Hydraulic Structures Design for Flood Control in the Nyabugogo Wetland, Rwanda

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Abstract

The negative consequences of floods on the socio-economic welfare of the global society cannot be over emphasized. Flood causes lost of lives, properties and destruction of environment, these result in several unwanted effects. Rwanda is not left out of the effect of this global disaster. Almost every year a series of flood events that have negative impact on the society are recorded. This necessitates taking measure to mitigate the impact of flood in the country. Nyabugogo wetland, located in the City of Kigali, is one of the major flood prone areas in the country, where almost every year flood events are recorded. This study aims at contributing to the mitigation of flood in the Nyabugogo wetland by proposing the design of hydraulic structure which, if implemented, can reduce the magnitude of the effect of flood in the area. The methodology involved the use of rainfall data for the period of 20 years (1993-2012), flow records of Nyabugogo River for 2011, interviews and analyses of flood control technologies to determine and propose the most appropriate measure for flood control in the concerned wetland. The results show that in 2011 the peak of flash flood in the area takes place in October and this coincide with the maximum recorded river discharge of 10.65 m^3/s, and water level of 2.01 m in the Nyabugogo river. Among the analyzed methods, Self-Close Flood Barrier (SCFD) was proposed as the most suitable flood control measure in the area as this technology can detect flood and protect the area while it does not requires the use of electricity. It is recommended that further studies be conducted to assess the economic feasibility of using this technology for flood control in the Nyabugogo wetland.

Keywords: Self-close flood barrier, flood control technology, Nyabugogo wetland, Kigali

1. INTRODUCTION

Floods are natural events. They mainly happen when the river catchment (that is the area of land that feeds water into the river and the streams that flow into the main river) receives greater water than usual amounts (for example through rainfall or melting snow). The river cannot cope and this extra water causes the level of the water in the river to rise and a flood to take place. This flooding may take place at any point along the river course and not necessarily at the place where the extra water has entered.

While the size of a lake or other body of water will vary with seasonal changes in precipitation and snow melt, it is not a significant flood unless such escapes of water endanger land areas used by man like a village, city or other inhabited area (Shelby, 1997). We can define some principal types: Riverine (request, 2001); Estuary (Wiki, 2000); Coastal (Gun, 1999); Catastrophic (Ben, 2005); Human – induced (Millan, 2003); Muddy (Wiki, 2000); and others (Wiki, 2000).

Floods can occur if water accumulates across an impermeable surface (e.g. from rainfall) and cannot rapidly dissipate (Mirza, 1993). Flood damages property and endangers the lives of humans and other species. In addition its rapid water runoff causes soil erosion and concomitant sediment deposition elsewhere (such as further downstream or down a coast). Furthermore the spewing grounds for fish and other wildlife habitats can become polluted or completely destroyed (Zimela, 2011). Some prolonged high floods can delay traffic in areas which lack elevated road ways and they can also interfere with farming. Structural damage can occur in bridge abutment, backlines, sewer lines and other structures without forget water way navigation and hydroelectric power are often impaired within flood ways (cebon, 2005). Financial losses due to floods are typically millions of dollars each year with the worst floods in U.S history having cost billions of dollars (wiki, 2000). High floods have been also observed in Nyabugogo river and these floods can be classified among flash floods which usually result from

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intense rainfall even over a relatively small area or if the area was already saturated from previous precipitation (Karuhunga, 2011). Especially, Nyabugogo flood is caused by the faulty drainage system of the area which is a swamp with many waterways flowing through.

Nyabugogo River flooding, usually causes some effects which can be classified as follows: (1) *Primary effects:* Physical damage which can damage any type of structure including bridges, cars, buildings, sewerage systems, roadways and canals (Brammer, 1990); (2) *Secondary effects:* Water supplies, diseases, crops and flood supplies, tress, vegetation and transport; (3) *Tertiary and long-term effects:* Economic (Rozens, 1994).

Recently (in 2013) flood have been affecting Nyabugogo wetland and causes loss of properties, loss of 4 human lives through a car which was drawn by the water (Fig. 1b) and animal life and disruption of socio-economic activities, disruption of the business in the area and other issues related to transport facilitation that at times become stand still due to flooding in the wetland during the rainy season (see Fig. 1).

a) b)

Figure 1: (a) A man lifting a lady to cross the flooded area in the Nyabugogo, and (b) a skeleton of car transported by floods of February 23rd 2013.

Rwanda, as a developing country, has to take serious measures to control floods. Because once they happen, many different effects occur and they destroy some development activities. This study proposed the construction of flood control hydraulic structures as one of the measures that can be used to control Nyabugogo flood or any other river flood. Therefore, the aim of this paper is to contribute to the mitigation of flood in Nyabugogo wetland by proposing an appropriate design of hydraulic structure which, if implemented, can reduce the magnitude of the effect of flood in the area.

2. STUDY AREA

Nyabugogo wetland is located between 1,354 m to 2,278 m above sea level and between 1°94'S and 30°04'E. The wetland drains a total area of 1,647 km^2. Nyabugogo is located within the Nyabugogo catchment and it covers both rural and urban areas including the City of Kigali which is the capital city of Rwanda (see plate 1).

Nyabugogo wetland cuts across two districts Nyarugenge and Gasabo with an estimated population of 825,767 inhabitants (Census report, 2012). The wetland is part of the Nyabugogo catchment which cuts across Eastern Province (Kayonza, Rwamagana, and Gatsibo districts), and Northern Province Gicumbi and Rulindo and other districts of Kigali city such as Kicukiro, Nyarugenge, and Gasabo districts where the current study area is located. Its estimated population is about 1,135,428 inhabitants (Census report, 2012).

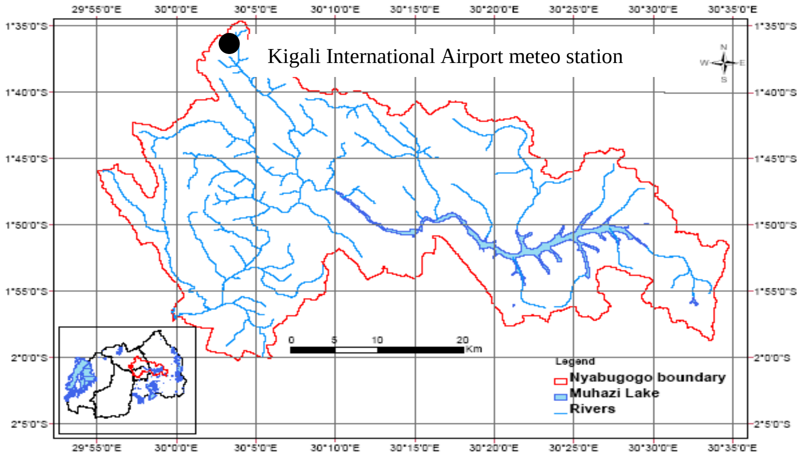

Figure 2: Location of Nyabugogo catchment within the administrative map of Rwanda

This study was carried out in the Nyabugogo wetland located in the Kigali city. Figure 3 shows wetland extracted from Nyabugogo catchment with a total area of 1,647 km^2 (CGIS, 2012).

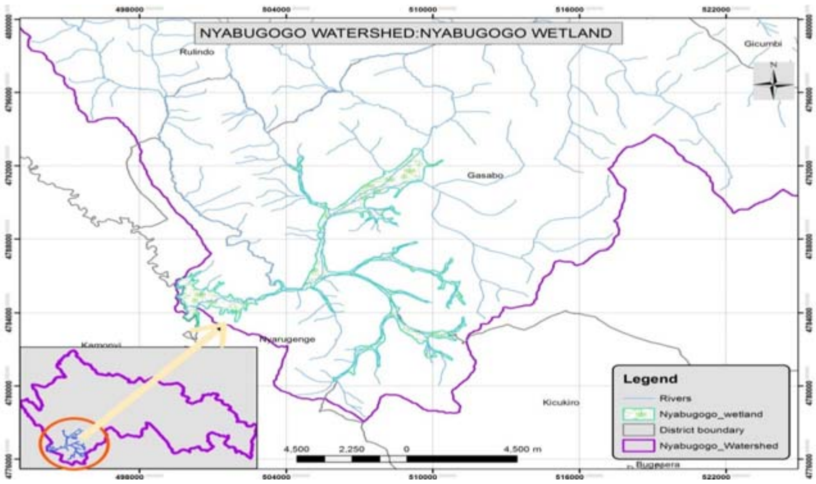

Figure 3: Location of Nyabugogo wetland within Nyabugogo catchment.

The major land use activity in the wetland is agriculture, which occupies about 897 km^2 (about 54%) of the wetland and is mostly of temperate and equatorial type with average temperature ranging between 16^{o}C and 23^{o}C, depending on the altitude of the area.

3. DATA AND METHODS

3.1. Meteorological Data Collection

In this study, we considered only one meteorological station of Kigali International Airport (located around southern part of the Nyabugogo wetland: lat: -01°58’, lon: 30^{o}08’, and Alt: 1,490.0 m a.s.l (Fig. 2)) with the records rainfall data for 20 years (1993-2012). We analyzed and computed the mean atmospheric temperature which varies with time but normally between 19°C and 21°C. There are 15 rainfall stations in and around the Nyabugogo catchment. However, since after the genocide of 1994, meteorological data have not been recorded in almost all stations except at Kigali Airport Station. Therefore, this triggered us to use the data available.

3.2. Average Annual Rainfall

Considering the period from 1993 to 2012 at Kigali Airport meteorological station, the minimum and maximum monthly rainfall at that station are 98.6 mm and 173.1 mm, respectively. Rainfall volume (in thousand m^3), was estimated using the following equation.

$$Rainfall\ volume = P \times A \tag{1}$$

Where: the Rainfall volume is expressed in thousand m^3, P is precipitation in mm, and A is the surface in km^2. To find the monthly and the annually average rainfall, the arithmetic mean average method was used as shown in Eq. 2 below.

$$P = \frac{\sum_{i-1}^{n} p_i}{n} \qquad (2)$$

Where:

P: Spatial average of precipitation,
i: number of rain gauge, and
n: total number of rain gauges

3.3. River Discharge Measurement

The discharge was measured using velocity-area method. The velocity was measured using current meter, while cross-sectional area of flow was measured manually using tape line and measuring rods. The discharge (Q) in m^3/s was calculated with Eq. 3.

$$Q = V * A \qquad (3)$$

Where: V is average stream velocity in m/s and A *is* a cross-section area in m^2.

One year (2011) flow data of the river gauging site (located downstream of the Nyabugogo wetland: lat: -01°57’36”, long: 30°00’10” and alt: 1,352.0 m a.s.l) were obtained from the Rwanda Natural Resources Authority (RNRA). These data were analyzed to show the flow distribution within the whole year.

3.4. Interview Method

Interviews were conducted at the site. The people interviewed included businessmen, shopkeepers, mechanics, drivers and neighborhoods. The people interviewed were among the victims of floods. The questions asked included: (1) How deep was the last observed flood in the Nyabugogo wetland? (2) What do you think causes the flood? (3) What can you say about the rainfall in Nyabugogo? (4) Where was the highest point that water reached in your house during flood period? (5) What do you think could be done to control flood problem in the area?, and (6) Do you think the canal of Mpazi (Ruhurura) contribute to Nyabugogo flood?

3.5. Self-Close Flood Barrier (SCFB) Design

Global Flood Defense Systems (GFDS) was established to meet the growing requirement for global solutions to extreme flooding events. With its global headquarters in the UK, GFDS is a leading provider of engineered, passive flood defense systems, offering an extensive range of solutions to public and private sector clients both in the UK and internationally.

In operational use globally since 1998, the Self-Close Flood Barrier (SCFB) is acclaimed as the world’s most effective flood protection system (Global flood, 1998).

Figure 4: SCFB in operation

3.5.1 Technical description

The standard SCFB consists of a prefab steel or concrete basin and a polyester floating floodwall. The required height depends on the site and installation location. Standard protection heights are 500 mm, 1,000 mm, 1,500 mm, 2,000 mm and 2,500 mm above ground level, with alternative heights available on request.

The steel or concrete elements measure 1,000- 6,000 mm. The steel elements are protected by a two-compound coating (redox EP Ferro flake) and a cathodic protection (PC). The side plates are welded on the base plate and are held vertically and supported by welded support plates on the exterior.

The flood wall itself is made from polyester, with a thickness of 4-8 mm. it is laminated in a climate controlled hall with permanent humidity and temperature control to guarantee a consistent lamination process. In order to minimize collision damage by flotsam, the floodwall is protected by Kevlar with high impact strength.

The floodwall is reinforced by laminated strips, and is filled with a PUR-foam core which forms an extremely strong and impact resistant construction. The walls are coupled in lengths of 990 mm by means of a rubber gasket. The steel lid closes off the basin to prevent any inflow of waste or debris under normal conditions when the SCFB is not in operation, the floodwall is not visible and cannot cause an obstruction to traffic in flow situation, the floodwall comes up instantly while the lid acts like a breakwater (Global flood, 1998). The SCFB is manufactured to TCVN ISO 9001/IS 09901 standards.

3.5.2 Design calculations

The floodwall is designed to withstand more than 10 times the hydrostatic pressure exerted by flood water at its maximum height. Calculations, based on project-specific data, are carried out to ensure that the rise times for the SCFB are such that the barrier will rise before flooding of the protected area can occur. The calculations will determine the positions and dimensions of intake structures. Water will rapidly enter inside the SCFB basin when flooding commences and the barrier would rise up immediately to control floods (Figs. 6 and 7). The calculations take into account type of flooding (flash flood, heavy rainfall, etc.), surface levels and gradients of surrounding area (Global flood, 1998).

3.5.3 Principle of operation

Sectional views of SCFB show the operation of the wall in a riverside or levee location (Fig. 5 to Fig. 7). Figure 5 shows the SCFB in non-flood conditions, all operational parts of the barrier are invisibly concealed in the ground inside its basin.

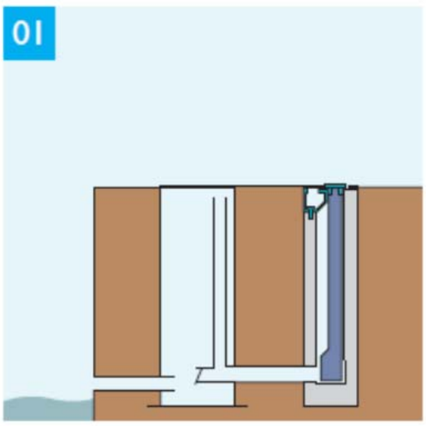

Figure 5: Cross section of the Self-Close Flood Barrier (SCFB)

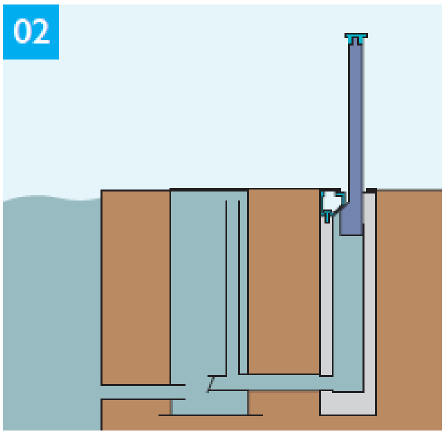

Figure 6: Cross section of the Self-Close Flood Barrier (SCFB) in operation

Figure 6 shows that when floodwater rises to within 10 cm below the pre-flood level, the enclosed basin, which houses the floating wall, starts to fill up through an inlet pipe from the adjacent flood pit. The flood wall floats rises when the basin is totally filled and the support block will lock the barrier into position making it watertight (Fig. 7).

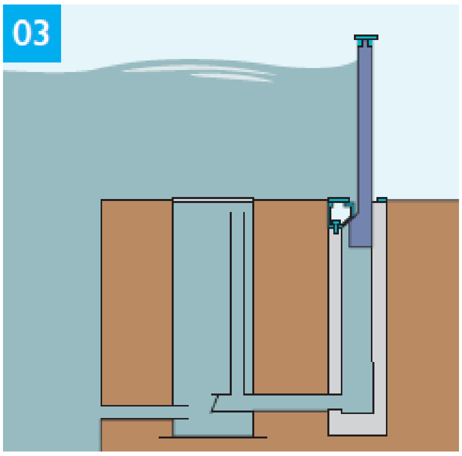

Figure 7: Cross section of SCFB in total operation

Figure 7 shows that the flood water can now continue to rise without flooding the protected area. As the water level subsides back to its normal level, the flood water in the basin is drained by a pump located in the flood pit, through drain pipes which are fitted with one way check valves. As the water leaves the basin, the flood wall returns to its resting position within the basin. In its closed resting position the lid of the barrier seals to prevent the inflow of waste or debris (Global flood, 1998).

4 RESULTS AND DISCUSSION

4.1 Mapping Flood Extent and Level

The data used for flood extent mapping were obtained from interviews at the site. To identify the flood extent, the flood plain was explicated by local people who live and work at the Nyabugogo wetland. The flood level from household surveys was estimated based on watermarks found on the houses with reference to the surface of the ground. To obtain data of flood level, the observed flood levels at a house location was first added to the corresponding elevation value from the Digital Elevation Model (DEM); interpolation was conducted to generate a flood surface level.

However, the elevation of the study area varied greatly (from 1,368 to 1,377 m) with a very small area and flooding is powerfully influenced by flatness or steepness of topography. Thus, interpolating flood level based on elevation would not produce an accurate result. To answer this issue, it was decided to analyze flood depth extent in two subdivisions based on the topographic similarities of the house samples (zones with almost the same altitudes and slopes).

Records of runoff flood were unified because that type of flood is much localized. The flood map was generated by interpolating flood height values based on average elevation of flooded houses and presents the spatial distribution of flood level, from a very low to a low to a high to a very high flood. The corresponding flood class values are listed as: very low (0- 0.30 m), low (0.30- 0.60 m), moderate (0.60- 0.90 m), high(0.90- 1.20 m) and very high(1.20- 1.50 m).

Based on flood level distribution, three high flood zones were distinguished; *the first zone*, in the south-west which lies near the confluence of the Yanze and Nyabugogo River. *The second zone* is located near the Kiruhura market where buildings obstruct the water ways and delay or hold back water flow. *The third zone* (north-east) is on very flat terrain where Nyabugogo valley is located. It was found that flood at Gatsata zone (downstream of Nyabugogo wetland) was caused by poor drainage infrastructure (an inadequate bridge and closed culverts). Nevertheless, this finding was not incorporated into the analysis because it is much localized and strongly dependent on topography and/ or drainage infrastructure.

4.2 Hydro-Meteorological Data Results

4.2.1 Rainfall in the Nyabugogo swamp

Twenty years (1993-2012) data of Kigali International Airport (Kanombe station) located not far away from the study area was used (Eq. 2) to estimate average monthly rainfall, while Equation 1 was used for rainfall volume from an area of about 1,647 km^2.

Only the inflow from precipitation to the wetland was used due to the fact that there are no records related to other sources of inflow and the following results were obtained (Fig. 8).

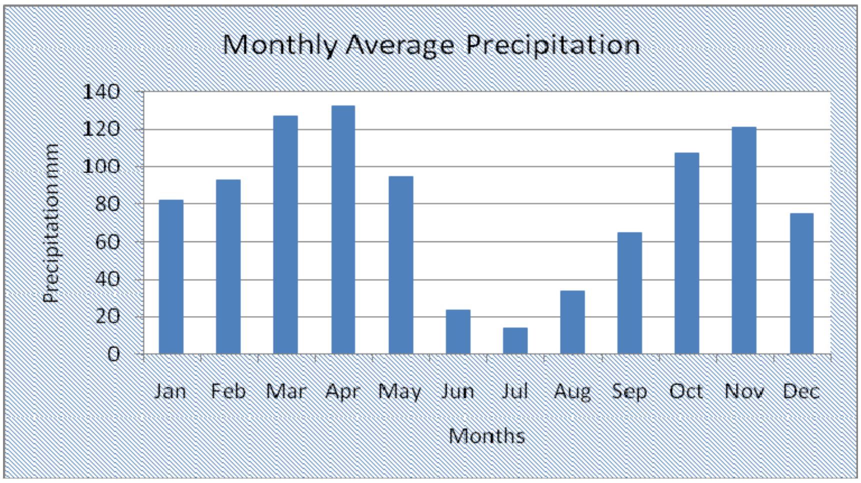

Figure 8: Average rainfall of 20 years from 1993 to 2012 (Kagabo, 2013)

Figure 8 shows the mean monthly of rainfall in Nyabugogo wetland; where the maximum rainfall was found in April 132.7 mm, the minimum in July 13.8 mm. The total monthly average rainfall was found to be 80.6 mm (132.7*10^3 m^3) and the annually rainfall average is 966.9 mm (1,592.5 *10^3 m^3).

4.2.2 Discharge of the Nyabugogo river

Water level records of 2011 recorded at the hydrometric station which is between Nyabugogo and Giticyinyoni were used to estimate the daily discharge, and then mean monthly discharge was determined. The station has rating curve developed by Rwanda Natural Resources Authority (RNRA) and the water levels were transferred to discharges using the same developed rating curves (Munyaneza et al., 2012). Table 1 shows the mean monthly discharges and mean annual discharge for 2011.

Table 1: Discharge of Nyabugogo river

Month	Discharge (m^3/s)
January	5.97
February	4.03
March	6.01
April	6.40
May	6.89
Jun	5.44
July	5.13
August	4.59
September	8.34
October	10.65
November	9.54
December	10.10
Annual average	**6.92**

Table 1 shows that the annual average flow of the Nyabugogo river for record data of 2011 is 6.92 m^3/s. Figure 9 shows the flow variation of the same river.

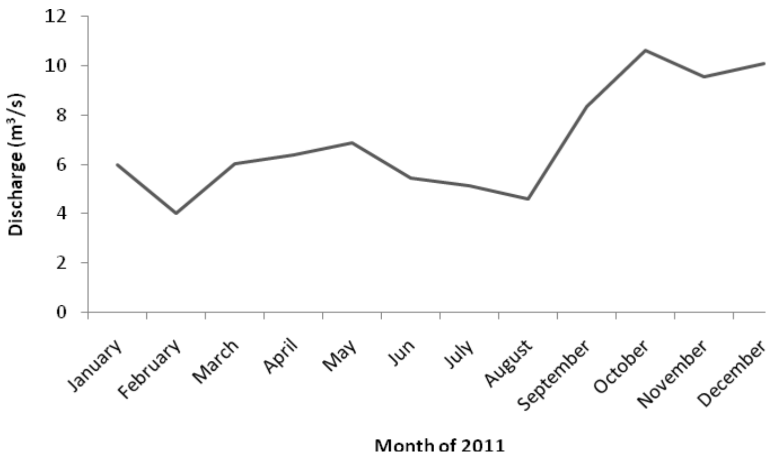

Figure 9: Discharge variation

Figure 9 shows how the discharge varied monthly in the Nyabugogo River, where the maximum discharge was found in October 10.65 m^3/s, the minimum flow discharge was observed in February 4.03 m^3/s.

4.2.3 Level of water in the Nyabugogo river

Level of water was measured in the Nyabugogo river the whole year; from January to December of 2011 (MINERENA, 2012). These water levels were recorded in 2011 at the hydrometric station which located between Nyabugogo and Giticyinyoni. Table 2 shows the mean monthly level of water for the whole year.

Table 2: Level of water in the Nyabugogo river

Month	Level of water (m)
January	0.85
February	0.48
March	0.34
April	0.97
May	1.05
Jun	0.72
July	0.72
August	0.61
September	1.27
October	2.01
November	1.45
December	1.53
Annual average	**1.09**

Table 2 shows that the annual average water level observed in the Nyabugogo river which was 1.09 m in 2011. The maximum water level was found in October 2.01 m (this is only for 2011) and the minimum in March 0.34 m.

4.3 Self-Close Flood Barrier (SCFB)

4.3.1 The self-close flood barrier in the Nyabugogo wetland

As the hydrological data and the data from the interview showed, we had a heavy rainfall in April (monthly average 132.6 mm) but the level of water and the discharge had moderate values as shown in Tables 1and 2. The monthly average water level and discharge raised up in September (1.27 m and 8.34 m^3/s) into October (2.01 m and 10.65 m^3/s) 2011 when the flooding occurred. The flood could be associated to a single rainfall event with rainfall larger than any other event during 2011, which means that mentioned flooding was due to a Flash Flood. Based on the data analyzed, which showed that the monthly average water level in October was 2.01 m, the Self-Close Flood Barrier was designed with a height of 2.50 m, having considered a 50 cm security range. Table 3 shows the important parts required of the SCFB 2500 with concrete basin and their measures.

Table 3: Self-Close Flood Barrier SCFB 2500 components

TYPE	SCFB 2500
Protection height	2.50 m
Depth in the ground	3.60 m
Bottom width	1.06 m
Wall thickness	0.20 m
Lid with	0.28 m
Element length(St.)	2.00 m
Total length	Unlimited
Closing time	1-5 min

The SCFB sections are in standard lengths of 1.00 meter which may be linked together. The use of pillars can facilitate changes of direction or deviations from a straight line in the run of the barrier. The route of the barrier therefore needs to be defined and divided into suitable section lengths up to 50 linear meters.

4.3.2 Warranty

All SCFB installed systems carry a warranty against fabrication/ installation faults including any incurring leakages of more than 0.5 l/M/ min. all barriers carry a 10 year manufactures guarantee.

The other types of hydraulic structures for flood control can be found in Pavel (2001). However, this study proposed the use of SCFB as a suitable flood control measure in the area as this technology can detect flood and protect the area while it does not requires the use of electricity. It is recommended that further studies be conducted to assess the economic feasibility of using this technology for flood control in the Nyabugogo wetland.

Note that when the barrier is in place, the area submerged during flooding will be less than at present and that will cause the water level to rise more than at present (refer to Fig. 7). Unfortunately, this study did not show how much more, which is dependent on how the flood wave propagates further downstream. To predict this, the flow in the river or at least the relevant part of the river needs to be modeled. However, this can be conducted for further studies.

5 CONCLUSION

The flood that occurred at Nyabugogo wetland during 2011 was a flash flood resulting from a single heavy rainfall event of 2011. Though, it is not possible to control over heavy rainfall events, it is totally possible to its control their expected consequences.

The self-close flood barrier (SCFB) is one of the many ways to prevent from flood consequences. Therefore, the proposed SCFB, if implemented, will contribute to the target of Rwanda 2020 vision in Kigali city. As the heavy rain occurs, and the level of water rises up, the SCFB deploys automatically depending on the approaching flood water without requiring labor or power to deploy. The proposed SCFB could be supported by other ancient methods like planting trees on the hills and terracing which were not studied in this study though these methods could contribute so much to flood control because they reduce the intensity of the runoff reaching the river.

It was found out that there is poor runoff management in the neighborhood. It is therefore recommended that the existing drainage systems within Nyabugogo be urgently rehabilitated before taking any further action on flood control. Immediate attention should be paid to Mpazi canal (Ruhurura) which contributes in the flooding of Nyabugogo.

SCFB is advantageous for flood control over concrete wall. It is concealed underground at the absent of flood. SCFB has earned a reputation around the world because it is about much cheaper than a concrete wall. It is recommended that further studies be conducted to assess the economic feasibility of using this technology for flood control in the specific Nyabugogo wetland area. However, it is also important to take into consideration some of the disadvantages of the used of this technology that include: possibility of (and failure due to) clogging the feed pipe, failure of the support to block the barrier, vandalism, etc.

We conclude by recommending to conduct further modeling studies at downstream of Nyabugogo wetland to predict water level raised due to the construction of Self-Close Flood Barrier (SCFB) along the river side for flood control.

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Plate 1: Google maps of Nyabugogo wetland