ASSESSMENT OF RAINWATER HARVESTING POTENTIAL FOR IRRIGATION AT KABIRUINI IN NYERI, KENYA

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Assessment of Rainwater Harvesting Potential for Irrigation at Kabiruini in Nyeri, Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature……………………………………Date……………………………………..

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This thesis has been submitted for examination with our approval as the University supervisors.

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DEDICATION

This work is dedicated to my dear wife Hannah and my children Ruth, Naomi, Elizabeth, Samuel and James for continuous support as a family.

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I wish to thank God for allowing this thesis to come this far. I humbly thank Professor J.M.Gathenya and Professor P.G. Home who supervised me patiently. I thank Kenya Polytechnic, the predecessor of Technical University of Kenya, who paid the fees. I thank my family for being there for me through the ups and downs of the entire study period.

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LIST OF ABBREVIATIONS AND ACRONYMS

Acre	1 acre= 4,047 m^2
AWBM	Australian Water Balance Model
EM 1110-2-1417	Engineering Manual 1110-2-1417 (US Army)
ESRI	Environmental Systems Research Institute
FAO	Food And Agricultural Organization
FEWS-NET	Famine Early Warning Systems Network
GIS	Geographic Information System
Ha	1 Ha = 10,000 m^2
HSG	Hydrologic Soil Group
ISRIC	International Soil Reference And Information Centre
JKUAT	Jomo Kenyatta University of Agriculture And Technology
M^3	Cubic Meter
mm	Millimetre
SCS-CN	Soil Conservation Service Curve Number
UNEP	United Nations Environmental Programme
WRA	Water Resources Authority

ABSTRACT

Constructed reservoirs sometimes fail to provide the required amount of water through unforeseen loses. This is the case with Kabiruini reservoir which failed to provide adequate harvested rainwater for irrigation on the second year of desiltation necessitating this research. Assessment of rainwater harvesting potential and determination of irrigation area were carried out using rainfall and evapotranspiration data obtained from SWAT GLOBAL. The rainfall data ranging from 1979 to 1989 obtained from Water Resources Authority (WRA) was used as calibrating runoff for the runoff simulation using Australian Water Balance Model (AWBM). The simulated runoff and the potential irrigation area were processed in Microsoft excel where monthly values were tabulated. The reservoir was found to runoff harvest of 78309 m^3 per year on average out of which 30955 m^3 (40%) was lost through seepage and evapotranspiration. The remaining 48114 m^3 was split into three cropping seasons whose total irrigation area was found to be 6 Ha per year. This proved that that the catchment can provide adequate runoff for the intended irrigation area. However, a good apportionment plan was found to be necessary to ensure that the reservoir can meet the irrigation demand which will avoid loses in excess land preparation. Increasing the capacity of the dam from the current 23302 m^3 to 35075m^3 would increase it storage capacity by 50%. This study recommends that seepage and evapotranspiration loses should be mitigated using appropriate means to reduce water depletion in the reservoir.

Keywords: *assessment, rainwater, irrigation, potential*.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Rain water harvesting has been done in many parts of the world to supplement existing water supply systems. Many countries such as Singapore, Japan, Germany, Thailand, Philippines and Bangladesh have established programmes to collect and store rain water. Africa has been slow in adopting rainwater harvesting technologies but countries like Tanzania and Botswana have taken initiatives to harvest and use rainwater. In Kenya, most of the urban dwellers have no idea that they could use rainwater with only 0.8% of them using rainwater according to 2009 Kenya population census (Mose, 2016). However, the Government of Kenya through Cabinet Secretary has promised to launch a National Water Harvesting and Storage Authority (Ngotho, 2018). Kabiruini show ground in Nyeri is the current site where agricultural displays are done every mid-September which falls in a dry season between the long and short rains.Kabiruini reservoir was constructed to supply irrigation water for the showground in Kabiruini, Nyeri. However, the reservoir was found to be losing water at a rapid rate despite recent desiltationby exposing the runoff to more seepage and evaporation space (Mueni, 2006). The addition of several check dams upstream of the reservoir also seemed to have aggravated the capacity inadequacy of the reservoir(Mueni, 2006). In addition, no studies were done to match the reservoir capacity with the irrigable area. The paths of water loss from the reservoir were not identified. It was, therefore, imperative to conduct a thorough analysis of the water flow within the catchment in order to assess the irrigable area the reservoir could command within the current climate change phenomenonwhich makes rainfall unreliable for crop production (Kisakye, Akurut, & Bruggen, 2018).

1.2 Statement of the problem

The reservoir had specified areas scheduled for irrigation of crops to be displayed in the agricultural show by different clients(Mueni, 2006) but it failed to supply the scheduled amounts of rainwater. This is because the reservoir was depleted within two years of desiltation and filling up to capacity. As a source of irrigation water the JKUAT owned farm that displays water management skills, an effective solution for the Kabiruini dam was mandatory. This was moreso since the community looked up to the University for Solution of this kind of a problem in the wider society.

The primary problem was that of the reservoirs inability to harvest and sustain rainwater to supply the irrigation area it commanded. There is therefore the need to assess the rainwater harvesting potential of Kabiruini Dam.

1.3 Objectives

The general objective was to assess rainwater harvesting potential of Kabiruini reservoir and the irrigable area from the reservoir storage. The specific objectives were to:

i. Assess the rainwater harvesting potential of Kabiruini dam using AWBM.

ii. Determine the potential irrigation area using harvested rainwater of Kabiruini dam.

1.4 Research questions

The specific objectives aimed to answer the following research questions:

i. What is the rainwater harvesting potential of Kabiruini dam?
ii. What is the area that can be irrigated with the rainwater stored in Kabiruini dam?

1.5 Justification

A lot of work was done during the desiltation of the Kabiruini reservoir with the expectation of a steady water supply to irrigate the crops meant for the mid-September Kabiruini Agricultural show. A lot of money and labour was spent in desilting the reservoir. Following the dam's failure to supply the expected irrigation capacity in the following year, it was justifiable to study the quantities of harvestable runoff, irrigation area potential and as well as, identify what caused the reservoir to deplete so rapidly. JKUAT, the owner of the Kabiruini reservoir and the shore grounds needed this information to identify the most cost-effective measure of combating the problem.

1.6 Scope of the study

The interest area for this work was the Kabiruini showground reservoir and the sub-catchment areas around it. This was a small part of the catchment area of Muringato River above regular gauging station 4AB01 on the road bridge on Nyeri to Nyahururu road before DedanKimathi University campus. Data sets spanned from 1970 to 2014 but the part used ranged from 1979 to 1989.

1.7 Limitations

There are so many models for transforming rain into runoff and making a choice to use one depended on personal preferences, ease of use, and the time it took to learn them. Manual for the software used was not easy to follow because it assumed the arrangement of data sets was straightforward. However, the data organization was done manually, hence, converting a data set from Microsoft excel to a set that could be understood by the AWBM model took a long time. The AWBM model is conceptual, lumped rainfall-runoff model that uses daily time series rainfall, runoff and evapotranspiration data as input(Balvanshi, 2017).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The assessment of rainwater harvesting was reviewed by looking at models that transform rain to rainwater or runoff. From the review classes of models emerged and some examples were noted before selecting one to in use in this work. Methods of determining irrigation water requirements were also reviewed before reviewing the reservoir management was looked at then summary of the review was conducted.

2.2 Hydrologic models

Hydrologic models relate the rainfall that an area receives to the water that flows on the surface, evaporates through the atmosphereor infiltrates into the soil, to come out as springs or wells. The surface flow occurs when the infiltration rate gets lower than the rainfall rate(Xu, 2002). The infiltration rate depends on the soil type, vegetation cover, the slope of land, and the rainfall intensity. Water infiltrates very fast if the soil is sandy since pores are large and slowly when the soil is clayey where pores are small(Najim, 2018). Vegetation slows the flow of surface water giving it more time to infiltrate. Steep slopes increase the speed of surface runoff denying it time to infiltrate while high rainfall intensity increases quantity of rainfall that surpasses the infiltration rate of the soil, hence, generating more surface runoff(Xu, 2002).

The parameters such as rainfall and vegetation are related in models that provide a preview of the runoff to expect from different potential rainfalls. The models are configured to report or answer a given question in specific ways (Lundin et al., 2014). They display results in tabular, graphical, statement or a combination of both. They are also modelled in analogue processes in which the models are physically manipulated or digital processes where digital manipulation is used.

Runoff models are broadly classified as symbolic or formal models and material or physical models. Symbolic models are grouped into non- mathematical and mathematical models while material models are grouped into laboratory and analogue models. Mathematical models then take different forms such as:

1. Empirical, conceptual or theoretical
2. Linear or non-linear
3. Time-invariant or time-variant
4. Lumped or distributed
5. Deterministic or stochastic

Nevertheless, a runoff model can fall in many of these classifications at the same time depending on its structure and the processes it imitates (Xu, 2002).

Empirical models are developed from the experience gained from observation and experimentation. A conceptual model is a representation of a system made of a composition of ideas meant to develop an understanding of the system. When data are fitted on a time series, they show either a straight line or a curve depending on the trend in the data. Some models change with time like those depending on infiltration rate while others do not. Others have one characteristic for all the catchment where all is lumped together while others describe a characteristic for each small part of the catchment in a distributed manner. Stochastic events have a random probability distribution or pattern that can be analysed statistically but cannot be predicted precisely while the deterministic model has no randomness and produces same result for same input.

The most commonly used model is the Soil Conservation Service Curve Number (SCS-CN) method shown in Equations 2-1 and 2-2.

a) SCS-CN model

$$\mathbf{Q = \frac{(P - 0.2S)^2}{P + 0.8S}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 2} - \mathbf{1}$$

(Saxton, 2009)

$$\mathbf{S = \frac{25400}{CN} - 254} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 2} - \mathbf{2}$$

Equations 2-1 and 2-2 relate curve number CN, potential runoff Q, potential rainfall P, and maximum soil water retention S. Other methods which could be used to assess runoff included:

b) **Linear regression**

$$\mathbf{Q = \alpha P + \beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation2} - \mathbf{3}$$

where Q is runoff, P is rainfall, α is a multiplying factor representing gradient and β is a constant representing intercept of the y-axis (L.Baker, 2010).

c) **Φ- index method**

This is defined as the rate of infiltration above which the rainfall volume equals runoff volume. The method to determine the **Φ** - index would usually involve some trial. Since the infiltration capacity decreases with a prolonged storm, the use of an average loss rate in the form of **Φ** - index is best suited for design storms occurring on wet soils in which case the loss rate reaches a final constant rate prior to or early in the storm. Although the **Φ** - index is sometimes criticized as being too simple a measure for infiltration, the concept is quite meaningful in the study of storm runoff from large watersheds(Pigrim, 1993).

d) **ω – index method**

This is the average infiltration rate during the time when the rainfall intensity exceeds the infiltration rate. Thus, W may be mathematically calculated by dividing the total infiltration (expressed as a depth of water) divided by the time during which the rainfall intensity exceeds the infiltration rate. Total infiltration may be fund out as under:

Total infiltration = Total precipitation – Surface runoff – Effective storm retention

The **ω** – index can be derived from the observed rainfall and runoff data. It differs from the - index in that it excludes surface storage and retention. The index does not have any real physical significance when computed for a multiple complex watershed. Like the **Φ** -index the **ω** - index, too is usually used for large watersheds(Pigrim, 1993).

e) **Rational method**

$$\mathbf{Q = \frac{CiA}{360} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Equation\ 2-4}$$

(Cooke, 2014)

Where

Q= Peak rate of runoff in cubic metres per second.

C = Runoff coefficient which is an empirical coefficient representing the relationship between rainfall and runoff

i = Average intensity of rainfall for the time of concentration (T_c) for a selected design storm (mm/h).

A = Drainage area in hectares

The cubic feet were converted to cubic meters by multiplying with 0.028m^3 while acres are converted to hectares by multiplying with 0.4047 Ha. This method is unsuitable for catchments larger than 80 Ha or one with various land covers. The method assumes that the catchment is impervious and is best for peak runoff (Cooke, 2014)

f) Digital grid or raster method

In this method the catchment area is split into grid cells whose location is identified by rows and column numbers. The quantity of the runoff catchment within each cell is recorded within the cell as a digital number for height or CN. Each cell is enabled to decide which cell among those surrounding it is lowest so that it should receive the runoff. Considering cell C in Figure 2-1, has received a certain amount of rainfall at its centre, the runoff flow will be based on the permeability of the catchment and height in that cell. That runoff will flow along the line of greatest slope as determined by the heights of the neighbouring cells C1 through C8. Whichever cell receives that runoff is subjected to the same analysis to determine the next recipient of the runoff until a chain of cells form a river trail along which the runoff will flow. Total runoff **Q** is obtained when all the river trails empty their runoff at the catchment outlet or reservoir (Juracek, 2014).

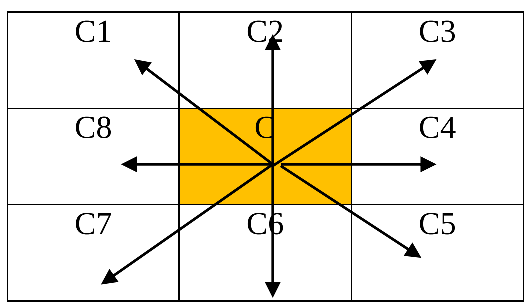

Figure2- 1:Grid cells or Raster

g) Hydrographs

Hydrographs are graphical displays of the catchment response to a rainfall input at a point of exit of a stream. When rain falls on a patch of the catchment, the ground gets saturated and releases the excess rainfall as surface runoff towards the stream exit. Different patches of the catchment dispatch surface runoff at different times and in different quantities to reach the stream exit at different times and in different quantities (Kharagpur, 2014).

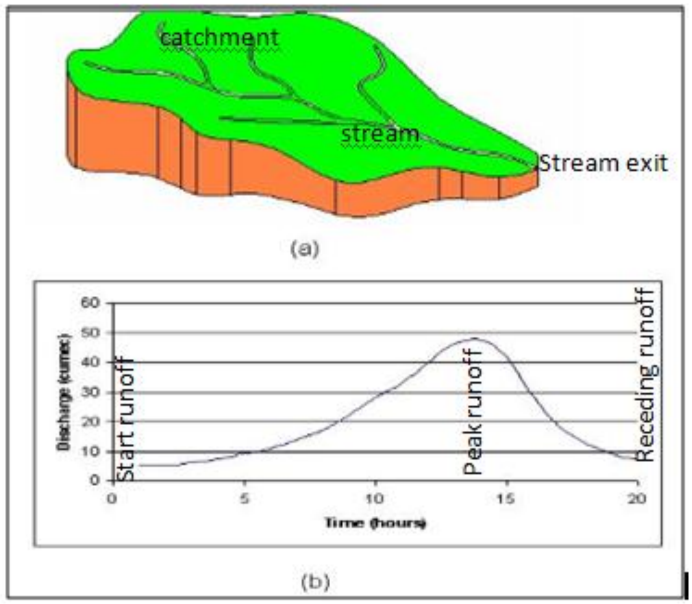

Figure2- 2:Using hydrograph to model runoff. Source: Tarboton, 2003

In Figure 2-2, the catchment receives rainfall in raindrops which infiltrate into the ground or runoff along the surface. The points of catchment which are farthest take the longest time to reach the stream exit and create a peak flow. Hydrographs are principally used to model peak runoff for design of engineering drainage systems because peak runoff display estimates the runoff that can be obtained for each hour.

h) Water balance model

In this model, the accounting for water received as rainfall P is traced through change in river flow Q, evapotranspiration E, and storage S as shown in Equation 2-5

$\boldsymbol{P = Q + E + S}$……………………………………………………………Equation 2-5

An example of this water balance model is GenRiver, a generic river model on a river flow, developed by World Agro forestry in South East Asia. It is made of four main sectors including Water balance, stream network, land cover and sub catchment parameter (Noordwjik, 2014). It has been applied in "Impact of land use changes on water balance" and could be applied in land use analysis (Nugroho, Marsono, Sudira, & Suryatmojo, 2013).

2.2.1 Analogue Rainfall to Runoff Modelling

The models discussed in section 2.2 could all be manipulated physically by creating prototypes or manually calculating the outcomes. When prototypes are created they take the place of human beings to measure and display outcomes of rainfall and runoff. Such a model is represented by a combination of automatic rain and tide gauges(Hansen, Naeve, & Shouse, 2012).

2.2.2 Digital Rainfall to Runoff Modelling

Runoff is modelling is done using different models. They include HEC – HMS, HEC – GeoHMS and GRASS developed by US Army Corps of Engineers. Other models include TOPMODEL by Beven and Kirkby (Beven, 1997) and Systeme Hydrologique European (SHE). IHACRES which is Identification of unit Hydrographs and Component flows from Rainfall Evaporation and Stream flow data software was developed by NERC (Littlewood, 2003). It has been shown that when hydrologic models are connected to databases in spatial environments such as GIS, they can model rainfall to runoff as used in SWAT (Maidment, 1996). Another rainfall to runoff software called Rainfall Runoff Library (RRL) developed in Australia has a model called the Australian Water Balance Model (Podger, 2004).

2.3 Australian Water Balance Model (AWBM)

The Cooperative Research Centre Catchment Hydrology (CRCCH) developed Australian Water Balance Model (AWBM) for of Australia. It was one of five models currently developed under the Rainfall Runoff Library (RRL) toolkit based on the practical experiences of CRCCH researchers and hydrologists. The other models in the library are Sacramento, Simhyd, and SMAR and tank model as illustrated in Figure 2-3. It has eight calibration optimizers, including genetic algorithm, eight objective functions and three calibration options.

As a water balance model, AWBM balances the moisture received from rainfall in three stores. The excess rainfall from each store was channelled to base-flow recharge and surface runoff as illustrated in Figure2-3(Podger, 2004).

The required input data was evapotranspiration, observed rainfall and runoff in mm-per-day from where runoff was simulated(Balvanshi, 2017). Observed runoff around the catchment as indicated by flow at the gauging station was used to calibrate the parameters that were to be used for runoff calculation. This model will be used in this work to simulate rainwater on daily bases. Its concept is that rain received in a catchment it is split into three and taken as being used to fill the evaporation, infiltration and surface runoff stores. These stores are portions of the rain split according to climatic and land characteristics as in Figure 2-3.

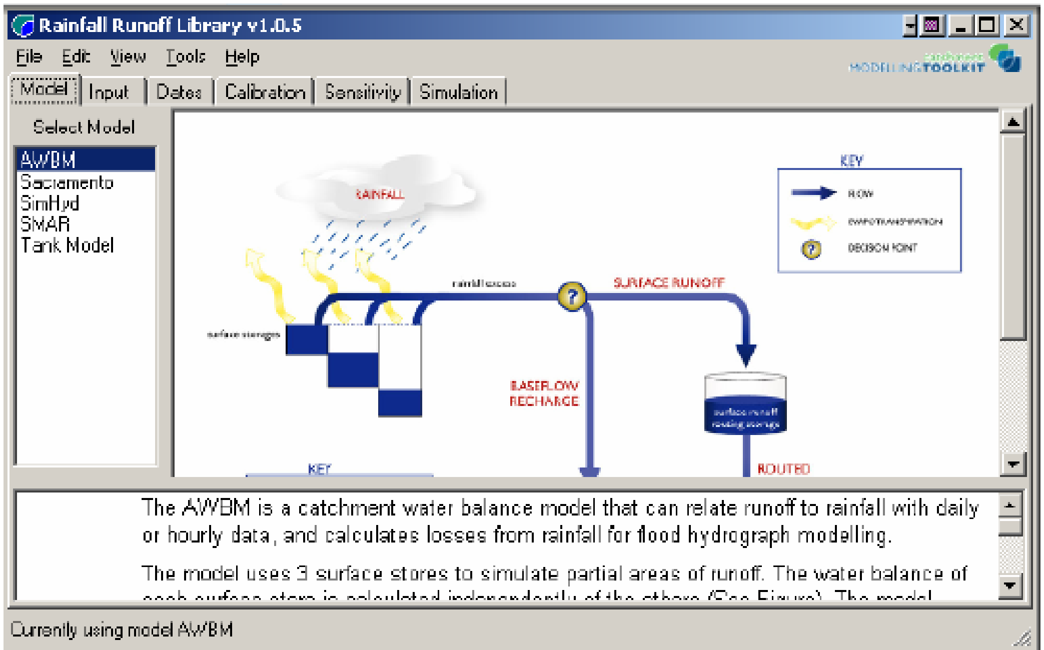

Figure2- 3:The stores and moisture excess in AWBM

$$Store_n = Store_n + rain - evap \ (where\ n = 1\ to\ 3)$$

2.3.1 Model calibration

This is the process of standardizing predicted values using deviations from observed values for the area to derive factors that when applied generate predicted values which are consistent with observed values. During calibration, default model parameters can be maintained and it can be done manually or automatically(Podger, 2004).

2.3.2 Model warm up

This is the initial estimation of soil moisture in each store done by assessing the rainfall conditions before starting the model or by selecting a warm up period where the stores in Figure 2-3 are at known levels of filling. The stores are taken as empty when warm up period is dry and full when that period is wet. The model estimates the warm up period by starting at different initial conditions and determining where the answers converge and this could be done manually or automatically (Podger, 2004).

2.4 Irrigation water requirement models

Irrigation is artificial application of water to plants so that they can evapotranspirate as a plant growth requirement. Plants express their water need by wilting so that the irrigators can sense the need for irrigation. Sensing crop irrigation needs requires the soil, plant, and air to be examined physically for the moisture content because plants intake water through the roots, transmit it through the plant, and lose it through the air. Crop requirement determining methods are, therefore, those that measure soil water, plant water, and atmospheric water (Martin et al., 1992).

2.4.1 Soil Water Measurement

The purpose of measuring soil water content is to estimate the crop water requirement that is to be replenished by rainfall or irrigation. The several methods that have been developed over the years are classified as direct or indirect soil measurement models(Martin, Stegman, & Fereres, 1992). The quantity of irrigation water supply is determined by soil water content which is expressed as mass or volume ratios shown in

Equations 2-6 and 2-7. Soil moisture is determined by directly measuring weight or volume of wet soil and the same soil after drying in an oven for 24 hours(Evans, Cassel, &Sneed, 1996). The weight comparison is done in Equation 2-6 and volume comparison is done in Equation 2-7.

$$\mathbf{W} = \frac{\boldsymbol{M_w}}{\boldsymbol{M_s}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \textbf{Equation 2} - \textbf{6}$$

$$\boldsymbol{\theta} = \frac{\boldsymbol{V_w}}{\boldsymbol{V_t}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \textbf{Equation 2} - \textbf{7}$$

Where

W is ratio of water mass to dry soil in kg

θ is ratio 0f water to soil volume in m^3(Evans, Cassel, & Sneed, 1996).

Other methods developed include Neutron thermolization which relies on the spread of neutrons that are slowed by the water molecule’s hydrogen neutron. The radius to which neutron probes can be sensed depends on the soil moisture content. These sensed neutron radius is then calibrated against actual soil water content so that the neutron thermolization methods can offer measurements of soil water content. Time Domain Reflectometry (TDR), measures the movement of electrical signal in soils of different water content which are produced as voltage pulse. Electrical pulses between parallel rods or wires would measure soil water content of the soil.

Some indirect methods measure soil water while others measure plant water. Those measuring soil water include thermocouple psychrometer, tensiometer, electrical resistance blocks, and thermal dissipation sensors. A Thermo-couple psychrometer measures vapor pressure in the field and relates it to soil water content. Tensiometers measure the soil matric potential in soil by exerting pressure on soil sample which releases its water through pores at the bottom of the soil container. The amount of pressure required to extract water from the soil indicates the suction pressure required by plant roots to absorb the water from the soil. Electrical resistance blocks consist of two parallel rods connected by gypsum whose water content causes difference in electrical resistance. Electrical resistance decreases with increasing water potential. Thermal dissipation sensors determine the rate of heat loss. The heat loss is commensurate to soil water content between the heater and the sensor(Martin, Stegman, & Fereres, 1992).

Plant water can be measured to assess plant water stress using the pressure chamber, stomatal resistance method, infrared thermometry, spectral measurements, microwave measurements and stem diameter measurements(Martin, Stegman, & Fereres, 1992).

Pressure chamber measures the leaf water potential by forcing pressure on the leaf and observing the pressure at which water is forced out of the cut plant. Stomatal resistance method measures the humidity in a porometer as a measure of stomatal closure and hence crop water stress. Spectral measurements carried out in remote sensing systems are used to discriminate crop temperatures and soil water. Infrared thermometer measures the foliage temperature in form of radiation energy emitted by the plants. Temperatures are lower on plant surfaces where water evaporation takes place. Based on temperature variations, a crop water stress index is developed. Radiometers measure soil water content to a depth of 10cm.

Atmospheric conditions cause the plant to evapotranspiration more or less and, therefore, measurement of evapotranspiration gives an indication of crop water requirement. These conditions can be measured at weather stations, evaporation pans, Energy Balance Bowen Ratio (EBBR) system, plant physiological methods and remote sensing methods(Martin, Stegman, & Fereres, 1992). They can also be measured with lysimeters which are containers of soil set in the field to represent soil and climatic conditions in order to accurately measure crop water requirement. They are also applied in the Penman-Monteith model developed by (FAO, 1998). Water balance model of Irrigation is the day to day accounting of the amounts of water entering and leaving the effective root zone based on the estimated soil water content in that root zone which is viewed as a system (Queensland, 2010).The system relates the parameters as in equation 2-8.

$$\mathbf{Dc = Dp + } \boldsymbol{ET_c} \mathbf{- P - Irr - U + SRO + DP} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \mathbf{Equation\ 2-8}$$

Where

Dc = Soil water deficit (net irrigation requirement on that day)

Dp = Soil water deficit on previous day

ETc = Crop evapotranspiration rate for current day

P = gross precipitation for current day

Irr = nett irrigation amount infiltrated into the soil for the current day

U = Up flux of shallow ground water into the root zone

DP = Deep percolation or drainage

SRO = Surface runoff

Some of these parameters are not determinable unless they are measured in the field and therefore discretion is advised (Queensland, 2010).

In equation 2-9, the crop evapotranspiration rate for current day (ETc) is calculated as,

$$\boldsymbol{ET_c = K_c \times ET_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \textbf{Equation 2} - \textbf{9}$$

Where

Kc is the crop coefficient which expresses the difference in evapotranspiration between the cropped and a reference grass surface. The Kc, root depth and depletion fraction have been determined for major crops as in Table 2-1 (Queensland, 2010).

Table2- 1:Kc root depth and depletion fraction . Source: (Queensland, 2010)

Crop	Kc initial	KcMid season	Max root depth(m)	Depletion Fraction
Barley	0.30	1.15	1.0 to 1.5	0.55
chickpea	0.40	1.00	0.6 to 1.0	0.50
cotton	0.35	1.15 – 1.20	1.0 to 1.7	0.65
maize	0.30	1.20	1.0 to 1.7	0.55
millet			1.0 to 2.0	0.55
mungbean	0.40	1.05	0.6 to 1.0	0.45
Navy bean	0.40	1.15	0.6 to 0.9	0.45
peanut	0.40	1.15	0.5 to 1.0	0.50
sorghum	0.30	1.00-1.10	1.0 to 2.0	0.55
Soy bean	0.40	1.15	0.6 to 1.3	0.50
sunflower	0.35	1.15	0.8 to 1.5	0.45
wheat	0.30	1.15	1.0 to 1.8	0.55

ETo is calculated using Penman-Monteith method and requires radiation, air temperature and wind speed as indicated in equation 2-10.

$$\boldsymbol{ET_o} = (\boldsymbol{Tmax} - \boldsymbol{Tmin})^{\mathbf{1/2}} \times \mathbf{0.0135} \times \boldsymbol{KT} \times \boldsymbol{R_a} \times (\boldsymbol{TC} + \mathbf{17.81}) \ldots \text{Equation } 2 - 10$$

(Samani,1985)

Where:

Tmax = maximum temperature °C

Tmin = minimum temperature °C

TC = Average daily temperature °C

Ra = extraterrestrial radiation (mm/day)

KT = empirical coefficient 0.162 for interior regions or 0.19 for coastal regions

2.4.2 Estimation of irrigation water requirement

The methods of soil water measurements above were to produce accurate results although at a higher cost than the estimation methods below that include the feel method and estimates for three crop types. In the feel method, soil sample is squeezed firmly in the hand and observed as it forms a ball and a ribbon by further pressure application. Soil moisture is then estimated by ability to form ball, ribbon, stain the fingers and the soil colour. For researchers who do not have accurate soil moisture measuring equipment and the experience of the feel method, the estimated soil water requirements for cereals, vegetables and paddy rice have been given in Table 2-2.

When technological and financial resources are low, farmers rely on personal experience or adopt water requirement figures suggested by (Hatcho & Kay, 1992) in Table 2-2.

Table2- 2:Indicative values of crop water needs and growth duration. Adopted from (Hatcho & Kay, 1992)

Crop	Crop Duration in Days	Cropwater requirement in millimetres
Cereals	120 to 140	450 to 650
Vegetables	90 to 120	400 to 600
Paddy Rice	90 to 120	800 to 1500

2.4.3 Irrigation Water Supply

Irrigation is the process of artificial delivery of water to a farm taking the place of rainfall on crops. If the irrigation does not replace the rainfall altogether, the type of irrigation is called supplemental irrigation. Supplemental irrigation therefore combines the rainfall received with the supplied irrigation water to meet the crop water requirement.

Irrigation problems such as water shortage have been addressed by scheduling the irrigation water applied usually by measuring and calculating the crop water demand. The rate of application is then applied to the pumping system or opening and closing times of gravitational supplies. Both runoff and irrigation planning require mapping which has been informed to the farmers manually. Nowadays, automated mapping is currently using computer software that applies mathematical models over phenomena distribution over space. Mapping software is either with or without databases such as GIS and AutoCAD respectively. Both mapping software represent geographic information by dividing the space into tiles called raster or by vectors (Eastman, 2003).

Irrigation scheduling is affected by both environmental and physical characteristics of an area. These characteristics were used by (FAO, 1997) in assessing irrigation potential for Africa by a basin approach but only the 'physical irrigation potential' in Figure 2-4 could be done in this work.

In addition to the characteristics, assessment of irrigation potential requires assessment of irrigation water requirements based on cropping pattern. The methods of determining irrigation water requirement are explained above but rainfall pattern was determined by graphing the average daily rainfall of the year while cropping pattern was based on length of crop season. Once the irrigation is commenced, farmers have difficulties as well as limitations in irrigation scheduling at farm level which includes limited water resources, variability of rainfall, and lack of reliable water stress monitoring system, irrigation efficiency, running costs, and incentives. Knowing that effective irrigation scheduling avoids reservoir depletion and extends the area of irrigation; giving more crops, could entice farmers to use water precisely (Pigrim, 1993).

Despite the many methods of sensing irrigation requirement, research is still required to determine the accurate and reliable irrigation water supply method. Once scientists assess the irrigation needs of a farm, the actual determination of areas to be irrigated, as well as when to start and stop irrigating is left to the farmers who are not experts on this matter. Realizing the assessed irrigation requirements largely depend on accurate irrigation scheduling and isolating irrigation potential areas can increase the area coverage of the available water. If the irrigation scheduling is inaccurate, excess irrigation which wastes water or inadequate irrigation which causes crop water stress will take place. Increasing the land under irrigation with inadequate water in the reservoir depletes the water before the crops are mature causing serious crop and financial losses.

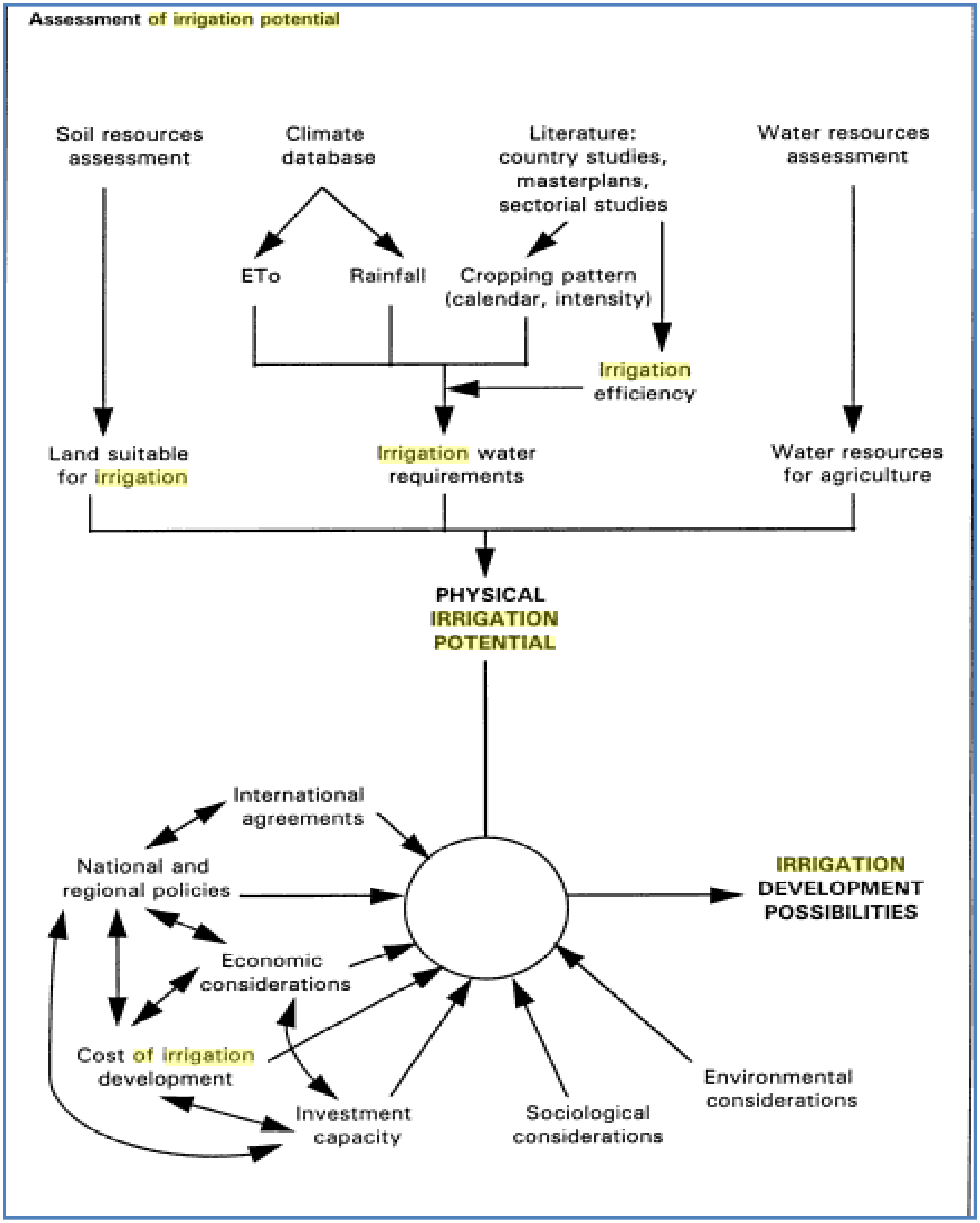

Figure2- 4: Considerations for irrigation potential. Source: (FAO, 1997***)***

It is important to establish whether the available irrigation water is adequate for the farms to be irrigated. Since not all lands can be irrigated at the same time, those that should be irrigated should be informed early enough for land preparation. When irrigation water is supplied, it should be precisely measured to serve the irrigation lands without flooding, causing crop water stress, or depleting the reservoir before the crops are harvested.

Some of the irrigation scheduling methods used are monitoring methods where soil, crop, and atmospheric water contents indicate when irrigation should be applied, and checkbook methods where soil water, irrigation depth, and maximum temperatures are monitored to compare water received in the soil to the water used by the crops and predict when irrigation is needed next. In computerized methods, scheduling models access databases of soil, crop and meteorological data to predict irrigation rates and dates (Martin, Stegman, & Fereres, 1992).

2.5 Reservoir management

A reservoir receives rainfall runoff from the catchment areas and use. The reservoir experiences drought when the catchment cannot supply the needed quantity of water. It also experiences floods after which the excess runoff is channelled to spillway. These two situations are inevitable and so the strategic management of the reservoir needs to lay down a plan to take care of the irrigating community as the customer that controls the areas prepared for irrigation. That plan should avoid preparation of land that cannot be irrigated to fruition of crops and also avoid reservoir depletion caused by excessive demand. In order to match potential irrigation area to available rainfall runoff in the reservoir, the potential rainfall runoff harvest should be assessed. As much as the mean rainfall runoff harvest may be used as the design value for potential irrigation area, there is a high chance of losing the crop because the rainfall runoff harvest was below average and also wasting a lot of runoff above the average because it was not designed to be used. Therefore, the reservoir management should develop a sensor of the runoff stored in the reservoir before the beginning of crop season; report the farm's possibility of seasonal irrigation, and then precisely supplying the water throughout the season. This system can mitigate the situation where the water apportionment board has to vary or stop water supply to a permitted irrigator because of drought(Scola, Takahashi, & Cequeira, 2014)

2.5.1 Reservoir storage model

Reservoirs store the runoff harvested from the catchment in the non-linear expression below

$$\boldsymbol{S = KQ^n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \boldsymbol{Equation\ 2-11}$$

(Das, 2000)

where S is storage quantity, Q is harvested quantity, K is a constant and *n* is an exponential. This equation is made linear by using n=1 to linearize it as illustrated in equation 2-12.

$$S = KQ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Equation\ 2-12$$

(Das, 2000)

If the storage is affected by withdrawals for irrigation, then the linear equation changes due to the reduction of S by irrigation I as indicated in Equation 2-13

$$s = KQ - 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Equation 2-13$$

The irrigation quantity **I** is made to vary with harvested runoff **Q** so that an increase in runoff harvest proportionally increases the potential area of irrigation. That change of irrigation areas affects farmers by including or excluding them from the potential irrigation list. They need to be informed of this change early enough to avoid incurring expenses of land preparation when they cannot potentially irrigate or receiving the irrigation water before they prepare their lands. The storage **S** can also include the dead storage for maintenance of aquatic life or sporting activities (Das, 2000). However, the amount of irrigation water requirement has to be designed according to the crop to be grown, climatic conditions and soil water at that time of application. These influencing factors are difficult to measure in real time, analyse, and apply as irrigation water requirement because irrigation water requirement models are rarely physical.

In addition to equation 2-11, there are other methods such as the graphical mass curve (ripple diagram) method and sequent peak analysis. Mass curve analysis can be done to determine reservoir capacity for known yield or determination of yield for a known reservoir capacity. The yield of a reservoir is the quantity of water, which is supplied for certain duration such as a few years, week, day or hour. It is a function of the inflow and reservoir capacity (Akintug, 2004).

2.5.2 Reservoir storage control

The harvesting of runoff requires runoff storage for it to be useful at the appropriate times. Storage facilities include both artificial and natural water holding bodies. Oceans, seas, and lakes are natural reservoirs where Rivers drain. Dams, water pans and tanks are artificial stores of runoff that are designed in accordance with the rate of harvest and disposal in order to maintain required efficiency, reliability and satisfaction(Scola, Takahashi, & Cequeira, 2014).

Management of a reservoir involves planning the runoff harvest and disposal quantities based on the design which considers the ability of the catchment to provide runoff and the farm's ability to use the irrigation water. Management also controls the rate of runoff disposal into the farms so that only the required water is supplied while ensuring that the reservoir is able to store the runoff until it is required(Scola, Takahashi, & Cequeira, 2014). Reservoirs lose water through seepage, evaporation, misuse or lack of replenishment which are difficulties that management endeavours to control. The process of management demand strategies by which the planned harvest and disposal do not deplete the reservoir before crops mature. To avoid reservoir depletion, the following factors should be considered; leakage, capacity, and demand of runoff. In order to manage the reservoirs, the storage model should include the disposal of runoff to irrigation. This ensures that the planned usage does not deplete the reservoir and avoids the preparation of a land that will never get adequate irrigation water(Scola, Takahashi, & Cequeira, 2014).

2.6 Summary

This chapter looked at models and methods of assessing rainwater harvesting and determining the irrigation potential for the rainwater. After reviewing the literature, the AWBM model in the rainfall runoff library was adopted to transform the SWAT GLOBAL obtained rainfall data to runoff. The evapotranspiration required in this software was calculated from SWAT GLOBAL data using(Samani,1985) equation while the actual runoff required for calibrating the model was obtained from a regular gauging station on Muringato River.In addition to assessing rainfall and runoff, irrigation potential area was to be determined by considering crop water requirement for a selected crop supplemented by the rain. In order to store the runoff for supplying the irrigation potential, reservoir capacity was to be determined by mass curve analysis of runoff supply and irrigation demand.

CHAPTER THREE

METHODOLOGY

3.1 RESEARCH DESIGN

The research design used an experimental approach based on field measurements and established models such as transformation of rainfall to harvested rainwater and correlation of harvested rainwater with irrigation potential. Daily rainfall was transformed to harvested rainwater using Australian Water Balance Model (AWBM), in software consisting five models known as rainfall runoff library. The rainwater harvested was analysed by arrangement in Microsoft excel tables where rain, evaporation and seepage were compared to crop water requirement for determination of irrigation water requirement.

This research was conducted at Kabiruini show ground where Jomo Kenyatta University of Agriculture and Technology owns the demonstration farm. This farm had an existing reservoir which was full of soil and could not store enough water to meet its irrigation demand. The reservoir is located between Nyeri-Nanyuki road, Nyeri-Nyahururu road, and Nyaribo-Kiganjo road but was accessed through the show ground gate which was on the Nyaribo-Kiganjo road as shown in Figure 3-1. The coordinates of the reservoir are in Zone 37M at 0274180 m E, 9956726 m S on the leeward side of Mt. Kenya.

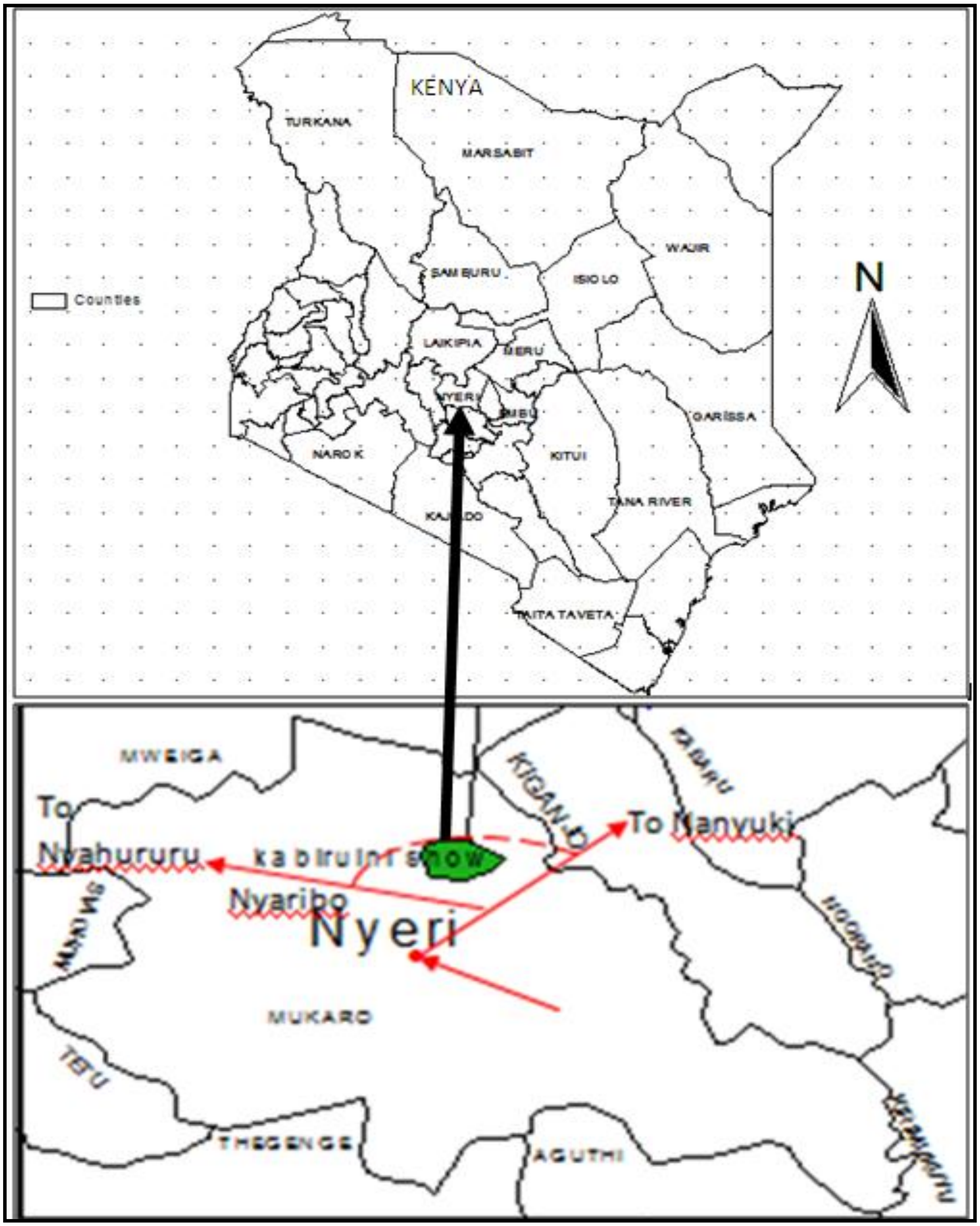

Figure3- 1:Diagram of Nyeri Kabiruini showground in Kenya

3.2 Data samples

Data samples collected and measured were in line with the models and outlined objectives. The main samples included rainfall which was the basic commodity in rainwater harvesting. Rain transformation into rainwater harvest was done using AWBM (Figure 2-3) which required a sample of measured daily rainwater harvest in rivers past a regular gauging station and evapotranspiration (ETo).

3.3 Sampling frame

Sampling data was obtained from different sources with different time frames. Rainfall data was obtained from SWAT GLOBAL data whose time frame ranged from January 1, 1979 to July 31, 2014. The rest of the SWAT GLOBAL data included location, temperature, wind, relative humidity and solar (Table 3-1). Evapotranspiration was calculated from the SWAT GLOBAL data using Equation 2-10. Rainwater harvesting daily flow records at the regular gauging station 4AB01 along Muringato River just next to Kabiruini dam were obtained from Water ResourcesAuthority (WRA) for 1979 to 2014. The rain data was related to the evapotranspiration and River flow data which had a lot of gaps making most of it unusable except for 1979 to 1989.

Table3- 1:Part of obtained SWAT GLOBAL data

Date	Longitude °	Latitude °	Elev (m)	Max Temp °C	Min Temp °C	Rain (mm)	Wind (m/s)	R. Humidity	Solar (mm/day)
1/1/1979	36.875	-0.4683	2128	18.02	3.81	1.13	2.04	0.83	24.52
1/2/1979	36.875	-0.4683	2128	17.27	5.64	1.37	1.97	0.85	22.55
1/3/1979	36.875	-0.4683	2128	18.75	10.61	0.39	2.15	0.85	19.69
1/4/1979	36.875	-0.4683	2128	17.84	9.70	0.71	2.07	0.87	14.89
1/5/1979	36.875	-0.4683	2128	18.93	9.76	0.21	2.28	0.81	23.08
1/6/1979	36.875	-0.4683	2128	18.51	5.73	4.01	2.25	0.86	21.06
1/7/1979	36.875	-0.4683	2128	13.96	11.58	4.59	1.77	0.95	5.48
1/8/1979	36.875	-0.4783	2128	12.91	10.99	8.65	1.98	0.97	3.70

Source: SWAT GLOBAL data via email

3.4 Data processing and analysis

Data processing was completed in two phases which constituted assessment of rainwater harvesting potential and determination of potential irrigation area. Daily rain, evapotranspiration, and sample runoff were processed together in AWBM to simulate the catchment runoff flowing into Kabiruini dam. In the simulation of runoff, the daily rain, evapotranspiration, and measured runoff were processed in AWBM. Simulated runoff from AWBM was saved in Microsoft excel as daily runoff corresponding to daily rain. The process of runoff simulation and determination of irrigation area was done shown in Figure 3 -2 where daily runoff at regular gauging station 4AB01, SWAT daily rainfall, and evapotranspiration were sorted in Microsoft excel. These data were then saved as formatted text (space delimited). They were renamed into a format that AWBM could process to simulate runoff as indicated in Figure 3-2.

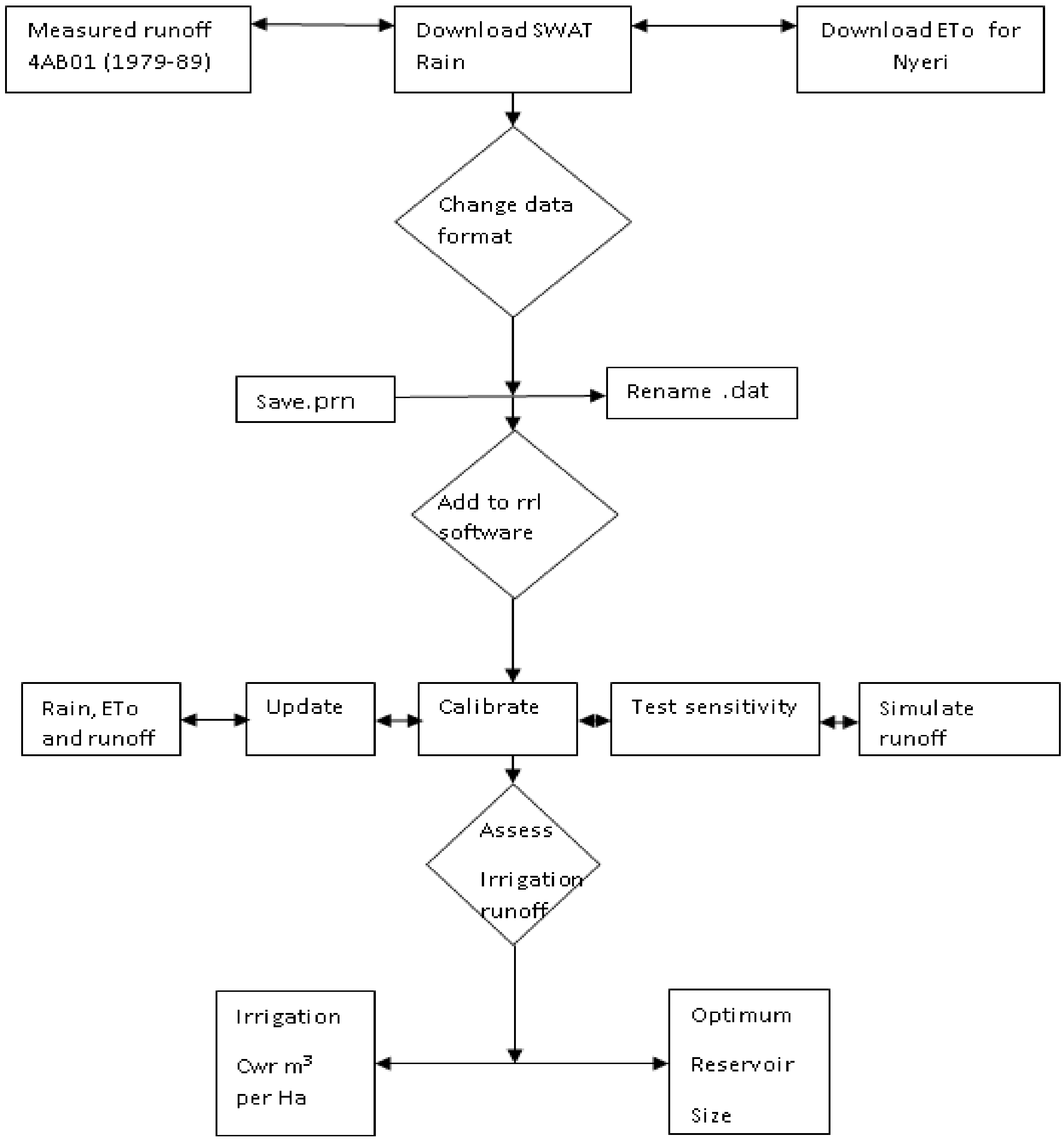

Figure3- 2: Flow diagram of project execution

The processing of the runoff involved updating, calibrating, sensitivity testing and simulation of runoff. The span of data was updated by changing the dates of the rainfall, evapotranspiration and calibrating runoff to coincide so that AWBM could carry out multiple regressions before simulating the catchment runoff. Simulated daily runoff in millimetres of depth over the catchment was converted into volume that flowed into Kabiruini dam for irrigation.

3.4.1 Assessment of rainwater harvesting potential

Runoff assessment constituted summarizing daily average into monthly totals so that it could be related to evaporation, seepage, and crop water requirement. Monthly runoff less seepage and evaporation constituted the runoff that was expected to provide irrigation water for crop water requirement from Kabiruini dam. Rainfall met part of the crop water requirement minimizing irrigation water requirement.

3.4.2 Determination of irrigation area potential

Irrigation area was determined from the available runoff in Kabiruini dam considering that evaporation and seepage increased the irrigation water demand. On the other hand, rainfall decreased the irrigation water demand by providing part of the irrigation water directly on the farm. Water provision data was arranged in a Microsoft excel table in which the variables including rainfall, runoff, seepage and evaporation were manipulated to report the different circumstances under which irrigation area could vary. If rain was increased, then runoff in Kabiruini dam would irrigate a larger area just as when seepage and evaporation effects are reduced. Rainfall was naturally provided and, therefore, variables that could be manipulated included seepage, evaporation, and runoff.

3.4.3 Dam water balance analysis

Determination of irrigation area based on the assessed runoff depended on Kabiruini dam storage capacity that could be increased for more runoff harvest or decreased for less. Balancing the variables of runoff inflow, evaporation and seepage was made as inflow less evaporation and seepage letting the balance of inflow be the capacity in need of storage. If for engineering or other reason, a smaller dam is built, then extra runoff is lost through the spillway in Figure 3 - 4. The runoff inflow obtained in the catchment was harvested in the reservoir and when evaporation and seepage has taken place, available runoff can be used for irrigation.

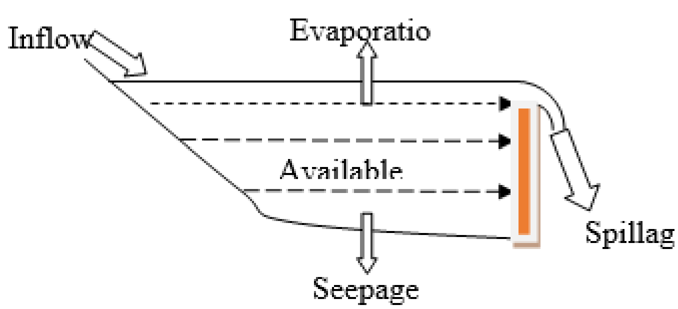

Figure3- 3:**Major factors affecting water stored in reservoir**

3.5 Summary

The data collected was used to assess the rainwater harvesting potential and determination of irrigation potential possible with the harvested rainwater. This data was collected by different entities such as evapotranspiration and precipitation from SWAT GLOBAL data while runoff Water resources Authority. There could be different achievements if all the data was collected by one entity. Average results which were obtained and used for analysis represent the catchment but may not apply every day or every year. So caution should be exercised in avoiding storage loss through seepage and evaporation.Irrigation area potential may vary if the harvest falls or

rises above the average rainwater harvest potential.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 ASSESSMENT OF RUNOFF HARVESTING POTENTIAL

Assessment of runoff harvesting potential required daily rainfall, ETo, and runoff. These parameters were put in the AWBM model as explained in Figure 3 – 2 and resulted in Figure 4-1. It was found that potential runoff harvest ranged from 1.90 to 9.26 mm depth per month over the 120 Ha catchment. When converted to m^3, the inflow harvest in the reservoir ranged from 2281m^3 to 11,110m^3 per month. The total runoff harvest per year was found to be 78,309m^3 and would provide for evaporation and seepage to the tune of 30,955m^3 letting the reservoir supply 47,353m^3.

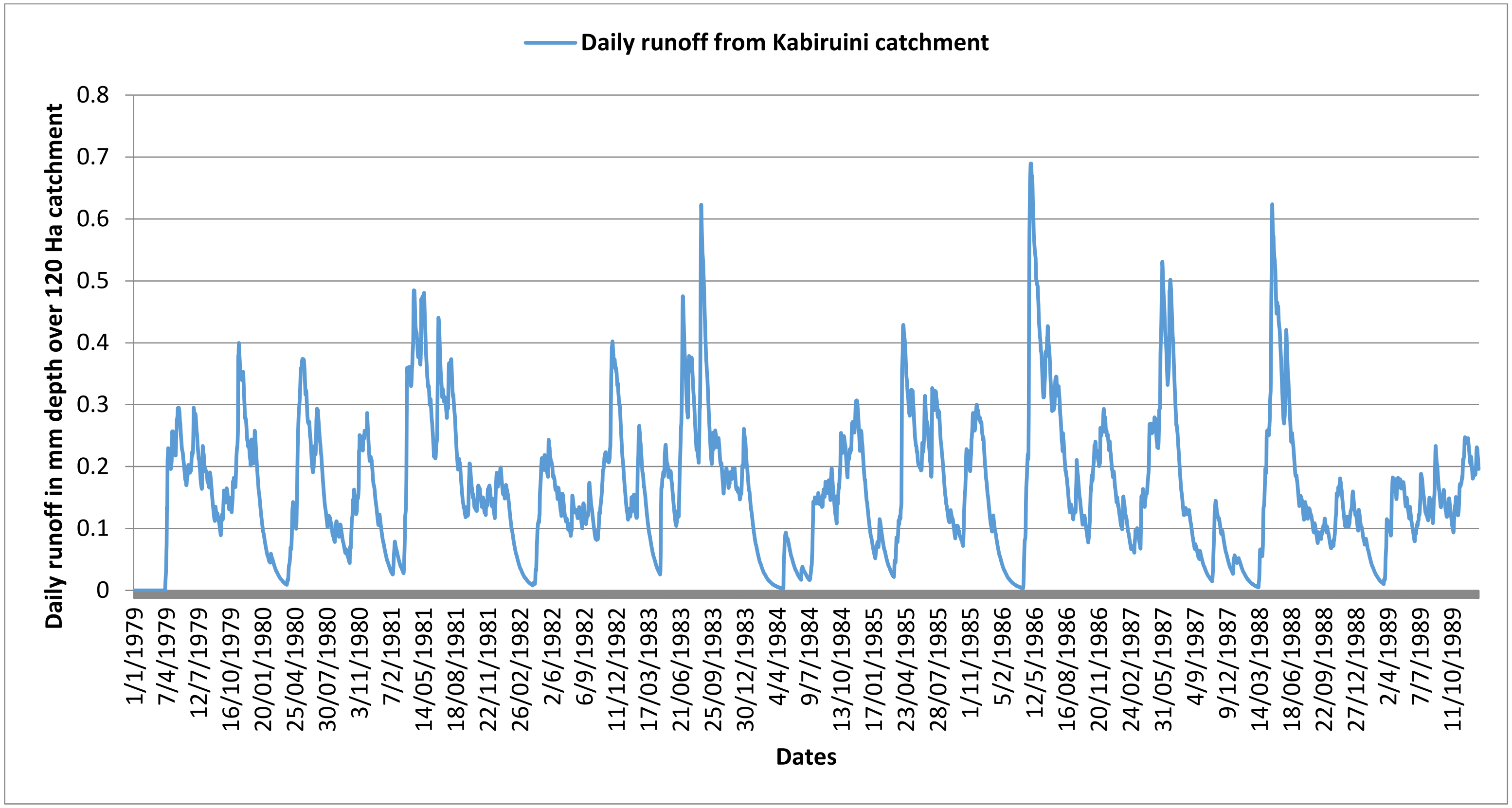

Figure4- 1:Result of running daily runoff for 1979 -89 in AWBM

4.1.1 Variables affecting harvested rainwater

Runoff obtained from AWBM was not flowing directly to the irrigation crops implying that there was a need for storage in Kabiruini dam. The problem of reservoir depletion was found to be caused by the following variables; soil, evaporation, catchment area, reservoir surface area, and the dam capacity. Crop water requirement was calculated for maize and its Kc values in addition to values of other variables were selected. These variables in Table 4-1 were used to generate Table 4-2 for calculation of evaporation, seepage and crop water requirement.

Table4- 1:Variables used in assessment of rainwater harvesting potential

VARIABLES:

Soil type mean Seepage rate mm/day	**sand**	**sandy loam**	**loam**	**clayey loam**	**loamy clay**	**clay**
	138	45	14	9	6	3
Penman ETo for Nyeri (Evaporation rate mm/day)	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**
	3.95	4.36	4.27	3.77	3.68	3.12
	JULY	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
	2.70	2.86	3.74	3.99	3.36	3.58
Reservoir surface m^2	6706					
Reservoir capacity m^3	23302					
Catchment area m^2	1200000					
Crop water requirement	**chosen crop**	**Kc initial**	**KcMid season**			
	maize	0.30	1.20			

Monthly rainfall totals transferred from SWAT GLOBAL daily rainfall data were added to monthly runoffs from AWBM to form the crop water supply. The Product of average monthly evapotranspiration for Nyeri and the days of the month resulted in monthly evaporation. Subsequently, the product of dam surface area and the seepage rate of clayey loam soil resulted in monthly seepage. Seepage and evaporation affected the water supply as a loss making the dam unable to supply enough water for irrigation. The product of the selected crop factor Kc, for maize and the evapotranspiration resulted in crop water requirement, which was modified by rainfall to result in irrigation water requirement.

Table4- 2:Monthly summary of rain, runoff and withdrawals in mm

Month	**Days per month**	**Monthly average rain totals**	**Monthly catchment runoff**	**Monthly evaporation from reservoir surface area**	**Seepage from reservoir floor in mm/m^2**	**Crop water or ETc =Kc x Eto**	**CWR-rain**	**Irrigation IWR**
January	31	66	2.76	122	279	183	118.09	118.09
February	29	51	1.90	126	261	189	139.14	139.14
March	31	119	1.93	132	279	198	79.87	79.87
April	30	253	7.41	113	270	169	-83.34	0.00
May	31	175	9.26	114	279	171	-4.12	0.00
June	30	143	7.55	94	270	140	-2.83	0.00
July	31	95	6.75	84	279	125	30.18	30.18
August	31	84	5.67	89	279	132	49.52	49.52
September	30	70	4.03	112	270	168	97.95	97.95
October	31	134	4.66	123	279	185	51.77	51.77
November	30	157	7.51	100	270	151	-6.50	0.00
December	31	90	5.84	110	279	166	75.84	75.84
sum annual		**1436**	**65.26**	**1322**	**3294**	**1983**		**642.37**

The product of runoff depth in mm from Table 4-2 and catchment area in Table 4-1 resulted in monthly catchment runoff in m^3 shown in Table 4-3. Monthly evaporation and seepage were products of their respective rates and when summed up with monthly catchment runoff resulted in monthly reservoir storage required in m^3. The difference between inflow and combined seepage and evaporation resulted in monthly runoff storage that could supply irrigation water requirement as shown in Table 4-3.

Table4- 3:Monthly runoff and withdrawals in m^3

Month	**Monthly catchment runoff (inflow)**	**Monthly evaporation from reservoir surface area**	**Seepage from reservoir floor**	**Monthly reservoir storage required**	**Inflow-evaporation -seepage**	**Monthly inflow of rainwater in reservoir**
January	3307.96	821.15	1870.97	6000.08	615.84	615.84
February	2281.42	847.91	1750.27	4879.59	-316.75	0.00
March	2314.29	887.67	1870.97	5072.94	-444.36	0.00
April	8886.62	758.45	1810.62	11455.69	6317.55	6317.55
May	11110.13	765.02	1870.97	13746.13	8474.14	8474.14
June	9061.56	627.68	1810.62	11499.86	6623.26	6623.26
July	8094.82	561.29	1870.97	10527.08	5662.55	5662.55
August	6808.97	594.55	1870.97	9274.50	4343.44	4343.44
September	4830.86	752.41	1810.62	7393.90	2267.83	2267.83
October	5594.75	829.47	1870.97	8295.18	2894.31	2894.31
November	9007.09	675.96	1810.62	11493.68	6520.51	6520.51
December	7010.08	744.23	1870.97	9625.29	4394.88	4394.88
sum annual	**78308.56**	**8865.80**	**22089.56**	**109263.93**	**47353.19**	**48114.30**

4.2 Determination of irrigation area potential

The following areas were identified as potential areas for irrigation as shown in Figure 4 – 2.

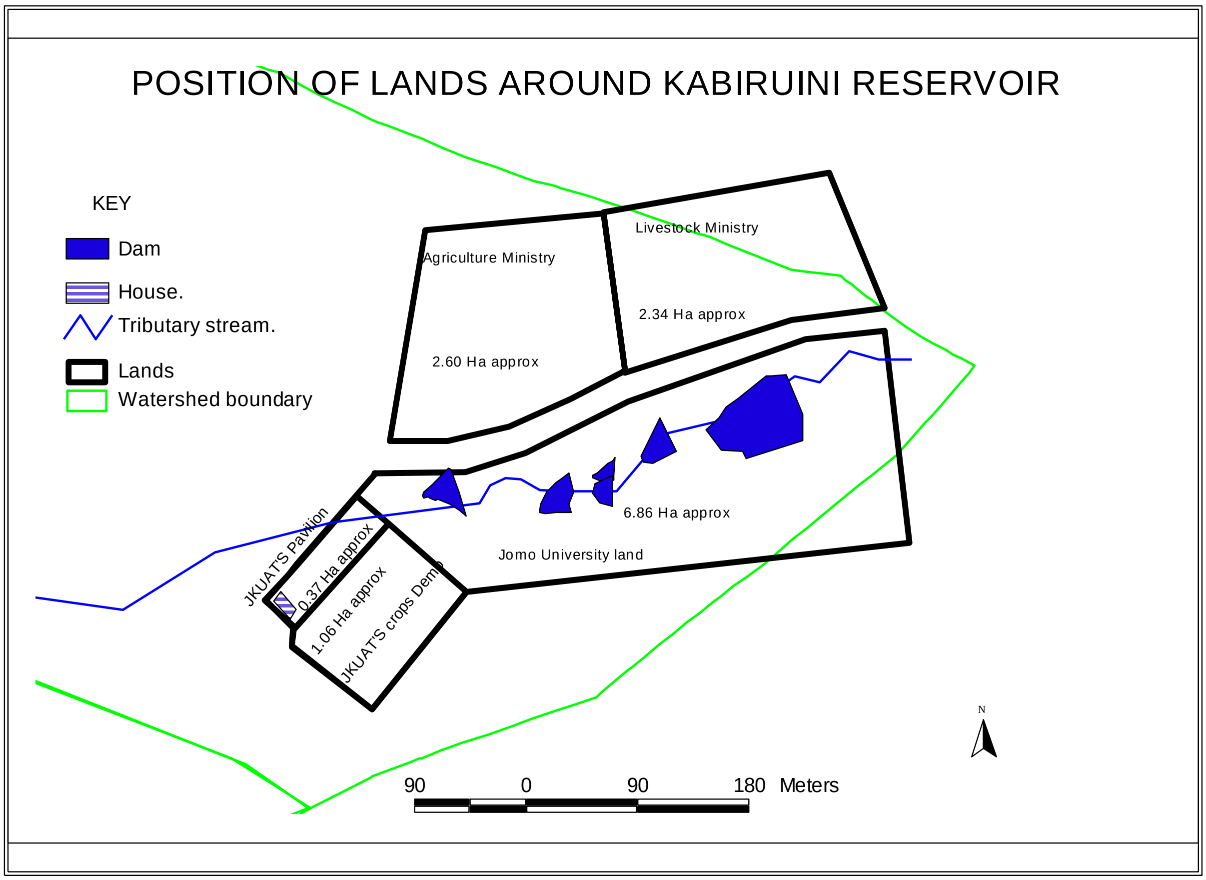

Figure4- 2:Lands around Kabiruini reservoir

Monthly irrigation water requirement was summarized in to three seasons of four months each and potential irrigation areas determined for each season. They were found to range from 0.50 to 4.40 Ha per season making a total of 6.07 Ha per year as illustrated in Table 4-4.

Table4- 4:Irrigation potential areas per season

season	runoff inflow m^3	Irrigation water requirement in mm	Potential irrigation area in m^2	Potential irrigation area in Ha
Jan - Apr	16790.29	337.11	49806.75	0.50
May - Aug	35075.48	79.70	440074.48	4.40
Sept - Dec	26442.79	225.56	117233.97	1.17
				6.07

4.3 Reservoir capacity

Annual runoff inflow of 78309 m^3 lost 30955 m^3 (40%) through seepage and evaporation.This implies the inflow balance of 48114 $m^3$was used for irrigation. However, ifloses were eliminated, the annual reservoir capacity would be 109264 m^3. Most crops grow in seasons of approximately 120 days among the seasons in Table 4 -4. May to August season had the largest inflow of 35075 m^3. If this maximum seasonal inflow is adopted as the optimum reservoir capacity, it would accommodate the other seasonal irrigation requirements.

4.4 Discussion

Daily rainfall, ETo, and runoff were used in the assessment of runoff harvesting potential. After the data on these three parameter was put in the AWBM model as explained in Figure 3 – 2 and resulted in Figure 4-1,it was found that the potential runoff harvest ranged from 1.90 to 9.26 mm depth per month. This translates to 2281m^3 to

11,110m^3 per month. The total annual runoff harvest was found to be 78,309m^3 which was only 5% of the rain received. This run-off capacity was determined using a mean seepage rate of 9 mm/day for the regions clayey soil, a reservoir surface and volume of 6706m^2 and of 23302 m^{3}respectively, a catchment area of 12 Ha, as well as 0.3 and 1.2 initial and mild-season Kc values of maize respectively. Evaporation and seepage loses summed up to 30,955m^{3}which was 40% of the harvested runoff. The depletion rate of the remaining capacity, 47,353m^3, was subject to the following variables; soil, evaporation, catchment area, reservoir surface area, and the dam capacity. With 40% of the harvested run-off getting lost through seepage and evaporation there was danger of depleting the reservoir before crop maturity. The potential area that could be irrigated adequately using this annual runoff harvest was established to be 6 Ha. The proposed increase of reservoir capacity from 23302 m^3 to 35075 m^3 can increases the dam's storage by 50%. However, even the increased capacity will be depleted by evaporation and seepage if they are not mitigated.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

After assessing the rainwater harvesting potential and finding the quantity it was concluded that the catchment could provide adequate runoff for the intended irrigation area. However, the actual values used in the analysis could greatly vary from the average runoff and in addition to mitigating seepage and evaporation from the reservoir it was concluded that a system should be put in place to apportion the harvested rainwater based on the actual runoff harvest residing in the reservoir before any season begun.

Determination of potential irrigation area indicated that 6 Ha could be irrigated per year. However, from the variation in runoff harvest residing in the reservoir, it was concluded that the irrigation area would similarly vary. That variation should have been determined before crop irrigation was planned in order to save land preparation costs when runoff was not adequate for the whole land.

5.2 Recommendations

The following are the major recommendations made from this study:

1. Existing reservoir was found to be smaller than the potential runoff harvest. Hence, the dam's capacity should be enlarged to at least 35075 m^3. It was found that 40% of the harvested runoff was lost to seepage and evaporation. Hence, it is

recommended that seepage and evaporation reduction measures should be incorporated in the expansion of the reservoir.

2. The potential irrigation area commanded by the potential runoff was found to be 6 Ha. It is recommended that this value should be taken as an average which requires the assessing of the available runoff at the beginning of every season. If the run-off is not adequate for the whole 6 Ha then less land should be prepared for the available runoff.

Other recommendations made based on the model used and data collection were:

1. Although there were very many models for transforming rain into runoff, they all seemed to be based on National interests. The Nations financed their hydrologists to come up with models that could be suitable for water management within them. It is recommended that a model suitable for this country should be explored because of our unique combination of arid and semi-arid lands.

2. Reservoirs should be mapped and their water capacities monitored more frequently to display irrigation area potential that could be relied on to project the country's food productivity every season.

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