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The Impact of Water Ponds on Stormwater Management "Case of Base -Rukomo Road

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ABSTRACT
The road construction projects in Sub Sahara Africa, where Rwanda is located, present a booming development with 7-10 Billion USD annual investment. This considerable development often needs the sound management to safeguard the road reserves and the external environments. Notably, the mismanagement of storm water runoff finally results in erosion, water quality disturbances and downstream flooding. This is a great challenge to the engaged stakeholders. It is the similar scenario along the 51.54 Km Base-Gicumbi-Rukomo road, the case study of this research. In response, this research clarifies how the typical sustainable drainage system involving the water ponds shall eradicate such frustration. Base - Gicumbi - Rukomo road has been implemented in the mountainous and densely rainy region of the Northern Province of Rwanda; a country of thousand hills. This study has been only limited to sample six (6) kilometers located between Mukeri center (Byumba sector) and Kisaro center (Kisaro sector) in Gicumbi district. This area knows the annual rainfall of 1400mm and the altitude of around 2200m. The diligent review of previous literatures has been used to have enough understanding on water pond facility. Also, meteo Rwanda has been referred to during the collection of rainfall data. GIS and Google Earth have been used in mapping and demarcation of catchment areas. Moreover, site inspections have been done to witness the site condition. The diligent calculation of runoff volume has been made for a return period of 100 years. It has been noticed that the topography of the study area can't accommodate huge water ponds which might be used based on computed catchment areas. Medium scale trapezoidal pond able to accommodate a volume of around 1714m^3 have been proposed where the runoff emitted from the outlets of culverts is very critical based on the tangible effects of runoff. This study recommends further research on the remaining sections of case study incorporating other experts like geo-technicians and civil engineers for the successful and plentiful implementation of the project.

Key words: Impact, water ponds and storm water management

LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

RTDA : Rwanda Transport Development Agency
MININFRA :Ministry of Infrastructures
AfDB : African Development Bank
GFDRR : Global Facility for Disaster Reduction and Recovery
GIS : Geographic Information System
GPS : Global Positioning System
Km : Kilometer
USD : United States Dollar
CHICO : China Henan international cooperation group Limited
STUDI : A Tunisian engineering firm which conducted the road project study
NEC : Net Environmental Consultant
UNILAK : University of Lay Adventists of Kigali
ESMP : Environmental and socio-economic plans
REMA : Rwanda Environment Management Authority
RMA : Rwanda Meteorology Agency
WEF : World Economic Forum
RSuDS : Rural sustainable drainage systems
EGIS : E - Government Infrastructure Services (road project consultant).

I. CHAPTER 1. INTRODUCTION

1.1. BACKGROUND OF THE STUDY

Worldwide, the sound road network is one of key engines of development for any country reason why each nation invests more to sustain or upgrade its system. This development of roads often presents discouraging impacts mainly floods from drains and cross structures. Obviously, the proper drainage of water outside the road reserves

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requires extra funds in addition to the normal road project cost (Global Risks Report, 2019).

According to the Global Risks Report 2019, there is a need for a renewed global focus on infrastructure resilience and investment to eradicate this burden. Persistent underfunding of critical infrastructures, like roads, is hampering the worldwide economic progress, and exposing communities to significant risks. Floods are the most tangible and devastating results of the road drainage. They increasingly affect communities across the planet. Over the last decade, the toll added up to tens of thousands of deaths, billions more people affected and damages of more than a trillion dollars (Word Bank, 2021).

It is crucial that societies adapt and governments prioritize, accelerate, and scale up their response mechanisms in the early future. Thus, the Global Facility for Disaster Reduction and Recovery (GFDRR) works hard to guide developing countries about the better understanding and reduction of their vulnerabilities to these hazards. According the word Bank, it is difficult to point to a region or country that will not face more challenges managing these extremes in the years to come. Countries can harness the power of water for development while avoiding the human suffering, economic losses, and ecological degradation that is associated with the hydrological cycle on overdrive. This requires innovative governance and risk management approaches that navigate uncertainty, protect communities, economies, and ecosystems, and improve efficiency of public resource use (Word Bank, 2021).

However, over the last 15 years, the road sector in Africa is the one where most progress has been made in both institutional and financing terms, in particular with the creation of road agencies and road funds. With 5.5 million kilometers of roads in sub-Saharan Africa alone, and road building continuing to be one of the largest public investments, the potential of roads for water harvesting is great. Although roads sector generally offer the qualitative transport services for African.

citizens, besides, the subjected damages constitute a major cost factor in road maintenance and the economic devastation in the neighborhood (Diego,et. Ali, 2014).

Rwanda is one the East African countries with the boom in road construction projects. The quality of the road network has improved during the last decade due to substantial investment and sustained improvement in maintenance. The national paved roads network has been cumulatively increased to 1,532.47km and 3,456.36km of feeder roads were cumulatively rehabilitated up to the end of 2020/221 fiscal year. The road condition survey performed between May up to September 2021 indicated that national paved roads is 96.8%, national unpaved roads is 47%, feeder roads is 60.66% and urban roads is 86.3% (Backward-looking jsr report for 2020/21 fiscal year, October 2021).

Accordingly, Rwanda's vision, in transport sub sector, is to become the main logistic hub for the East and Central due its geographical location. In this regard, Rwandan government through RTDA, the institution affiliated to MININFRA, targets to properly optimize the sound expansion, rehabilitation, upgrade and maintenance of the national road network. It has been also initiated toprovide the modernization, cost effectiveness and quality in every subjected plan to ensure the development of an eco-friendly transport system and the national sustainable economic growth (Rwanda Infrastructure Sector Annual Report for Fiscal Year 2019/20).

Therefore, Rwandan government will gradually have so much pressure to ensure the proper drainage system, drained water conveyance and disposal for the entire road network. This is considerably indispensable for road projects implemented in mountainous regions which are abundant in Rwanda known as a country of thousand hills.

The economy of any rural area in Rwanda mainly relies on agriculture which is the same concern for the surrounding area of Base-Rukomo Road, the case study of this research. The current operation of the constructed road does not have enough measures of proper conveyance and disposal of water highly emitted from outlets of hydraulic structures which results in downstream inundations. Thereafter, crops, lands, other private and public properties are damaged or lost during each rainy season. The proposed water ponds will help those farmers by regulating the speed of runoff which can endanger their production

1.2. PROBLEM STATEMENT

The uncontrolled storm water in the case study is currently warning in the first year of road operation. The cost of storm water conveyance lines and the provision of collecting facilities were not quoted in the initial project cost. This is a big challenge to the project neighborhood because the dramatic widening of natural drain ways, at outlets of ditches and culverts, extremely induces soil erosions and severe inundations of private and public properties. We can also mention the subjected downstream flooding and stream bank erosion. This therefore puts the local authority in the position of frequently receiving the subjected claims from the local residents.

1.3. PROJECT OBJECTIVES

1.3.1. Main objective

To highlight the contribution of an optimized management of storm water runoff along the recently upgraded 51.54 Km Base-Rukomo Road.

1.3.2. Specific objectives

- To determine the peak discharges and runoff volumes for demarcated subcathments
- Sizing of water ponds to accommodate the computed runoff

1.3.2. Research questions

- What is the peak discharge/runoff volume for respective catchment areas?
- What is the size of water pond can accommodate the computed runoff?

1.4. PROJECT HYPOTHESIS

If water ponds are introduced to complement road drainage system; the proper management of storm water will be achieved.

1.5. PROJECT SCOPE AND LIMITATIONS

The major scope of this research is to design the water ponds facilities based on the rainfall distribution in the study area. The study was only conducted ion a hilly section between Mukeri center of Byumba sector and Kisaro center of Kisaro sector as the critical section in Gicumbi district. Kisaro center is at 34 kms far from Kigali Musanze Road while Mukeri center is located at 10 Km from Kigali-Gatuna Road. This study took six months since October 2021 to April 2022.

1.6. SIGNIFICANCE AND RATIONALE

1.6.1. Significance

1.6.1.1. Personal significance

Prominently, the author of this research will find the right opportunity to strengthen and practice the knowledge gained from the recent academic studies. An attentive review of the previous works, onsite data acquisition, conducting the deep analysis on gathered data set, the researcher will raise the reliable concluding statements and sound engineering judgment about the improvement needed in the case study. He will also have the proven consultancy know-how in environmental economics and natural resource management which is a significant asset for every prudent environmentalist.

1.6.1.2. Academic Significance

The accreditation of the final report resulting of the forwarded research will also be fruitful as the researcher will be awarded the Master's degree to justify his academic qualifications. The research report will be available within the library of UNILAK for documentation purpose.

1.6.1.3. Public and Administrative Significances

Moreover, this project report will be a helpful material for RTDA which orchestrates road construction projects. This will be a reference document for engaged contracting and consulting firms in beforehand preparation of the environmental and socio-economic plans (ESMP). This proves that MININFRA and REMA may also use this report to guarantee the construction and operation processes of road projects which are at high speed as witnessed in the recent reports of the world economic forum which ranked Rwanda among top 10 countries with the best road network in Africa (WEF report, 2017-2018).

1.6.2. Rationale

Currently, the 51.54 Km Road linking Base and Rukomo has been paved with asphalt concrete and the subjected surface and subsurface drainage system have been ensured to protect it from any damage may be caused by water activity. This design was mainly limited to the road reserve, which is the close environment (STUDI, 2011). The mobilized budget was not extended to the conveyance and disposal of storm water dramatically emitted from road drainage facilities to the external environment.

The present effect of uncontrolled storm water runoff to local neighborhood, in the first year of operation, immediately warns about the need of new measures in response. The previous studies are acceptable according to the contractual specifications, but do not include the needed ancillary works to safeguard the external environment. This study intends to evaluate the specific situation within the concerned site to save its environment which is in danger. The result of this research will be highly recognized by local residents, administration, and RTDA frequently challenged by damages after heavy rains which are dense in the study area. The detention ponds are therefore proposed to mitigate this continuous frustration

1.6.3. Conceptual framework

This section intends to analytically give the overall picture of the research for conceptual distinction and organization of core ideas. It simply aims to best give an explanatory progression of the study phenomenon. This is therefore envisaged to interconnect the espoused key concepts, empirical research and theories (Dickson, 2018).

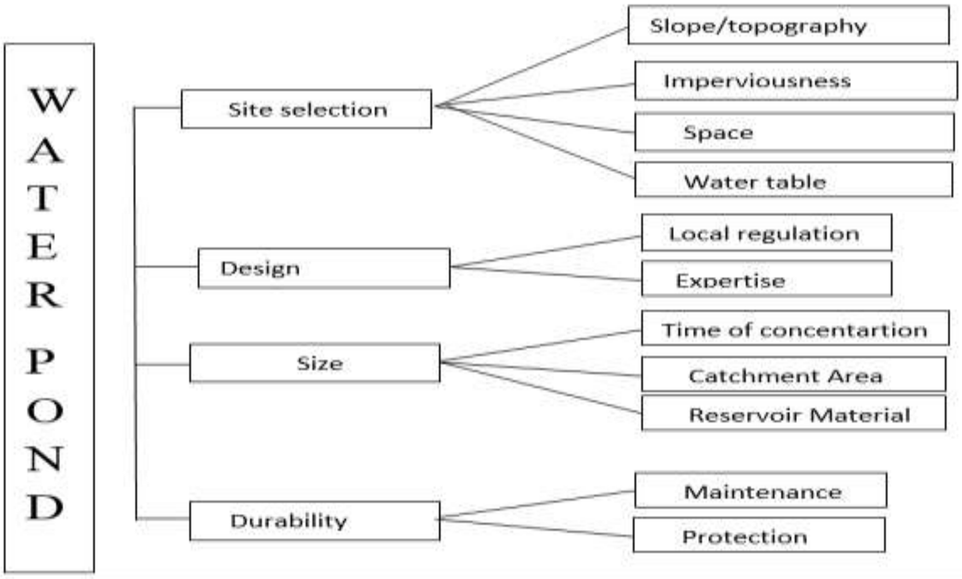

Figure 1: Illustration of the conceptual framework

II. CHAPTER 2. LITERATURE REVIEW

2.1. Water ponds

Many researches have been undertaken to find specific options significantly applicable in rainfall-runoff management. Some successful practices have been adopted in rural sustainable drainage system but this research only emphasizes on the provision of sound storm water detention ponds to ensure the proper conveyance, disposal and use of storm water runoff drained off from the drain way of constructed road. According to UK RuSDS report (2012), the specific findings for detention ponds proposed in this research, are tabulated as follow:

Table 2. 1. Findings on detention ponds in sustainable drainage system

Rural SUDS component	Detention basin/pond
Summary	Normally dry basins designed to temporally store and slowly release runoff water[1,2].
Description	Basins/depressions which are usually dry and are designed to temporally store and slowly release runoff water to meet flow and water quality criteria. Water leaves the basin via a restricted outflow control leading to a longer detention time and improved particulate pollution sedimentation. Pollution removal improved by including features such as pre-treatment sediment traps, deeper areas at or near inlets and low flow channels[1,2]. Detention time greater than 24 hrs = extended detention basin. These can also provide flood control by providing additional flood detention storage.

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Cost (£)	**Set up**	***High***[6], construction and provision of outflow control likely to require expert advice and specialist equipment.
	Running/ Maintenance	***Moderate,*** monthly removal of leaves and debris[1,2]. As required, mowing of side slopes and repair of damaged vegetation[1,2]. Annually or every three years, bank clearance, manage wetland plants[1,2]. Three to seven years, remove sediments from sediment trap[1]. Remove sediments from main pool, typically every 25 years[1].
Performance	**Flow**	***High,*** retains water and slowly releases it[2,7]
	Suspended solids (SS)	***High,*** encourages sedimentation and nutrient uptake by plants[1,2,3,4,5,6,8,9,10,11,12]
	Total Phosphorus (TP)	***Medium,*** encourages sedimentation and nutrient uptake by plants[1,2,3,4,5,6, 9,10,11]
	Total Nitrogen	***Medium,*** encourages sedimentation and nutrient uptake by plants[1,2,3,5,6, 9,12]
	Pesticides	***Medium***[E,11]
	Pathogens	***Medium***[E,12]
Cost effectiveness	***Medium value,*** High initial costs, but low maintenance costs, long life time and reasonable effectiveness	
Additional Benefits	**Biodiversity**	***High,*** increases habitat diversity, temporary water with large drying margins. Must be designed well to achieve full benefit[2].
	Amenity	***Medium,*** normally dry therefore lower amenity value than retention ponds
Common factors affecting performance	Detention time, vegetation, depth to water table, soil moisture content, soil permeability	
Reliability/ consistency		
Lifespan (years)	Indefinite[2]	
Design guidelines	Key factors, for extended detention basin, taken from CIRIA (2004)[1] unless otherwise stated: • Same as retention ponds, although permanent pool much smaller or non-existent. • Irregular shape with bars • Length: width 1.5:1 to 4:1[1,13] • 0.3-0.5m/s inlet velocity • Sediment trap should be approximately 20% of the pool volume	

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	• Potential to include small ponds and inlet and outlet to prevent re-suspension in heavy storms[1,13]. • Side slopes 1:3 maximum, any steeper and they will require stabilisation[1,13] • No more than 50% of the water quality volume should drain within 24 hours, complete drawdown should occur within 72hours[13].  Establishing a detention pond. Photographs courtesy of Andy Vinten
Site suitability/ Limitations	Suitable for most sites where space is available, can be used with almost all soils and geology, with minor design adjustment for highly permeable sand soils i.e. inclusion of impermeable liner. Base should not intercept water table, and should become dry between storms. May not be suitable where water contaminated with dissolved pollutants and groundwater contamination maybe an issue, especially in permeable soils[2].
Utilisation examples	Bottom of the slope in fields particularly those draining to a single corner. Storage of run-off collected through other RSuDS e.g. from tracks and hardstanding
Associated SuDS	Sediment trap before inlet [1,2] Permanent wetland at outlet increases treatment and biodiversity [2] Collection or diversion via other RSuDS e.g. swales, cross drains, berms etc.
Further Guidance	CIRIA (2004) *Sustainable drainage systems: hydraulic, structural and water quality advice*. CIRIA C609

Source (UK RuSDS report, 2012).

2.2. Road drainage system

2.2.1. Significance of drainage system in road construction

Sub Saharan Africa uses annual investment of 7-10 Billion USD in road construction projects with the accomplishment of 70,000 kilometers a year which immediately exerts a major impact on water management and on the neighboring environment (AfDB, 2014).

The fundamental role of a road drainage system is to effectively remove water from the road and its surroundings. The road drainage system consists of two parts: dewatering and drainage. “Dewatering” means the removal of rainwater from the surface of the road. “Drainage” on the other hand covers all the different infrastructural elements to keep the road structure dry which maintain its designed bearing capacity and comfort along the predicted serviceable life span. Thus, the drainage system becomes an important and integral consideration in the planning, design and operation of the road infrastructure (Frank, 2017).

2.2.2. Requirements of an effective road drainage system

To provide an appropriate and economic drainage system, all road projects, irrespective of location, size, cost or complexity, must consider and address the following items:

- provision of an acceptable level of flood immunity and accessibility,
- effects of flooding of public and private property,
- conveyance of storm water through the road reserve at a developmental and environmental cost that is acceptable to the community as a whole protection of the roadway asset,
- safety of all road users,
- pollutant discharge from the road reserve to receiving waters,

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- land degradation caused by erosion and sedimentation during road construction, operation and maintenance,
- any effect on habitats for terrestrial and aquatic flora and fauna,
- Any effect on the movement of terrestrial and aquatic fauna.

2.2.3. Community engagement in road projects

All stakeholders, including government, private and the public organs are both concerned with any road construction project. The Community engagement can assist in integrating economic, social, and environmental objectives of road infrastructure delivery.

The road construction project is an important asset to the community and their collective efforts are required to understand the real concept of storm water activity, drainage and subjected effects to their lives

Members of the public may also provide local data/knowledge for use in the environmental safeguard. Flooding and drainage are relevant in several parts of community engagement programs. Information gathered from the community and other stakeholders, particularly those who have long term firsthand knowledge of the area is often very valuable and helps to establish relevant approaches. The community affected by a road project can be consulted to discuss the individual levels of effects (Queensland Road Drainage Manual, 2019).

2.4.4. Future development in road projects

This can be difficult but, nonetheless, important. Changes in conditions can occur during the life of drainage infrastructure. These changes can affect the runoff to the road or changed flood plain/channel conditions may affect flood levels adjacent to the road. The local and national transport agencies, in close collaboration with affiliated organs, have a responsibility to provide advice on any development applications to ensure the suitable mitigation measures indeed. If not properly ensured, the catastrophic destructions of private and public properties may lead to economic backslides. Mitigation measures include detention storages, channel works or other similar measures may be applicable indeed. Some mitigation measures may not be effective in the long term. It is important that the responsible authority maintain close review of any potential effects on drainage and ensure that they are managed appropriately (Queensland Road Drainage Manual, 2019).

2.3. Link between water pond and road drainage

2.3.1. Introduction to storm water activity

Storm water runoff herein refers to the rainfall that runs off the ground or impervious surfaces like roads and drains into natural or manmade drainage ways. In some cases, it drains directly into streams, rivers, etc. In other cases, particularly urbanized areas, it drains into streets and manmade drainage systems consisting of inlets and underground pipes commonly referred to as "storm sewers. Storm water entering storm sewers does not usually receive any treatment before it enters streams, lakes and other surface waters (Queensland development agency, 2012).

2.3.2. Flooding mechanism and activity

The control of storm water runoff and its impacts is a serious issue facing many nations. Flooding is the most common natural hazard faced by the world, and extreme flood events have attracted significant attention over the past few years.

The figure 1 below shows the principle of flood occurrence (Queensland development agency, 2012).

Figure 2: Flood occurrence mechanism**(Source: Queensland development agency, 2012)**

According to www.chathamnc.org, the Storm water runoff problems and impacts are most evident in areas where urbanization has occurred, including the elaboration of a modern road network facility. Changes in land use have a major effect on the quantity of storm water runoff. Urbanization, if not properly planned and managed, can dramatically alter the natural hydrology of any concerned area. Increased impervious cover decreases the amount of rainwater that can naturally infiltrate into the soil and increases the volume and rate of storm water runoff. These changes lead to more frequent and severe flooding and potential damage to public and private properties. Figure 4 below mentioned explains what really happens on the rainfall after the rainfall reaches the pavement.

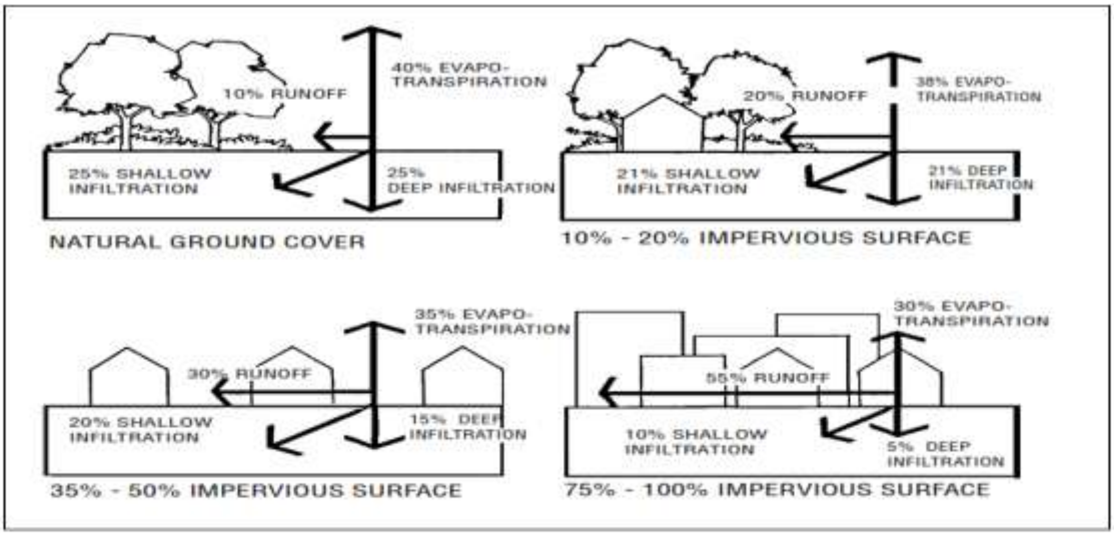

Figure 3: Runoff changes due to pavement effect

Source: Judith, 199.

Practically, the development of the site increases the percentage of impervious surfaces. As the percentage of impervious surfaces increases, the percentage of runoff increases since there is less vegetated area to soak up the rainwater. Thus, the rate of runoff and stream flow after a storm event also shows dramatic increases. There is a considerable difference between measurements obtained under post development and predevelopment of the site conditions as shown on figure 4 below.

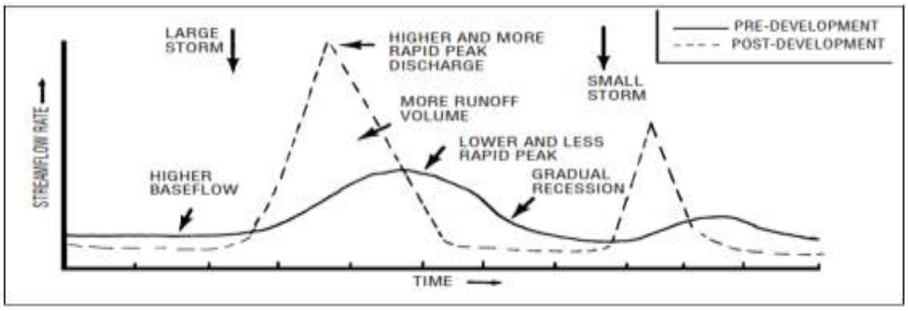

Figure 4: Pre versus post development flow rates **(Source: Dickson, 2018).**

2.3.3. Water ponds part of the sustainable drainage system

The proper management of the storm water runoff in road construction projects is a critical concern to engineers all over the world (Adams, 2000). In the light of progressing climate change, the likelihood of such events will further increase (Audrey, et. Ali, 2013). This will, in particular, be the sophisticated case in countries with developing economies and hilly topographies, such as Rwanda (IPCC, 2014). According to Rwanda Water resources Board (RWB), during the rainy season, large part of the rainfall is lost as runoff without usage which in turn results in erosion of soil and downstream floods.

Thus, different options in rural sustainable drainage system, including water ponds, have been tried in response. According to Queensland Environment Agency (June 2012), the rural sustainable drainage systems are measures that primarily intercept run-off or drainage pathways. They are comprised of individual or multiple linked component structures replicating natural processes, designed to attenuate water flow by collecting, storing and improving the quality of run-off water within rural catchments.

Water ponds have been incorporated in drainage system to control the storm water run-off in the external environments of the roads. They involve collection, storage and cleaning processes before allowing water to be released slowly back into the environment.

Therefore, the water pond is a significant element in rural sustainable drainage system to control surface run-off, by helping to buffer peak flows and thereby contributing to flood risk management. It is an indispensable facility introduced to complement the road drainage in safe conveyance and disposal of storm water runoff from the road reserve, through the external environment to water bodies.

2.3.4. Research gap

According to the reviewed literatures on the topic of concern, it is clear that no specific study was yet done on the use of water ponds to complement the road drainages of such hilly road. The previous studies in the concerned area were only conducted to design road drainage components but did not go beyond the road reserve. This research has been conducted to address the interaction of this road drainage and its surrounding environment.

III. CHAPTER 3. RESEARCH METHODOLOGY

This part clarifies specific procedures or techniques to be used in identification, selection, and analysis of the target data for the successfulness of the concerned research. Primary data will be collected through onsite surveys while secondary input will be gathered from libraries of concerned institutions. This part also shows the analysis approach to be used in processing the set of gathered data set to raise reliable the sound conclusion and applicable recommendations.

3.1. DESCRIPTION OF THE STUDY AREA

Specifically, according to the Execution survey report prepared by the contractor of fulfilled construction works (CHICO, March 2020), the concerned road project, Base-Gicumbi-Rukomo, is precisely located in mountainous zone of Rwandan Northern Province which presents a difficult topography in ensuring the proper management of storm water runoff. It links Kigali- Musanze and Kigali-Gatuna roads. The origin is Rukomo Center which is around 60 Kms from Kigali while Base, the destination, is around 45 kms far from Kigali City.

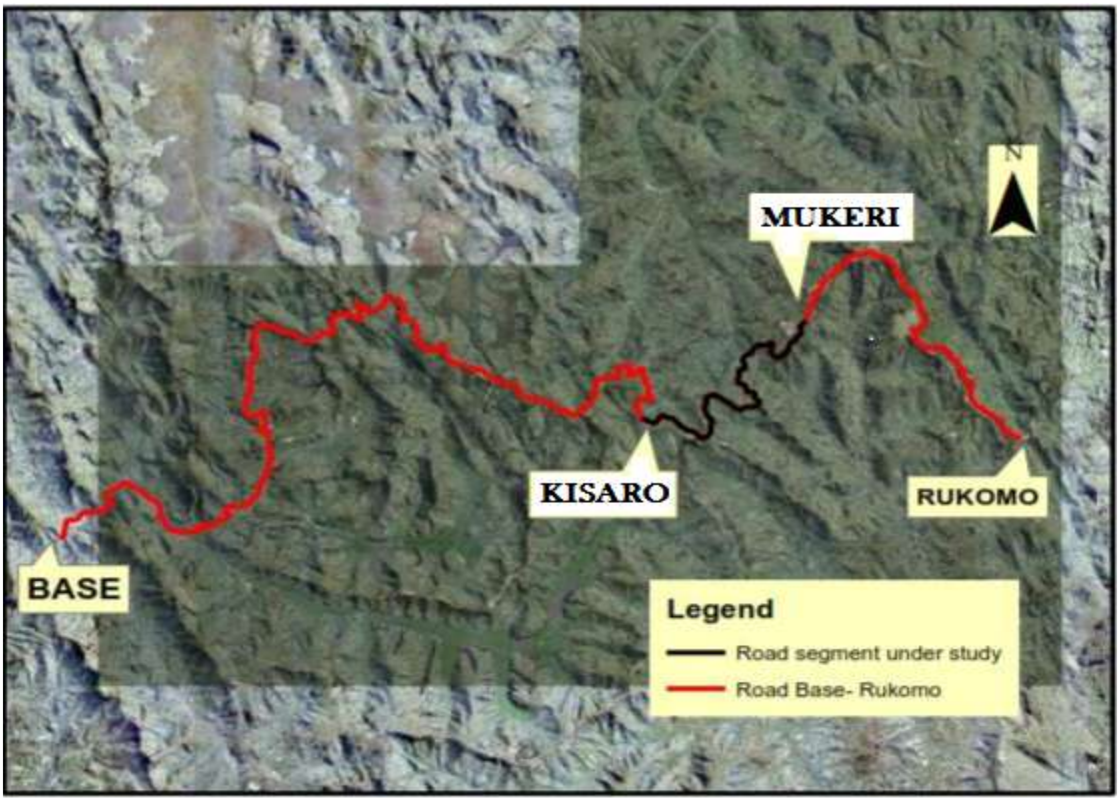

Figure 5: Illustration of the study area on a map

(Source: STUDI, June 2011)

The Rwandan Northern Province, where Base-Gicumbi-Rukomo road is located, has relatively abundant rainfall with high intensity and suffers a lot of high run-offs causing, soil erosion, flooding and landslides. The figure below presents the repartition of rainfall intensities within Rwanda.

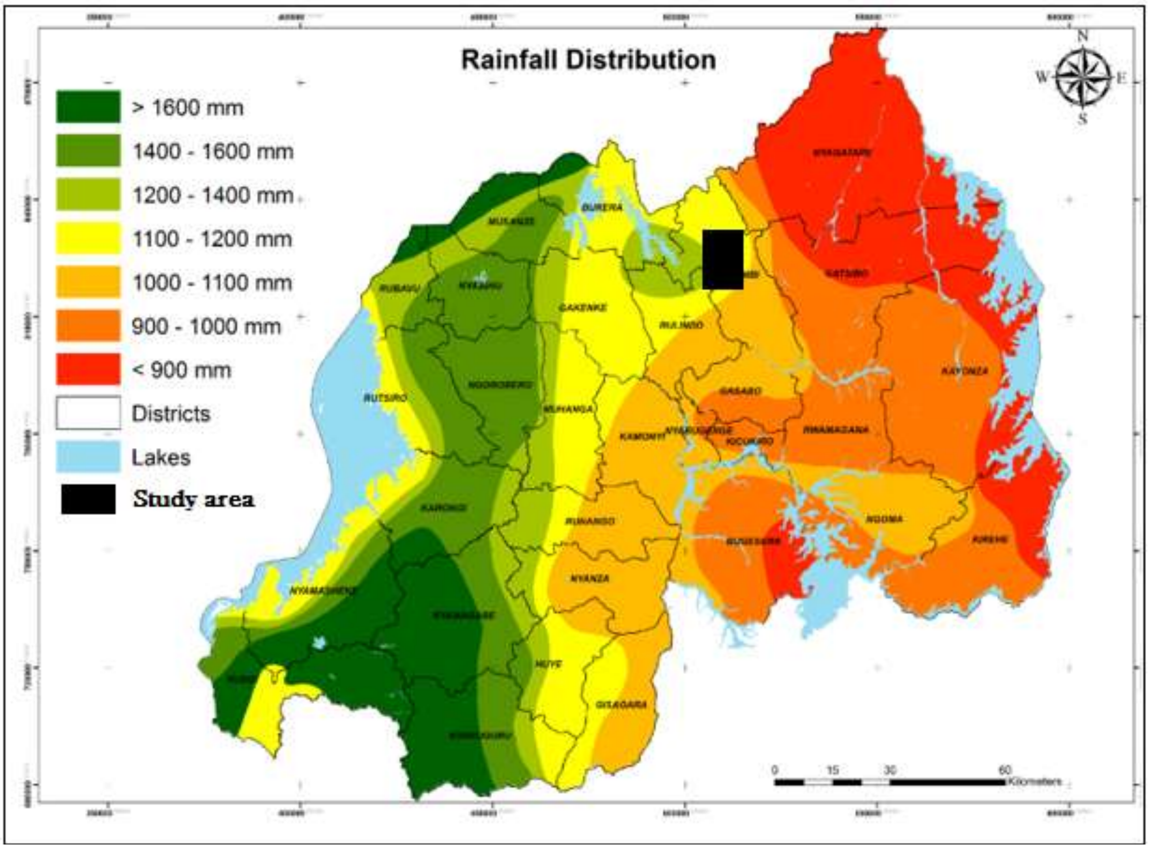

Figure 6: Rainfall distribution in Rwanda**(Source: RNRA, 2016).**

3.2. RESEARCH DESIGN

The descriptive quantitative research method will be used to establish significant statistical conclusions about a population by studying representative sample. Keeping in mind that the region surrounding Base-Rukomo Road considerably suffers a lot of the effects of water highly emitted from outlets of hydraulic structures, the researcher intends to conduct research to evaluate the size of effects and to recommend accordingly.

The researcher will analyze the situation based on quantitative approach herein chosen. The researcher will start by gathering the data set through review of archived documents, questionnaire and observations. The data will be numerically analyzed to evaluate the correlation between variables and, if so, regression may be used to predict future outcome based on the studied variables.

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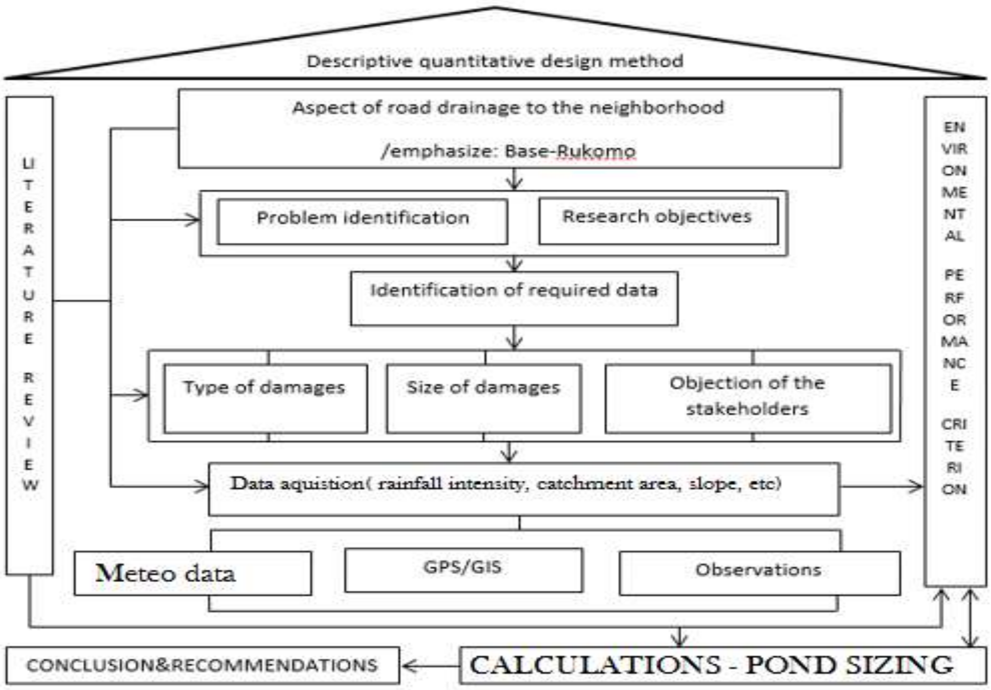

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Figure 7: Illustration of the research design

3.3. **DATA COLLECTION**

Use of literatures has been significantly used to learn more from the previous publications, notably to discover the gap in the area of investigation. Also, other objections been sourced from documents available in libraries of African Development Bank (AfDB), Rwanda Environment Management Authority (REMA), Minsistry of Infrastructures (MININFRA), Rwanda Transport Development Authority (RTDA), Rwanda Meteorology Agency (RMA), China Henan International Cooperation Group (CHICO) and EGIS International, organs and firms involved in the project's funding, administration, study, execution.

i). Rainfall data

For this study, the rainfall data to be used are the daily rainfall data provided by the Rwanda Meteorology Services for a period of 35 years (from 1980 to 2015). So, considering the location of the study area, meteorological data of Byumba station have been referred to (see appendices 3 and 4). The annual average rainfall is around 1400 mm and the maximum rainfall observed at the nearest stations to the study area is 78, 7 mm.The following figure shows the distribution of the annual maximum daily rainfall following the law of Gumbel (used for the extremes) as mentioned in the the previous studies.

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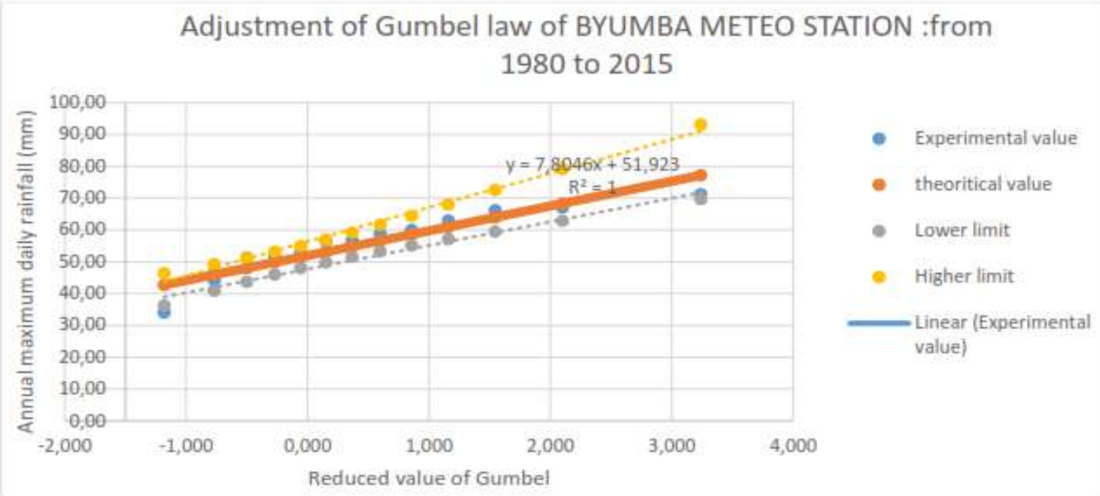

Figure 8: Gumbel distribution of the annual maximum daily rainfall (**Source: Hydrological study of Base-Rukomo Road (2016).**

Therefore, the daily rainfall of ten-year recurrence is equal to 78, 7 mm and the daily rainfall of Centennial recurrence is equal to 104 mm.

iii). Use of GPS/GIS/Google earth

The GPS/GIS and Google earth have been used in location and mapping of the areas concerned with the case study. The land demarcation has been realized using Google earth. Below is the map showing 8 areas subdivided in the study catchments.

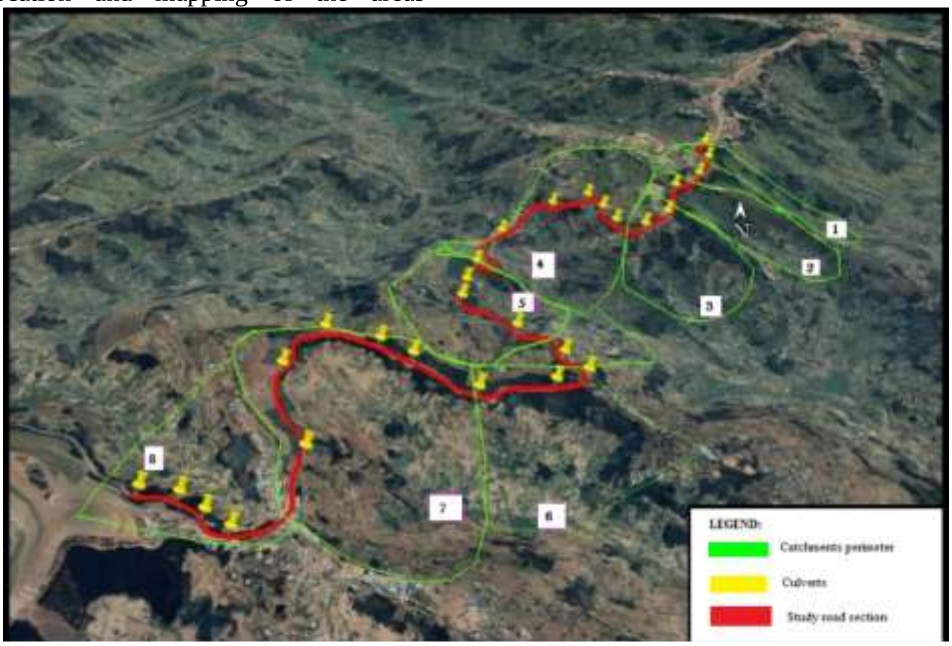

Figure 9: Illustration map of the study catchment area

From the above demarcation, the following table shows the computed areas (in hectares) of the subdivided catchments.

Table 3.1. Areas computed for each individual sub catchment

Sub catchment **No**	1	2	3	4	5	6	7	8
Area (**Ha**)	93.8	56.4	48.9	101	74	54.1	118	52.2

IV. CHAPTER 4. DATA PROCESSING AND DISCUSSION

4.1. Catchment characteristics

The following table shows fundamental characteristics for the study catchment which has been divided into 8 Subcatchments to ease the computation of peak discharge.

Table 4.1. Sub catchments characteristics

Sub catchment No	Area(ha)	Longest distance (L in m)	Difference in elevations (ΔH in m)	Slope(S): ΔH/L
1	93.8	1020	304.2	0.30
2	56.4	1190	233.7	0.20
3	48.9	930	257.4	0.28
4	101	1260	252.0	0.20
5	74.0	900	256.8	0.28
6	54.1	660	258.3	0.39
7	118	1220	267.9	0.22
8	52.2	810	125.4	0.15

4.2. Determination of the peak discharge

The rational method has been used to compute the peak discharge:

$\boldsymbol{Q} = \boldsymbol{KCIA}$

Where,

Q: peak discharge for the return period (in m^3/S)

C: Runoff coefficient (unitless)

I: Rainfall intensity (in mm/hr) in a given concentration time Tc

A: Catchment area (in ha)

K: conversion factor (unitless)

i)- Selection of the Return Period (Rp) in years:

$10 \leq Rp \leq 100$

ii)- Time of Concentration (Tc)

Pasini formula below, has been therefore chosen and used (Pasini, 1914) to calculate it.

$$T_c = 0{,}108 A^{0{,}333} L^{0{,}333} S^{-0{,}5}$$

Where:

- A: area (in ha)
- Tc: time of concentration (in min)
- L: the largest length of talweg (m)
- S: slope (dimensionless)
- L = maximum length of travel of water (m)

Table 4.2: Computed times of concentration

Sub catchment No	Area (ha)	Max. Length of travel (L in m)	Slope(S): ΔH/L	$(AxL)^{0.333}$	$(S)^{-0.5}$	Time of Concentration (Tc in min)
1	93.8	1020	0.3	45.74	1.82	9
2	56.4	1190	0.2	40.64	2.24	10
3	48.9	930	0.28	35.7	1.9	7
4	101	1260	0.2	50.3	2.24	12
5	74	900	0.28	40.53	1.9	8
6	54.1	660	0.39	32.93	1.6	6
7	118	1220	0.22	52.41	2.13	12

8	52.2	810	0.15	34.84	2.58	10

ii)- Runoff coefficient (C)

The following table shows the runoff coefficients for different catchments.

Table 4.3. Runoff coefficients(C)

Type of catchment	Values of C
Rocky and impermeable	0.8 – 1
Slightly permeable, bare	0.6 – 0.8
Cultivated of covered with vegetation	0.4 – 0.6
Cultivated absorbent soil	0.3 – 0.4
Sandy soil	0.2 – 0.3
Heavy forest	0.1 – 0.2

Source: Pascal (September 2016)

Therefore, let us take the runoff coefficient equal to 0.57 as the terrain in the study area is mainly covered with vegetation.

iii)- Rainfall intensity (I)

The rainfall intensity is derived from the following Montana's Formula:

$$I(T,tc) = a(T) \times t_c^{-b(T)}$$

Where,

- I: Rainfall intensity for the specific return period and time of concentration (unit: mm/hr)
- a and b Montana's coefficients (a = 572.45 and b= 0.647 for $2 \leq T_c \leq 15$ min for a return period of 10 years).
- T_c: Time of concentration.
- **iv) - Passage coefficient**
- The discharge Q for a specific time of concentration Tc also relies on the passage coefficient R(T, Q) as shown in the following formula:
- $\mathbf{Q_T = R\ (T, Q) \times Q_{10}}$
- Q_{10}: discharge for a return period of 10 years
- Q_T: discharge for a certain return period after the application of passage coefficient,
- $R_{(T,\ Q)}$: Passage coefficient (see the table below).

Table 4.4. Passage coefficients for various return periods

T	20 ans	50 ans	100 ans
R(T,Q)	1,12	1,28	1,39

(Source: RNRA, 2015)

Therefore, the peak discharge is calculated in the following table.

Table 4.5. Discharge calculations for individual sub-catchment areas.

Sub catchment **No**	Area **(ha)**	Time of Concentration (**T**c in **min**)	Runoff coefficient **(Constant)**	Rainfall intensity **(mm/hr)**	Discharge(m^3/S)			
					Q_{10}	**Q_{20}**	**Q_{50}**	**Q_{100}**
1	93.8	9	0.57	137	20.4	22.8	26.1	28.3
2	56.4	10	0.57	126	11.2	12.6	14.4	15.6
3	48.9	7	0.57	137	10.6	11.9	13.6	14.8
4	101	12	0.57	114	18.3	20.5	23.4	25.4
5	74	8	0.57	149	17.4	19.5	22.3	24.2
6	54.1	6	0.57	177	15.2	17.0	19.4	21.1
7	118	12	0.57	114	21.4	23.9	27.4	29.7
8	52.2	10	0.57	126	10.4	11.6	13.3	14.5

Let us design for the biggest area of 118 corresponding to sub catchment number 8.
Depending on the size of drainage area and high risk of failure, the chosen return period is 100 years (i.e use of Q100 equal to 29.7m^3).

4.3. Sizing of the pond

According to the PA Storm water Best Practices Manual (2006) and CIRIA (2004), below are core steps way forward:

Step 1: Determination of the runoff volume (V_r)

The runoff volume (V_r) = Peak discharge x Time of concentration

V_r= 29.7m^3/s x12min x 60 sec/min

V_r= 21,384 m^3

Step 2: Determination of the required pond Volume (V_p)

As the target is to maximize during design, the required pond volume equals to the runoff volume.

Pond volume (cum) = Runoff Volume (cum).

V_p= **21,384 m^3**

Step 3: Determination of pond dimensions

Assuming the rectangular reservoir:Volume = height x length x width

The minimum required freeboard: 1ft or 0.30m

Length =70m, Width = 45m and height of 7m

Note: As it is not easy to find the combined area of land to accommodate such higher volumes of water in one huge reservoir, the right option is to predict ponds where we have culverts to condition the storm water runoff before it is released downstream.

Let us use the data archived in the folder of Base-Gicumbi-Rukomo Road, specifically for the 6 Kms under study. The following table shows discharges computed at each culvert in the study area.

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Subbassins	Culverts location	Area	Cumulative area	Runoff coeffient [C]	Reduced area		Flow Length of Talweg	Slope [S]	Time of flow		Intensity [I]	Discharge	Discharge	Discharge	Discharge
					part.	cumul			Passini	Kirpich		Q10	Q20	Q50	Q100
N°	Pk	[ha]	[ha]	[-]	[ha]	[ha]	m	[m/m]	[min]	[min]	[mm/h]	[m3/s]	[m3/s]	[m3/s]	[m3/s]
40	00+026,230	2,853	2,85	0,50	1,43	1,43	230,60	0,13	3,47	3	256	1,022	1,144	1,308	1,420
41	00+212,940	0,850	3,70	0,50	0,43	1,86	228,30	0,17	1,99	2	367	0,437	0,489	0,559	0,607
42	00+489,280	1,638	5,34	0,50	0,82	2,67	268,70	0,15	2,63	3	292	0,670	0,751	0,858	0,932
43	00+713,070	2,451	7,79	0,50	1,23	3,90	283,80	0,16	3,15	3	272	0,935	1,047	1,197	1,300
44	00+979,320	6,848	14,64	0,50	3,42	7,32	413,90	0,14	5,29	4	199	1,867	2,091	2,390	2,596
45	01+233,370	5,367	20,01	0,40	2,15	9,47	436,40	0,14	4,97	4	203	1,219	1,365	1,560	1,694
46	01+461,780	3,754	23,76	0,40	1,50	10,97	332,50	0,15	3,93	3	236	0,993	1,113	1,272	1,381
47	01+693,060	3,045	26,81	0,40	1,22	12,19	183,70	0,30	2,09	2	355	1,212	1,357	1,551	1,685
48	01+877,620	23,908	50,72	0,40	9,56	21,75	874,90	0,13	10,50	8	125	3,347	3,749	4,285	4,653
49	02+167,850	18,383	89,10	0,40	7,35	29,11	824,70	0,16	8,76	7	141	2,894	3,242	3,705	4,023
50	02+417,060	5,892	74,99	0,40	2,36	31,46	392,40	0,30	3,40	3	259	1,710	1,915	2,189	2,377
51	02+723,980	1,613	76,60	0,50	0,81	32,27	327,30	0,22	2,40	3	325	0,734	0,823	0,940	1,021
52	03+154,880	7,574	84,18	0,50	3,79	36,06	738,90	0,12	7,12	7	161	1,704	1,909	2,182	2,369
53	03+488,940	10,025	94,20	0,40	4,01	40,07	548,10	0,24	5,03	4	201	2,259	2,530	2,891	3,140
54	03+728,370	11,787	105,99	0,40	4,71	44,78	571,80	0,24	5,42	4	192	2,531	2,835	3,240	3,518
55	04+020,400	7,672	113,66	0,40	3,07	47,85	359,10	0,43	2,99	2	282	2,423	2,714	3,102	3,368
56	04+307,760	17,117	130,78	0,40	6,85	54,70	579,20	0,26	5,91	4	181	3,477	3,894	4,450	4,833
57	04+571,990	6,409	137,19	0,40	2,56	57,26	390,20	0,32	3,36	3	261	1,877	2,102	2,402	2,609
58	04+835,220	1,617	138,80	0,40	0,65	57,91	89,70	0,48	1,06	1	550	0,997	1,117	1,276	1,386
59	05+122,630	3,357	142,16	0,40	1,34	59,25	185,40	0,36	1,99	2	367	1,380	1,545	1,766	1,918
60	05+450,000	3,538	145,70	0,50	1,77	61,02	173,70	0,36	1,99	1	366	1,815	2,033	2,324	2,523
61	05+741,810	3,891	149,59	0,50	1,95	62,96	143,40	0,32	2,03	1	361	1,969	2,205	2,520	2,737
62	05+988,490	0,858	150,45	0,50	0,43	63,39	208,20	0,11	2,37	3	327	0,393	0,441	0,503	0,547

Table 4.6. Discharge for each culvert in the study area(Source: Hydrologic study, Base-Rukomo Road (2016)

Thus, the biggest Q_{100} computed during the preliminary hydrological study is $4{,}833m^3$ corresponding to the concentration time Tc of 5.91min.

Therefore, the Runoff Volume (V) = $Q_{100}*T_c$

V= $4.833m^3/S$ x 5.91min x60S/min

V= $1714m^3$

Pond dimensions:

Let us use the trapezoidal pond having the following dimensions:

- Bottom area: 35.5mx15.5m
- Top area: 37.5*17.5m
- Height: 3m

Note: The details on proposed well are shown in appendix 1.

Step 4: Determination of the drain time of the dry well

Drain rate (Cu ft/hr)

$$= \text{Soil permeability rate} \left(\frac{\text{in}}{\text{hr}}\right) X \frac{1\text{ft}}{12\text{in}} \text{ X Bottom Area(Sq ft)}$$

NB: Based on the experience in earth behavior observation, let us use the soil permeability rate: of 0.5 in/hr as there is no current measured data.

$$\text{Drain rate} \left(\text{Cu}\frac{\text{ft}}{\text{hr}}\right)$$

$$= 0.5\left(\frac{\text{in}}{\text{hr}}\right) X \frac{1\text{ft}}{12\text{in}} \text{ X 6458.35(Sq ft)}$$

$$= 269.1 \text{ Cu}\frac{\text{ft}}{\text{hr}}$$

Drain Time < 72 hours

$$\text{Drain Time (hr)} = \frac{\text{Runoff Volume(Cu ft)}}{\text{Drain rate}(\frac{\text{Cuft}}{\text{hr}})}$$

$$\text{Drain Time (hr)} = \frac{1714 \text{ Cu ft}}{269.1\ (\frac{\text{Cuft}}{\text{hr}})} = 6.4 \text{ hrs}$$

V. CHAPTER 5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. SUMMARY AND CONLUSION

Below is the outlined brief of findings and conclusion on this study:

- Rainfall data records collected from meteo Rwanda indicated that the road section under study is located in the heavily rainy zone with annual rainfall of 1400mm, while the maximum daily rainfall is 78.7 mm which conveys to the higher probability of food occurrence.
- The topography in the study area is hilly and characterized by high altitude of around 2200m.
- If implemented, water ponds shall improve the storm water management in the study area by the fact that most sensitive water (from culvert downstream downspouts) will be first moderated before reaching the vulnerable external environment.
- The diligent site inspections revealed that there are tangible facts of continuously damaged properties due to the uncontrolled storm water runoff.
- Based on the topography in the study area, it is not easy to have enough space to set out the bigger water ponds which can fully accommodated the estimated runoff for each catchment among eight subdivided. The sound option will be to adopt the small ponds (see appendix 1) which can condition the runoff in the subcatchmnet of each sensitive culverts.
- An expert shall make technical judgement and recommend adjustments where necessary during the implementation of the proposed water pond with the target of minimizing the effect of storm water runoff to the external environment.
- Medium scale trapezoidal pond able to accommodate a volume of around 1714m^3 will accommodate the runoff highly emitted from the outlets of culverts as has been attentively proved through calculations.

5.2. RECOMMENDATIONS

5.2.1. Recommendations to the stakeholders

- RTDA may continuously work hand in hand with REMA to organize Environmental assessments on Base-Rukomo Road project to provide further government's assistance in the study area.
- The local people surrounding Base-Rukomo Road which are highly disturbed with the questionable storm water runoff shall be required to be flexible during the implementation of the proposed water ponds.

5.2.2. Recommendations to researchers

- Further study may be expanded to include other researchers, especially geotechnicians and civil engineers for the successful implementation of the proposed water ponds.
- This study was only limited to most critical six kilometers only (between Mukeri and Kisaro of Gicumbidstrict, Northern Province of Rwanda. Further study can be expanded to the remaining 45 Kms (between Rukomo and Mukeri, and Between Kisaro and Base centers).

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