

**ASSESSMENT OF SURFACE WATER AVAILABILITY IN SOLWEZI
RIVER BASIN, NORTHWESTERN PROVINCE, ZAMBIA**

By

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**A Dissertation Submitted to the School of Mines University of Zambia in
Fulfillment of the Requirements for the Postgraduate Diploma in
Integrated Water Resources Management**

University of Zambia

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DECLARATION

I, Mirriam Fulayi, do declare that this dissertation represents my own work, has not been submitted for a postgraduate diploma at this school or any other University. All the work of other persons and literature used in this dissertation have been duly acknowledged.

Signed:.....

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APPROVAL

This dissertation of Mirriam Fulayi is approved as fulfilling the requirements for the award of the Post Graduate Diploma in Integrated Water Resources Management of the University of Zambia.

Name of supervisor: Dr. Henry M. Sichingabula

Signature..... Date.....

ABSTRACT

This study assessed surface water availability in Solwezi River basin in Northwestern Province of Zambia. The main objective was to quantify various components of the water balance to ascertain surface water availability in Solwezi River Basin in view of the increasing water demand. Climate data collected comprising rainfall, temperature and water abstraction were analyzed using Runoff coefficient approach, Thornthwaite and Water Balance methods to determine inflows and outflows in the catchment. The water balance model developed revealed that the total inflows of the surface runoff generated in the catchment was 985,841m³/day while the outflows amounted to 1,078,209.8 m³/day. The outflows were comprised of 885,938m³/day of water lost via evapotranspiration, 42,678.9 m³/day water abstracted for anthropogenic activities, 13,599.36m³/day environmental flow and 135, 993.6m³/day water leaving the catchment as stream flow. The inflows were exceeded by the outflows such that the water balance results indicated a negative value of -92,368.86m³/day of the surface water available in the catchment. Consequently, there was a surface water deficit indicating that there is no surplus water in the catchment to meet the current water demand. However, the river was still flowing because of the groundwater recharge which was not accounted for as the study only focused on the surface water runoff generated from rainfall received in the catchment. Overall, it is concluded that there is inadequate water in Solwezi River Basin to meet the current water demand. The local water utility company is encouraged to find additional water sources to meet the apparent current surface water deficit in Solwezi River basin.

DEDICATION

This report has been dedicated to my Provincial Water Officer for his persistent and tireless support that availed me a chance to complete my Postgraduate diploma.

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ACRONYMS AND ABBREVIATIONS

| | |
|---------|--|
| CUMECS | Cubic meter per second |
| ET | Evapotranspiration |
| FAO | Food and Agriculture Organization |
| JICA | Japan International Cooperation Agency |
| NWWSSCO | Northwestern Water Supply and Sewerage Company |
| USA | United States of America |
| WARMA | Water Resource Management Authority |
| WWDR | World Water Development Report |
| ZESCO | Zambia Electricity Supply Cooperation |
| LWSC | Lusaka Water Sewerage Company |

CHAPTER ONE: INTRODUCTION

1.1 Background

Water is a finite resource and vulnerable to human intervention. Rapid population growth and intensification in the competing uses of water for economic growth is creating pressure on the water resources. Solwezi is the Provincial Headquarter for Northwestern Province and one of the fast growing towns in Zambia. The recent development of Kansanshi, Kalumbila and Lumwana Mines over the years has caused population growth and urbanization in the township due to employment being created by the mines and available business opportunities. Water used for the entire population, mining and agricultural activities is obtained from Solwezi River Basin.

Northwestern Water Supply Sewerage Company (NWWSSC) and Kansanshi Mine obtain water from Solwezi River Basin for domestic water supply and mine operations. Currently, NWWSSC does not have the capacity to meet the existing water demand and is supplying water to only 9,000 customers out of the current urban population of 96,775. As a result, the Northwestern Water and Supply Sewerage Company is upgrading the water plant in order to increase the water supply to Solwezi Town.

According to FAO (2007) the quantity of water required for human consumption and other usage per individual ranges from 140 to 200 litres for adults and 50 litres for children per day. Industrial production use about twice the water required for household use for mineral extraction, processing and cooling. Population growth, urbanization and industrial development ultimately increase the existing water demand and other goods and services and this may have negative impact on the water availability in Solwezi in the near future.

It is therefore imperative that water availability assessment is conducted to ensure sustainable utilization and management of the water resources. Thus, this research was aimed at developing a water balance model to determine water availability in view of the increasing water demand in Solwezi Town.

1.2 Problem Statement

Despite the growing water demand from Solwezi River for domestic use, irrigation and mining activities, the quantity of the water available for the current and future water demand is not known. Water supply for domestic use in the town, mining and irrigation activities is drawn from Solwezi River. The rapid increase in population due to recent development of mines and business investment in the district has attracted many migrants into town in search of jobs and business opportunities. Population increase and intensification in socio-economic activities exacerbate water demand for domestic water supply.

However, adequate data on inflows and outflows is required to determine water availability to ensure sustainable utilization and management of the water resources. Therefore, it is for this reason that this research was undertaken to assess for water availability in view of the increasing water demand in Solwezi River basin.

1.3 Purpose of the Study

The purpose of the study was to assess the water availability in Solwezi River basin in view of the increasing water demand in Solwezi town, Northwestern Province, Zambia, in order to ascertain whether the basin has sufficient water for the current and future use.

1.4. Objectives of the Study

In order to achieve the intended purpose, this study was guided by the overall objective and specific objectives.

1.4.1 General Objective

The general objective of the study was to quantify the various components of the water balance model in order to determine the quantity of water available in the Solwezi River Basin in view of the increasing water demand.

1.4.2 Specific objective

In order to achieve the general objective of the study, three specific objectives were formulated.

- i. To quantify the water input and output in the Solwezi River catchment.
- ii. To determine if there is sufficient water to meet the current and future water demand.

- iii. To provide baseline data for water balance assessment in Solwezi district.

1.5 Research questions

- i. How much water is there in the various components of the water balance in the catchment?
- ii. Is there sufficient water in Solwezi River to meet the current and the future demand?
- iii. What data is available for water balance assessment Solwezi district?

1.6 Justification

The rationale of this research was the need to assess the quantity of water and the potential impact of the increasing water demand on the quantity of water available in the Solwezi River Basin in order to promote sustainable utilization of the water resource. This is because there is no adequate data on the water availability on the Solwezi River Basin for efficient and equity utilization of the available water resources now and in the future.

The new legal framework on management of water resources draws attention to management of water resources by the water association users, even at the sub basin level (Water Resource Management, 2011). It is imperative that such a research is undertaken to aid the management of water resources. As such, this research contributes to raising awareness for sustainable management of water resources among the local water authority and the water utility company.

The findings of this research will provide a baseline for monitoring of water resources and effectiveness in the allocation of water in the catchment. Moreover, the study contributes to the buildup of site-specific knowledge on the surface water availability in Solwezi River Basin.

1.7 Organisation of the Dissertation

This dissertation is organized into seven chapters. Chapter One presents the introduction for the study. Chapter Two presents literature review, while Chapter Three describes the study area. In Chapter Four, the methodology approaches are discussed and interpretation of findings is given in Chapter Six. Finally, summary, conclusions and recommendations are provided in Chapter Seven.

CHAPTER TWO: LITERATURE REVIEW

2.1 Surface water availability

Surface water is a valuable resource for public, industrial, navigation and agricultural supply purposes. Therefore, understanding surface water resources potential and use is a key aspect of water resource assessment, evaluation and development.

The assessment of water availability at watershed, river basin and catchment level is realised by quantifying runoff generated in the watershed (Vandas *et al.*, 2002). Water availability assessment relies on a full understanding of all the water flows and storages in the river basin or catchment under consideration.

Water availability is defined as the quantity of water available to meet the current and the future water demand (Vandas *et al.*, 2002). Water availability can also be referred to the available quantity of water flowing in rivers and streams after water abstraction for various use and environmental flow to support the ecosystem.

Water availability in rivers and stream is dependent on the water recharge from rainfall contributing to the flows in the river. The quantity of water varies over time due to climatic changes and human activities. Assessment of water availability is a very vital activity in monitoring of water variation and prediction of floods and drought occurrence in water bodies (Beca, 2008).

2.2 Water Balance Assessment

Water balance is a qualitative technique applied in evaluating of water resources. Water balance accounts for inflows, out flows of water and changes in the storage in a particular catchment (Kumar, 2002). The concept of water balance provides a framework for studying the hydrological characteristics and behavior of the catchment. The estimation of water balance is necessary in water resources development not only for economic appraisal of the project but also for checking the reliability and general pattern of availability of water on a monthly or yearly basis (Shams, 2013). Planning, development and operation of water resources project is dependent upon the availability of quantity of water required (Shams, 2013).

Water balance simply describes the various components of the hydrologic cycle (Farnsworth *et al.*, 2008). The hydrological cycle present the movement of water in form of precipitation and evapotranspiration on the earth's surface and into the atmosphere (Sharms, 2013).

This implies that all the component of the hydrological cycle are quantified to determine the amount of water available in a catchment. Hydrological cycle components include; Precipitation (P), Evaporation (E), Evapotranspiration (ET), Surface runoff (SRO), and Groundwater flow (GF). The water balance is therefore, expressed as an equation relating to hydrological cycle components rewritten as;

$$\Delta S = P - E - ET \pm SRO \pm GF \dots\dots\dots (2.1)$$

Where;

ΔS is the change in storage.

Change in the storage is attributed to inflows into the system or out of the system. The difference between the inflows and the outflow is the water available in the storage. Changes in the river system depends on how much is coming into and out of the catchment. Water balance equation is based on the principles of conservation mass, where water entering into the system is equal to water leaving the system plus or minus changes in water storage. Water input into the system is equal to water output and can be rewritten as;

$$I \text{ (water entering system)} = D \text{ (water leaving system)} \pm \Delta S \text{ (change in storage)} \dots\dots\dots (2.2)$$

2.3 Components of a water budget

The water balance has a number of components discussed below.

2.3.1 Precipitation

Precipitation is the primary water input to the hydrologic cycle and is responsible for depositing the fresh water on the planet. Approximately 505,000 cubic kilometers of water falls as precipitation each year; 398,000 cubic kilometers of it over the oceans (Chowdhury 2005). Given the Earth's surface area and the globally averaged annual precipitation the volume of rainfall water can be determined and evaluated using water balance equation

2.3. 2 Evapotranspiration

Evapotranspiration (ET) is the combined process of evaporation and transpiration. It is the water transported into the atmosphere from soil surface, vegetation and water bodies. The process of evapotranspiration requires solar energy to change the state of molecules of water from liquid to gas called latent heat of vaporisation.

Evaporation is measured using an evaporation pan at meteorological station. Evaporation from open water bodies such as river is often estimated by multiplying the pan evaporation by 0.75. Evapotranspiration is oftenly calculated using Thornthwaite equation.

$$ET = 16 \left(\frac{L}{12}\right) \left(\frac{N}{30}\right) \left(\frac{10T_a}{12}\right)^\alpha \dots\dots\dots (2.1)$$

Where;

ET is the estimated Evapotranspiration (mm/month).

T_a is the average daily temperature (degrees Celsius; if this is negative, use 0) of the month being calculated.

N is the number of days in the month being calculated.

L is the average day length (hours) of the month being calculated.

$$\alpha = (6.75 * 10^{-7})I^3 - (7.71 * 10^{-5}) + (1.792 * 10^{-2})I + 0.49239$$

I is the heat index that depends on the 12 monthly mean temperature T_{ai}.

$$I = \sum_{i=1}^{12} \left(\frac{T_{ai}}{5}\right)^{1.514}$$

2.3.3 Surface Runoff

Surface runoff is the water which travels over the ground surface to a channel generated by precipitation that occurs after groundwater recharge through infiltration and percolation. The surface runoff that falls directly on the surface water is called stream flow which is generally

regarded as direct runoff. The volume of water received from rainfall in a given catchment which is often calculated using Rainfall-Runoff relationship equation expressed as;

$$\text{Direct runoff} = C i A \dots\dots\dots(2.1)$$

Where;

i is rainfall intensity in a time t ,

A = catchment area

C is runoff coefficient

2.3.4 Base flow

Base flow is the groundwater contribution from the aquifers bordering the river, which go on discharging slowly with time (Sharm, 2013). Base flow is the underground recharge that percolates into the ground during rainy period which results into elevation of the groundwater table. Base flow can be determined by either direct runoff hydrography using annual rainfall versus time or stream flow of a given section of the river (Chow et al., 1988).

2.3.5 Research Gaps

In Zambia, very few studies have been done to assess water availability for the growing water demand for various uses. According to the research that was conducted on surface water availability on Kafue, Luangwa, Chambeshi, Luapula and Tanganyika (JICA, 1995) the results indicates that Zambia has sufficient surface water to meet the current and the future demands.

There has been some research done on water availability study in Kafue River Basin to investigate water availability potential for sugar cane expansion on Lwena Sugar Cane Scheme without significantly reducing the present energy production at the Kafue Gorge in Zambia (Palerm, 2010). The water balance analysis indicated that the expansion of irrigated sugar cane in the Kafue Flats would not reduce the present energy production at Kafue Gorge.

A similar study was also conducted in Kaleya basin to investigate surface water availability for water use in Mazabuka in Zambia (Sichingabula, *et al.*, 2012). The results revealed that the catchment has adequate water for various purposes.

There is no research conducted on Solwezi River basin particularly on the assessment of water availability or related on Solwezi River Basin despite the increasing water demand from the water body. Therefore, this study fills the gap in the study area by providing the missing information, hence, adding to the body of existing knowledge.

In this study various components of the water balance equation were used to determine water availability in Solwezi River Basin.

CHAPTER THREE: STUDY AREA

3.1 Location

Solwezi River Basin is located in Solwezi District the Provincial Headquarters of Northwestern Province. The district covers the total area of 1500 km² and shares borders with Chingola, Kasempa and Mwinilunga districts. It is approximately 600km² from Lusaka, the capital city of Zambia. Solwezi River drains into Kifubwa River. It covers about 36km² before it joins Kifubwa from the source called Mulenga National Forest with the catchment area of 258.37 km². The geographical extent of this catchment lies between 12⁰- 15⁰ E in longitude and 15⁰- 30⁰ S in latitude as shown in Figure 1.

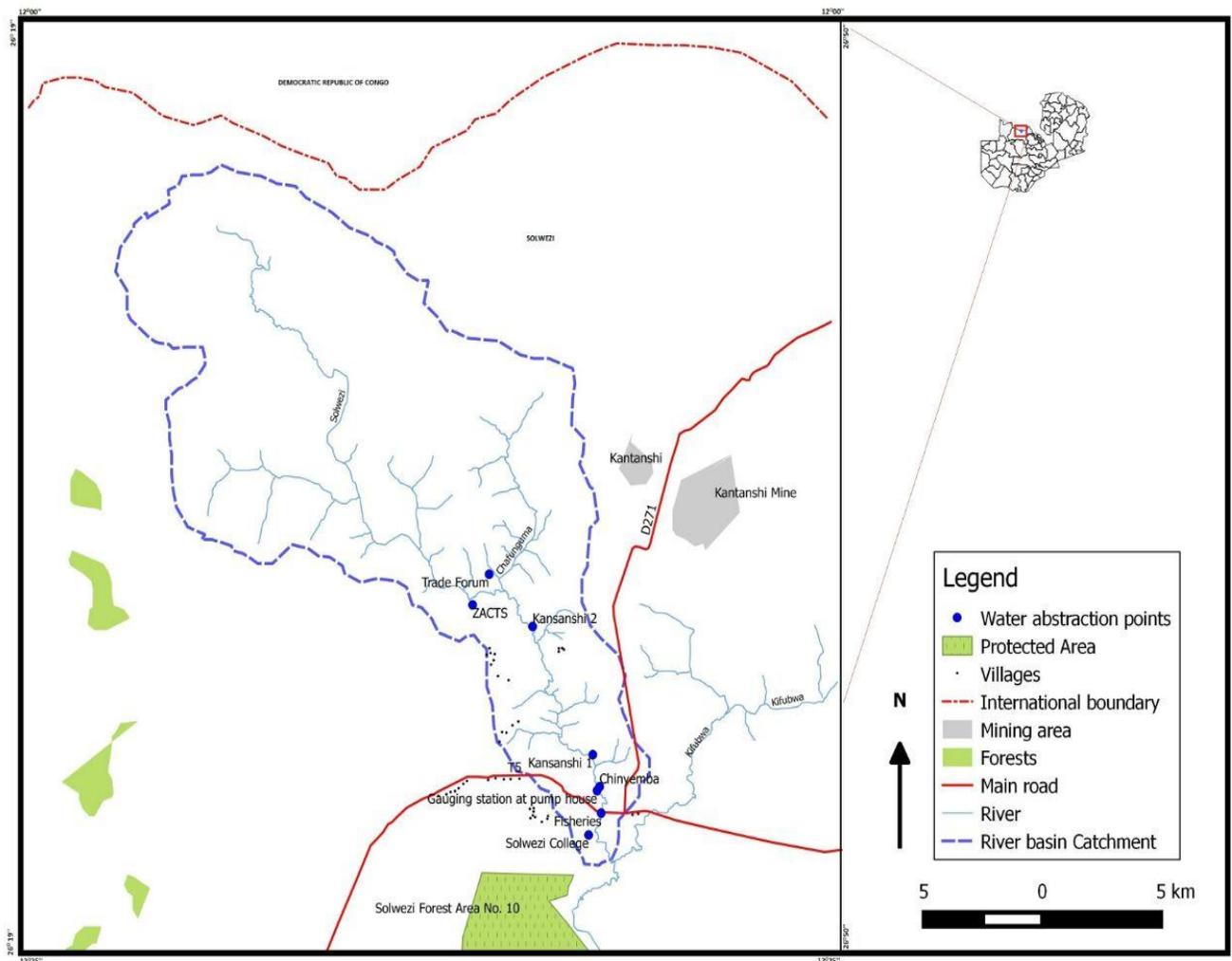


Figure 1: Location of the study area of Solwezi River Basin.

3.2 Physical Characteristics

Physical characteristics of the study area are described below.

3.2.1 Climate

The catchment occurs within Region III of the agro-ecological regions of Zambia. The climate of the area is slightly cooler with maximum temperatures ranging from 15⁰ – 25⁰C and is characterised by three distinct seasons. The winter season ranges from April to July, summer season from August to November and the rainy season occurs from December to March. The winter season average temperature ranges from 15⁰ -17⁰C. The average rainfall received during rainy season is between 800mm and 1200mm with the mean relative humidity varying from 34 percent in September to about 82 percent in February while the mean sunshine hours duration varies from 5.4 hours per day in January and February to 9.8 hours in July.

3.2.2 Topography

Catchment area lies within the higher portion of the Central African Plateau, at roughly 1400m elevation with relatively steep slopes and hilly landscape.

3.2.3 Soils

The types of soils found in the area are sandy reddish clay containing high ferralsols, nitrosoils and acrisols composed of kaolinite and quartz enriched with iron oxide (Karolk, 2013).

3.2.4 Vegetation

The catchment is covered by natural savannah vegetation. The predominant vegetation types are the *brachystegia* (miombo) and Julbernadia composed of *Chipya*, *miombo* and *Mateshi* trees (Karolk, 2013). However, due anthropogenic activities portions of the river basin as it stretches into the town has been encroached for settlement and farming and most of the vegetation is cleared. But, vegetation at source of the river is still intact showing that there are less human activities at the source as compared to where the river traverses the urban area as shown in Figure 2.



Figure 2: Photograph showing the source of Solwezi River at Mulenga Forest, 19th September, 2016.

3.2.5 Hydrology

Solwezi catchment lies within the Mutanda and Kifubwa catchments with three major streams joining it, namely, Kyafukuma, Kakishila and Kofugoma streams. The morphology of the river basin is altered due settlement and farming activities that occur in the catchment.

3.2.6 Geology

The geology of the area is mainly comprised of the basement rocks overlain by the Katanga system divided into two groups comprised of biotite gneisses and schist gneisses (Karolk, 2013).

3.3 Socio-Economic Characteristics

The population of Solwezi district and the available social and economic are outlined below.

3.3.1 Population

Solwezi district has the largest population in the Northwestern Province of Zambia. It has a population of 237,728 with a growth rate of 2.4 percent per annum and the urban population stands at 96, 775 with 18,145 households (Central Statistics Office, 2010). Population size over the years in the district has increased from 203,797 in 2000 to 237,728 in 2010.

3.3.2 Social Amenities

Solwezi town has inadequate social amenities looking at the number of people and the major economic activities taking place in the district. The majority of the residents are not connected to

pipied water, such that out of 20,145 households only 9,000 residents are being supplied with pipied water by Northwestern Water Supply Sewerage Company (NWSSCO). Other sources of water supply are scooping wells and streams including boreholes which the majority of the people cannot afford.

On the other hand, the district has adequate health and educational facilities. The district has one general hospital which has been recently renovated and extended to accommodate more people and offers quality medical service and a number of clinics in each ward.

In terms of educational facilities, the district has five private colleges and two government colleges for tertiary education.

3.3.3 Economic Activities

The major socio-economic activities serving this population include agriculture and mining. The primary industry is copper mining at Kansanshi Mine located about 10km North of Solwezi, Lumwana Mine 65km to the west and the recently developed Kalumbila Mine. The booming economy due to industrialization and population increase has created market for farm produce, thus encouraging more farming activities i.e, fishing farming and crop production in the catchment.

CHAPTER FOUR: METHODOLOGY

This chapter describes the methodology used in this study in terms of research design, methods of data collection and analysis. The methods were based on the set objectives of the research presented in Chapter One of this dissertation.

4.1 Data Requirements

The data required for this project included;

- i. Climatic data such as rainfall records, temperature, evapotranspiration.
- ii. Stream flow data.
- iii. Water abstracted from Solwezi River for domestic, mines and irrigation

The methods used in collection of this data are described below.

4.2 Data collection

The types of data used are discussed below.

4.2.1 Rainfall data

The rainfall or precipitation data from the period 2000 to 2015 used in this study was obtained from Solwezi Airport Weather station. The data was readily available at the station and had no missing values that needed to be filled.

4.2.2 Stream Flow Data

Stream flow data at Solwezi River Pump House was collected from the Department of Water Affairs (DWA) for the period 2002 to 2015. The available flow data at Solwezi River at Pump House station was used for this study but had some gaps which required to be filled.

4.2.3 Evapotranspiration

Evapotranspiration from vegetated land surfaces (quantity of water that is actually removed due to the combined effect of evaporation and plant transpiration) was calculated using Thornthwaite equation (1948) expressed as;

$$ET = 16 \left(\frac{L}{12}\right) \left(\frac{N}{30}\right) \left(\frac{10T_a}{12}\right)^\alpha$$

Where;

ET is the estimated Evapotranspiration (mm/month).

T_a is the average daily temperature (degrees Celsius; if this is negative, use 0) of the month being calculated.

N is the number of days in the month being calculated.

L is the average day length (hours) of the month being calculated.

$$\alpha = (6.75 * 10^{-7})I^3 - (7.71 * 10^{-5}) + (1.792 * 10^{-2})I + 0.49239$$

I is the heat index that depends on the 12 monthly mean temperature T_{ai}.

$$I = \sum_{i=1}^{12} \left(\frac{T_{ai}}{5}\right)^{1.514}$$

4.2.4 Water Abstraction for Various Uses

Information about water abstractions out of the catchment for various uses was collected from Water Resource Management Authority (WARMA) by way of water permit holders.

4.3 Primary data

Primary data included on site data geographical coordinates collected from the field using Geographical Position System (GPS) for generating a map indicating points of water abstraction by various users along the river.

4.4 Secondary data

Secondary data on daily flows and water abstractions from the river was collected from Department of Water Affairs and WARMA.

Other secondary data was obtained through literature review of existing documents, for example, the National Water Report by JICA (1995).

4.5 Data Analysis Methods

Data was analyzed using water balance model in determining inflows and outflows in the catchment and some of the components of the water balance were analyzed using Runoff Coefficient approach and Thornthwaite equation. The water balance components included precipitation and water losses through evapotranspiration and anthropogenic abstraction out of the catchment.

4.5.1 Water Balance Equation Used for the Study

A water balance was developed for the Solwezi River catchment in Solwezi using annual precipitation, evapotranspiration and flow data. This study also assessed change in water storage in the catchment. The water balance equation used is given as:

$$\text{Inputs} = \text{Outputs} + \text{Change in storage} \dots\dots\dots (3.1)$$

$$P * A_{\text{catch}} \pm Q_{\text{in}} = ET * A_{\text{catch}} + ANTH_{\text{out}} + \Delta S \dots\dots\dots(3.2)$$

Where,

P= precipitation (m/year)

Q_{in} = Streamflow (surface runoff plus ground-water discharge to stream) into the catchment (m³/day)

ET = evapotranspiration (m³/day)

ANTH_{out}= anthropogenic or human removals or abstractions such as water used for irrigation (m³/day)

A_{catch}= area of the catchment in (m²)

ΔS_a = change in storage in (m³/day)

Annual averages of measured data for P and Qin were available for the study area. The water balance was assessed based on annual average values. Particular attention was directed toward evaluating the relative importance of the different input and output terms within the catchment because of the relevance of this information for understanding the water balance equation for Solwezi River Basin.

4.6 Limitation of the study

The researcher faced a number of challenges during the data collection process due to the following reasons;

- i. Data on the evaporation for the study area was not collected as it was not available because it is not recorded by Mutanda Research Institute and Solwezi Airport weather station.
- ii. Limited time and long distance from Lusaka to the research area.
- iii. There was no data on ground water flow within Solwezi River catchment

CHAPTER FIVE: ANALYSIS AND FINDINGS

5.1 Introduction

This chapter presents the data collected and provides the results of the analysis carried out.

5.2 Total Inflow into the catchment

Total Inflow in the Solwezi basin is dependent on the amount of rainfall received and streamflow (Q_{in}). Thus, it is important to understand the rainfall amount and streamflow and the variation of these parameters in time when determining the available water in the basin.

Data collected on rainfall at Solwezi Airport in the period 2000 to 2015 was used to determine total inflow in the catchment which was found to be $985,841.82\text{m}^3/\text{day}$ as discharge as shown below.

$Q = \text{Average annual Precipitation} * \text{Area of the Catchment}$

$$Q = \frac{1392.7\text{mm}}{1000\text{m}} * 258.37\text{km}^2 * 10^6/365$$

$$Q = 359,831,899\text{m}^2/365$$

$\text{Discharge} = \mathbf{985,840.82\text{m}^3/\text{day}}$

5.3 Total Outflow in the catchment

Total outflow in the catchment is dependent on the amount of evapotranspiration and water abstracted from the basin for agriculture, mining and domestic use ($ANTH_{out}$). Total outflows of the catchment was determined by quantifying the total amount of water being abstracted from the river according to the issued water permits and the water losses from the catchment via evapotranspiration.

The quantity of water currently being abstracted from the river was found to be $42,678.9\text{ m}^3/\text{day}$ and the average daily evapotranspiration value was $885,938\text{ m}^3/\text{day}$ which sum to $928,616.79\text{ m}^3/\text{day}$ as the total outflows in the catchment.

ET value was calculated using Thornthwaite equation (1948) using the data collected on temperature and average day length hours (month) collected from the weather station for the year 2014, as shown below.

$$ET = 16 \left(\frac{L}{12} \right) \left(\frac{N}{30} \right) \left(\frac{10T_a}{12} \right)^\alpha = 16 * 1.03333 * 7.254187 = 119.94 \text{mm/month}$$

$$\alpha = (6.75 * 10^{-7})I^3 - (7.71 * 10^{-5}) + (1.792 * 10^{-2})I + 0.49239$$

$$\alpha = (0.00000675) * (10.4^3) - (0.0000771) * (108.16) + (0.01792) * (10.4) + (0.49239)$$

$$\alpha = (0.000759283) - (0.008339136) + (0.186368) + (0.49239)$$

$$\alpha = \mathbf{0.671178147}$$

I is the heat index that depends on the 12 monthly mean temperature T_{ai} .

$$I = \sum_{i=1}^{12} \left(\frac{T_{ai}}{5} \right)^{1.514} = \sum_{i=1}^{12} \left(\frac{23.5}{5} \right)^{1.514} = \mathbf{10.41253}$$

Using the same procedure monthly average temperatures and day length hours were calculated and the annual evapotranspiration for the catchment was found to be **1251.567mm**.

*Total Outflows = Evapotranspiration * Catchment Area + Anthropogenic abstraction*

$$\text{Total Outflows} = \frac{1251.567 \text{mm}}{1000 \text{m}} * 258.37 \text{km}^2 * 10^6 / 365 + 42678.9 \text{m}^3 / 365$$

$$\text{Total Outflows} = 885937.99 \text{m}^3 / \text{day} + 42678.9 \text{m}^3 / \text{day}$$

*Therefore total outflows in catchment = **928,616.79m³/day***

Table 1 shows average monthly evapotranspiration calculated using Thornthwaite equation (1948) using daily temperature and day length hours for year 2014.

Table 1: Calculated Annual Average Evapotranspiration for Solwezi River Basin for the year 2014.

| Month | Temperature | Day length hours (month) | Number day (month) | Monthly ET (mm) |
|--------------------------|-------------|--------------------------|--------------------|--------------------|
| January | 23 | 12 | 31 | 119.9358959 |
| February | 22 | 12 | 28 | 105.1457594 |
| March | 22.2 | 12 | 31 | 117.1204282 |
| April | 20.9 | 11 | 30 | 99.77436298 |
| May | 18.2 | 11 | 31 | 93.96132797 |
| June | 17 | 11 | 30 | 86.86244144 |
| July | 16.5 | 11 | 31 | 87.97777441 |
| August | 21.3 | 11 | 31 | 104.4200649 |
| September | 23.9 | 12 | 30 | 119.0952274 |
| October | 24.2 | 12 | 31 | 124.099467 |
| November | 11.5 | 12 | 30 | 72.89833639 |
| December | 20.5 | 13 | 31 | 120.275938 |
| Average annual ET | | | | 1251.567024 |

5.4 Annual Precipitation

Table 2 shows the recorded annual precipitation at Solwezi Airport Meteorological station for the period 2000 to 2016.

Table 2: Total rainfall received Solwezi Airport weather station, 2000-2016.

| Year | Annual precipitation (mm) |
|--------------------------------|---------------------------|
| 2000 | 1150.7 |
| 2001 | 1677.2 |
| 2002 | 1230.3 |
| 2003 | 1393.5 |
| 2004 | 966.9 |
| 2005 | 1111.4 |
| 2006 | 1228.2 |
| 2007 | 1296.8 |
| 2008 | 1170.1 |
| 2009 | 1454.6 |
| 2010 | 1510.5 |
| 2011 | 1423.8 |
| 2012 | 1363.4 |
| 2013 | 1216.5 |
| 2014 | 1677.8 |
| 2015 | 1018.57 |
| 2016 | 1131.30 |
| Total Annual Rainfall | 20,890.27 |
| Average Annual rainfall | 1392.68 |

Source: Solwezi Meteorological station.

From Table 2 the highest rainfall measured was 1677.8 mm in the year 2014 and the lowest measured rainfall was 966.9 mm in 2004. The calculated annual average total rainfall for the station amounts to 1392.68 mm. This rainfall value was used as the contribution to the total inflow in assessment of the water balance for Solwezi River catchment.

However, the average value of 1392.68mm for the years 2000-2015 was converted into discharge as the total inflow received in the catchment and the total inflow found was 985,841m³/day.

5.5 Streamflow (Qin)

Measured Streamflow (Qin) and its variation at Solwezi River Pump House station is presented in Table 3 and Figure 3, respectively. The available data on flows was used for the study. The data on flows had some gaps which required to be filled and the missing values were estimated from available monthly mean flows from the nearest gauging station Kifubwa using regression method as shown in Figure 4.

A linear equation was derived for each year where data was missing as shown in the equation 5.1 for year 2000.

$$y = 0.036x + 1.4215 \dots\dots\dots (5.1)$$

Where the value of y denotes the missing value for Solwezi gauge station, which is the unknown value at a known value x for Kifubwa gauge station.

Table 3: Annual flow at Solwezi River Pump House Gauge Station for the period 2000 - 2015

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Annual flows Q in (cumecs) |
|----------------------|--------------|-------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|----------------------------|
| 2000 | 1.631 | 1.716 | 2.069 | 1.723 | 1.723 | 1.542 | 1.593 | 1.517 | 1.418 | 1.375 | 1.499 | 1.506 | 19.310 |
| 2002 | 1.668 | 1.668 | 1.898 | 1.564 | 1.641 | 1.641 | 1.583 | 1.526 | 1.506 | 1.497 | 1.522 | 1.524 | 19.236 |
| 2003 | 1.776 | 1.816 | 1.898 | 2.021 | 1.678 | 1.633 | 1.628 | 1.600 | 1.595 | 1.593 | 1.599 | 1.599 | 20.437 |
| 2006 | 2.362 | 1.559 | 1.818 | 1.670 | 1.450 | 1.449 | 1.414 | 1.418 | 1.365 | 1.401 | 1.380 | 2.001 | 19.285 |
| 2007 | 1.936 | 2.120 | 1.908 | 2.100 | 2.317 | 1.840 | 1.802 | 1.488 | 1.430 | 1.367 | 1.394 | 1.488 | 21.189 |
| 2008 | 1.590 | 1.667 | 1.721 | 1.569 | 1.475 | 1.446 | 1.440 | 1.412 | 1.379 | 1.314 | 1.607 | 1.697 | 18.316 |
| 2009 | 1.673 | 1.783 | 2.004 | 1.691 | 1.557 | 1.786 | 1.515 | 1.459 | 1.407 | 1.302 | 1.549 | 7.295 | 25.021 |
| 2010 | 2.083 | 2.066 | 2.184 | 2.102 | 1.824 | 1.749 | 1.700 | 1.698 | 1.697 | 1.555 | 1.669 | 1.910 | 22.236 |
| 2011 | 1.931 | 1.983 | 2.274 | 1.955 | 1.744 | 1.698 | 1.699 | 1.699 | 1.592 | 1.428 | 1.622 | 1.968 | 21.593 |
| 2012 | 1.948 | 2.153 | 2.100 | 2.201 | 2.115 | 1.936 | 1.844 | 1.832 | 1.848 | 1.731 | 1.618 | 1.816 | 19.378 |
| 2013 | 2.244 | 2.200 | 2.379 | 2.213 | 2.058 | 1.957 | 1.810 | 1.750 | 0.975 | 1.773 | 1.987 | 1.007 | 22.353 |
| 2014 | 2.573 | 2.528 | 2.649 | 2.179 | 2.218 | 2.105 | 2.034 | 1.960 | 1.817 | 1.909 | 2.046 | 0.000 | 24.017 |
| 2015 | 2.105 | 2.200 | 2.119 | 2.257 | 1.972 | 1.778 | 1.588 | 1.667 | 1.661 | 1.608 | 1.759 | 1.858 | 22.571 |
| Annual flows | | | | | | | | | | | | | 274.944 |
| Average flows | | | | | | | | | | | | | 21.150 |

Source: Department of Water Affairs, 2016

Note: The values in bond were the missing values estimated using regression method.

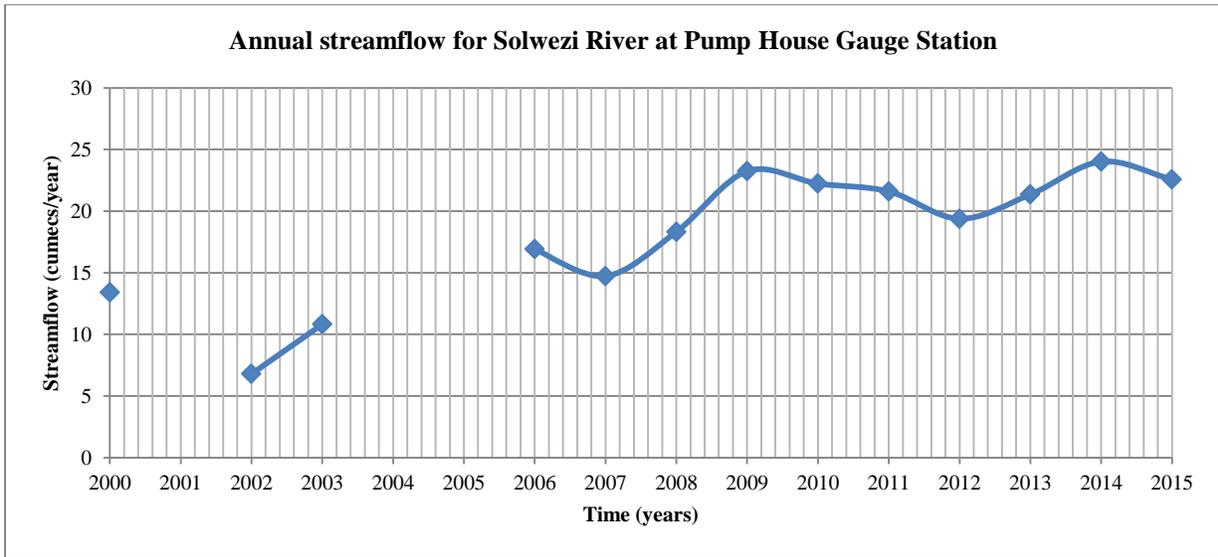


Figure 3: Recorded Annual Streamflow (Q_{in}) at the Solwezi Pump House

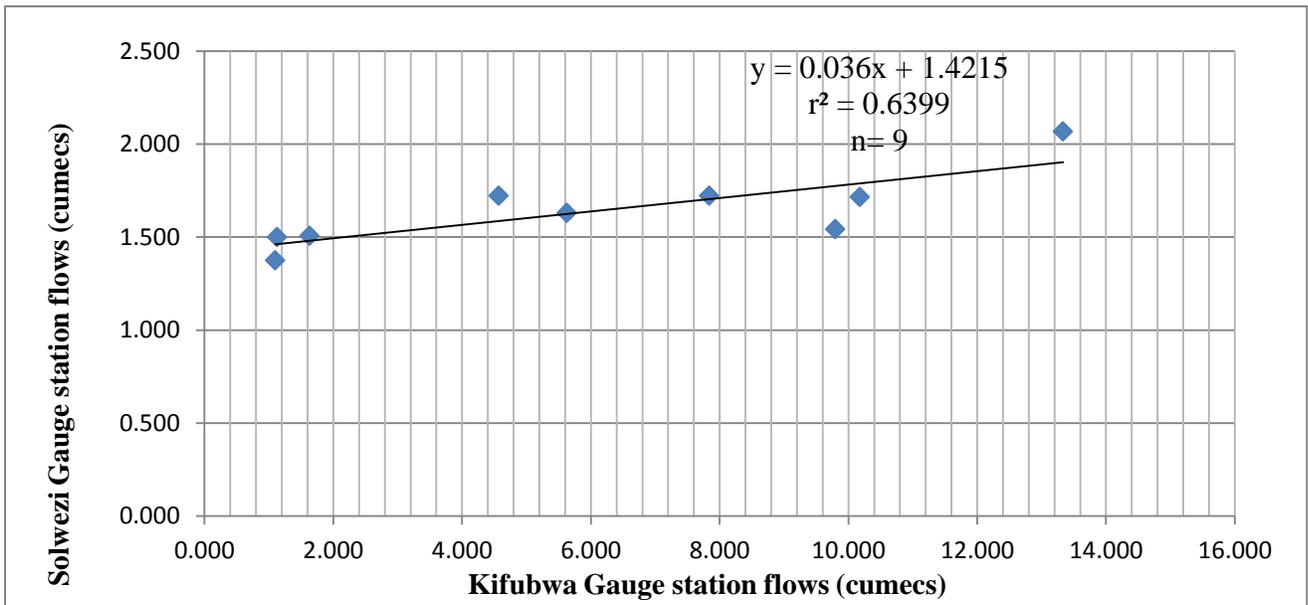


Figure 4: Linear Graph for Solwezi River Gauge station monthly flows plotted against Kifubwa Gauge Station, 2000.

From Table 3 the highest measured streamflow was 25.021m³/s in 2009 while the lowest flow was 18.316m³/s. The flows at Solwezi River Pump House station were based on reported daily flows from Department of Water Affairs. These flows were calculated from daily water level data using previously established stage-discharge (or rating) curves. Continuous data for three

years were not available for this station from 2003-2005. The average daily flow of 135, 993.6 m³/s was calculated from the available data set and used as input into the water balance equation.

5.6 Current Water Demand in Solwezi River Basin

The current water demand situations in the catchment include uses for irrigation, mining and domestic purposes. Domestic water use keeps on increasing due to the development of mines that has attracted more migrants to the town in search for jobs and business opportunities. According to Water Resource Management Authority (WRMA) the current water demand for irrigation, mining and domestic water supply on Solwezi River amounts to 42,678.9m³/day. From which, water demand for irrigation accounts 6,678.9m³/day, mines 31000m³/day and domestic water supply accounting for 5,000m³/day.

Table 4 shows the list of major water users abstracting water from Solwezi River basin with valid water permits in 2016 while the figure 5 shows the photography of some of the water users found along Solwezi River Catchment.

Table 4: Current Water Demand for various uses in Solwezi River basin, 2016.

| No | Water user name | Water demand (m ³ /year) | Actual water abstraction (m ³ /day) | Usage of water |
|-------------------------|---|-------------------------------------|--|-----------------------|
| 1 | North Western Water Supply and Sewerage Company | | 5000 | Domestic water supply |
| 2 | Kansanshi Golf Estate | | 7000 | Mine operation |
| 3 | Fisheries Department | | 206.9 | Fish farming |
| 4 | Mr Chinyemba | | 4000 | Irrigation |
| 5 | Unknown water user | | 2438 | Irrigation |
| 6 | Kansanshi Mine second abstraction point | | 24000 | Mine operation |
| 7 | ZACTS | | 25 | Irrigation |
| 8 | Trades farm | | 9 | Irrigation |
| NET WATER DEMAND | | 15,5577,798.5 | 42,678.9 | |

Source: Water Resource Management Authority, 2016



Figure 5 Photographs showing (a) NWWSCO Water Pumping station, (b) Kansanshi Mine water Pumping station (c), Fisheries Department water abstraction point and (d) Chinyemba's Farm water abstraction point, 19th September, 2016.

5.7 Assessment of Surface water availability in Solwezi River Basin

Surface water availability Solwezi Catchment was determined by quantifying the amount of water abstracted according to the water permits, evaporation losses, stream flow and environmental flow. The inflows in the catchment were subtracted from the outflow in the catchment as shown in Table 5.

Table 5: Parameters used for the Solwezi Catchment water balance assessment.

| Parameter | Average flows m³/day |
|--|--|
| Inflow in the Solwezi Catchment | (+)985,841.00 |
| Permits Granted | (-) 42,678.90 |
| ET | (-)885,938.00 |
| Outflow as Streamflow | (-)135,993.60 |
| Outflow as Environmental flow 10% of stream flow | (-)13,599.36 |
| Water balance | (-)92,368.86 |

The water balance for Solwezi Catchment can be further summarized as follows;

$$P * A_{catch} + Q_{in} = ET * A_{catch} + ANTH_{out} + \Delta S \dots \dots \dots (5.3)$$

The calculations were done as shown below.

i. Total inflow into the catchment

*Q = Average annual Precipitation * Area of the Catchment*

$$Q = \frac{1392.7mm}{1000m} * 258.37km^2 * 10^6/365$$

$$Q = 359,831,899m^2/365 = \mathbf{985,840.82m^3/day}$$

ii. Streamflow

$$Q_{in}=1.574 m^3/s=(1.574*3600*24) = \mathbf{135,993.6m^3/day}$$

iii. Total Inflows in the Catchment

Total Outflows = Evapotranspiration * Catchment Area + Anthropogenic abstraction + s

$$= \frac{1251.567mm}{1000m} * 258.37km^2 * 10^6/365 + 15577798.5m^3/365$$

$$= 885937.99m^3/day + 42,678.9 m^3/day$$

$$= \mathbf{928,616.89 m^3/day}$$

iv. Water Balance

$$\Delta S = \text{input} - \text{output} = 985,841 \text{ m}^3/\text{day} - 1,035,531 \text{ m}^3/\text{day} = -92,368.8 \text{ m}^3/\text{day}$$

Table 6 shows the summary of the average daily quantity of the inflows and outflows and the changes that occur in Solwezi River Basin.

Table 6 Summary of the daily water balance for Solwezi River Basin, 2016.

| YEAR | Input (m ³ /day) | Output (m ³ /day) | | | | ΔS (m ³ /day) |
|------|-----------------------------|------------------------------|------------------|------------------|--------------------|--------------------------|
| | | ET | ANTHout | Flow Qin | Environmental Flow | |
| 2016 | Precipitation | | | | | |
| | 985,841m | 885,938 | 42, 678.9 | 135,993.6 | 13,599.36 | |
| | 985,841 | 1,078,209.86 | | | | -92,368.8 |

CHAPTER SIX: DISCUSSION OF FINDINGS

This chapter presents the discussion of the main finding of the study.

6.1 Surface Water Availability in Solwezi River Basin

The water balance study for Solwezi River Basin was evaluated by taking into consideration the inflows and outflows to ascertain water availability for the current and future water use in Solwezi River Basin. The results of the water balance assessment for Solwezi River Basin indicated a negative water balance ($-92,368.86\text{m}^3/\text{day}$) available in the catchment. The total inflows obtained were $985,841\text{m}^3/\text{day}$ lower than the total outflows of $1,078,209.86\text{m}^3/\text{day}$ of the water abstracted for anthropogenic activities plus evapotranspiration in the catchment. The total inflows were exceeded by the outflows and resulted into a surface water deficit of $92,368.86\text{m}^3/\text{day}$.

This implies that the available water in the catchment is not adequate for the current and future water demands. Further allocation of water permits for water use would diminish the available water needed for sustainability of the ecosystem in form of environmental flows given the surface water deficit in the catchment. However, to meet the current water demand in Solwezi River Basin a total of $92,368.86\text{m}^3/\text{day}$ of water is required to be sourced from elsewhere.

The findings of this research are similar to the water balance study conducted by Sichingabula *et al.*, (2012) in Kaleya Catchment on assessment of surface water availability for water use and management. The study revealed that without interbasin transfer of water from Kafue River into the Kaleya River catchment there was a surface water deficit of $80,000\text{m}^3/\text{day}$. But, due to interbasin transfer there was adequate water for various purposes in the catchment.

A similar research was conducted by Sikazwe (2007) in Kafue River Basin to investigate water availability for water allocation between Nakambala Sugar cane production and energy production by ZESCO at Kafue Gorge using the same methods though the findings of study were different. Sikazwe's study revealed that there was adequate water for the current water demand in the Kafue River subbasin.

6.2 Current and future water Demand in Solwezi River Basin

The findings on evaluation of the existing water users were used to determine current and future water demand in the catchment. The quantity of current water demand for irrigation, mining and domestic water supply in the catchment amounts to 42,678.9m³/day. Out of this volume, irrigation accounts for 6,678.9m³/day, mines 31,000m³/day and domestic water supply accounting for 5,000m³/day, with Kansanshi Mine accounting for more water of 10 percent of the existing current water demand followed by irrigation at 8.5 percent and lastly Northwestern Water Supply and Sewerage Company at 1.5 percent. This means that, among the water users Kansanshi Mine is currently demanding more water for its operations. Also based on the quantity of water NWASSCO is supplying, it is clear that the district is under supplied and that there is a deficit between water supply and population water demand. Out of 96,725 urban population with 20,145 households in Solwezi Town, only 9,000 households are currently connected with piped water. This indicates that there is no correlation between the current water demand and water supply.

Kansanshi Mine have further applied for water permits and once granted the mines will be abstracting more water from the Solwezi River Basin than the amount of water currently obtained for their operations. On the other hand water abstraction for domestic supply is expected to increase from 5,000m³/day to 120,000m³/day once Northwestern Water Supply Sewerage Company water plant under rehabilitation is completed.

This reveals that there is an increasing water demand in Solwezi River Basin and more water would be required from other sources to meet the current and future demand.

The problem of increasing water demand has become a common phenomenon in Zambia and in other countries. Increase in population and intensification of socio-economic activities for development are the major drivers of the increasing water demand. According to United Nation World Water Development Report (WWDR) (1999) over the next 25 years serious conflicts are likely to arise between water for irrigated agriculture, power generation and water for other human and ecosystem uses, and this is slowly becoming a reality. Lusaka city is among the towns in Zambia already experiencing increasing water demand due to population growth, infrastructure development and industrial activities. Water supply for domestic use and industrial activities is obtained from Kafue River and groundwater sources but still the water supplied cannot meet the water demand and this has resulted into water rationing by LWSC in order to

cope up with the increasing water demand. But due to lack of adequate water infrastructure to supply water with the expanding economy and population growth the problem still persists and some compounds are not supplied with water by the water utility company.

The current water demand in Solwezi Township can be addressed with adequate investment in water infrastructure development and unlike what is obtained in Lusaka City. There is still abundant water sources other than Solwezi River basin that can be used for water supply in the catchment. The water supply network is restricted to a small population of people in the urban area where water supply is continuous without electricity power loading shedding.

6.3 Water losses in the Solwezi River Catchment

The water loss via evapotranspiration was calculated using Thornthwaite equation (1948) by taking into consideration of the sunshine duration hours and annual average temperature recorded in the catchment. The evapotranspiration value obtained of 1251.56 mm was compared with the ET value of 1400 mm obtained using Turnic formula (1954, 1955) by JICA (1995) and showed that the value is within range.

Based on the results obtained on evapotranspiration in the catchment, it is clear that evapotranspiration has implications on the water availability in the catchment. The results reveals that ET accounts for the greatest amount of water loss (90%) from the total inflows into the catchment compared to anthropogenic water abstraction (4%), streamflow (14%) and environmental flows (1.4%). The results indicated that evapotranspiration accounts for about 90 percent from the total inflows in the catchment, which is ten times greater than anthropogenic abstraction accounting for 4 percent, streamflow 14 percent and environmental flows accounting for 1.4 percent from the total inflows received in the catchment.

This implies that most of the water received from rainfall is returned into the atmosphere through evapotranspiration than the quantity of water that is put into use in the catchment. This proves that despite an increase in the inflows the catchment would receive provided that evapotranspiration value ($885,938\text{m}^3/\text{day}$) remains constant. Water received in the catchment would still be conveyed back to the atmosphere via evapotranspiration that returns as rainfall to the earth surface in the hydrological cycle.

Another study on water balance was conducted in Central of Zambia in Lukanga and Chambeshi River Basin over a period of 17- 20 years by Sharma (1988). The results indicated that more than 80 percent of annual rainfall returns to the atmosphere by evapotranspiration. This accords well with the findings of this study, where the value of evapotranspiration for Solwezi River basin was found to be 90 percent of the total inflows received in the catchment.

The conclusion of this study are summarized in the next chapter

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

This chapter concludes and makes recommendations based on results obtained in this study.

7.1 Conclusion

The water balance study for Solwezi River basin was evaluated taking into consideration the inflows and outflows in the catchment and all the objectives of the study have been largely achieved as discussed in Chapter Six. The water balance assessment for Solwezi River Basin revealed that out of the total inflows of 985,841 m³/day of the average stream flow received in the basin from rainfall runoff, 1,078,209.8m³/day of water were lost as outflows. The current water utilization out of the total inflows received in the catchment accounts for 42,678.98 m³/day and stream flow 135,993.36m³/day. The results also indicated that about 90 percent of the water received in the catchment is lost via evapotranspiration which was found to be 885,938m³/day. The inflows were exceeded by the outflows which indicated a surface water deficit of - 92,368.86m³/day as the water balance in the catchment.

This implies that there is no readily available surplus amount of water for future water allocation in the catchment. The current water demand is greater than the available surface water and that all the available water in the catchment is exhausted by the current water demand.

It is therefore concluded that there is inadequate water in Solwezi River Basin to meet current water demand and there is no surplus surface water available for future allocation. However, to meet the current water demand in Solwezi River Basin 92,368.86m³/day additional water is required in the catchment. The Northwestern Water Supply Sewerage Company ought to find additional water sources as the available water cannot meet the projected water demand for domestic water supply at the pumping rate of 120,000m³/day. The river was still flowing because of the groundwater recharge, which was not studied. This study focused on the assessment of surface water availability based on the runoff generated from rainfall as inflows into the catchment. The groundwater component of the water balance was not accounted for because no groundwater data was available for the catchment.

7.2 Recommendations

Based on study findings, the following recommendations were made.

- i. Due to inadequate water availability in the catchment, WARMA should not allocate more water permit to water users in order to ensure sustainability of the ecosystem and the water resource.
- ii. The Northwestern Water Supply Sewerage Company should put up a water reservoir to increase water storage as an alternative water source to supplement the current apparent water deficit in the catchment in order to meet the future projected water demand.
- iii. More research is required on groundwater flow to improve the understanding of the water balance status in Solwezi River Basin.

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APPENDIX

Appendix I: Recorded Annual Mean Temperatures for Solwezi Air Port, 2005 -2015.

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total Temperature | Annual Mean Temperature |
|------|------------------|------|------|------|------|------|------|------|------|------|------|------|-------------------|-------------------------|
| | Mean Temperature | | | | | | | | | | | | | |
| 2005 | | | | | 19.6 | 17.9 | 16.7 | 19.8 | 21.9 | 24.1 | 22.4 | 21.8 | 164.2 | 23.5 |
| 2006 | | 22.0 | 23.0 | 19.5 | 17.8 | 15.2 | 15.3 | 22.1 | 21.4 | 22.0 | 22.0 | 19.6 | 219.9 | 20.0 |
| 2007 | 21.3 | 23.1 | 20.3 | 21.7 | 19.0 | 17.5 | 15.6 | 19.0 | 22.0 | | 21.0 | 20.0 | 220.5 | 20.0 |
| 2008 | | 20.5 | 23.3 | 17.2 | 19.6 | 18.0 | 16.3 | 19.4 | 22.0 | 24.0 | 20.6 | 21.0 | 221.9 | 20.2 |
| 2009 | 22.5 | 22.0 | 20.0 | 18.5 | 17.0 | 15.0 | 18.0 | 19.7 | 22.7 | 23.5 | 21.8 | 21.5 | 242.2 | 20.2 |
| 2010 | 21.6 | 18.9 | 21.0 | 23.7 | 19.0 | 16.3 | 19.7 | 23.3 | 21.3 | | 23.5 | 22.0 | 230.3 | 20.9 |
| 2011 | 20.0 | 22.3 | 23.5 | 22.3 | 18.4 | 17.3 | | | | | | | 123.8 | 20.6 |
| 2012 | | | | | | | 16.7 | 20.2 | 24.5 | 21.9 | 25.2 | | 108.5 | 21.7 |
| 2013 | 21.0 | 21.8 | 22.0 | 23.0 | 17.0 | 15.4 | 15.7 | 19.7 | 23.0 | 22.1 | 20.9 | 21.9 | 243.5 | 22.1 |
| 2014 | 23.0 | 22.0 | 22.2 | 20.9 | 18.2 | 17.0 | 16.5 | 21.3 | 23.9 | | 11.5 | 20.5 | 217.0 | 19.7 |
| 2015 | 21.9 | 24.1 | 22.2 | 18.4 | 17.2 | 16.9 | 13.7 | 25.0 | 22.2 | 24.1 | 22.9 | 21.7 | 250.3 | 20.9 |

Appendix II: Recorded Monthly Water Flows for Kifubwa Gauge Station 2000-2013.

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| 2000 | 5.629 | 10.179 | 13.335 | 7.837 | 4.572 | 9.799 | 3.494 | 2.377 | 1.396 | 1.099 | 1.128 | 1.631 |
| 2001 | 2.404 | 0.088 | 2.496 | | 2.238 | 2.063 | 1.783 | 0.054 | 1.379 | 1.259 | 1.296 | 1.603 |
| 2002 | 7.688 | 10.672 | 11.960 | 9.184 | 5.446 | 8.909 | 4.312 | 3.890 | 3.442 | 3.558 | 4.107 | 4.774 |
| 2003 | 5.608 | 6.354 | 7.782 | 9.314 | 8.401 | 6.567 | 5.221 | 4.505 | 3.910 | 3.527 | 3.687 | 5.468 |
| 2004 | 8.190 | | 11.384 | 7.676 | 4.698 | 4.283 | 3.961 | 3.664 | 3.370 | 3.093 | 3.362 | 5.436 |
| 2005 | 10.052 | 6.690 | 5.896 | 5.386 | 3.809 | 6.856 | 3.420 | | 3.088 | 2.916 | 2.979 | 3.351 |
| 2006 | 4.047 | 5.649 | 11.938 | 8.708 | 4.319 | 3.795 | 3.778 | 3.765 | 3.111 | 2.992 | | 7.620 |
| 2007 | 20.446 | 19.906 | 12.353 | 8.191 | 6.043 | 4.799 | 4.701 | 4.211 | 3.801 | 3.533 | 3.369 | 4.398 |
| 2008 | 8.722 | 12.446 | 14.177 | 6.997 | 4.818 | | 3.693 | | 2.912 | | | 9.545 |
| 2009 | 11.713 | 13.733 | 20.350 | 11.489 | 8.205 | 6.489 | 5.496 | 4.456 | 3.817 | 3.414 | | 6.619 |
| 2010 | 8.674 | 18.137 | 13.972 | 7.951 | 7.534 | 7.062 | 6.063 | 4.750 | 0.742 | 0.974 | 5.775 | |
| 2011 | 7.728 | | 13.888 | 7.780 | 7.414 | 7.238 | 7.106 | 6.543 | 5.492 | 4.768 | | |
| 2012 | 7.756 | 7.812 | 8.006 | 7.344 | 5.197 | 0.973 | 0.779 | | 0.865 | | | 2.671 |
| 2013 | 9.885 | | 22.755 | | 7.641 | 6.885 | 0.815 | 0.789 | | | 0.740 | 2.952 |