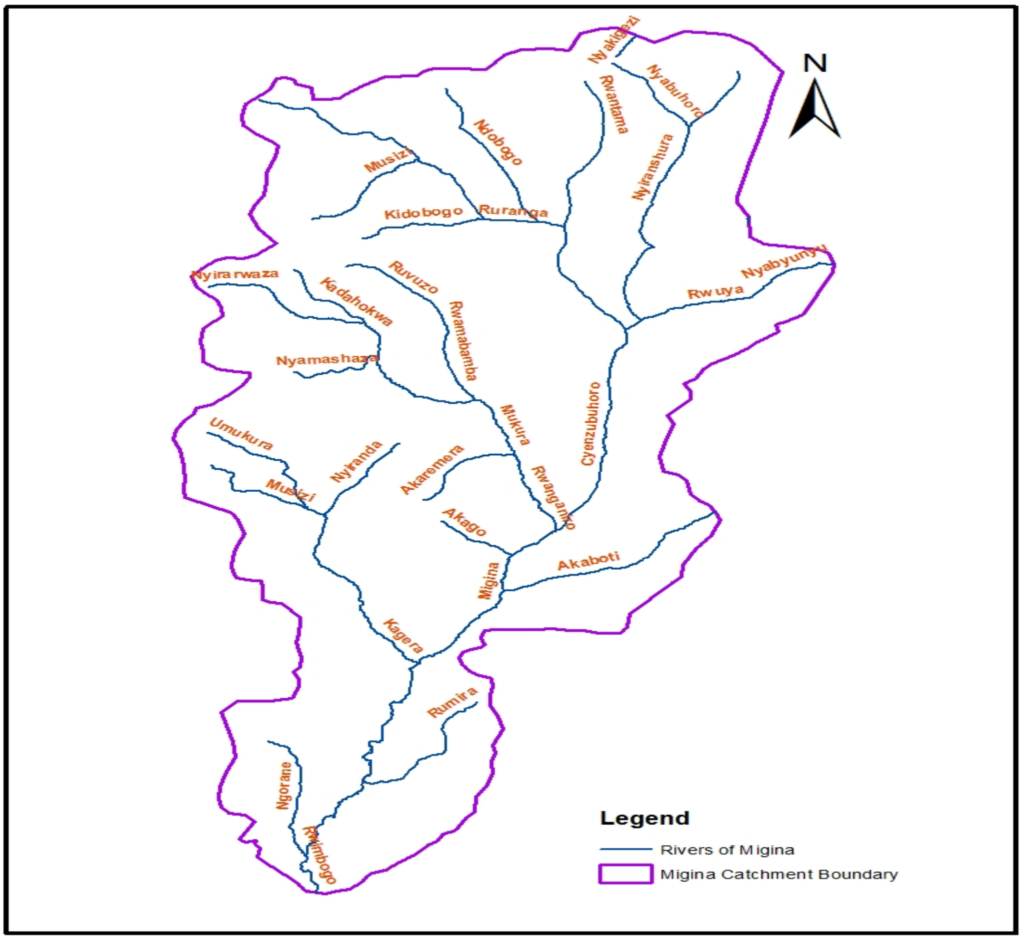

Figure 1: Hydrological network of Migina Catchment boundaries

1.3 Migina catchment land use map

The vegetation has impact on the infiltration capacity; the area densely covered by vegetation produces less amount of runoff than the bare ground place. Land cover such as forest delays runoff flow on gentle slopes giving the more time to infiltrate and to evaporate [6].

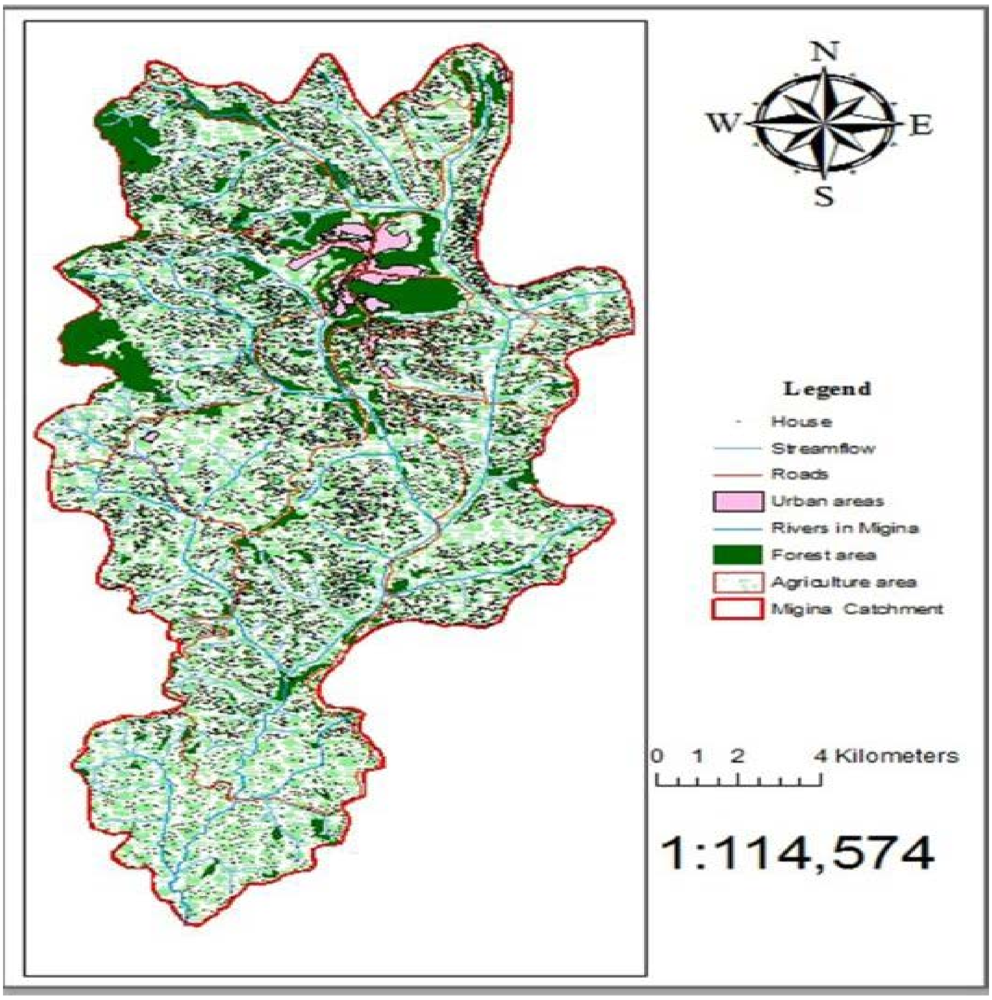

Figure 2: Migina catchment land cover and land use

2. Methodology

The available data used in this study in Migina catchment were provided by the Ministry of Natural Resources (MINIRENA) and Rwanda meteorological office. Some additional data like topographic map, DEM map, land use and land cover; crop factors were obtained from other institutions like, FAO, National University of Rwanda (NUR-CGIS Center) and others were collected manually. After getting all data, we did a detailed analysis with mass curve of rainfall, average annual precipitation, average monthly precipitation and daily quantity of precipitation in the catchment area. This has helped us to estimate the total volume of rainfall received in catchment during this period as given in eq. 1.

Total Volume of rainfall (m^3) is expressed below: $\boldsymbol{TR} * \boldsymbol{A}$ *(1)*

Where TR: Total rainfall (mm) and A is area of catchment (m^2). In Migina meso–scale catchment, there are thirteen (13) rain gauges, five (5) river gauging stations with divers, two (2) evaporation pans, two (2) weather stations, three (3) tipping buckets and eleven (11) piezometers have been installed from April to July 2009 on two transactions. All these 13 stations were visited and coordinates were recorded as shown in Table 1.

The variation of hydrology study (Migina catchment) is depending on the amount of rainfall (inflow) and outflow (evapo-transpiration-runoff) variability.

***The inflow*:** This is contributed by the rainfall falling in the catchment; it is calculated from data obtained at Ten stations; Sovu, Save, Mpare, Vumbi and C-GIS (Butare) Muyira, Kansi and Kibirizi, Rwasave by using Excel Software and the Theissen polygon method.

Table 1: Stations installed in the Migina catchment

Station	Latitude(UTM)	Longitude(UTM)	Altitude(m)	Period	Collected data
Rango	805464	9707671	1708	2010-2011	Precipitation
Mubumbano	803144	9705574	1808	2010-2011	Precipitation
Murama	800129	9699128	1720	2010-2011	Precipitation
Vumbi	800382	9709831	1824	2010-2011	Precipitation
Mpare	803030	9711007	1691	2010-2011	Precipitation
Sovu	800824	9717176	1764	2010-2011	Precipitation
Save B	808328	9718265	1770	2010-2011	Precipitation
Muyira	809227	9708819	1725	2010-2011	Precipitation
Kibirizi	809300	9706476	1712	2010-2011	Precipitation
Gisunzu	805956	9701364	1684	2010-2011	Evaporation
Rwasave	806184	9712510	1665	2010-2011	Evaporation
Kansi A	805555	9702817	1685	2010-2011	Discharge
CGIS(nur)	801485	9713790	1726	2010-2011	Precipitation, Wind, T^o
Munyazi-Rwabuye	806263	9713884	1662	2010-2011	Discharge

The *outflow:* was contributed by the discharge at the outlet of the catchment measured at Munyazi-Rwabuye station, Mukura station and the evapo-transpiration calculated from evaporation, measured by evaporation pan at Rwasave fishpond.

- Water balance of the catchment was given by eq. 2.

STORAGES= INFLOWS - OUTFLOWS.

$$\Delta S \quad = P \quad - \quad (ET + Q) \qquad (2)$$

With ΔS: Storage, R: Runoff, ET: Evapo-transpiration and P: Precipitation.

The rainfall has been determined by using arithmetic mean method as expressed in the equation 2.The monthly average rainfall has been calculated in Table 2 by using data recorded for period of 2 years (2010-2011) at 13 rain gages installed in Migina catchment.

Table 2: Average depth method or arithmetic mean method for rainfall determination.

Year	Month	Rango	Mubumbano	Murama	Vumbi	Mpare	Sovu	Save B	P(mm)
2010	January	199.3	209.8	182.5	335.3	226.4	151.9	190.3	
	February		260.6	238.9	237.6	183.4	180.5	183.6	
		208.4							
	March	320.9	161.6	159.9	153	148	158	84.9	
	April	390.9	168.2	144.9	226.4	245.6	158.8	123.5	
	May	390.9	259.2	177.4	154	234.6	163.3	111.6	
	June	32	33.4	53.8	46.8	27.5	23.3	11.9	
	July	0	0	0	0	0	0	0	
	August	0	0	0	0	0	0	0	
	September	256.7	77.1	103	51	74.2	126.5	103.1	
	October	231	51.8	114.3	47.3	90.7	107.7	53.1	
	November	286.9	147.4	157.1	108.4	141.2	39.9	115.9	
	December	151.3	87.4	108.6	109.4	154	77.5	185.1	
2011	January	196.2	100.8	101.6	97.9	118.2	118.2	98	
	February	239.3	144.7	89.8	74.4	132.9	192	150.8	
	March	220	130.5	178.2	126.9	132.4	126.9	123.7	
	April	481.7	174.2	130.5	137.2	174.8	131.1	158.1	
	May	383.1	170.6	192.3	169	204.1	136.6	205.2	↓
	June	0	0	68.7	0	0	0	144.8	

Year	Month	Muyira	Kibirizi	Gisunzu	Rwasave	Kansi A	CGIS	P(mm)
2010	January	213.6	148.9	219.7	134.4	147.1	183.2	195
	February	280.2	167.9	253.5	288.7	288.2	221.2	230.2
	March	229.4	134	161.4	205.5	194	154.2	174.2
	April	196.1	142.6	181.8	112.6	138.8	179.4	185.3
	May	214.8	176.3	141.1	172.2	166.3	198.6	196.9
	June	11	7.7	27.5	17.9	37.5	17.2	26.7
	July	0	0	0	0	0	0	0
	August	0	0	0	0	0	0	0
	September	66.9	59.1	79.4	106.3	97.8	71.4	97.8
	October	62.3	45.8	45.9	92.1	52.3	69.9	82
	November	172.3	99.8	120.5	138.4	89.8	114.8	133.2
	December	70.1	103.2	119.6	107.2	93.6	91.9	112.2
2011	January	87	108.1	73.6	154.9	293.3	119.1	128.2
	February	166.8	132.5	125	197.5	179.7	141.8	151.3
	March	326.8	126.5	186.1	145.3	148.6	143.3	162.7
	April	546.3	343.3	228.6	198.5	179.3	234.3	239.8
	May	145.6	266.3	187.2	190.2	157.8	189	199.8
	June	75.1	0	78.7	0	70.6	67.9	38.9
Total Average Monthly Rainfall obtained from gauges stations of the Catchment								
Departing from station monthly Rainfall.								130.78

The evapo-transpiration data were collected from Rwasave and Gisunzu stations by using evaporation class A pan and were calculated as given in eq. 3, 4 and 5.

$$Er=K*Ep \quad (3)$$

$$PET=Kc*Epan \quad (4)$$

$$PET=0.66*Epan \quad (5)$$

Where; Er=Reservoir Evaporation

Ep=Pan Evaporation

Kc=pan coefficient and Kc=0.66.

The runoff was calculated by using the rating curve method which shows relationship between discharge and water level at a given gauging station in time and the results are shown in Table 4.

Table 3: Determination of E & ET at Rwasave and Gisunzu stations

Station year	Rwasave evaporation pan			Gisunzu Evaporation pan	
	Month	**E(mm)**	**PET(mm)**	**E(mm)**	**PET(mm)**
2010	January	134.4	88.7	134.4	88.7
	February.	100.9	66.6	100.9	66.6
	March	103.6	68.4	103.6	68.4
	April	124.9	82.4	124.9	82.4
	May	116.35	76.8	116.35	76.8
	June	135.58	89.5	130.5	86.2
	July	198	130.7	147	97
	August	194	128.1	170	112.2
	September	179.33	118.4	154.48	101.9
	October	170.13	112.3	153.93	101.6
	November	147.42	97.3	138.54	91.4
	December	151.25	99.8	129.63	85.5
2011	January	154.92	102.3	116.61	76.9
	February	183.54	121.2	127.03	83.8
	March	181.29	119.6	141.17	93.3
	April	98.0375	64.7	157.75	104.1
	May	91.245	60.2	87.32	57.6
Average monthly E &ET			95.7	131.42	86.72
Average annual E &ET			1148.4	1577.04	1040.64

Note that the data described in given table helped to determine, by combination of all water balance components, the behavior of the hydrology of Migina catchment.

Table 4: Discharge water level in selected station of Migina catchment

Date	Mukura river		Kihene-Kansi river		Munyazi- Rwabuye river	
Month& Year	Av.Level H(m)	Discharge Q(m3/s)	Av.Level H(m)	Discharge Q(m3/s)	Av.Level H(m)	Discharge Q(m3/s)
Jan-10	0.74	0.44	0.52	0.51	-	--
Feb-10	0.67	0.24	0.75	0.85	-	--
Mar-10	0.61	0.18	0.5	0.39	--	---
Apr-10	0.66	0.24	0.51	0.43	--	--
May-10	0.75	0.39	0.52	0.49	0.69	0.06
Jun-10	0.66	0.25	0.45	0.31	0.66	0.05
Jul-10	0.61	0.17	0.39	0.26	0.53	0.03
Aug.2010	0.55	0.09	0.33	0.18	0.5	0.01
Sept.2010	0.52	0.09	0.32	0.19	0.48	0.02
Jan.2011	0.4	0.23	0.52	0.44	0.61	0.08
Feb.2011	0.67	0.24	-	-	--	--
Mar.2011	0.61	0.18	-	-	0.7	0.14

3. Results and discussion

3.1. Investigation of hydrological data analysis

From the data collected at Muyira, Mubumbano, Save, Sovu, Rango, Kansi, Kibirizi, Mpare, Vumbi, Murama, Gisunzu, Rwasave and C-GIS stations. The total rainfall volume in m^3 is then determined by multiplying the monthly rainfall (mm) for all stations by corresponding area of the Migina catchment (257.4 km^2). The chart shows that the maximum rainfall in Migina catchment was 230.2mm (in February2010) and 239.8mm (in April2011), the minimum is 0mm (July&August2010) and 38.9mm (June2011). So in general, the rainfall varies periodically.From the evaporation (crop) coefficient Kc (Ke) =0.66 (Table 6) and soil water stress coefficient Ks=0.83 [7], we determine the adjusted coefficient as shown in eq. 6. (climateprediction.net, 2012)

$$K_{adj}=(\sum Ks*Kc)/n \qquad (6)$$

Table 5: Annual average rainfall volume in the Migina catchment

	Year 2010												Year 2011					
Month	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
P(mm)	195	230	174	185	196	26	0	0	97	82	133	112	128	151	162	239	199	38

Months	Rainfall P(mm)	Rainfall in m^3 $P(m^3)=P(mm)*Area(m^2)$,with $260km^2$
Jan-10	195	50700000
Feb-10	230.2	59852000
Mar-10	174.2	45292000
Apr-10	185.3	48178000
May-10	196.9	51194000
Jun-10	26.7	6942000
Jul-10	0	0
Aug-10	0	0
Sep-10	97.8	25428000
Oct-10	82	21320000
Nov-10	133.2	34632000
Dec-10	112.2	29172000
Jan-11	128.2	33332000
Feb-11	151.3	39338000
Mar-11	162.7	42302000
Apr-11	239.8	62348000
May-11	199.8	51948000
Jun-11	38.9	10114000
Monthly Average	**130.7**	**34 005 111.1**
Annual Average	**1 569.5**	**408 061 333.3**

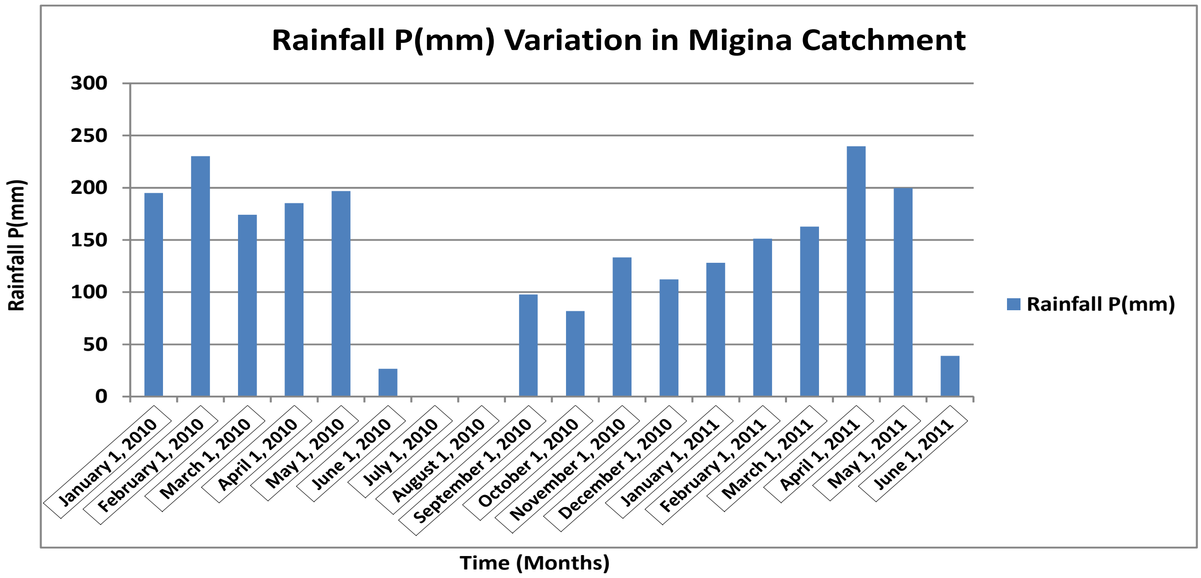

Figure 3: Monthly average rainfall variation in Migina catchment

Table 6: Crop adjusted coefficient

Crop	Kc&Ke	Kadj=(Kc*Ks)/n
Rice	1	0.83
Sorghum	0.25	0.21
Tomatoes	0.22	0.18
Beans	0.76	0.63
Soybeans	0.95	0.78
Cotton	0.5	0.41
Maize	0.2	0.17
Sugarcane	0.8	0.66
Banana	0.65	0.53
Cassava	1.05	0.87
Forest	1	0.83
Sweet potatoes	0.9	0.75
Open ground	0.3	0.25
Kadj= (7.1/13)=0.55		

Table 7 shows that the evapo-transpiration at Rwasave is monthly varied and the monthly average rainfall is 52.6mm with the annual average rainfall of 631.2mm which is different from **917mm/year** what found by Bizirema 2011. This difference shows that it varies with respect to period and used method. The diagram of monthly evaporation and evapo-transpiration variation is drawn below:

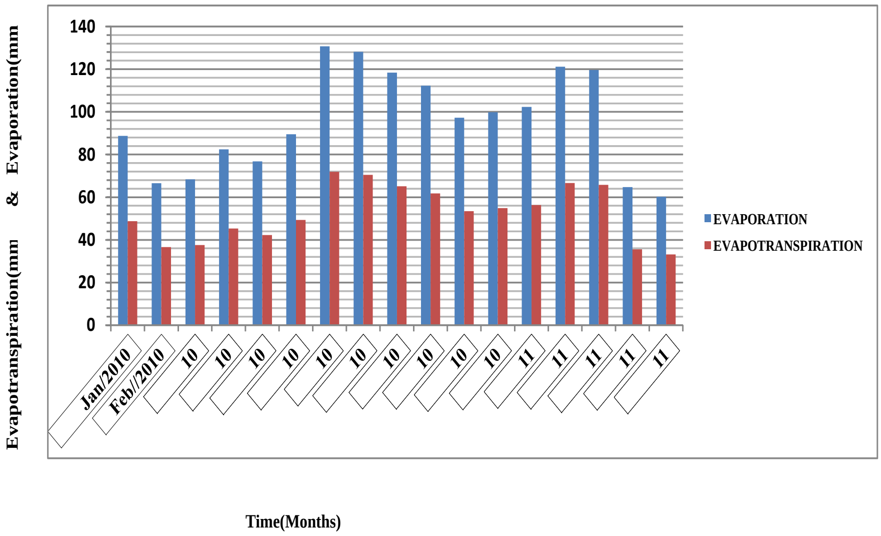

Figure 4: Evaporation-evapo-transpiration variability in the Migina (Rwasave evaporation pan)

Table 7: Actual evapo-transpiration in the Migina catchment.

Months	Rwasave Evaporation pan			Gisunzu Evaporation pan		
	Eref(mm)	AET=Eref*Kadj (mm)	AET(m^3)= AET*A(m^2)	Eref(mm)	AET=Eref*K (mm)	AET(m3)= AET*A(m^2)
Jan-10	88.7	48.8	12 688 000	88.7	48.8	12 688 000
February	66.6	36.6	9 516 000	66.6	36.6	9 516 000
March	68.4	37.6	9776000	68.4	37.6	9776000
April	82.4	45.3	11778000	82.4	45.3	11778000
May	76.8	42.3	10998000	76.8	42.3	10998000
June	89.5	49.3	12818000	86.2	47.4	12324000
July	130.7	71.9	18694000	97	53.4	13884000
August	128.1	70.5	18330000	112.2	61.7	16042000
September	118.4	65.1	16926000	101.9	56.1	14586000
October	112.3	61.8	16068000	101.6	55.9	14534000
November	97.3	53.5	13910000	91.4	50.3	13078000
December	99.8	54.9	14274000	85.5	47.1	12246000
Jan-11	102.3	56.3	14638000	76.9	42.3	10998000
February	121.2	66.7	17342000	83.8	46.1	11986000
March	119.6	65.8	171080000	93.2	51.3	13338000
April	64.7	35.6	9256000	104.1	57.3	14898000
May	60.2	33.2	8632000	57.6	31.7	8242000
Monthly Average	**95.7**	**52.6**	**21442353**	**86.72**	**55.5**	**11100471**
Annual Average	**1148.4**	**631.2**	**257308235**	**1040.64**	**666.1**	**133205647**

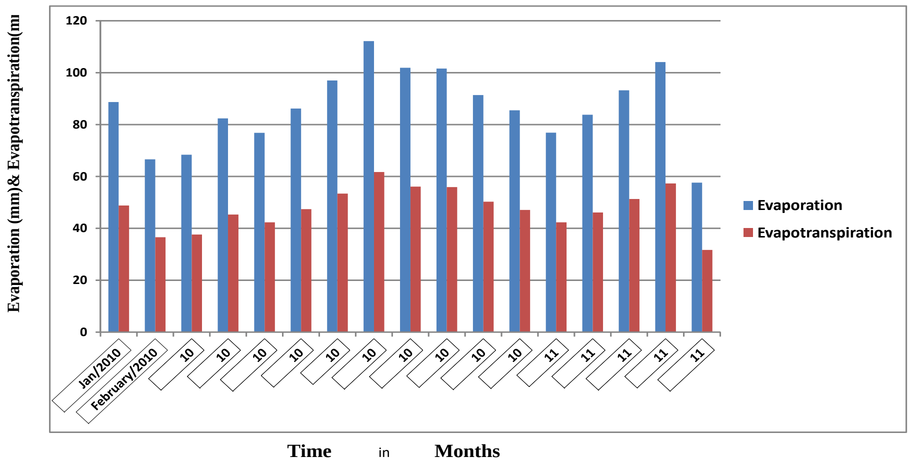

Figure 5: Evaporation-evapo-transpiration variability in Migina (Gisunzu-evaporation pan).

- Figure 4 shows that from Rwasave, the evaporation and evapo-transpiration are monthly varied. The maximum evapo-transpiration was 71.9mm (in July2010) and 66.7mm (Feb 2011), the minimum was 36.6mm (in February 2010) and 33.2mm (in May 2011).The evapo-transpiration from Gisunzu station is drawn in Figure 5.

3.2. Effect of seasonal hydrological variation on catchment's environment

The variation of hydrology of the catchment depends on availability and/or scarcity of rainfall, runoff and storage quantity. The stored water determines how much water table is raised on. This has a strong effect on crop rooting zone and favors the time-period for agricultural activity.

Table 8: Seasonal variation of the hydrology in Migina catchment

Seasons in Year	Rain season1 (Sept-November)	Dry season1 (December-February)	Rain season2 March-May	Dry season2 June-August)	Annually Catchment balance
Rainfall P(mm)	325.2	391.7	1158.7	65.6	**2001.9**
Evapo-transpiration ETC(mm)	273.3	293.1	525.3	354.2	**1445.9**
Runoff Q(mm)	$4.5x10^{-3}$	$33.5x10^{-3}$	$28.9x10^{-3}$	$23x10^{-3}$	**$89.9x10^{-3}$**
Change in Storage(mm)	150.69	59.26	633.4	-288.6	**554.75**
Change in Storage(m^3)	**39179 400**	**15 407 600**	**164 684 000**	**-75 036 000**	**144235000**

Table 8 shows that when rainfall increases, it increases either runoff or infiltration capacity contrary to its decreasing, so is the hydrology variation. This variation affects not only the hydrology but also the environment in general through flooding, drainage capacity requirements and the hydraulic structures for the public health safety and agricultural purpose.

3.3. Generation rating curve

To establish a relationship between discharge and water levels for Munyazi/Rwabuye river in Migina catchment, several discharge measurements were carried out at the gauging stations at different water levels. Munyazi River from January 2010 to March 2011, the corresponding discharge is determined by eq. 7.

$$Y=01.009X^{0.183} \tag{7}$$

Where Y represents water level and

X represents discharge.

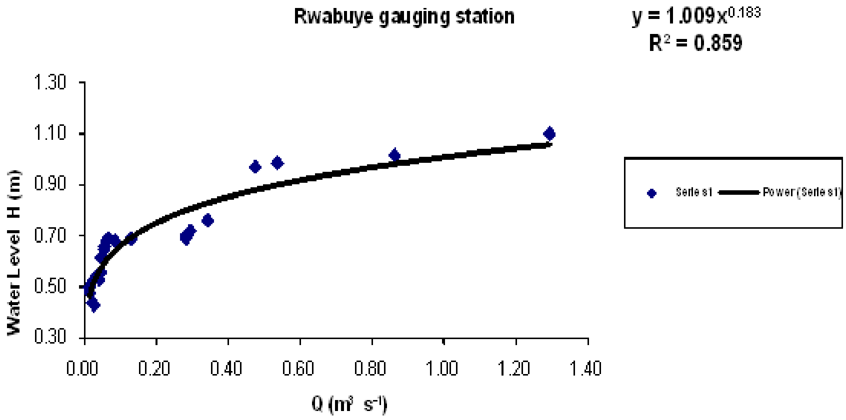

Figure 6: Water Level Vs Discharge at Munyazi-Rwabuye gauging station

Figure 7: Munyazi river discharge measurement and rainfall records (photo taken by eng. Theoneste T. on 28/12/2017, 10:00am)

4. Concluding remarks

The hydro-meteorological data in Rwanda are scarce in time and space with many data gaps due to historical challenges (genocide war, poor filing and data management system). Based on data taken from 2009 to 2011 at different stations installed in Migina catchment (214 km^2) and different visits done to the area in which the research has been conducted, the analysis has been done to determine monthly and annual rainfall, runoff, evapotranspiration and change in storage and the results were presented in various tables. Some of materials used in data collection, shape files of Migina catchment were presented through different figures. Photos taken in different media during the field works were presented and the results were interpreted on different charts. The interpretation and analysis done through all catchment show that total monthly and annual average rainfall in the Migina catchment are respectively 130.78mm and 408 033 600m^3. Total monthly and annual runoff are 2247.44m^{3}and 26 968.5m^3. Total monthly and annual evapo-transpiration are respectively 32542823.4m^3 and 390 513 882.4m^3 and by using equation 10, the total annual storage of the catchment is found to be 17 492

749.1m^3.

5. Recommendations

It is recommended to contribute to the amelioration of Agricultural activities to increase the Rwandan primary sector production and sensitize the population on Rwanda seasonal changes and good governmental catchment protection plan.

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