Setup of a Hydrological Instrumentation Network in a Meso-Scale Catchment - the Case of the Migina Catchment, Southern Rwanda

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Abstract
The proper implementation of Integrated Water Resources Management (IWRM) plans requires the collection and analysis of hydrological and meteorological time series. This paper introduces the current situation of existing hydro-meteorological stations in Rwanda and describes a detailed hydrological and meteorological instrumentation network that was setup in the Migina catchment (214 km^2). This compromises 13 rain gauges and three tipping buckets gauges, two evaporation pans, one weather station, five river gauging stations and eleven shallow piezometers for groundwater monitoring. Based on the data collected, rating curves for the 5 river gauging stations have been established. During the period from May to December 2009, the maximum rainfall of 52.5 mm d^{-1} was observed in November at Mpare rainfall station (1691 m a.s.l.). The highest peak flow was observed on 19 November 2009 at the outlet of the Migina catchment at Migina River (4.8 m^3 s^{-1}), and the lowest flow was observed on 8 August 2009 at Munyazi-Rwabuye River (0.0002 m^3 s^{-1}), which is located at upstream of the Migina catchment. In future, this catchment will be developed further to the water resources and environmental management research site of the National University of Rwanda.

***Key words*:** Hydrological and meteorological process observations, integrated water resources management, meso-scale catchment, Rwanda, hydrological instrumentation.

1. INTRODUCTION

Accurate and comprehensive information about water resources form the basis for effective water resources management. It is now widely recognized that the monitoring and assessment of water resources, in terms of both quantity and quality, require adequate hydrological and meteorological data (e.g. Maathius et al., 2006), which is an often a challenge due to the spatio-temporal variation of processes (e.g. Uhlenbrook 2006). Wagener et al. (2008) stated that about 1 billion people live in water-scarce or water-stressed regions, and by 2025 this number is expected to increase by the factor of 3.5. The magnitude of this water scarcity and its variations in both space and time are largely unknown because of lack of hydro-climatological data (Oyebande, 2001; Kipkemboi, 2005). Hydrological and meteorological instrumental setup in meso-scale catchments as the Migina catchment can assist in enhancing the observation capabilities by providing additional data and variables (rainfall, evaporation, temperature, solar radiation, soil moisture, wind speed and wind direction, etc) complementing existing data in Rwanda.

Before the 1994 Genocide there were about 136 meteorological stations and 39 river gauging stations in Rwanda, but currently only 11 meteorological stations and 22 river gauging stations are in full operation all over the country (MINITERE, 2005; NWRMP, 2008; Munyaneza et al., 2009). This paper describes the efforts conducted at the National University of Rwanda (NUR) in collaboration with UNESCO-IHE to install hydrological and meteorological stations in the Migina catchment to facilitate research undertaken in this catchment and support education within the newly established MSc program at NUR. The research is an important component assisting Rwanda in preparing IWRM plans as part of their contribution to national and trans-boundary water resources development plans as well as the improving capacity in the field of hydrology and water resources.

2. DESCRIPTION OF THE STUDY AREA

The hydro-meteorological instrumentation took place in the meso-scale Migina catchment (214 km2), southern Rwanda (Figure1). Approximately 56,500 inhabitants with a growth rate of about 3% (Nahayo, 2007) are living within the catchment. The site is mountainous with elevation ranging from 1,434 m at the outlet of the Migina River to 2,251 m at Huye Mountain. The topographic conditions are very variable and show slopes of the valleys which varies from 5 to 10% in the upstream and 1 to 15% in the downstream part (average slope is between 2 and 3%) (see Nahayo, 2008). Land use is dominated by pasture and farm land where e.g. rice, sorghum, maize, and sweet potato are cultivated.

The Migina catchment (2o32'S to 2o48'S and 29o42'E to 29o48'E) is divided into 5 sub-catchments according to the main rivers draining the area. Two are located at the upstream (Munyazi and Mukura), two in the center (Cyihene at Kansi and Akagera), and one is located downstream part (Migina River).

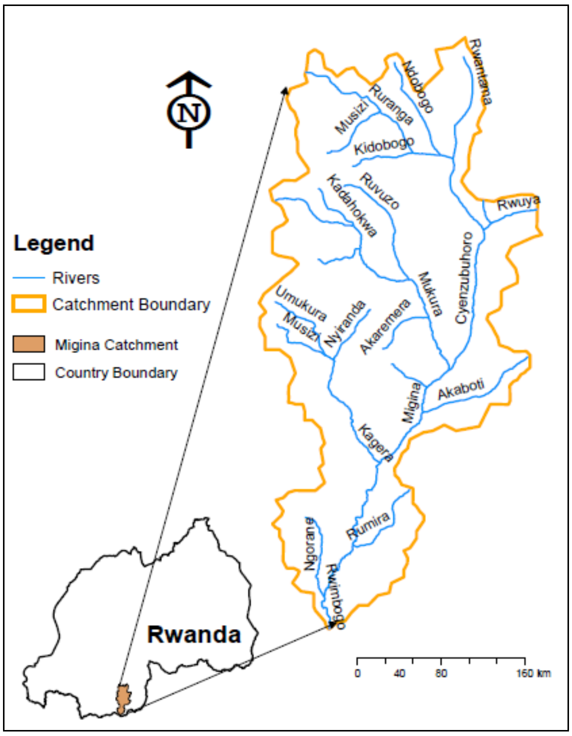

Figure 1: Location of the Migina catchment in Rwanda and its hydrologic network.

In the Migina catchment the mean annual rainfall is approximately 1200 mm a-1 and the temperature is about 20oC. The annual average evaporation in the area is estimated to 917 mm a-1 (Nahayo, 2008). The annual average of the relative soil moisture, calculated over the 11 years is 75.7% with minimum in June of 59.8% and the maximum in April of 86.3% (Nahayo, 2007). The wind speed varies mostly between 1 to 3 m s-1 and rarely exceeds 6 m s-1.

3. METHODOLOGY

This study provides an overview over the current situation of existing hydro-meteorological stations in Rwanda using a manual screening method to compile a data set with reasonable length and with a minimum of missing values (Munyaneza et al., 2009). This data provides the information on the spatial-temporal distribution and variability of meteorological and hydrological variables in Rwanda.

The paper describes the setup of hydrological and meteorological stations in Migina catchment and presents the hydro-climatic data collected so far. All maps were produced by using ArcGIS. All rainfall and climatic stations have been installed near Primary Schools for security reasons and for getting accurate readings done by teachers. Local people were trained on how to carry out data collection and on the important benefits of the installation and setup of hydro-meteorological stations in the catchment.

Rainfall stations were built using PVC tubes grounded with concrete. The height is 50 cm to 1 m; on average around 70 cm above the surface (Appendix 1). Funnels and plastic cylinders were used for some stations and manual rain gauges were used at other stations. Daily rainfall and evaporation data were collected at 7AM using trained local people. Rainfall intensity was measured using tipping buckets.

Gauging stations have been installed in the main 5 rivers at the outlet of each sub-catchment of Migina catchment (Figure. 2). PVC tubes were used and iron stills were fixed with concrete for protection. A pressure transducer (mini diver, Van Essen Instruments) was installed inside the PVC tube for automatic water level measurements (Appendix 1). Instantaneous river discharge measurements were taken once a week or bi-weekly according on the change in water level using area-velocity method (Photo 1; Waterloo et al., 2007). Daily water level measurements were collected by local people as a back-up for the diver data. Rating curves are generated and daily river discharges were prepared, see below.

Shallow piezometers were installed in the upstream part of the Migina catchment in Kadahokwa marshland for groundwater level monitoring. A gravel pack (highly permeable) around the screen was made, filter stocking to leave the (bigger) soil particles outside and to avoid clogging of the piezometers were used. Clay to close the top part of the soil surrounding the piezometer was used to avoid (preferential) infiltration alongside the tube. An iron still was fixed with concrete on top of the piezometer for protection. Continuous groundwater level measurements with an interval of 5 to 15 minutes were collected using pressure transducers (Mini Diver, Van Essen Instruments). The stations installed and period of available data records are given in Table 1; the locations of these installed stations are shown in (Figure 2). The pictures of some of hydrological and meteorological stations during their installation are shown in (Appendix 1).

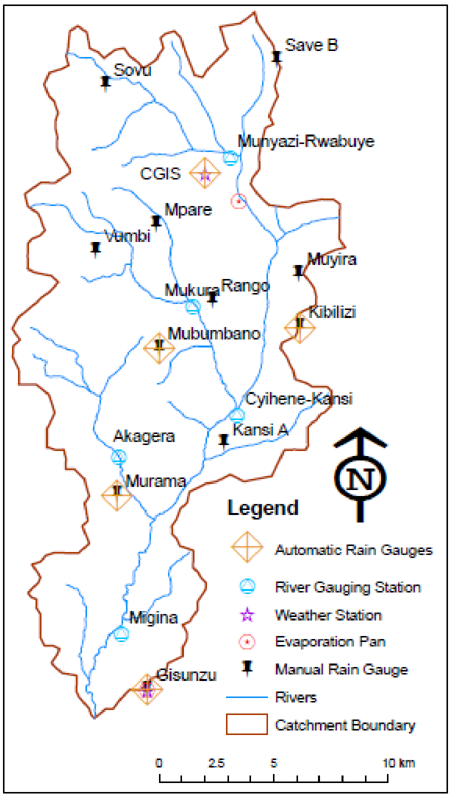

Figure 2: Spatial distributions of installed hydro-meteorological stations in the Migina catchment.

Table 1: Hydrological and meteorological stations installed in the Migina catchment

Parameter	Station No	Station name	Period of data availability	Coordinates (UTM) UTM Zone: 35M X (m)	Y (m)	Altitude (m)
Discharge	1	Munyazi-Rwabuye	From May 2009	806263	9713884	1662
	2	Mukura	From May 2009	804606	9707366	1618
	3	Cyihene-Kansi	From May 2009	806555	9702617	1577
	4	Akagera	From Jul 2009	801597	9699935	1575
	5	Migina	From Jul 2009	801454	9692989	1520
Precipitation	1	Murama	From May 2009	800129	9699128	1720
	2	Vumbi	From May 2009	800382	9709831	1824
	3	Mpare	From May 2009	803030	9711007	1691
	4	Sovu	From May 2009	800824	9717176	1764
	5	Save B	From May 2009	808328	9718265	1770
	6	Muyira	From May 2009	809227	9708819	1725
	7	Kibilizi	From May 2009	809300	9706476	1712
	8	Gisunzu	From June 2009	805956	9701364	1684
	9	Rwasave	From May 2009	806184	9712510	1665
	10	Kansi A	From May 2009	805555	9702817	1685
	11	Rango	From May 2009	805464	9707671	1708
	12	Mubumbano	From May 2009	803144	9705574	1808
	13	CGIS*	From Jan 2006	801485	9713790	1726
Temp., RH, Wind,	1	Gisunzu	From Jun 2009	805956	9701364	1684
Soil moisture,	2	CGIS*	From Jan 2006	801485	9713790	1726
Solar radiation						
Evaporation	1	Rwasave	From May 2009	806184	9712510	1665
	2	Gisunzu	From Jun 2009	807902	9700518	1684
Groundwater level		Piezometers at Kadahokwa				
	1	Piezo 1	From Jun 2009	802224	9708159	1645
	2	Piezo 2	From Jun 2009	802247	9708163	1649
	3	Piezo 3	From Jun 2009	802275	9708165	1643
	4	Piezo 4	From Jun 2009	802253	9708164	1634
	5	Piezo 5	From Jun 2009	802282	9708167	1633
	6	Piezo 6	From Jun 2009	802211	9708156	1627
	7	Piezo 7	From Jul 2009	802232	9708165	1645
	8	Piezo 8	From Jul 2009	802199	9708217	1641
	9	Piezo 9	From Jul 2009	802230	9708232	1649
	10	Piezo 10	From Jul 2009	802214	9708225	1647
	11	Piezo 11	From Jul 2009	802190	9708204	1649

4. RESULTS AND DISCUSSIONS

4.1 Overview Over Existing Meteorological Stations in Rwanda

The spatial distribution of meteorological stations in Rwanda from the first station installed in Rwanda in 1910 at Save rainfall station which is located in Migina catchment (see Figure 2) up to 1993 (due to Rwanda genocide of 1994) is shown in Figure 3.

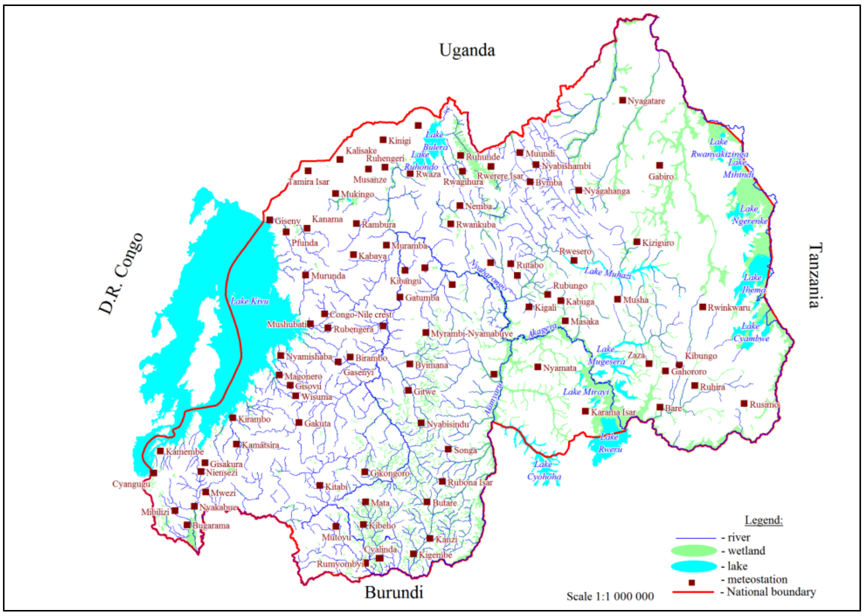

Figure 3: Spatial distributions of meteorological stations and location of main water resources in Rwanda (source: Mikova et al, 2010).

In total 136 meteorological stations were available in the whole Rwanda from 1910 to 1993 (Figure 3). Based on these available stations a manual screening method was used according to Munyaneza et al. (2009) and 27 meteorological stations and 16 hydrological stations were selected for further analysis. Figure 4 shows inter-annual variability of rainfall, based on these selected stations. Figure 5 shows intra-annual variability of mean monthly stream flows for selected discharge stations in 1985. This year was selected because the rainfall and stream flow data are continuous and complete for that year.

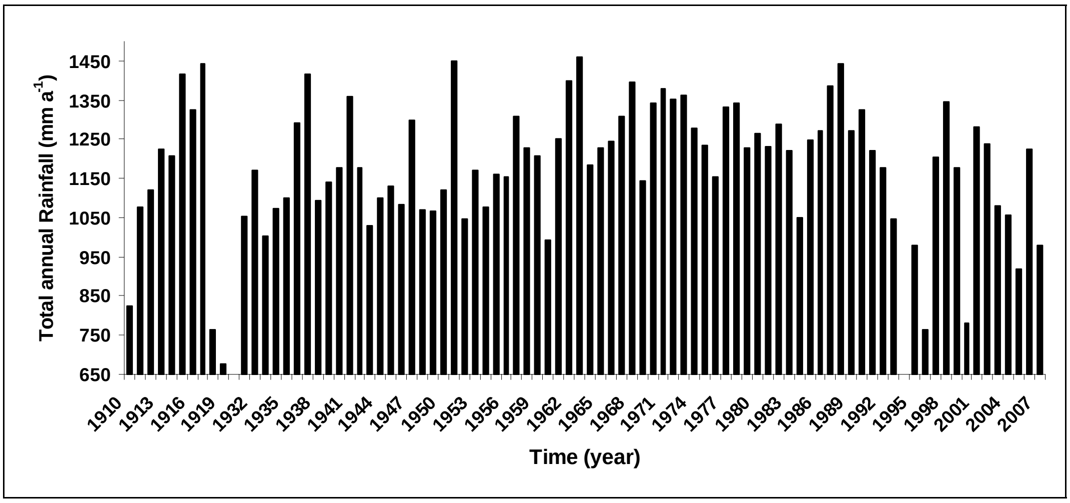

Figure 4: Inter-annual variability of mean rainfall based on selected stations in all Rwandan catchments (1910–2008).

Figure 4 shows that there is a data gap from 1920 to 1930 and in 1994. The figure also shows the maximum annual rainfall in Rwanda from 1910 to 2008 which is 1450 mm a-1 in 1951 and the minimum of 677 mm a-1 in 1919. The years of 1995, 1996 and 2001 presented drought periods in Rwanda.

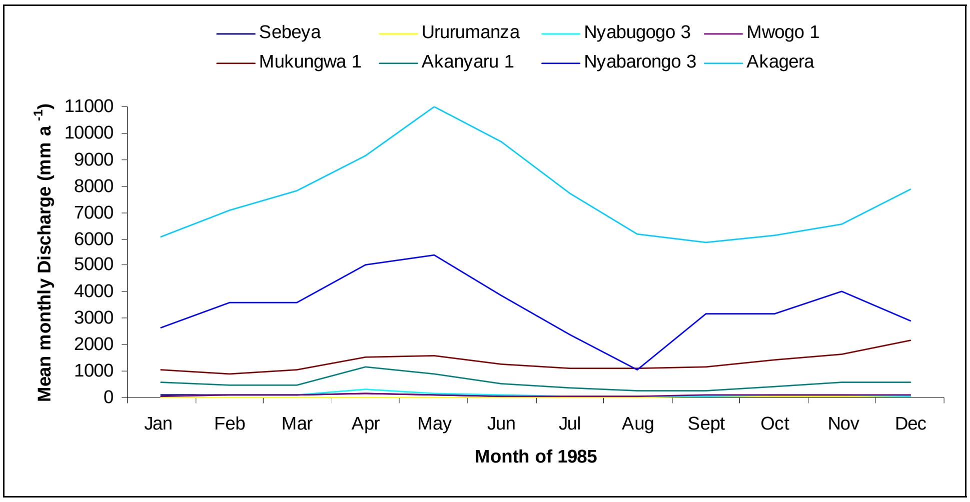

Figure 5: Intra-annual variability of mean monthly stream flows for selected stations in 1985.

Figure 5 shows that the hydrograph peaks occurs in April and May, roughly one month later than the month with the highest precipitation. The minimum flows occur in the months of August and September.

4.2 Instrumental Setup in the Migina Catchment

During this research, 13 manual rain gauges were installed at different Primary Schools. Three automatic rain gauges (tipping buckets) in the West, Central and Eastern parts of Migina Catchment were installed additionally to the already existent tipping bucket at CGIS-NUR station in the Northern part of the catchment. Two evaporation pans at Rwasave (upstream) and Gisunzu Primary School (downstream) and one climate station were installed in the downstream part of Migina catchment (Gisunzu) additional to the already established climate station at CGIS-NUR in the upstream part of the catchment (see Table 1 and Figure 2).

In total 5 river gauging stations were installed in the 5 main rivers of Migina catchment at Rwabuye, Mukura, Akagera, Migina and Kansi bridges. The Kadahokwa marshland was selected for groundwater monitoring and eleven piezometers were installed in that marshland (see Table 1 and Figure 2). The Kadahokwa marshland was selected because it is an interesting site for investigating surface water-groundwater interactions. The area is use for agriculture.

4.3 Preliminary Results of Rainfall Data Collected in the Migina Catchment

Figure 6 shows box plots of monthly rainfalls observed in the Migina catchment at (a) Butare Airport from 1969 to 1992 and (b) Butare Mission from 1935 to 1963. The two locations are less than a kilometer apart and at the same altitude. Rainfall measurements form May to December 2009 from all 13 rain gauges installed for this study are presented in the box plot as well (represented by circles). The thick black circles represent the rainfall observed at Rwasave, which is the closest (less than 500 m) to both the Butare Airport and the Butare Mission. It is interesting to see that all the monthly rainfalls observed in almost all the stations except the October rainfall at a couple of stations fall well within the maximum and minimum ranges based on the historic rainfall data observed at the Butare Airport. The Rwasave monthly rainfall measurements are also within the maximum/minimum ranges observed at the Butare Mission with the exception of the November rainfall at few stations. These results provide some confidence on the plausibility of the rainfall measurements carried out in this study. The comparisons also show that the months May, June, July and September were relatively dry and the month November was very wet in 2009. Further investigations will show how representative this year is.

(a)

(b)

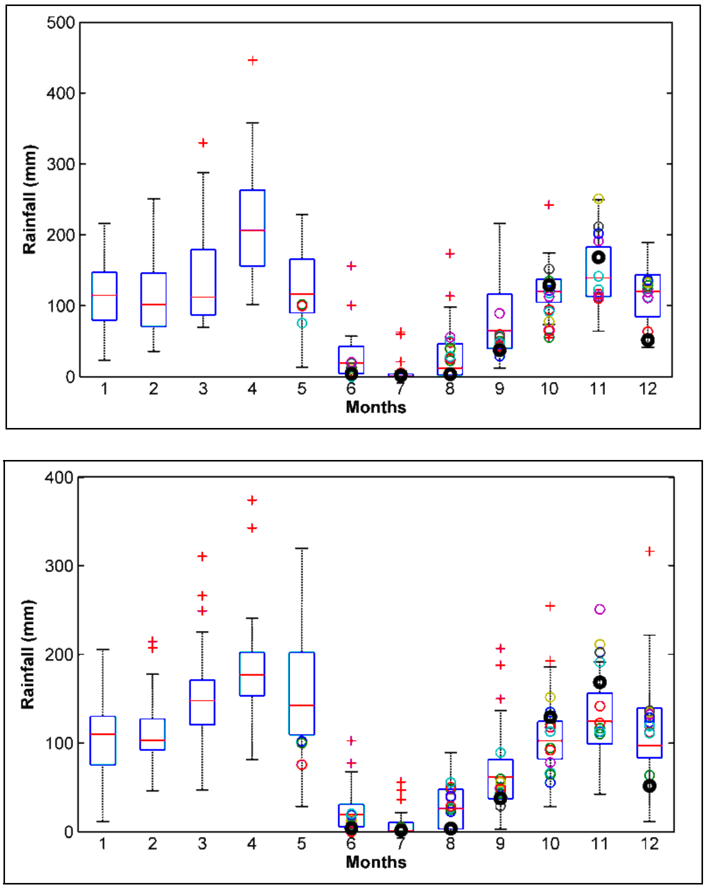

Figure 6: Box plots of mean monthly rainfall observed at (a) Butare Airport from 1969 to 1992, and (b) Butare Mission from 1935 to 1963 together with the monthly rainfalls from May to December in 2009 at the 13 rain gauges installed in this study, which are represented by circles.

The rainfall shown by thick dark circles are from the Rwasave station which is the closest from both the Butare Airport and Butare Mission. In the figure the boxes are defined by 25th and 75th percentiles and the symbol '+' represents the outliers.

4.4 Generation Rating Curve

In order to establish a relationship between water levels and discharge for the five main rivers in the Migina catchment, several discharge measurements were carried out at the gauging stations at different water levels. The picture below shows how river discharge measurements were taken by propeller measurements using the area-velocity method. The rating curve generated referring to the recommendations of Show (2004) and using data collected from the Mukura station is shown in Figure 7. Mean daily discharges are shown in Figure 8 after considering data from all stations. The discharge was calculated using the average of 2 daily river depth measurements that are taken at 7am and 5pm. That is why we called it mean daily discharge. However this can also be replaced by daily discharge.

Photo 1: Mukura River discharge measurement (picture taken by Harmen van den Berg on 06/05/2009) and Akagera River discharge measurement (Picture taken on 10/08/2009 by Emille (BSc student) when NUR Civil Engineering students were instructed how to measure discharge using a propeller).

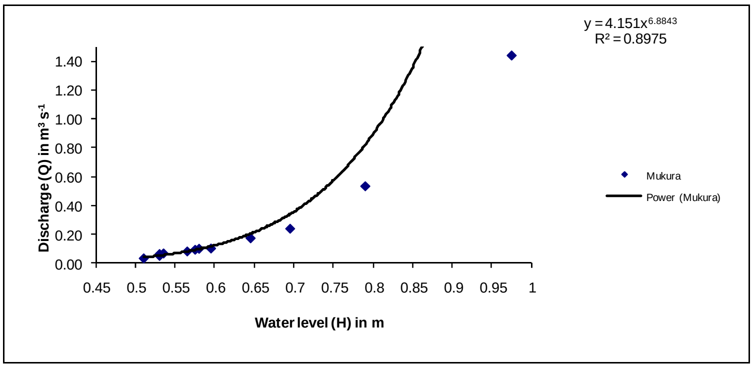

Figure 7: Rating curve generation based on data collected from the Mukura River gauging station installed in May 2009, fourteen discharge measurements were taken from May to Dec 2009.

Figure 7 shows the rating curve generated from data collected at the Mukura river gauging station located in the center of Migina catchment (see Photo. 3). Mukura station has been selected as one example sample but the same method was used for all stations. The daily river discharges are shown in Figure 8.

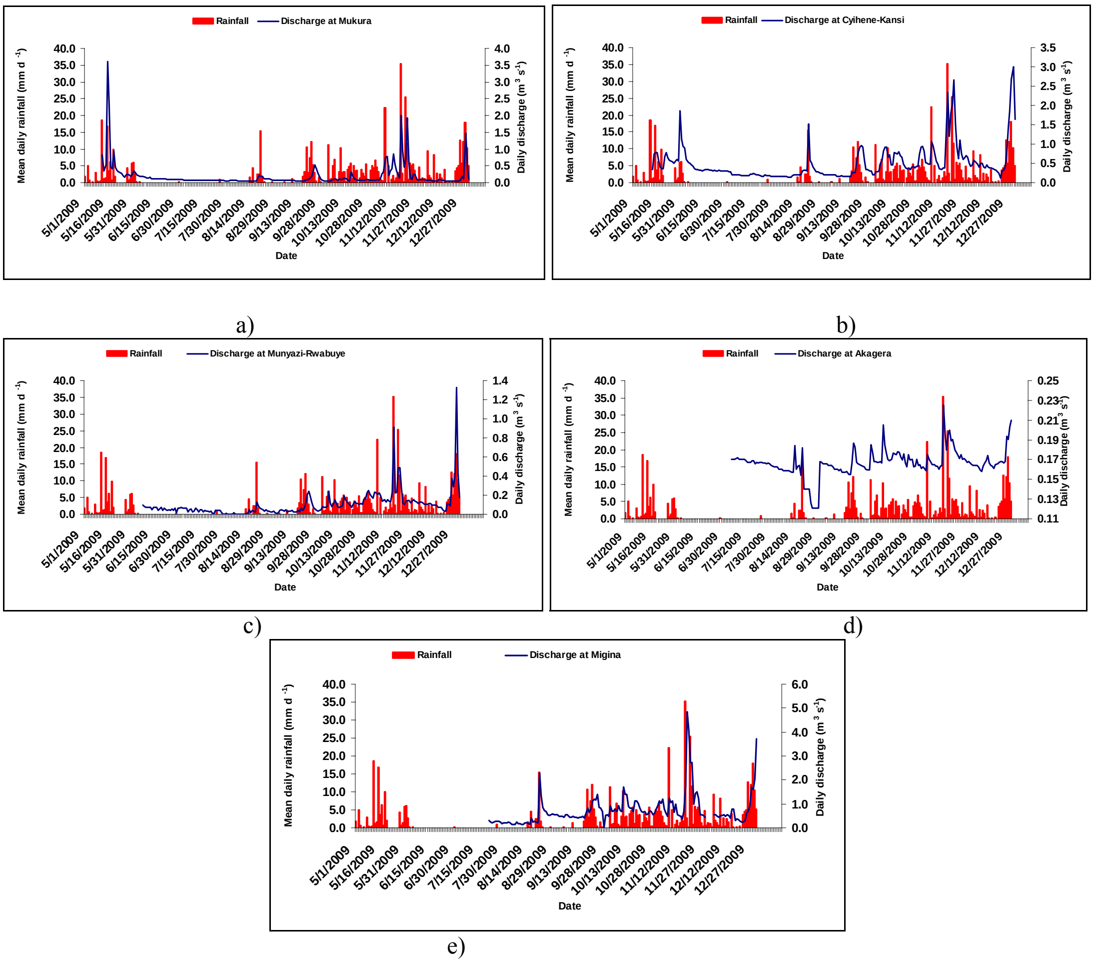

Figure 8: Mean daily rainfall and river discharge observed in the Migina catchment (May to Dec 2009) at a) Mukura; b) Cyihene-Kansi; c) Munyazi-Rwabuye; d) Akagera; and e) Migina stations.

Figure 8 shows that during the period of data collection (May to December 2009) two significant events were observed on 31 May 2009 and 31 December 2009 which had peak discharges of about 1.9 m3 s-1 and 3.7 m3 s-1, respectively. High peak flow was also observed at the Migina River (4.8 m3 s-

1) on 19 November 2009. The lowest flow was observed on 8 August 2009 at Munyazi-Rwabuye River (0.0002 m3 s-1) which is located at upstream of the Migina catchment. The Migina River is located in the downstream of Migina catchment (outlet of the catchment) and has two main tributaries, Cyihene-Kansi and Akagera Rivers. The Migina River which is the main river in the Migina catchment was the source of the name of this catchment.

5. CONCLUSIONS AND RECOMMENDATIONS

Hydro-meteorological data in Rwanda are scarce in time and space with many data gaps (durations often more than one year). After the Genocide in 1994 the data situation got even worse and never reached the pre-war level again. Data used were collected from 27 stations distributed in the whole country including five stations installed in the Migina catchment (214 km2) and (re-)installed during this research. Only 22 discharge gauging stations and 11 meteorological stations are available at the moment. The stations installed in the Migina catchment assist in enhancing the observation capabilities by providing additional data and variables complementing the existing limited data in Rwanda. The maximum total monthly rainfall at the Murama station amounted to 132 mm in December and the minimum is 0 mm in July, but Munyaneza et al. (2009) found that mean maximum monthly rainfall in Rwanda from 1970 to 1993 is 203.8 mm in April and the mean minimum monthly rainfall is 10.5 mm in July. This shows that long time series data is needed for better water resources development and prediction. Further measurements will show how representative the recent investigation period is.

The applied experimental techniques to study the hydrological processes can be transferred to other catchments in Rwanda or neighboring countries for a better understanding of the available water resources in the headwaters of the Nile River basin. This is the basis for an efficient and effective implementation of IWRM plans. In future the Migina Catchment will be developed further as research site for the Water Resources and Environmental Management Project of the National University of Rwanda.

6. ACKNOWLEDGEMENT

This work was conducted in collaboration with a number of staff from the National University of Rwanda (NUR), UNESCO-IHE and students from the VU University of Amsterdam. The authors would like to recognize the involvement of Hon. Amb. Stanislas Kamanzi, Minister of Natural Resources in Rwanda (MINIRENA), for his encouragement and continues financial support. The financial support of Nile Basin Capacity Building for River Engineering (NBCBN-RE) is also highly appreciated. A Nuffic/NPT PhD research fellowship provided by The Netherlands is also recognized.

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(Appendix 1) Instrumental setup in Migina Catchment (Apr.-Jul. 2009)

Photo 2: Climate station, evaporation pan, manual and automatic rainfall gauge (tipping bucket) installed in Migina catchment.

Photo 3: Staff gauge (left), automatic gauging station (center) and piezometer with diver (right).

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